Series Capacitor Application in Ontario: SSR Mitigation Final Report

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Executive Summary:

This document presents the results of the work related to the assessment of the risk of subsynchronous resonance (SSR) as it relates to the installation of five proposed series capacitor banks in the Hydro One electrical power system. This assessment was done with reference to seven existing power plants in the Hydro One system, namely Bruce A & B, Lambton, Nanticoke, Pickering, Darlington and Lennox. The primary objective of this work was to identify if the potential for SSR exist and if so whether or not it can be effectively mitigated.

The analysis was performed for an extensive number of contingency scenarios for each power plant and combinations of generating units on-line at the plant. Based on the analysis, and for the particular location and size of series capacitors chosen, the power plants at Lambton, Pickering, Darlington and Lennox are at little to no risk of experiencing destabilization of the torsional mechanically modes of their turbine-generator shafts due to SSR. In each of these cases, it takes the loss of twelve or more transmission elements (500 kV lines, 230 kV lines or 500/230 kV transformers) in order to result in a significant resonant condition between the turbine-generator and the series capacitors.

For the Bruce and Nanticoke power plants, resonant conditions can result with as little as one to four transmission element outages.

For Nanticoke, the 230 kV units become susceptible to SSR once all the 500 kV Nanticoke units are off-line and we have three to four transmission elements out of service. For the 500 kV units at Nanticoke, a significant resonant condition that may lead to destabilization of a couple of the torsional modes occurs for an N-4 condition (loss of both 500 kV circuit towards Milton and Clairville as well as both 500/230 kV transformers). If from a power flow/stability perspective that the series compensation is not needed under this condition, this problem may be addressed by bypassing the series capacitor on the Longwood – Nanticoke line. It should be noted that some of the shaft model data for the Nanticoke units have not yet been received. Once that information has been received some further analysis will be performed to identify if this is a suitable mitigation option or other mitigation options are needed.

For the Bruce power plant, there are a number of N-1, N-2 and N-5 conditions that lead to potentially destabilizing conditions for the torsional modes around 22 to 23 Hz. For the Bruce A 500kV units the trouble outages are the loss of Bruce A to Clairville and Bruce A to Bruce B. The problem is further aggravated if all the 500/230 kV transformers are also lost. For Bruce B, the loss of either the Bruce B to Bruce A 500 kV line or the outage of both this line and the Bruce B to Milton line results in a potentially problematic condition. Again, the concern is for the higher frequency torsional modes. It is shown in this study that by introducing a thyristor-controlled series capacitor (TCSC) as a portion of the total series compensation on the Bruce to Longwood 500 kV lines, then these potential destabiliting conditions can be effectively eliminated.

Thus, based on this study the general conclusion is that the problem of SSR is manageable and can be mitigated for all units with a combination of operating strategies (i.e. bypassing in part or in whole specific series capacitors under given outage conditions) and the application of TCSC. Further analysis, beyond the scope of this present study, will be required to fully define and specify the most cost effective configuration of the series capacitors and the portion of TCSC required. Such additional work should also aim to more acurately quantify transient torques based on fine tuning the series capacitor protection systems.

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1 Introduction

The Hydro One transmission system in the province of Ontario has been studied by both Hydro One and the Independent Electric System Operator (IESO) in Ontario for the purpose of significantly increasing the transfer capability over the bulk 500 kV transmission lines. This analysis has shown the need for series compensation of five of the 500 kV transmission lines in the Hydro One system. Figure 1-1 shows the diagrammatic representation of the system and the lines that are to be compensated.

Since series compensation has not been applied in the Hydro One system in the past, one of the major concerns is that of subsynchronous resonance. Subsynchronous resonance (SSR) is a phenomenon whereby the electrical resonant frequency established through the combined inductance of the transmission system and the applied series capacitance may introduce negative damping at modes of torsional mechanical vibration on the shafts of nearby thermal turbine-generators. As a result, there is a potential for significant damage to the mechanical shaft of thermal power plants. The first, and to our knowledge only, reported damage to the shaft of a generating unit was observed in the 1970's at the Mohave Generating Station in Southern Nevada [1]. Since that incident, established techniques have been developed for analyzing and mitigating the possibility of (SSR). Thus, the purpose of this study is to identify the potential for SSR between the electrical network and the power plants on the Hydro One system and to present possible SSR mitigation options.

This report presents the results of the SSR mitigation study. The sole objective of this study was to determine if the proposed series capacitors can be applied together with an effectively SSR mitigation strategy. In addition, at the request of the generating facilities and Hydro One, the mitigation options investigated were to be within the transmission system and not require additional control or mitigation equipment to be installed or retrofitted on the generating units (or generator step-up transformer).

This report is organized as follows:

- Section 2 presents a brief write-up on the entire study methodology and approach.
- Section 3 presents the core of the report discussing the results of the various SSR analyses and the mitigation options.
- Sections 4 presents a qualitative discussion on the potential risk of SSR for future generating units that may be introduced into the Hydro One system.
- Sections 5 presents the conclusions and recommendations of this report and gives a brief outline of the future work that is required.

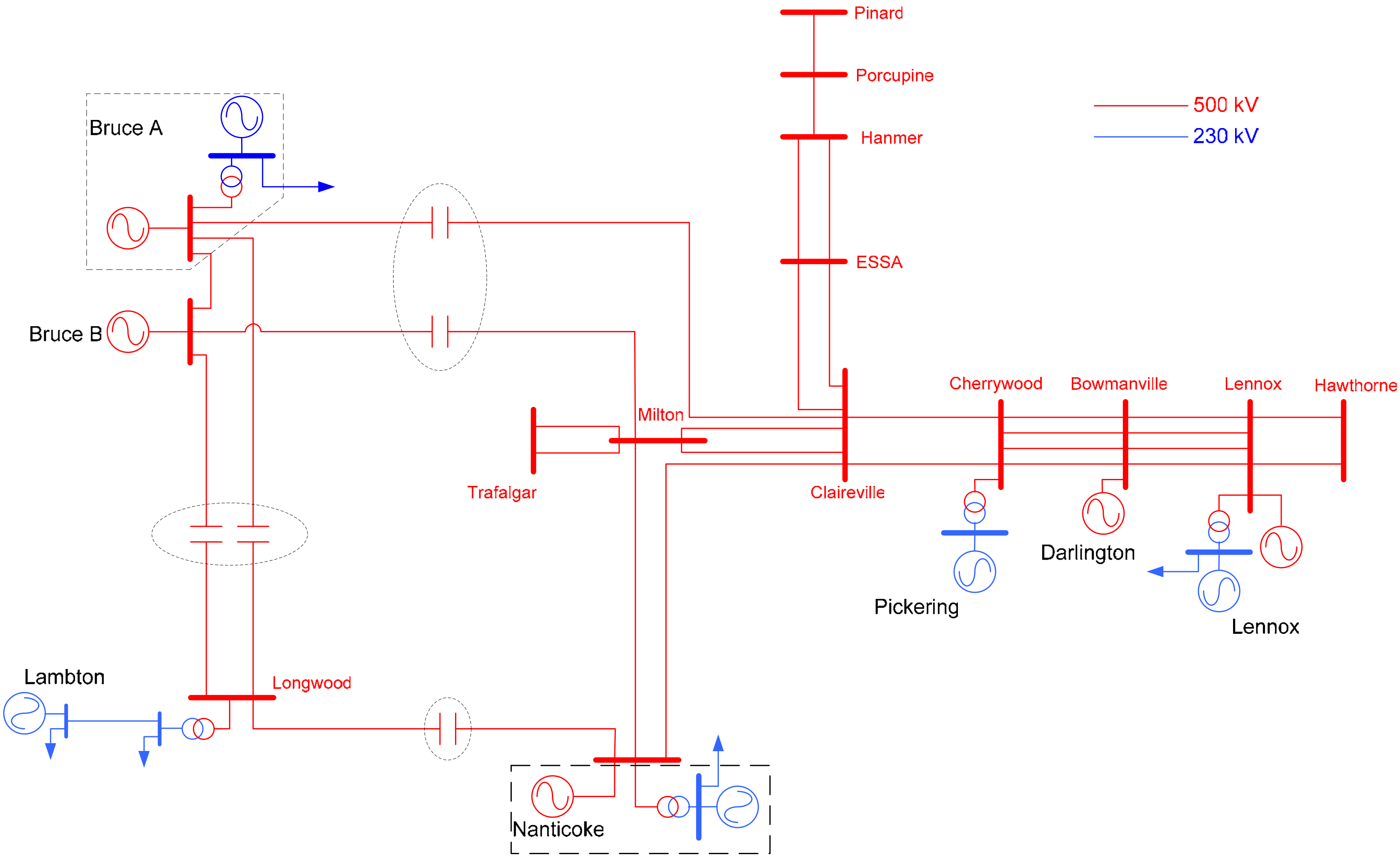

Figure 1-1: Hydro One 500 kV bulk transmission system. Proposed new series capacitors shown encircled by dotted lines.

2 Study Methodology

2.1 The Phenomenon of Torsional Interaction

Torsional interaction (TI) is defined as the phenomenon by which an event, device or resonance on the electrical power system interacts with torsional modes of vibration (oscillation) on the mechanical shaft of a turbine-generator. This may occur in several ways.

2.1.1 Interaction Due to Generator/Turbine Controls

In the early days of power system stabilizer (PSS) design, when the primary input signal for PSSs were mechanical speed measured on the shaft of a turbine-generator, it was possible to induce negative damping at torsional frequencies due to feedback through the PSS control loop [2]. Present day PSSs are primarily based on the integral of accelerating power as their input signal. In addition, most designs employ filtering to ensure that the PSS output is significantly attenuated at higher frequencies – the purpose of a PSS is to induce damping for modes of electromechanical oscillation ranging from 0.2 to 2 Hz, whereas torsional modes of mechanical oscillation occur typically between 8 to 50 Hz. In a similar way, it is plausible to cause torsional interaction through the turbine governor control loop [3]. Once again, this can be mitigated through proper control design. In this study torsional interaction due to either the PSS or turbine governor controls is not considered. It is assumed that these controls have been designed per present day industry practice, which would thus ensure that the controllers do not have any adverse interaction with the turbine-generator torsional modes.

2.1.2 Subsynchronous Torsional Interaction (SSTI)

Torsional interaction can potentially also result from the fast control loops associated with nearby active transmission devices such as High Voltage DC (HVDC) systems, Static VAr Compensators (SVC) and Static Compensators (STATCOM) [4]. However, it should be noted that such devices, if properly designed and tuned, may even have a beneficial effect on torsional damping. In fact, for some thermal power plants in the Western Electric Coordinating Council (WECC), an SVC is used to provided the necessary active damping at torsional frequencies to mitigate the potential for SSR with nearby transmission series capacitors. As such, one should be cautious not to assume that the mere vicinity of a power plant to such transmission devices is a cause for alarm. Instead, detailed studies and proper control design are needed to ensure safe operation of the transmission equipment and no adverse interaction with nearby generators. This has been illustrated through more than two decades of HVDC and SVC installation around the world with no reported damage to nearby generation. Again, in the analysis presented in this report there is no study of such phenomena, since there are no HVDC or SVC in the vicinity of the plants being studied.

2.1.3 Subsynchronous Resonance (SSR)

SSR is a phenomenon caused by a passive series capacitor installation. The phenomenon can be simply explained by referring to Figure 2-1. For this system one can easily show that there exists an electrical resonance at a frequency given by the expression

$$f_n = f_o \sqrt{\frac{X_C}{X_L}} \tag{1}$$

where X_L is the total network reactance as seen from the driving point, i.e. $2\pi f_o(L''_d+L_t+L_e)$ in this case. Since the level of series compensation never exceeds the total impedance of the transmission system ($X_C<X_L$) the resonant peak is always at a subsynchronous frequency; that is, a frequency less that the nominal system frequency f_o. With this in mind, consider an example of the mechanical turbine-generator shaft of a typical steam turbine as shown in Figure 2-2. This example figure shows six masses: the exciter, the generator, the HP and IP turbines and the two segments of the LP turbine. In practice, when designing a turbine-generator the manufacturer will use techniques such as finite-element analysis to represent the mechanical shaft in much greater detail (down to each stage of turbine buckets on the shaft). The rotating bucket-wheels associated with each turbine stage are very tightly coupled as compared to the segments of the shaft between each turbine-generator component. Therefore, it is sufficient for the purposes of subsynchronous torsional analysis to model the turbine-shaft system as a sequence of lumped masses connected by shaft components of given spring constant.

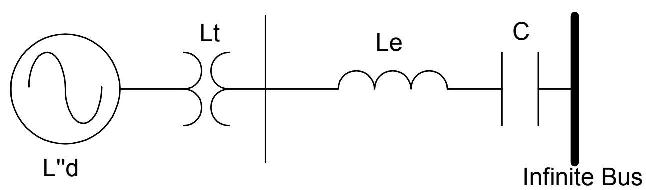

Figure 2-1. Simple example of series compensated system

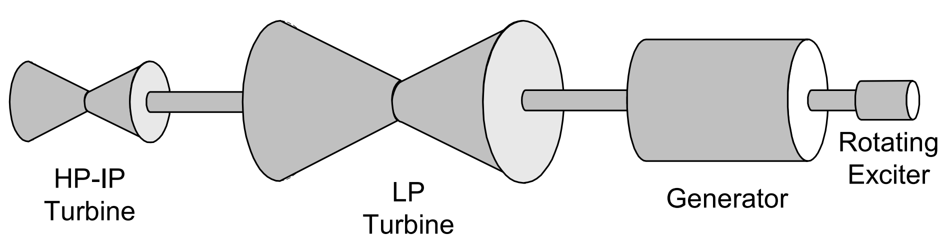

Figure 2-2. Example turbine-generator shaft

For a shaft consisting of *n* components, there exist *n-1* modes of torsional oscillation. For the example system in Figure 2-2 there are five modes of torsional oscillation. Of these torsional modes, those of particular concern are the torsional modes at subsynchronous frequencies. Furthermore, one can determine the mode shape for each torsional mode from the eigenvectors corresponding to the calculated eigenvalues. Based on the mode shapes, one can identify which masses (turbine-generator elements) participate in each mode. For example, in Figure 2-2 it is conceivable that for a given torsional mode, the generator might oscillate against the LP turbine stage, with the HP turbine being located at or near an anti-node of the torsional mode. Thus, when this mode is excited, there is little movement by the HP turbine. The HP turbine would then be said not to participate in the mode.

Now consider a mechanical torsional mode of frequency f_m in which the generator participates. If this torsional mode is excited, then the generator rotor will oscillate at a frequency of f_m. This will then result in current injection by the generator at two side-band frequencies of $(f_o - f_m)$ and $(f_o + f_m)$. If the electrical resonance frequency (Equation (1)) corresponds to or is close to the lower side-band frequency (i.e. f_n approximately equal to $(f_o - f_m)$), then energy exchange can easily take place between the electrical resonance and the mechanical resonance. The system then experiences the phenomenon of subsynchronous resonance (SSR). Such a torsional interaction may lead to growing mechanical and electrical oscillations and damage to the turbine-generator shaft.

The mechanical modal frequencies are determined by the mechanical characteristics of the turbine generator and remain constant throughout the lifetime of the shaft provided that the mechanical components are not changed. The electrical resonance frequency, however, is determined by a number of factors, most noticeably network topology and the level of series compensation.

2.1.4 Transient Torque

Another phenomenon that may result in mechanical damage on the shaft of turbine generators due to excessive torsional oscillations is that of large signal phenomena that give rise to excessive transient torque oscillations on the turbine-generator shaft. This is typically caused by switching events on the system such as high-speed reclosing of EHV transmission lines near a turbine-generator. The accepted practice is that should a switching event result in a torque swing of greater than 0.5 pu (on the machine MVA rating), then the event may require more detailed analysis using a 3-phase model [5, 6]. Such transient torques can also be aggravated by nearby series compensated lines since the network resonance caused by the series capacitor may potentially reduce the total damping of the mechanical torsional modes.

2.2 The Study Methodology

The focus of this study is the potential for SSR due to the introduction of series capacitors. Furthermore, time domain simulations are performed related to transient torque analysis and observing modal stability for critical cases identified by the SSR screening analysis.

There are a number of well established methods for studying SSR. These include time-domain simulations, frequency-domain simulations, modal eigenvalue based methods and network-impedance frequency-scan methods. In this study the time-domain, frequency-domain and network-impedance frequency-scan techniques have been employed.

2.1.5 Network-Impedance Frequency-Scan Technique for SSR Analysis

Consider a system disturbance that results in a perturbation in the mechanical speed of a synchronous generator. This would excite a number of torsional modes. Moreover, this would result in two ac side-band frequency components of voltage and current on the stator for each frequency of mechanical oscillation on the shaft. Both side-band currents contribute to the electromechanically induced torque. It can be shown that the resultant damping of electromagnetic origin can be calculated by the following equation [7]:

$$\Delta\sigma = \frac{Q_m^2}{4M_m}\left(\left(1-\frac{f_0}{f_m}\right)\mathrm{Re}\left(\frac{1}{Z_{LO}}\right)+\left(1+\frac{f_o}{f_m}\right)\mathrm{Re}\left(\frac{1}{Z_{LU}}\right)\right) \tag{1.0}$$

Where:

Z_{LO} is the generator and network impedance evaluated at the lower side-band frequency associated with a torsional frequency f_m.

Z_{LU} is the generator and network impedance evaluated at the upper side-band frequency associated with a torsional frequency f_m.

M_m is the modal inertia for mode "m"

Q_m is the generator modal component of the mode shape for mode "m"

and

$$\gamma_m = \frac{Q_m^2}{4M_m}\left(1-\frac{f_0}{f_m}\right) \tag{2.0}$$

where γ_m is the interaction factor for mechanical torsional mode "m".

The modal inertia, M_m, generator modal component, Q_m, and mode shape are all determined primarily by the mechanical characteristics of the shaft.

The elements of system modeling for SSR based frequency scans include all frequency dependent impedance elements that affect the driving point impedance as seen from the generator being studied over the frequency range of 0-120 Hz. This includes line and load (R, L, C), and active load contribution such as motors, and all generation.

The frequency scan approach for SSR torsional interaction calculation is limited to a one-machine, one-frequency-at-a-time approach. The contribution of a second machine in the network may not be accounted for and so care must be taken when dealing with almost identical units and units with similar frequencies of oscillation so as to interpret the results properly.

The series capacitors that are of concern are those that change the network resonant frequencies to coincide with a machine's torsional modes. In a system, some series compensated lines are electrically separated from the study units enough that they may be eliminated from the study by performing a network reduction. However, for the purposes of this study, all of series capacitors and all of the Ontario electrical system have been explicitly modeled. The only equivalents are at the boundaries of the system (see section 3).

Load Modeling

The load model is import in SSR phenomena because it provides:

- a resistive effect that increases damping of electrical oscillation,
- a short circuit impedance and negative resistance contribution from motors that raises system natural frequencies and lowers electrical damping
- super-synchronous natural frequency oscillations due to power factor correction provided by shunt capacitors on the distribution system.

These effects have been documented by test on a total system basis for gross effects and have led to the important conclusion that conventional bus elimination and the netting of load is not appropriate in SSR system modeling for load buses in the vicinity of the plant under study.

The load model for the SSR study is based on a synthetic approach that builds on the knowledge of the actual load power (real and reactive), typical feeder characteristics, a fixed basis for division between resistive and motor load, and a fixed basis for motor power-factor correction.

The synthetic feeder model used in this study has the following components:

Ratio of feeder loading to feeder transformer rating = 0.6 p.u.
Fraction of active power load that is resistive = 0.40 p.u.
Feeder reactance on own base = 0.15 p.u.
Feeder X/R ratio = 10:1
Ratio of motor load to rating = 0.9
Motor sub-transient reactance on own base = 0.2 p.u.

Motor loss on motor base = 0.10
Feeder capacitive compensation, p.u. of feeder rating = 0.4 p.u.

Generator Modeling

The generator, for purposes of frequency scan analysis, has been modeled as an operational impedance (as used for small signal power swing stability analysis) using the standard operation impedance parameters given in the Siemens PTI PSS/E® dynamics database provided by Hydro One.

Torsional Dynamic Modeling

The torsional dynamic model provides the distribution of mass and stiffness of the complete turbine-generator by providing the polar moment of inertia of the rotors and stiffness of the connecting shafts.

There are typically three basic kinds of turbine-generators that require modeling: 1) steam turbines; 2) gas turbines; and, 3) single-shaft combined-cycle units that constitute a steam turbine, gas turbine and generator all connected in tandem on a single mechanical shaft. The steam turbines may be found in nuclear, conventional fossil fuel or multi-shaft combined-cycle power plants. Furthermore, in any one of these plants the steam turbine may be equipped with shaft driven auxiliaries such as feed-pumps and exciters, both of which require modeling.

The appropriate model consists of two masses per rotor and one mass for each coupling. This is generally mandatory for accurate modeling of Nuclear steam supplied turbine-generator units. For high-speed fossil units it is possible to use lower order modeling, such as lumping the coupling mass into the rotor. In any event an accurate model is required that provides a faithful representation in natural frequency and mode shape. Calculated data is generally adequate and has performed well against test results except for damping.

After the mode-shape and frequency, the damping is the most important parameter establishing stability in the presence of torsional interaction effects. Typically, the damping is small and cannot be calculated owing to its origin in the flow processes of the turbine at load and friction, windage and frettage at no-load. Damping is generally load dependent and generally very small – being the smallest when the unit is initially synchronized to the system at full-speed no-load.

The accuracy of torsional modeling can generally be established by test and is recommended at any stage in a study where there is a question of stability for the projected level of series compensation.

Multiple Units

In the case of the study of multiple units care is required in interpreting and handling the data. Generally, only multiple identical units at a single bus may be evaluated by the frequency scan method. In this case the units are modeled as a single larger unit rated for the combined rating of the units. For this condition the inertia increases and the stiffness decreases for multiple units to maintain the same natural frequency, mode shape, and damping ratio.

It is possible to handle dissimilar units of differing mode frequency by modeling the second unit electrically only. This case assumes the units are completely different and do not interact with one another.

The Study Methodology for SSR Screening using Network Freqeuncy Scans:

For SSR analysis the most important system variations are the level of series compensation and the network topology – that is, the electrical relationship between the unit(s) of concern and the series capacitors on the system. Unit commitment is the next most important variable for SSR effects (due to damping). For a multiple unit plant, the units will share any network sub-synchronous current in a ratio that is inversely proportional to their short circuit impedance. Two identical units will share the current equally and therefore have half the effect of a single unit operating alone. However, with one unit it takes a higher level of compensation to achieve the same natural frequency achieved with two units for the same network topology. Such compensation may not be available so it is possible that the multi-unit (identical units) case may have worse interaction than a single unit case.

The basic procedure for the SSR screening is to establish the conditions leading to: 1) the highest electrical system natural frequency (leading to interaction with mechanical modes having largest interaction potential); 2) the highest coupling between capacitor current and generator current; and 3) the lowest mechanical damping.

Generally speaking the conditions leading to the highest electrical system natural frequency are those in which the system is completely connected as planned, without outage and units at full load. By contrast the conditions leading to the highest coupling between series capacitor current and generator current are for single units operating at no-load during outages that leave the unit radial to the bus at which the series compensated line is connected. This latter case generally produces the lowest electrical natural frequencies for any given level of compensation.

This description of SSR potential as a function of system condition leads to a procedure for system analysis that can be formalized as follows:

- Establish outages for a radial topology to the series compensated line.
- Rank (list) the outages in order of their contribution to system strength, weakest first.

- Establish the radial configuration and then restore the outages one at a time weakest first.
- Evaluate torsional interaction levels for each topology.

The above procedure will establish whether or not SSR instability is possible for the study unit, and will also establish the margin of stability between worst cases and most probable operating conditions, if any. From these results a strategy for dealing with SSR can be established.

The focus of this present study is the main thermal units of the system namely, Bruce A, Bruce B, Lambton, Nanticoke, Pickering, Darlington and Lennox. Since Lakeview generation is being decommissioned, it was not studied. The hydro generators were also not studied, for two reasons:

1) They are electrically remote from the series compensated lines.
2) More importantly, it is a well know and documented fact in SSR literature that hydro generators are typically not susceptible to SSR. This is because the typical hydro turbine-generator consists of a relatively large and heavy generator connected through a long slender shaft to the turbine, which is a much smaller mass than the generator. This means that the single torsional mode that exists between the two is often neither observable nor controllable at the generator mass. Thus, it is not possible to affect an electro-mechanical resonance between the electrical network and the mechanical torsional mode.

2.1.6 Transfer Function Calculations

The above section describes the network impedance screening technique. This technique is very useful in quickly and effectively searching for the critical cases that lead to a network resonance that is problematic and likely to lead to damaging effects due to SSR. For example, as shown in section 3 and the Appendices, using this technique over a thousand cases were screened. However, in order to illustrate the effectiveness of a proposed solution strategy one may need to use other techniques such as calculating the actual transfer function from machine speed to electrical torque. This is often necessary since it is not possible to successfully illustrate the effectiveness of mititgation strategies such as a TCSC with the network impedance screening tool.

The transfer function technique uses a time domain three-phase model of the system to calculate the transfer function from the machine's electrical speed to the machine's electrical torque. Then the component of electrical torque that is in-phase with speed perturbations is calculated. This component, by definition, is the damping torque of electromagnetic origin and is the combination of inherent damping in the machine combined with the electrical interaction with the network and all other nearby active devices (other generators, HVDC, SVC etc.). Figure 2-3 illustrates the technique.

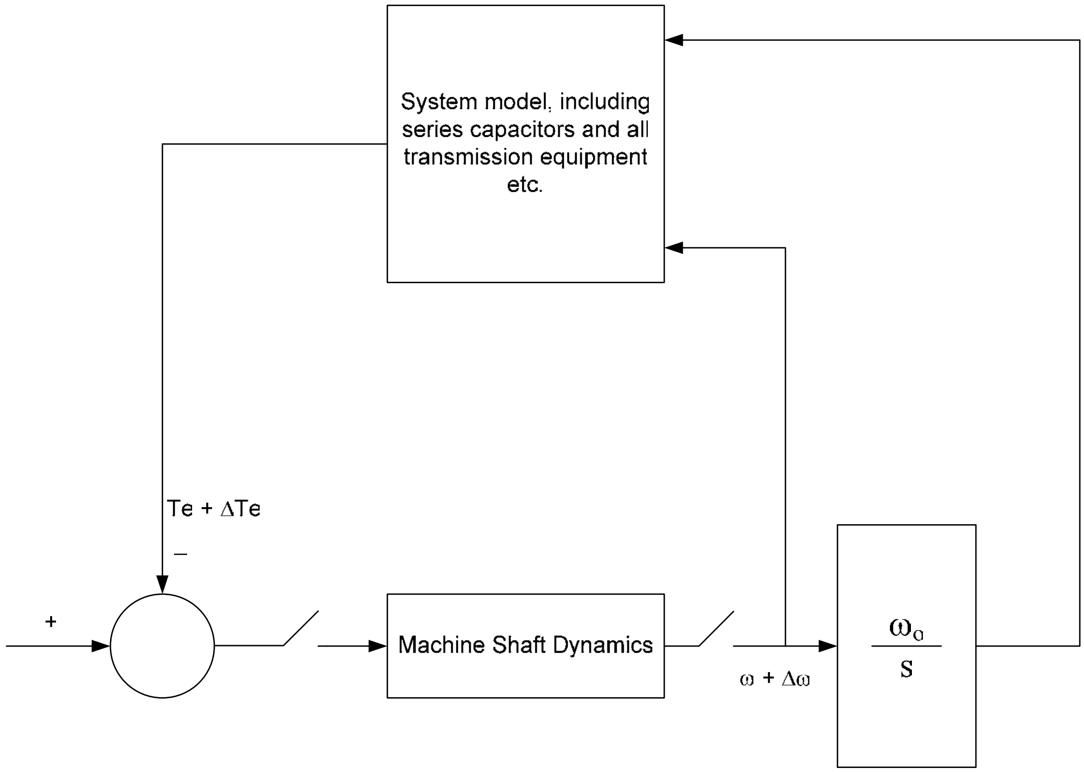

Figure 2-3. Calculation of speed to electrical torque transfer function

As shown, the mechanical systems of all generating units are removed (or disabled) from the model. This is not merely a simplification, it is an essential aspect that is needed in order to isolate the characteristics of the electrical system and to measure them properly.

A sinusoidal speed perturbation signal is injected into the machine model ($\Delta\omega$) and the resulting perturbation in electrical torque (ΔTe) is measured. The transfer function from speed to electrical torque is then calculated ($\Delta Te/\Delta\omega$). As described earlier, the real part of this transfer function, which is in phase with the initial speed perturbation, represents a damping torque:

$$De = \mathrm{Re}\left(\frac{\Delta Te}{\Delta\omega}\right) \tag{5}$$

This real part is then extracted. The calculation is repeated over the requested frequency interval, and the results are depicted as a family of curves showing electrical damping versus rotor frequency, with a separate curve for each studied system condition. In addition, since the focus here is on small-signal response, the sinusoidal speed perturbation injected into the model is of relatively small magnitude. What is produced by this technique, then, is the small-signal characteristics of the system valid at the operating point of interest.

2.1.7 Time-Domain Simulations

Finally, for the critical cases identified, time domain simulations are performed with all components, including machine mechanical shafts, represented. In this case transmission faults are simulated in order to observe both the initial transient torque response of the machine as well as to identify whether the torsional modes are stable or unstable in the aftermath of the event. The transient torque analysis performed here is very much preliminary and with the objective of simply illustrating the effectiveness of the proposed mitigation strategies. Detailed transient torque analysis will be necessary once an actual design has been chosen. Much of the transient torque response of the machine is dependent on actual fault clearing times and the nature of the series capacitor protection system, e.g. gapped, fast-bypass breaker, MOV or a combination of these. While the detailed design of the system was not a part of the scope of this work, reasonable assumptions were made in providing MOV protection for all of the series capacitors.

3 Results of the SSR Analysis

3.1 Base Case Development for Network Freqeuncy Scans

To perform the system frequency scan analysis described in the previous section, a system model had to be developed. This was done by starting with the Siemens PTI PSS/E® data provided by the IESO. The model used was 'jul05f_rev3final.sav'. To this model was added all five series capacitors shown in Figure 1-1. The following assumptions were made:

1) The Bruce to Longwood lines are compensated by 70% each (that is the impedance of the series capacitor is 70% of the total line reactance between the two substations).
2) The Longwood to Nanticoke line is also compensated by 70%.
3) The Bruce to Milton and Claireville lines are compensated by 10%.
4) All series capacitors are physically located at the mid-point (50% along the line) of each respective line.

These assumptions are based on the recommendations of studies performed by Hydro One and IESO for the location and size of the series capacitors. In parallel with this SSR analysis work, ABB performed loadflow and stability studies to verify these assumptions and make any other necessary recommendations. However, for the purposes of the SSR analysis the objective is to identify potential SSR concerns and means of mitigation. To proceed with the study, a proposed size and location for all of the series capacitors had to be assumed. Thus, the size and location of series capacitors proposed by Hydro One and the IESO based on studies performed hitherto were adopted.

Figure 3-1 shows diagrammatically the boundaries of the model. As shown, the Ontario system interconnects to five other states/provinces within the eastern North American interconnected system. The interconnections to Quebec, as represented in the power flow case, were radial. That is, they are lines that go into the province of Quebec that feed load but are not actually connected to the electrical grid in Quebec. As such, these radial loads were kept in our model. All other interconnecting lines are remote from the bulk 500 kV transmission system in Ontario and are on underlying transmission voltages (i.e. 345 kV, 230 kV, and 118 kV). As such, these interconnections were represented at the boundaries of Ontario as a source behind a positive sequence Thevenin equivalent. The Thevenin equivalent impedance was determined by short-circuit calculations using a short-circuit database provided by Hydro One (also in PSS/E® format but separate from the power flow case). These Thevenin equivalent impedances are listed in Appendix A. This is a reasonable representation for what is being studied here, since sensitivity analysis showed that the results of the frequency scans change negligibly between the case where all these equivalents are removed and when they are all in-service. As an example, Figure 3-2 shows a sample frequency scan plot for one of the critical conditions discussed in the next section. The plot shows the case with all these boundary equivalents connected and disconnected. As can be seen, disconnecting the boundary equivalents has a negligible effect on the results.

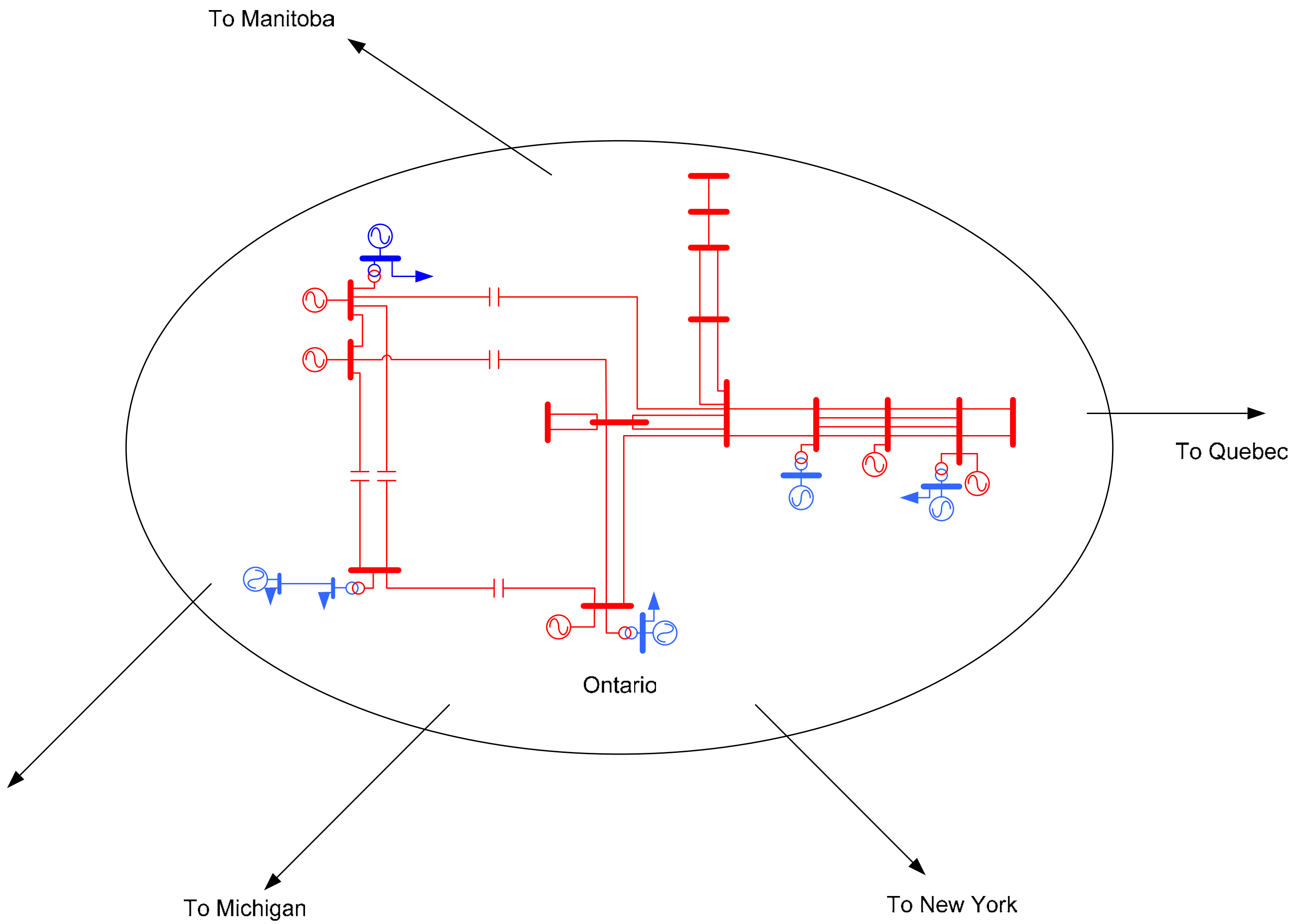

Figure 3-1: Model boundaries.

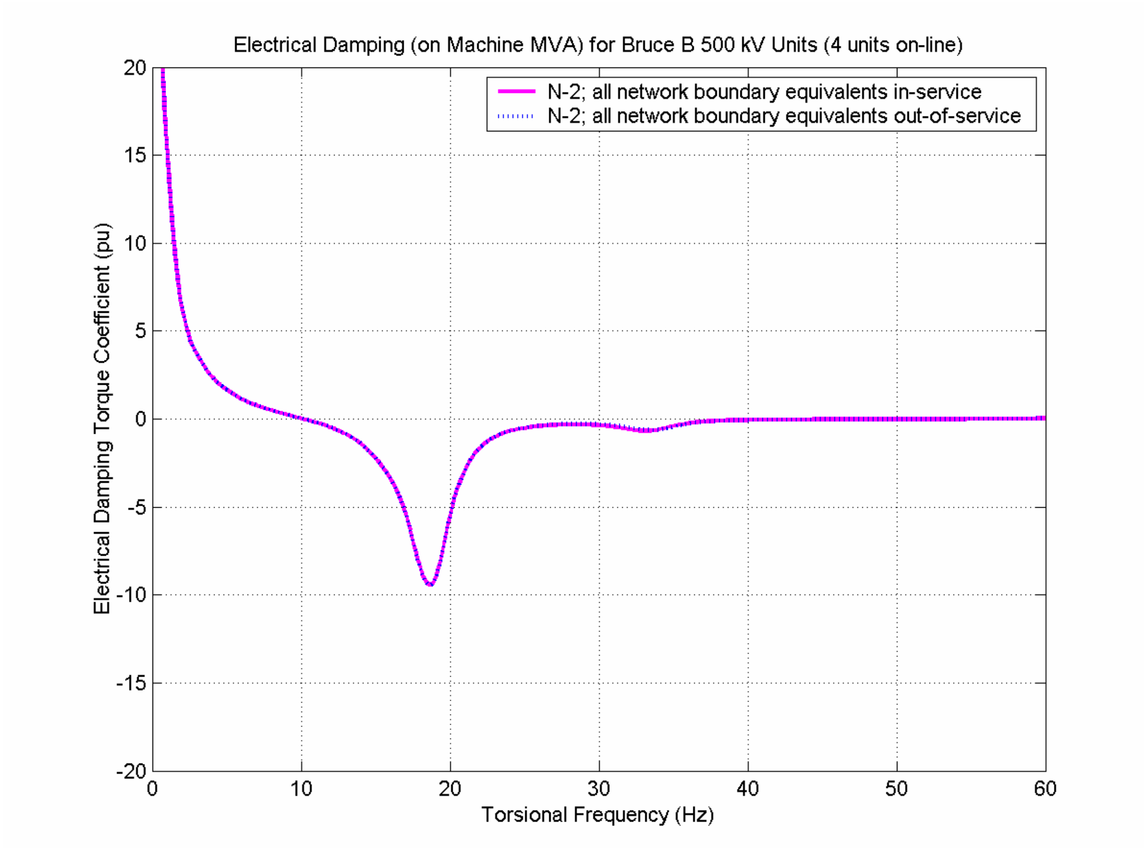

Figure 3-2: Comparison of frequency scan results with and without the boundary equivalents connected to the model.

3.2 Torsional Data

The torsional mechanical data for the turbine-generator shaft of each of the study units is needed for several reasons:

1. *<u>To assess the potential impact of SSR on the generator based on the frequency scan results</u>:* The network frequency scan analysis helps to identify the induced damping torque coefficient of electromagnetic origin on the shaft of each study unit. If significant resonant conditions leading to negative electrical damping torque are identified, then the points of resonance and the region of negative electrical damping torque need to be compared with the expected mechanical damping and mechanical torsional frequencies in order to identify the potential for destabilization of the mechanical torsional modes. If the amount of negative electrical damping exceeds the mechanical damping at a torsional frequency, then the corresponding mode will become unstable and potentially lead to shaft damage.
2. *<u>To be able to model the mechanical shaft for more detailed transient torque analysis:</u>* For some of the key cases identified in the analysis in this report,

additional studies were performed to further quantify the potential risk of damage to the shaft of turbine-generators. Some of this work involved performing detailed time-domain simulations using a three-phase model of the electrical network as well as the turbine-generators and the mechanical shafts. By simulating disturbances on the system one is able to identify the transient torques on the turbine-generator shafts as well as whether or not the shaft torsional modes destabilize in time following a given disturbance/contingency. For such an analysis the turbine-generator shaft needs to be modeled as a multi-mass mechanical system.

Presently, torsional frequencies have been provided by Bruce Power and OPG for all of the units under study. Spring-mass models have also been provided by Bruce Power for the Bruce units. However, spring-mass have not been provided for any of the OPG units. As shown in the analysis in section 3.3, the only units significantly affected by SSR that thus required further analysis were Bruce A, B and Nanticoke. As such, the only OPG unit for which a spring-mass model is required is Nanticoke. OPG has indicated that the turbine-generator manufacturers will provide this information for the Nanticoke units soon. As of January 16th, 2006 this data has been received for Nanticoke units 7 & 8, however, the data for units 1 through 6 has not yet been received.

No mechanical damping information has been supplied by any of the manufacturers for any of the units under study.

3.3 Results of the Network Frequency Scan Analysis

The frequency scan analysis was performed for seven power plants:

- Bruce A – a nuclear power plant with units connected to both the 500 and 230 kV[1] networks
- Bruce B – a nuclear power plant with units connected to the 500 kV network
- Lambton – a fossil fuel steam power plant connected to the 230 kV network
- Nanticoke – a fossil fuel steam power plant with units connected to both the 500 and 230 kV networks
- Pickering – a nuclear power plant connected to 230 kV lines that feed radially into a 500 kV substation
- Darlington – a nuclear power plant connected to 230 kV lines that feed radially into a 500 kV substation
- Lennox – a fossil fuel steam power plant with units connected to both the 500 and 230 kV networks

Figure 1-1 shows diagrammatically the relative location of all these power plants to the proposed series capacitors.

[1] On system one-lines, the underlying transmission voltage below the 500 kV network is referred to as 230 kV. However, in the actual power flow database the system per unit voltage base for this lower voltage level is set at 220 kV.

The approach taken was to study each of these seven plants, one at a time, with the series compensation levels as stated in section 3.1. Also, the system load and generation dispatch was kept the same as that presented in the base case power flow database 'jul05f_rev3final.sav'. For each plant, however, various combinations of units in and out of service were investigated to cover the range of possible operating scenarios at each plant.

In general, many of the scenarios studied and described below are not necessarily indicative of typical operating conditions. In fact, most of the system configurations considered are extreme – some may be operationally unsustainable from a steady-state and transient stability perspective. This approach is intentional since the objective in this analysis is to find conditions conducive to SSR and establish mitigations techniques. One clear mitigation technique is that if the condition is an extremely or rather unlikely operating condition, then the system should be operated around that condition and automated protection be put into place to bypass the series capacitors prior to reaching that condition.

3.3.1 Lambton, Lennox, Darlington and Pickering

A vast number of network frequency scans were performed for Lambton, Lennox, Darlington and Pickering power plants. The results are presented in Appendices F to I. The plots in Appendices F to I show that in order to achieve a resonant condition that would result in any significant negative electrical damping torque, system conditions leading to the loss of twelve or more transmission elements[2] are required. To be more specific, the first significant indication of resonance for each of these four power plants and the series capacitors on the 500 kV lines are seen when:

- Darlington is left radial to the series capacitor on the Longwood to Nanticoke 500 kV line. This requires the outage of twenty transmission elements.
- Lambton is left radial to the series capacitors on the 500 kV series capacitors on the lines into Longwood. This requires the outage of at least twelve transmission elements.
- Lennox is left radial to the series capacitor on the Longwood to Nanticoke 500 kV line. This requires that at least thirty-seven transmission elements be out of service.
- Pickering is left radial to the 500 kV series capacitors. This requires that at least twenty-eight transmission elements are out of service.

It is clear from the above results that truly extreme conditions are required to result in a resonance (SSR) between the torsional modes of units at Lambton, Lennox, Darlington or Pickering and the series capacitors of the proposed size and location shown in Figure 1-1. This is not an unexpected result. A review of Figure 1-1 shows that there are numerous substations (and in some cases one level of voltage transformation) between the generating units at these four power plants and the proposed series capacitors. As such,

[2] By transmission elements here is meant 500 or 230 kV transmission lines, or 500/230 kV substation transformers.

all these shunt and parallel paths essentially shield the units from a resonant condition. One needs to eliminate all of these shunt paths to establish an essentially radial configuration between the units and the series capacitors to cause resonance. It is noted that even then the resonant conditions are, in some cases, not within the range of the torsional modes of the unit. For example, for Lambton under an N-12 (twelve elements out) condition there is a negative dip in damping torque due to resonance but it occurs around 37 Hz, which is not in the vicinity of any of the torsional modes of this unit.

In essence, the basic conclusion in terms of these four power plants is that in the extremely rare event that the bulk transmission system is being restored after the loss of a large number of transmission lines, all the series capacitors on the 500 kV lines should be bypassed until the bulk transmission system has been restored. Once the system is fully in tact and heavy power transfers commence, then the series capacitors may be inserted.

Given the above results, it is not necessary at this stage to perform any more detailed analysis related to torsional interaction for these four power plants since under a fully intact or under standard planning contingency criteria (i.e. NERC Category A, B, C and D) there is no noticeable resonant conditions between any of these turbine-generators and the proposed series capacitors. As such, transient shaft torques should not be impacted by the presence of the series capacitors (for the proposed size and locations in this study) following an electrical network disturbance leading to a NERC Category B or C outage.

3.3.2 Nanticoke

There are eight units at Nanticoke. Four connected to the 500 kV substation and four at 230 kV. The electrical parameters and torsional modal frequencies of the machine were updated and new parameters provided by OPG after the study meeting in October 2005. As such, the simulation work presented in the interim report (dated 10/14/05) had to be redone. These new simulation plots are presented in this report. The changes in machine electrical parameters did not significantly affect the simulation results and thus did not change any of the conclusions of the analysis. In essence, units 1, 3, 6 and 8 are identical electrically, and units 2, 4, 5 and 7 are also identical electrically, but the two groups differ from one another. Mechanically, units 1 to 6 are indentical, and units 7 and 8 are identical, but the two groups differ from one another. This was all taken into consideration for the analysis performed.

A complete set of plots are provided for the frequency scan analysis for Nanticoke in Appendix E. A quick perusal of the results presented in that appendix shows that it takes at least two line outages to start to see a significant resonant condition. For the 230 kV connected units, it takes at least an N-4 conditions in addition to all the 500 kV units being off-line in order to get some significant level of negative damping torque due to resonance. The exact outages, and numerous other cases, are explained in Appendix E.

In general, it can be said that the 500 kV units are much more susceptible to SSR. Furthermore, the least number of lines that need to be outaged to lead to a problematic condition are:

(i) An N-2 condition – loss of the Nanticoke to Milton and Nanticoke to Claireville 500 kV lines, or

(ii) An N-4 condition – loss of both Nanticoke to Milton and Nanticoke to Claireville 500 kV lines, and the two 500/230 kV transformers at Nanticoke.

The above two conditions were investigated further by performing sensitivity runs to variations in the level of series compensation. This was done by calculating the damping torque coefficient (for the 500 kV units) at the torsional modal frequencies (given in Appendix B) for various levels of series compensation. The results are plotted in Appendix J in the form of 3-D plots. Each plot in Appendix J shows the electrical damping torque coefficient plotted versus variations in the level of series compensation on all five series capacitors.

A perusal of the results in Appendix J leads to the following conclusions:

1) In general, the SSR problem at Nanticoke is not highly influenced by the level of series compensation on the Bruce to Milton and Bruce to Claireville lines. In fact for the highest and lowest frequency torsional modes, the level of series compensation on these lines has little effect on electrical torsional damping.
2) There is very little negative damping introduced at the lowest and highest torsional modes, even at 70% compensation.
3) As might be expected, the capacitor that most influences the SSR phenomenon on the Nanticoke units is that on the Longwood to Nanticoke 500 kV line. (Note: electrical connections down to the 230 kV level, and thus the load at Longwood, essentially shield out the effect of the series capacitors on the Bruce to Longwood lines. Cases with the loss of the transformers down to 230 kV at Longwood were simulated and are reported on in Appendix E – these cases alone are not as severe as the N-2 and N-4 cases discussed here.)

In general, the frequency scan results indicate that the Nanticoke 500 kV units are more succeptible to SSR than the 230 kV units, as would be expected. Furthermore, their succeptability to SSR is likely a concern only for N-4 conditions and above. Also, the results show that the primary influence comes from the Nanticoke – Longwood series capacitor. Thus, a plausible solution would be to simply bypass the Nanticoke – Lonwood capacitor for say N-3 and higher contingency scenarios. To fully illustrate this further time and frequency domain analyses on the 3-phase model are necessary. This work has been done for the Bruce units, but for the Nanticoke units it remains to be completed pending the receipt of all the spring-mass shaft models for these units.

3.3.3 Bruce A

There are four nuclear units at Bruce A. Two units are connected to the 500 kV transmission and two are connected to the 230 kV. All have identical electrical parameters and are assumed to be identical mechanically as well. As such, they have been treated as identical units for the purposes of the SSR screening analysis.

A complete set of plots are provided for the frequency scan analysis in Appendix C for Bruce A. A perusal of the results in Appendix C leads to the following conclusions:

1) With all lines and generating units at Bruce in service, there is no region of negative damping torque at the modal frequencies.
2) For the 230 kV units, the worst condition is with all Bruce A 500 kV units off line, and with both the Bruce A to Bruce B 500 kV line and the Bruce A to Claireville 500 kV lines out of service (contingency N-2e).
3) For the 500 kV units, the worst two conditions are (i) the loss of both the Bruce A to Bruce B 500 kV line and the Bruce A to Claireville 500 kV line (contingency N-2e), while the Bruce A 230 kV units are off-line, and (ii) the loss of five elements, namely the loss of Bruce A to Bruce B 500 kV line, Bruce A to Claireville 500 kV line and all three 500/230 kV transformers (contingency N-5d).

For these particular outages, a sensitivity analysis was performed for variations in the level of series compensation. These results are given in Appendix K. Based on a perusal of these results, the following conclusions can be drawn:

i. For the lower frequency torsional modes (8.66 Hz and 16.06 Hz) there is negligible negative damping torque induced even with the series compensation at 70% on the Bruce to Longwood and Longwood to Nanticoke lines. So the likelihood of destabilizing these modes is extremely low even under these severe outage conditions.
ii. For the two torsional modes around 23 Hz, there is some significant negative electrical damping torque due to resonance, which increases with increasing compensation on the Bruce to Longwood and Longwood to Nanticoke lines. At a compensation level of roughly 40% or less, even for these critical outages, there is little negative electrical damping torque. Also, note that even at 70% compensation, the worst negative damping torque coefficient observed is around -15 pu. The manufacturer data provided damping information for only one mode, the 8.66 Hz mode. Assuming the same damping ratio as this mode for the higher frequency modes, at no-load the mechanical damping available for the 23.27 Hz mode would be 0.65 pu and for the 23.89 Hz mode it would be 4.4 pu. At full-load the mechanical damping will be higher (possibly as much as five times or more higher). As such, for partially loaded or fully loaded conditions there may in fact be enough mechanical damping to avoid instability of the 23.89 Hz mode. For the 23.27 Hz mode, however, this may not be true under the most severe case (N-5 case). Thus this condition must either be operated around (i.e. by-pass all three capacitors) or a portion of the capacitors should be replaced by a thyristor controlled series capacitor (TCSC).

3.3.4 Bruce B

There are four nuclear units at Bruce B. All have identical electrical parameters and are assumed to be identical mechanically as well. As such, they have been treated as identical units for the purposes of the SSR screening analysis.

A complete set of plots are provided for the frequency scan analysis in Appendix D for Bruce B. These results indicate that for Bruce B it takes only a single or double line outage to lead to a significant resonant condition. The worst outages are either the loss of the Bruce A to Bruce B 500 kV line (N-1) or the loss of both this line and the Bruce B to Milton 500 kV line (N-2). For these two conditions a series of sensitivity runs was performed for variations in the level of series compensation. These results are given in Appendix L. Based on a perusal of these results, the following conclusions can be made:

i. For the lowest frequency torsional mode (7.5 Hz) there is no negative damping torque induced even with the series compensation at 70% on the Bruce to Longwood and Longwood to Nanticoke lines. So the likelihood of destabilizing this mode is unlikely.
ii. For the higher torsional modes, the dominant series capacitors are those on the Bruce to Longwood line. At a compensation level of roughly 40% or less, even for these outages, there is little negative electrical damping torque. Thus, if the series compensation is not required for operating purposes, one may by-pass all or part of the series capacitors for these conditions. Otherwise a portion (e.g. 30 to 40 %) of the capacitors should be replaced by a thyristor controlled series capacitor (TCSC).

A point of interest is that the 22.25 Hz torsional mode for Bruce B is actually not observable at the generator (the generator does not participate in this mode). As such, it is not possible to destabilize this mode through SSR.

3.3.5 Other Sensitivity Analyses

Compensation and Load Sensitivity
Appendix M and N present results for various sensitivity runs associated with varying the level of series compensation and load level for the critical units and outages. The analyses show two key conclusions:

1) The load level does have some impact of damping. Namely at lower system load levels the amount of electrical damping becomes more negative at the resonant frequencies. The frequency of resonance is impacted only a slight amount by such variation. Nonetheless, even at 50% system load the level of damping does not reduce by a large amount.
2) The 10% series capacitors on the Bruce to Milton/Claireville lines may potentially be increased to as much as 20 or 30% without significantly affecting the electrical damping at the torsional frequencies of the Bruce units. Even at 30%, the negative resonant dip of the damping torque curve is still

about 35 Hz – the highest frequency torsional modes for the Bruce A and B units are around 23 Hz.

Induction Generator Effect

Note that in all the Appendices, plots have also been provided showing the apparent resistance as a function of frequency as seen from the generator under study. In no case was a negative effective resistance at or around the frequency of resonance observed. Thus, there does not appear to be any cases potentially susceptible to an electrical resonance or more commonly referred to as the ‘induction generator effect [7].

3.3.6 Summary of Frequency Scan Results

In summary, based on the network frequency scanning technique, only three of the exisiting generating plants were found to be significantly succeptible to SSR. These are the Bruce A, Bruce B and Nanticoke power plants. All other power plants are sufficiently remote from or meshed into the transmission grid, relative to the location of the proposed series capacitors, that it would take at least twelve or more transmission element outages to introduce a potential resonance. In most cases this is still not necessarily a problem, from an SSR point of view, since the resonance dose not correspond to a torsional frequency of the turbine-generator.

Based on these results, the rest of this report focuses on these three power plants, Bruce A, Bruce B and Nanticoke. Furthermore, based on the frequency scanning techniques the most critical conditions for these units are as follows:

Bruce B:

N-1 – loss of Bruce A to B 500 kV line
N-2 – loss of Bruce A to B and Bruce B to Milton 500 kV lines

Bruce A:

N-1b – loss of Bruce A to B 500 kV line
N-2e – loss of Bruce A to B and Bruce A to Clairville 500 kV lines (for 230 kV units with all 500 kV units off-line)
N-5d – loss of Bruce A to B and Bruce A to Clairville 500 kV lines and all three 500/230 kV transformers (critical case for 500 kV units)

Nanticoke:

N-4a – loss of both Nanticoke to Middleport 500 kV lines and both 500/230 kV transformers at Nanticoke (critical case for 500 kV units)
N-6 – loss of both Nanticoke to Middleport 500 kV lines and all four 230 kV lines out of the Nanticoke 230 kV substation, with all four 500 kV units off-line (critical case for 230 kV units)

Figures 3-3, 3-4 and 3-5 show the electrical damping plots for the above listed cases. The following section will further quantifiy and revalidate the concerns related to these cases and then present clear and effective mitigation strategies for dealing with these concerns.

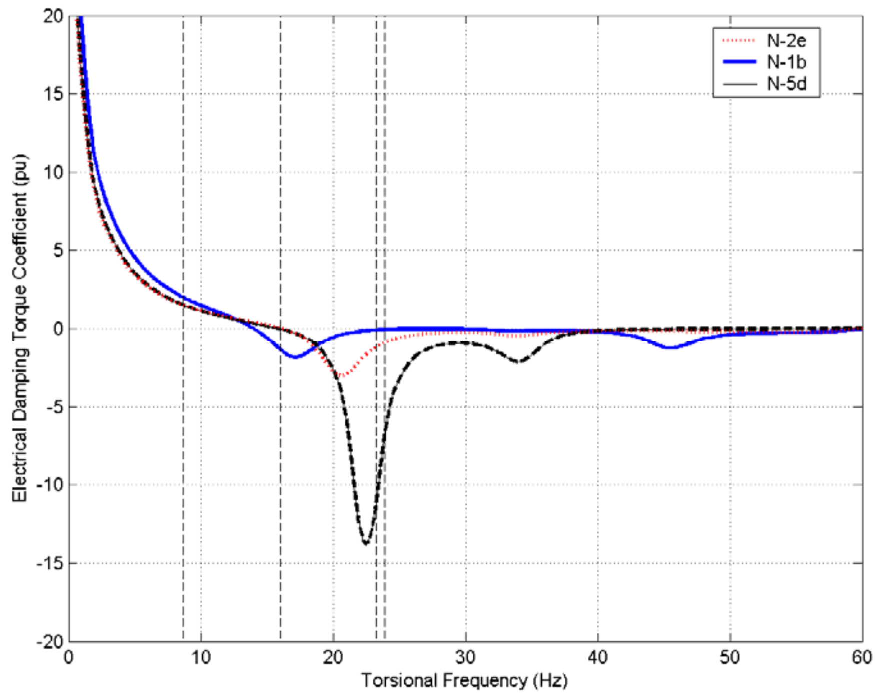

Figure 3-3: Key contingencies for Bruce A generating units. The plots for contingencies N-1b and N-5d are for the 500 kV units with the 230 kV units off-line. Contingency N-2e is for the 230 kV units with the 500 kV units off-line. The dashed vertical lines indicate the frequencies of shaft subsynchronous torsional modes.

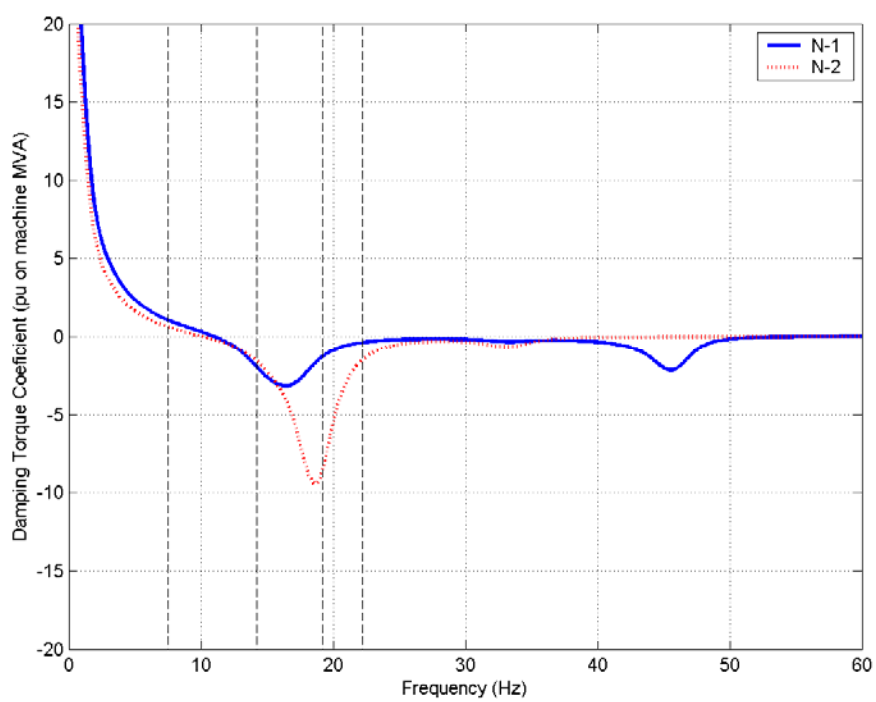

Figure 3-4: Key contingencies for Bruce B 500 kV generating units. The dashed vertical lines indicate the frequencies of shaft subsynchronous torsional modes.

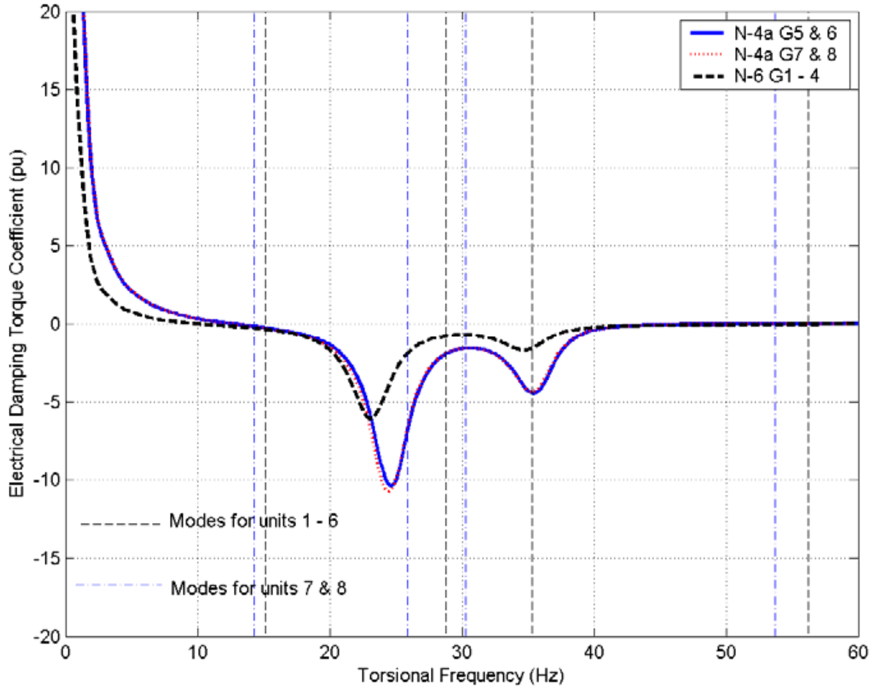

Figure 3-3: Key contingencies for Nanticoke generating units. The plots for contingencies N-4a are for the 500 kV units. Contingency N-6 is for the 230 kV units with the 500 kV units off-line. The dashed vertical lines indicate the frequencies of the shaft subsynchronous torsional modes.

3.4 Transfer Function Calculations

The network frequency scanning technique reported in the previous subsection was used to identify the critical cases. As shown, the only units with significant risk of SSR are the Bruce A and B power plants and the Nanticoke units. As such, transfer function calculations and transient torque/time-domain simulations are only necessary for these generators. As a first step a model was developed for such analysis.

3.4.1 Three Phase System Model for Transfer Function and Time Domain Smualtions

A three-phase model of the system was developed in the PSCAD/EMTDC® simulation platform. Initially, an attempt was made to model the entire Ontario power system (same boundaries as the model used for network frequency scans). This proved to be impractical from a simulation time perspective. That is, it would take more than 8 hours to run a single simulation. As such, the approach taken was to develop a simplified model adequate to capture the resonant phenomena for the area of interest. The extent of the simplified model is shown in Figure 3-5. In essence the major 500 kV loop from Bruce to Claireville to Nanticoke and back to Bruce has been modeled explicitly, together with all transmission and generator step-up transformers. Also, the generating units have been modeled explicitly. All the 230 kV network and the 500 kV network east of Claireville was then reduced to source and transfer impedances. The results that are presented below with no SSR mitigation, illustrate the validity of the model for the present analysis. Also, in Appendix U a comparision is given between 3-phase short circuit levels at key buses for the full and simplified system model showing good agreement between the two. Loads were modeled as constant impedance loads and lumped at the boundary buses at 230 kV. Power plant loads were modeled explicitly at the terminals of each generator.

To verify that this simplified model would give the same network frequency response as the full system model (in the range of torsional frequencies), the critical outage scenarios were simulated again using the frequency scanning technique of section 3.3 using the simplified model. An example of these results is shown in Figure 3-6. A complete set of comparisons between the full system model, the simplified model and the transfer function calculation is given in the next subsection.

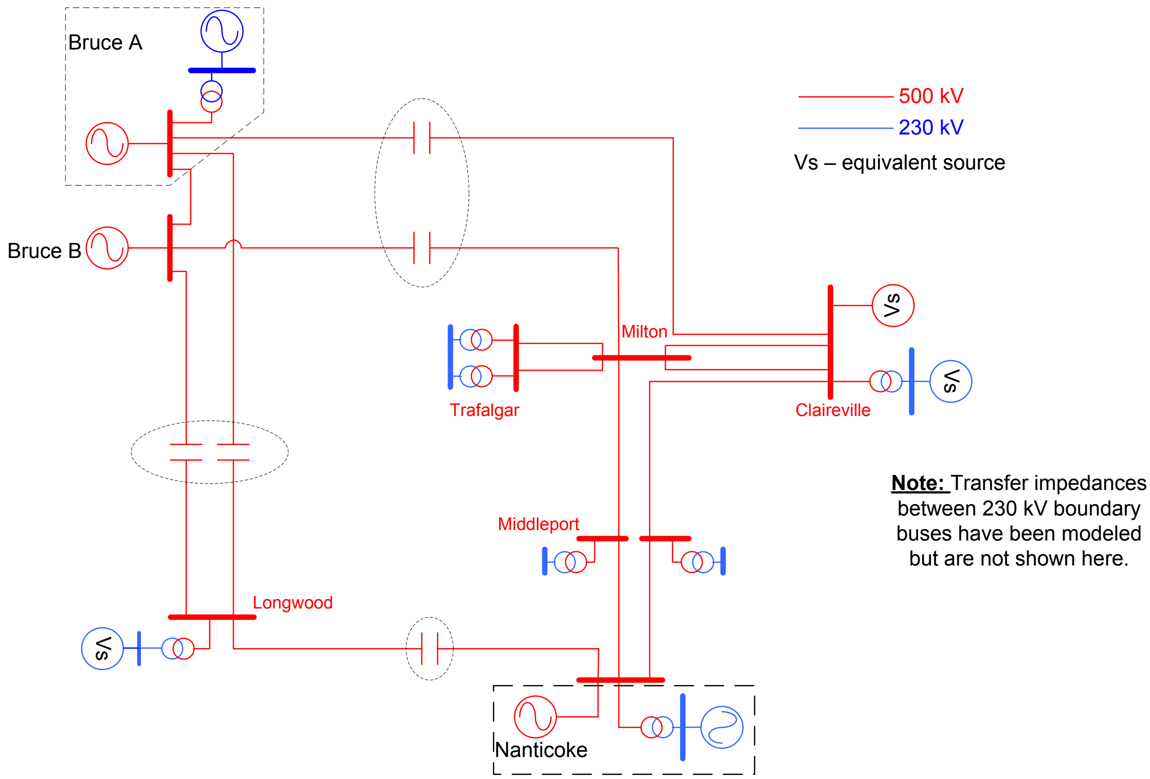

Figure 3-5: Simplified system model developed in PSCAD/EMTDC®. Boundary buses are at Clariville 500 & 230 kV, Middelport 230 kV, Nanticoke 230 kV, Longwood 230 kV, Trafalgar 230 kV and Bruce A 230 kV.

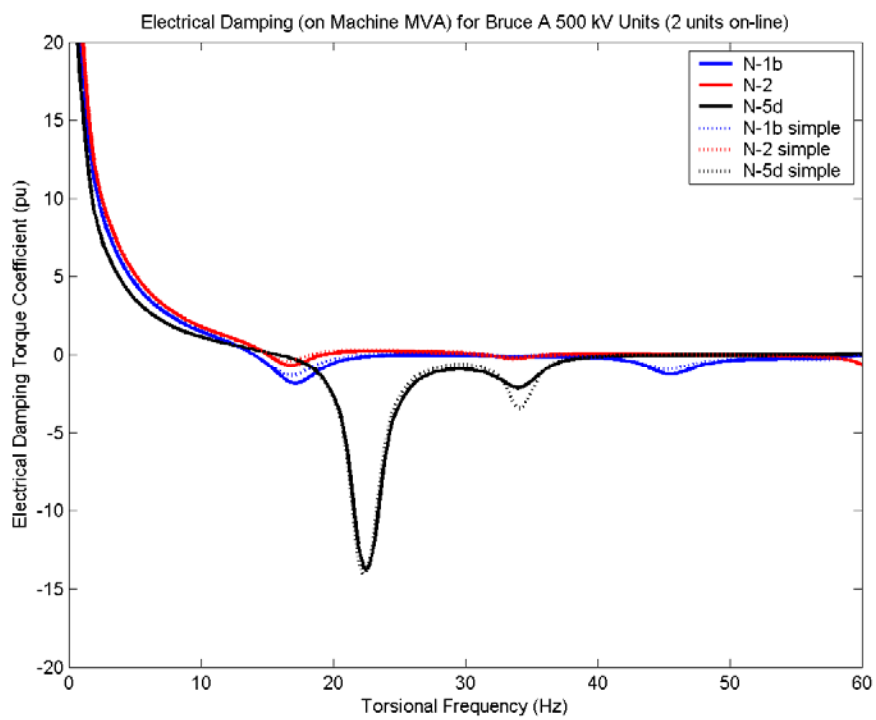

Figure 3-6: Network frequency based calculation of electrical damping torque. Comparison between simplified system model and full-system model.

3.4.2 Results of the Transfer Function Calculations – Without Mitigation

Transfer function calculations were made to determine the electrical damping torque for the Bruce B, A and Nanticoke untis under the critical outages determined through frequency scanning techniques. The cases evaluated were:

- All four Bruce B units on-line and the outage of the Bruce B to A 500 kV line (N-1)
- All four Bruce B units on-line and the outage of the Bruce B to A and Bruce B to Milton 500 kV lines (N-2)
- Both Bruce A 500 kV units on-line (230 kV units off-line) and the outage of the Bruce B to A 500 kV line (N-1b)
- Both Bruce A 500 kV units on-line (230 kV units off-line) and the outage of the Bruce B to A 500 kV, Bruce A to Clairville 500 kV and all three Bruce A 500/230 kV transformers (N-5d)
- Both Bruce A 230 kV units on-line (500 kV units off-line) and the outage of the Bruce B to A 500 and Bruce A to Clairville 500 kV lines (N-2e)
- Nanticoke units 5 & 6 500 kV on-line (all 230 kV units on-line) and the outage of Nanticoke to Middleport 500 kV lines (2-circuits) and both Nanticoke 500/230 kV transformers (N-4a)
- Nanticoke units 7 & 8 500 kV on-line (all 230 kV units on-line) and the outage of Nanticoke to Middleport 500 kV lines (2-circuits) and both Nanticoke 500/230 kV transformers (N-4a)
- All 230 kV Nanticoke units on-line (all 500 kV units off-line) and the outage of Nanticoke to Middleport 500 kV lines (2-circuits) and all other 230 kV circuits out of the Nanticoke 230 kV substation (N-6)

Plots of the results of the transfer function based calculation of electrical damping torque are given in Appendix O. In addition, on each plot the calculated electrical damping torque based on the network frequency scanning technique used in section 3.3. is also given, for both the full and simplified network model. As shown, there is good agreement between the three results. This provides greater confidence in the general observation that these particular scenarios are succeptible to torsional mode destabilization due to SSR conditions.

<u>*Data Issues:*</u>
After the bulk of the analysis was performed, updated machine model parameters were provided for the Bruce A units by Bruce Power on 11/16/05 and then again on 1/9/06. Thus, with the exception of a few sensitivity cases performed to quantify the impact of the change, the results presented in this reportv are based on the originally supplied machine data, since these modifications were not received in time to be included in the bulk of the simulation work. Plots have been provided in Appendix P to show the comparison of the calculated electrical damping torque (based on the transfer function calculation technique) for the Bruce A machines under the most critical contingency scenarios. As shown, the new machine electrical parameters have no significant impact on the resonant frequency or level of damping in the torsional range of frequencies.

Bruce Power also indicated that the PSSs on their units are presently being retuned. As such, none of the PSSs were incorporated in our analysis. This should not impact any of the results, since properly tuned and designed PSSs should not affect electrical damping torque in the range of frequencies outside of 0.1 to 2 Hz.

One other data issue that was identified during the October 2005 meeting with Hydro One and other stake holders was related to the way that transformers have been modeled in the PSS/E® database. In early November, 2005 Hydro One (and Bruce Power and OPG) provided name plate data for the various transmission transformers and generator step-up transformers. As such, the PSCAD/EMTDC® model developed for the purpose of time domain and transfer function calculations was developed by using transformer models based on name plate data, as opposed to the PSS/E® data originally supplied. Since the frequency scaning technique looks purely at the impedance of branch elements (ignoring transformer taps) this results in a slight discrepancy in the effective impedance of the transformers between the network frequency scanning model and the PSCAD/EMTDC® model. This is the primary reason for the slight (1 or 2 Hz) difference between the resonant peaks observed using the frequency scan techniques versus actual damping torque calculations using the PSCAD/EMTDC® model (see plots in Appendix O). The difference in damping (between the network frequency scanning model and the PSCAD/EMTDC® model) is due mainly to differences in load modeling and the nature of the model. In PSCAD/EMTDC® the loads were modeled as constant impedance loads. Furthermore, all simulation were based on time domain calculations that result in perturbations in voltage as well as frequency. There is no way of capturing the effect of voltage perturbations in the network frequency scaning techniques.

Note: ***In the following sections, with few specifically discussed exceptions, the analysis pertains only to the Bruce A and B units. Analysis pertinent to the Nanticoke units will be performed once all the necessary data for all of those units have been received.***

3.4.3 Results of the Transfer Function Calculations – With Mitigation by using TCSC

The results discussed in the previous section, and presented in Appendix O, showed good agreement between the network frequency scaning technique and the transfer function calculation methodology. This confirms that the critical cases identified in the frequency scanning phase of the work as indeed of concern. Now the results including a mitigation strategy to eliminate the SSR phenomena in these case for the Bruce A and B generators will be presented. This was done with the introduction of a thyristor-controlled series capacitor as a portion of the series capacitors on the Bruce to Longwood lines. It should be noted that other means of mitigating SSR have been used in the past, e.g. supplemental damping controls designed and implemented directly into the generating unit excitation system or passive filters tuned to subsynchronous frequencies and integrated into the generator step-up transformers. However, there are two concerns/considerations with these strategies:

1. Bruce Power, OPG and Hydro One indicated that they did not want to pursue generator based SSR mitigation solutions.
2. Generator based solutions needed to be implemented on each generating unit affected by SSR and tuned one by one. Furthermore, if new thermal turbine-generators are introduced into the system which may be susceptible to SSR, they too will required similar mitigation devices. Finally, if the rotor or turbine of an existing unit is refurbished resulting in a significant shift in a torsional mode of concern, then the generator based SSR mitigation device (e.g. supplementary damping controller) will require retuning and testing.

A TCSC based solution tends to eliminate the network resonance in the frequency range of concern and thus removes the problem for existing and future units – there are some special considerations, however, pertaining to wind generating units that are further discussed in section 4.

First a brief description of the thyristor-controlled series capacitor (TCSC) is pertinent. The ABB TCSC control strategy is based on the concept of synchronous voltage reversal (SVR). This concept is described in more detail in the literature [8, 9]. Figure 3-7 shows the general concept of TCSC control. The forward biased thyristor is fired just prior to a capacitor voltage zero crossing. This effects an additional amount of current being injected into the capacitor (reverse current coming through the thyristor). As such, the voltage across the capacitor "jumps up" further when crossing zero and thus the effective voltage across the capacitor is increased and so to is the apparent impedance of the capacitor at fundamental frequency – that is the capacitor, at 60 Hz, appears to be a higher impedance capacitor. In this way the apparent impedance of the capacitor, at fundamental network frequency, can be regulated. This control strategy is shown pictorially in Figure 3-8. A phasor measurement is made of the line current and capacitor voltage. Based on this measurement the apparent impedance of the capacitor is calculated at fundamental frequency. This apparent impedance is then compared to the reference (K_{Bref}) – this reference is commonly refered to as the boost factor and is equal to the ratio of the desired apparent impedance of the capacitor to the actual physical impedance of the capacitor at fundamental network frequency. The boost controller then sends a control signal to the SVR controller based on the error between desired and actual apparent impedance of the series capacitor. The SVR controller then adjusts the firing angle of the thyristors in order to yield the desired apparent impedance. One of the consequences of this control strategy (described in more detail in [8] and [9]) is that the apparent impedance of the series capacitor effectively becomes inductive in the range of frequencies (on the network reference frame) that may be conducive to SSR. Thus, resonances in the range of frequencies typical of rotor torsional modes are eliminated. This is shown pictorially in Figure 3-9.

<u>TCSC Model Development:</u>

A detailed model of the ABB TCSC control strategy was developed in EMTDC/PSCAD® by the ABB FACTS group in Sweden. This is the same control design used in the Stöde TCSC in Sweden, which was installed near a nuclear power

plant for the purpose of mitigating SSR [10]. This model was then incorporated into the model developed for the Hydro One system.
The two series capacitors on the Bruce A and Bruce B to Longwood lines were then broken into two parts:

- 30% fixed series compensation
- 40% TCSC

Both segements were designed to operate at 3500 A rms continuous current and protected by metal-oxide varistors (MOV). The TCSC nominal boost factor was set to 1.2. It should be noted that these design parameters were chosen simply to facilitate a reasonable first cut design. Further and more detailed studies will be required to determine the most cost effective and technically favorable design. The objective of this study was simply to illustrate that a practical and viable SSR mitigation strategy is available, not to optimize or fine tune the design.

<u>Transfer Function Calculations with TCSC:</u>
With a TCSC on each of the two Bruce to Longwood lines, the electrical damping torque induced on the Bruce A and B machines were recalculated for the key contingency scenarios. Note that the effective amount of series compensation at network fundamental frequency (60 Hz) is still the same as before, that is 70% on the Bruce to Longwood lines (and the Longwood to Nanticoke line).

The results are shown in Figures 3-10 and 3-11. By comparing these graphs with Figures 3-3 and 3-4 (the cases without TCSC), it can been that the TCSCs have eliminated the negative damping or resonance in the range of torsional modal frequencies. The TCSC has the effect of moving the resonance outside of the range of concern, namely to roughly 5 Hz. At 5 Hz there are no torsional modes of concern (this may be a concern for wind generators, see section 4). The slight resonance seen above 40 Hz, is due to the remaining fixed series compensation on the 500 kV lines. Again, this is of no consequence for the Bruce units since they do not have a torsional mode in that range. In each plot, for the most severe contingency, a slight negative dip in the damping torque at around 11 Hz is seen. This is as a result of the tuning of the TCSC controls at the lower end of the torsional frequency range. The tuning was not optimized but was done in such a way to ensure that this dip does not occur at or near (i.e. within 1 Hz) a torsional modal frequency. In any case, the amount of negative damping is quite small (less than 1 pu).

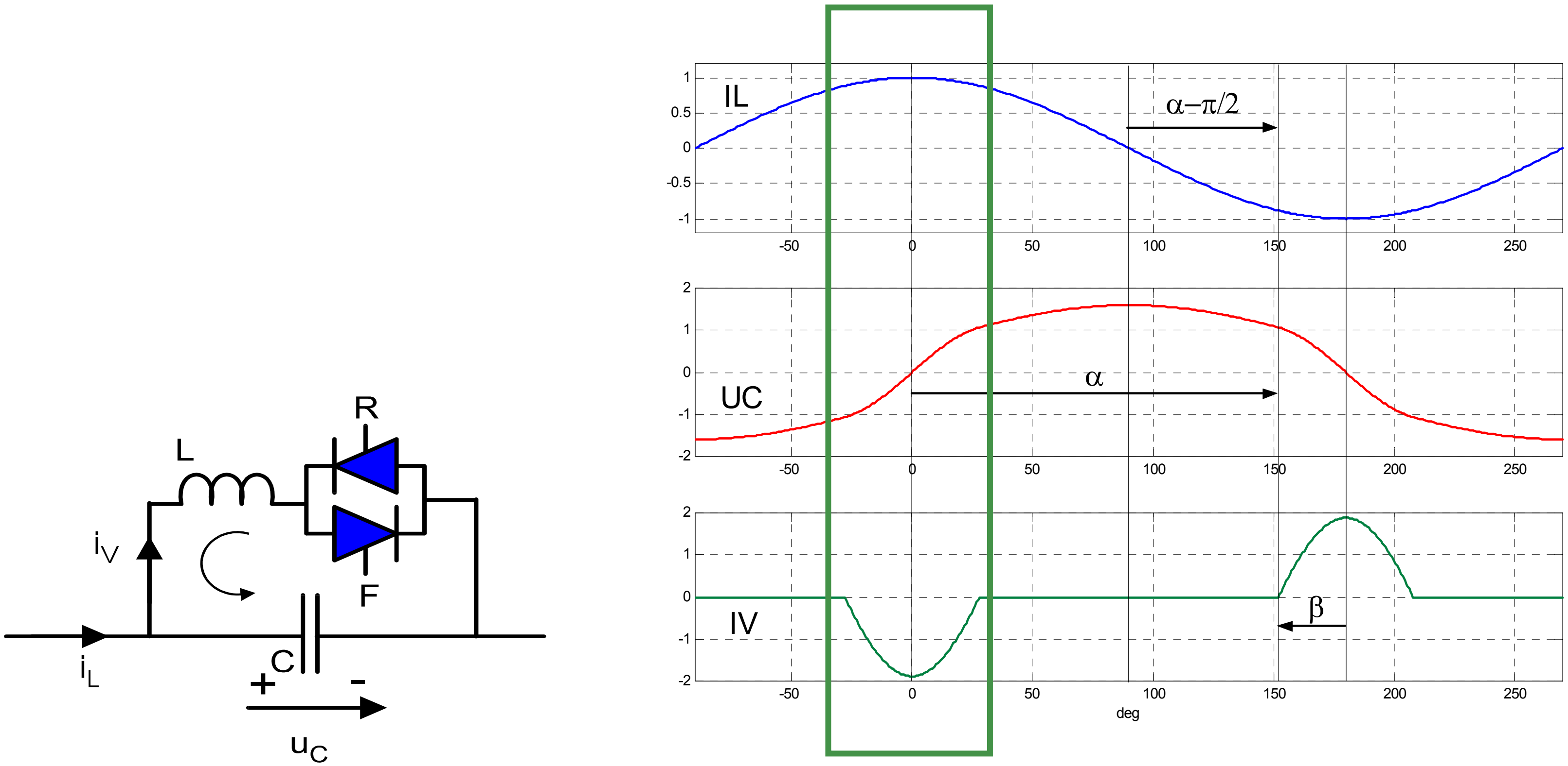

Figure 3-7: General concept of the control of a TCSC.

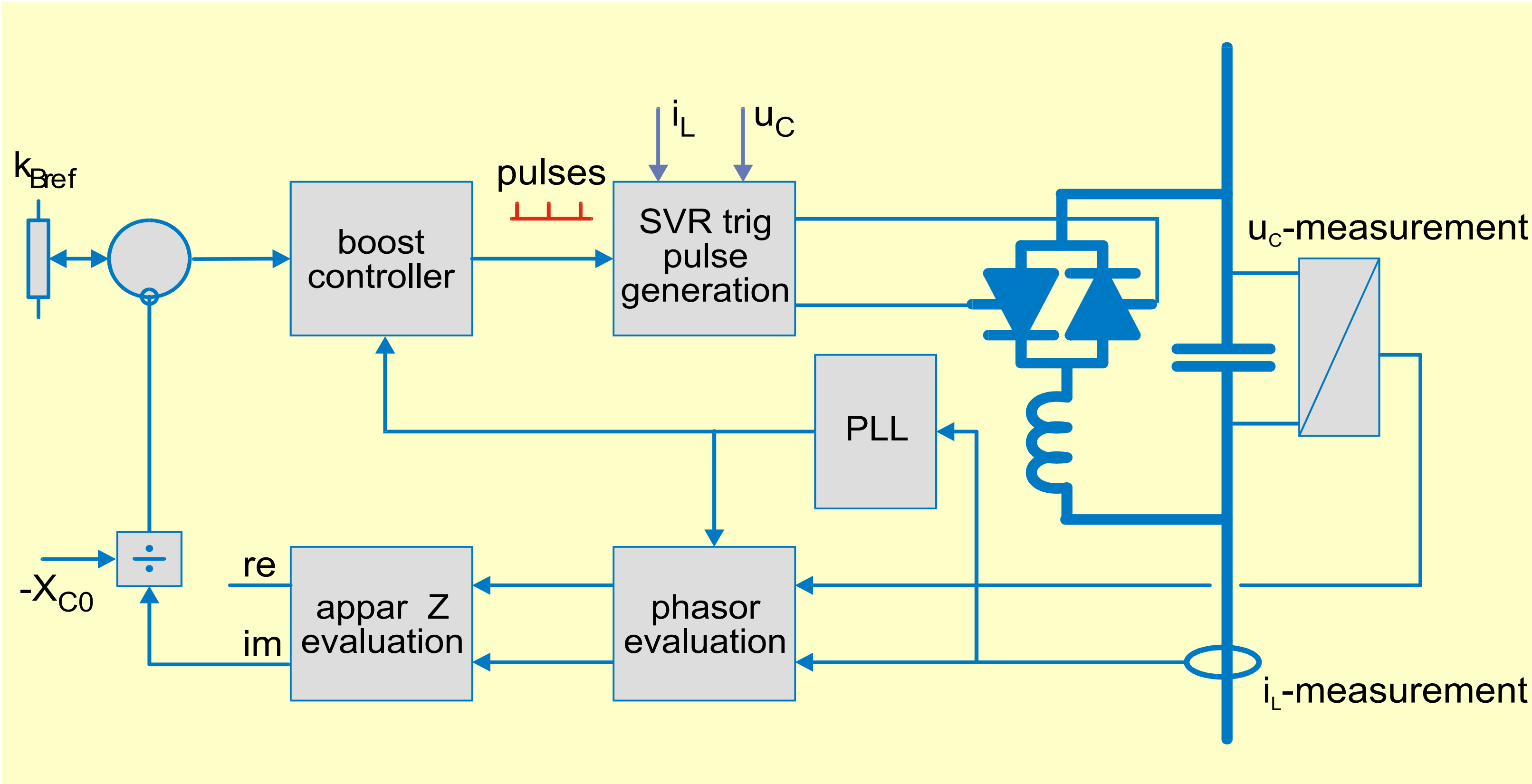

Figure 3-8: ABB thyristor-controlled series capacitor control strategy.

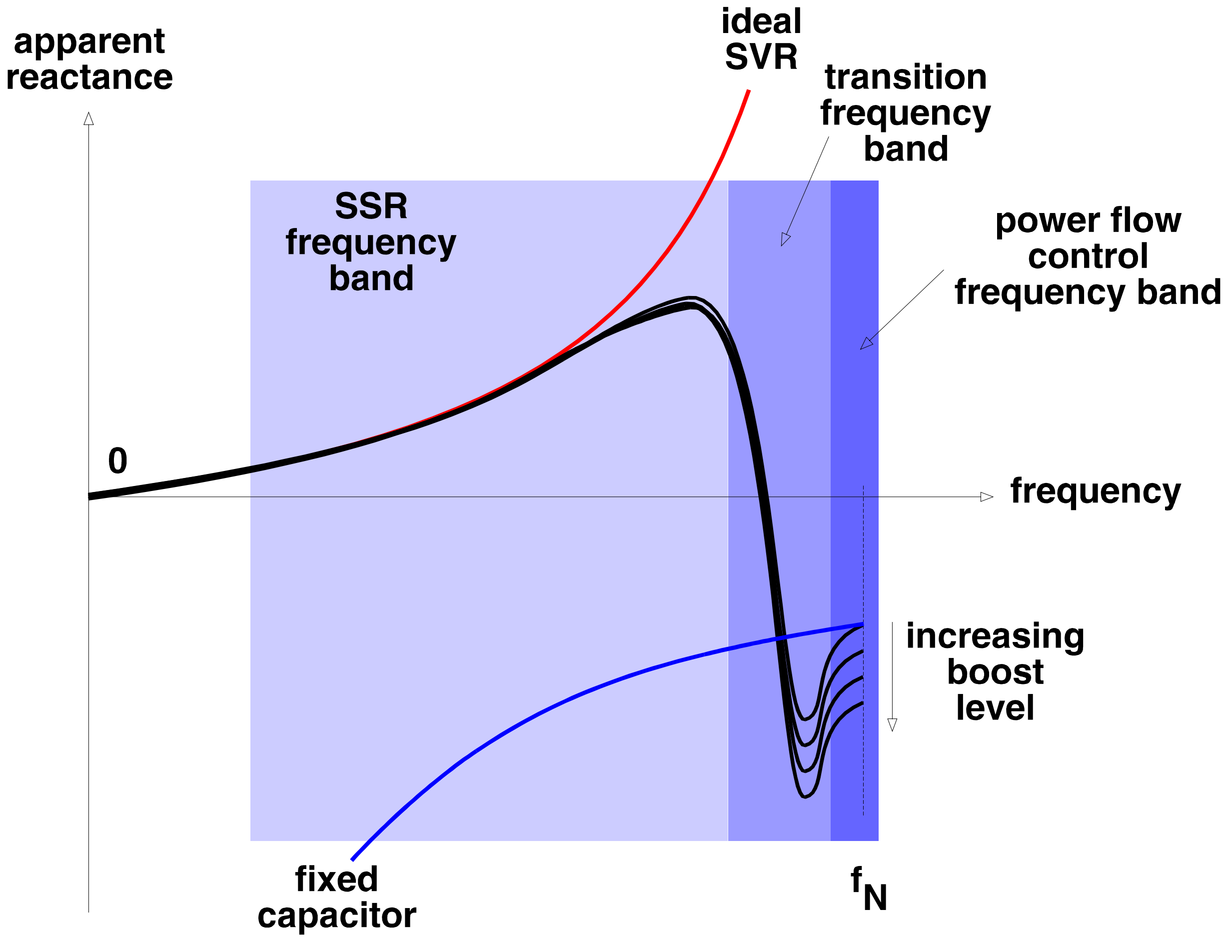

Figure 3-9: Apparent impedance of a TCSC over the range of network electrical frequencies.

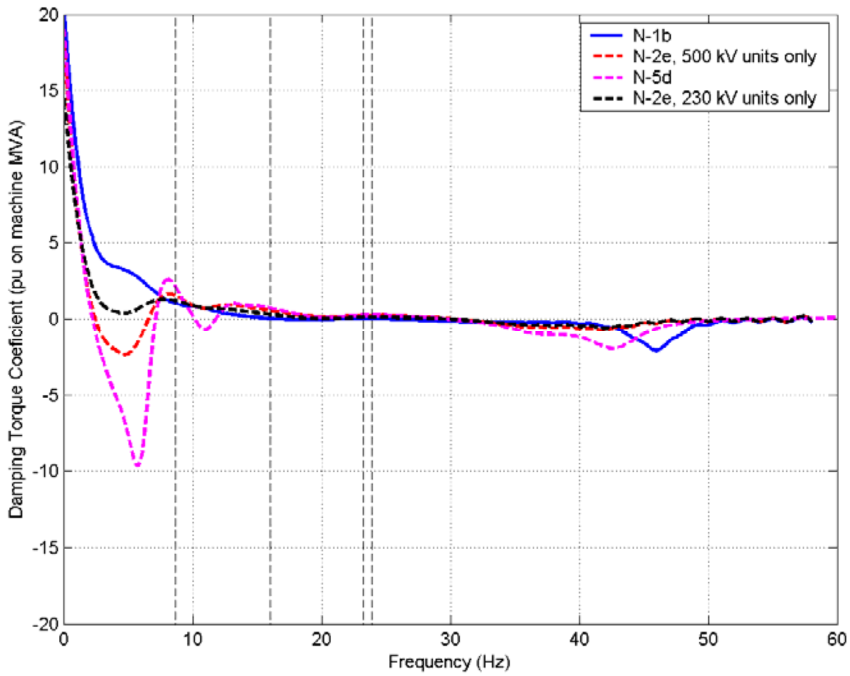

Figure 3-10: Plots of electrical damping torque calculated for the Bruce A units with TCSCs modeled on the Bruce to Longwood lines. For cases N-1b and N-5d only the two 500 kV units are on-line. For the N-2e cases, as indicated, either both 500 or both 230 kV units are on-line. The dashed vertical lines indicate the frequencies of the shaft subsynchronous torsional modes.

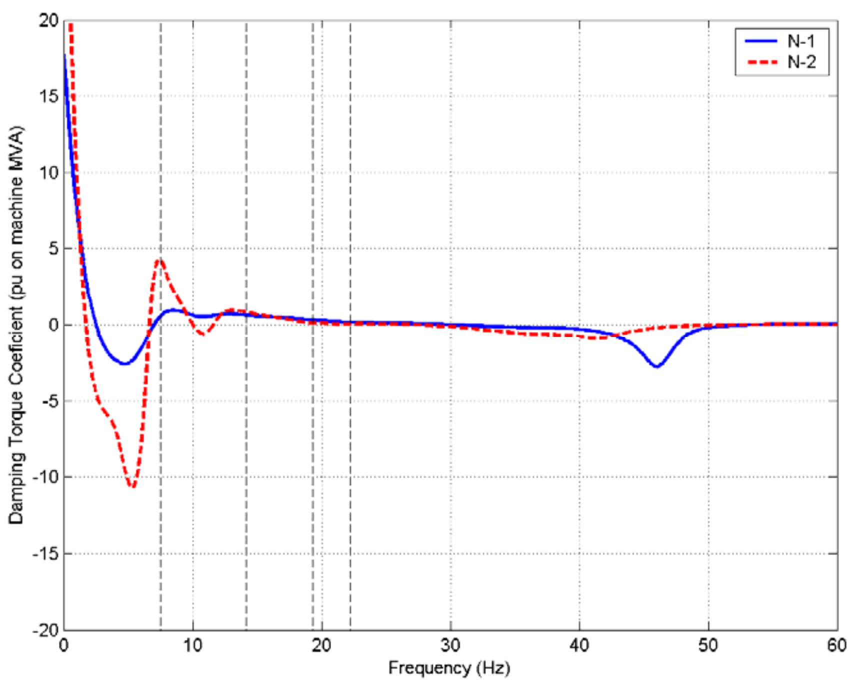

Figure 3-11: Plots of electrical damping torque calculated for the Bruce B units with TCSCs modeled on the Bruce to Longwood lines. All four units in-service. The dashed vertical lines indicate the frequencies of the shaft subsynchronous torsional modes.

3.5 Transient Torque and Time-Domain Simulations

The critical cases identified in section 3.3 and then studied again in section 3.4 using transfer function calculations, were also studied in time domain simulations. For this time domain analysis it was also necessary to model the mechanical shaft of the turbine-generators of interest. At this stage time domain simulations have not been performed for the Nanticoke units, since all the necessary data for modeling their turbine-generator mechancical shafts have not been received. The power system model used was the PSCAD® model developed in section 3.4 (Figure 3-5). The turbine-generator shafts were modeled as lumped spring-mass models based on manufacturer supplied data, received from the power plant owners – based on non-disclosure confidentiality agreements signed by ABB Inc. between ABB and Bruce Power, and ABB and OPG, respectively, this data is not disclosed here in this report. The electrical parameters of the generating units and their excitation systems were based on data received from the IESO, and later updated with data received from the power plant owners[3].

The list of cases simulated are shown in Table 3-1.

3.5.1 Base case simulations – Present System, No Series Compensation

As a benchmark, the outages listed in Table 3-1 were initially simulated with the present system conditions, namely with no series compensation on the the 500 kV lines. The results are shown in Appendix T-1. As excpected, all these cases are stable from the perspective of torsional response.

3.5.2 Cases with Fixed Series Compensation

The outages listed in Table 3-1 were then simulated with the proposed series compensation (70% on the Bruce to Longwood and Longwood to Nanticoke lines and 10% on the Bruce to Milton/Clairville lines). For this case two scenarios were simulated. First, the mechanical damping on the shafts was assumed to be negligible. In this case, as expected, all of the scenarios resulted in unstable torsional response, since as shown by the network frequency scan calculations and the transfer function calculations of the previous sections, there is significant negative damping torque at one or more torsional frequencies in each case. However, this seemed to be a too pessimistic assumption. So the simulations were repeated, this time with an assumed mutual damping coefficient of 1.0 pu on each turbine section. Based on the base case simulation results, this assumed

[3] The bulk of the simulations performed are based on updated machine electrical parameters for the Nanticoke units received from OPG on 10/21/05, by email. Similarly, the exciter data for the Bruce A units are the updated parameters/model provided by Bruce Power by email on 9/6/05. However, the updated electrical parameters for the Bruce A generators (received on 11/16/05 and then updated again on 1/9/06) were used only in a few sensitivity cases to illustrate that these changes have little impact of the results (see section 3.5.4 and Apendix P).

level of mechanical damping gave torsional damping that may be reasonably assumed for the torsional modes of these units. There is, however, no guarantee that the actual amount of mechanical damping available may not be more or less than this amount. As stated previously, the manufacturers did not supply any definitive damping data for the torsional modes. Damping data is typically not available except by measurement [11].

The results with this assumed amount of mechancical damping are shown in Appendix T-2. The observations are as follows:

1. The initial transient torques due to fault inception and clearing are increased by the introduction of the series capacitor. However, based on this preliminary analysis they do not seemed to be excessive enough to warrant alarm. Further, more detailed analysis will be needed once an actual series compensation design has been chosen and the series capacitor protection has been better defined. Nonetheless, some sensitivity analysis was performed with respect to fault clearing and results are shown in Appendices Q and R. Also, despite asking for S-N diagrams (stress curves for the shaft material) for the shafts of the generating units, this data was not supplied by the turbine-generator manufacturers. As such, based on what might be the typical endurance of shafts of such large turbine-generators, it is expected that the observed transient torques are not too excessive. After more detailed analysis is peformed, it would be prudent to share some of the results with the turbine-generator manufacturers.
2. Even with the assumed level of mechanical damping it was found that the outages for the Bruce B units still result in destabilization of the torsional mode at 19.3 Hz.
3. For Bruce A, the less severe outages (N-1b and N-2e) are stable since the assumed level of mechanical damping is higher than the induced negative damping due to series compensation. However, for the N-5d condition, the 22 Hz torsional mode becomes unstable after the disturbance.

Some sensitivity analysis was then done to identify the level of mechanical damping that would yield stable torsional response in all cases. This was done for the two most critcal cases: the N-2 outage for Bruce B and the N-5d outage for Bruce A. The results are shown in Figures 3-12 and 3-13. As shown, to stabilize the torsional response for the case of the Bruce B units the amount of mechanical damping available would have to be ten times greater than what has been assumed and for Bruce A it would have to be five times greater. In practice, it is unlikely that this is the case but not necessarily impossible. Even if such high levels of mechanical damping were available, it would only be the case at or near full-load conditions.

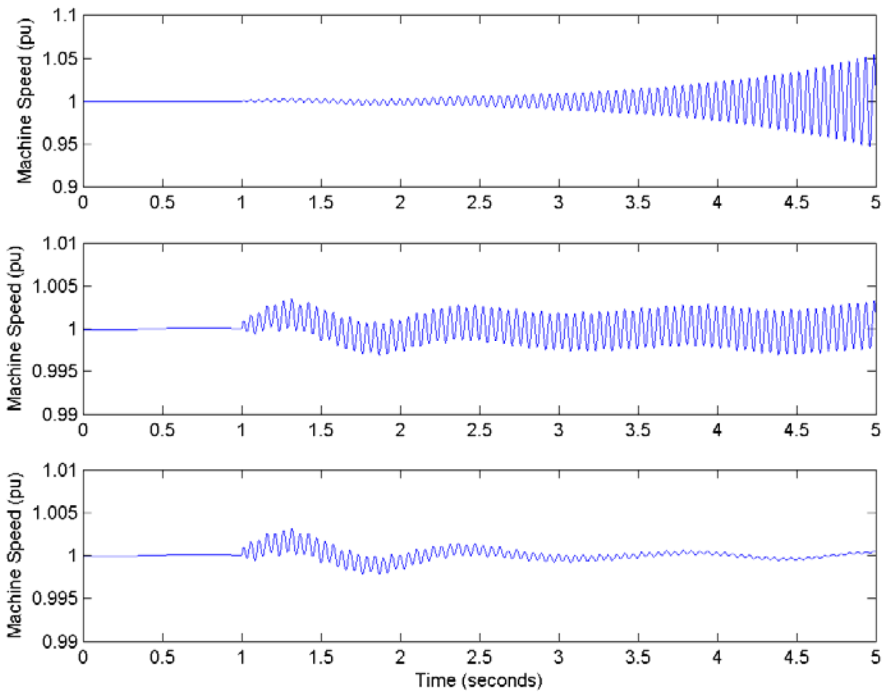

Figure 3-12: Speed on Bruce B unit follwing a 3-phase fault at the Bruce B end of the Bruce B to A 500 kV line and trip; prior outage of Bruce B to Milton 500 kV line. Assumed mechanical damping coefficient of (a) 1.0 pu, (b) 5.0 pu and (c) 10 pu.

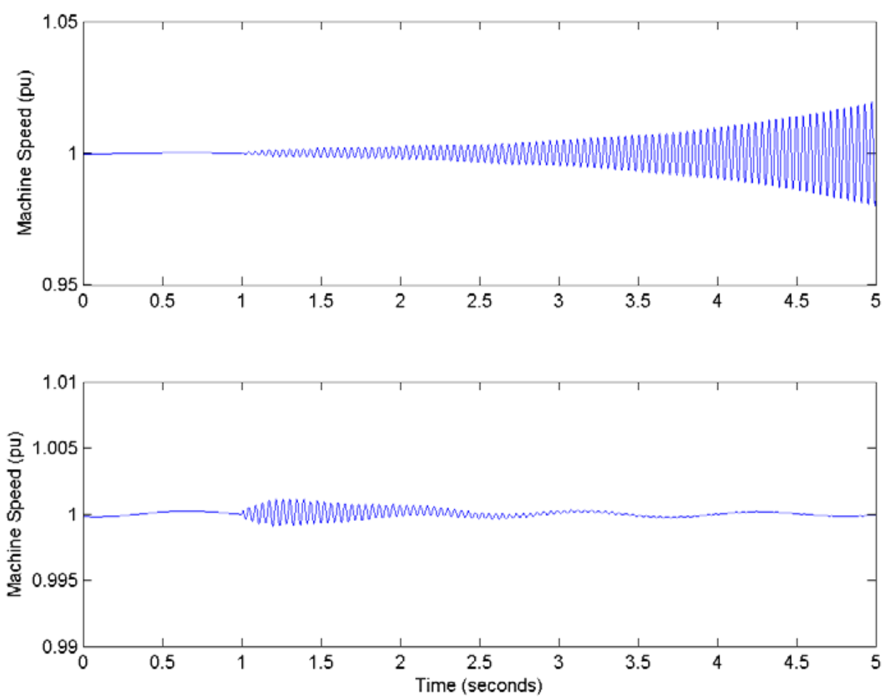

Figure 3-13: Speed on Bruce A (500 kV) unit follwing a 3-phase fault at the Bruce A end of the Bruce B to A 500 kV line and trip; prior outage of Bruce A to Clairvillie 500 kV line and 3 x Bruce A 500/230 kV transformers. Assumed mechanical damping coefficient of (a) 1.0 pu and (b) 5.0 pu.

3.5.3 Cases with Fixed Series Capacitors, Supplemented with TCSC

The outages listed in Table 3-1 were re-simulated with the proposed series compensation implemented as follows:

- 30% fixed series compensation augmented by 40% TCSC on both Bruce to Longwood 500 kV lines. These will be referred to as TCSC1 (on Bruce B to Longwood line) and TCSC2 (on Bruce A to Longwood)
- 70% fixed series compensation on Longwood to Nanticoke 500 kV
- 10% fixed series compensation on the Bruce to Milton/Clairville 500 kV lines

All of the cases were stable. Thus, the TCSC clearly ensures stability of the torsional modes even under the most severe cases. The results are shown in Figures 3-14 and 3-15.

Looking at the most critical cases (for Bruce B, N-2 and for Bruce A, N-5d), some interesting results can be seen in Figures 3-16 and 3-17. Figure 3-16 shows the case of the N-5d scenario, that is the loss of the Bruce A to B 500 kV circuit due to fault with the prior outage of the Bruce A to Clairville line and the three Bruce A 500/230 kV transformers. It can be seen that if in this case both of the TCSCs are blocked, then as expected the 22 Hz torsional modes on the Bruce A shaft become unstable – as soon as the TCSCs are unblocked then the modes becomes stable again. It should be emphasized that the blocking of a TCSC is a simulation artifice employed here to illustrate a point. In practice the thyristors can only be blocked from firing due to a deliberate intervention into the controls. It is more interesting to note that if only TCSC2 is blocked (i.e. the TCSC on the Bruce A to Longwood line) then the Bruce A torsionals are not destabilized. At first this seems to suggest that TCSC1 is able to eliminate resonances for both the Bruce B and A units. This, however, is not quite correct. Further investigation identifies the reason for this. Figure 3-18 shows the electrical damping torque calculation for this scenario. This shows that the presence of TCSC1 alone reduces the level of negative damping at the torsional frequencies of the Bruce A unit by reducing the apparent level of compensation on the Buce B to Longwood line at torsional frequencies. Thus, with the assumed level of mechanical damping on the Bruce A shaft, there is enough mechanical damping to keep its torsional mode stable. If the actual mechanical damping were less, this would not be true.

Figure 3-17 shows the case of the N-2 scenario, that is the loss of the Bruce A to B 500 kV circuit due to fault with the prior outage of the Bruce B to Milton line. It can be seen that if in this case just TCSC1 is blocked, then as expected the 19.3 Hz torsional mode on the Bruce B shaft becomes unstable. As soon as this TCSC is unblocked then mode becomes stable again. Blocking or unblocking TCSC2 has no effect on this case.

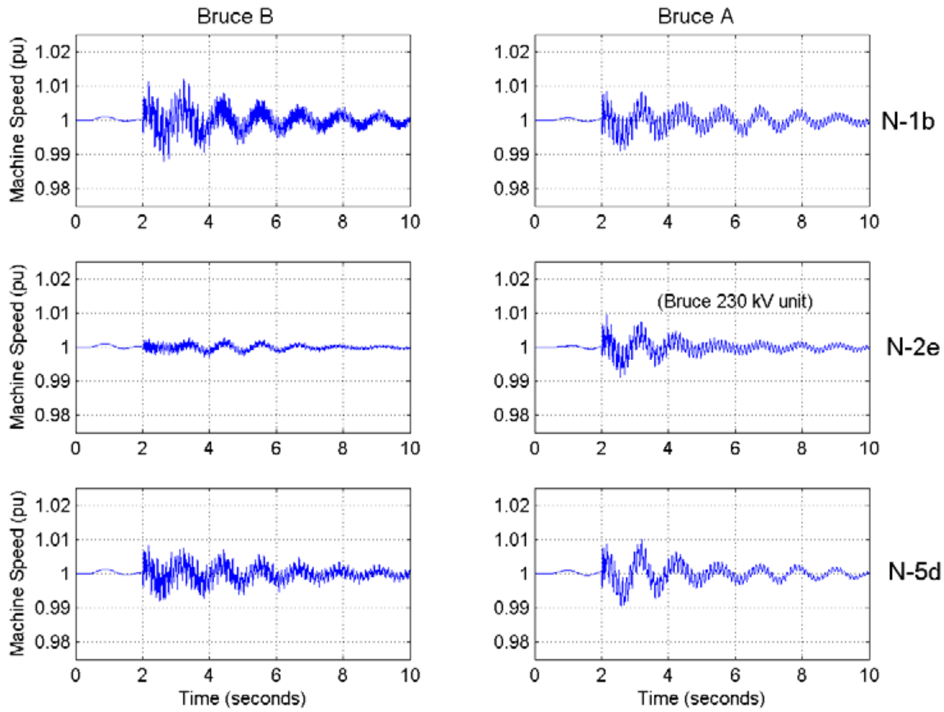

Figure 3-14: Speed on Bruce B (left column) and Bruce A (right column) machines for contingencies N-1b (first row), N-2e (second row) and N-5d (third row), associated with the Bruce A machines (see Table 13-1 for description of contingencies).

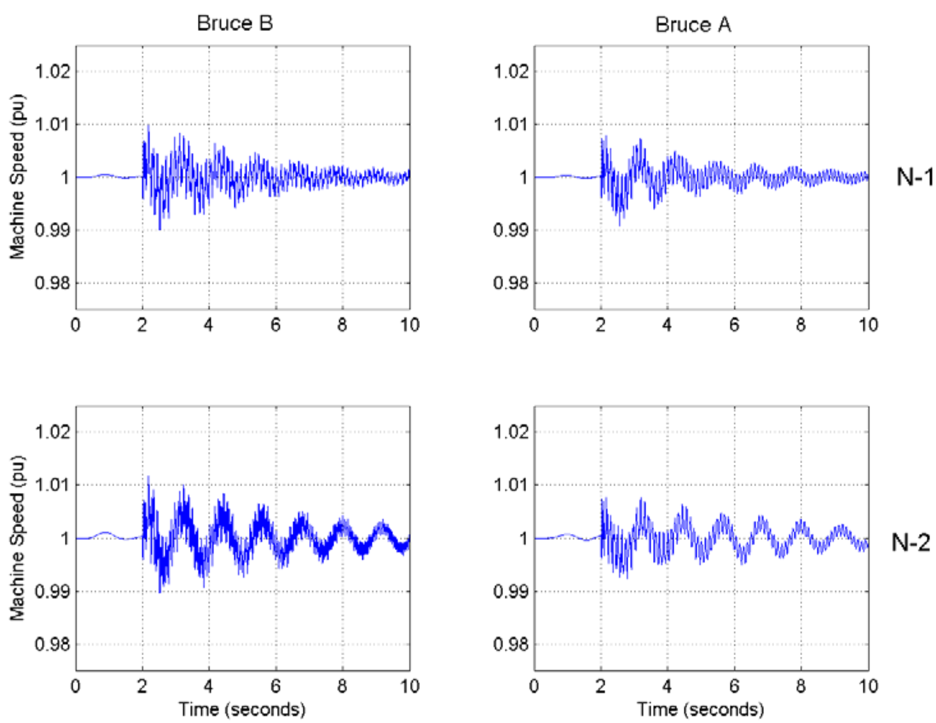

Figure 3-15: Speed on Bruce B (left column) and Bruce A (right column) machines for contingencies N-1 (first row) and N-2 (second row), associated with the Bruce B machines (see Table 13-1 for description of contingencies).

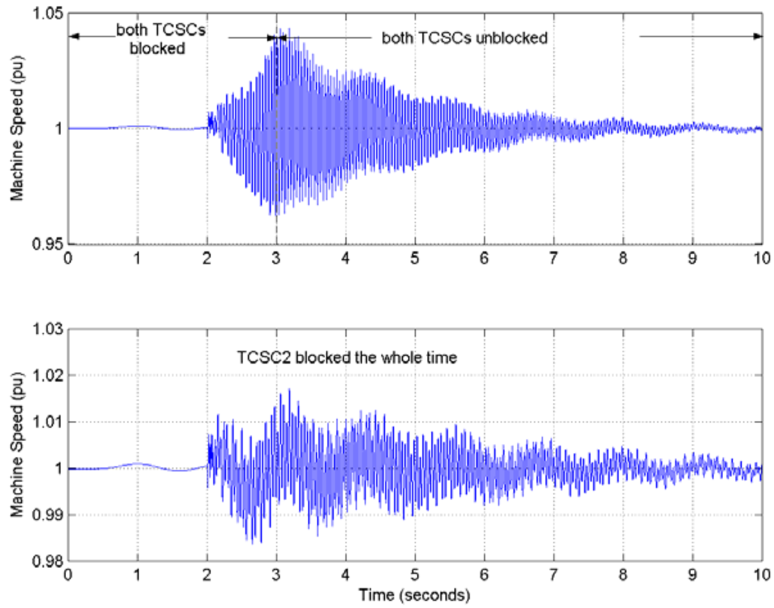

Figure 3-16: Speed on Bruce A (500 kV) units for the N-5d case. Note that if both TCSCs (on both Bruce to Longwood lines) are blocked then the 22 Hz torsional modes become unstable, they are immediately stabilized when the TCSCs are unblocked again. If only TCSC2 (on the Bruce A to Longwood line) is blocked, then the Bruce A torsionals are still stable since the assumed level of mechanical damping is adequate to over come the negative damping due to the fixed series capacitors (see Figure 3-18).

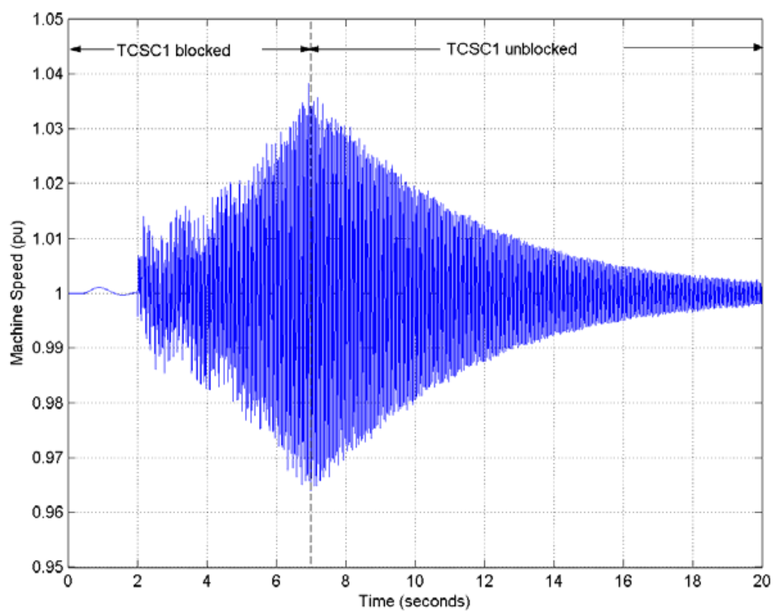

Figure 3-17: Speed on Bruce B units for the N-2 case. In this case only TCSC1 is blocked and unblocked (the TCSC on the Bruce B to Longwood line) and TCSC2 is operational throughout the simulation. Clearly, if TCSC1 is blocked then the 19.3 Hz torsional mode becomes unstable. Once the TCSC is unblocked the torsional mode becomes stable immediately.

Table 3-1: Cases simulated in time-domain. Unless otherwise indicated, all faults are cleared in 5 cycles.

Contingency Designation	Bruce A (500 kV)	Bruce A (230 kV)	Bruce B	Critical Units to Observe	Outage Description
N-1	All on-line	All off-line	All on-line	Bruce B	3-phase fault at Bruce B end of Bruce B to Bruce A 500 kV line and trip
N-2	All on-line	All off-line	All on-line	Bruce B	3-phase fault at Bruce B end of Bruce B to Bruce A 500 kV line and trip; prior outage of Bruce B to Milton 500 kV
N-1b	All on-line	All off-line	All on-line	Bruce A (500 kV)	3-phase fault at Bruce A end of Bruce B to Bruce A 500 kV line and trip
N-5d	All on-line	All off-line	All on-line	Bruce A (500 kV)	3-phase fault at Bruce A end of Bruce B to Bruce A 500 kV line and trip; prior outage of Bruce A to Clairville & 3 x 500/230 kV Transformers
N-2e	All off-line	All on-line	All on-line	Bruce A (230 kV)	3-phase fault at Bruce A end of Bruce B to Bruce A 500 kV line and trip; prior outage of Bruce A to Clairville

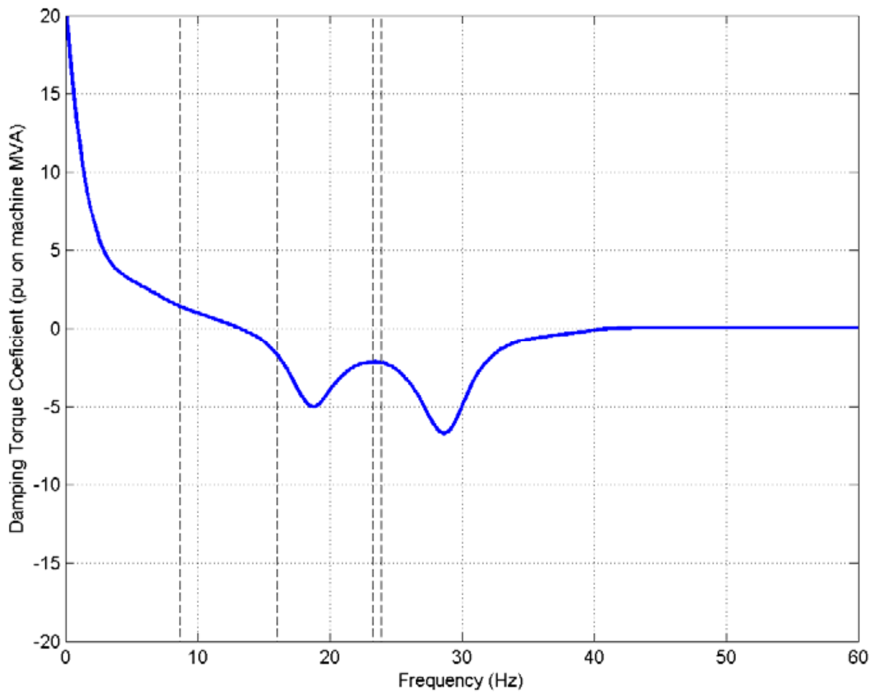

Figure 3-18: Electrical damping torque for Bruce A machines under the N-5d scenario with only one TCSC in-service on the Bruce B to Longwood line. All other capacitors are fixed series capacitors.

3.5.4 Sensitivity Cases with Latest Bruce A Machine Electircal Data

On 11/16/05 and then latter on 1/9/06 updated electrical parameters were provided for the Bruce A generators. This data was received too late to be incorporated into the bulk of the study. Nonetheless, two sensitivity simulations were performed to quantify the effect of this change on the study results. The electrical damping torque calculations (using the transfer function method) was recalculated for the most critical case for the Bruce A machines (i.e. N-5d case). Similarly, the time-domian simulations for the critical case with the fixed series capacitors were also resimulated. These were then compared to the same cases with the original machine electrical data. The comparison for the transfer function calculation with TCSSs is shown in Figure 3-19. The time domain simulation comparisons are provided in Appednix S. It can be seen that the latest updates in the Bruce A machine electrical data have no significant effect on torsional response.

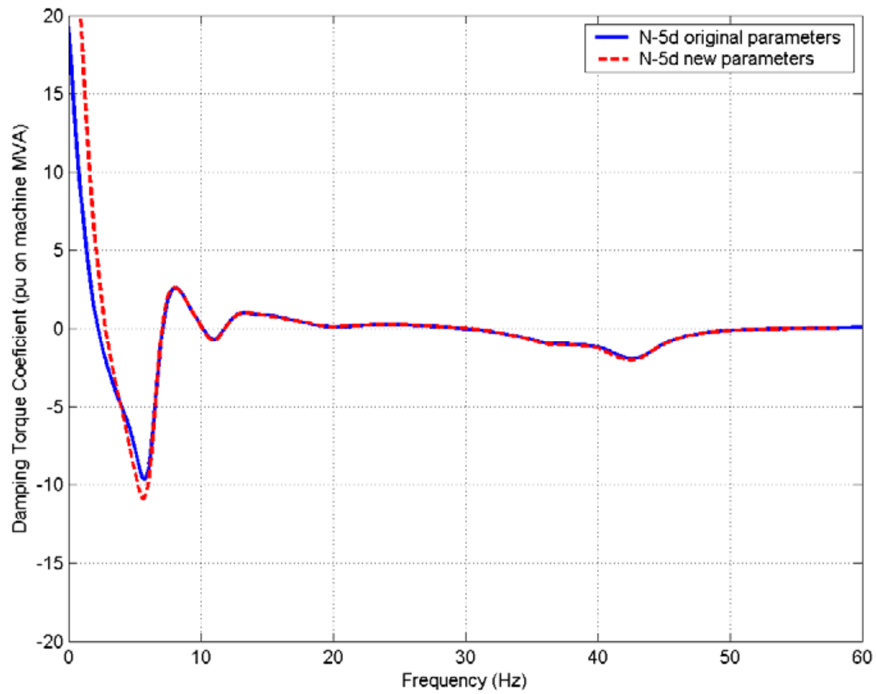

Figure 3-19: Plot of electrical damping torque calculated for the Bruce A units with TCSCs modeled on the Bruce to Longwood lines. For case N-5d and with only the two 500 kV units on-line. Results shown with the original and latter new updated Bruce A generator electrical machine parameters.

3.6 Summary of SSR Analysis Results and Remaining Work

First consider the Nanticoke units, for which all the necessary modeling data has not yet been received. Pending receipt of all the necessary data to model the mechanical shaft of the Nanticoke units, some further time domain (and potential transfer function) simulations are necessary for these units. However, with the simulations performed thus far, the following general comments and conclusions can be made about the Nanticoke units:

1. Even with TCSCs on the Bruce to Longwood lines, the Nanticoke units (primarily the 500 kV units) are susceptiable to SSR, particularly under the identified N-4a contingency scenario. Figure 3-20 illustrates this.
2. Although the introduction of a third TCSC on the Longwood to Nanticoke line would surely solve this problem, it is not believed that this is warranted or prudent, for the following reasons:
    a. There is likely enough mechanical damping on the units shaft to avoid destabilizing the torsional modes for less severe outages.
    b. For the N-4a contingency scenario (i.e. loss of both Nanicoke to Middleport 500 kV lines and all three Nanicoke 500/230 kV transformers), based on discussions with Hydro One, it is expected that this is not a viable operating condition. In this case power is flowing in the wrong direction and some if not all of the Nanticoke 500 kV units may

have to be tripped anyway. This also means that under this condition the series capacitor is no longer needed and thus may be bypassed there by eliminating the source of SSR.

Thus, it is believed that a capacitor bypass scheme would be a suitable and acceptable solution for these units in the interim before they are shut down and/or converted to synchronous condensers. Synchronous condensers (with static non-rotating exciters) are not suceptiable to SSR since they have no subsynchronous torsional modes.

In summary the basic findings of this report are that the only units potentially susceptible to SSR are the Bruce A, B and Nanticoke units. Furthermore, transmission solutions can be implemented to mitigate this SSR concerns. More specifically, for the Bruce B units the most prudent approach would be to implement the series capacitor on the Bruce B to Longwood line as a combination of a fixed series capacitor bank (30%) and a thyristor-control series capacitor bank (40%). Depending on the risk tolerance of the stake holders, for the Bruce A units a capacitor bypass scheme may be used under the most extreme scenario. Alternatively, a TCSC may be incorporated into the Bruce A to Longwood line. For the Nanticoke units, pending final simulation work, the most cost effective solution is likely capacitor bypass under the most critical contingency scenario. More detailed analysis is needed to optimize the size, rating, protection system and propotion of fixed series compensation to TCSC for these applications. Such analysis is beyond the scope of the current study. The objective of this study was to identify whether the proposed level of series compensation can be applied together with a means of mitigating the risk of SSR. It has been established that this can indeed be achieved and optimization of the design is left to further study.

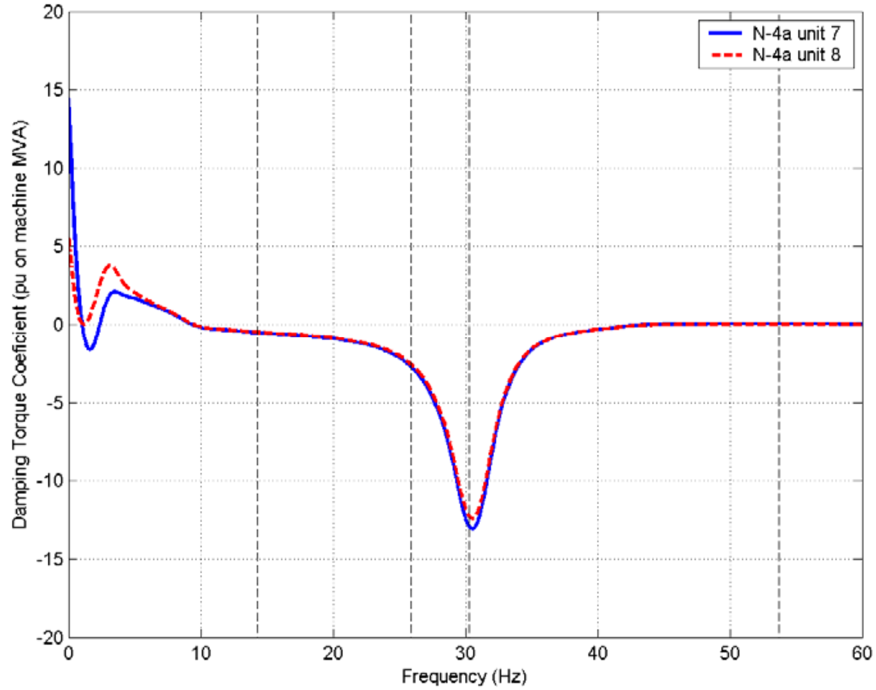

Figure 3-20: Key contingencies for Nanticoke generating units. The plot is for contingencies N-4a, with units 7 & 8 on-line only and 40% TCSC on both Bruce to Longwood lines. The only effect of the TCSC is to shift the resonance slightly to the right since they have effectively reduced the apparent level of compensation on the Bruce to Longwood line in the torsional frequency range. As expected, the TCSCs on the Bruce to Longwood line are not effective in eliminating the potential for SSR for the Nanticoke units – for these units the most cost effective solution is likely capacitor bypass on the Longwood to Naticoke line for this scenario.

4 Risk of SSR for Future Generating Units

Hydro One provided ABB with a list of potential future generating additions to the system. The list has intentionally not been reproduced here, since some of this data may be considered confidential. Based on the data received, the following observations can be made:

1. The restart of the Bruce A G1 and G2 units, which is within this list, have been explicitly studied here. The results are as presented in section 3. The mitigation strategies presented in this report address these units as well as the other Bruce units.
2. Most of the generators listed are wind turbine generators and are connected to the underlying 230 kV, 115 kV and distribution voltage level.
3. There are only two generating facilities, both wind generation, proposed for interconnection in the vicinity of the series capacitors. Both wind farms are presently proposed for interconnection on the Bruce to Longwood 500 kV lines. Although the chosen wind turbine technology is not firmly known, it is likely that both these wind farms will use conventional induction generators.

Based on the results presented in this report, particularly for the network frequency scan analysis, it is evident that for there to be a resonant condition of concern for generating units connected to the 230 kV system and below (particularly if electrically remote from the series capacitor locations), a large number of line/transformer outages are needed. As such, for the bulk of the proposed generation additions, there is likely to be very little risk of SSR. In addition, wind turbine generators typically have torsional modes in the 1 to 5 Hz range due to the fact that the turbine has a relatively long and slender shaft connecting a rather large mass (the turbine rotor) to a rather small mass (the electrical generator). As such, the resonant frequencies established by straight series compensation of the proposed 500 kV circuits cannot cause resonant frequencies low enough in frequency to interact with the torsional modes of wind turbine generators. However, there are two other potential concerns:

1. Induction generator self-excitation. This is essentially a purely electrical phenomenon where an electrical resonance can be established between the magnetizing reactance of the induction generator and series capacitance in the transmission line(s) feeding the generation. As such, the two wind farms being proposed for interconnection with the Bruce – Longwood 500 kV lines may be susceptible to this phenomenon, particular during start-up since self-excitations typically occurs at off-nominal frequencies. Both conventional and doubly-fed induction machines are susceptible. However, full-converter wind turbine generators (i.e. units that incorporate a full back-to-back frequency converter between the electrical generator and the system) are unlikely to be susceptible since the electrical generator is esseintially isolated from the transmission grid. Detailed machine data and modeling is needed to determine if this is likely to be a problem for wind generators interconnecting to the Bruce – Longwood lines. A

possible solution may be to trip the farm under contingency scenarios that lead to self-excitation. Further analysis would be required to quantify this.

2. As shown in section 3 a mitigation strategy for resolving the problem of SSR with the exisiting Bruce nuclear units is the introduction of TCSCs on the Bruce to Longwood lines. As shown (Figures 3-10 and 3-11), the TCSCs eliminate negative damping torques in the range of torsional frequencies for the Bruce units. However, as shown in Figures 3-10 and 3-11, the resonance is shifted down to roughly 5 Hz. This might be a concern for wind turbine generating units. There are possible solutions to this potential concern:
    a. Since the typical collector system voltage of a wind farm is 34.5 kV (or in that range) to design a substation transformer to step this voltage straight up to 500 kV would be challenging and unique – this is typically not done due to the relatively large transformation ratio. Generator step-up (GSU) transformers (e.g. at Bruce and Nanticoke units) can have such a high transformation ratio, however, GSU and substation transformers are designed and operated differently. An option might be to step the collector voltage up to an intermediate voltage level (e.g. 230 kV) and then up to 500 kV. This added inductance may also detune the resonance to a frequency that is inconsequential from the perspective of the wind turbine generators.
    b. The wind farms could be connected to the 230 kV network, if this is feasible from both a megawatt injection perspective and an economic perspective.
    c. Full converter wind turbine technologies can be used which would essentially isolate the wind turbine-generator from the network and thus isolate them from the consequences of any network resonances.
    d. Active damping can perhaps be introduced at the wind turbine generators to mitigate the negative damping introduced.
    e. Whenever a contingency results in leaving the wind farm radial to the series capacitors and TCSC on the Bruce Longwood line, the wind farm can be tripped.

The above statements are qualitative comments provided for guidance only. Should future generation be connected to the 500 kV lines in the vicinity of the series capacitors, then it would be prudent to perform some limited but detailed analysis to quantify any SSR effects and identify mitigation strategies.

5 Conclusions and Recommendations

This document presents the results of the study work related to the assessment of the risk of subsynchronous resonance (SSR) as it relates to the installation of five proposed series capacitor banks in the Hydro One electrical power system. This assessment was done with reference to seven existing power plants in the Hydro One system, namely Bruce A, Bruce B, Lambton, Nanticoke, Pickering, Darlington and Lennox.

The analysis was performed for an extensive number of contingency scenarios for each power plant and combinations of generating units on-line at the plant. Based on the analysis, and for the particular location and size of series capacitors chosen, the power plants at Lambton, Pickering, Darlington and Lennox are at little to no risk of experiencing destabilization of the torsional mechanical modes of their turbine-generator shafts due to SSR. In each of these cases, it takes the loss of twelve or more transmission elements (500 kV lines, 230 kV lines or 500/230 kV transformers) in order to result in a significant resonant condition between the turbine-generator and the series capacitors.

For the Bruce and Nanticoke power plants, resonant conditions can result with as little as one to four transmission element outages.

For Nanticoke, the 230 kV units become susceptible to SSR once all the 500 kV Nanticoke units are off-line and an additional three to four transmission elements are out of service. Similarly for the 500 kV units at Nanticoke, a significant resonant condition that may lead to destabilization of the torsional modes occurs for an N-4 condition (loss of both 500 kV circuit towards Milton and Claireville as well as both 500/230 kV transformers). Based on discussions with Hydro One, from a power flow/stability perspective the series compensation is not needed under this condition, thus this problem may be address by bypassing the series capacitor on the Longwood – Nanticoke line. It should be noted that some of the torsional data for these units (units 1 to 6) have not yet been received and thus the results are subject to change once the final analysis for these units has been performed.

For the Bruce power plant, there are a number of N-1, N-2 and N-5 conditions that lead to potentially destabilizing conditions for the torsional modes around 19 to 23 Hz. For the Bruce A 500kV units the trouble outages are the loss of Bruce A to Claireville and Bruce A to Bruce B. The problem is further aggravated if all the 500/230 kV transformers are also lost. For Bruce B the most onerous condition is the loss of both Bruce A to B and the Bruce B to Milton 500 kV lines. In both cases the risk of SSR may be mitigated by replacing a portion of the series compensation on these line by a thyristor-controlled series capacitor (TCSC).

Thus, based on this study the general conclusion is that the problem of SSR is manageable and can be mitigated for all units with a combination of operating strategies (i.e. bypassing in part or in whole specific series capacitors under given outage conditions) and the application of TCSC.

Future/Further Work:

Some analysis related to the Nanticoke units remains once all the necessary torsionl shaft models for those units have been received. This is within the scope of the present study.

Further analysis, beyond the scope of this present study, will be required to fully define and specify the most cost effective configuration of the series capacitors and the portion of the capacitors that should be TCSC. Such additional work should also aim to more acurately quantify transient torques based on fine tuning the series capacitor protection systems.

Torsional testing of the Bruce A, Bruce B and Nanticoke units may be prudent to quantify the exact amounts of mechanical damping available on these untis for their subsynchronous torsional modes.

Protection Recommendations:

The power plant owners at Bruce and Nanticoke may wish to consider, as a means of protection, the installation of subsynchronous torsional relays on their units if the proposed series capacitors are built. This is because the source of SSR is a network resonance, and although precautions and controls are put into place to mitigate the effects of SSR in the extremely rare event that all the operating precautions and primary active control schemes fail, it would be prudent to have a backup protection scheme. One should be aware that the risk or likelihood of false trips by such relays should also be assessed and weighed against the potential benefits.

It should be noted that this protection strategy is not recommended in the case of SSTI associated with poor PSS design and tuning or interactions due to nearby SVC, HVDC etc. In these cases the source of the problem is control interaction and thus the solution is proper tuning and design of the control systems. In the very rare event that the controls fail, the associated device is shut-down and the source of the interaction eliminated. Thus, in the case of SSTI the probability of a false trip of a torsional relay may in fact be higher than the risk of damaging SSTI, once proper control designs have been effected after thorough studies.

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[11] P. Pourbeik, C. E. J. Bowler and V. L. Crocker, “Model Validation Testing for the Purpose of Determining Generation Equipment Dynamic Performance and Torsional Mechanical Response”, Proceedings of IEEE PES General Meeting, June 2004, Denver, Colorado.

APPENDIX A: Thevenin Equivalent Impedances at the Model Boundaries

Boundary Bus	R (pu on 100 MVA base)	X (pu on 100 MVA base)
5138	0.00112	0.01330
5244	0.00093	0.01146
7001	0.00034	0.00632
7104	0.00110	0.01276
7113	0.00054	0.02200
9107	0.01687	0.13060
9314	0.01957	0.16753
79584	0.00031	0.00737
79589	0.00610	0.01178

APPENDIX B: Torsional Data

The torsional modal frequencies for the units studies are presented below, as supplied by Bruce Power and OPG, since this information is necessary for one to be able to view and make sense of the damping torque plots and other discussions through the report. However, all other data submitted by Bruce Power and OPG is not being furnished to comply with the confidentiality agreements separately signed by ABB with Bruce Power and OPG.

Power Plant	**Subsynchronous Torsional Modes (Hz)**	**Comments**
Bruce A	8.66, 16.06, 23.89 and 23.27	Confirmed by Siemens, however, manufacturer indicated that testing in the field performed at some stage (details unknown) showed the first torsional mode to be at 9.17 Hz. Since there is little information on the test data, for the purposes of this study the calculated modes based on manufacturer supplied data was used. All four units are identical.
Bruce B	7.5, 14.19, 19.31 and 22.25	These numbers were received 10/12/05, and are pending some review and possible revision. The four units are all identical.
Nanticoke	15.1, 28.8, 35.3 and 56.2 (G1 – 6) 14.3, 25.9, 30.3 and 53.7 (G7 – 8)	Waiting on confirmation and spring-mass models. Units 1 to 6 are indetical mechanically and units 7 & 8 are also identical mechanically, but the two groups are different from each other. Electrically, units 1, 3, 6 and 8 are identical and units 2, 4, 5 and 7 are identical but the two groups differe from each other.
Lambton	16.88, 26.93, 34.83 and 56.30	Only available data at this point. All units identical.
Lennox	16.88, 26.93, 34.83 and 56.30	Only available data at this point. All units identical. It is odd that the mechanical modes for Lambton and Lennox are identical even though based on the PSS/E® database the units are at least electrically different.
Darlington	10.9, 18.2, 22.4 and 27.7[4]	Only available data at this point. All units identical.
Pickering	8.4, 22.6, 31.1[5]	Torsional supposed the same on all units.

[4] Based on hand delivered data from OPG at October 20, 2005 meeting.
[5] Based on hand delivered data from OPG at October 20, 2005 meeting.

APPENDIX C: Bruce A Frequency Scan

Appendix C – Bruce A Frequency Scan

This appendix contains 1) the electrical damping plots and 2) the effective resistance plots for the Bruce A generators. The electrical damping plots are provided first, ordered by generator combination (Set ID) as identified in Table C-1 below. The effective resistance plots are then provided in the same order.

Table C-1: Bruce A Generator Combinations

Set ID	Bruce A 500kV		Bruce A 230kV		Bruce B
	G3	G4	G1	G2	500kV Units
A1	√				√
A2	√	√			√
A1a	√				
A2a	√	√			
B1	√	√	√		√
B2	√	√	√	√	√
B1a	√	√	√		
B2a	√	√	√	√	
B1b			√		√
B2b			√	√	√
B1c			√		
B2c			√	√	

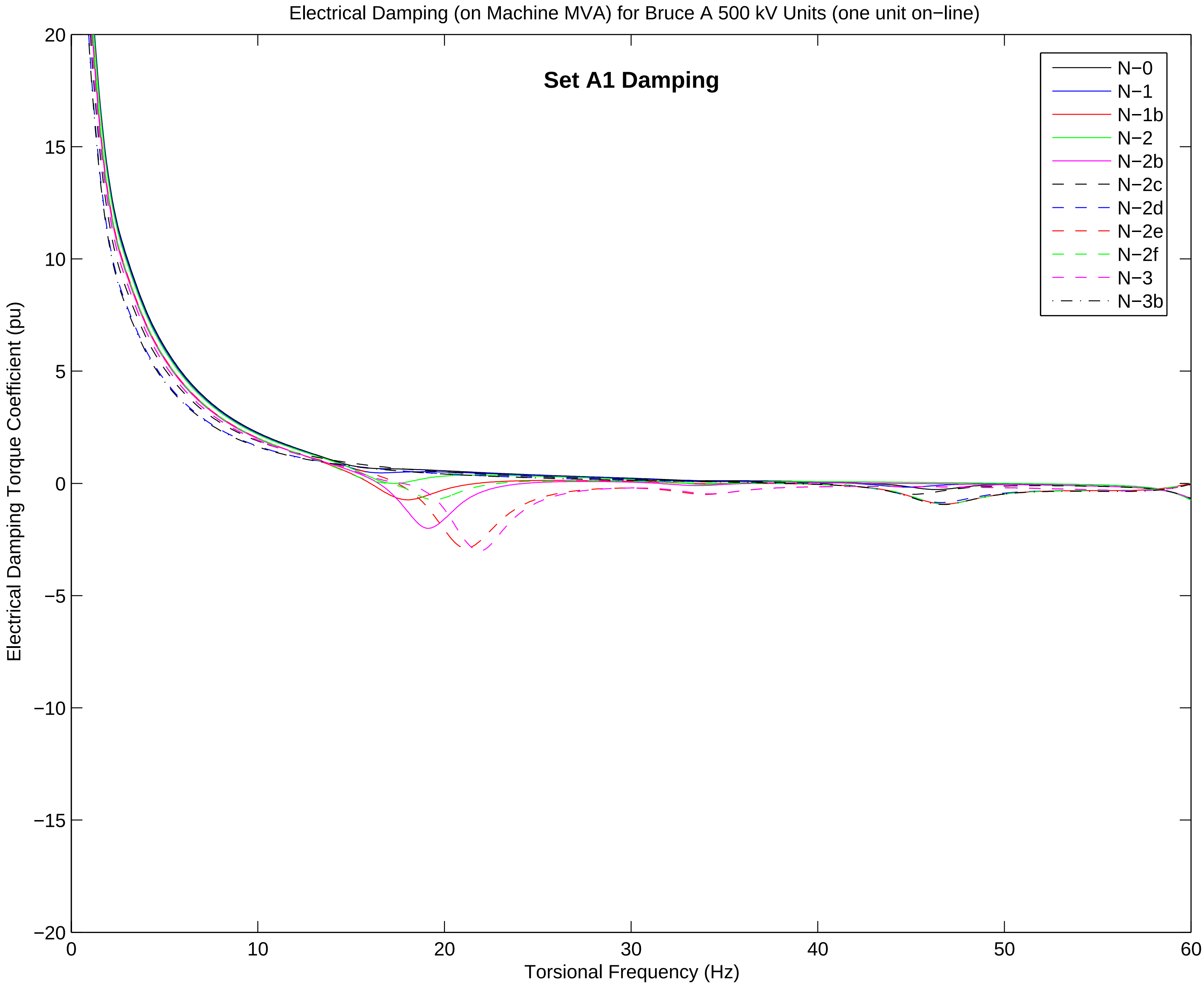
√ - indicates the generator is in-service

Table C-2: Contingency Descriptions

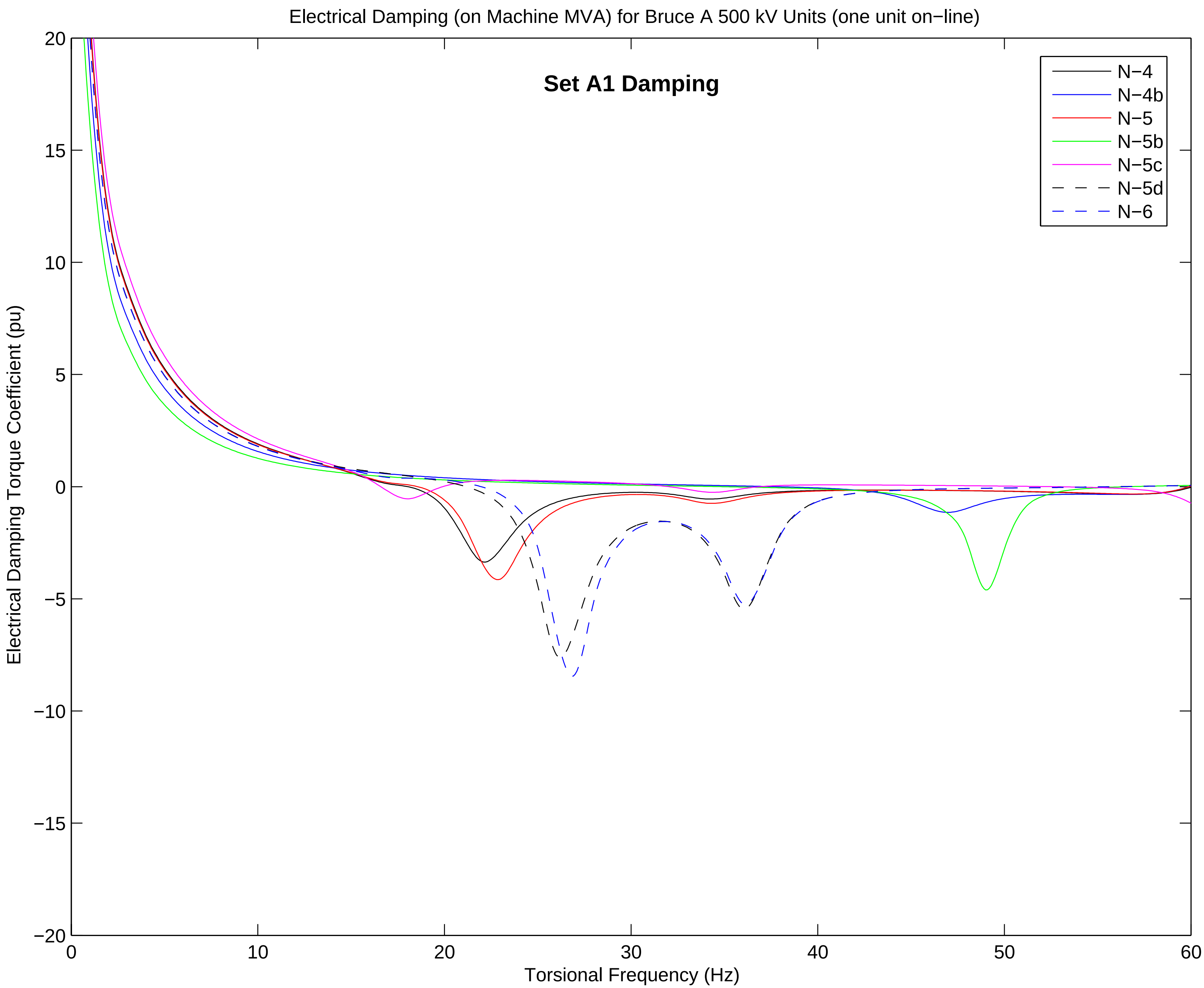
Contingency ID	Bruce A – Clairville 500kV Line 1	Bruce B – Milton 500kV Line 1	Bruce A – Bruce B 500kV Tie	Bruce A 500/230/27.6kV Transformer 25	Bruce A 500/230/27.6kV Transformer 27	Bruce A 500/230/27.6kV Transformer 28	Bruce A – Longwood 500kV Line 1	
N-0								
N-1	X							
N-1b			X					
N-2	X	X						
N-2b*	X		X					Bruce A 230kV Units on-line
N-2c*			X				X	Bruce A 230kV Units on-line
N-2d			X				X	
N-2e	X		X					
N-2f		X	X					
N-3	X	X	X					
N-3b			X	X			X	
N-4	X	X	X	X				
N-4b			X	X	X		X	
N-5	X	X	X	X	X			
N-5b			X	X	X	X	X	
N-5c	X	X		X	X	X		
N-5d	X		X	X	X	X		
N-6	X	X	X	X	X	X		

X – indicates the branch is out-of-service

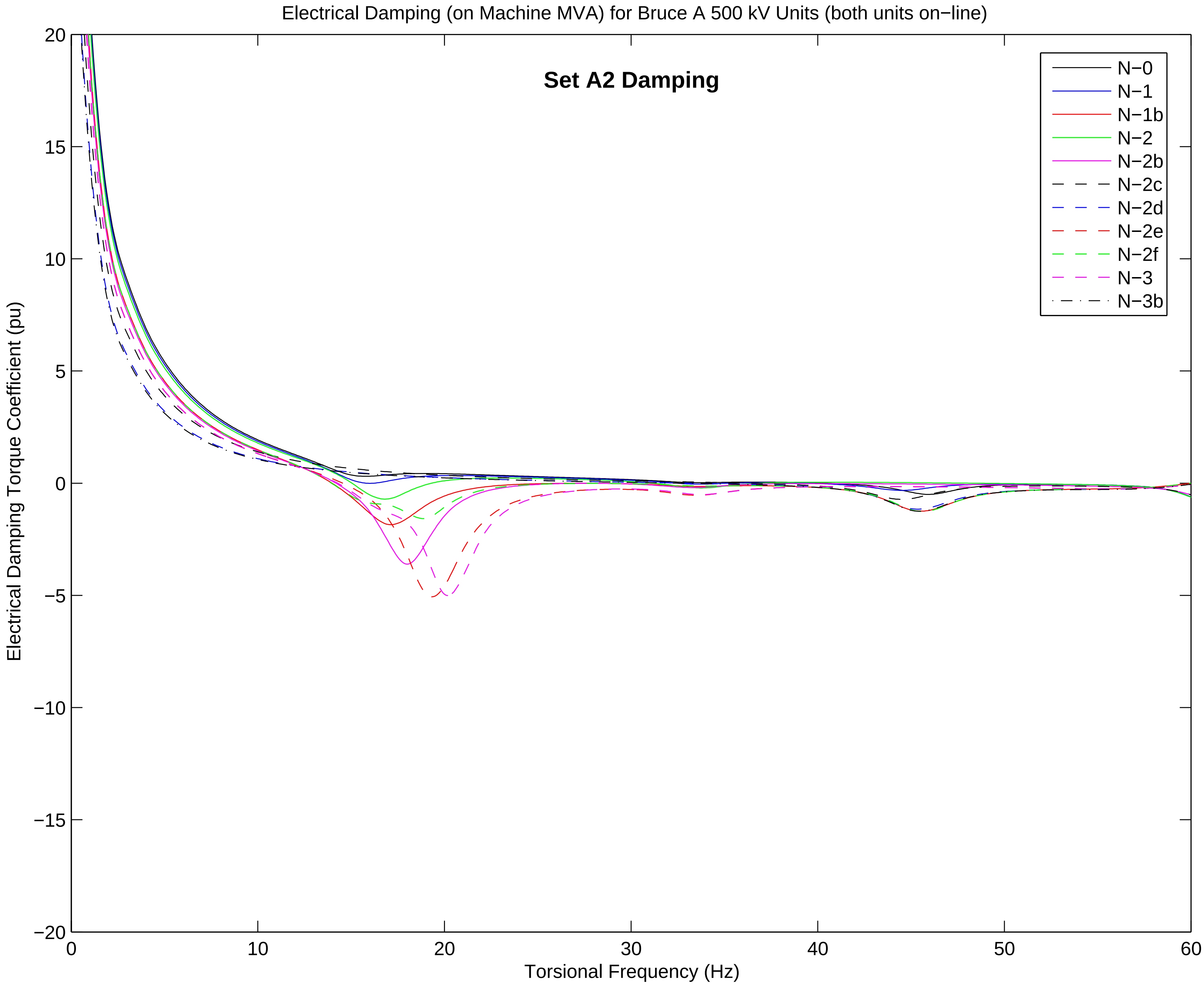
* – performed for Sets A1 & A2 only

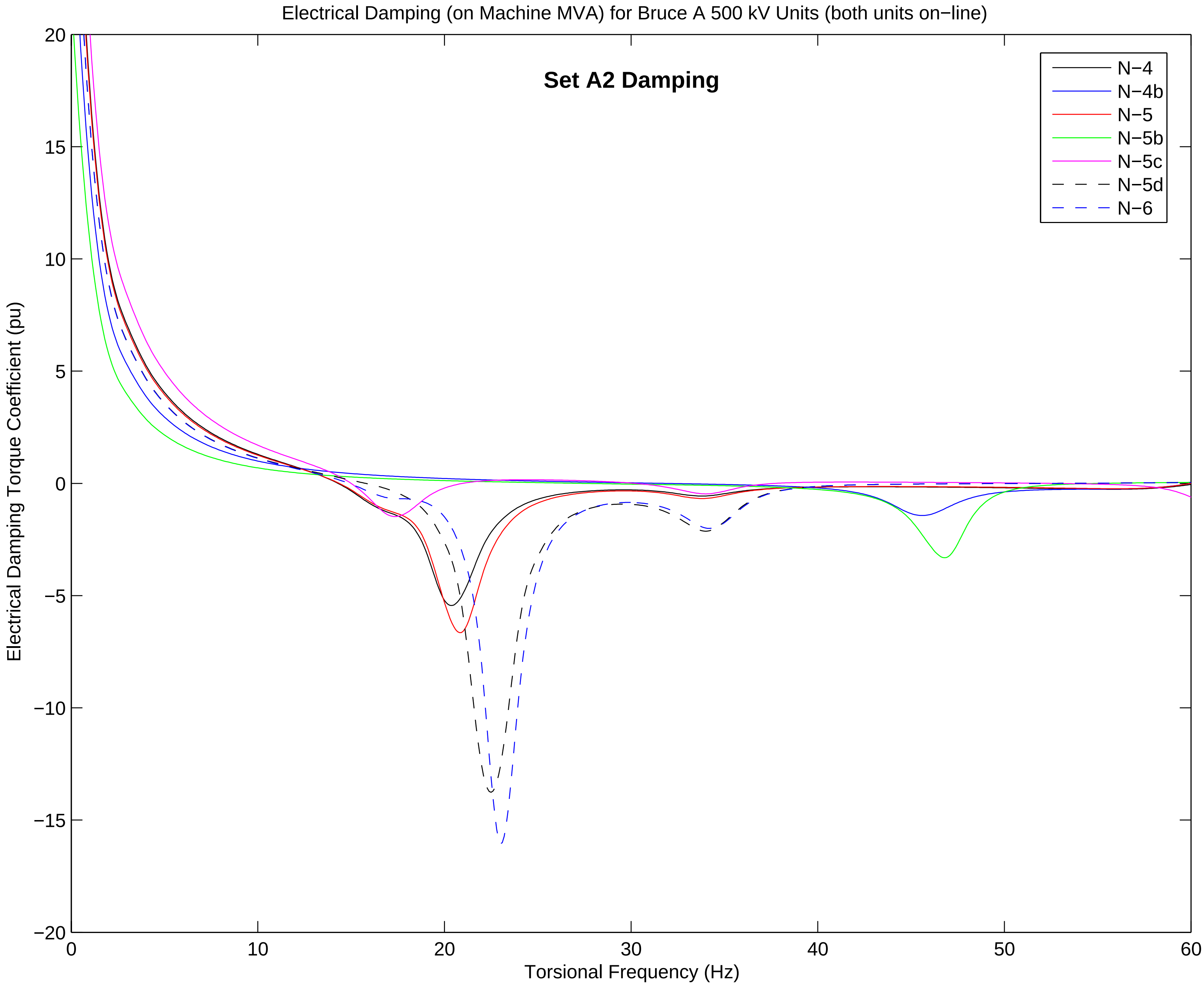


Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line)
Set A1 Damping
N−0
N−1
N−1b
N−2
N−2b
N−2c
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

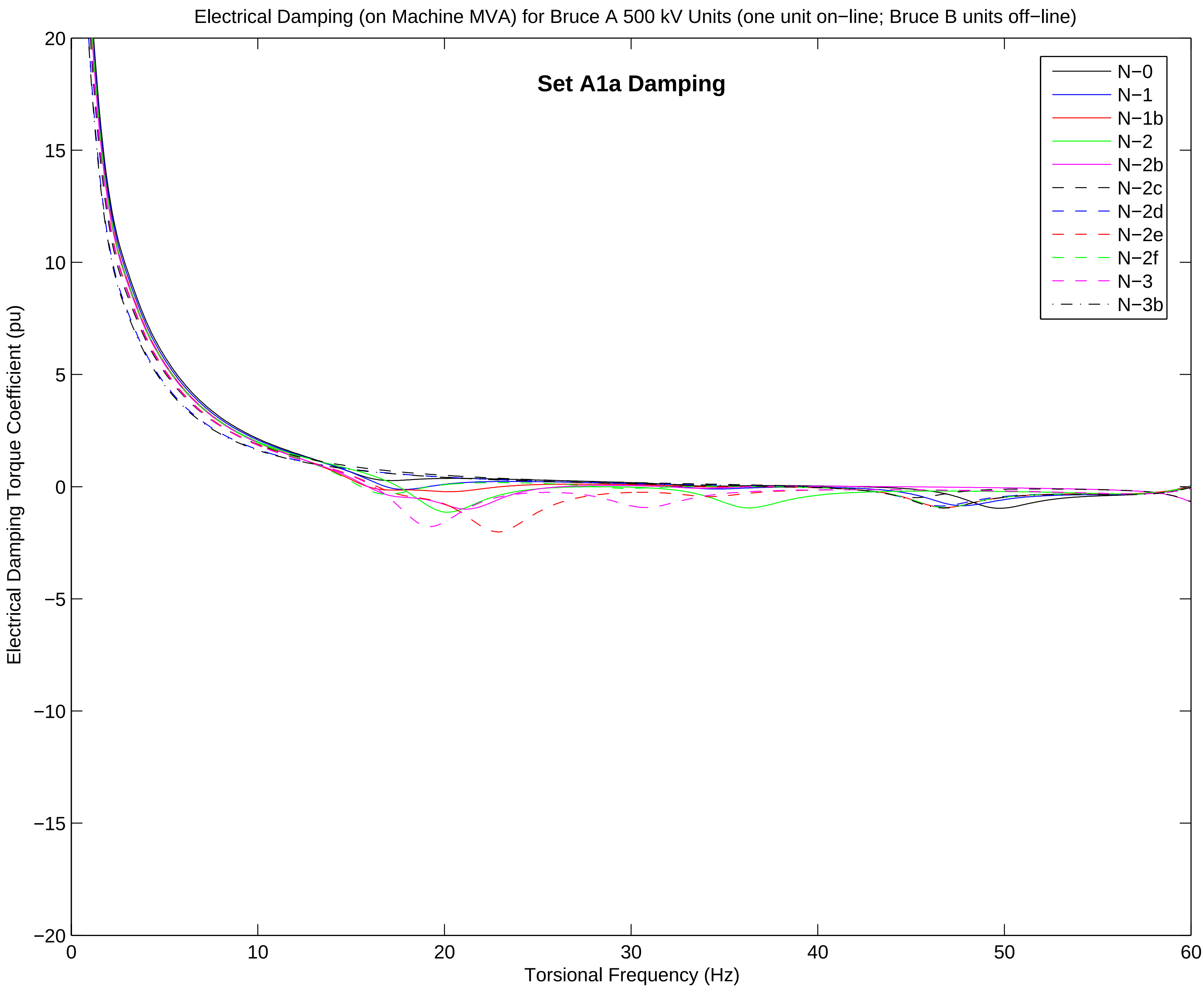


Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line)
Set A1 Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

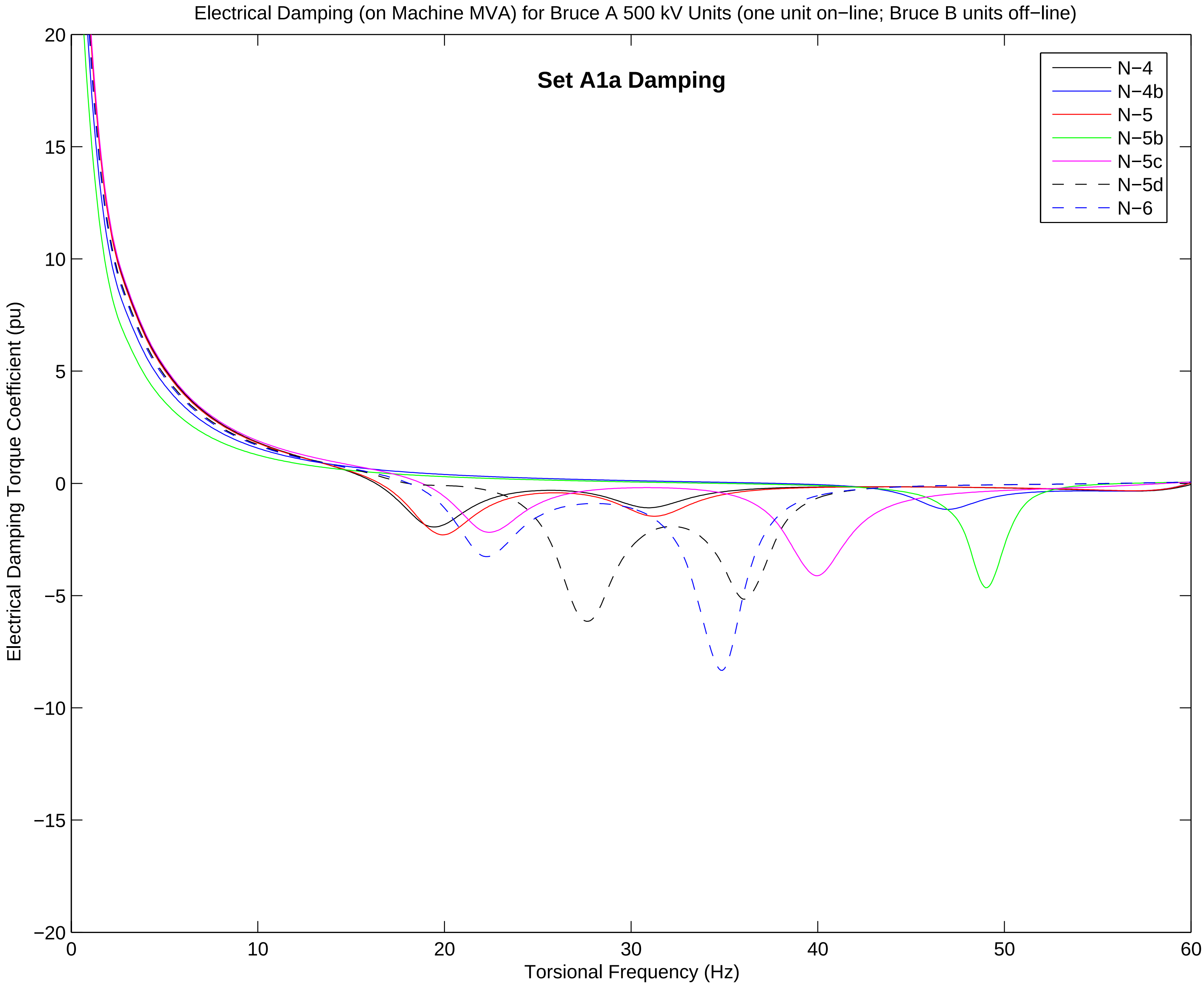

Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
Set A2 Damping
N−0
N−1
N−1b
N−2
N−2b
N−2c
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



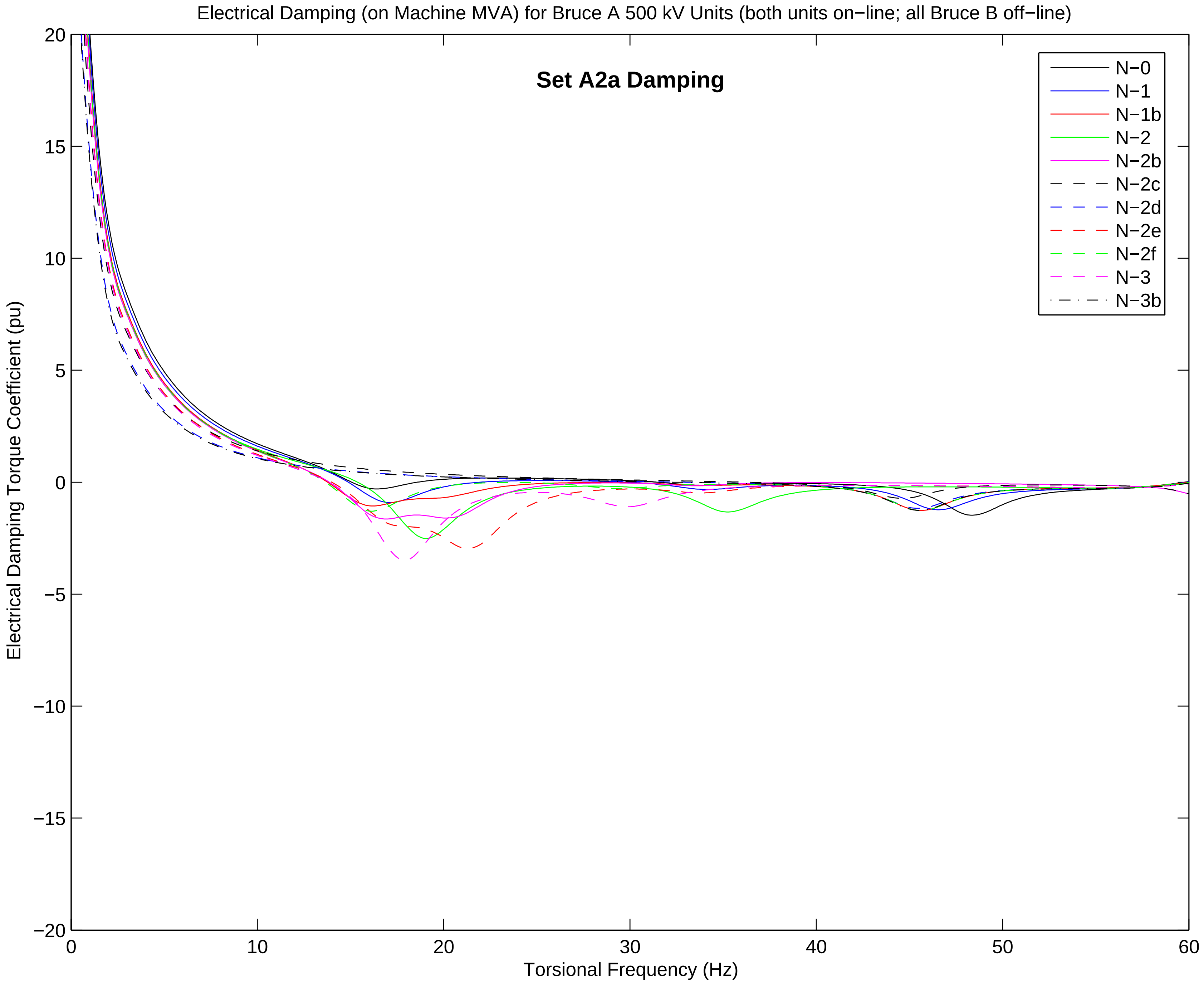
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
Set A2 Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
20
15
10
5
0
−5
−10
−15
−20
Electrical Damping Torque Coefficient (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



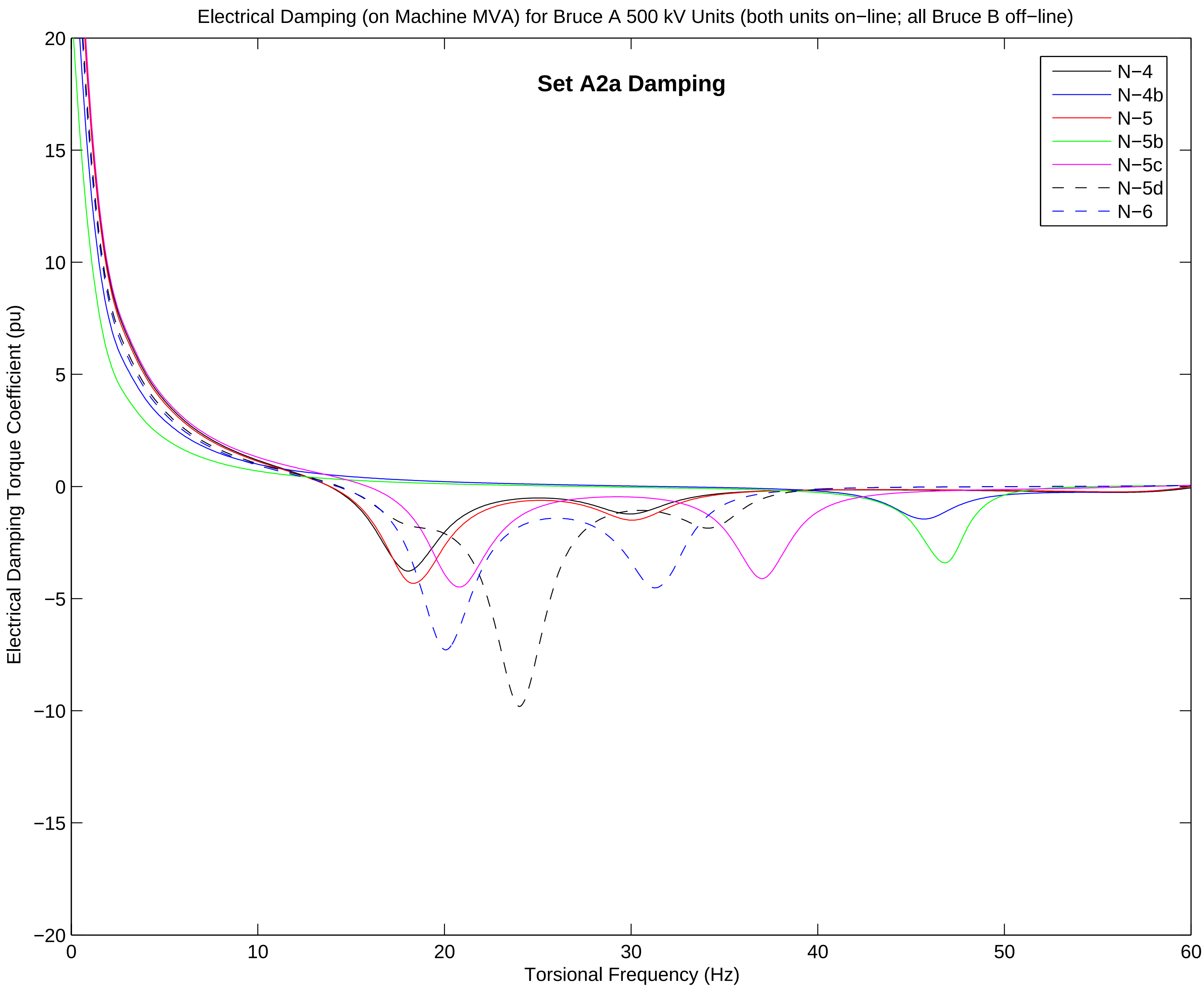
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line; Bruce B units off−line)
Set A1a Damping
N−0
N−1
N−1b
N−2
N−2b
N−2c
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



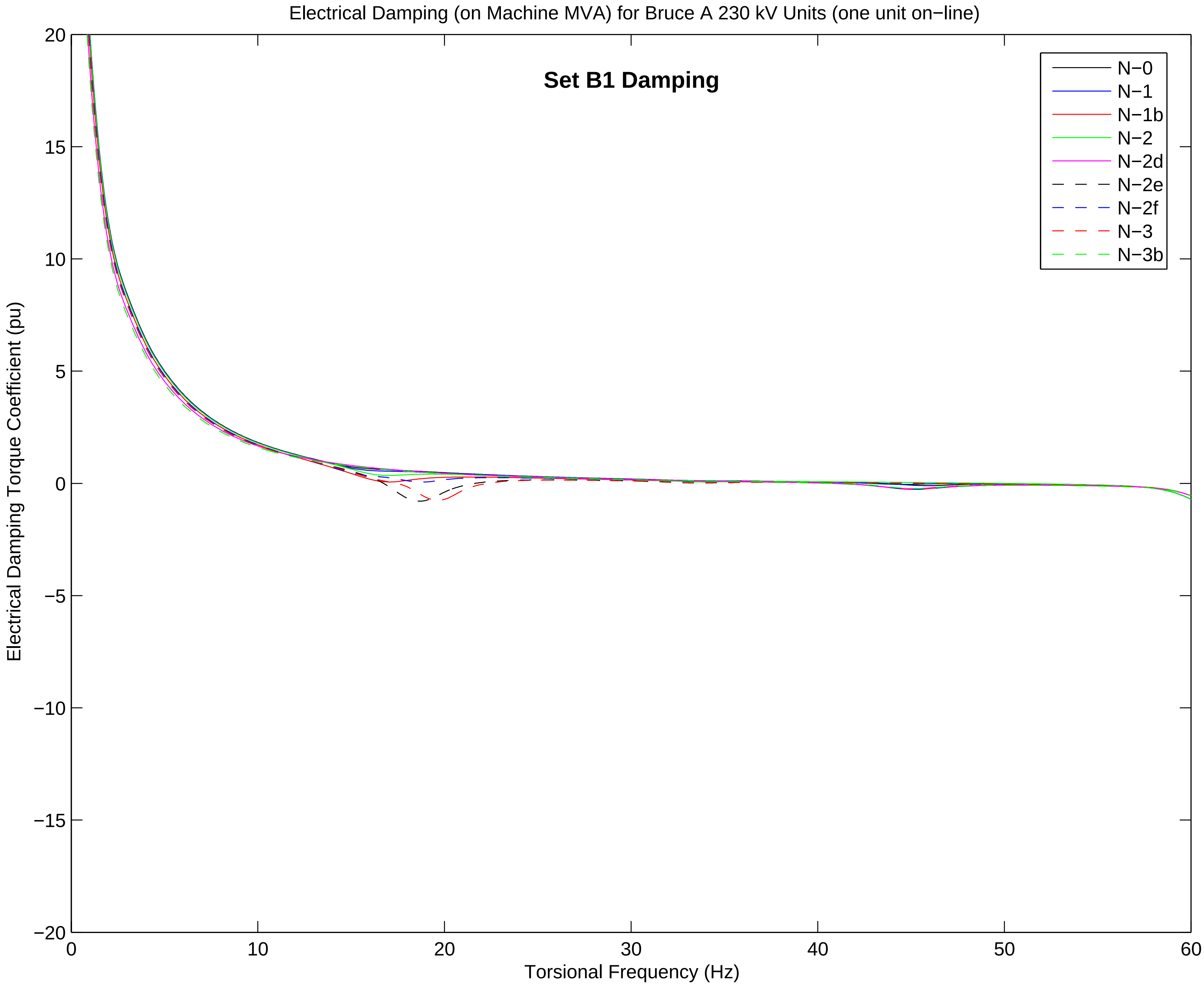
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line; Bruce B units off−line)
Set A1a Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



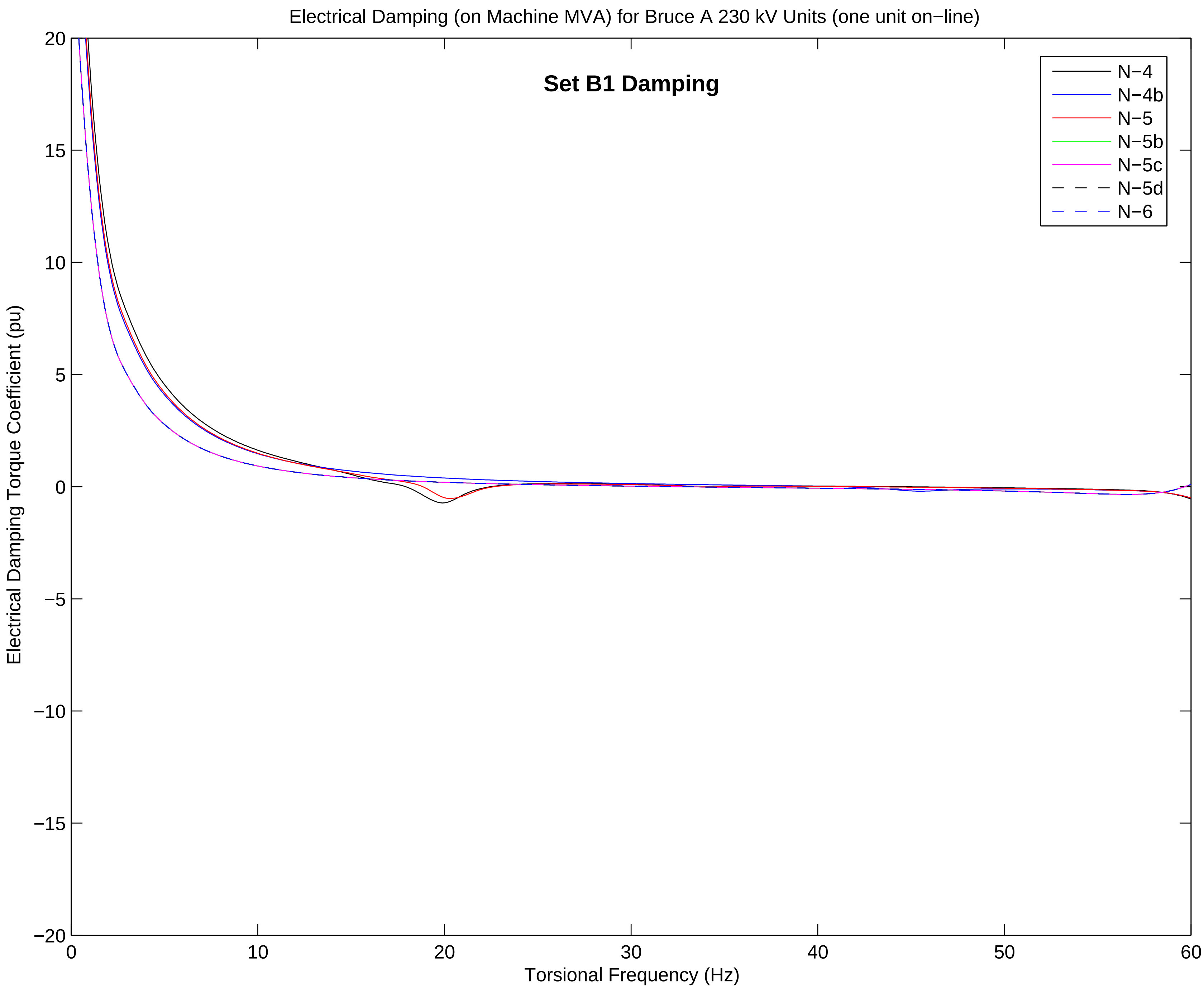
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line; all Bruce B off−line)
Set A2a Damping
N−0
N−1
N−1b
N−2
N−2b
N−2c
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



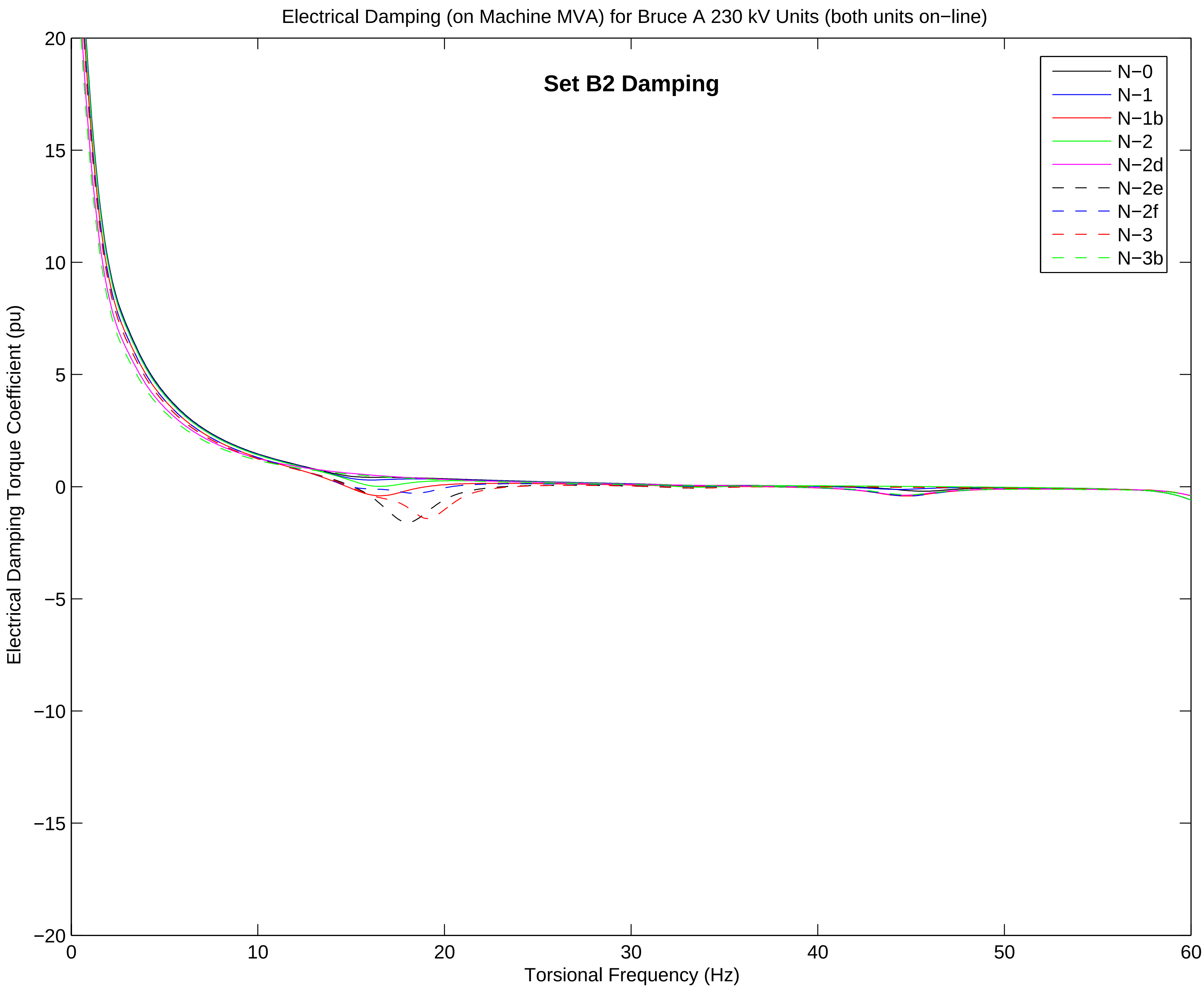
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line; all Bruce B off−line)
Set A2a Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



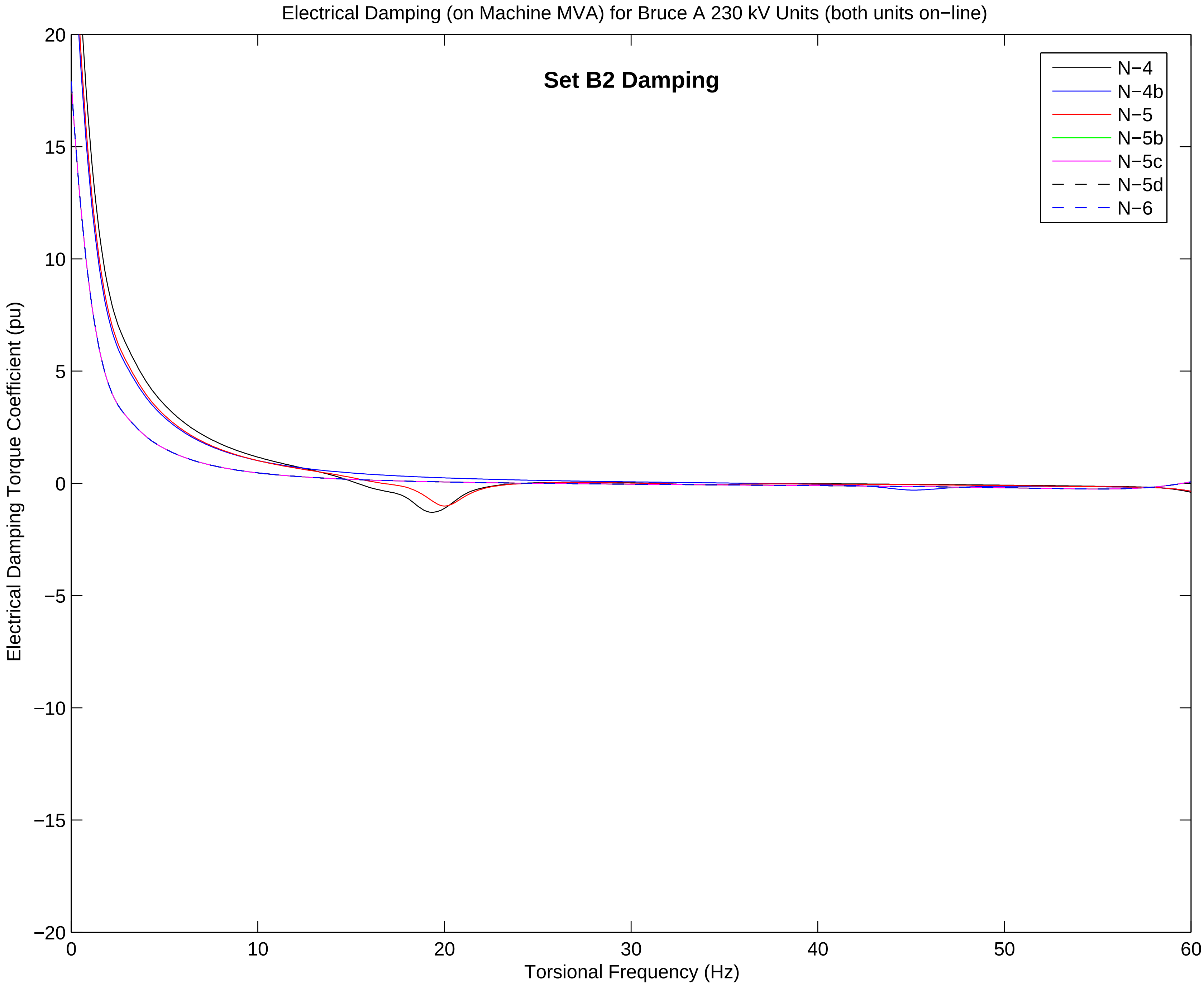
Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (one unit on−line)
Set B1 Damping
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

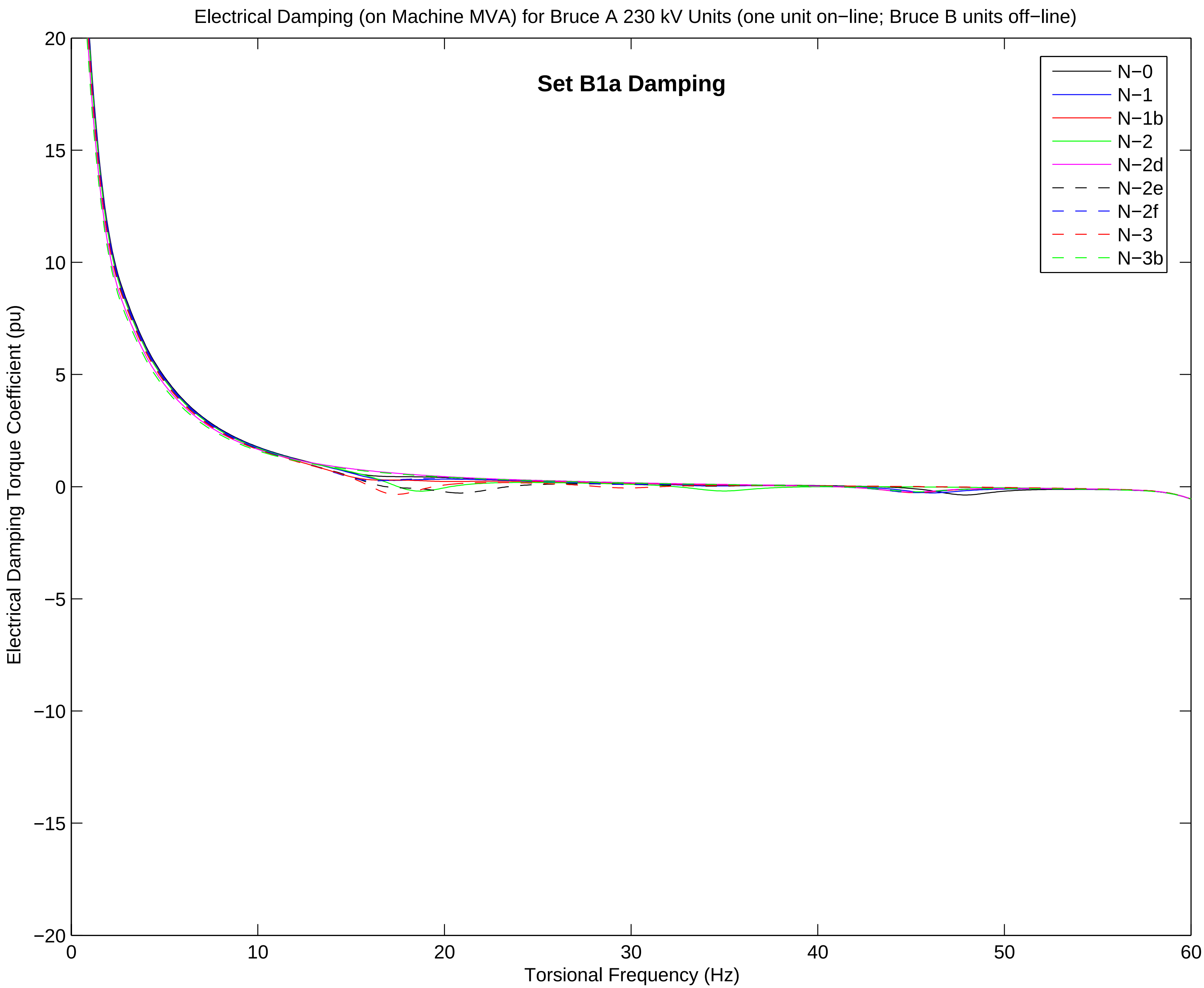


Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (one unit on−line)
Set B1 Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)

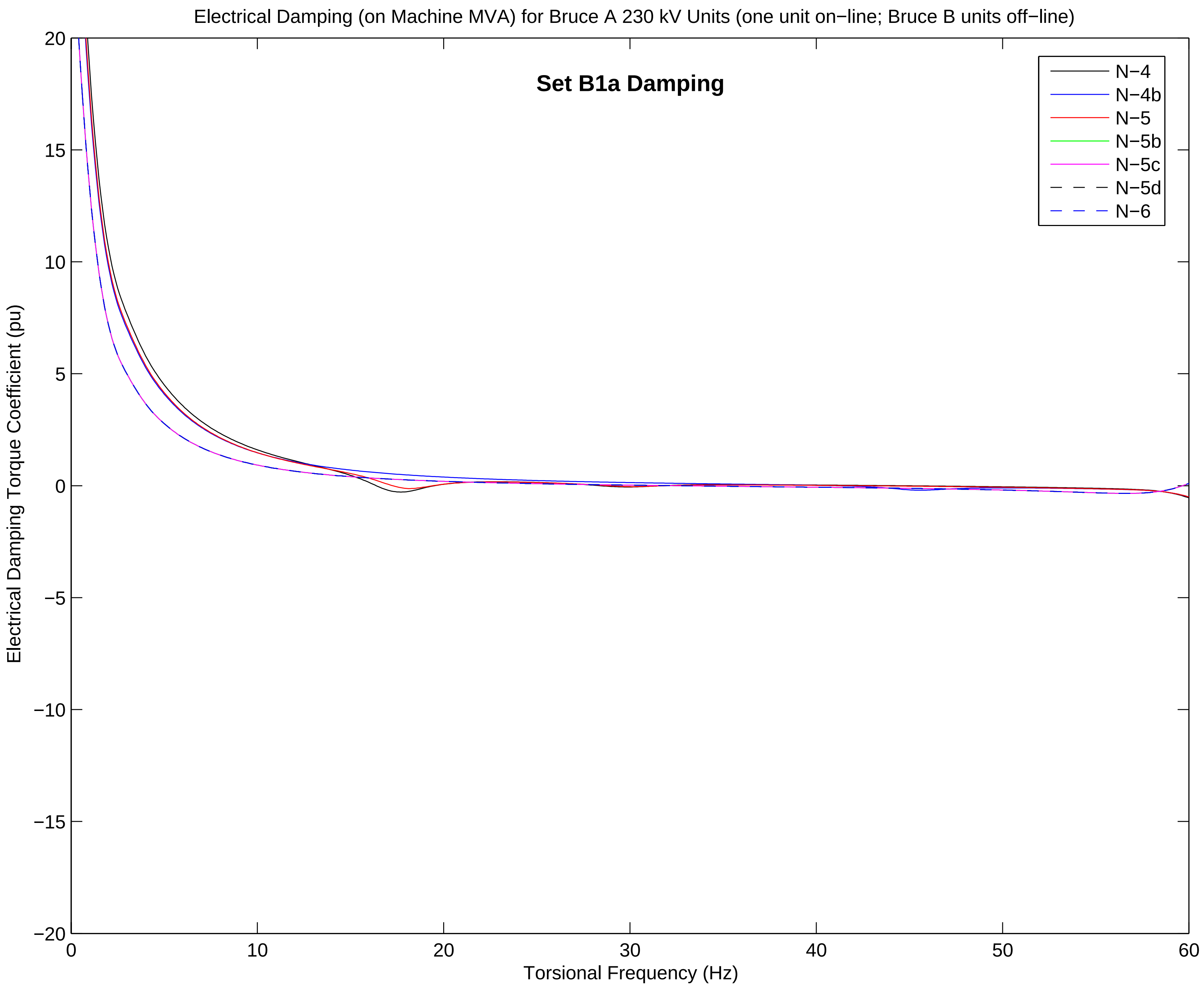


Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line)
Set B2 Damping
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

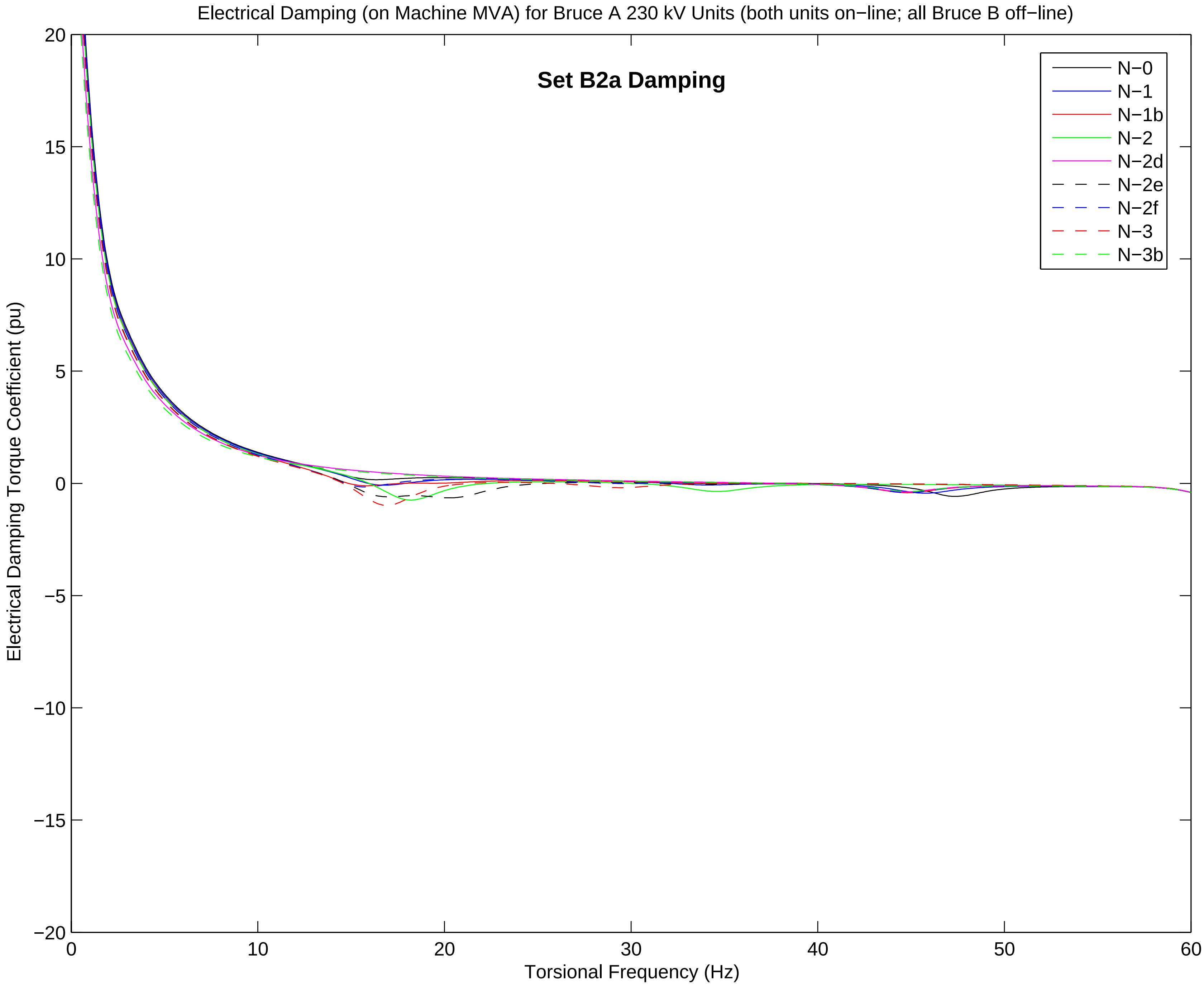

Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line)
Set B2 Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



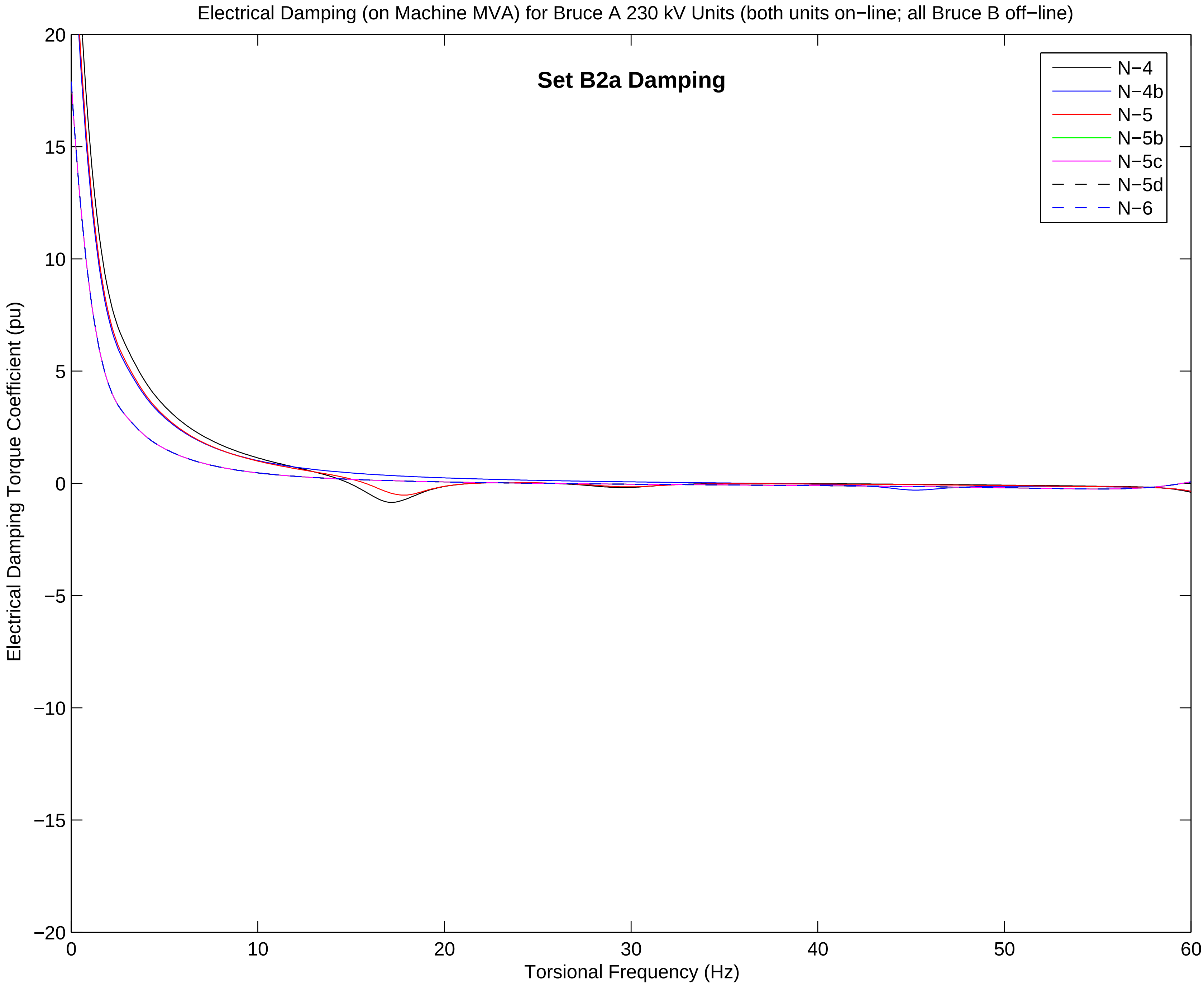
Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (one unit on−line; Bruce B units off−line)
Set B1a Damping
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

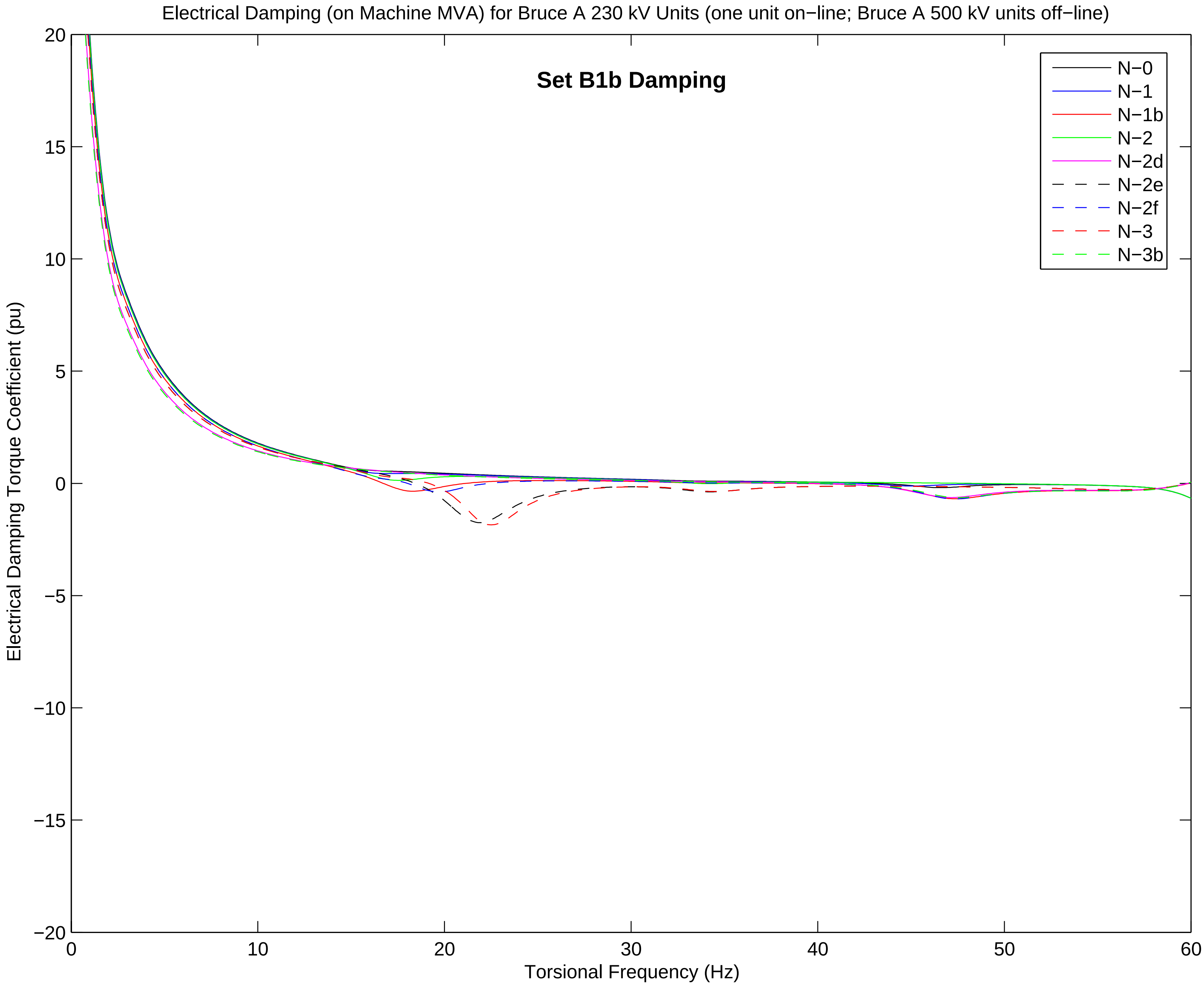


Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (one unit on−line; Bruce B units off−line)
Set B1a Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

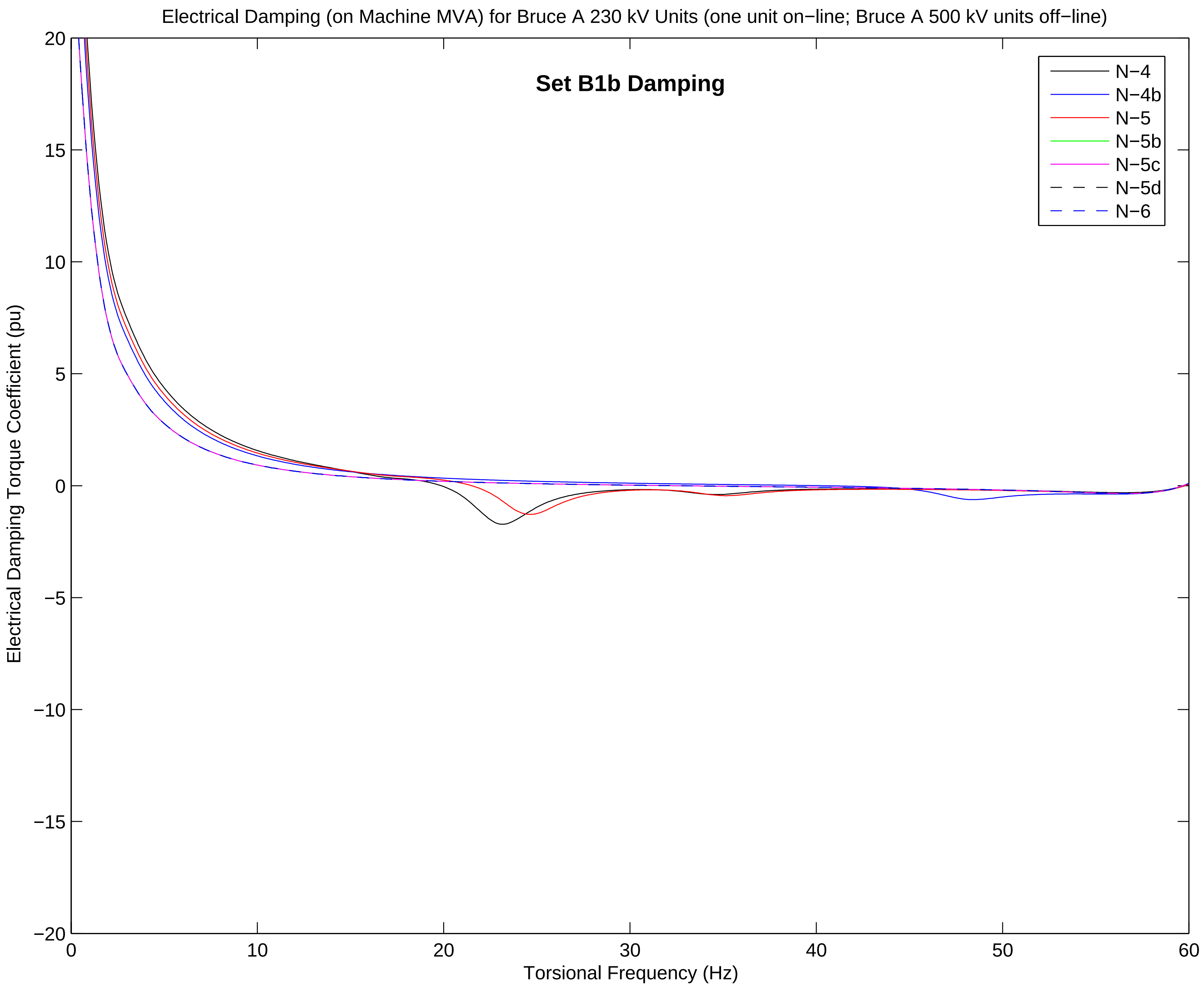


Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line; all Bruce B off−line)
Set B2a Damping
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

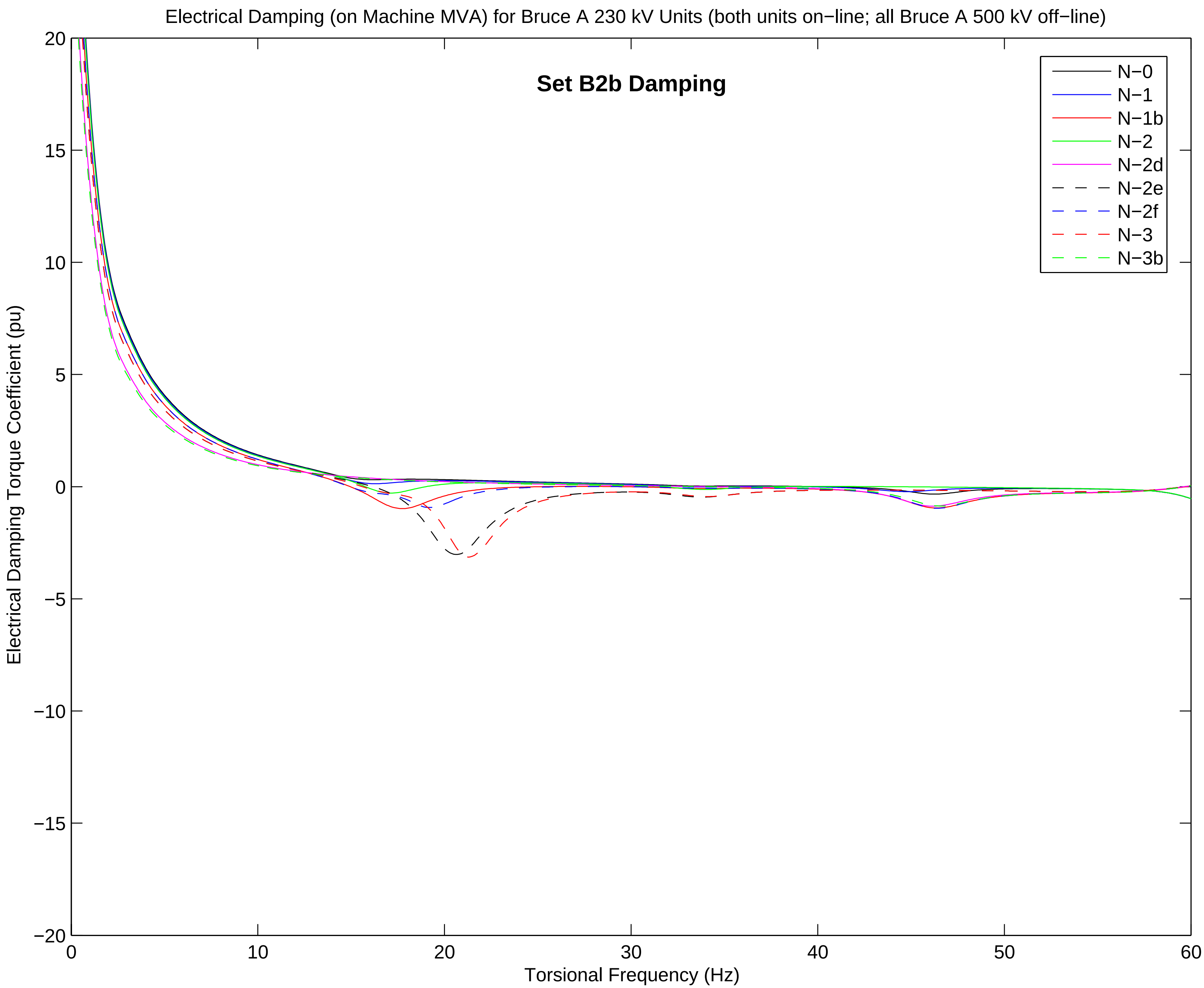

Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line; all Bruce B off−line)
Set B2a Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

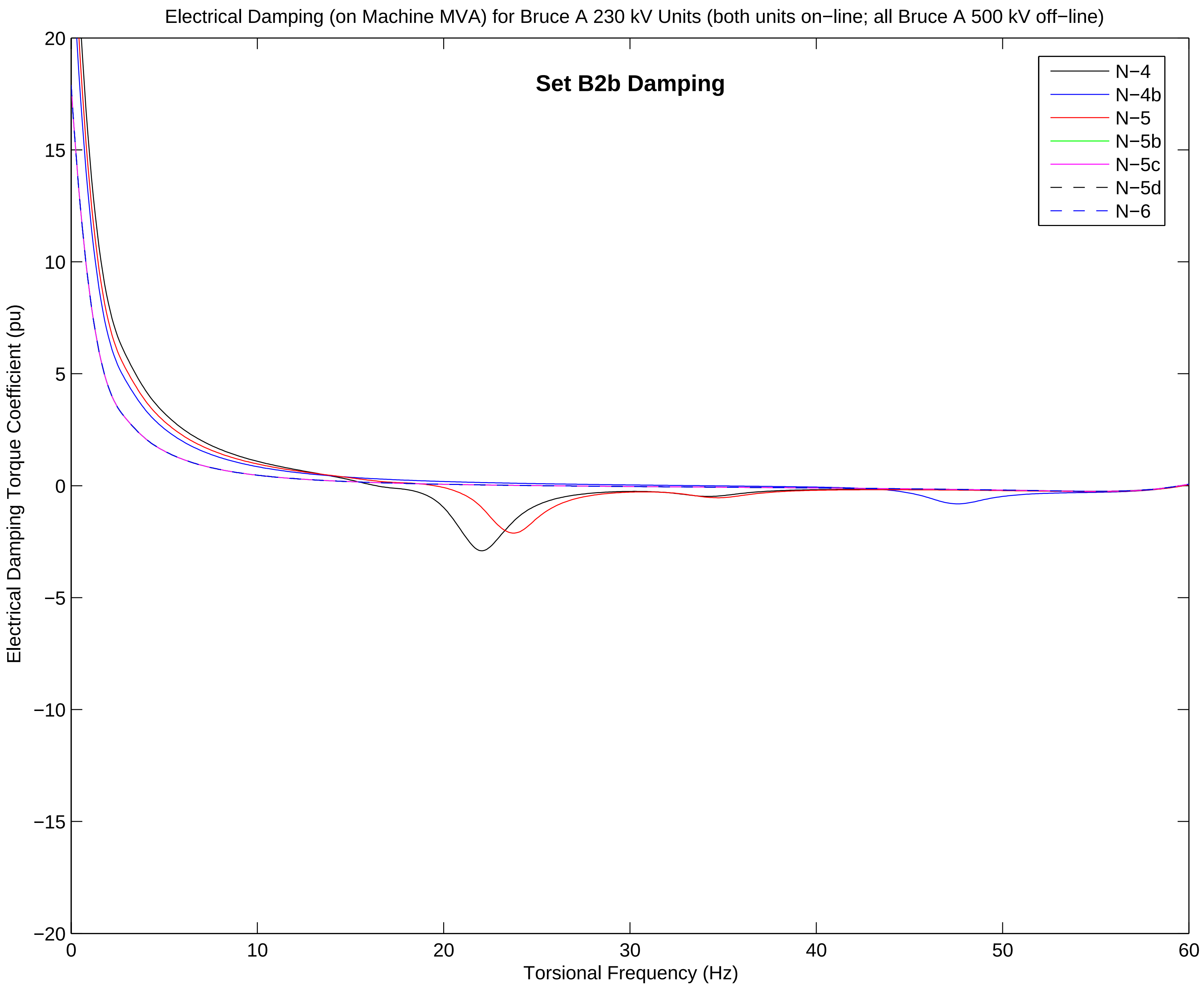


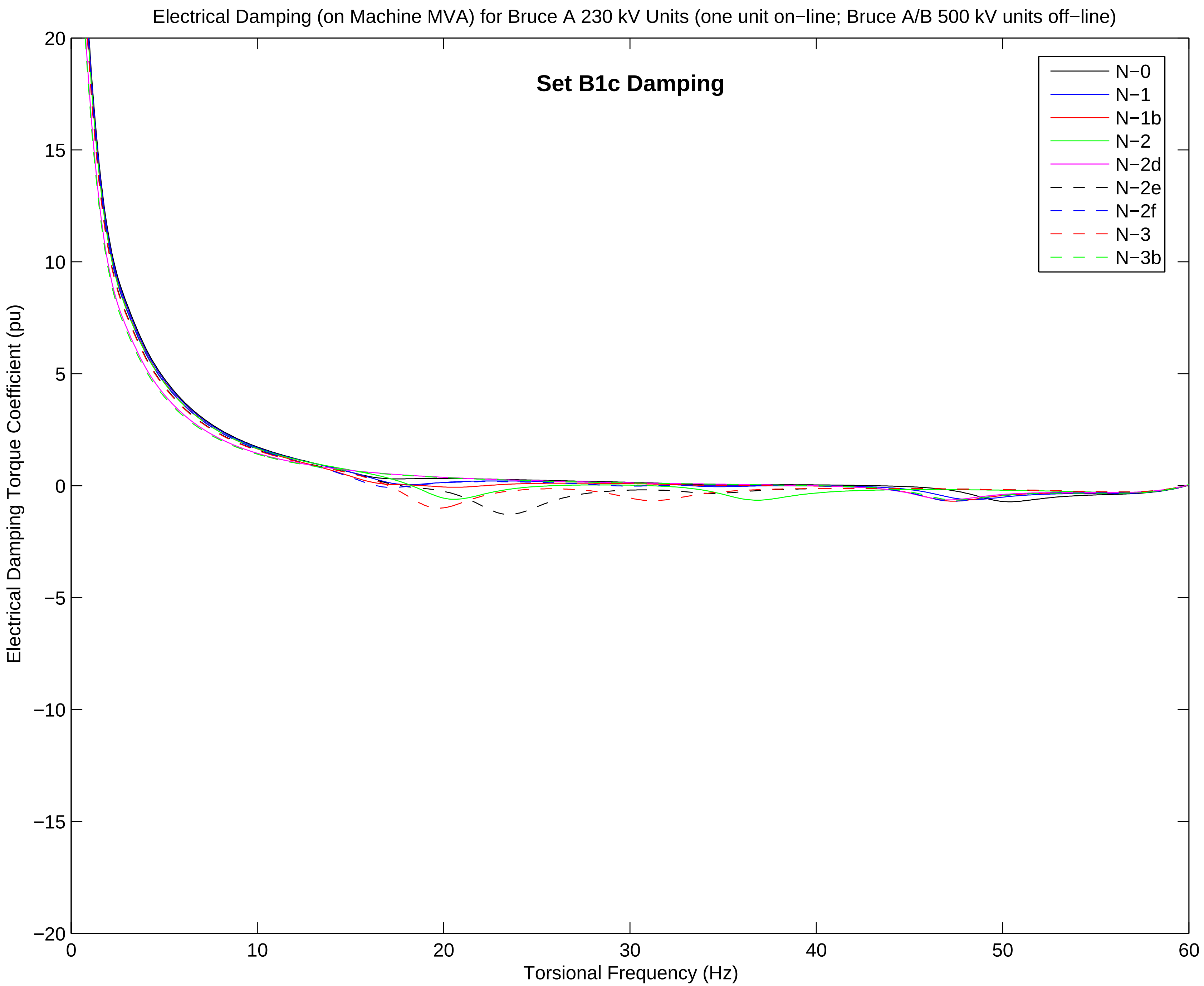
Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (one unit on−line; Bruce A 500 kV units off−line)
Set B1b Damping
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

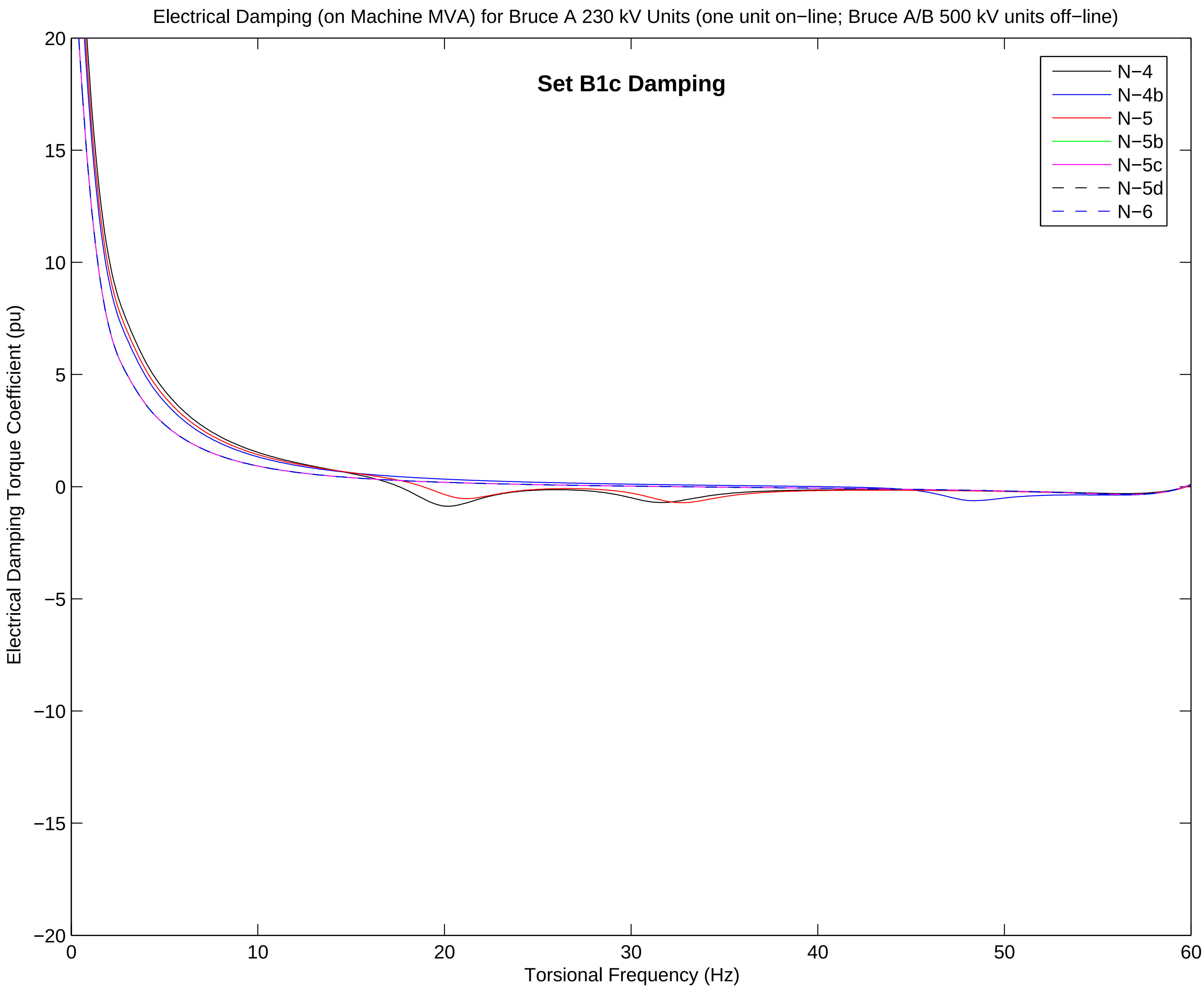


Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (one unit on−line; Bruce A 500 kV units off−line)
Set B1b Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

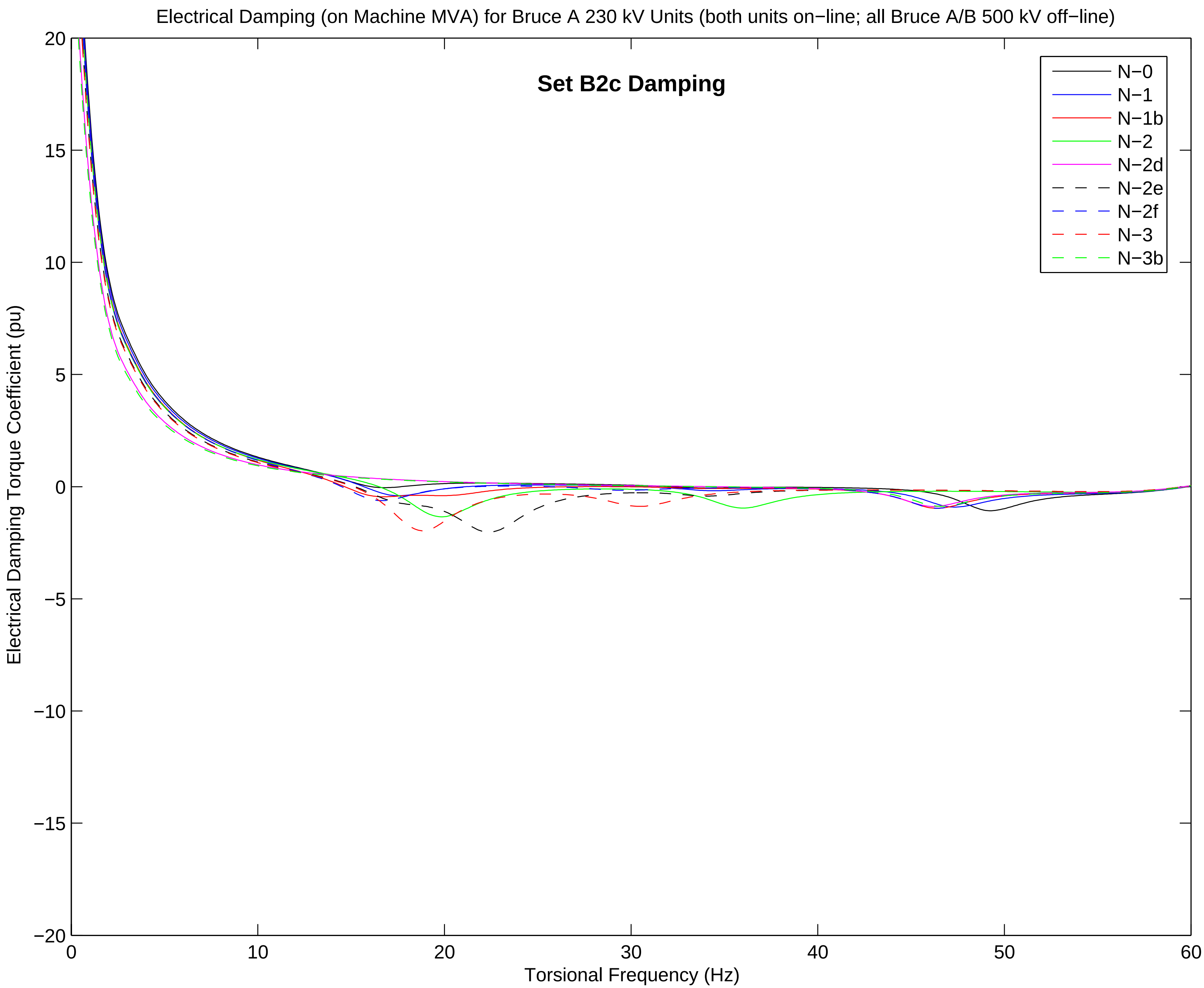

Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line; all Bruce A 500 kV off−line)
Set B2b Damping
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line; all Bruce A 500 kV off−line)
Set B2b Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

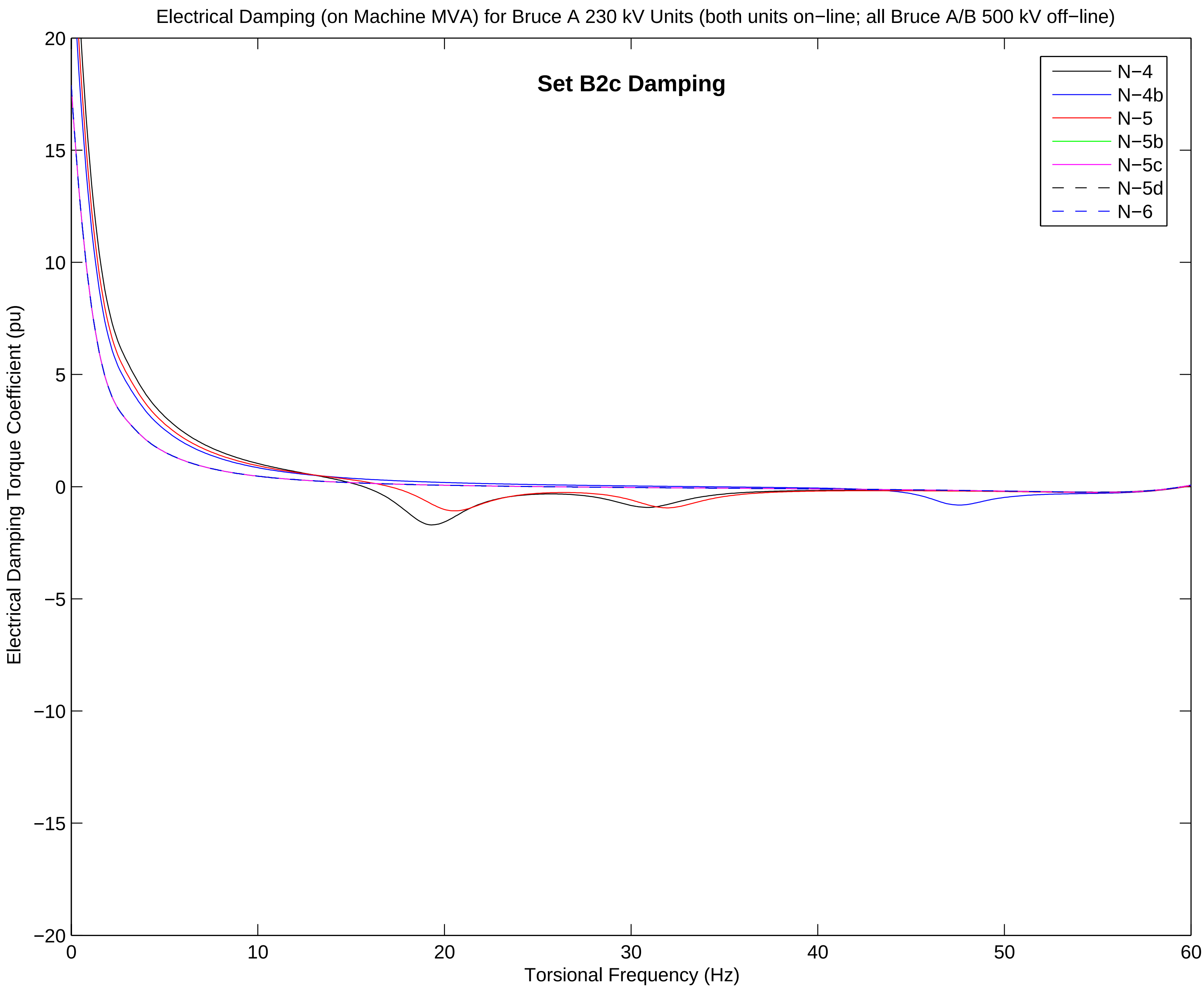

Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (one unit on−line; Bruce A/B 500 kV units off−line)
Set B1c Damping
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



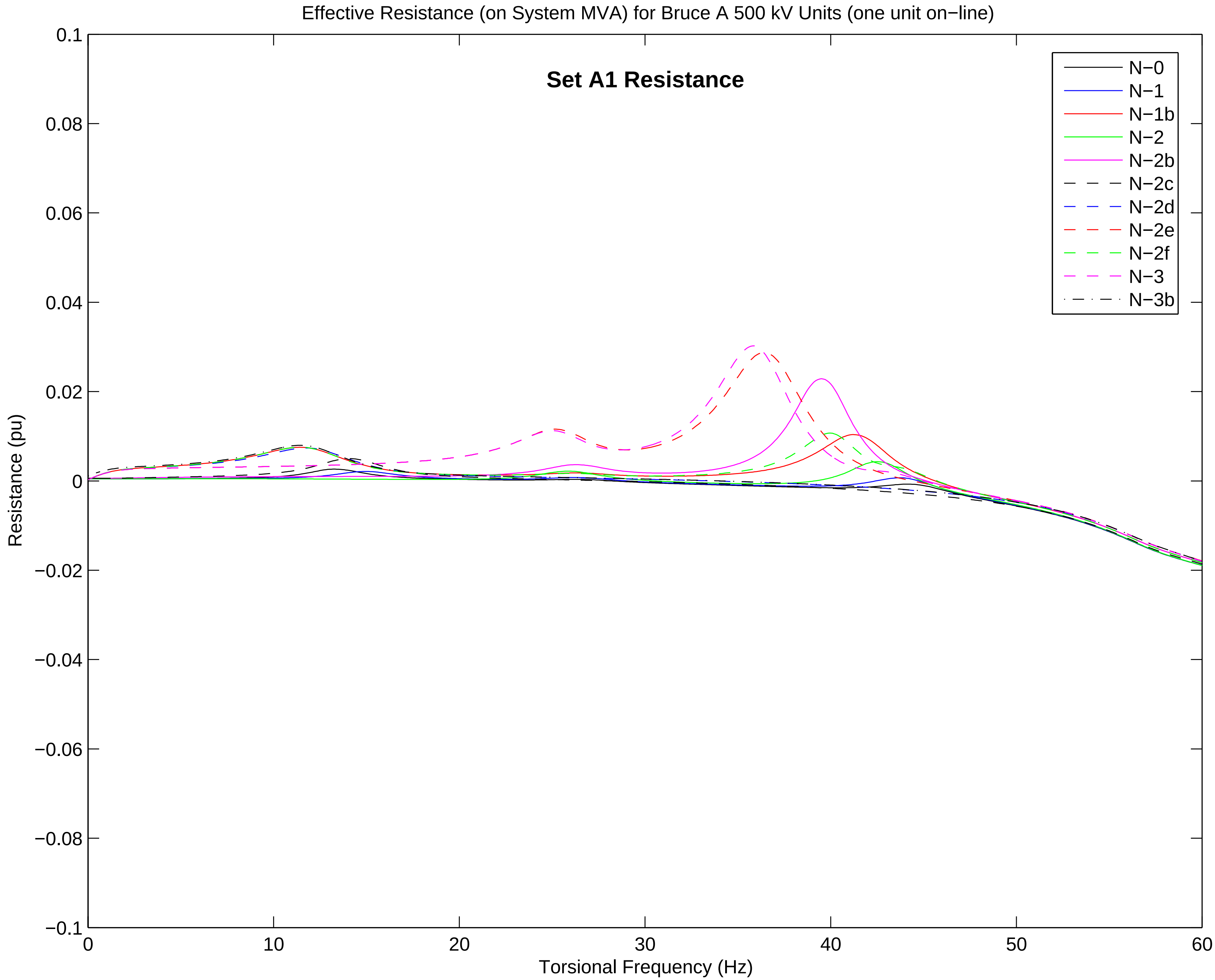
Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (one unit on−line; Bruce A/B 500 kV units off−line)
Set B1c Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

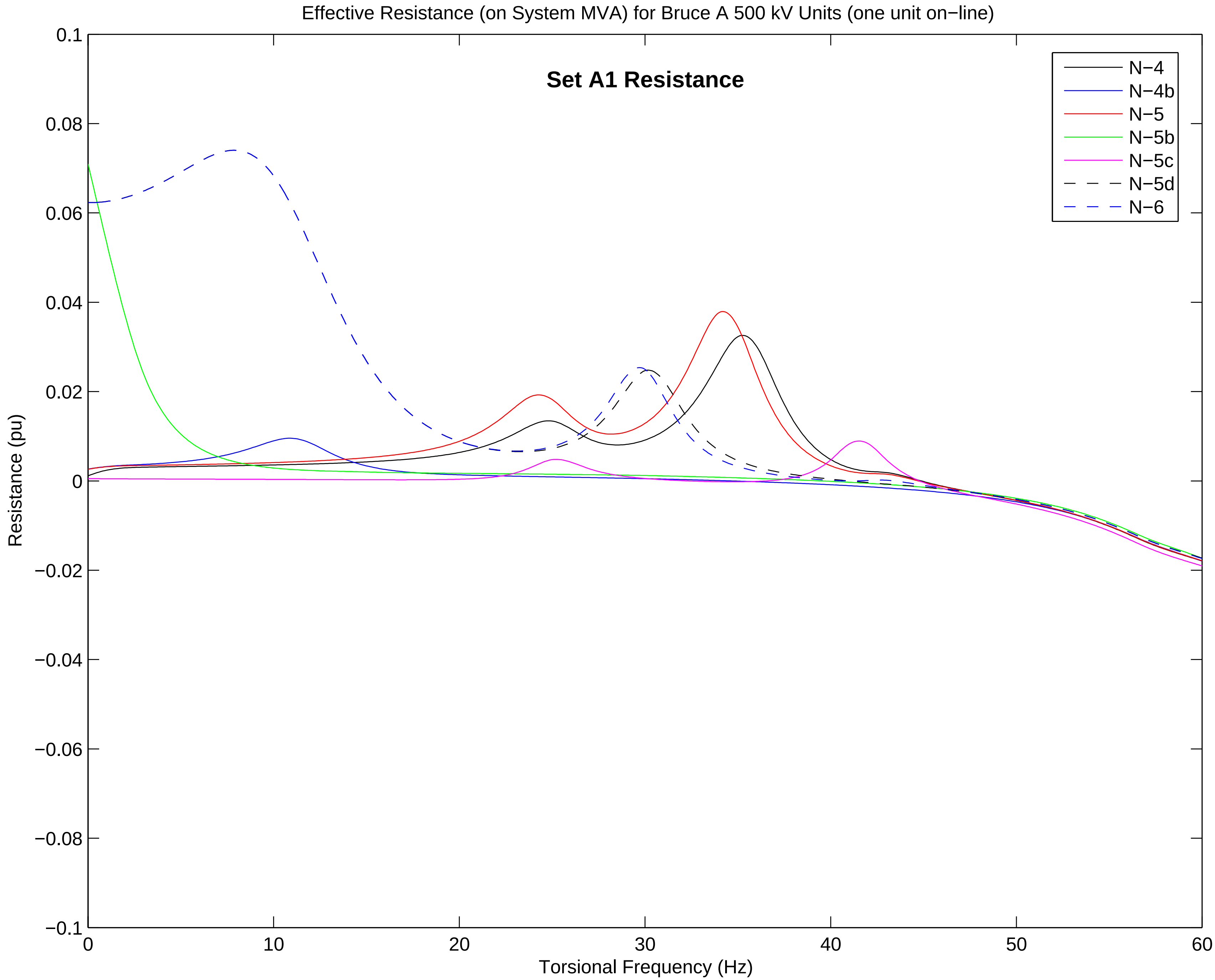


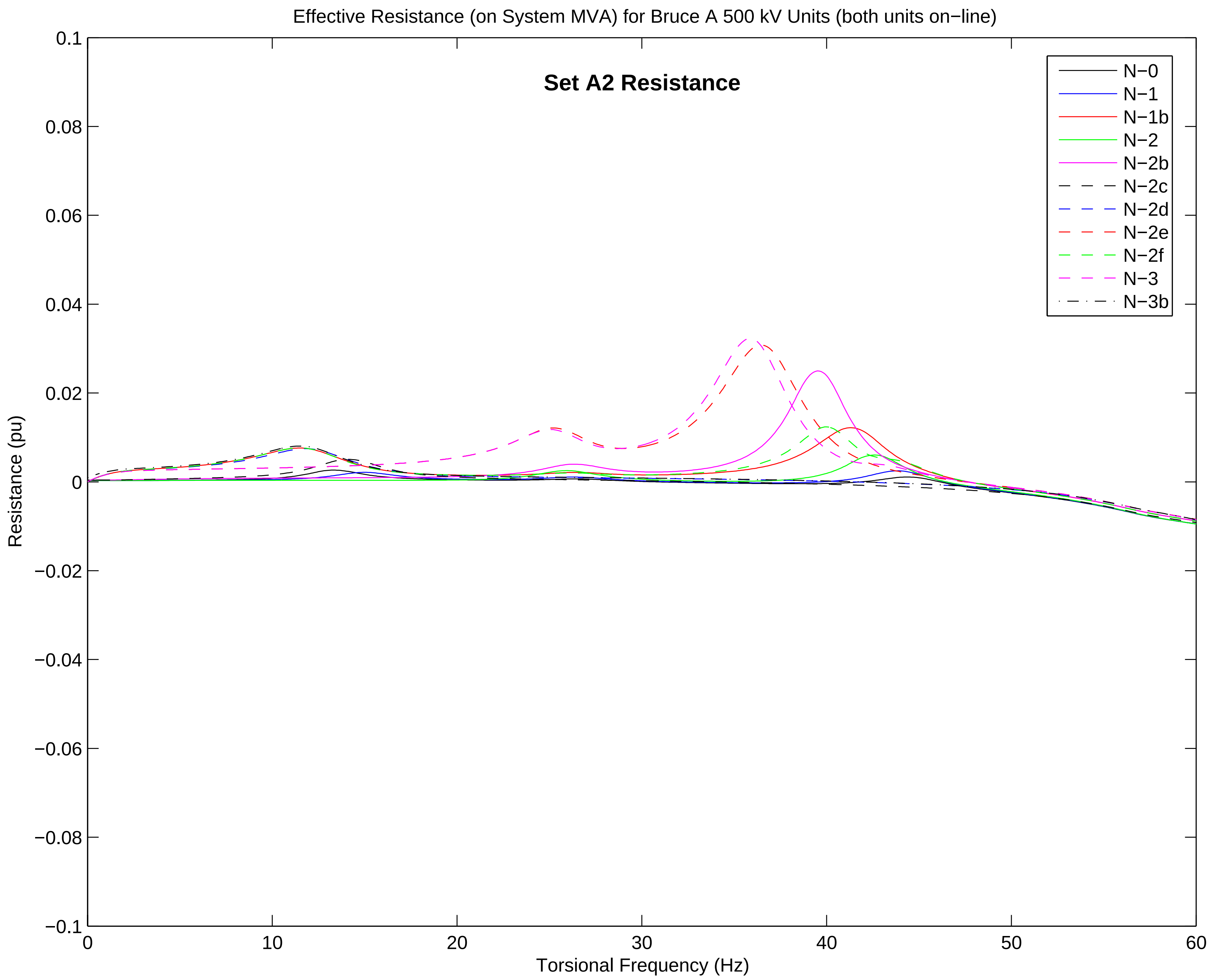
Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line; all Bruce A/B 500 kV off−line)
Set B2c Damping
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



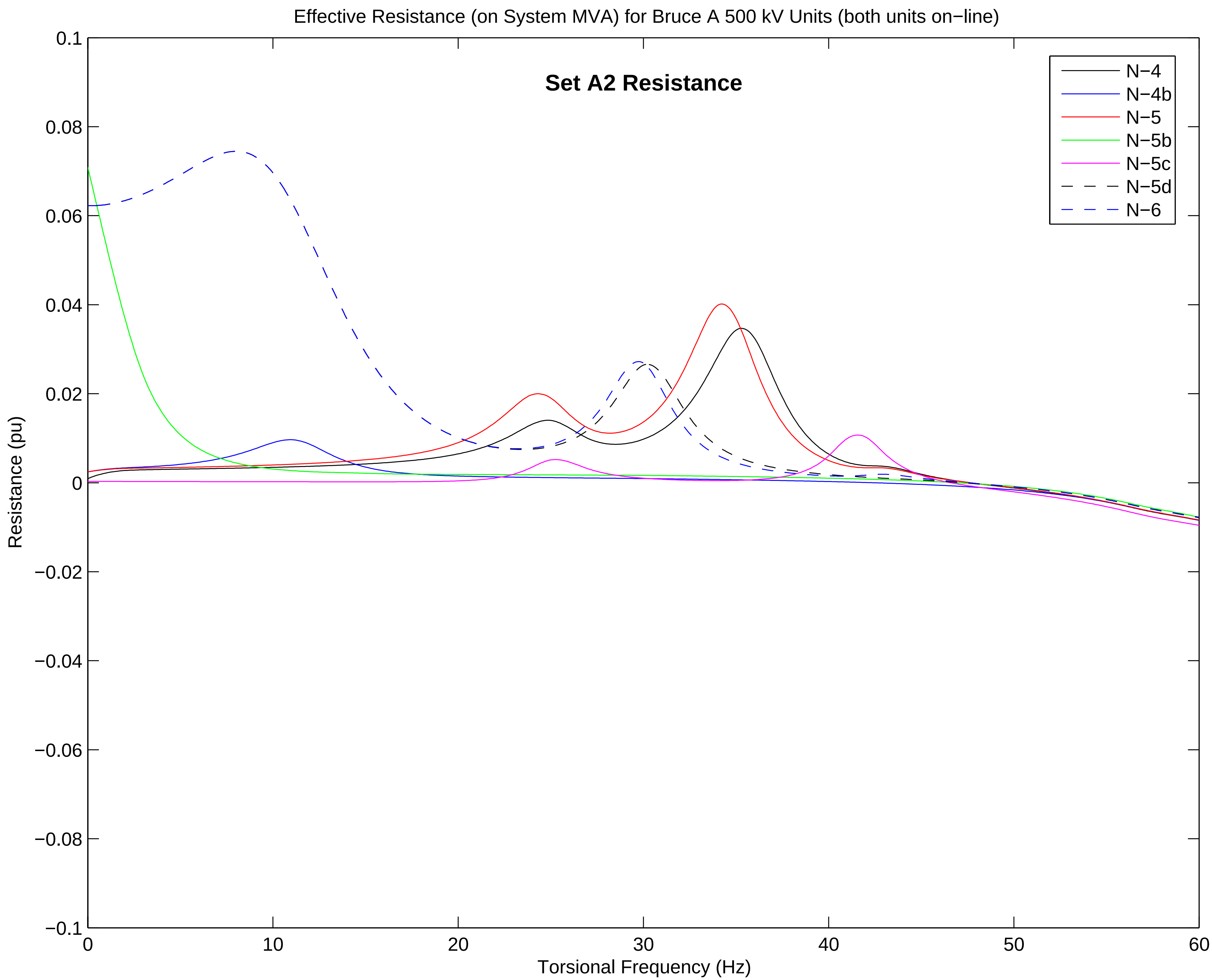
Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line; all Bruce A/B 500 kV off−line)
Set B2c Damping
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Bruce A 500 kV Units (one unit on−line)
Set A1 Resistance
N−0
N−1
N−1b
N−2
N−2b
N−2c
N−2d
N−2e
N−2f
N−3
N−3b
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

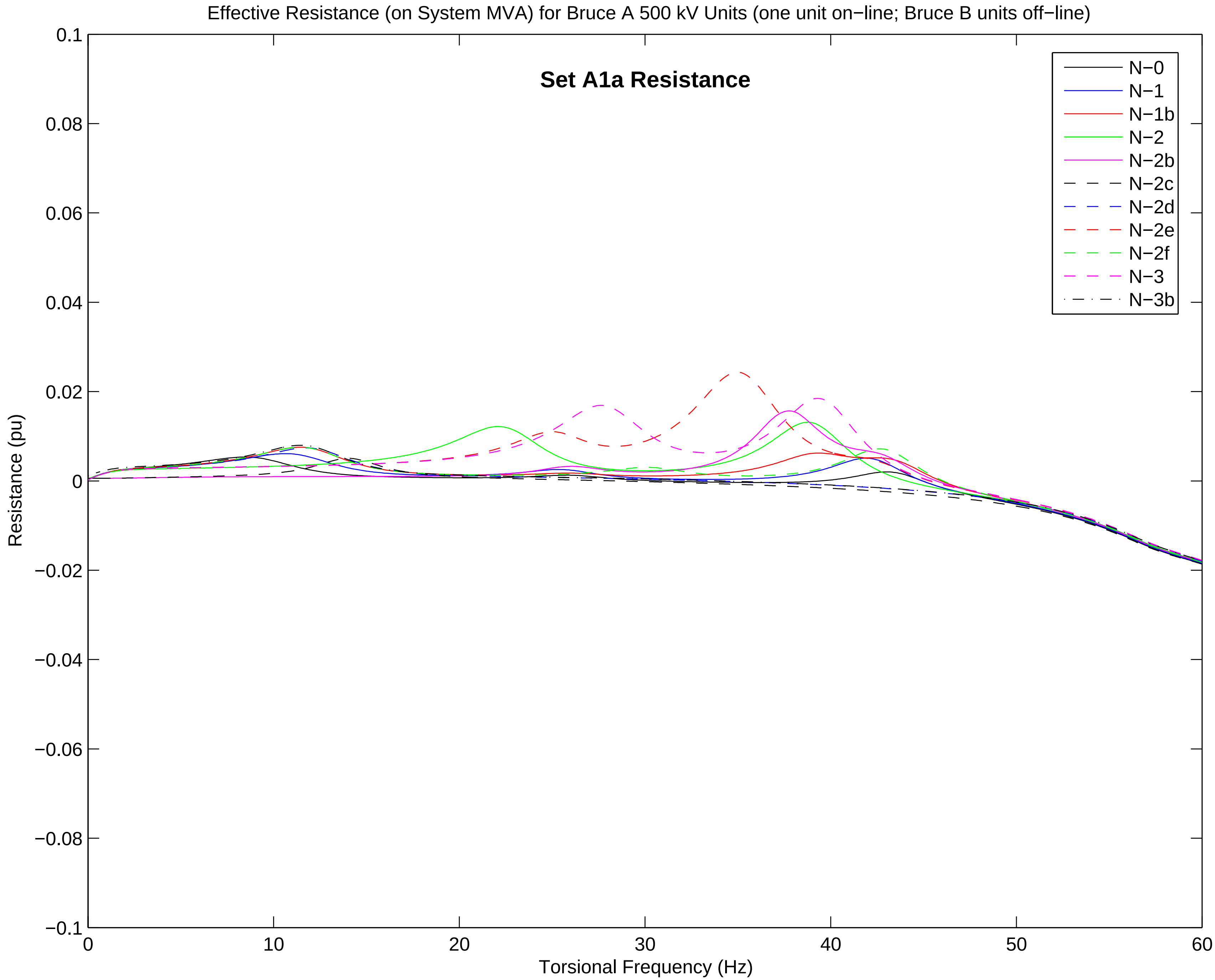

Effective Resistance (on System MVA) for Bruce A 500 kV Units (one unit on−line)
Set A1 Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



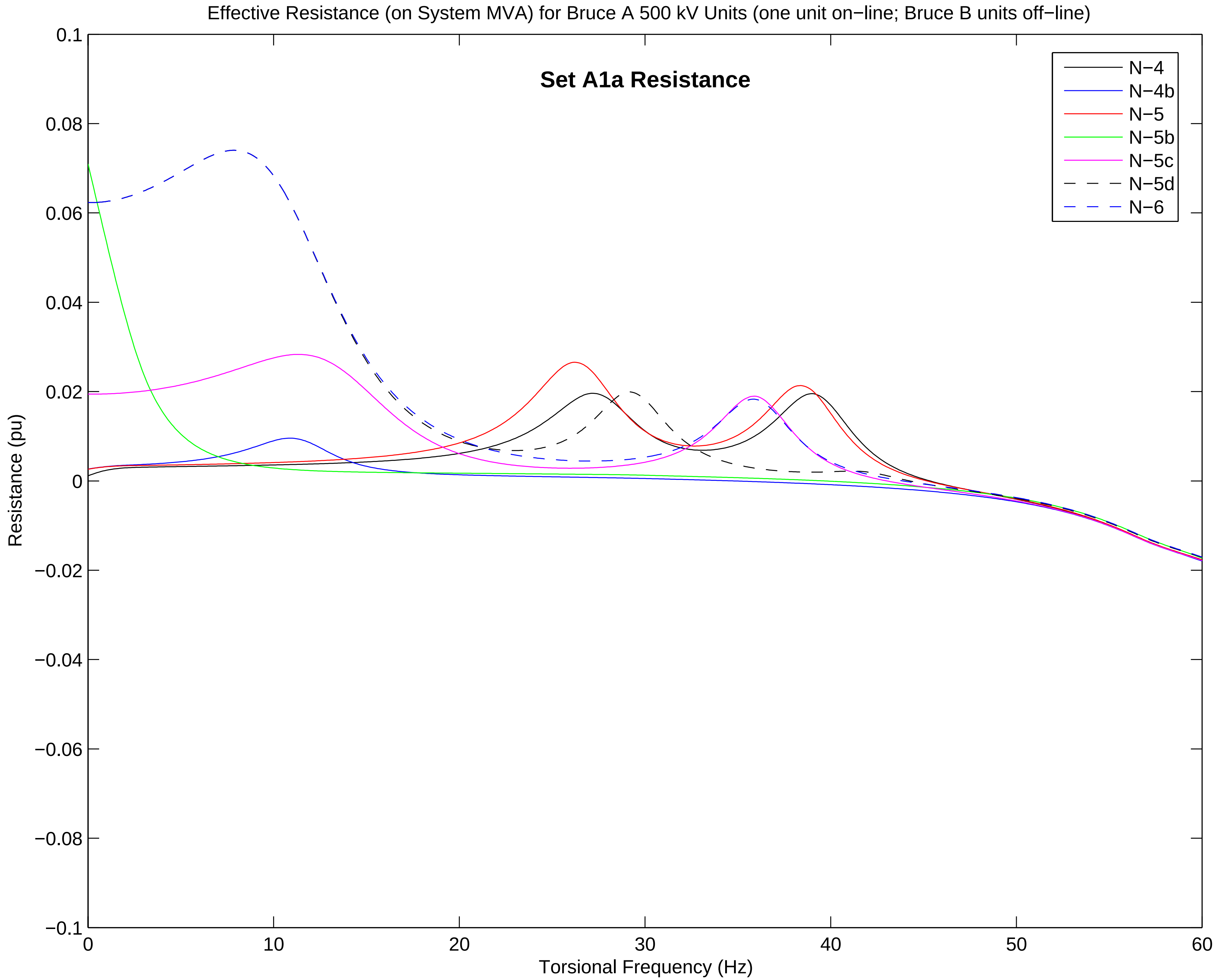
Effective Resistance (on System MVA) for Bruce A 500 kV Units (both units on−line)
Set A2 Resistance
N−0
N−1
N−1b
N−2
N−2b
N−2c
N−2d
N−2e
N−2f
N−3
N−3b
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



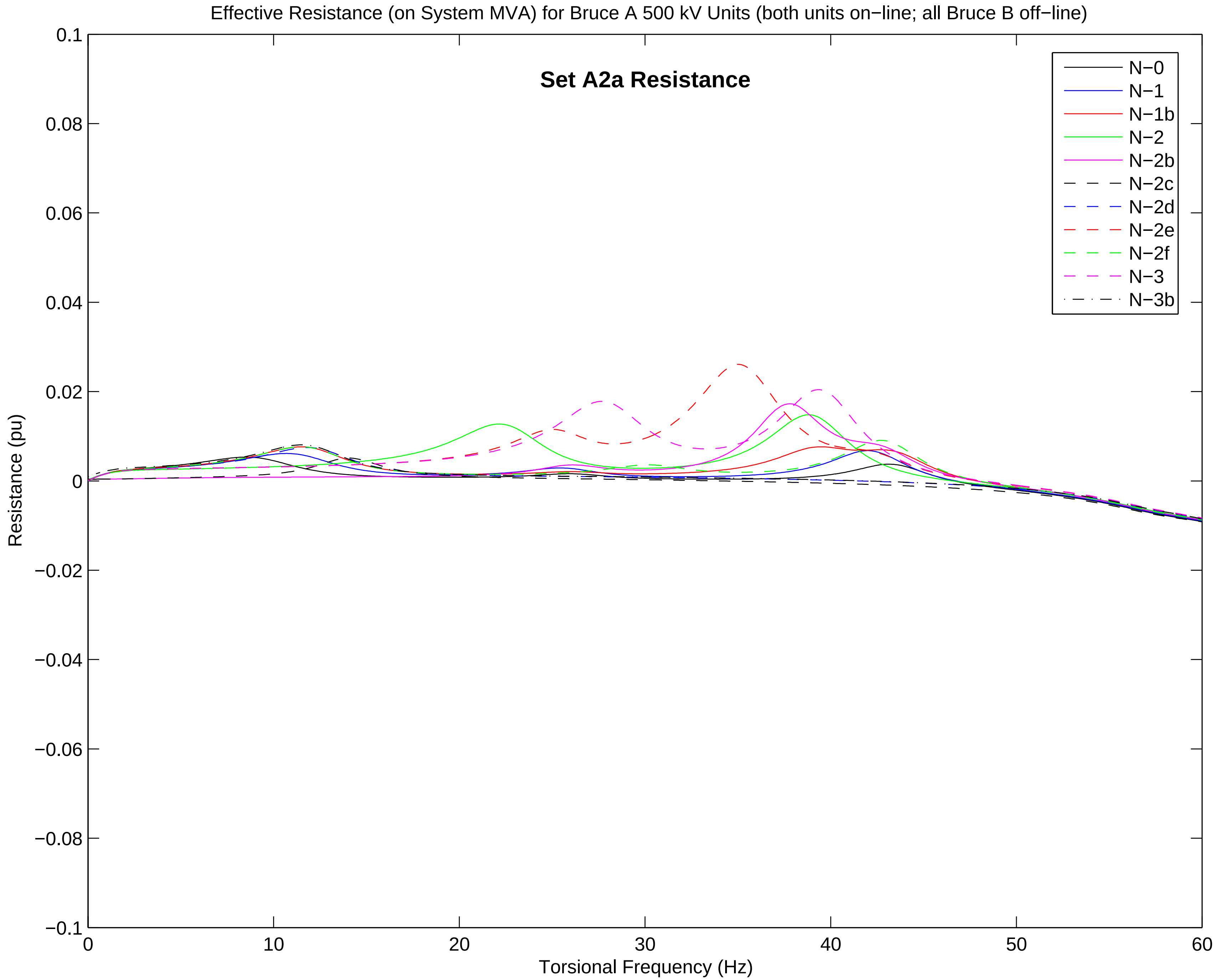
Effective Resistance (on System MVA) for Bruce A 500 kV Units (both units on−line)
Set A2 Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



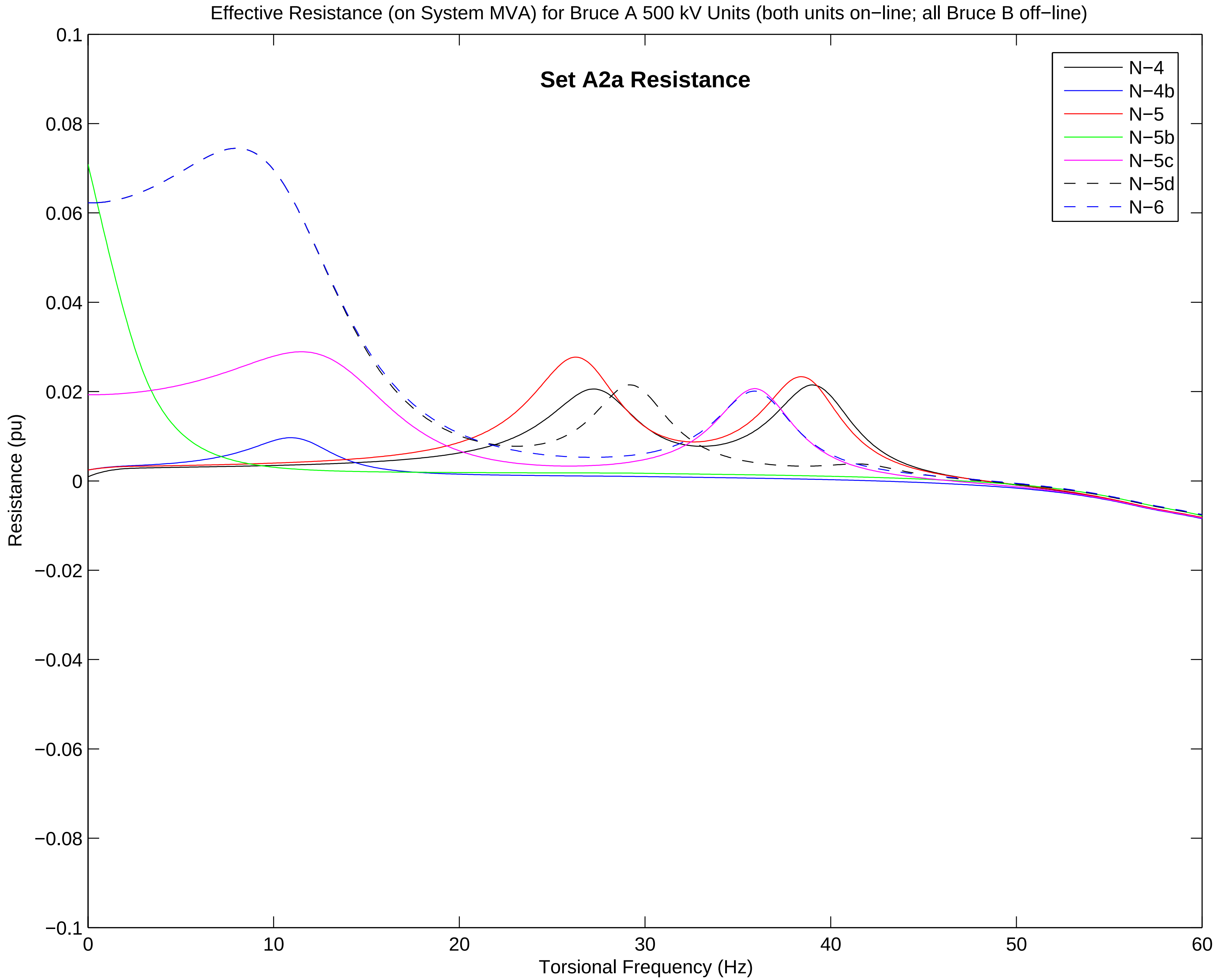
Effective Resistance (on System MVA) for Bruce A 500 kV Units (one unit on−line; Bruce B units off−line)
Set A1a Resistance
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
N−0
N−1
N−1b
N−2
N−2b
N−2c
N−2d
N−2e
N−2f
N−3
N−3b

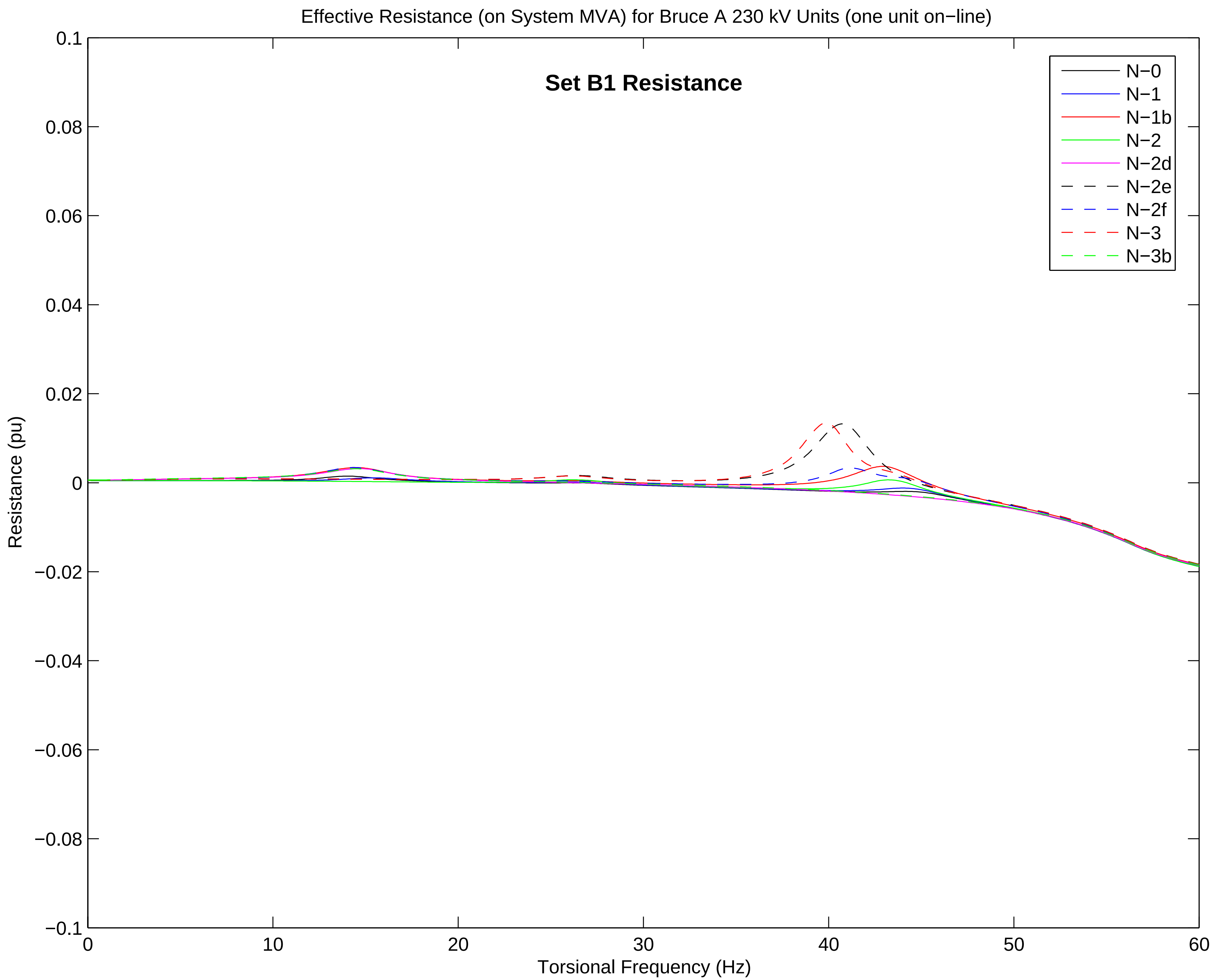


Effective Resistance (on System MVA) for Bruce A 500 kV Units (one unit on−line; Bruce B units off−line)
Set A1a Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

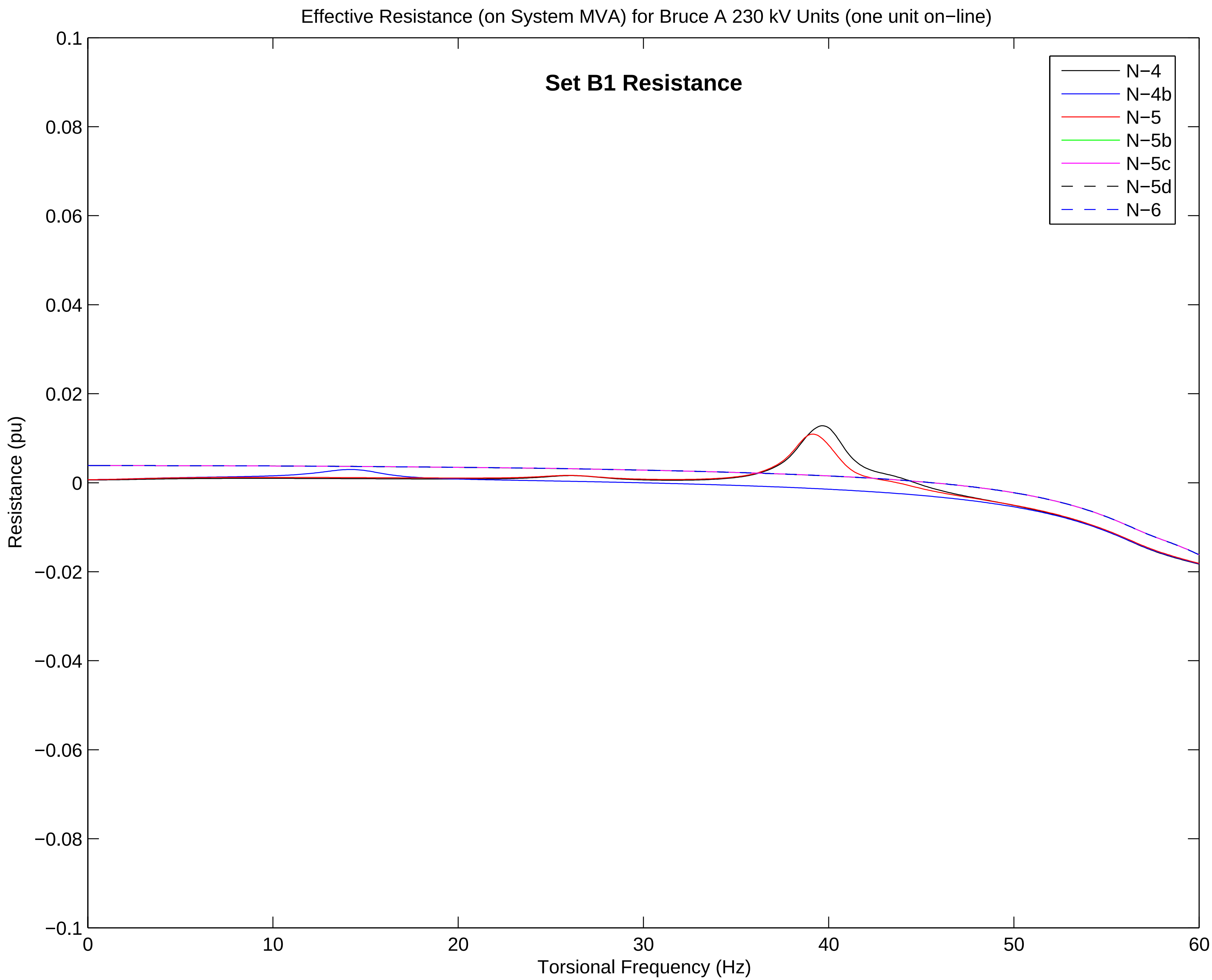


Effective Resistance (on System MVA) for Bruce A 500 kV Units (both units on−line; all Bruce B off−line)
Set A2a Resistance
N−0
N−1
N−1b
N−2
N−2b
N−2c
N−2d
N−2e
N−2f
N−3
N−3b
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

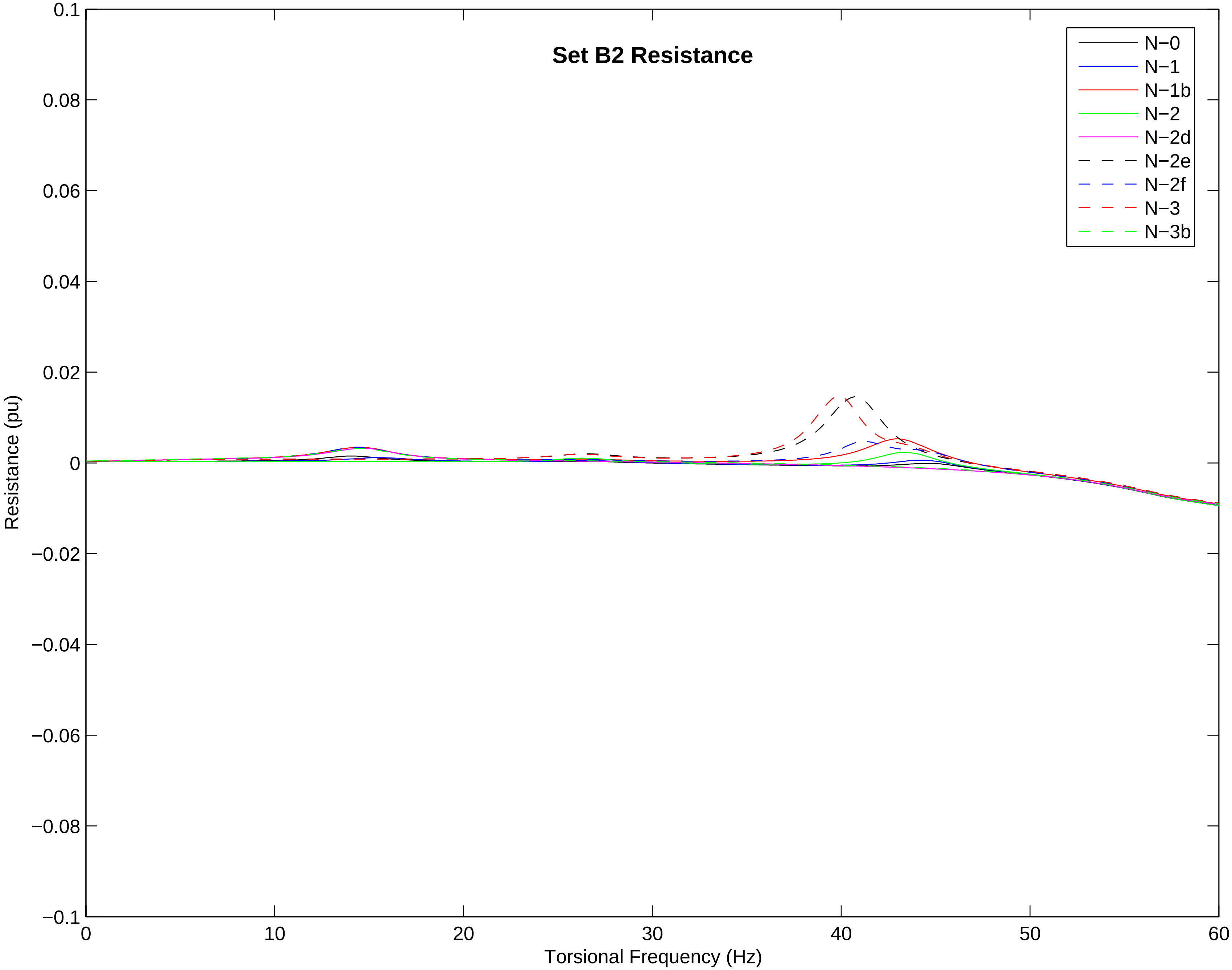

Effective Resistance (on System MVA) for Bruce A 500 kV Units (both units on−line; all Bruce B off−line)
Set A2a Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

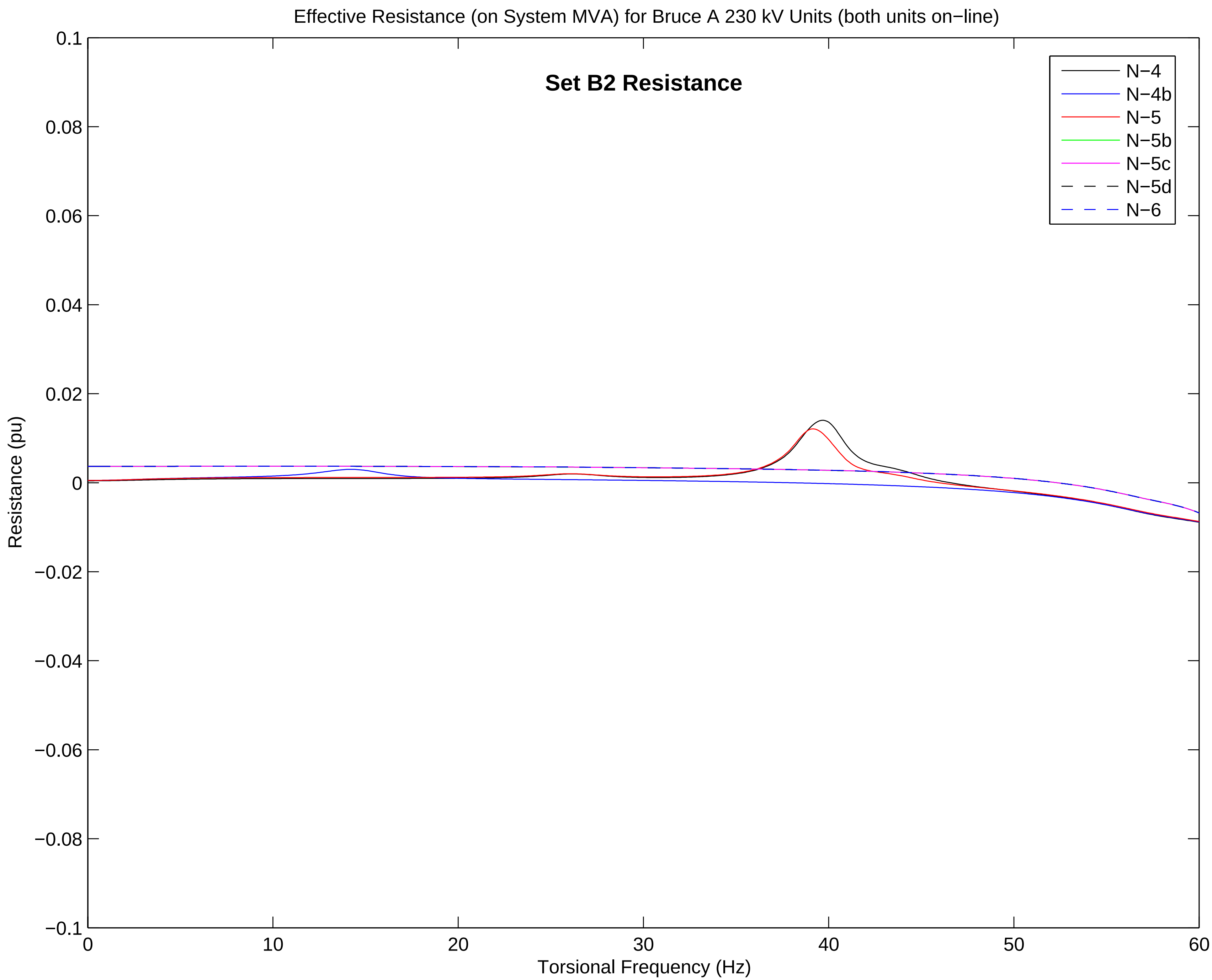


Effective Resistance (on System MVA) for Bruce A 230 kV Units (one unit on−line)
Set B1 Resistance
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

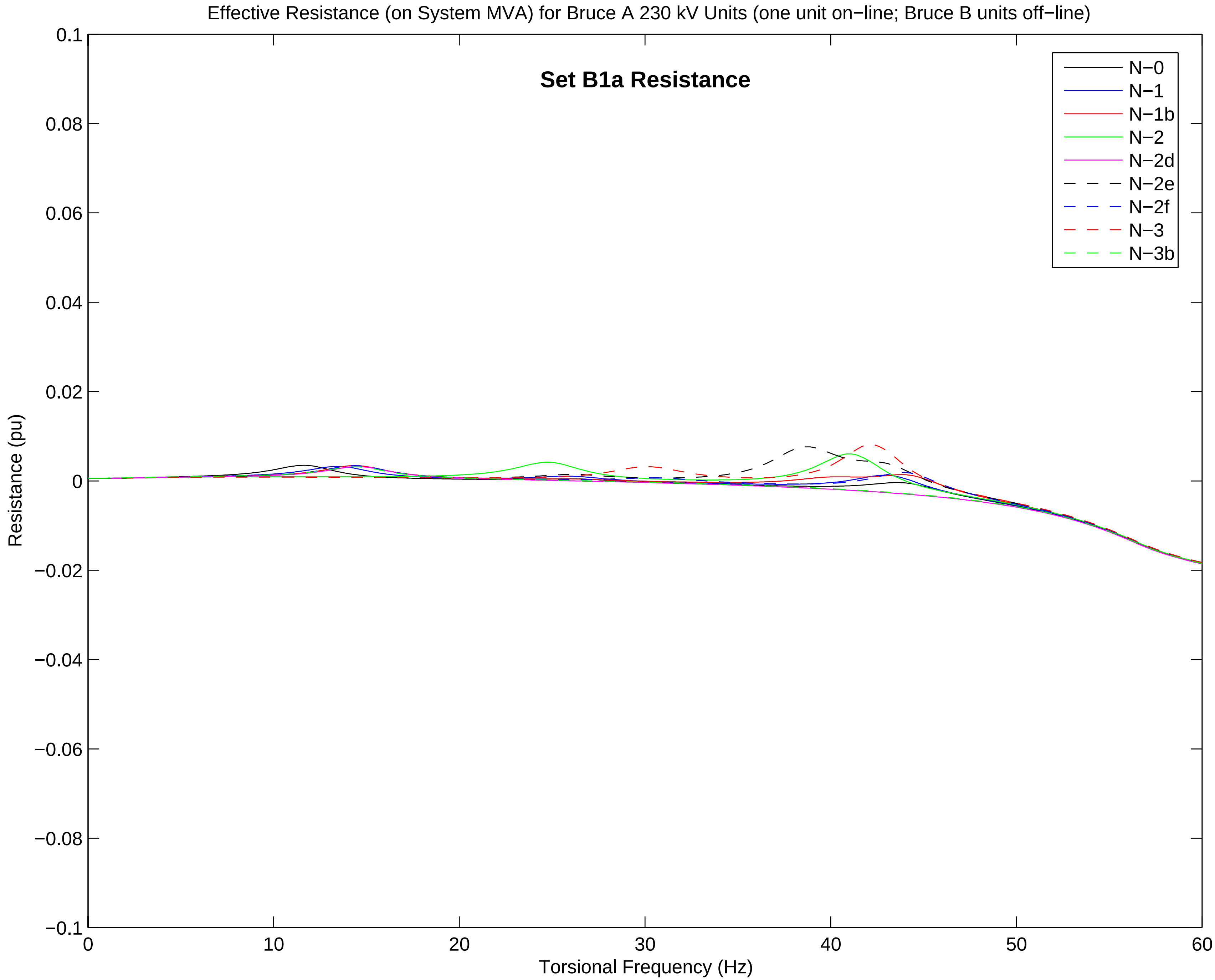

Effective Resistance (on System MVA) for Bruce A 230 kV Units (one unit on−line)
Set B1 Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

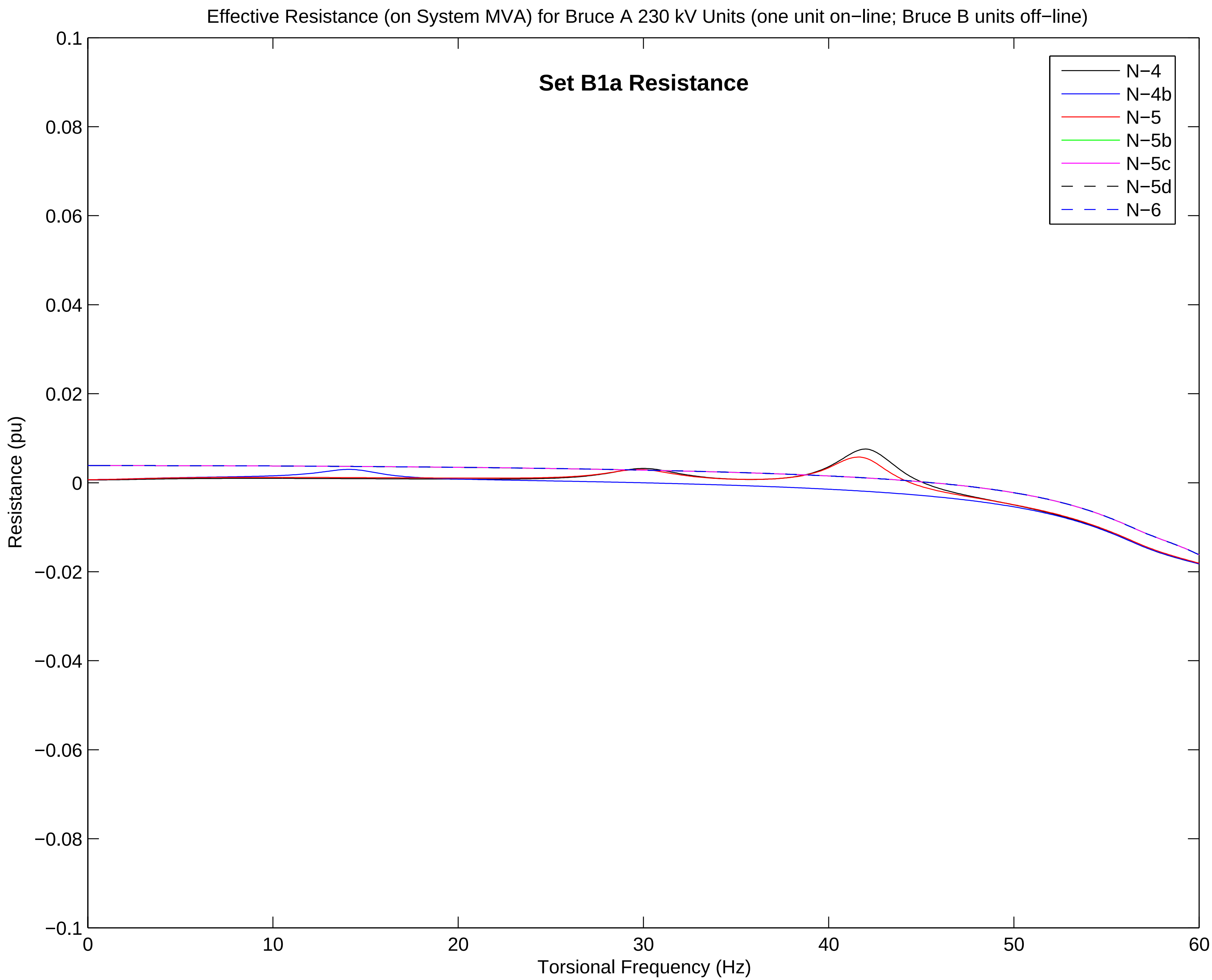
Effective Resistance (on System MVA) for Bruce A 230 kV Units (both units on−line)



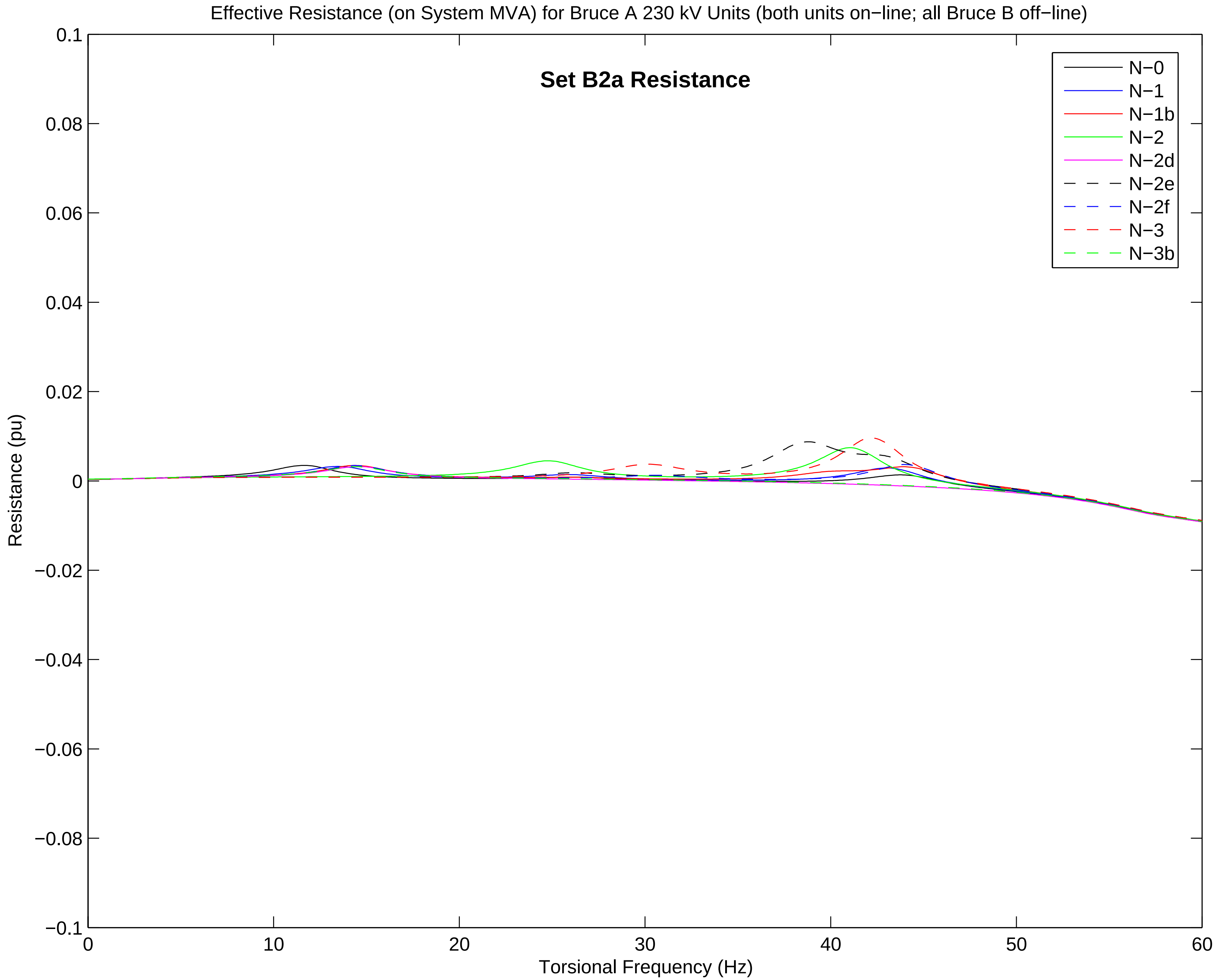


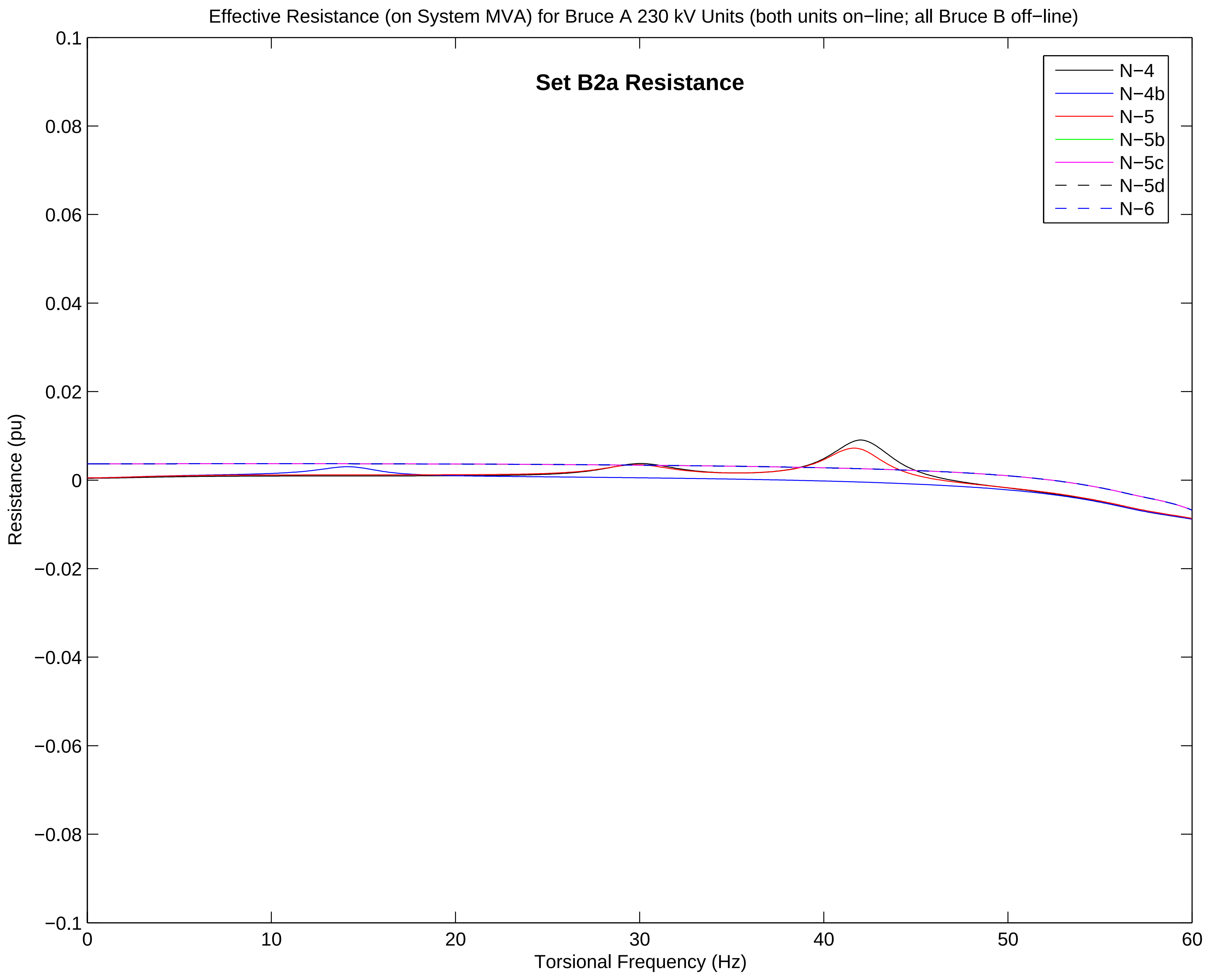
Effective Resistance (on System MVA) for Bruce A 230 kV Units (both units on−line)
Set B2 Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Bruce A 230 kV Units (one unit on−line; Bruce B units off−line)
Set B1a Resistance
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

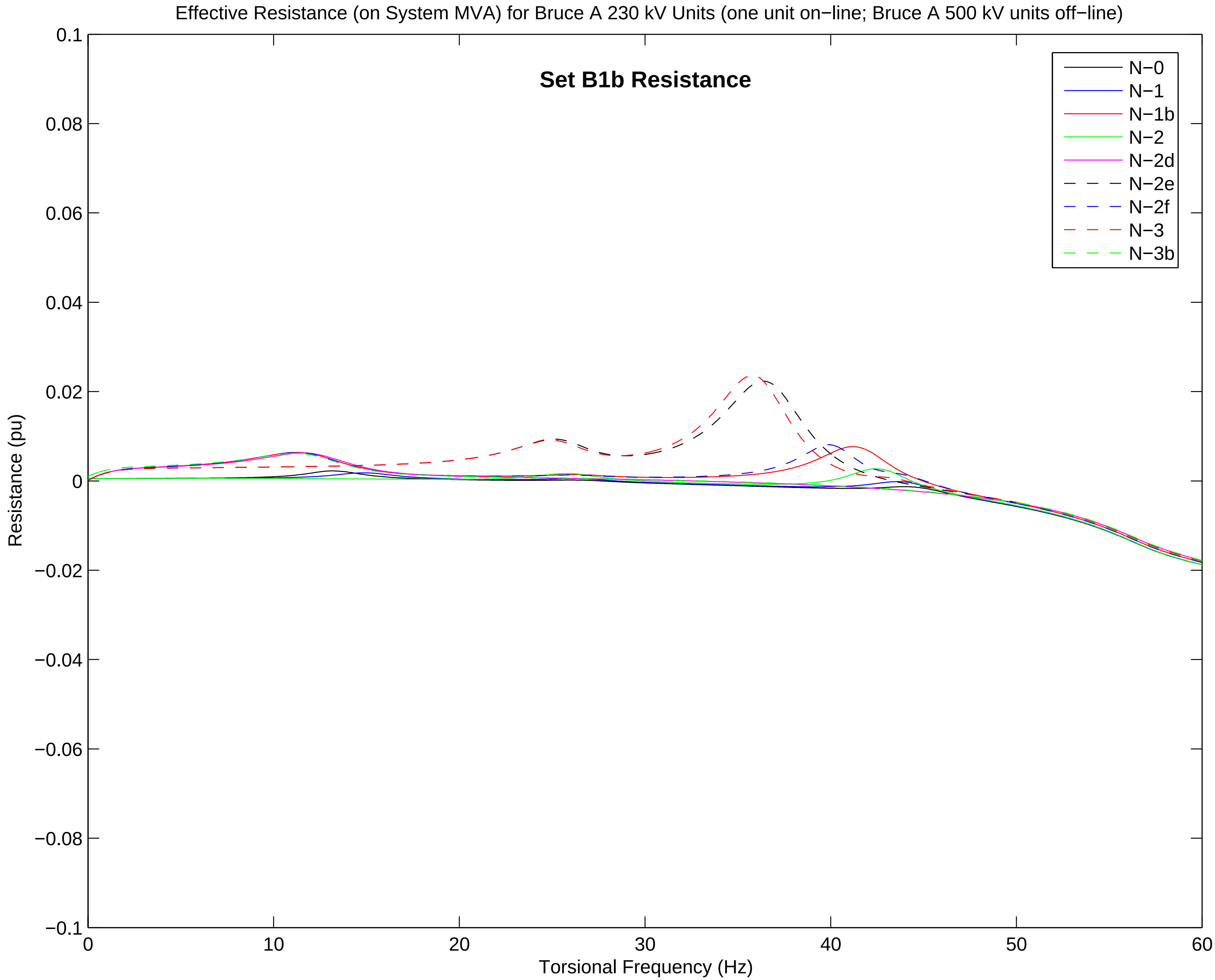


Effective Resistance (on System MVA) for Bruce A 230 kV Units (one unit on−line; Bruce B units off−line)
Set B1a Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

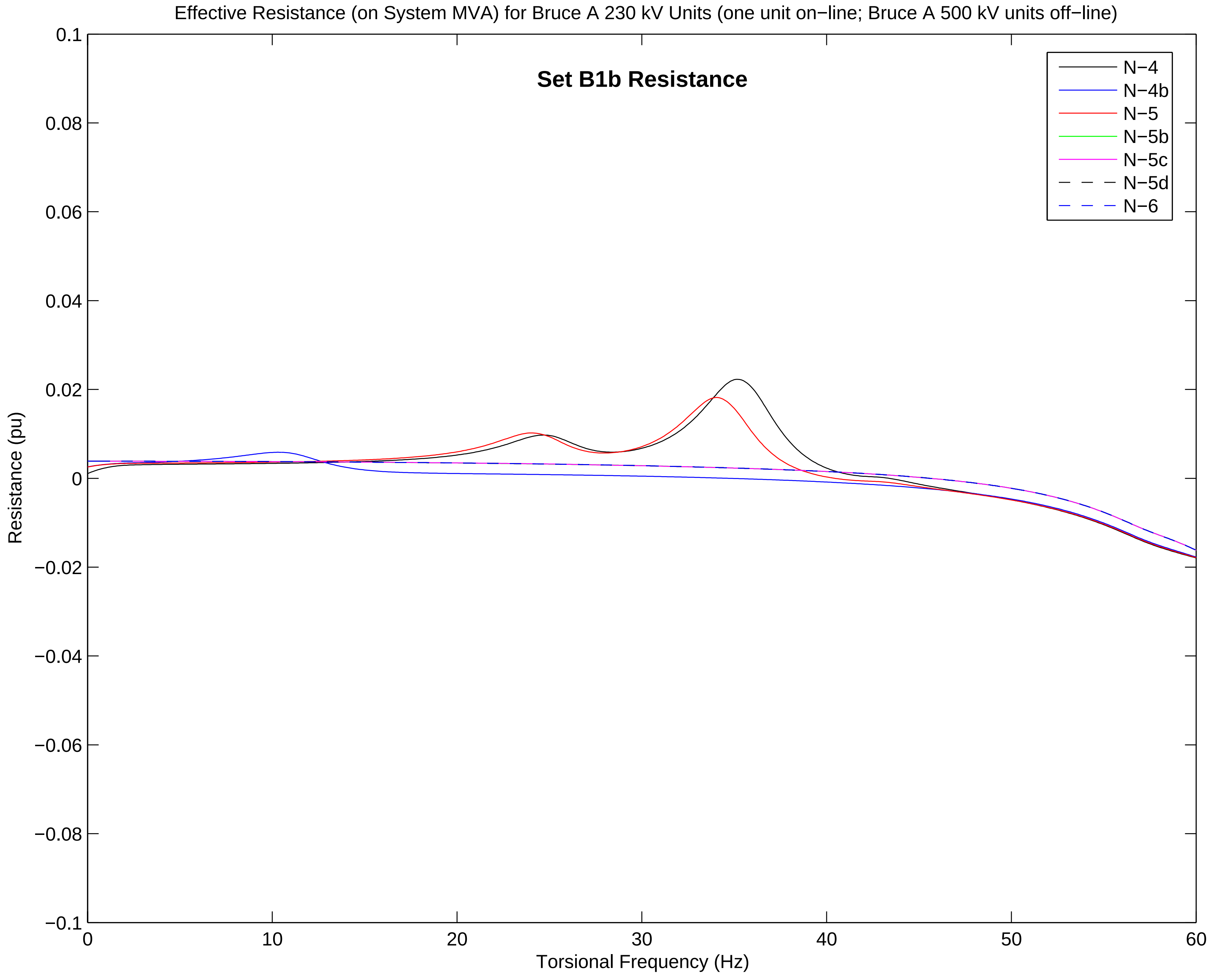

Effective Resistance (on System MVA) for Bruce A 230 kV Units (both units on−line; all Bruce B off−line)
Set B2a Resistance
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



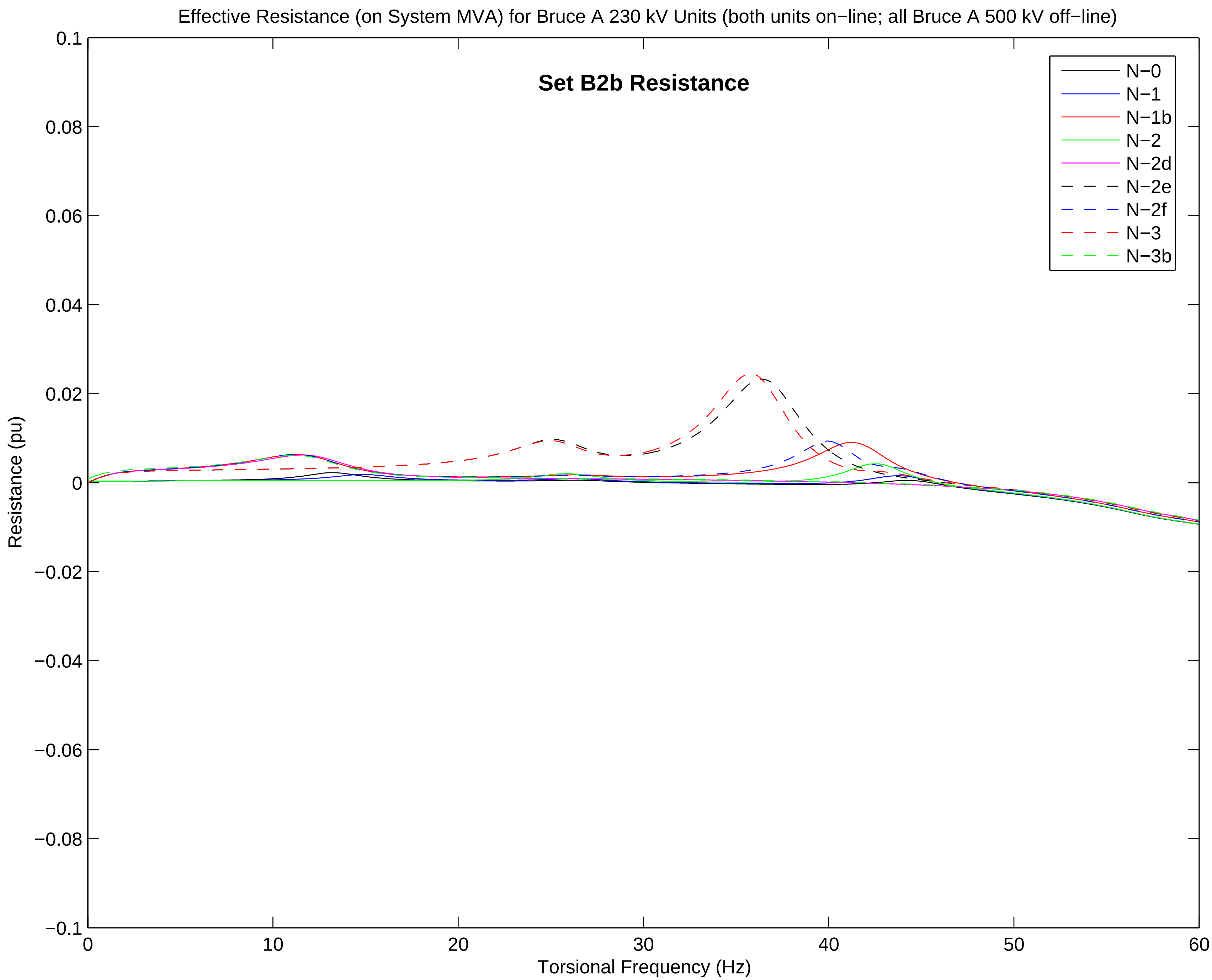
Effective Resistance (on System MVA) for Bruce A 230 kV Units (both units on−line; all Bruce B off−line)
Set B2a Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

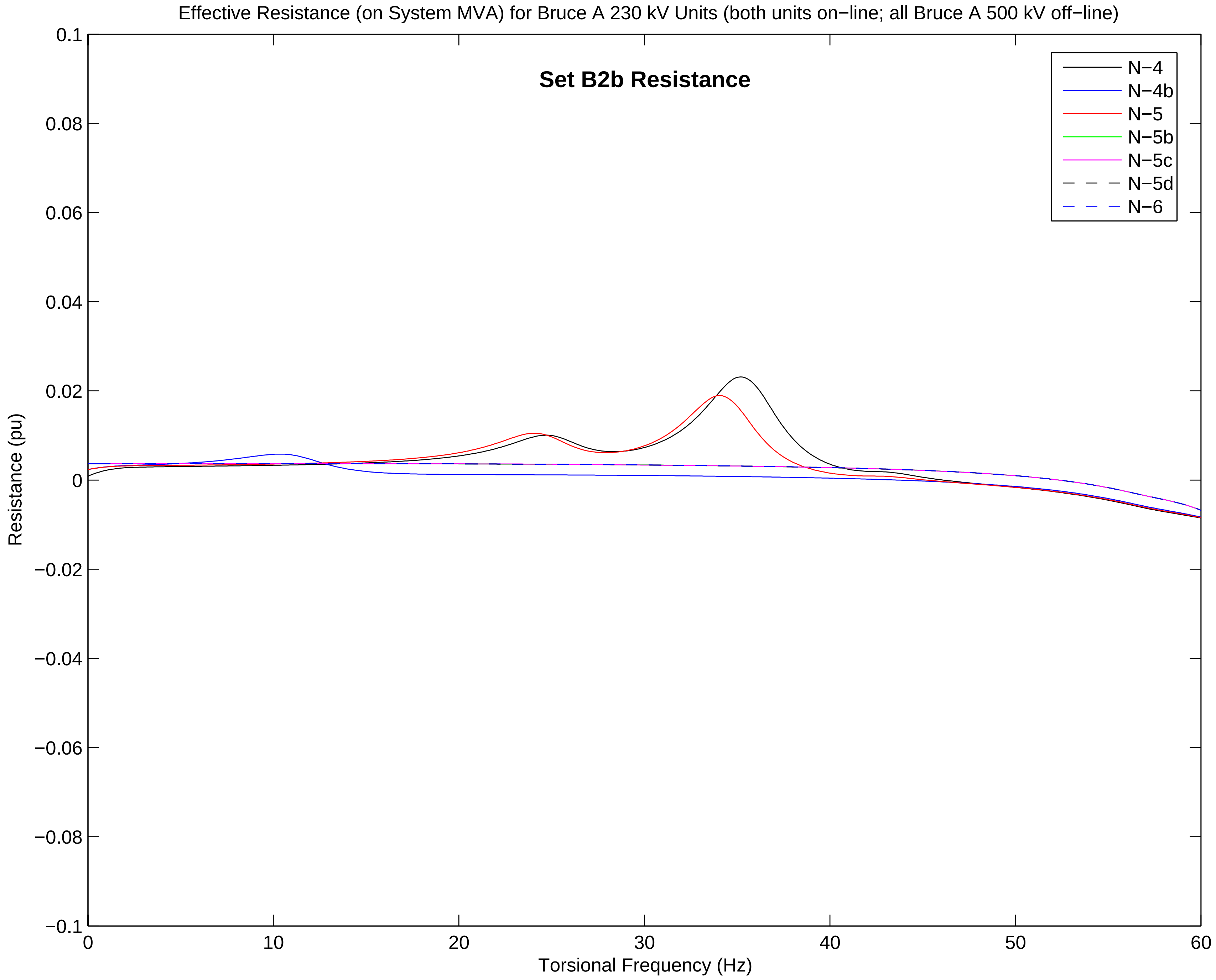


Effective Resistance (on System MVA) for Bruce A 230 kV Units (one unit on−line; Bruce A 500 kV units off−line)
Set B1b Resistance
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

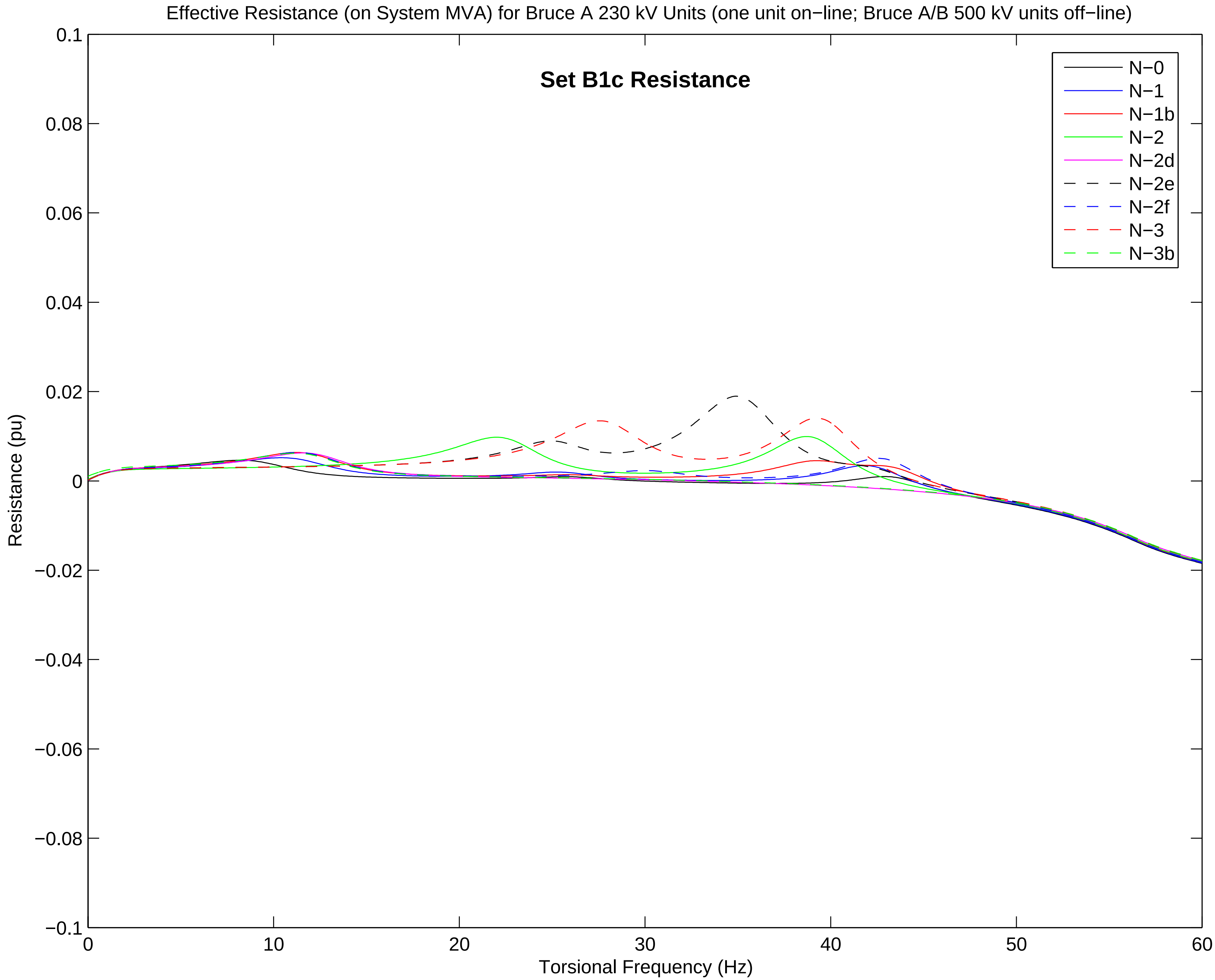


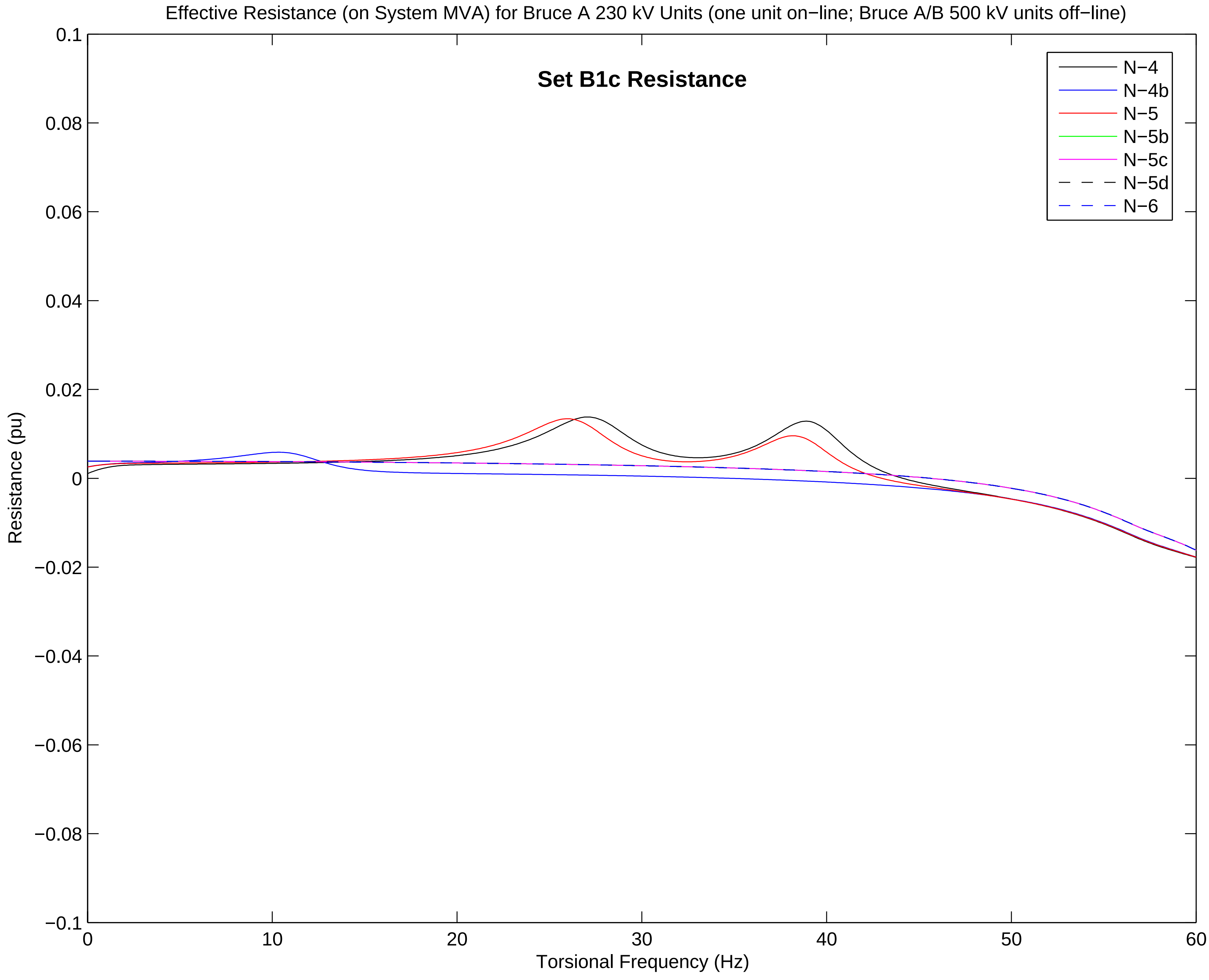
Effective Resistance (on System MVA) for Bruce A 230 kV Units (one unit on−line; Bruce A 500 kV units off−line)
Set B1b Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Bruce A 230 kV Units (both units on−line; all Bruce A 500 kV off−line)
Set B2b Resistance
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

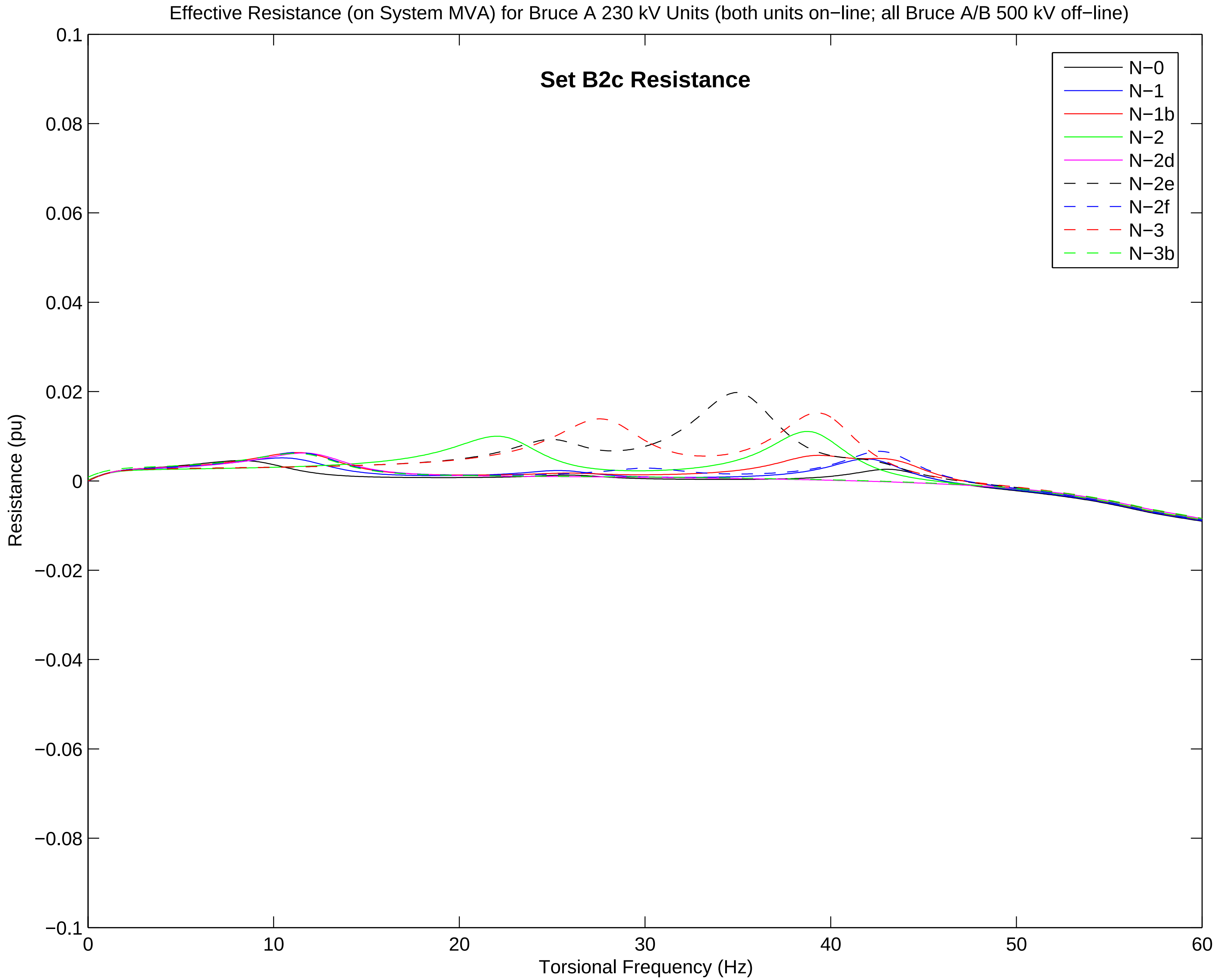


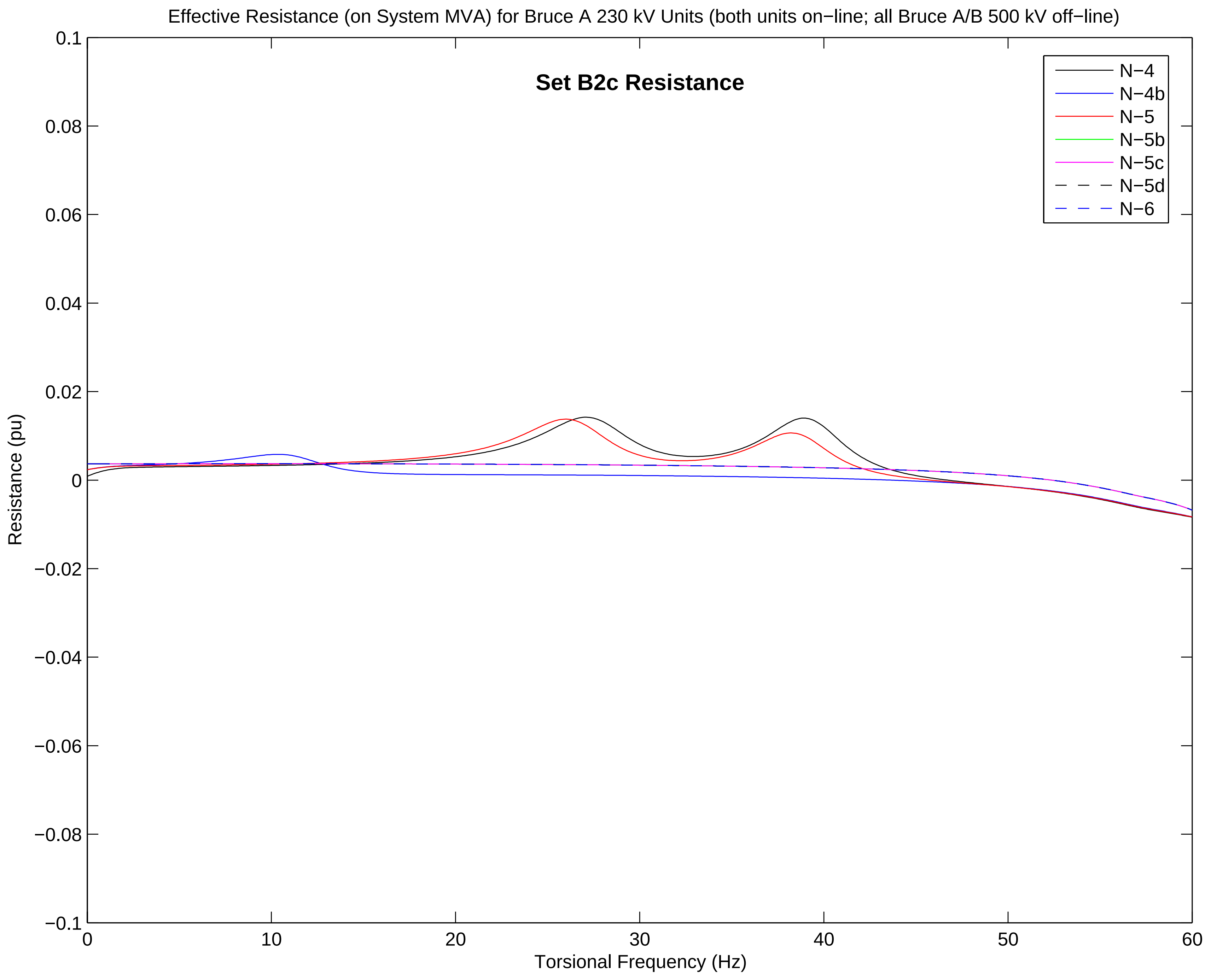
Effective Resistance (on System MVA) for Bruce A 230 kV Units (both units on−line; all Bruce A 500 kV off−line)
Set B2b Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Bruce A 230 kV Units (one unit on−line; Bruce A/B 500 kV units off−line)
Set B1c Resistance
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



Effective Resistance (on System MVA) for Bruce A 230 kV Units (one unit on−line; Bruce A/B 500 kV units off−line)
Set B1c Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Bruce A 230 kV Units (both units on−line; all Bruce A/B 500 kV off−line)
Set B2c Resistance
N−0
N−1
N−1b
N−2
N−2d
N−2e
N−2f
N−3
N−3b
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



Effective Resistance (on System MVA) for Bruce A 230 kV Units (both units on−line; all Bruce A/B 500 kV off−line)
Set B2c Resistance
N−4
N−4b
N−5
N−5b
N−5c
N−5d
N−6
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

APPENDIX D: Bruce B Frequency Scan

Appendix D – Bruce B Frequency Scan

This appendix contains 1) the electrical damping plots and 2) the effective resistance plots for the Bruce B generators. The electrical damping plots are provided first, ordered by generator combination (Set ID) as identified in Table D-1 below. The effective resistance plots are then provided in the same order.

Table D-1: Bruce A Generator Combinations

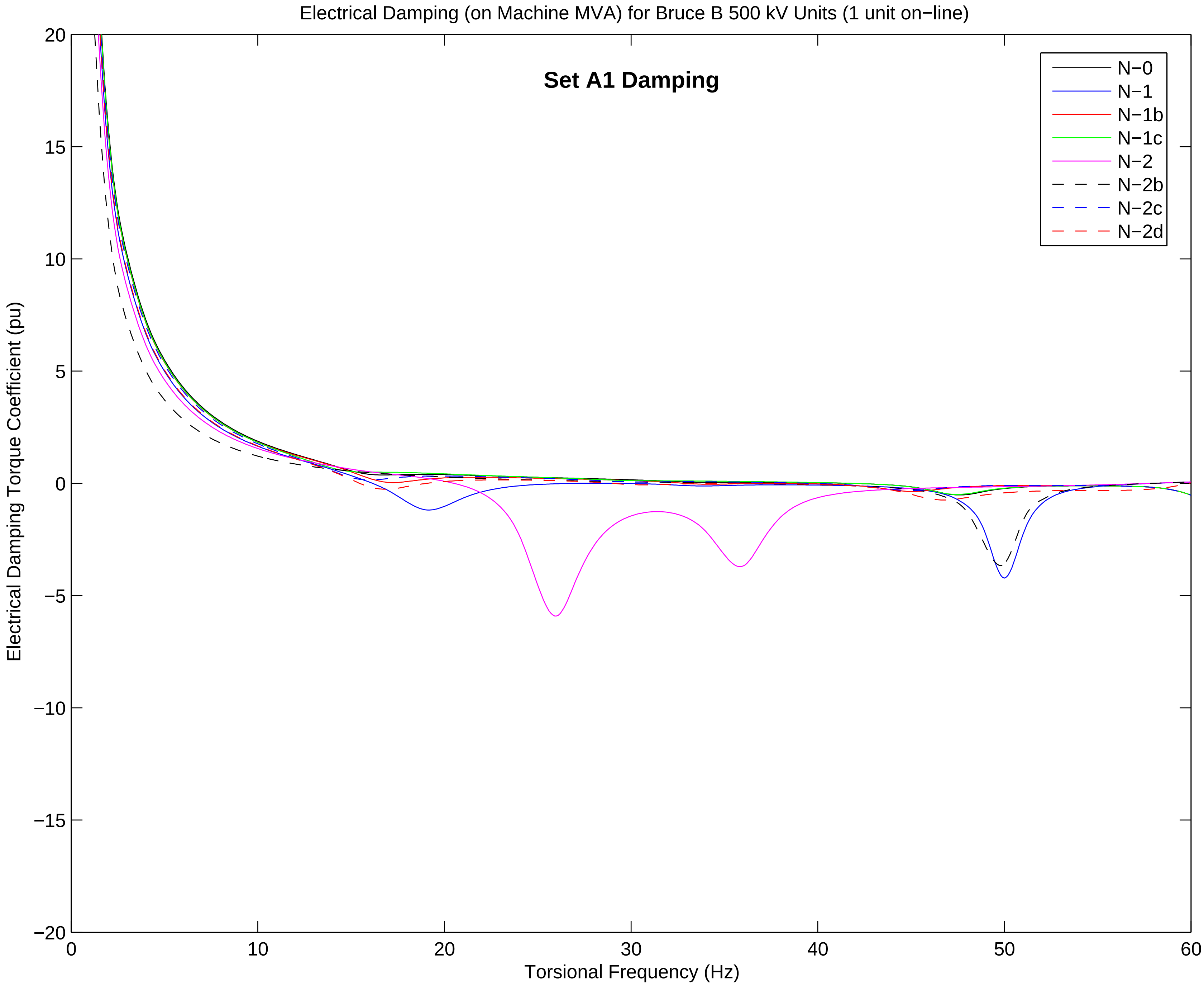
Set ID	500kV Generators				Bruce A
	G5	G6	G7	G8	500 kV Units
A1	√				√
A2	√	√			√
A3	√	√	√		√
A4	√	√	√	√	√

√ - indicates the generator is in-service

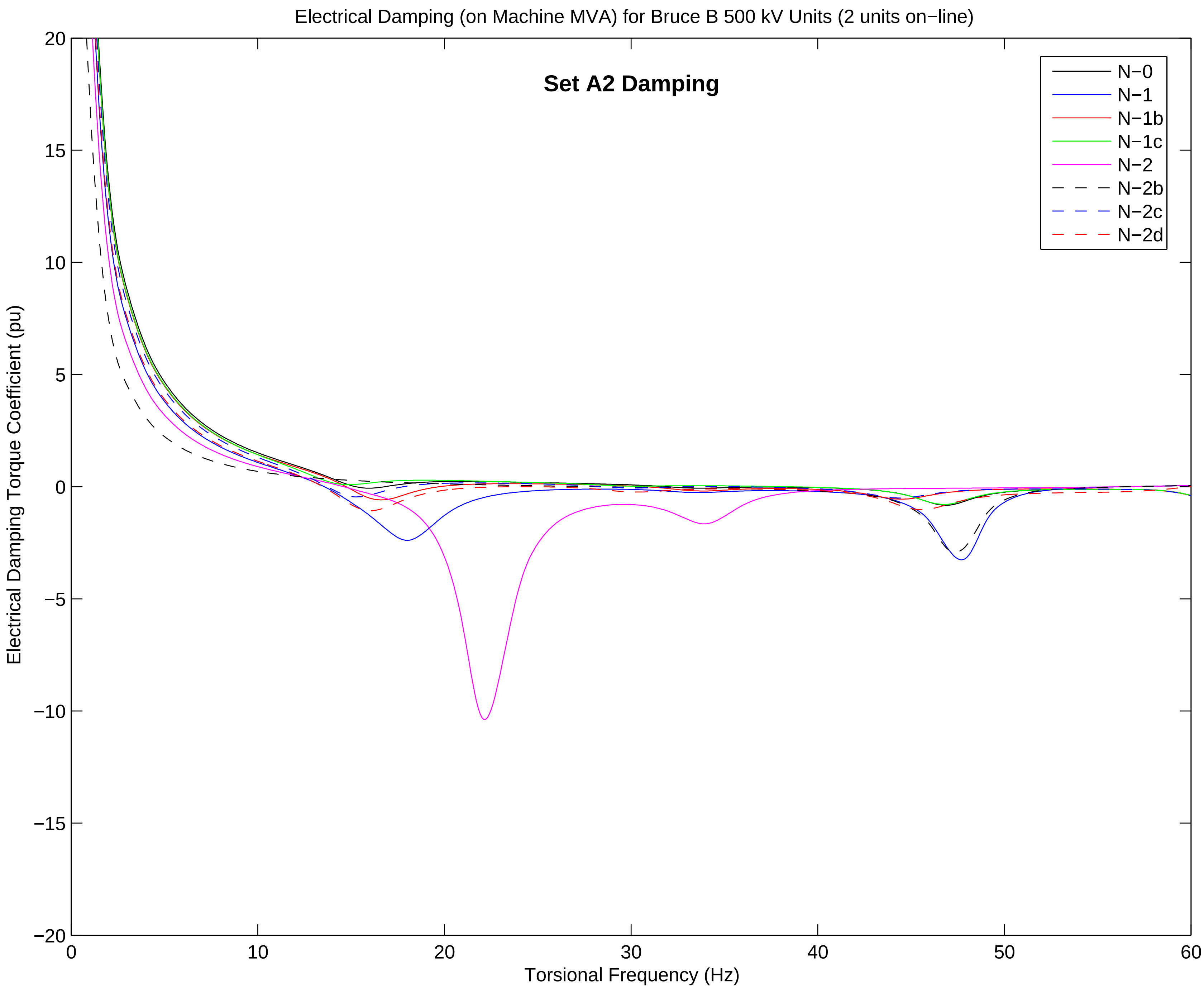
Table D-2: Contingency Descriptions

Contingency ID	Bruce A – Bruce B 500kV Tie 1	Bruce B – Milton 500kV Line 1	Bruce B – Longwood 500kV Line 1	
	For all Generator Sets			
N-0				
N-1	X			
N-1b		X		
N-1c			X	
N-2	X	X		
N-2b	X		X	
N-2c		X	X	
N-2d		X	X	Bruce A Generators off-line

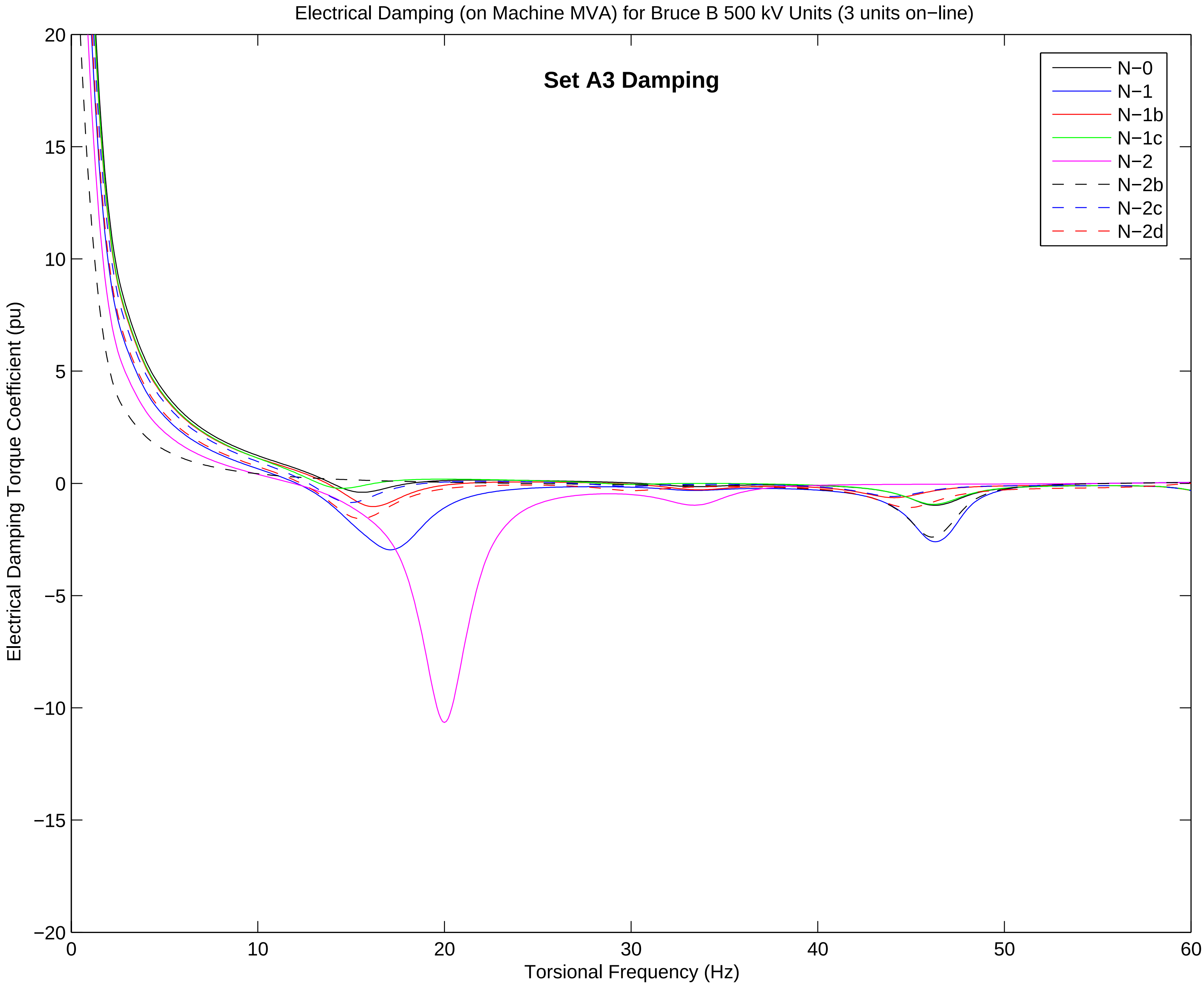
X – indicates the branch is out-of-service



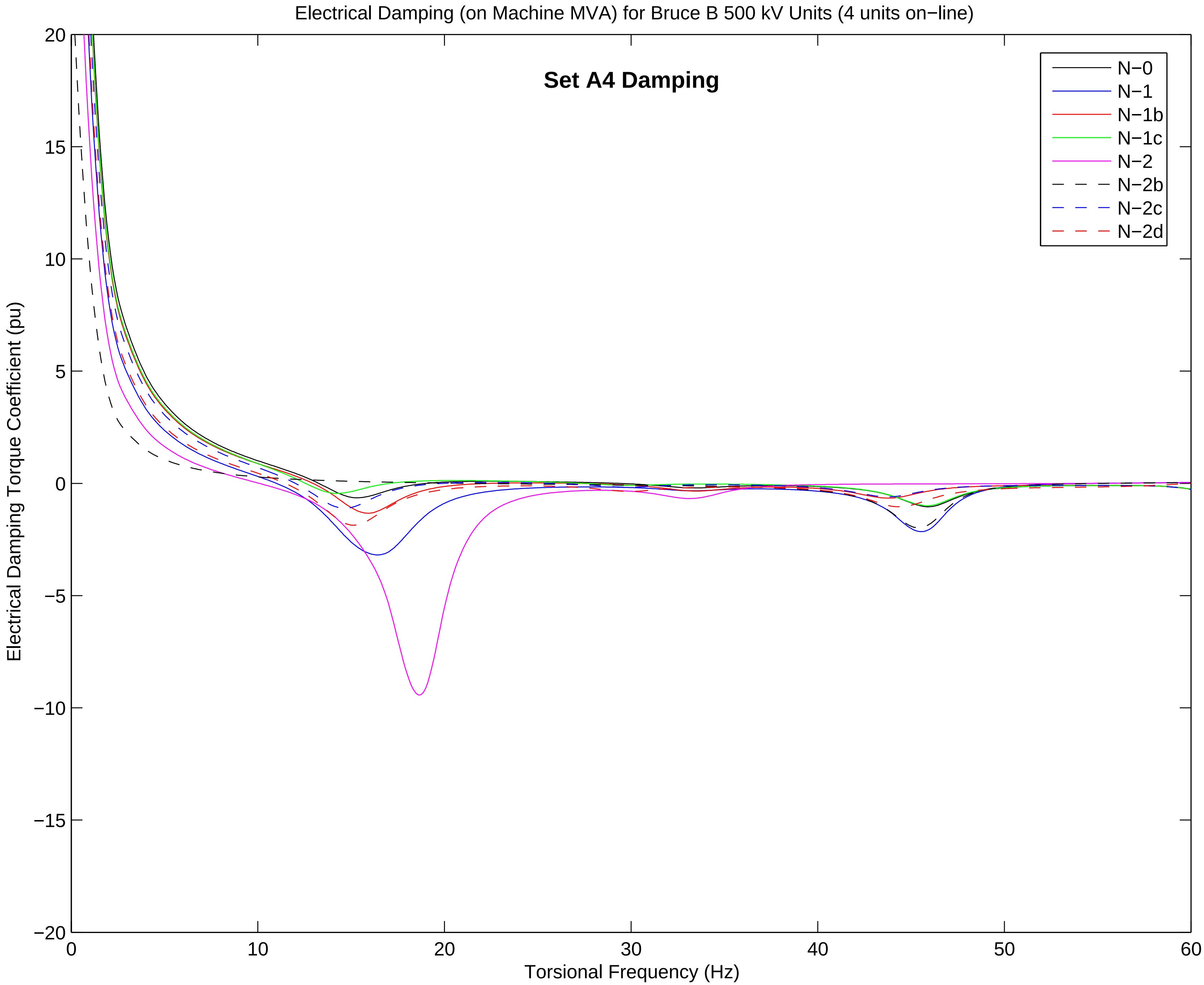
Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (1 unit on−line)
Set A1 Damping
N−0
N−1
N−1b
N−1c
N−2
N−2b
N−2c
N−2d
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



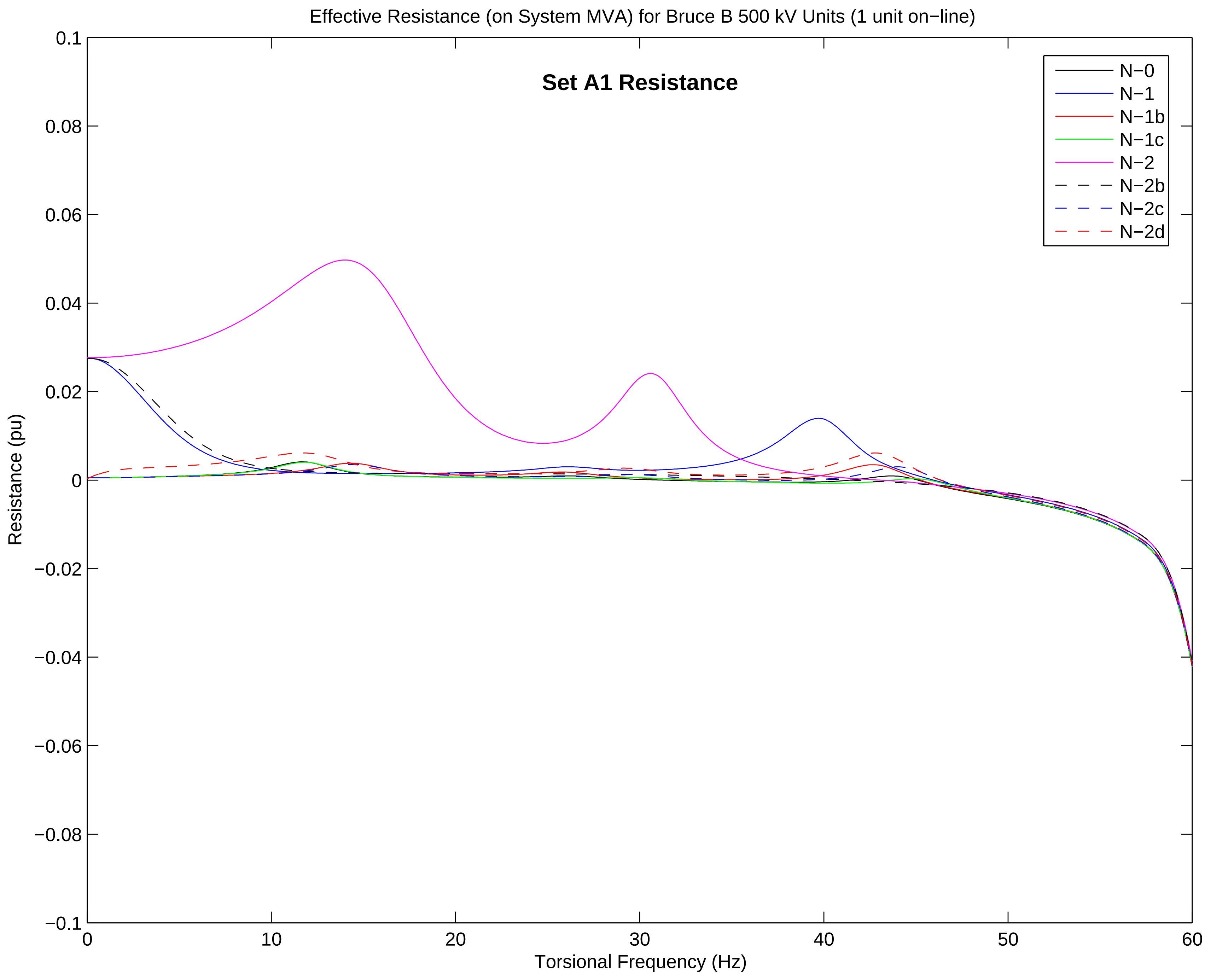
Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (2 units on−line)
Set A2 Damping
N−0
N−1
N−1b
N−1c
N−2
N−2b
N−2c
N−2d
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

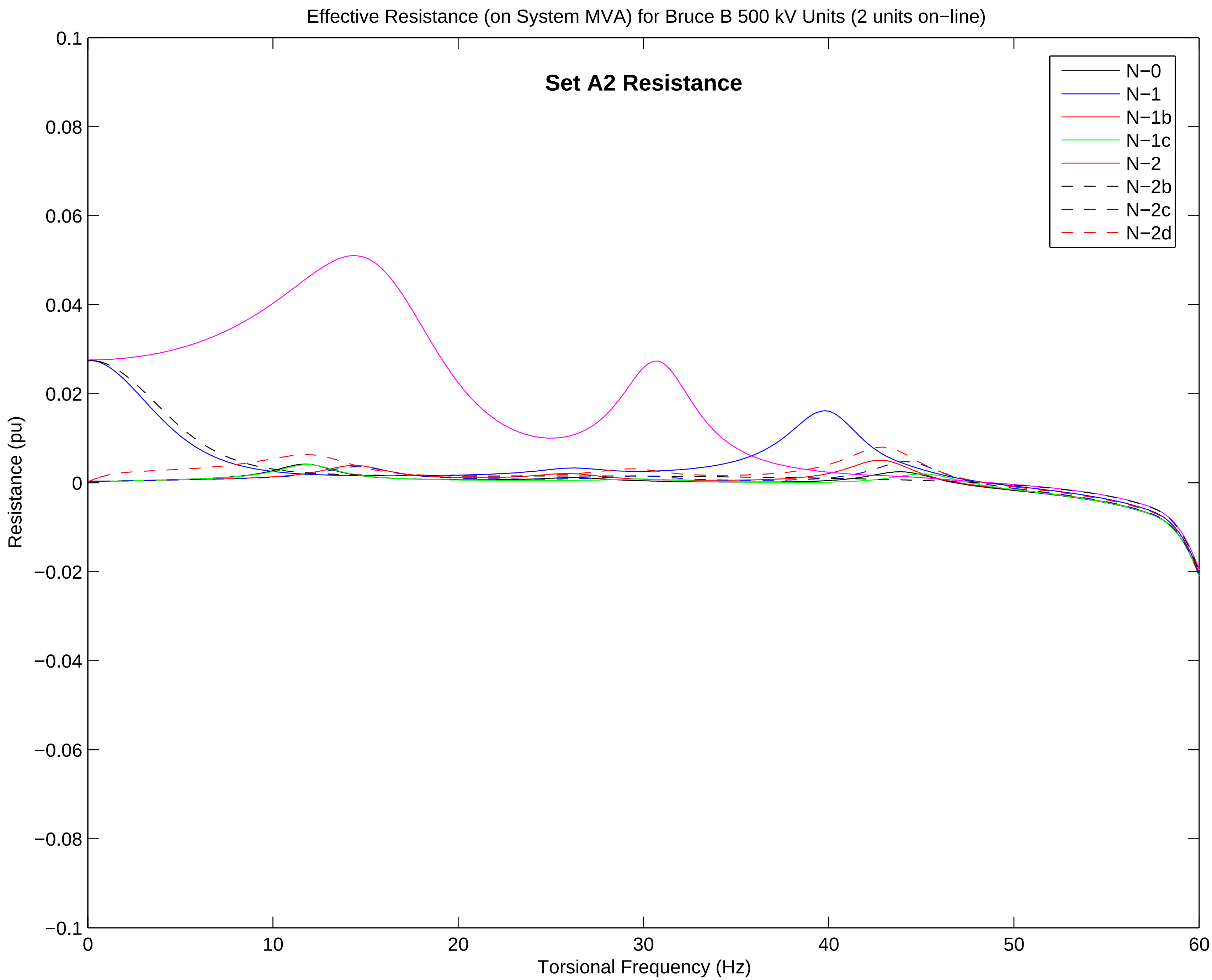


Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (3 units on−line)
Set A3 Damping
N−0
N−1
N−1b
N−1c
N−2
N−2b
N−2c
N−2d
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

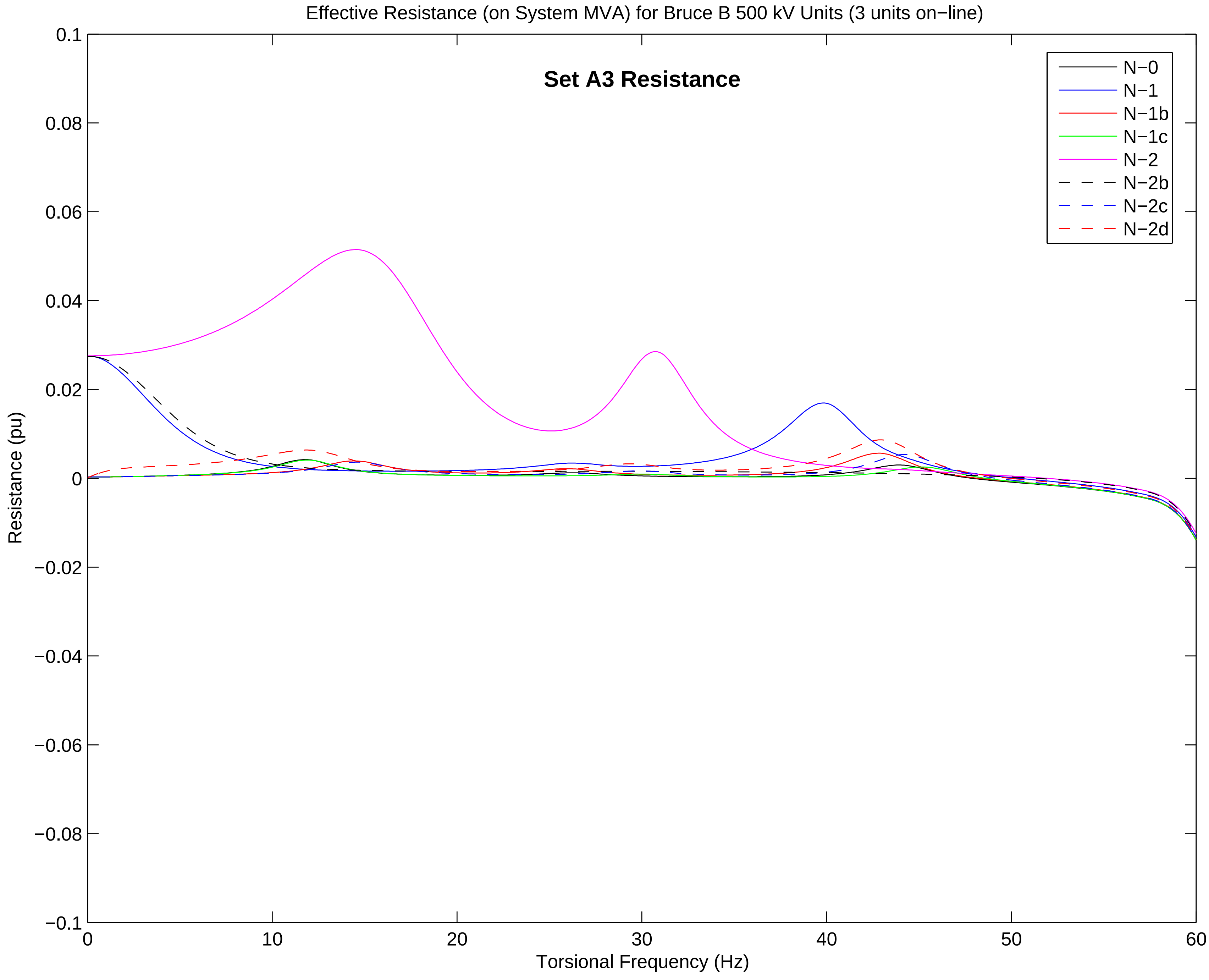


Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (4 units on−line)
Set A4 Damping
N−0
N−1
N−1b
N−1c
N−2
N−2b
N−2c
N−2d
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

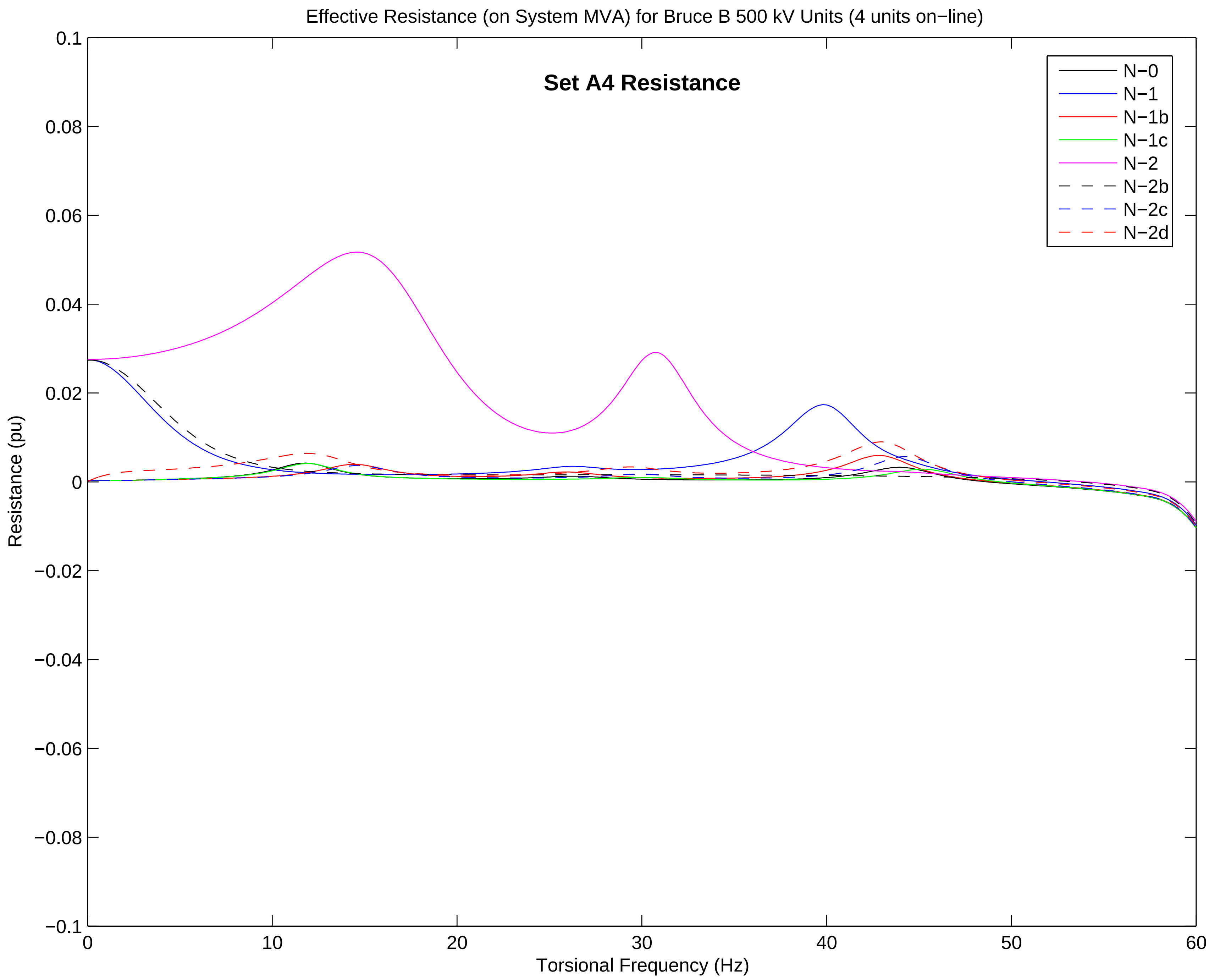

Effective Resistance (on System MVA) for Bruce B 500 kV Units (1 unit on−line)
Set A1 Resistance
N−0
N−1
N−1b
N−1c
N−2
N−2b
N−2c
N−2d
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



Effective Resistance (on System MVA) for Bruce B 500 kV Units (2 units on−line)
Set A2 Resistance
N−0
N−1
N−1b
N−1c
N−2
N−2b
N−2c
N−2d
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



Effective Resistance (on System MVA) for Bruce B 500 kV Units (3 units on−line)
Set A3 Resistance
N−0
N−1
N−1b
N−1c
N−2
N−2b
N−2c
N−2d
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Bruce B 500 kV Units (4 units on−line)
Set A4 Resistance
N−0
N−1
N−1b
N−1c
N−2
N−2b
N−2c
N−2d
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

APPENDIX E: Nanticoke Frequency Scan

Appendix E – Nanticoke Frequency Scan

This appendix contains 1) the electrical damping plots and 2) the effective resistance plots for the Nanticoke generators. The electrical damping plots are provided first, ordered by generator combination (Set ID) as identified in Table E-1 below. The effective resistance plots are then provided in the same order.

Table E-1: Nanticoke Generator Combinations

Set ID	500kV Generators				230kV Generators			
	G5	G6	G7	G8	G1	G2	G3	G4
X1	√				√	√	√	√
X2	√	√			√	√	√	√
Y1			√		√	√	√	√
Y2			√	√	√	√	√	√
W	√	√	√	√	√	√	√	√
Z1					√			
Z2					√	√		
Z3					√	√	√	
Z4					√	√	√	√

√ - indicates the generator is in-service

Table E-2: Contingency Description

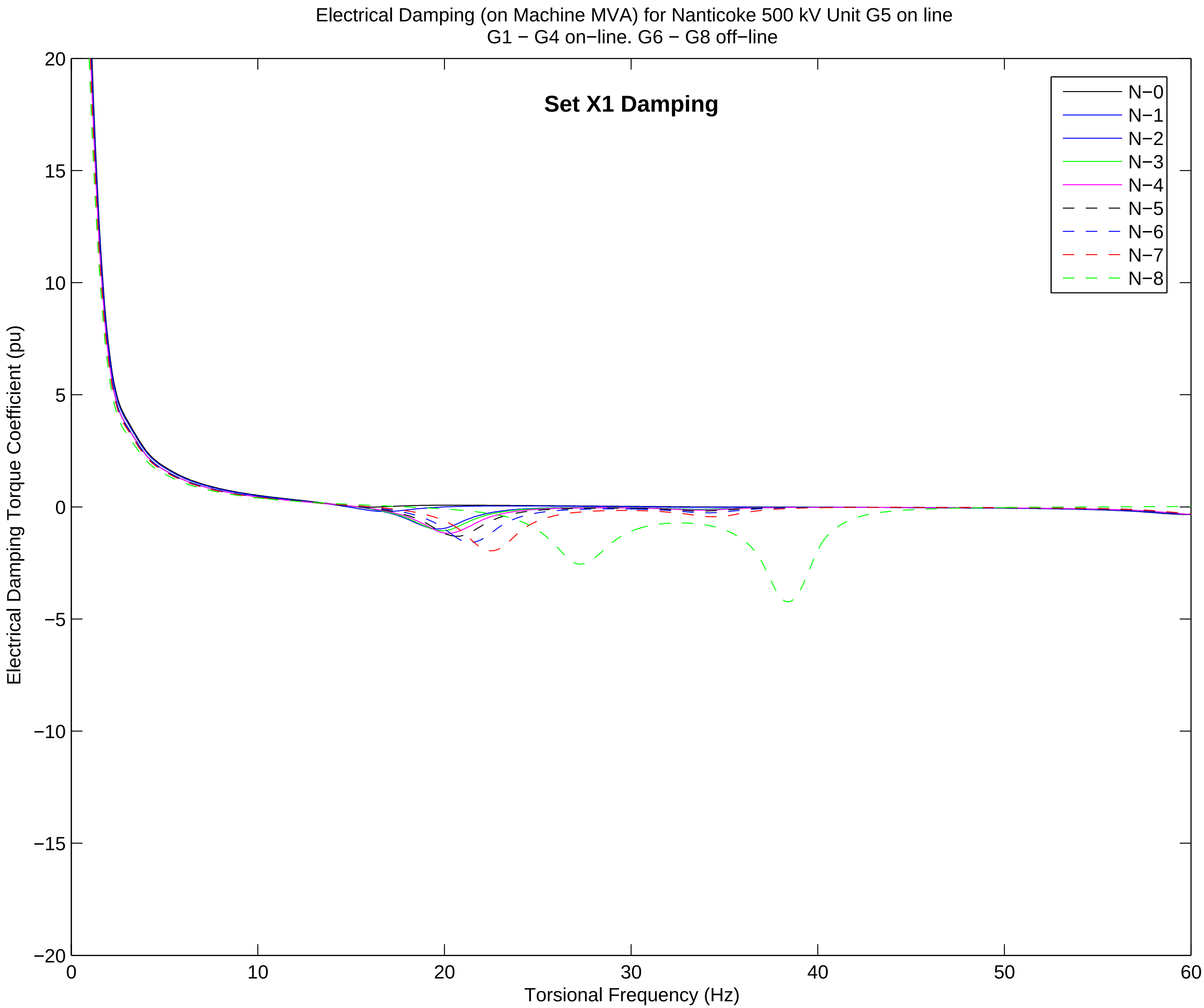
Contingency ID	Midd8086 – Nanticoke 500kV Line 1	Midd8185 – Nanticoke 500kV Line 1	Nanticoke – Imp NanJ 230kV Line 1	Nanticoke – CaledJn1 230kV Line 1	Nanticoke – CaledJn5 230kV Line 1	Nanticoke – CaledJn6 230kV Line 1	Nanticoke 500kV/230kV Transformer 11	Nanticoke 500kV/230kV Transformer 12	Longwood 500kV/230kV/27.6kV Five (5) Transformers #3-#7
	For all Generator Sets								
N-0									
N-1	X								
N-2	X	X							
N-3	X	X	X						
N-4	X	X	X	X					
N-5	X	X	X	X	X				
N-6	X	X	X	X	X	X			
N-7	X	X	X	X	X	X	X		
N-8	X	X	X	X	X	X	X	X	
	For Generator Sets X1, X2, Y1, Y2, W								
N-1a							X		
N-2a							X	X	
N-3a	X						X	X	
N-4a	X	X					X	X	
N-5a									X
N-7a							X	X	X
N-9a	X	X					X	X	X

Continued

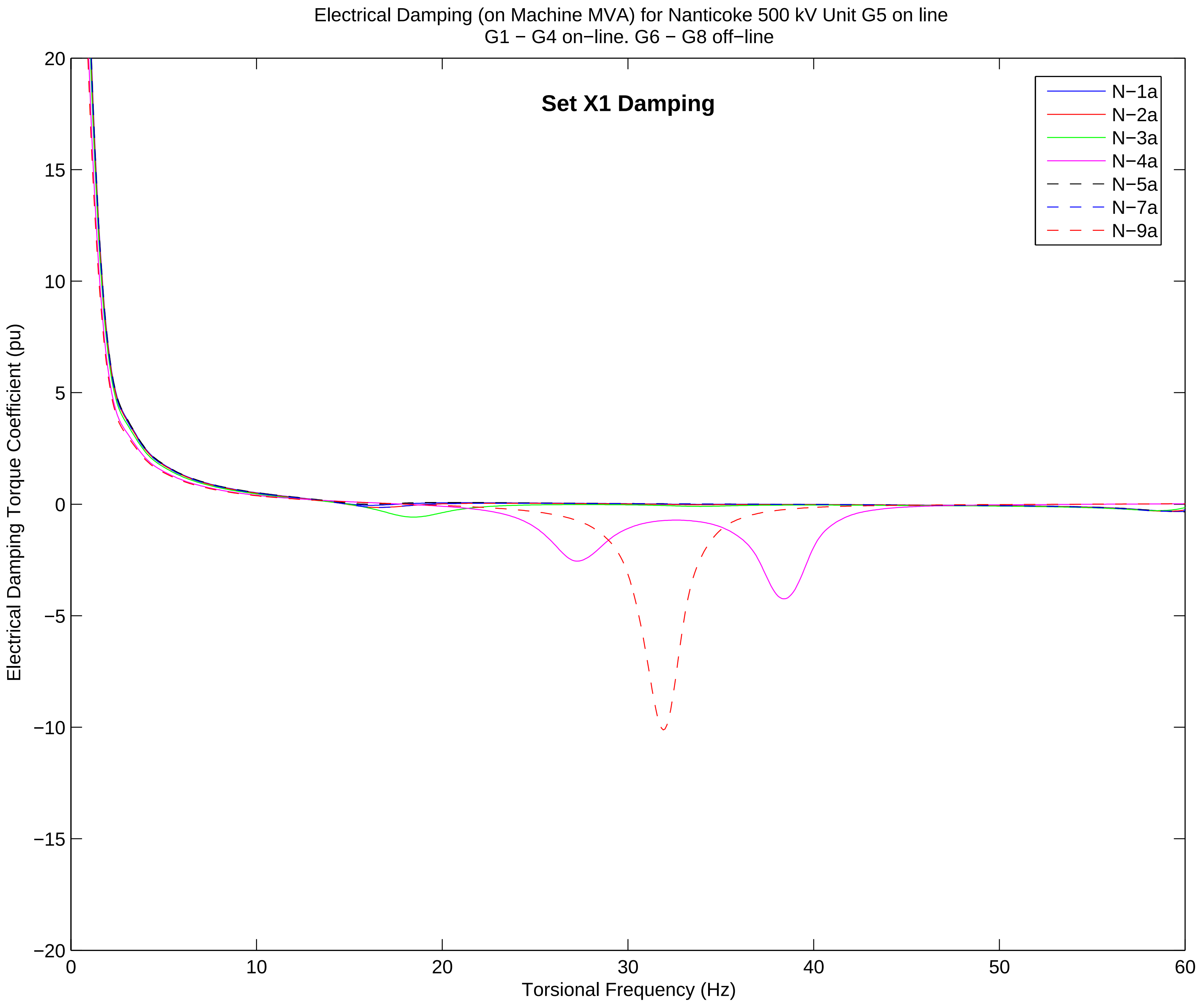
Table E-2: Contingency Description, continued

Contingency ID	Midd8086 – Nanticoke 500kV Line 1	Midd8185 – Nanticoke 500kV Line 1	Nanticoke – Imp NanJ 230kV Line 1	Nanticoke – CaledJn1 230kV Line 1	Nanticoke – CaledJn5 230kV Line 1	Nanticoke – CaledJn6 230kV Line 1	Nanticoke 500kV/230kV Transformer 11	Nanticoke 500kV/230kV Transformer 12	Longwood 500kV/230kV/27.6kV Five (5) Transformers #3-#7
	For Generator Sets Z1 - Z4								
N-1b							X		
N-2b							X	X	
N-3b			X				X	X	
N-4b			X	X			X	X	
N-5b			X	X	X		X	X	
N-6b			X	X	X	X	X	X	

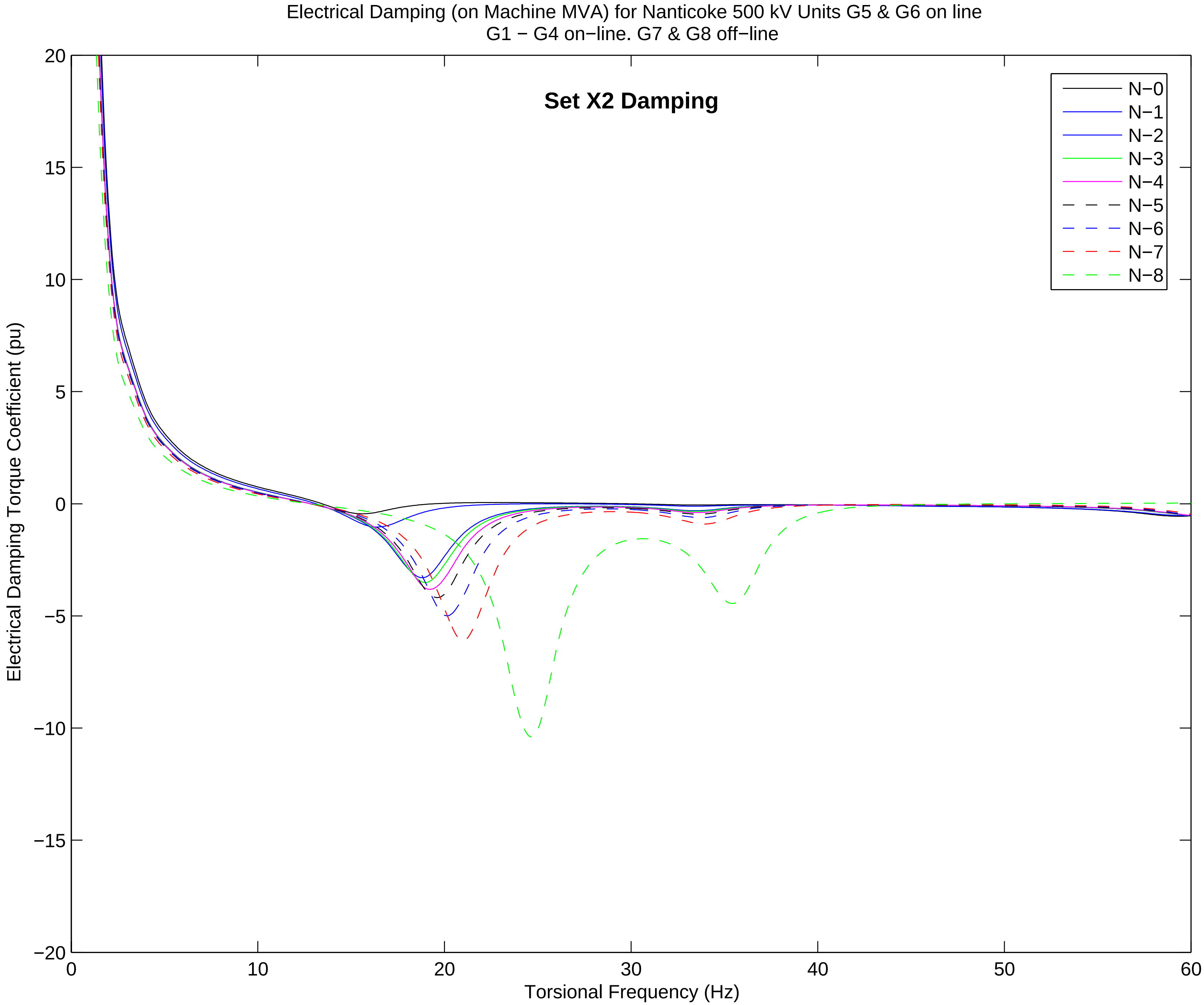
X – indicates the branch is out-of-service



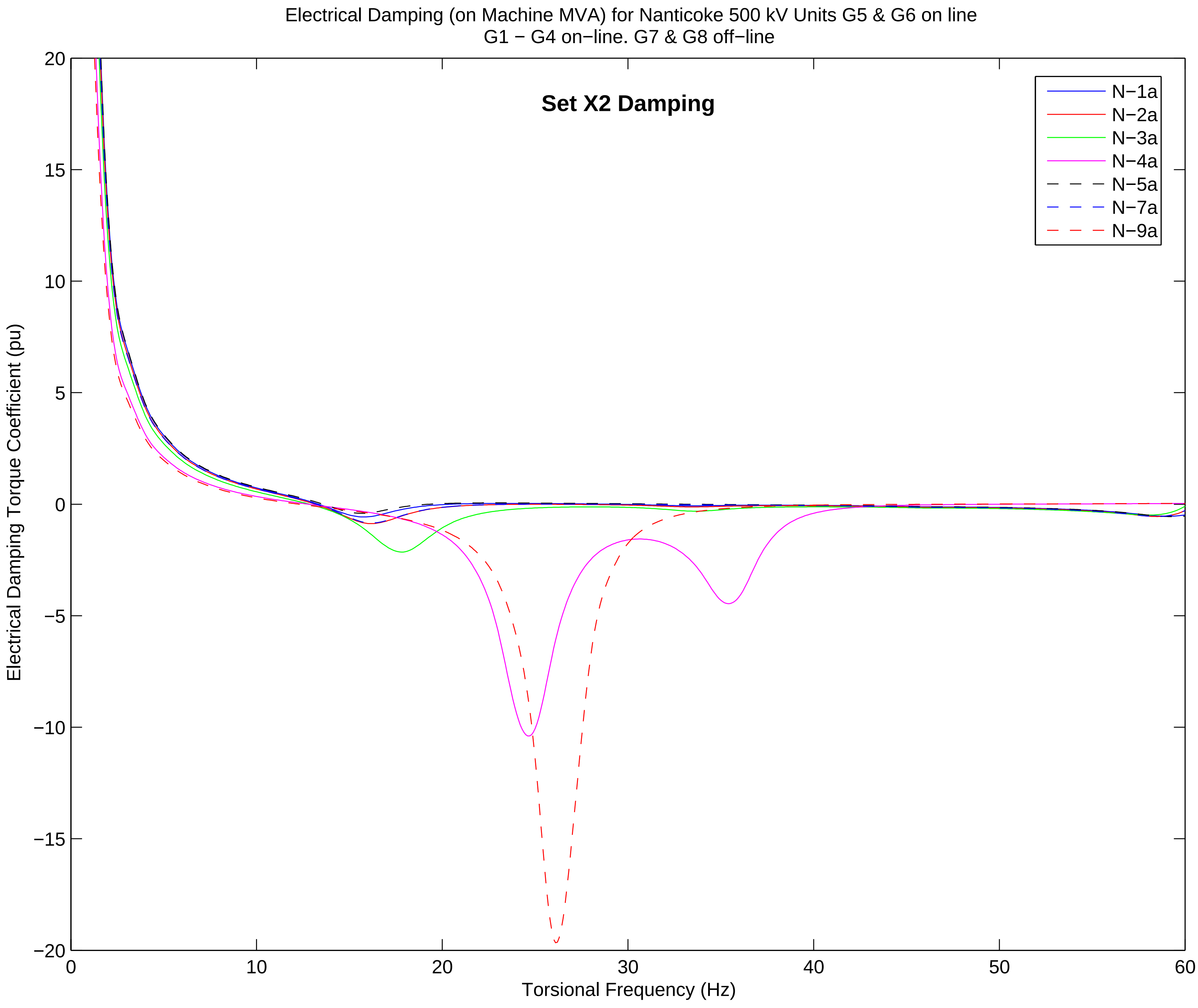
Electrical Damping (on Machine MVA) for Nanticoke 500 kV Unit G5 on line
G1 − G4 on−line. G6 − G8 off−line
Set X1 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



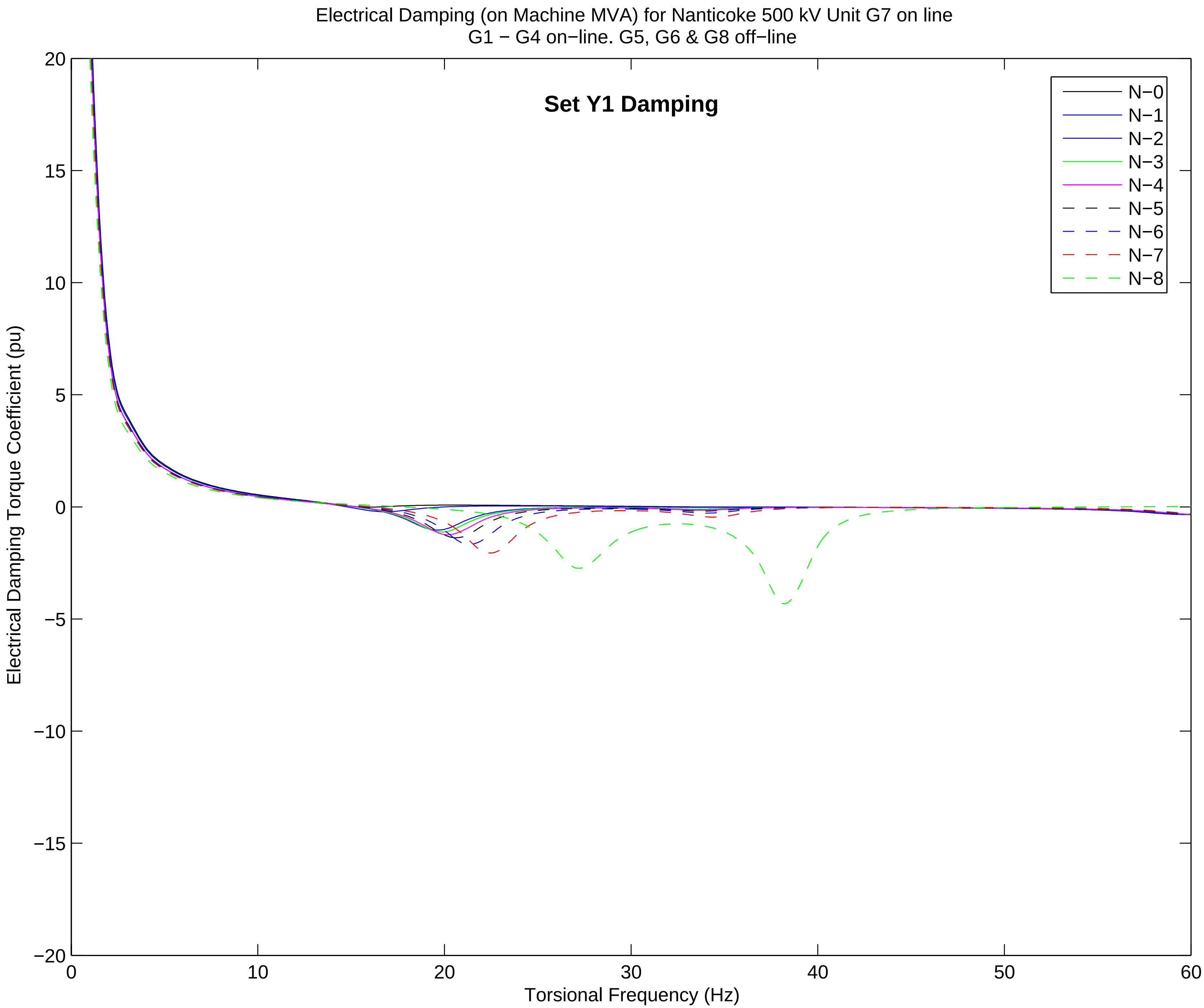
Electrical Damping (on Machine MVA) for Nanticoke 500 kV Unit G5 on line
G1 − G4 on−line. G6 − G8 off−line
Set X1 Damping
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

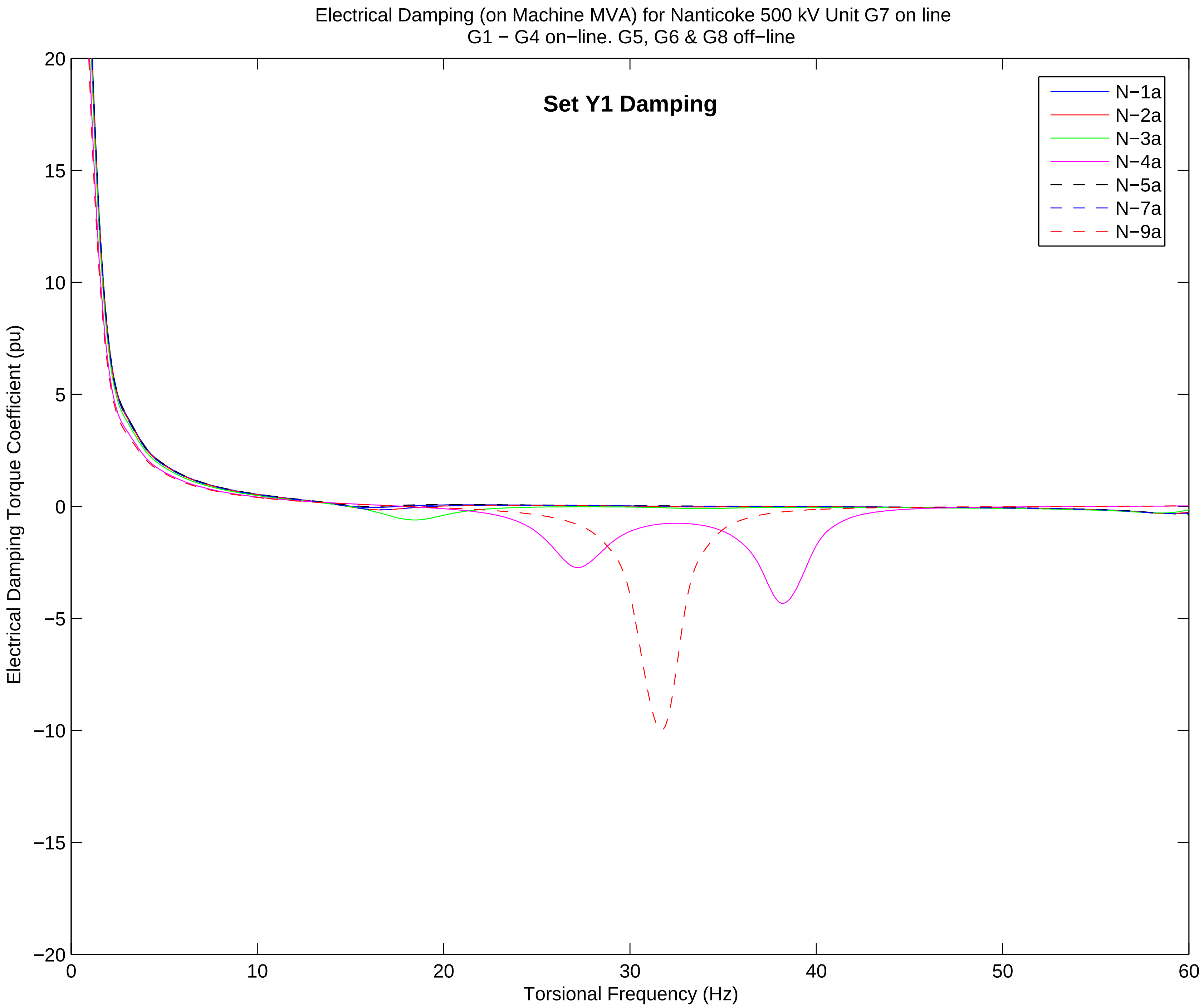


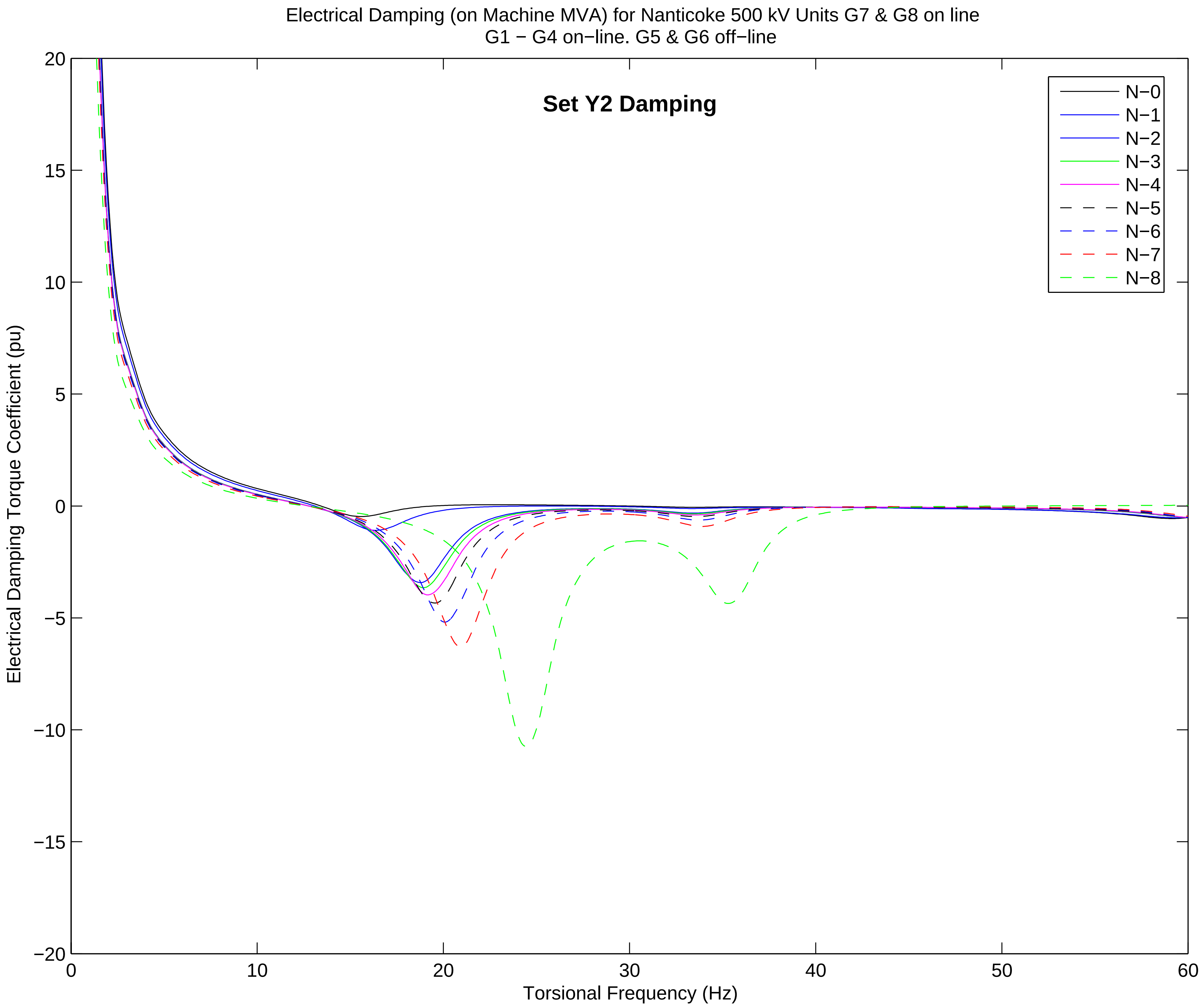
Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units G5 & G6 on line
G1 − G4 on−line. G7 & G8 off−line
Set X2 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
20
15
10
5
0
−5
−10
−15
−20
Electrical Damping Torque Coefficient (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



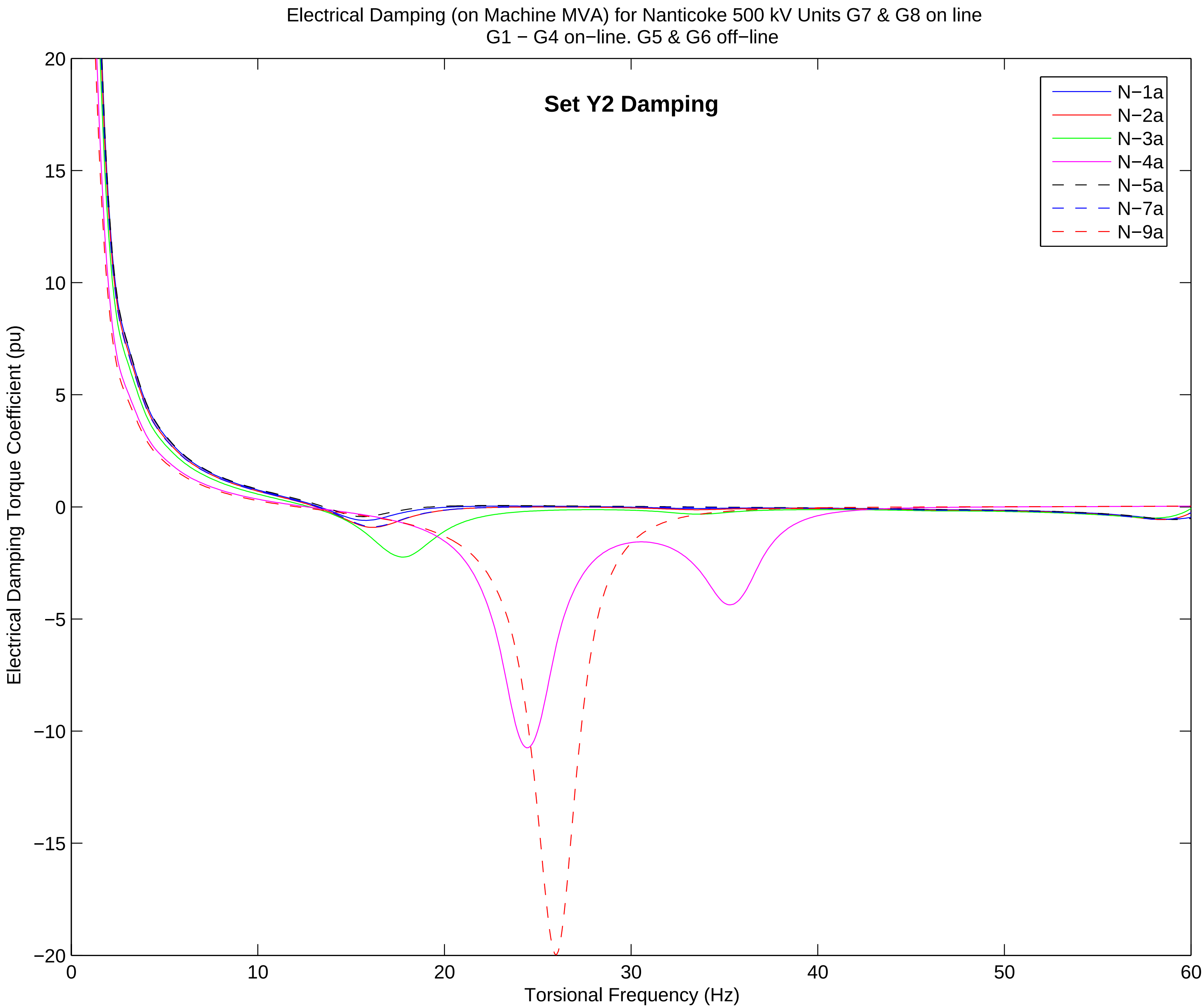
Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units G5 & G6 on line
G1 − G4 on−line. G7 & G8 off−line
Set X2 Damping
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

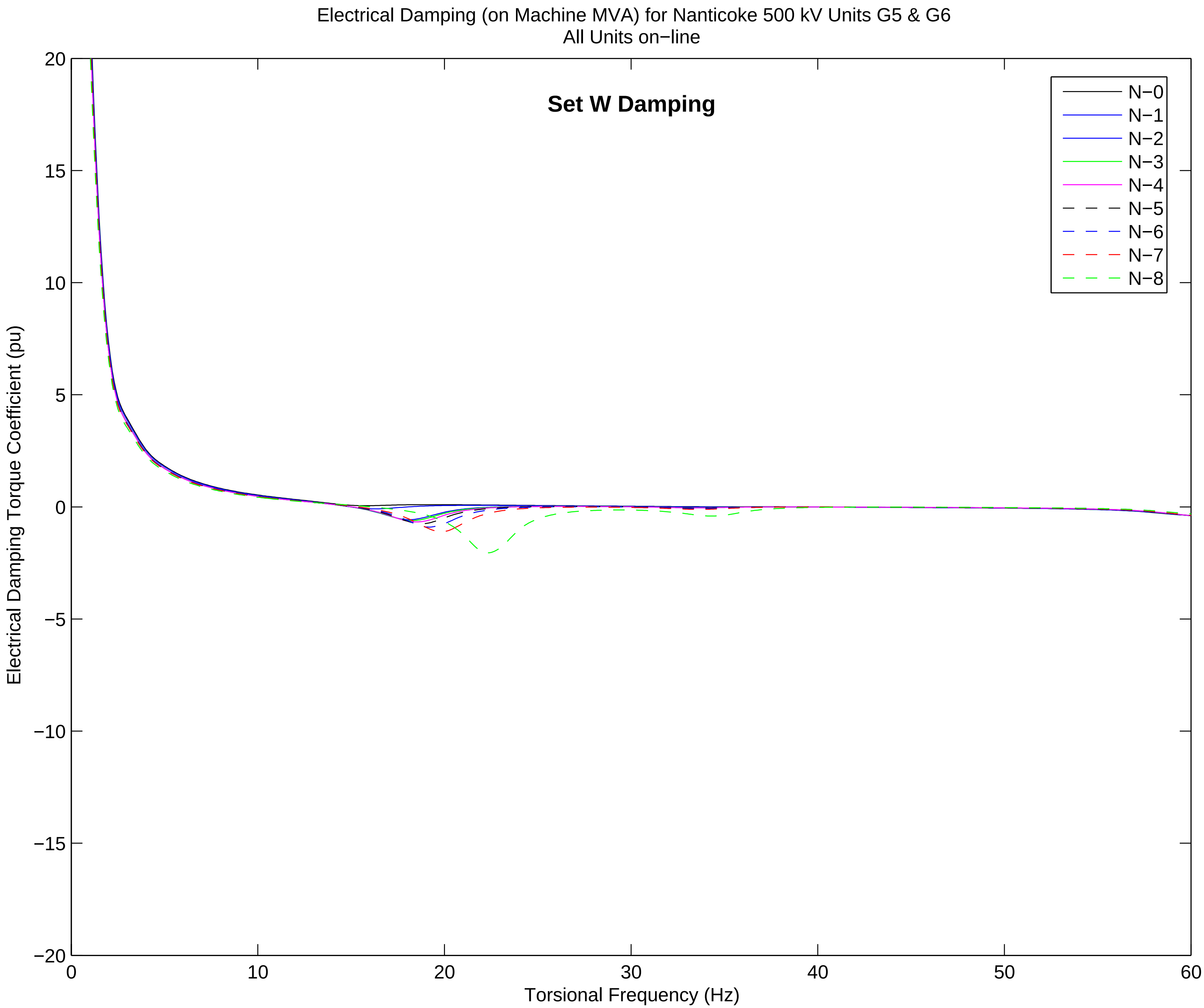

Electrical Damping (on Machine MVA) for Nanticoke 500 kV Unit G7 on line
G1 − G4 on−line. G5, G6 & G8 off−line
Set Y1 Damping
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8


Electrical Damping (on Machine MVA) for Nanticoke 500 kV Unit G7 on line
G1 − G4 on−line. G5, G6 & G8 off−line
Set Y1 Damping
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

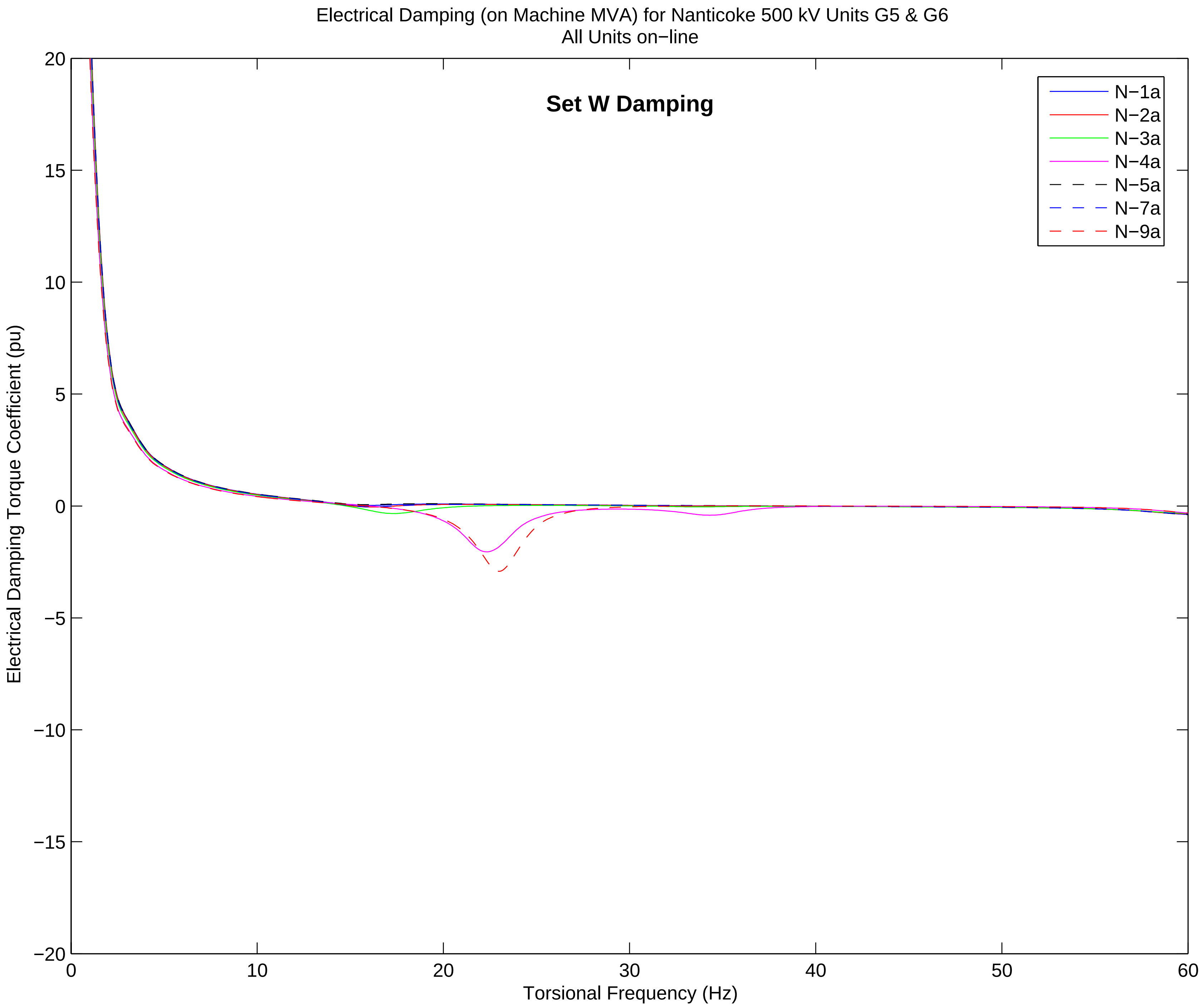


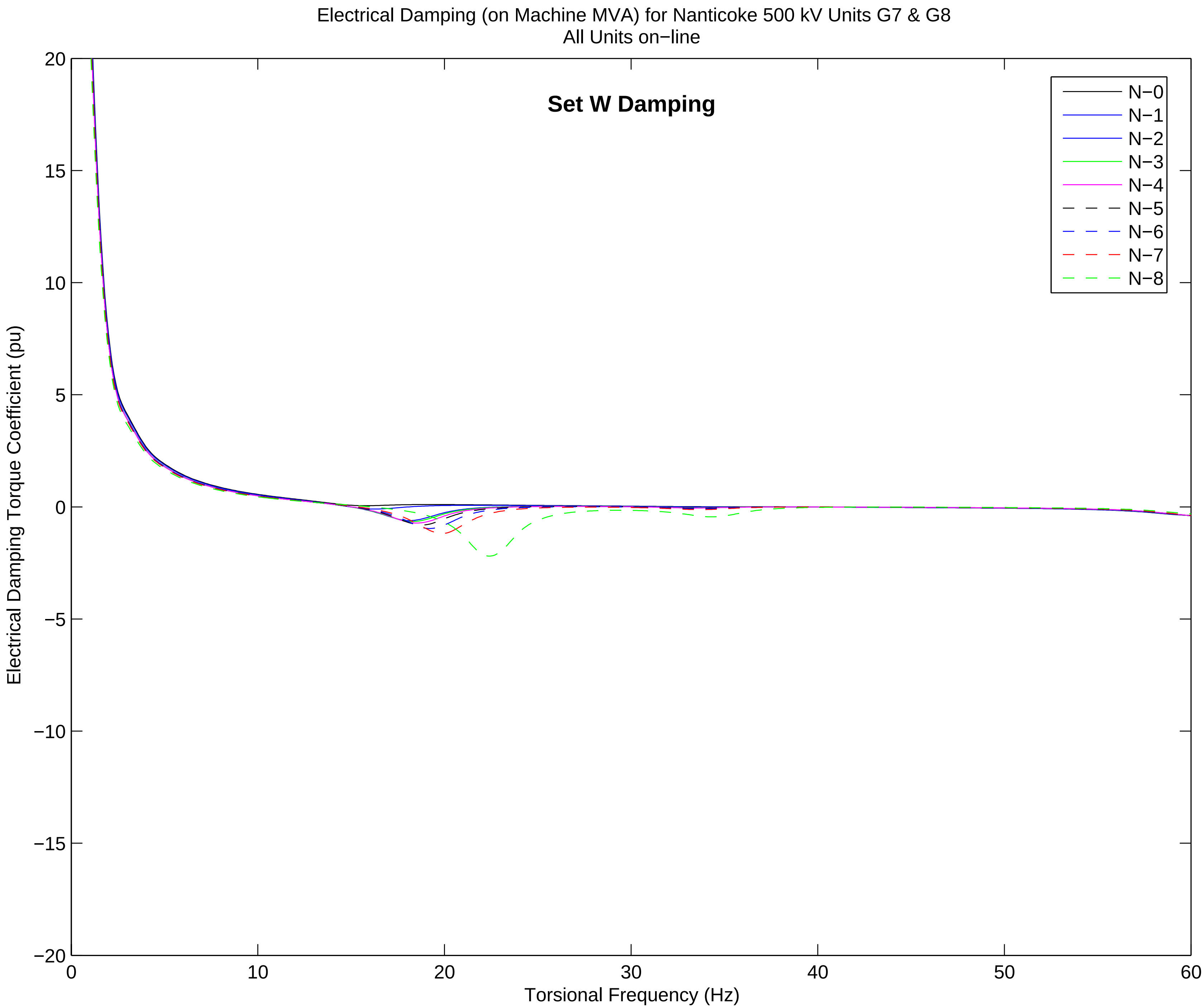
Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units G7 & G8 on line
G1 − G4 on−line. G5 & G6 off−line
Set Y2 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
Electrical Damping Torque Coefficient (pu)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)

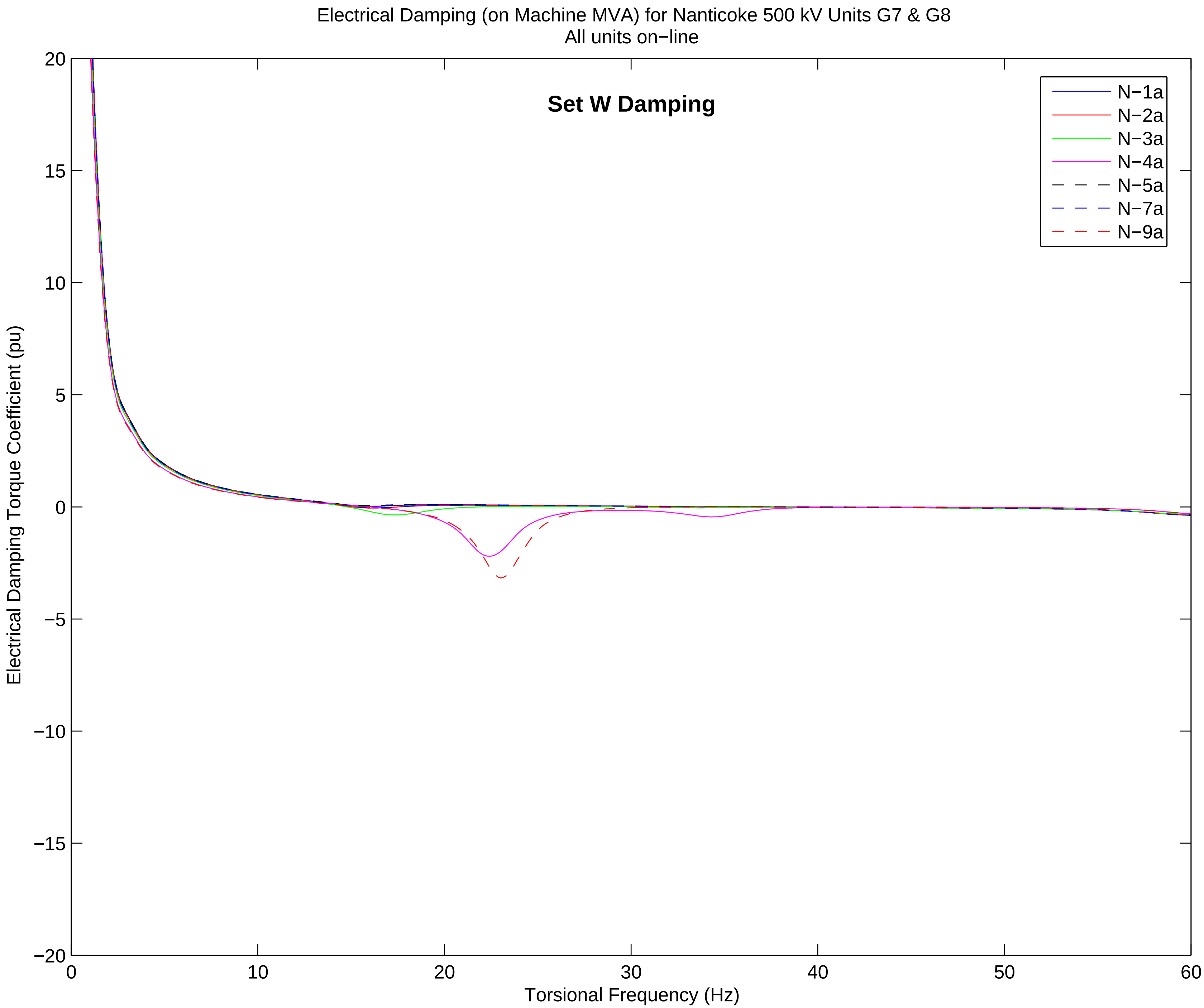

Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units G7 & G8 on line
G1 − G4 on−line. G5 & G6 off−line
Set Y2 Damping
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)
Electrical Damping Torque Coefficient (pu)

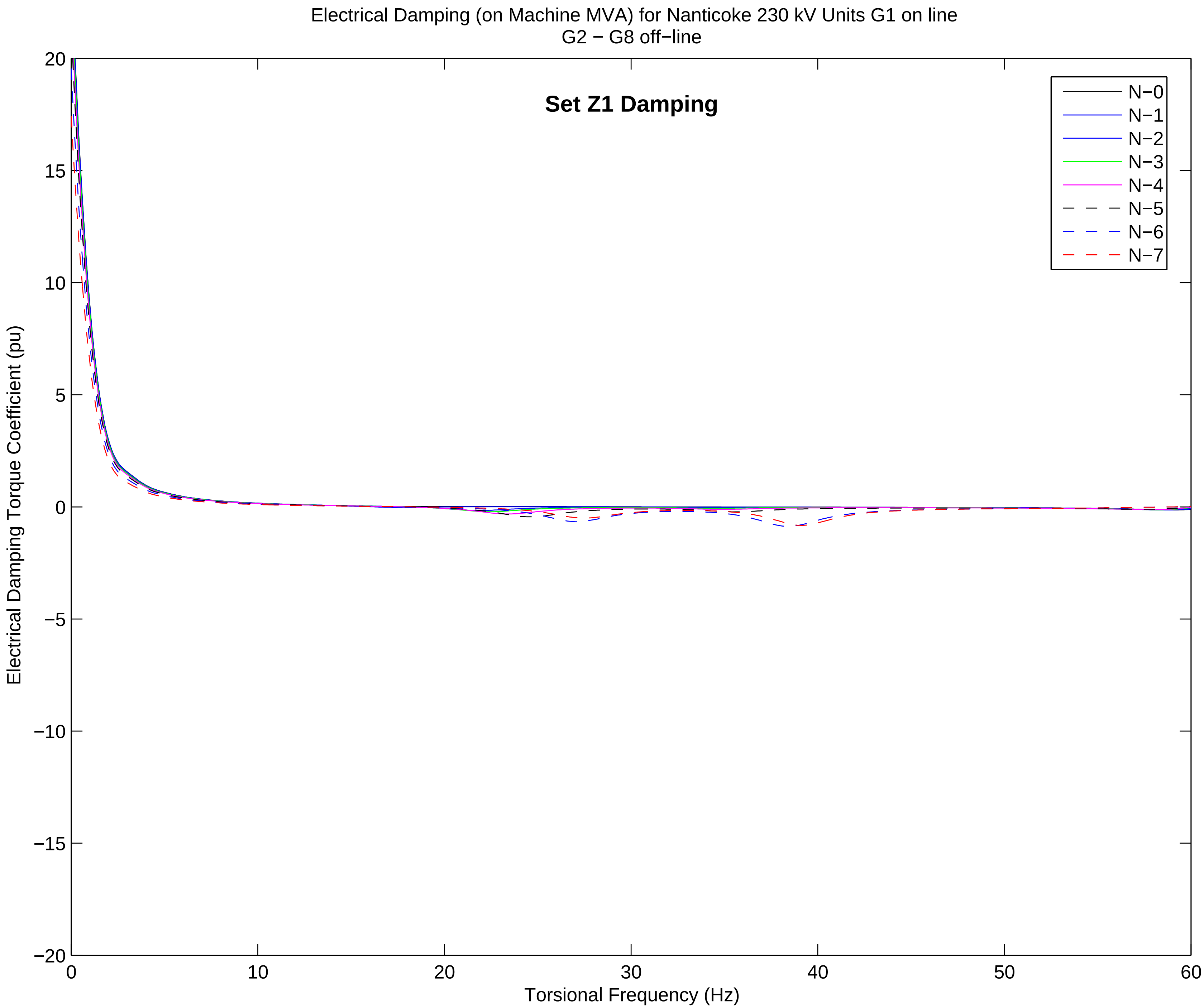


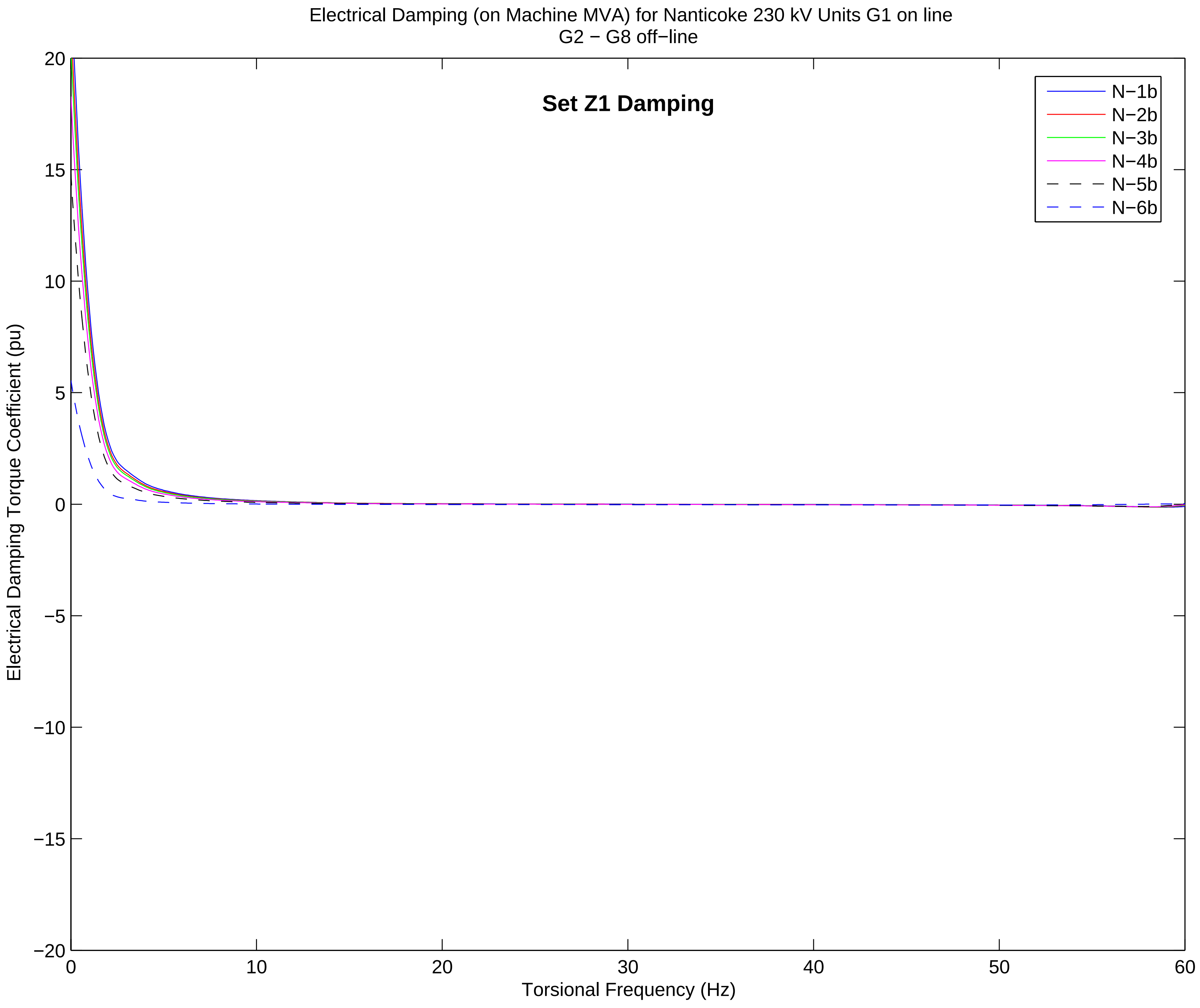
Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units G5 & G6
All Units on−line
Set W Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)


Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units G5 & G6
All Units on−line
Set W Damping
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

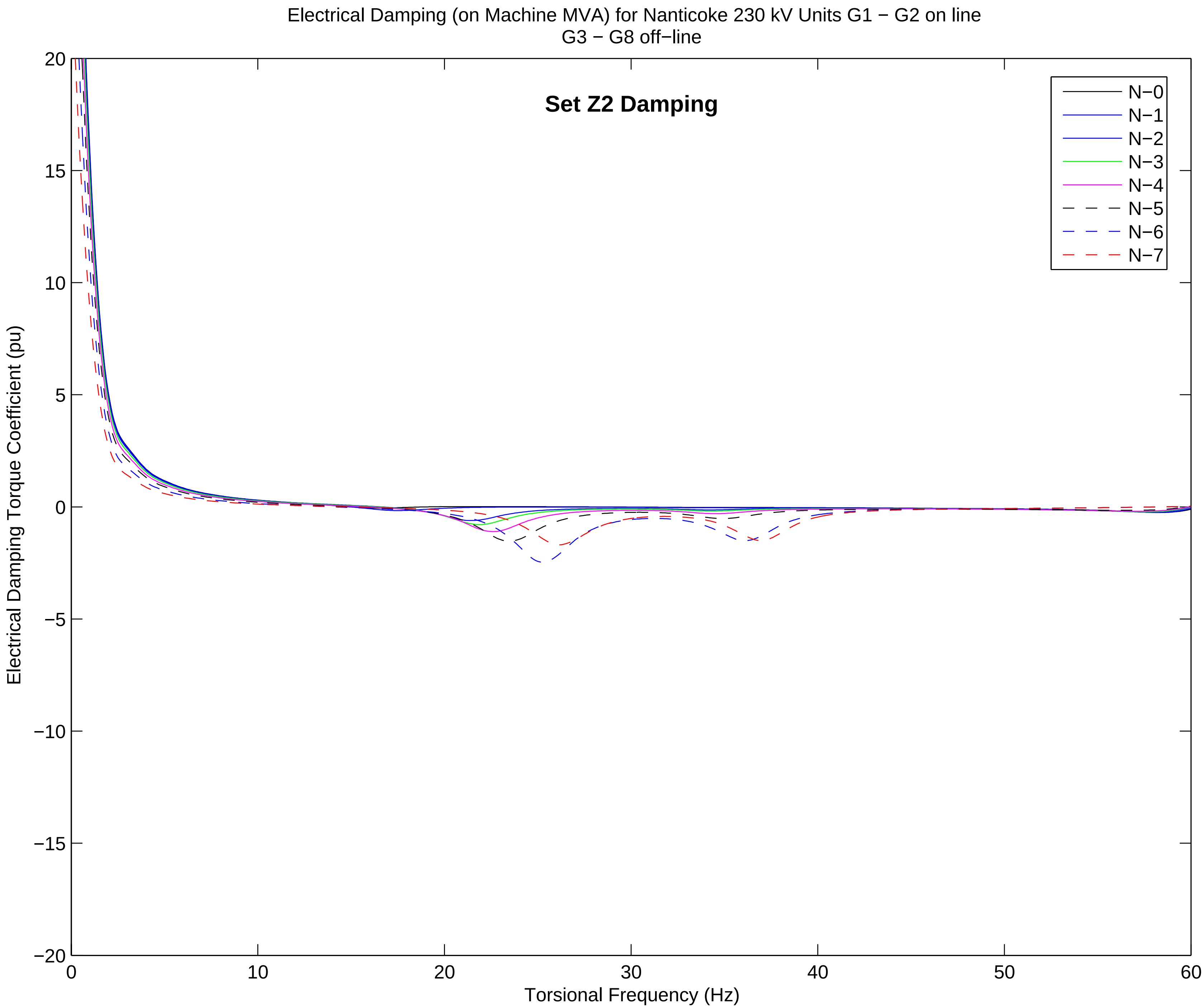

Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units G7 & G8
All Units on−line
Set W Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

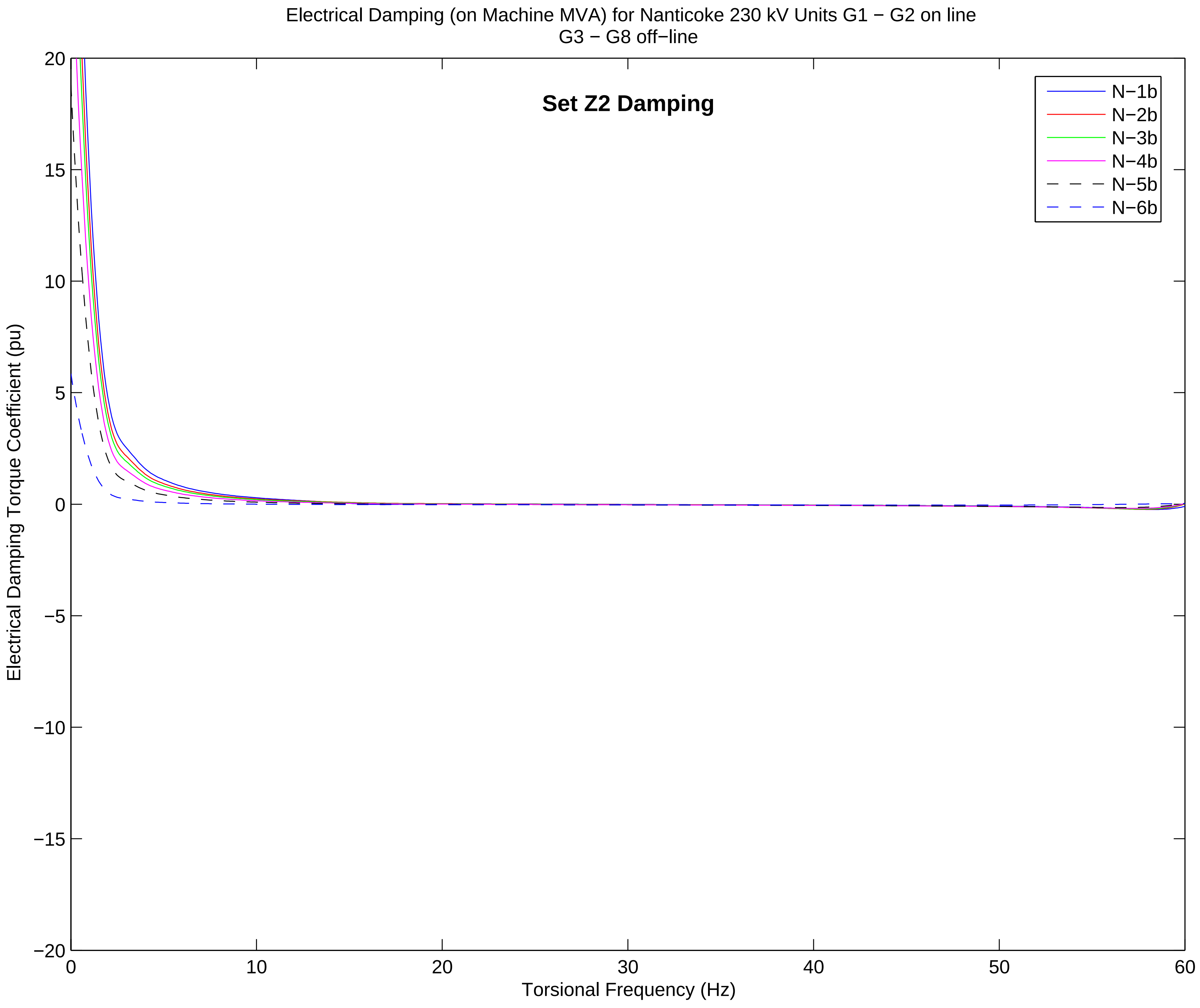

Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units G7 & G8
All units on−line
Set W Damping
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units G1 on line
G2 − G8 off−line
Set Z1 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

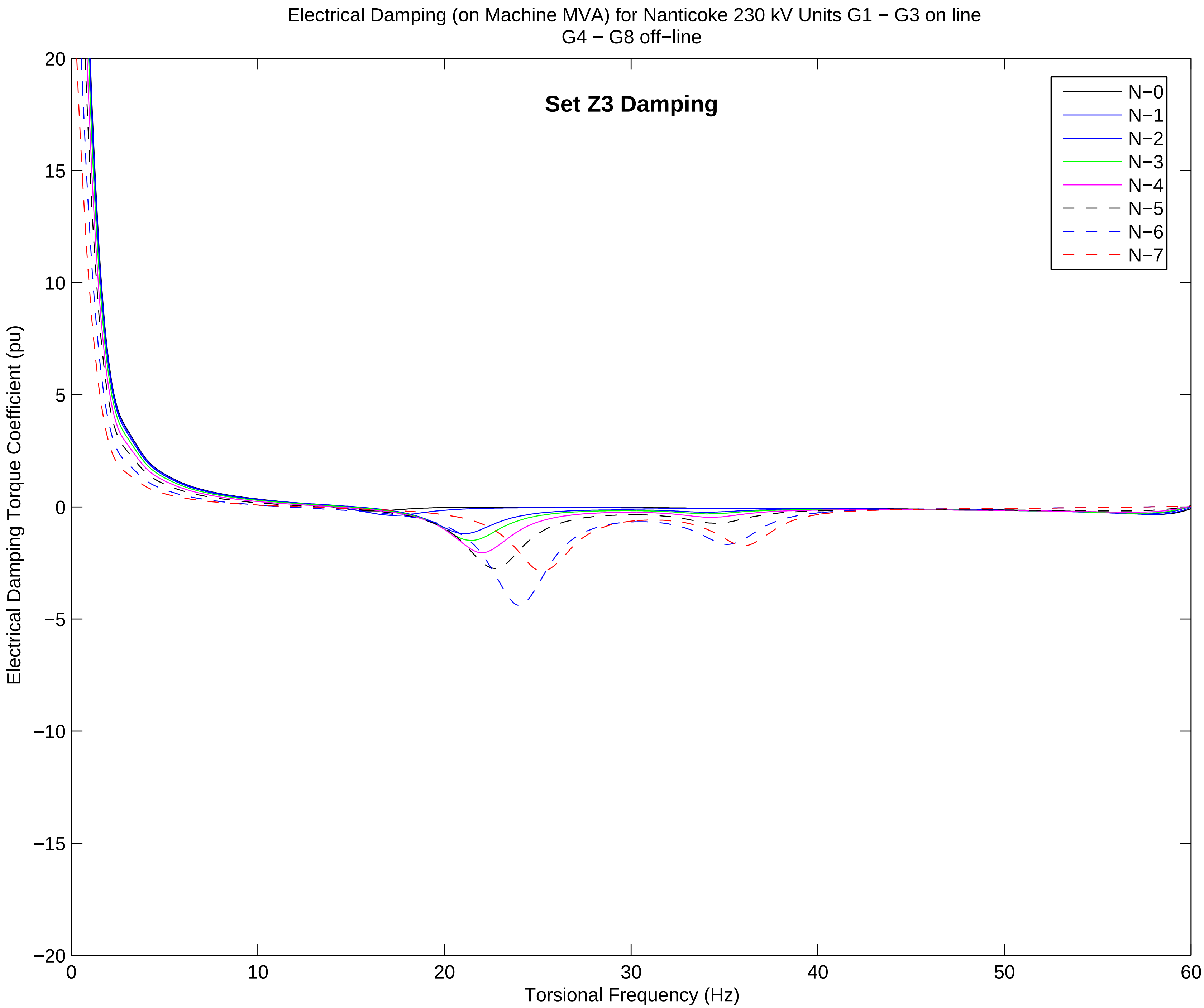


Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units G1 on line
G2 − G8 off−line
Set Z1 Damping
N−1b
N−2b
N−3b
N−4b
N−5b
N−6b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

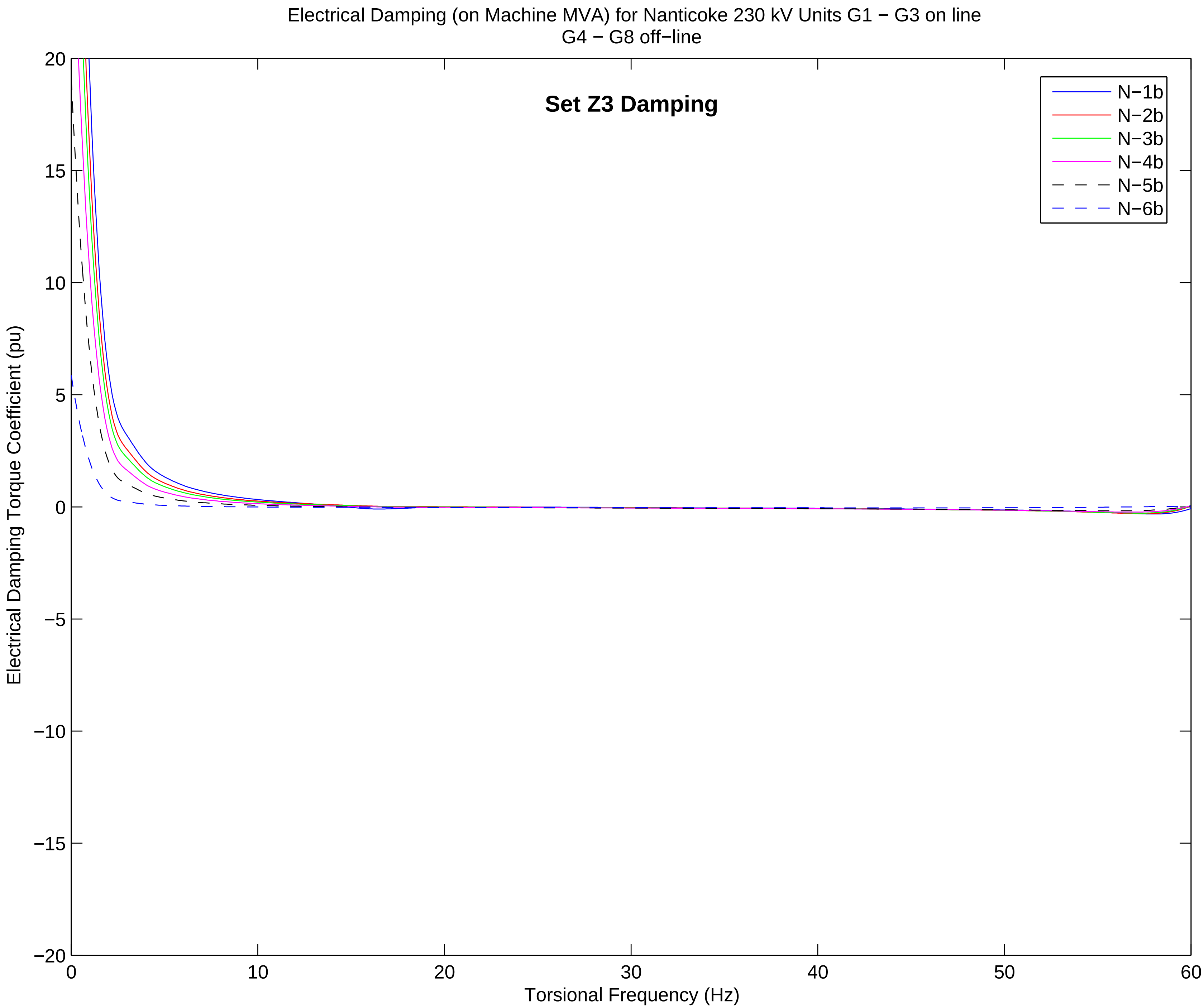

Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units G1 − G2 on line
G3 − G8 off−line
Set Z2 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



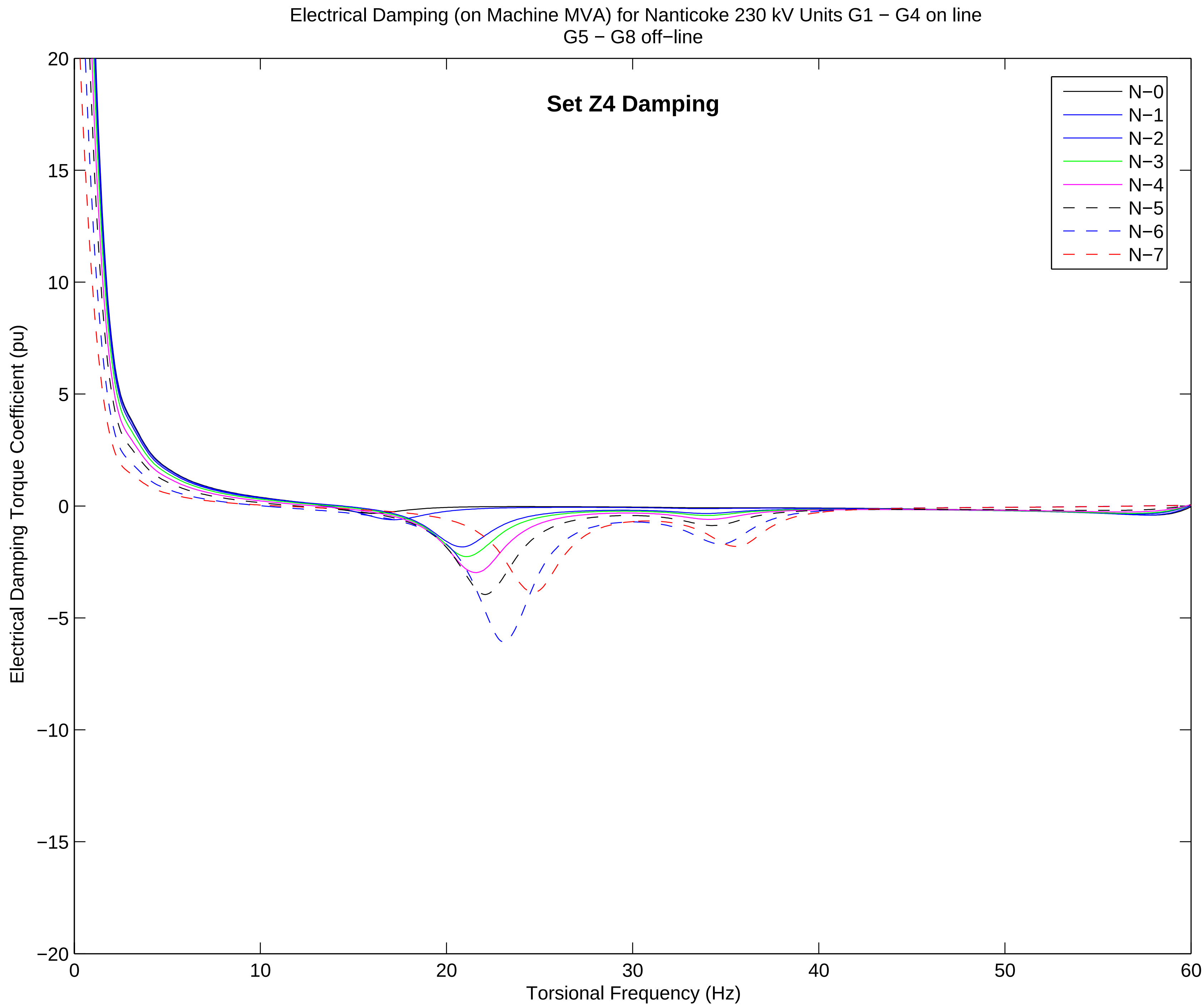
Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units G1 − G2 on line
G3 − G8 off−line
Set Z2 Damping
N−1b
N−2b
N−3b
N−4b
N−5b
N−6b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



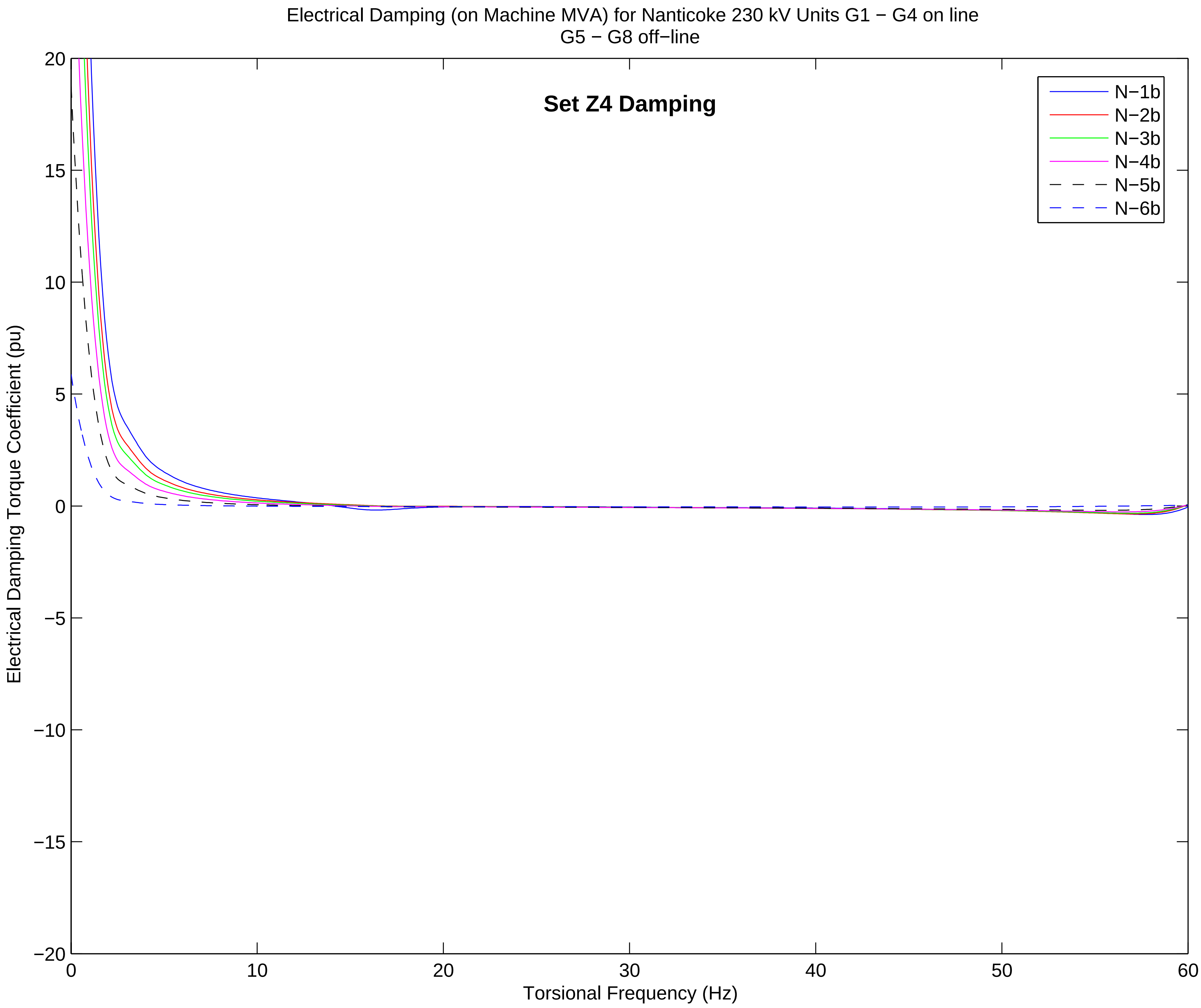
Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units G1 − G3 on line
G4 − G8 off−line
Set Z3 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



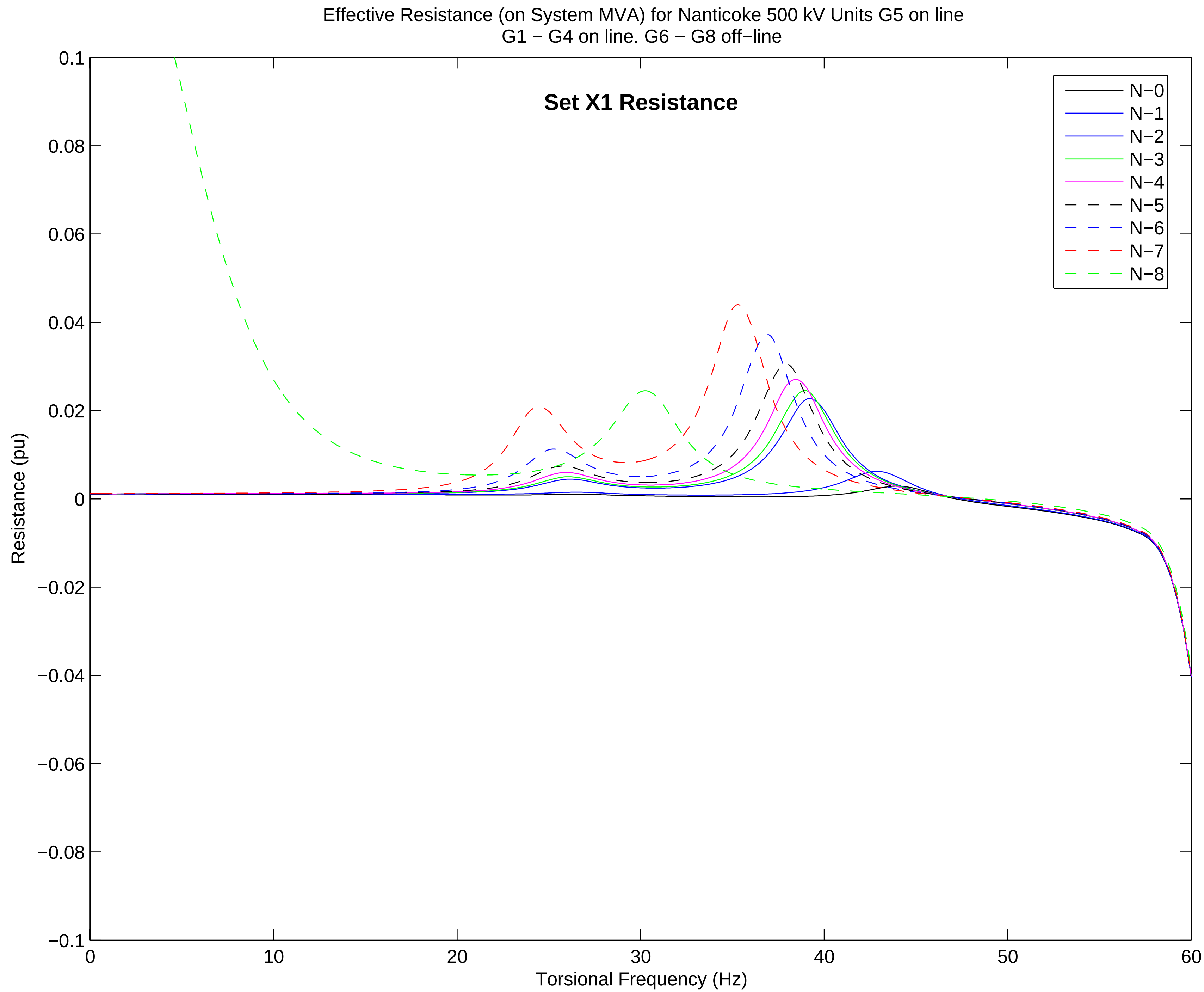
Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units G1 − G3 on line
G4 − G8 off−line
Set Z3 Damping
N−1b
N−2b
N−3b
N−4b
N−5b
N−6b
Electrical Damping Torque Coefficient (pu)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)



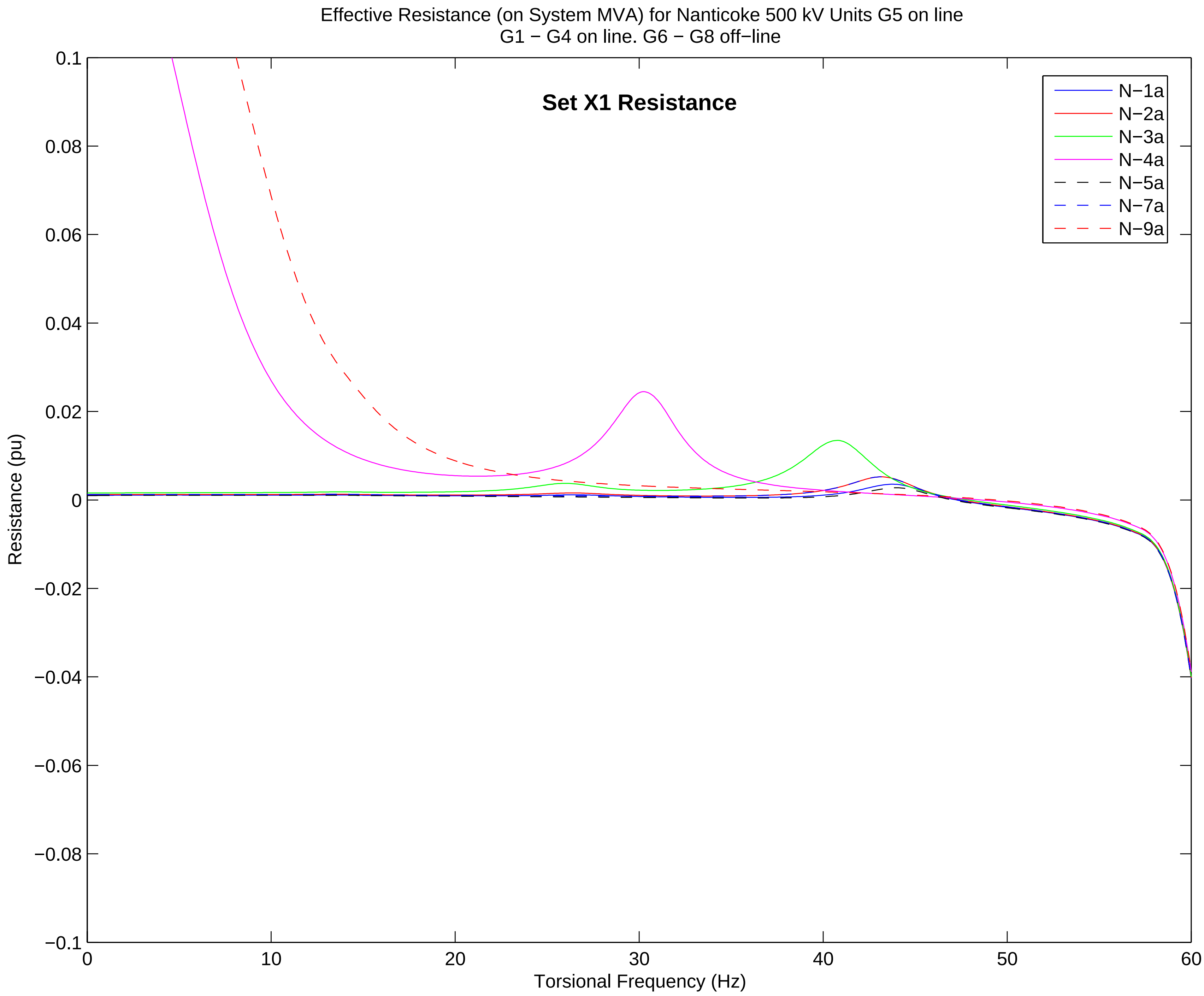
Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units G1 − G4 on line
G5 − G8 off−line
Set Z4 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



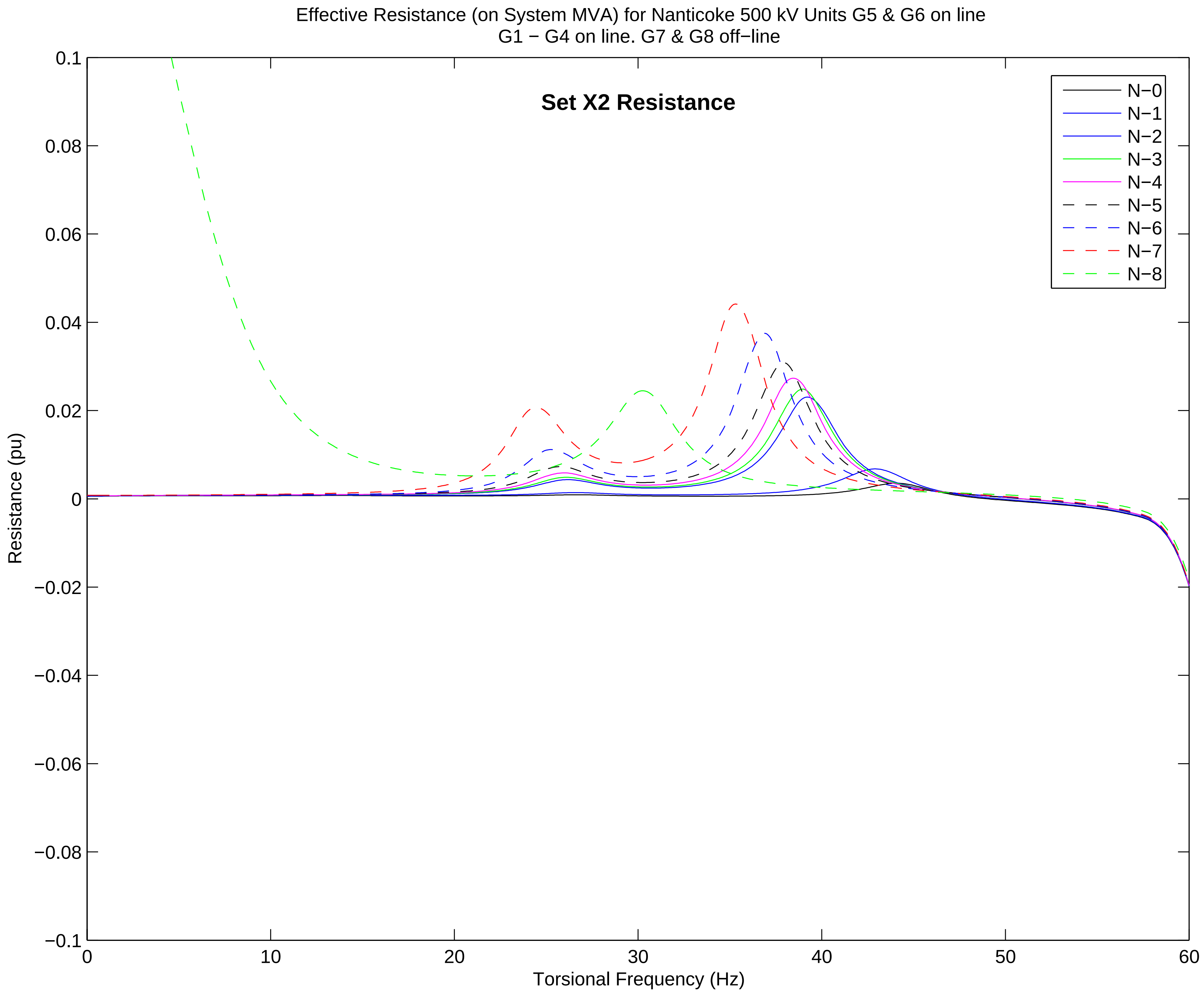
Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units G1 − G4 on line
G5 − G8 off−line
Set Z4 Damping
N−1b
N−2b
N−3b
N−4b
N−5b
N−6b
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



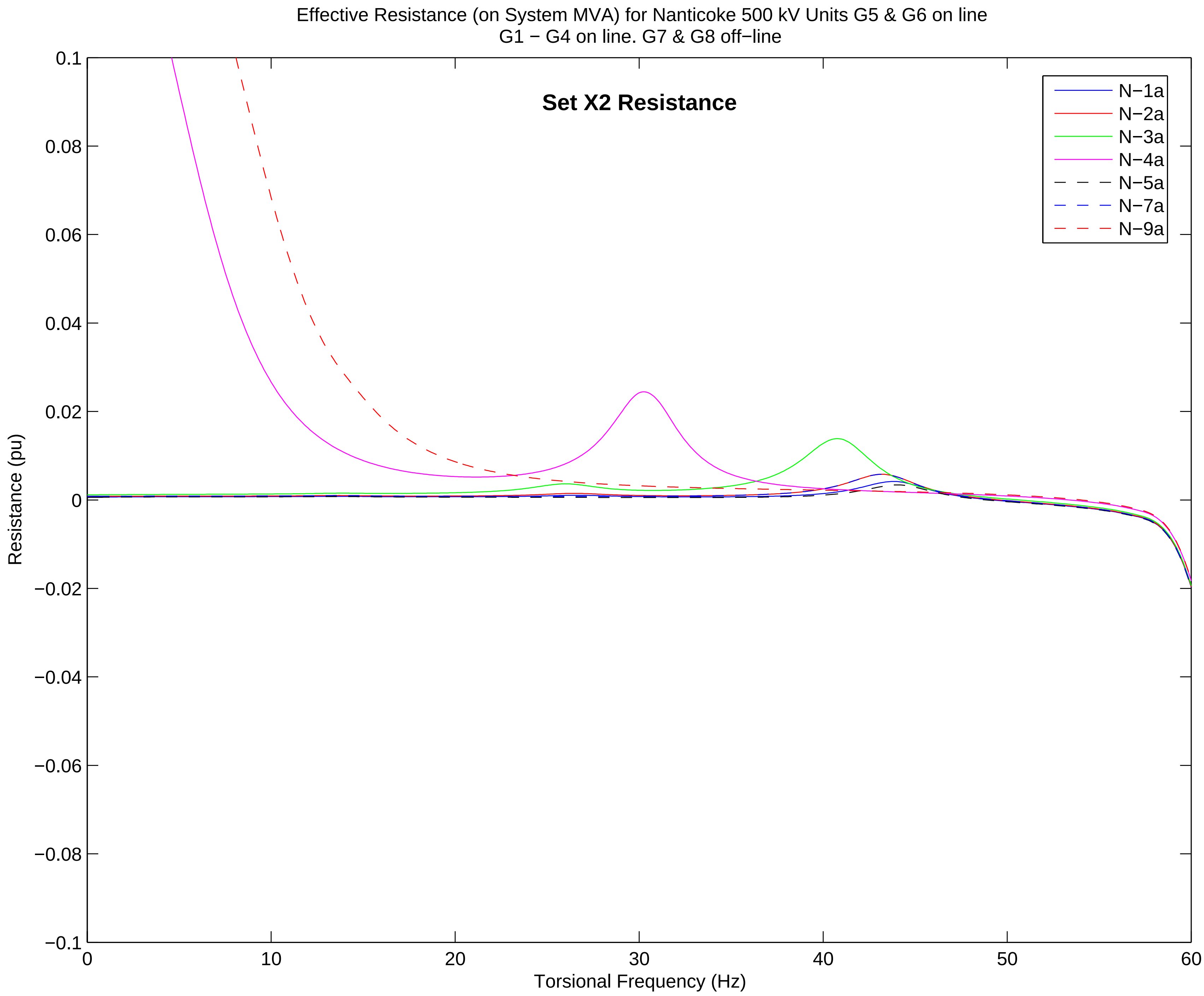
Effective Resistance (on System MVA) for Nanticoke 500 kV Units G5 on line
G1 − G4 on line. G6 − G8 off−line
Set X1 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Torsional Frequency (Hz)
0
10
20
30
40
50
60



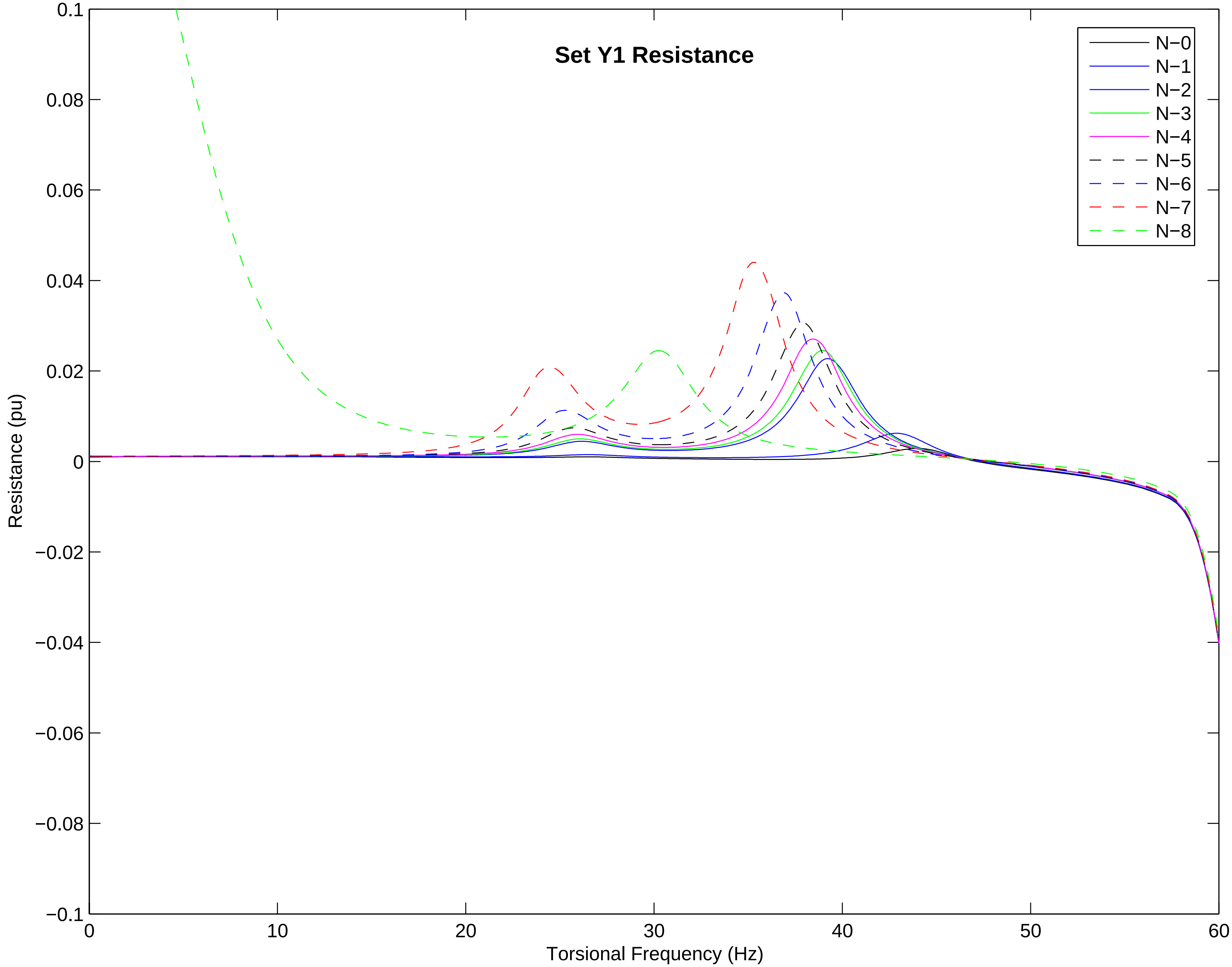
Effective Resistance (on System MVA) for Nanticoke 500 kV Units G5 on line
G1 − G4 on line. G6 − G8 off−line
Set X1 Resistance
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

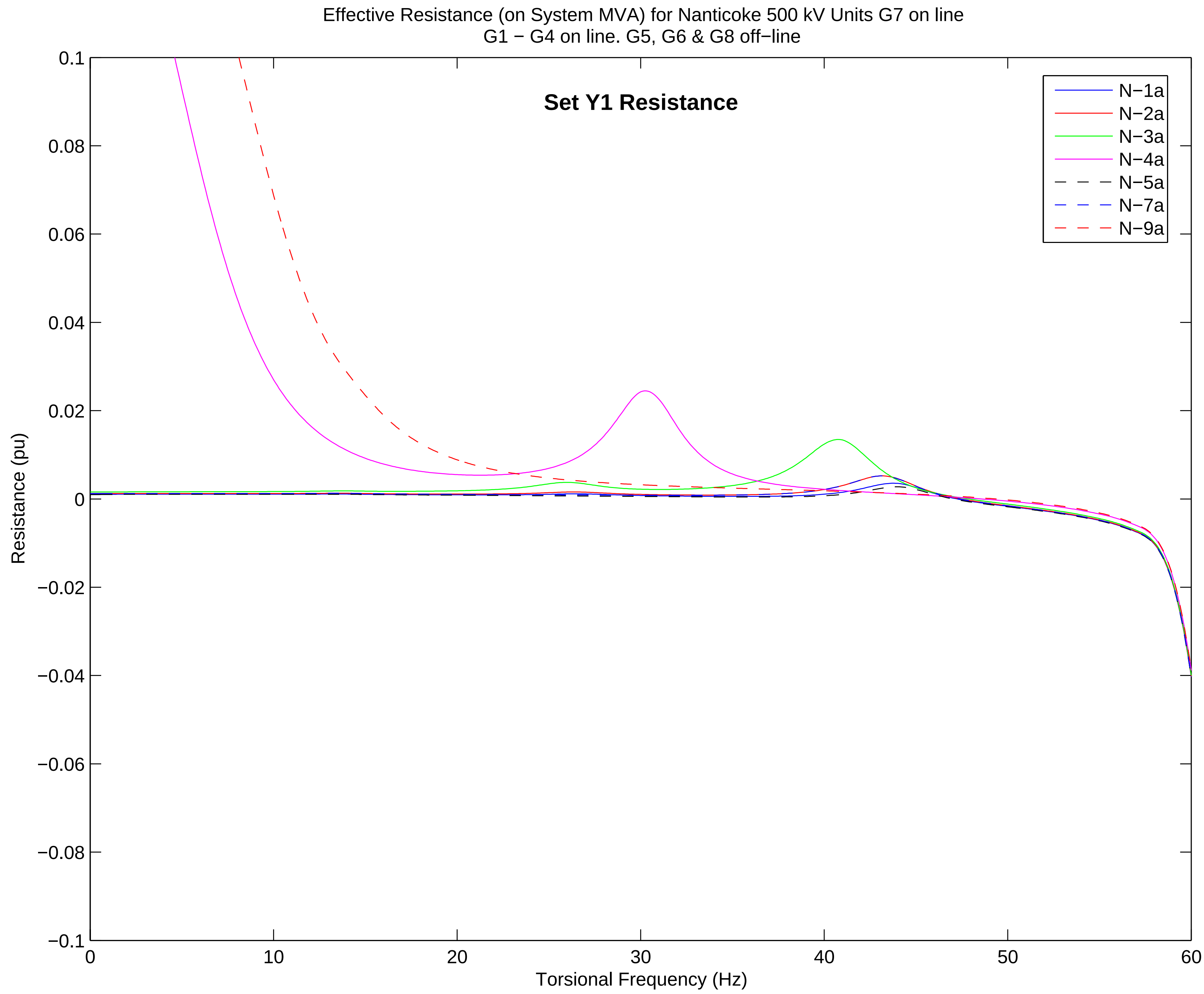


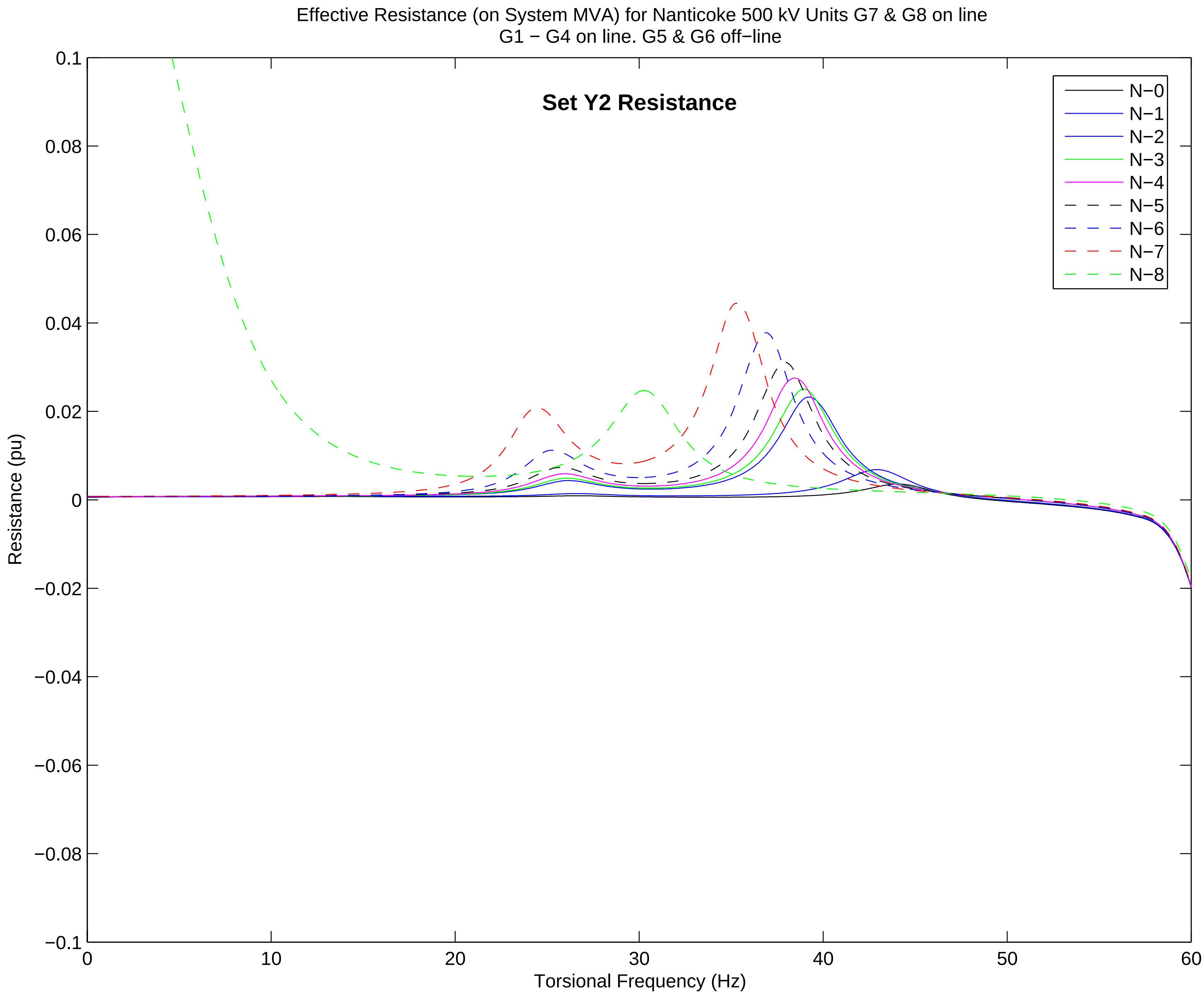
Effective Resistance (on System MVA) for Nanticoke 500 kV Units G5 & G6 on line
G1 − G4 on line. G7 & G8 off−line
Set X2 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

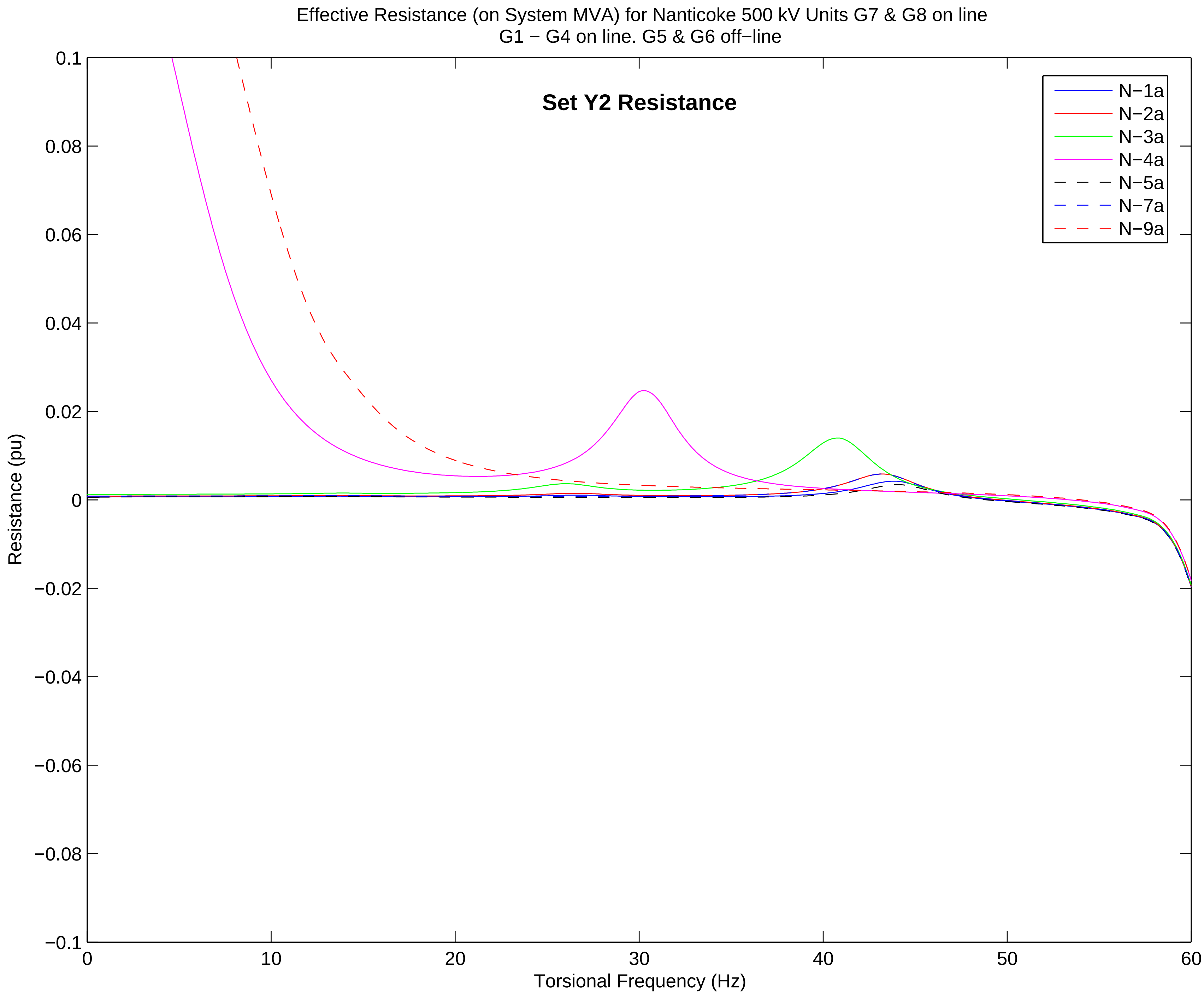

Effective Resistance (on System MVA) for Nanticoke 500 kV Units G5 & G6 on line
G1 − G4 on line. G7 & G8 off−line
Set X2 Resistance
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

Effective Resistance (on System MVA) for Nanticoke 500 kV Units G7 on line
G1 − G4 on line. G5, G6 & G8 off−line

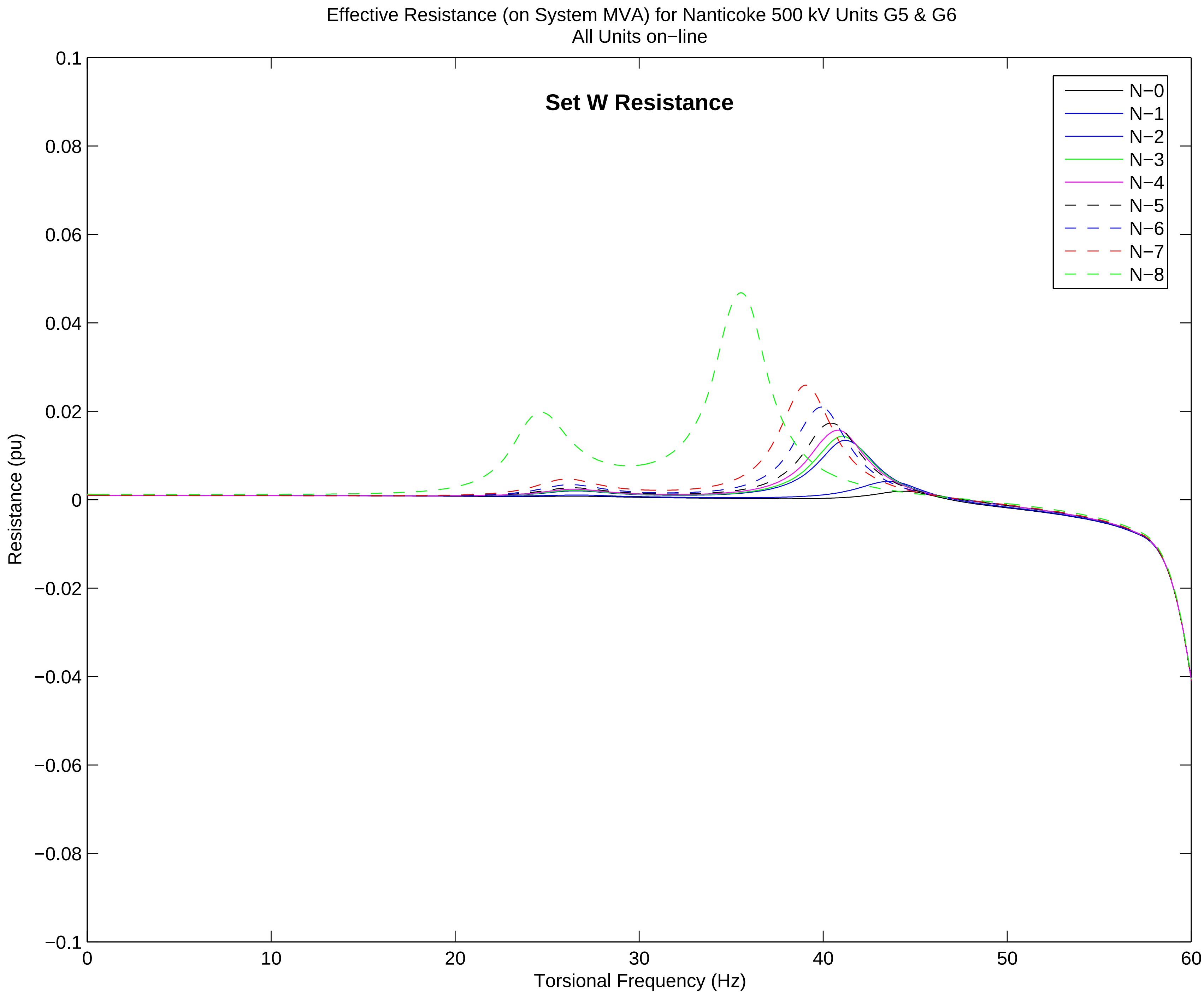



Effective Resistance (on System MVA) for Nanticoke 500 kV Units G7 on line
G1 − G4 on line. G5, G6 & G8 off−line
Set Y1 Resistance
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

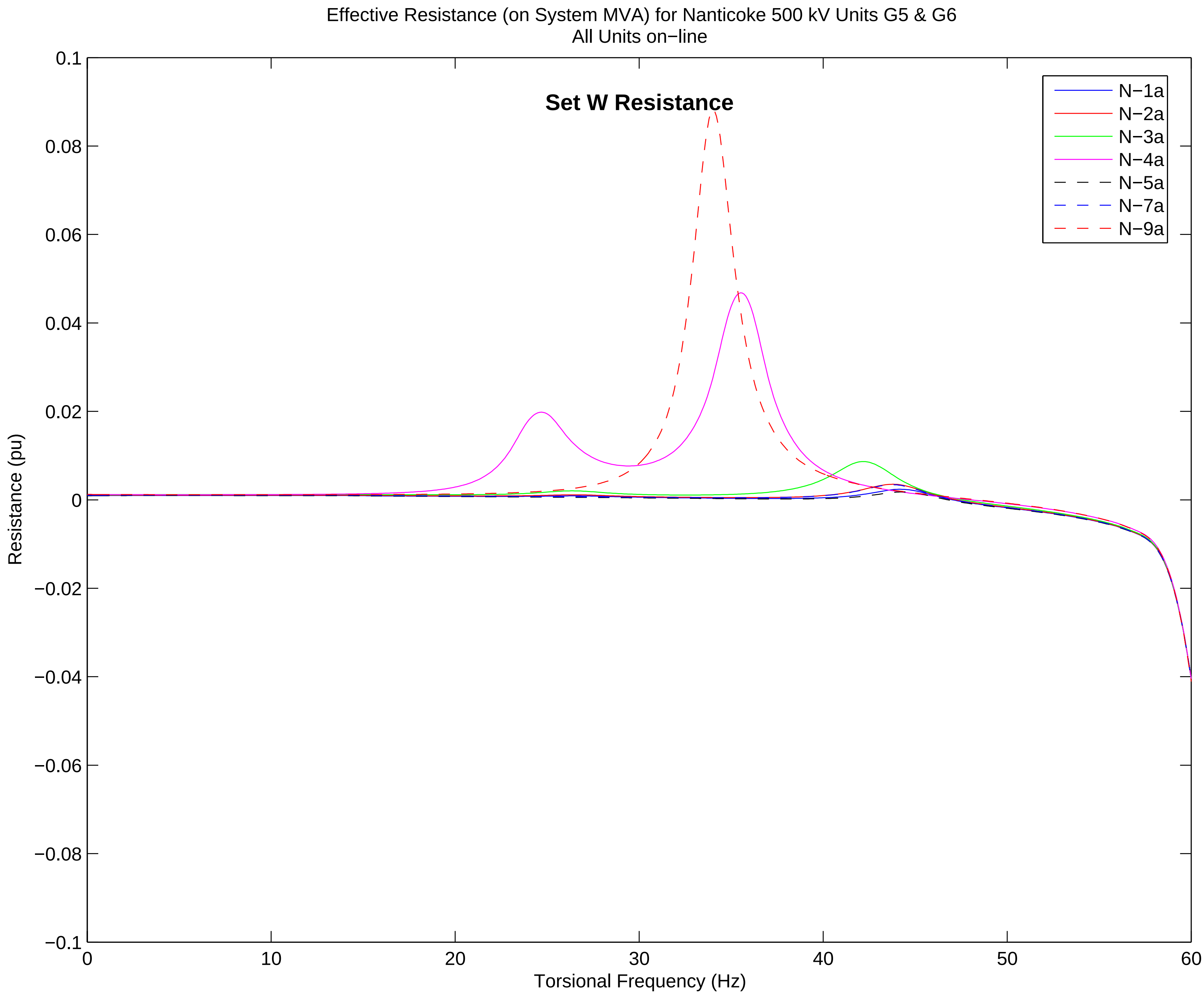

Effective Resistance (on System MVA) for Nanticoke 500 kV Units G7 & G8 on line
G1 − G4 on line. G5 & G6 off−line
Set Y2 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



Effective Resistance (on System MVA) for Nanticoke 500 kV Units G7 & G8 on line
G1 − G4 on line. G5 & G6 off−line
Set Y2 Resistance
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

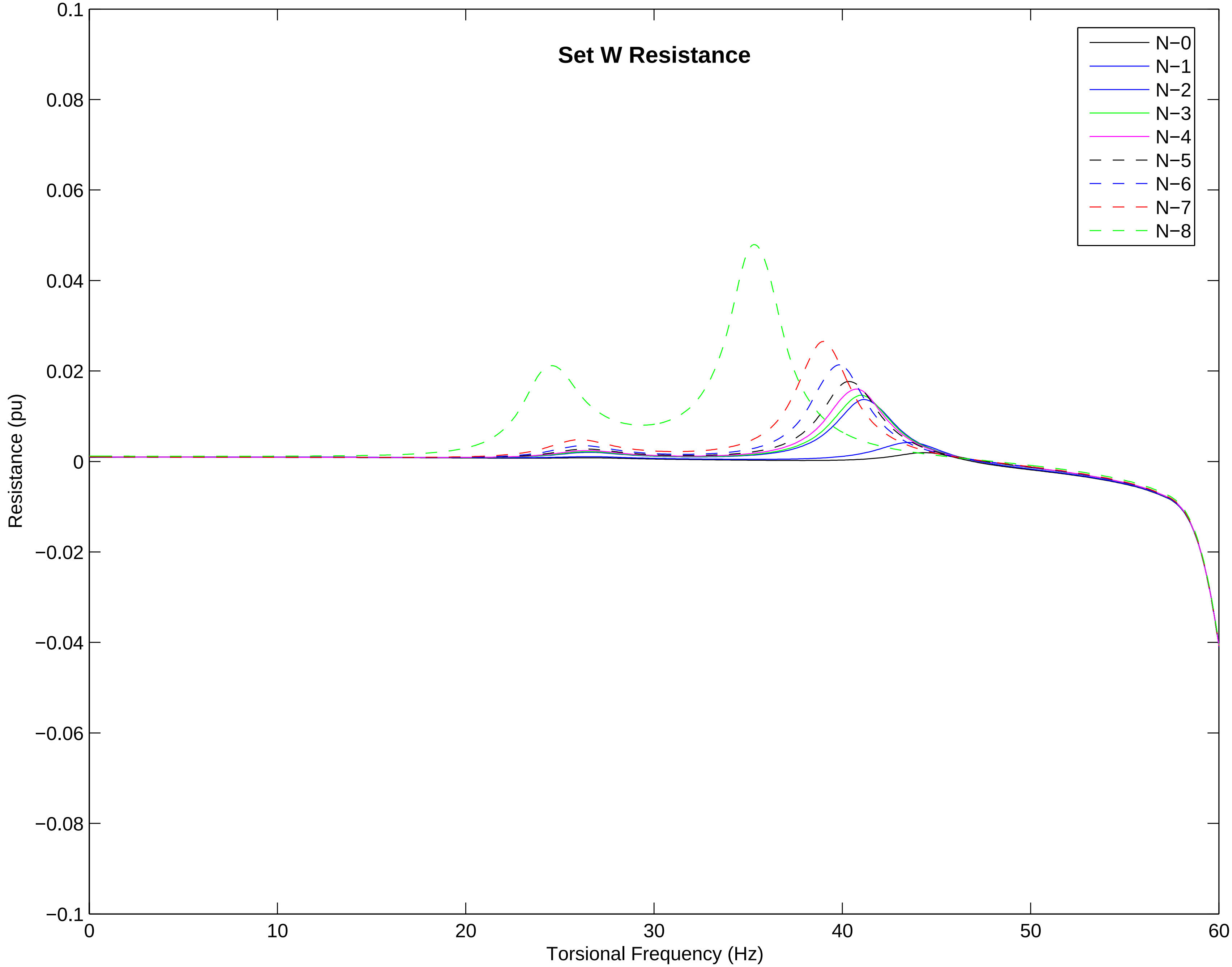


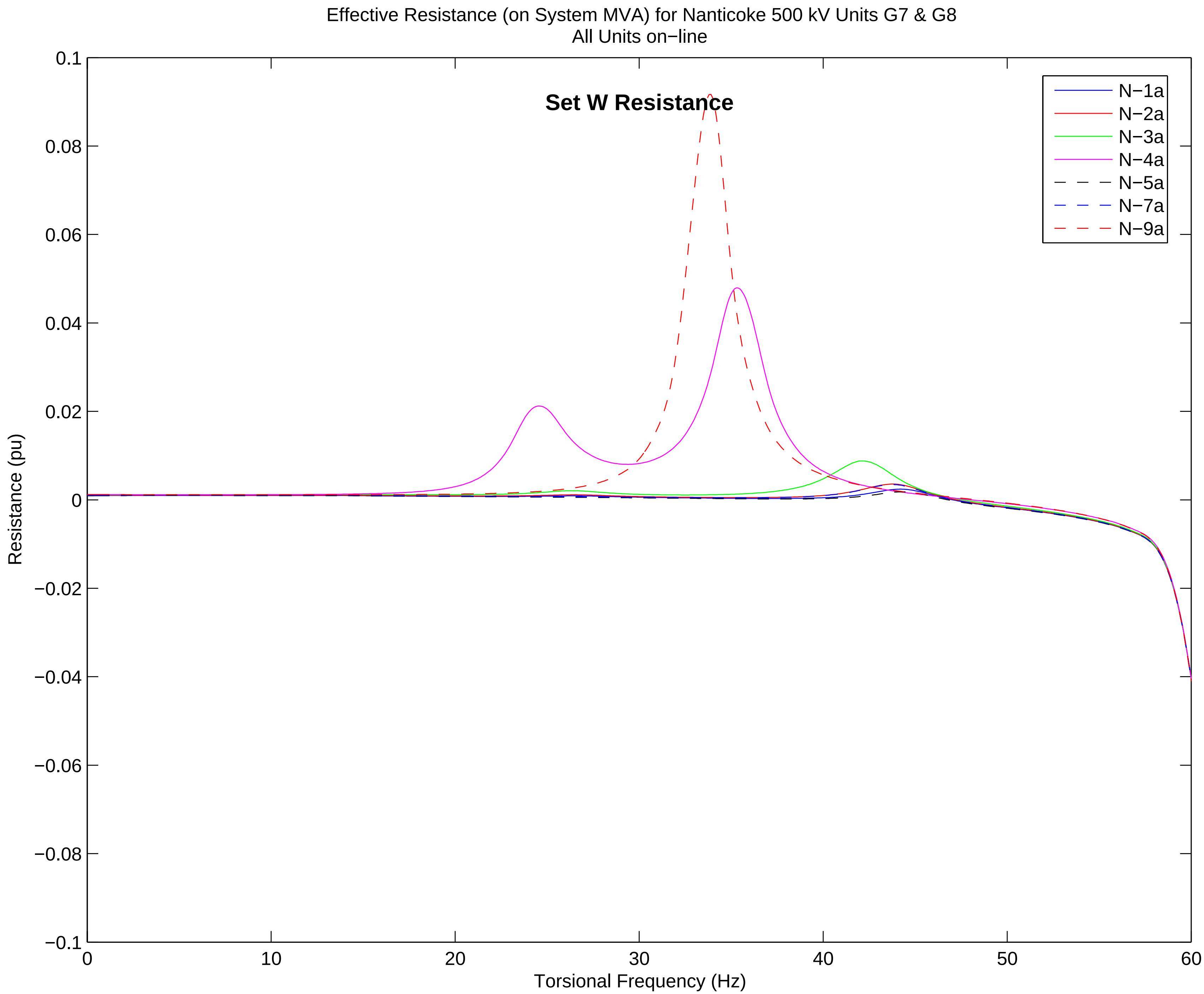
Effective Resistance (on System MVA) for Nanticoke 500 kV Units G5 & G6
All Units on−line
Set W Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
N−8
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



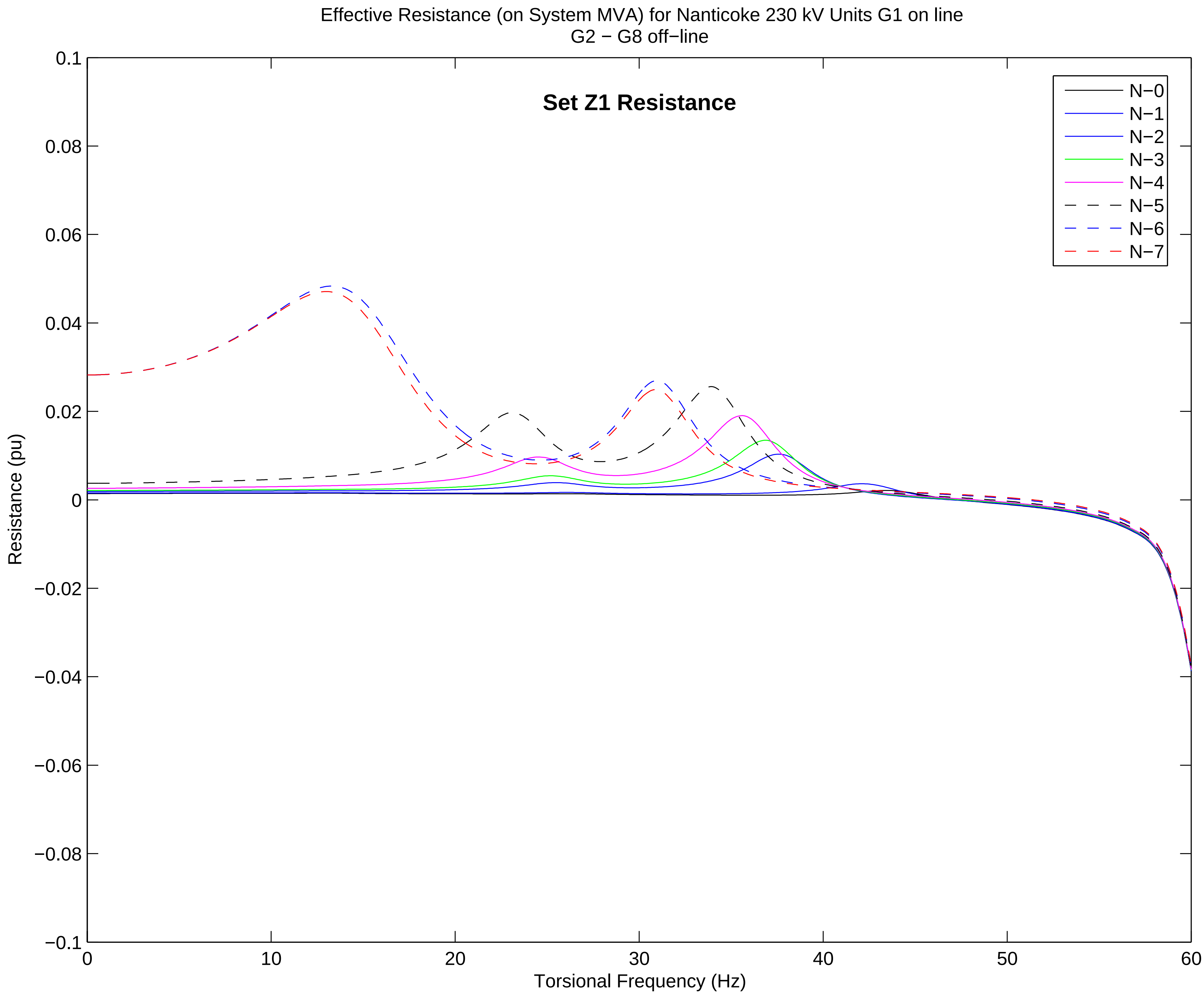
Effective Resistance (on System MVA) for Nanticoke 500 kV Units G5 & G6
All Units on−line
Set W Resistance
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

Effective Resistance (on System MVA) for Nanticoke 500 kV Units G7 & G8
All Units on−line

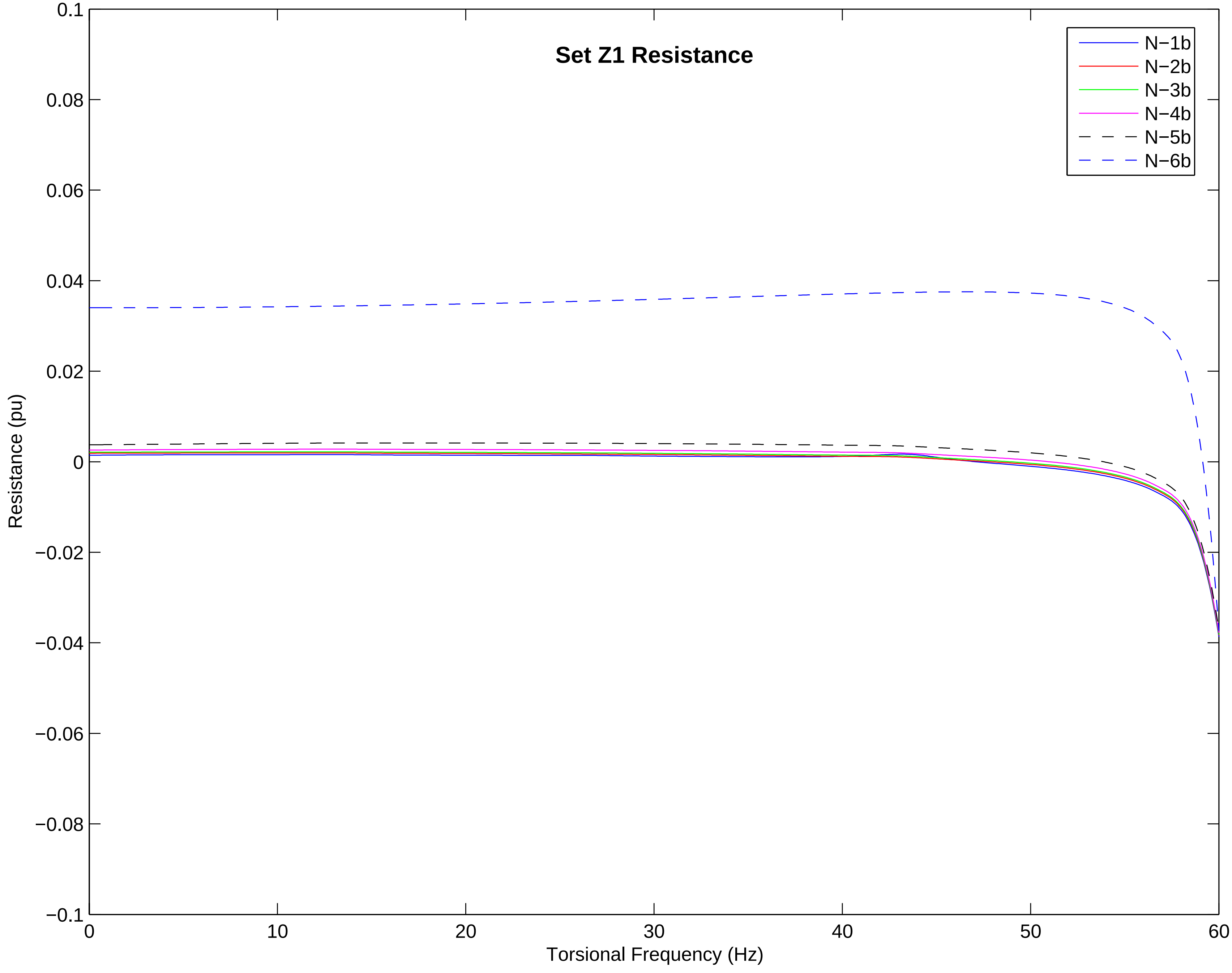


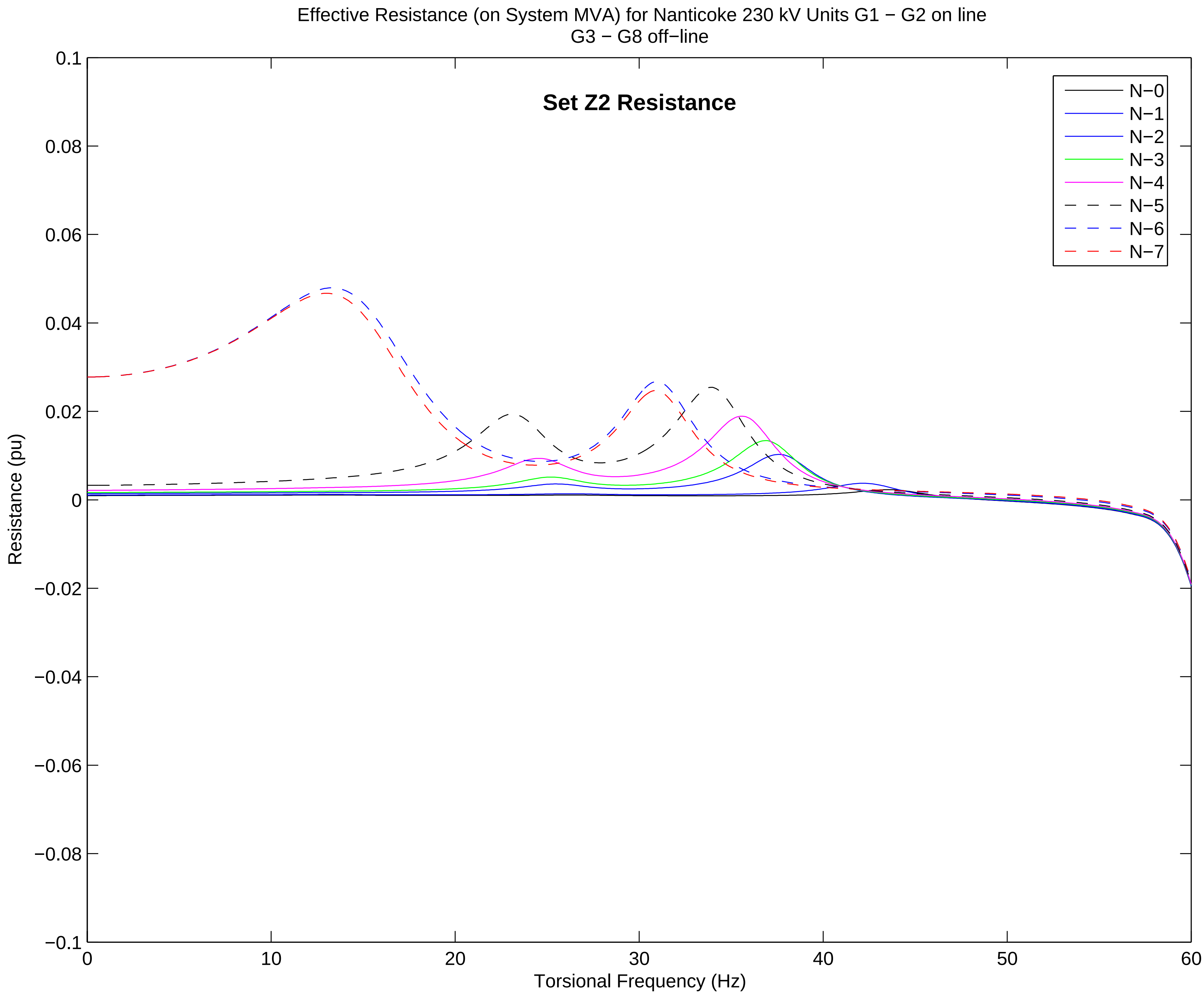


Effective Resistance (on System MVA) for Nanticoke 500 kV Units G7 & G8
All Units on−line
Set W Resistance
N−1a
N−2a
N−3a
N−4a
N−5a
N−7a
N−9a
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

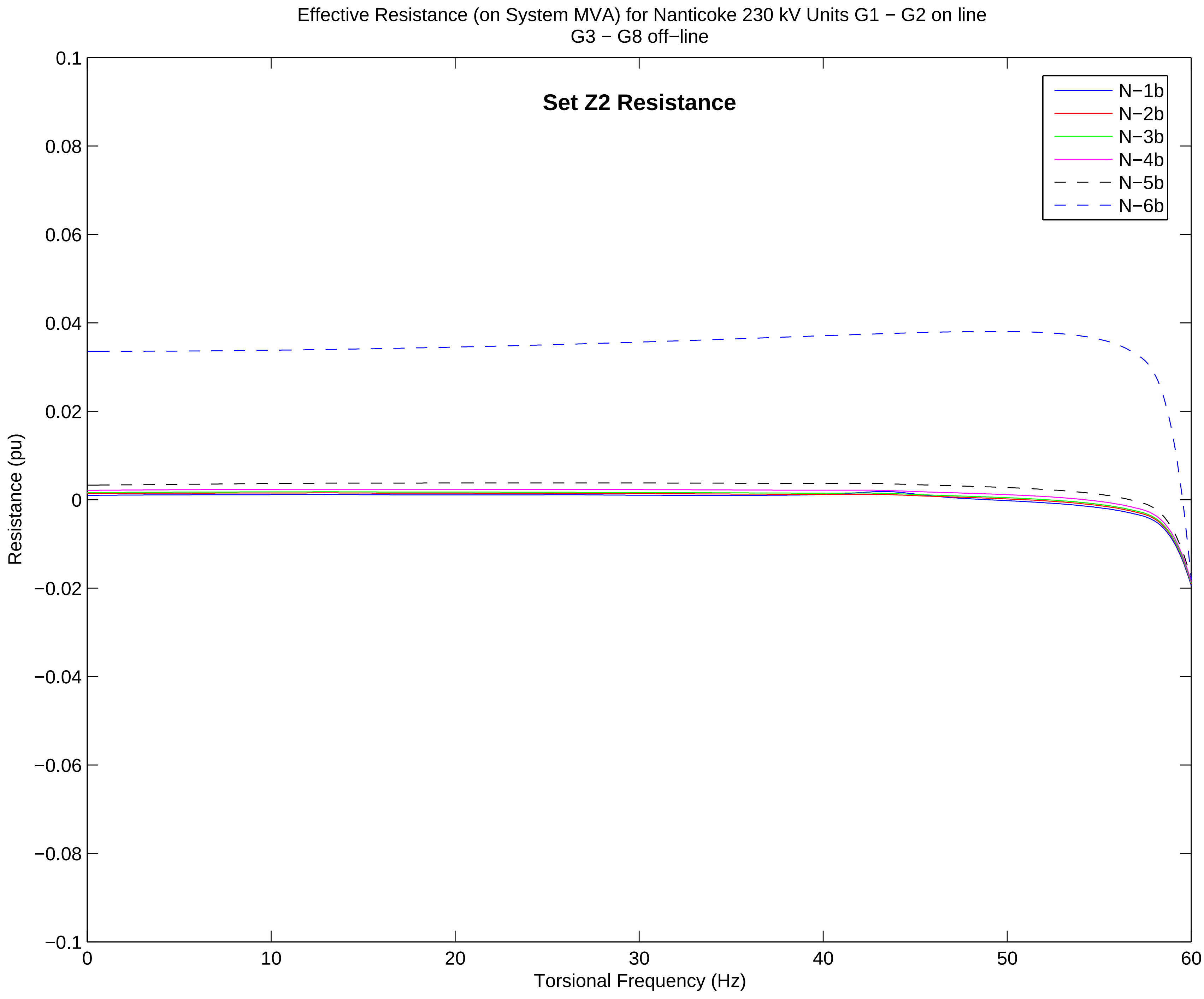

Effective Resistance (on System MVA) for Nanticoke 230 kV Units G1 on line
G2 − G8 off−line
Set Z1 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

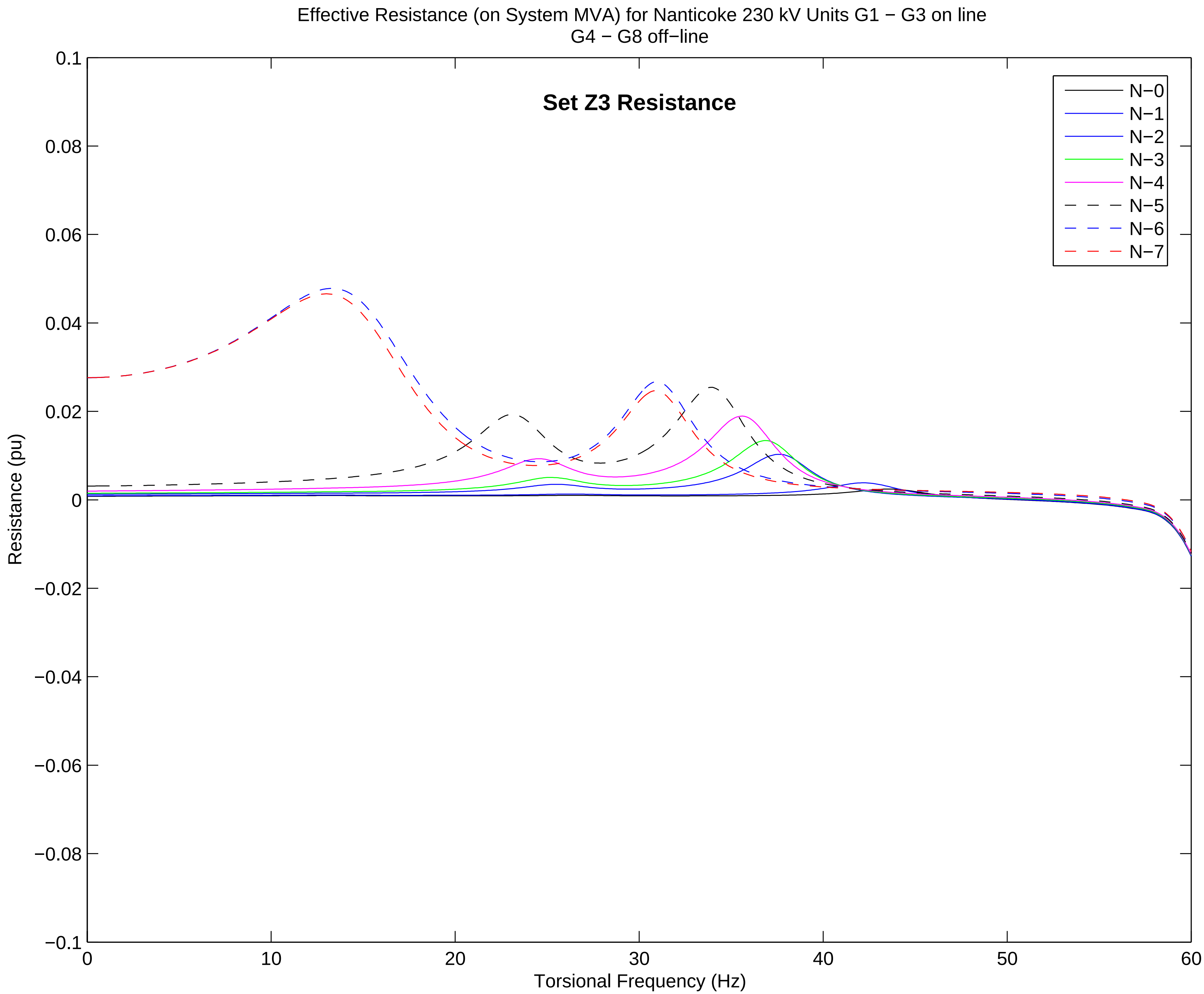
Effective Resistance (on System MVA) for Nanticoke 230 kV Units G1 on line
G2 − G8 off−line

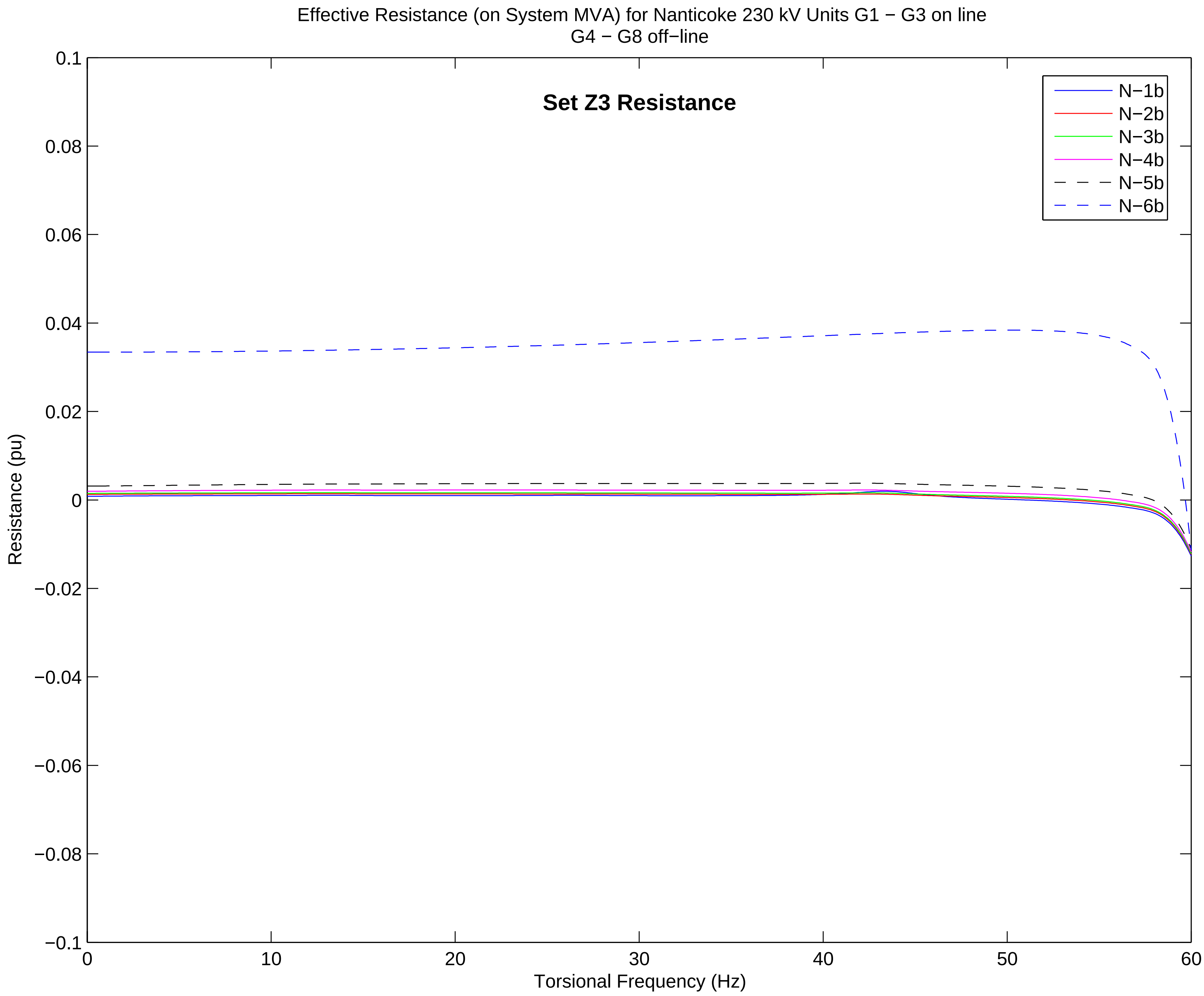




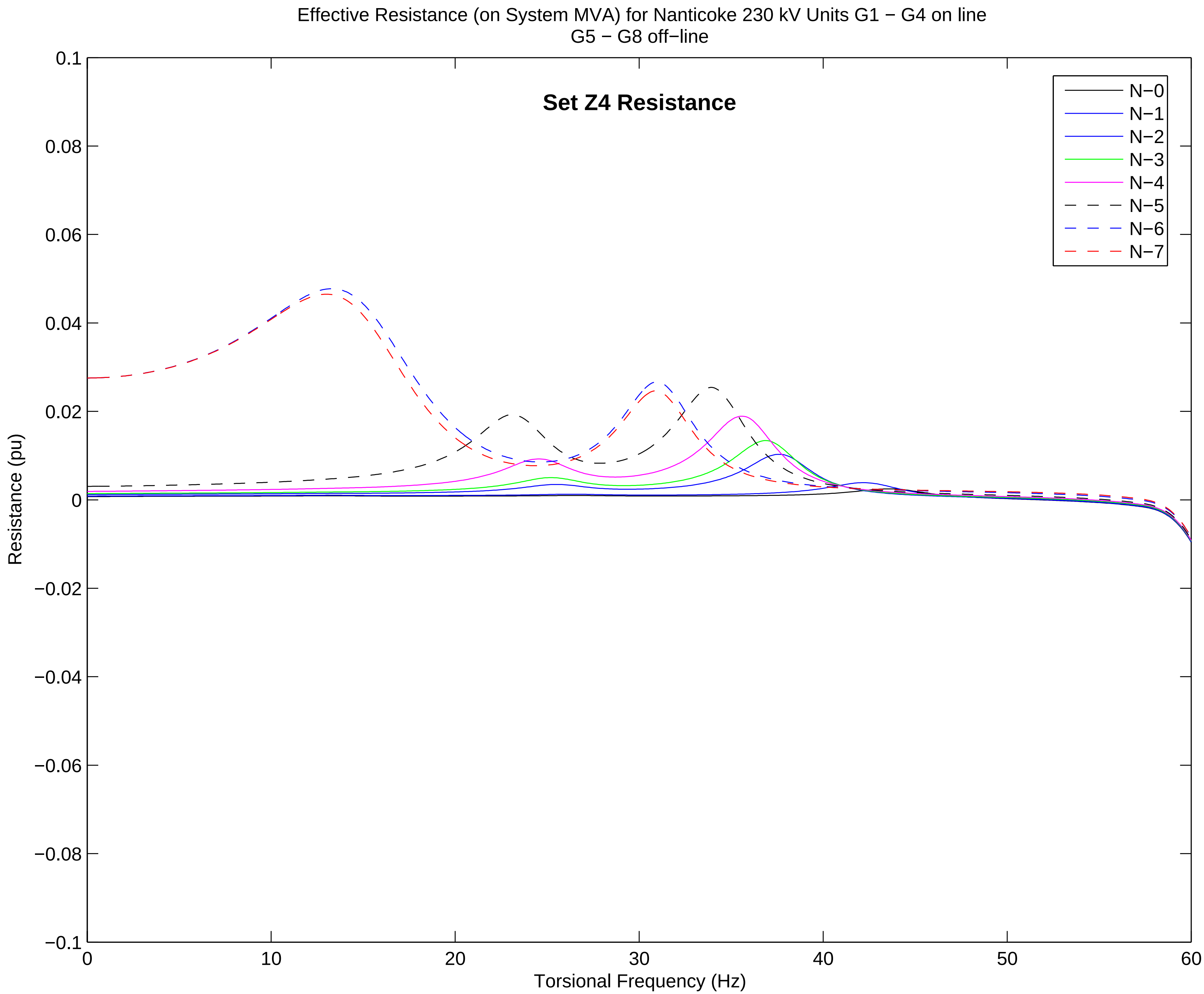
Effective Resistance (on System MVA) for Nanticoke 230 kV Units G1 − G2 on line
G3 − G8 off−line
Set Z2 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

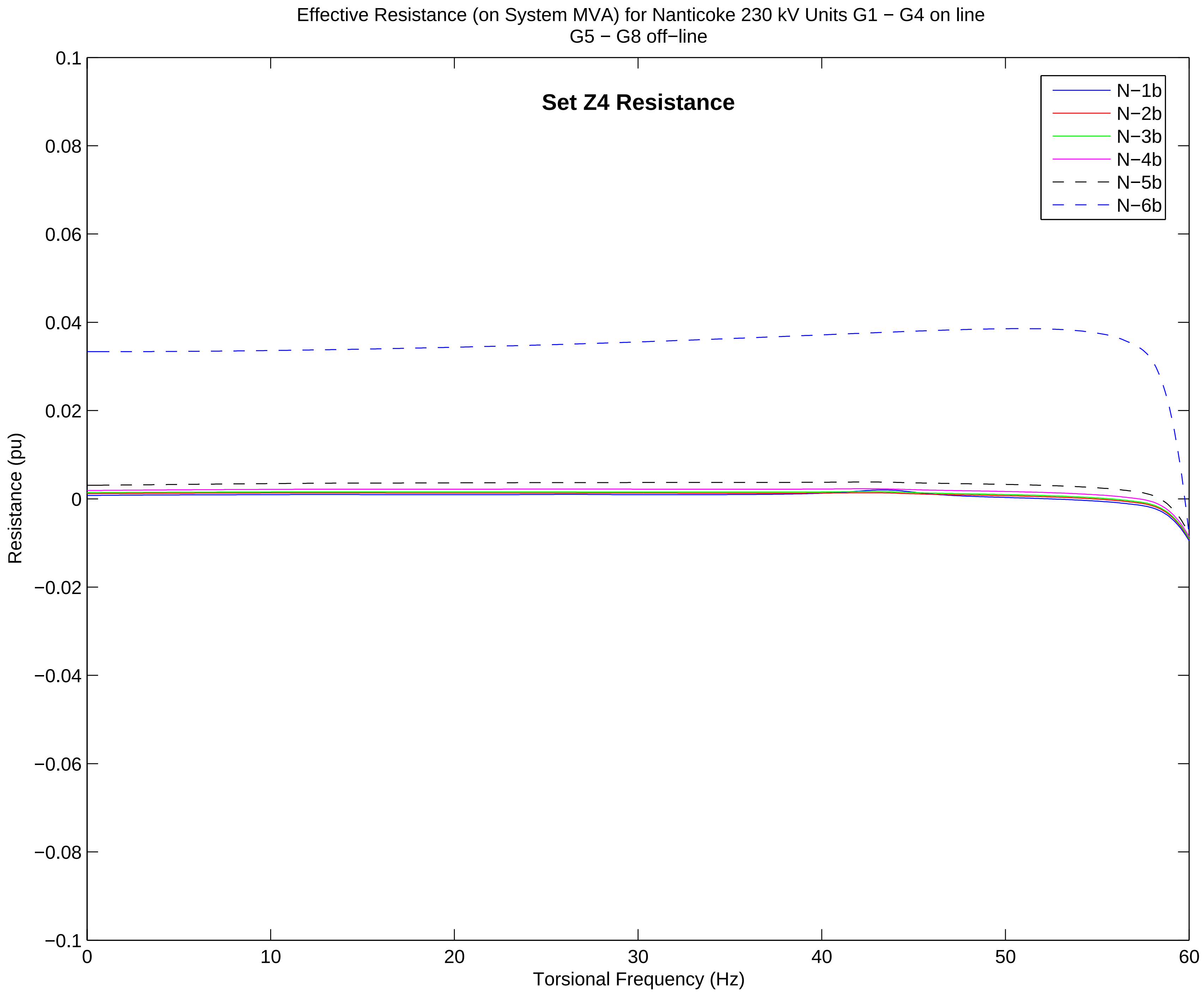

Effective Resistance (on System MVA) for Nanticoke 230 kV Units G1 − G2 on line
G3 − G8 off−line
Set Z2 Resistance
N−1b
N−2b
N−3b
N−4b
N−5b
N−6b
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Nanticoke 230 kV Units G1 − G3 on line
G4 − G8 off−line
Set Z3 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



Effective Resistance (on System MVA) for Nanticoke 230 kV Units G1 − G3 on line
G4 − G8 off−line
Set Z3 Resistance
N−1b
N−2b
N−3b
N−4b
N−5b
N−6b
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Nanticoke 230 kV Units G1 − G4 on line
G5 − G8 off−line
Set Z4 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
N−7
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



Effective Resistance (on System MVA) for Nanticoke 230 kV Units G1 − G4 on line
G5 − G8 off−line
Set Z4 Resistance
N−1b
N−2b
N−3b
N−4b
N−5b
N−6b
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

APPENDIX F: Lambton Frequency Scan

Appendix F – Lambton Frequency Scan

This appendix contains 1) the electrical damping plots and 2) the effective resistance plots for the Lambton generators. The electrical damping plots are provided first, ordered by generator combination (Set ID) as identified in Table F-1 below. The effective resistance plots are then provided in the same order.

Table F-1: Generator Combinations

	Lambton Generators			
Set ID	G1	G2	G3	G4
A1	√			
A2	√	√		
A3	√	√	√	
A4	√	√	√	√

√ - indicates the generator is in-service

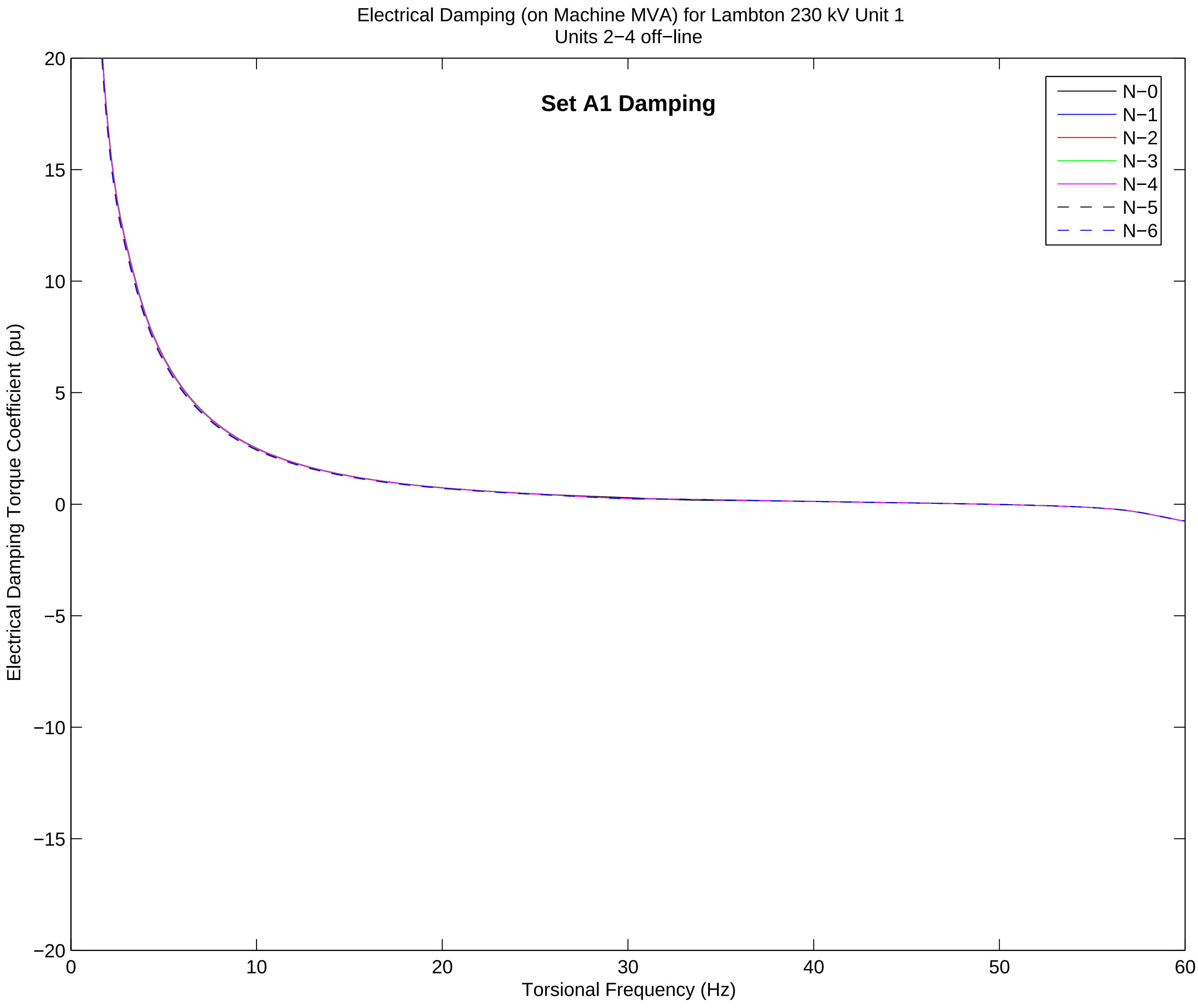
Table F-2: Contingency Descriptions

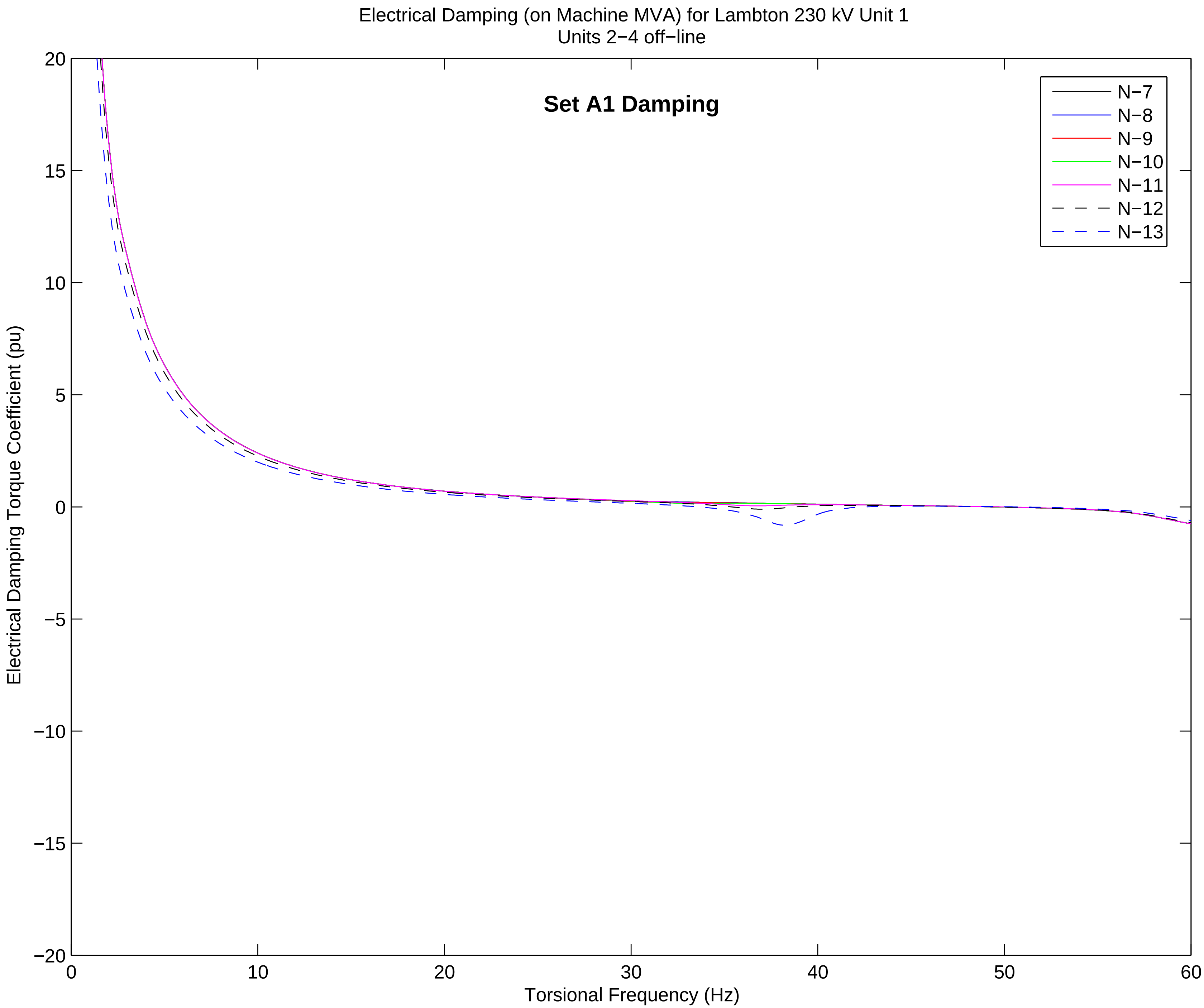
Contingency ID	Bruce A – Longwood 500kV Line	Bruce B – Longwood 500kV Line	Longwood – Nanticoke 500kV Line	Longwood – CowalJ44 230kV Line	Longwood – CowalJ45 230kV Line	Longwood – BuchJW42 230kV Line	Longwood – BuchJW43 230kV Line	Lambton 345kV/230kV Transformer #S4	Lambton 345kV/230kV Transformer #51	Lambton – LynwdJ28 230kV Line	Lambton – LynwdJ29 230kV Line	Lambton – NovaJL25 230kV Line	Lambton – NovaJL27 230kV Line	Lambton – TalfdJ23 230kV Line	Lambton 230kV/27.6kV Transformer
N-0															
N-1			X												
N-2			X												X
N-3			X											X	X
N-4			X										X	X	X
N-5			X									X	X	X	X
N-6			X								X	X	X	X	X
N-7			X							X	X	X	X	X	X
N-8			X				X			X	X	X	X	X	X
N-9			X			X	X			X	X	X	X	X	X
N-10			X		X	X	X			X	X	X	X	X	X
N-11			X	X	X	X	X			X	X	X	X	X	X
N-12			X	X	X	X	X		X	X	X	X	X	X	X
N-13			X	X	X	X	X	X	X	X	X	X	X	X	X
N-2a	X	X													
N-3a	X	X													X
N-4a	X	X												X	X
N-5a	X	X											X	X	X
N-6a	X	X										X	X	X	X
N-7a	X	X									X	X	X	X	X
N-8a	X	X								X	X	X	X	X	X

(continued below)

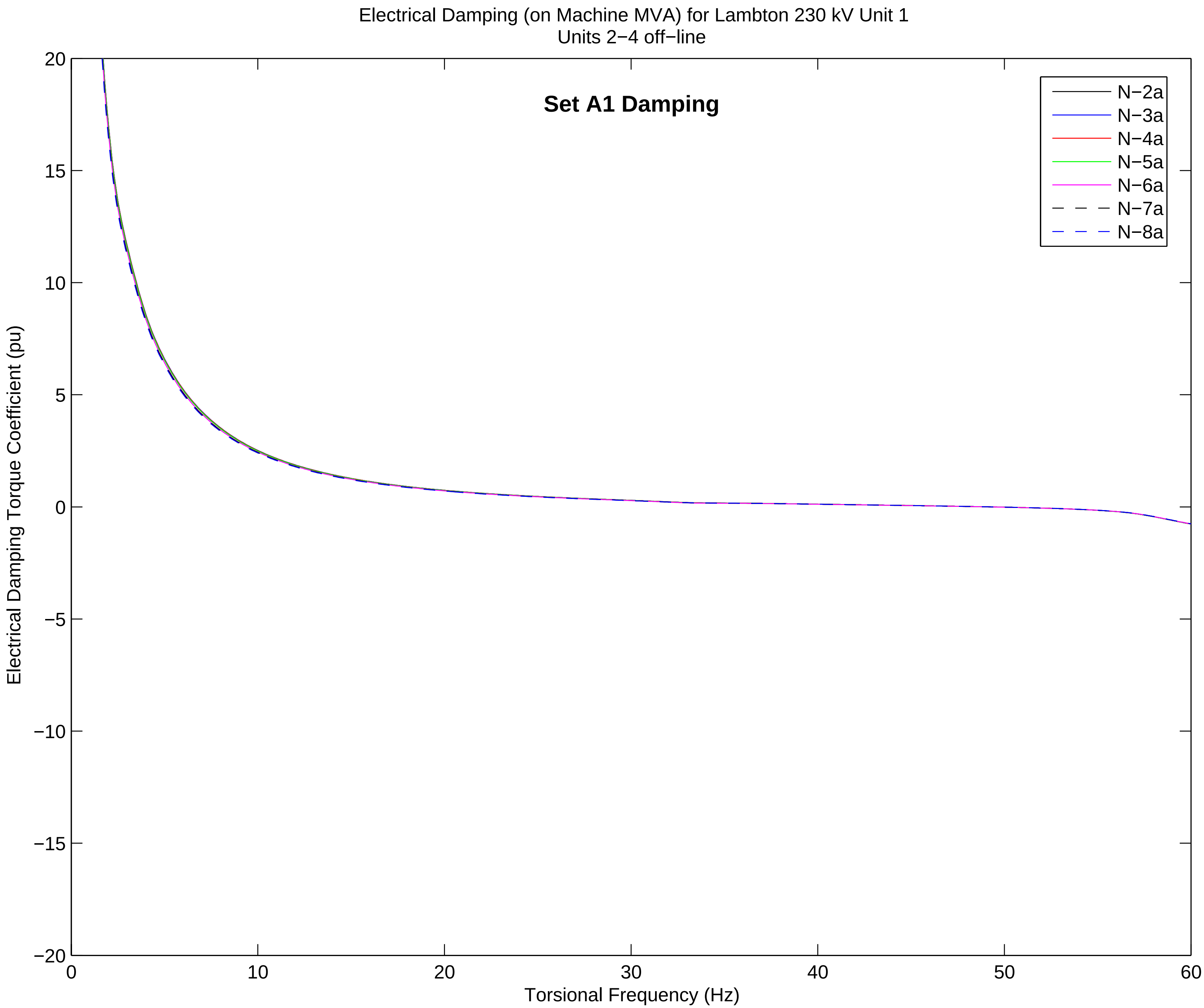
Contingency ID	Bruce A – Longwood 500kV Line	Bruce B – Longwood 500kV Line	Longwood – Nanticoke 500kV Line	Longwood – CowalJ44 230kV Line	Longwood – CowalJ45 230kV Line	Longwood – BuchJW42 230kV Line	Longwood – BuchJW43 230kV Line	Lambton 345kV/230kV Transformer #S4	Lambton 345kV/230kV Transformer #51	Lambton – LynwdJ28 230kV Line	Lambton – LynwdJ29 230kV Line	Lambton – NovaJL25 230kV Line	Lambton – NovaJL27 230kV Line	Lambton – TalfdJ23 230kV Line	Lambton 230kV/27.6kV Transformer
N-9a	X	X					X			X	X	X	X	X	X
N-10a	X	X				X	X			X	X	X	X	X	X
N-11a	X	X			X	X	X			X	X	X	X	X	X
N-12a	X	X		X	X	X	X			X	X	X	X	X	X
N-13a	X	X		X	X	X	X		X	X	X	X	X	X	X
N-14a	X	X		X	X	X	X	X	X	X	X	X	X	X	X
N-13b	X			X	X	X	X	X	X	X	X	X	X	X	X
N-13c		X		X	X	X	X	X	X	X	X	X	X	X	X

X – indicates the branch is out-of-service


Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1
Units 2−4 off−line
Set A1 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)

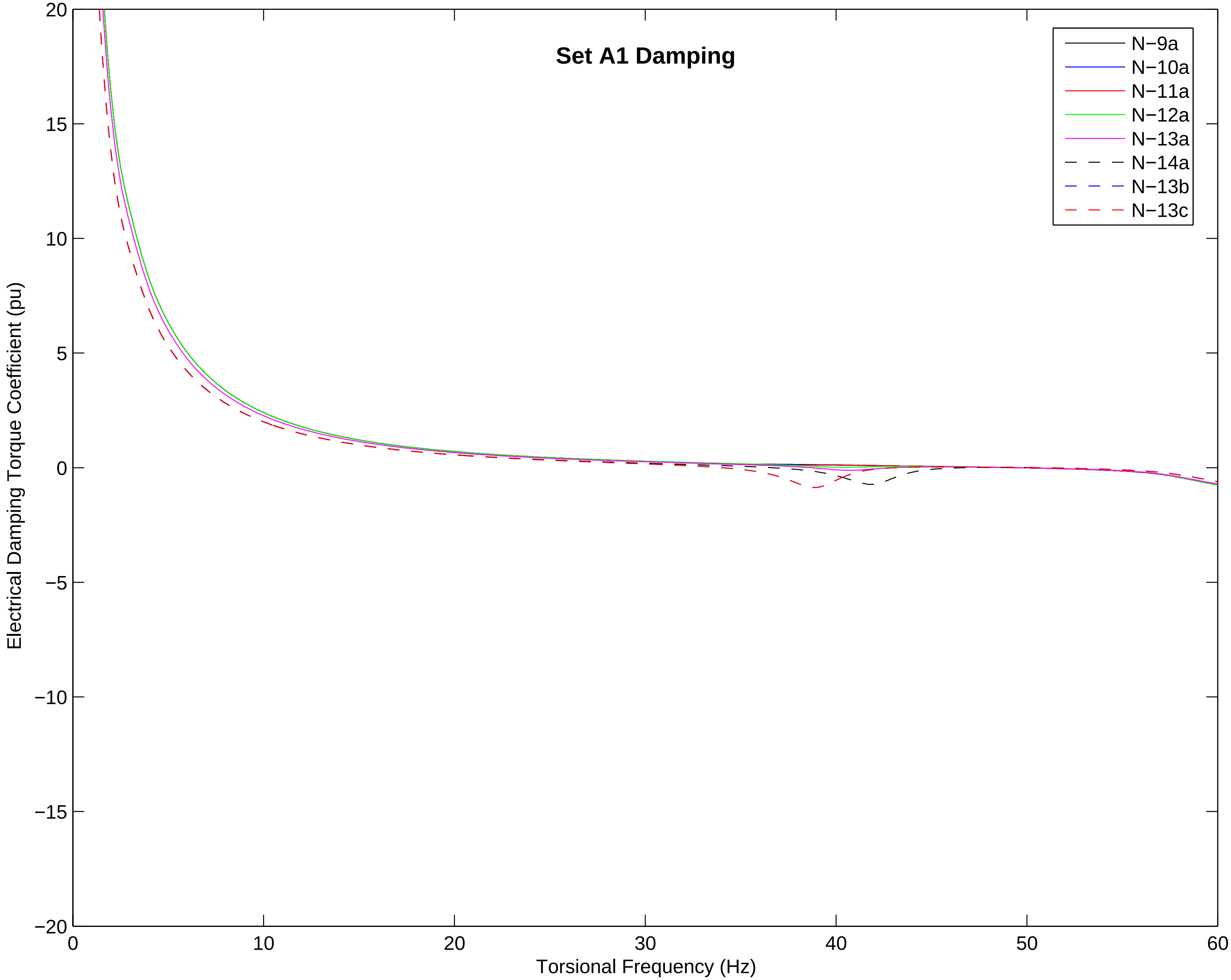


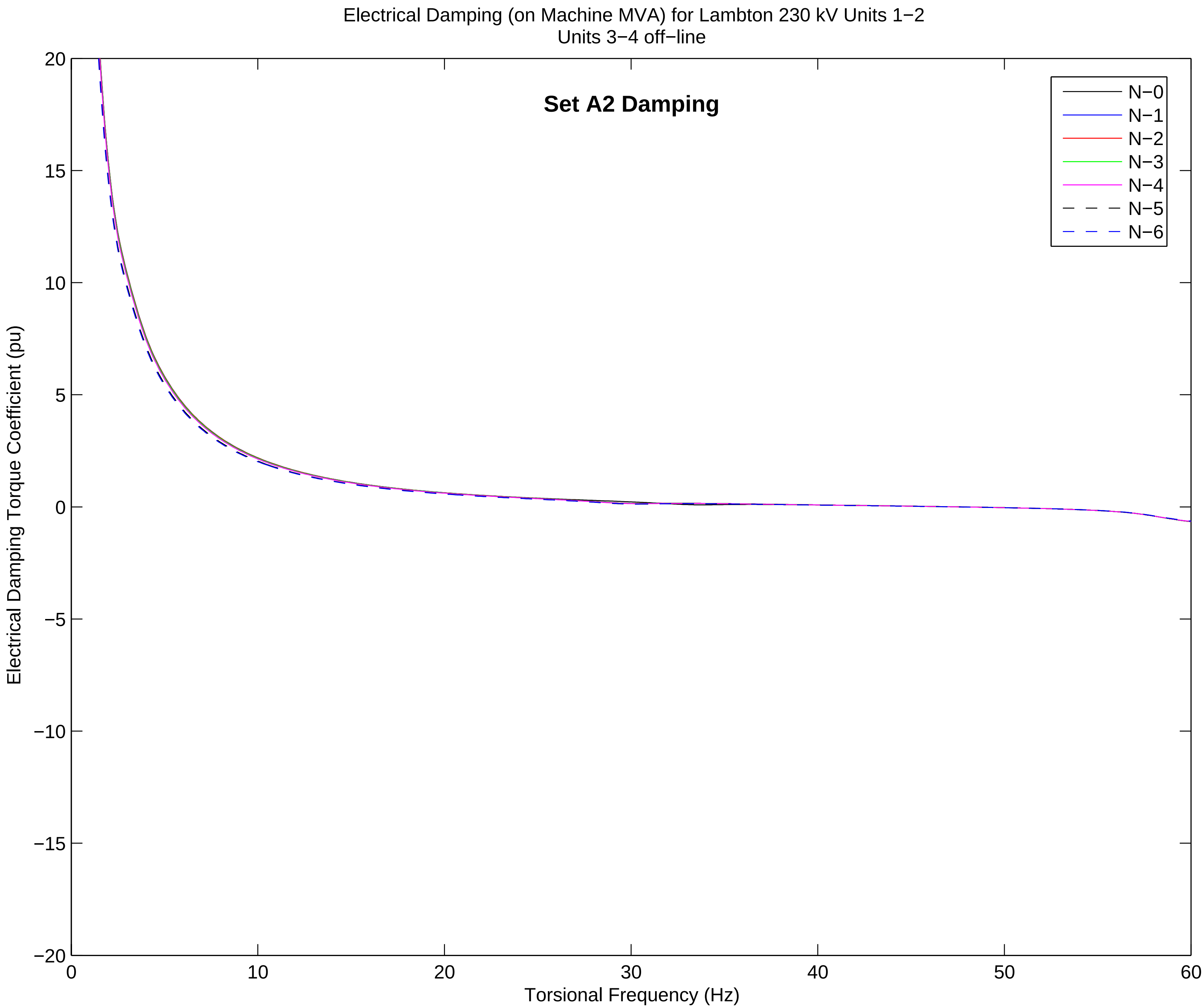
Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1
Units 2−4 off−line
Set A1 Damping
N−7
N−8
N−9
N−10
N−11
N−12
N−13
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

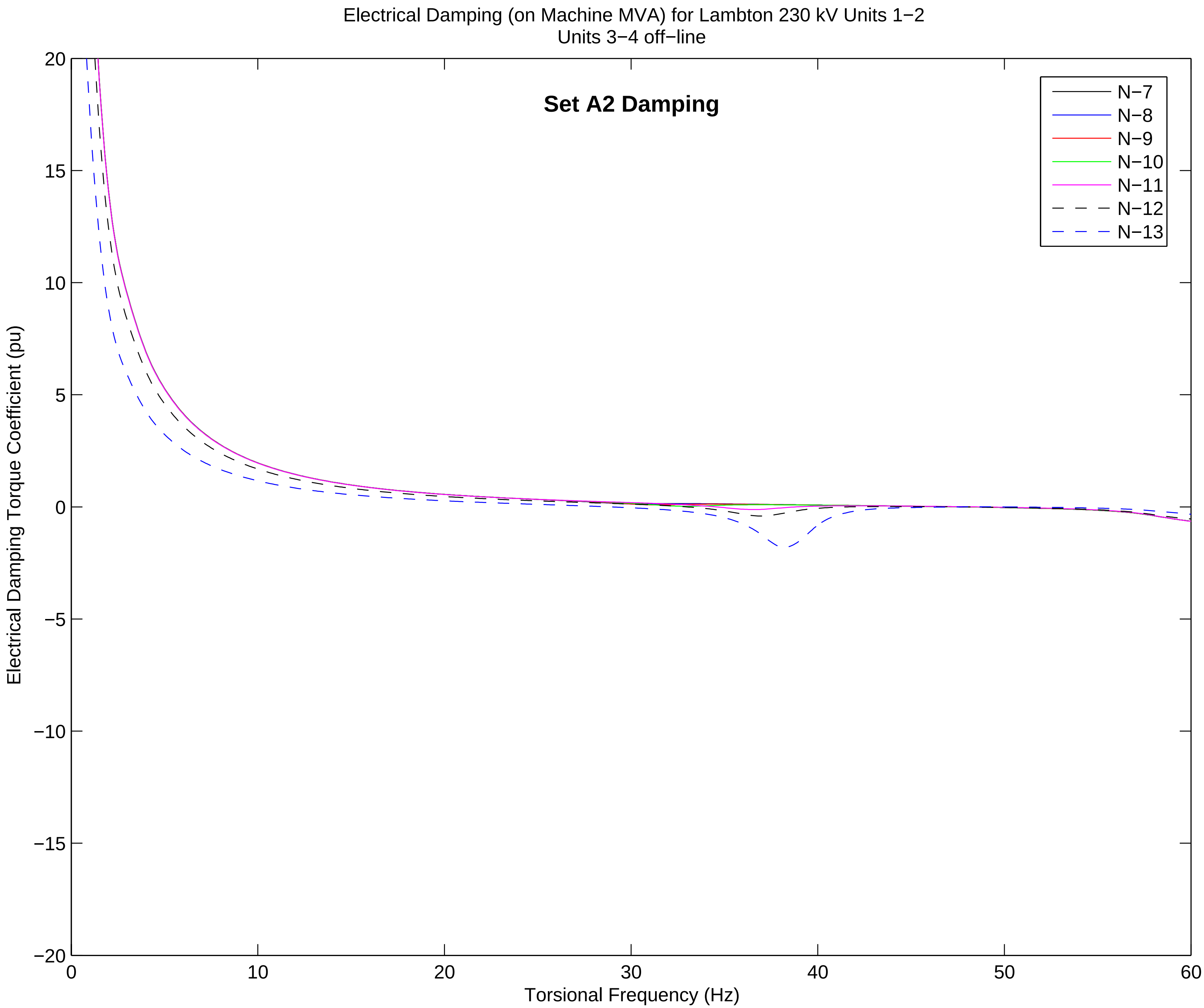


Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1
Units 2−4 off−line
Set A1 Damping
N−2a
N−3a
N−4a
N−5a
N−6a
N−7a
N−8a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

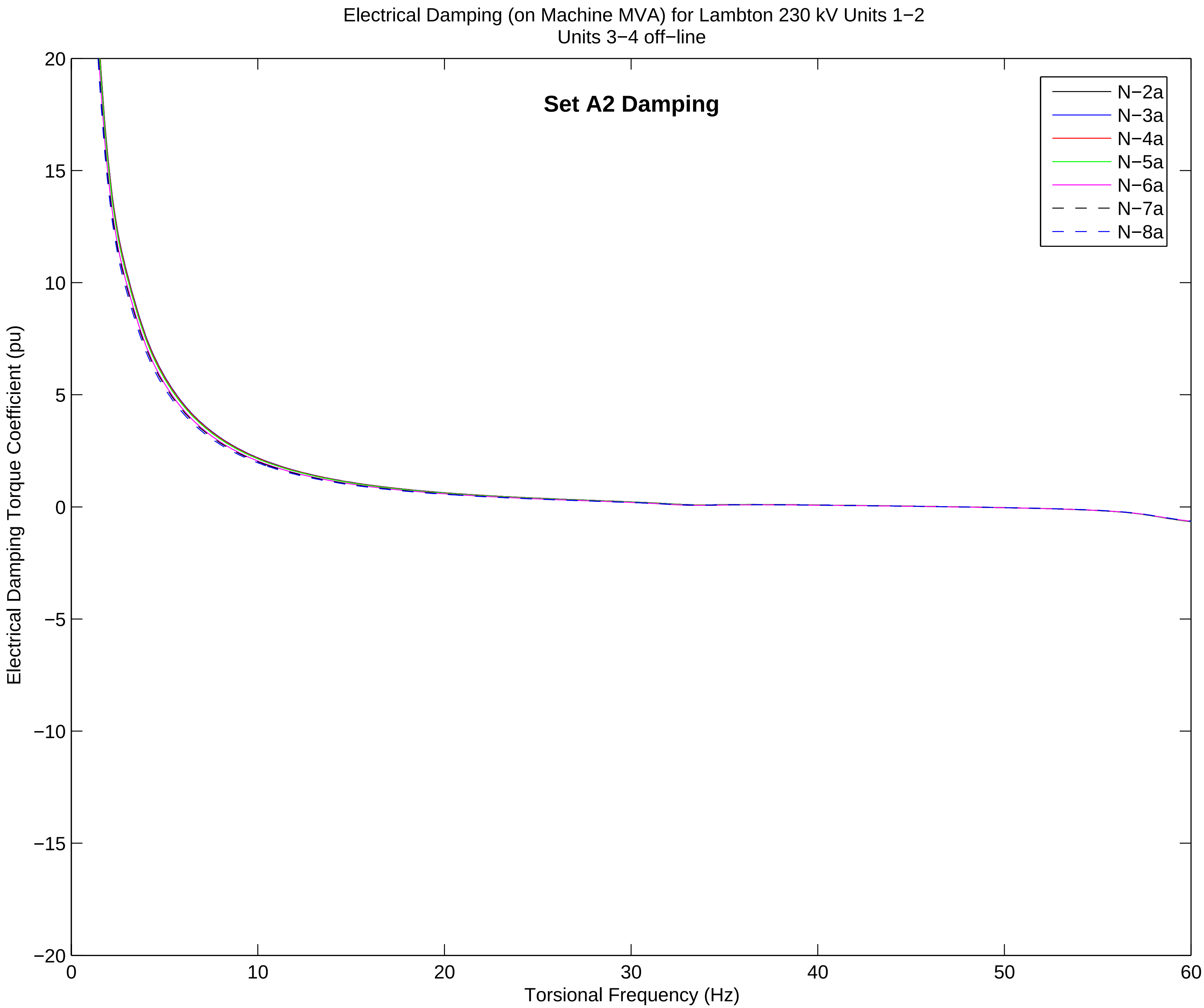
Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1
Units 2−4 off−line



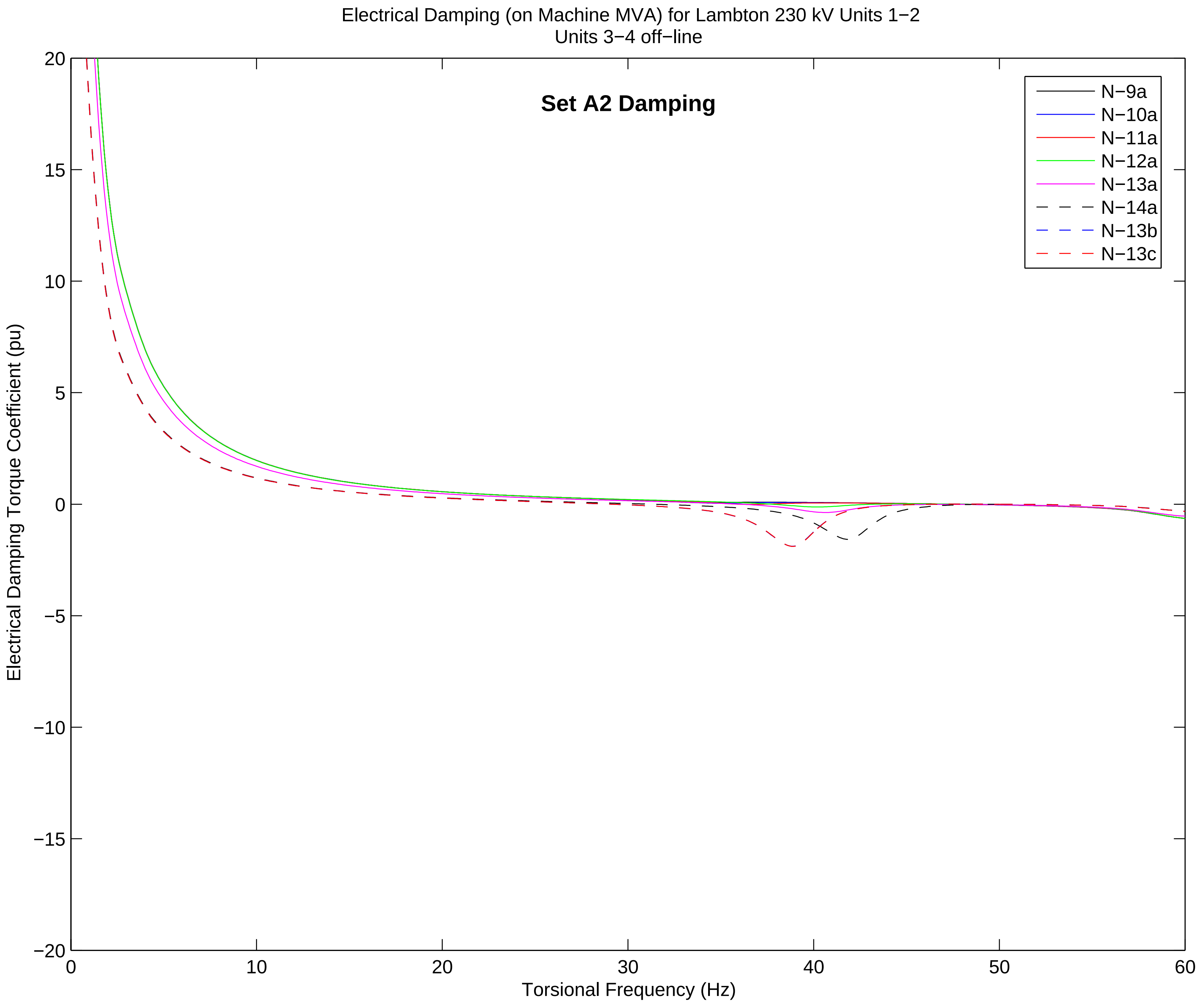

Electrical Damping (on Machine MVA) for Lambton 230 kV Units 1−2
Units 3−4 off−line
Set A2 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

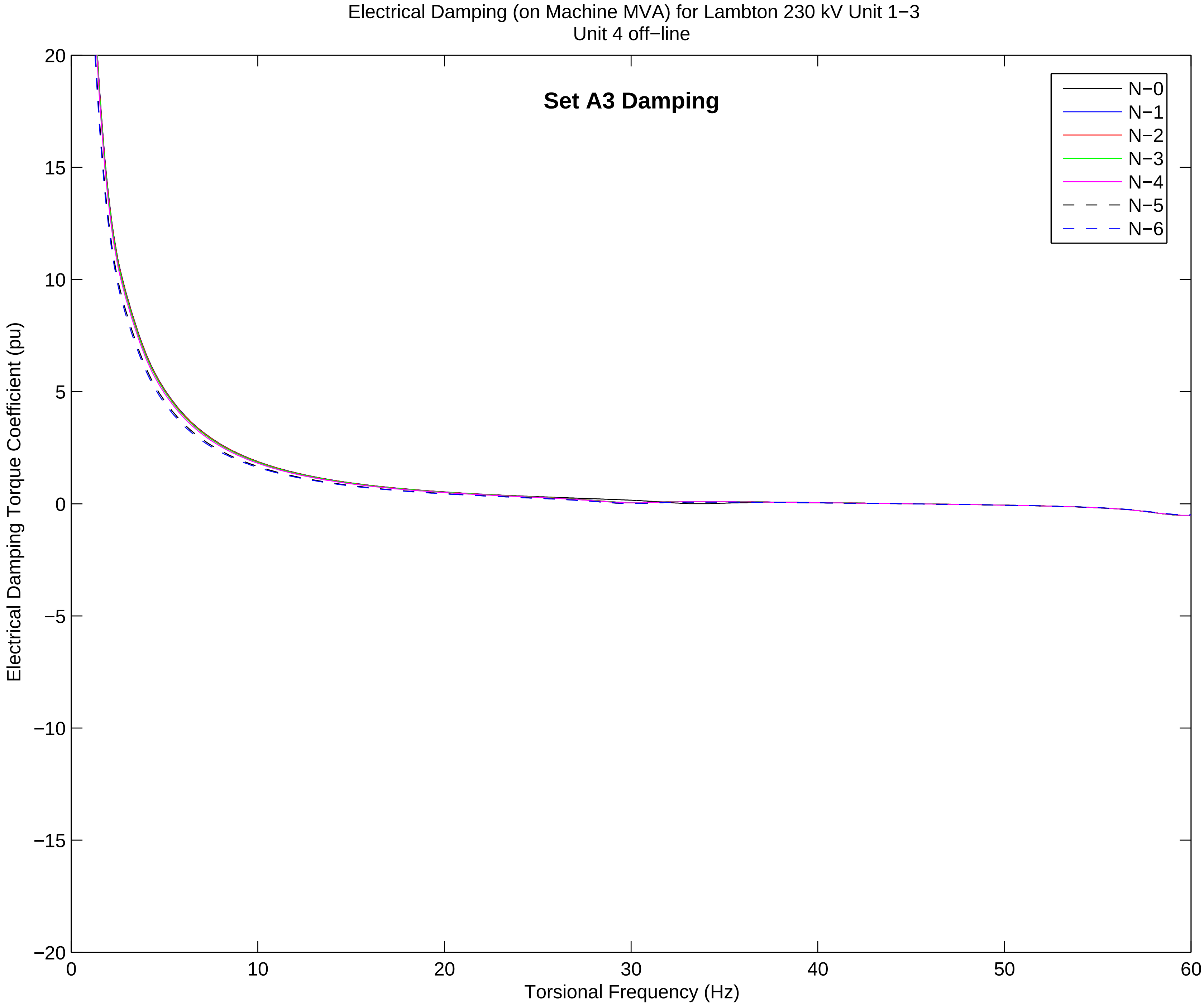


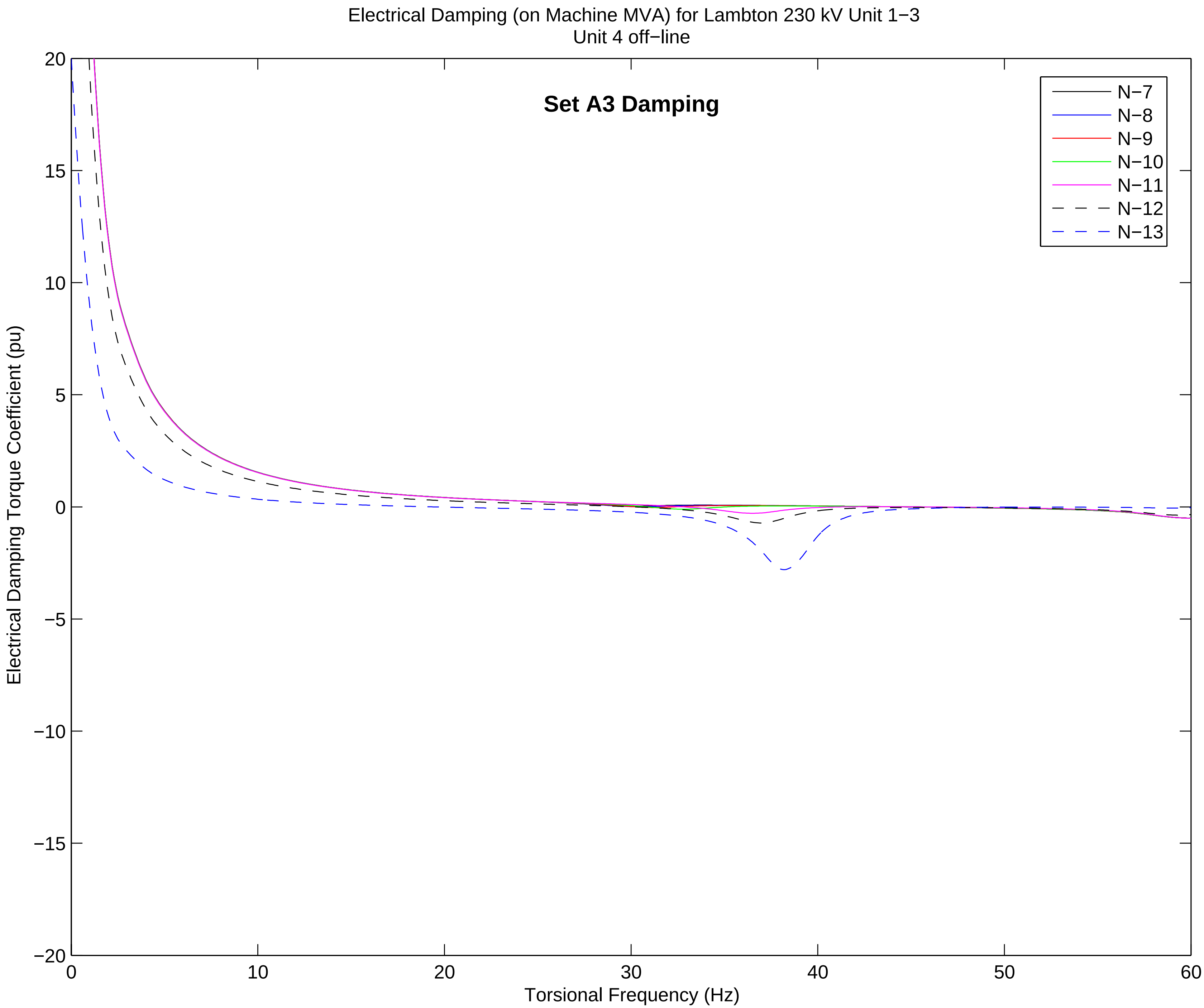
Electrical Damping (on Machine MVA) for Lambton 230 kV Units 1−2
Units 3−4 off−line
Set A2 Damping
N−7
N−8
N−9
N−10
N−11
N−12
N−13
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



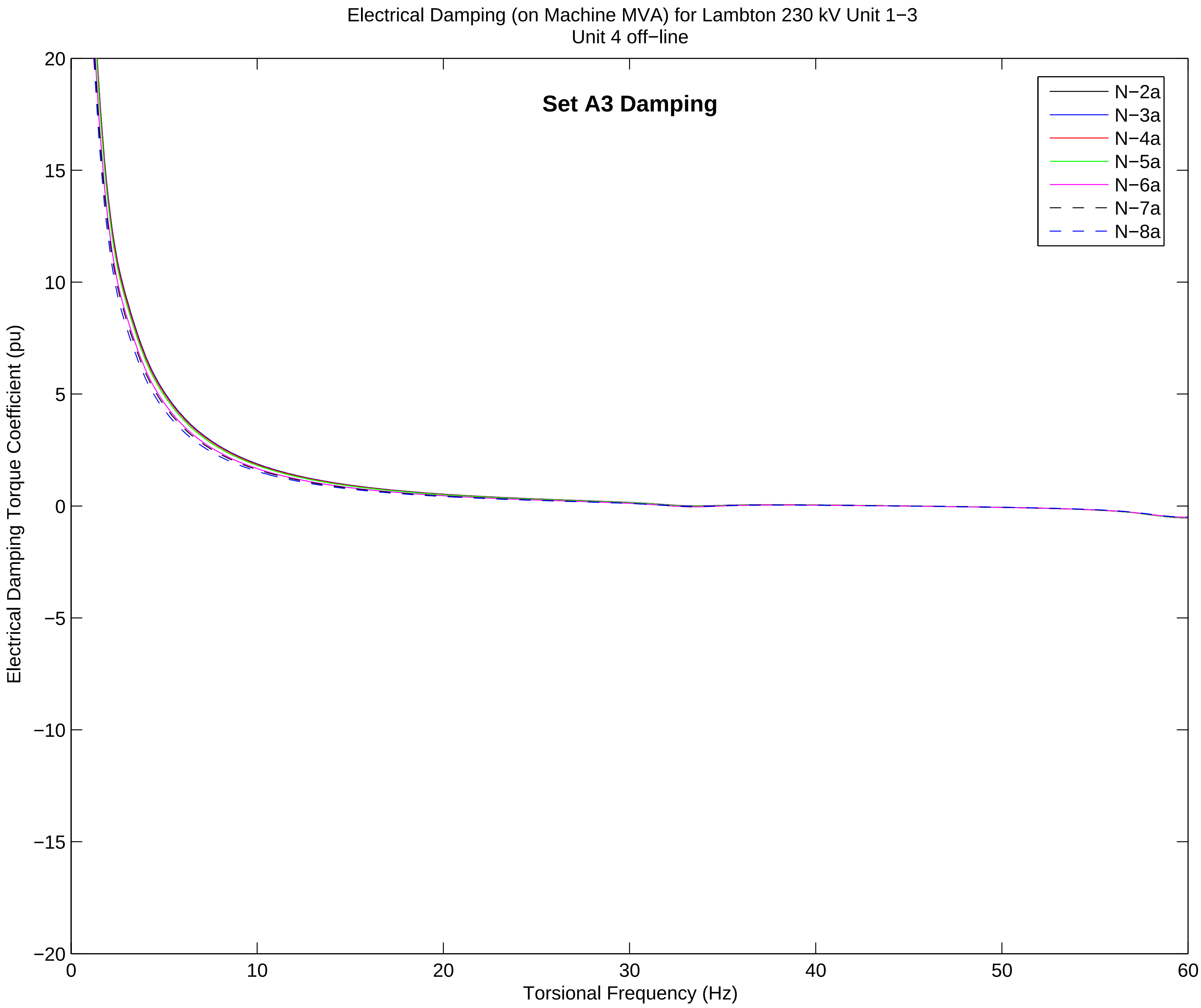
Electrical Damping (on Machine MVA) for Lambton 230 kV Units 1−2
Units 3−4 off−line
Set A2 Damping
N−2a
N−3a
N−4a
N−5a
N−6a
N−7a
N−8a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

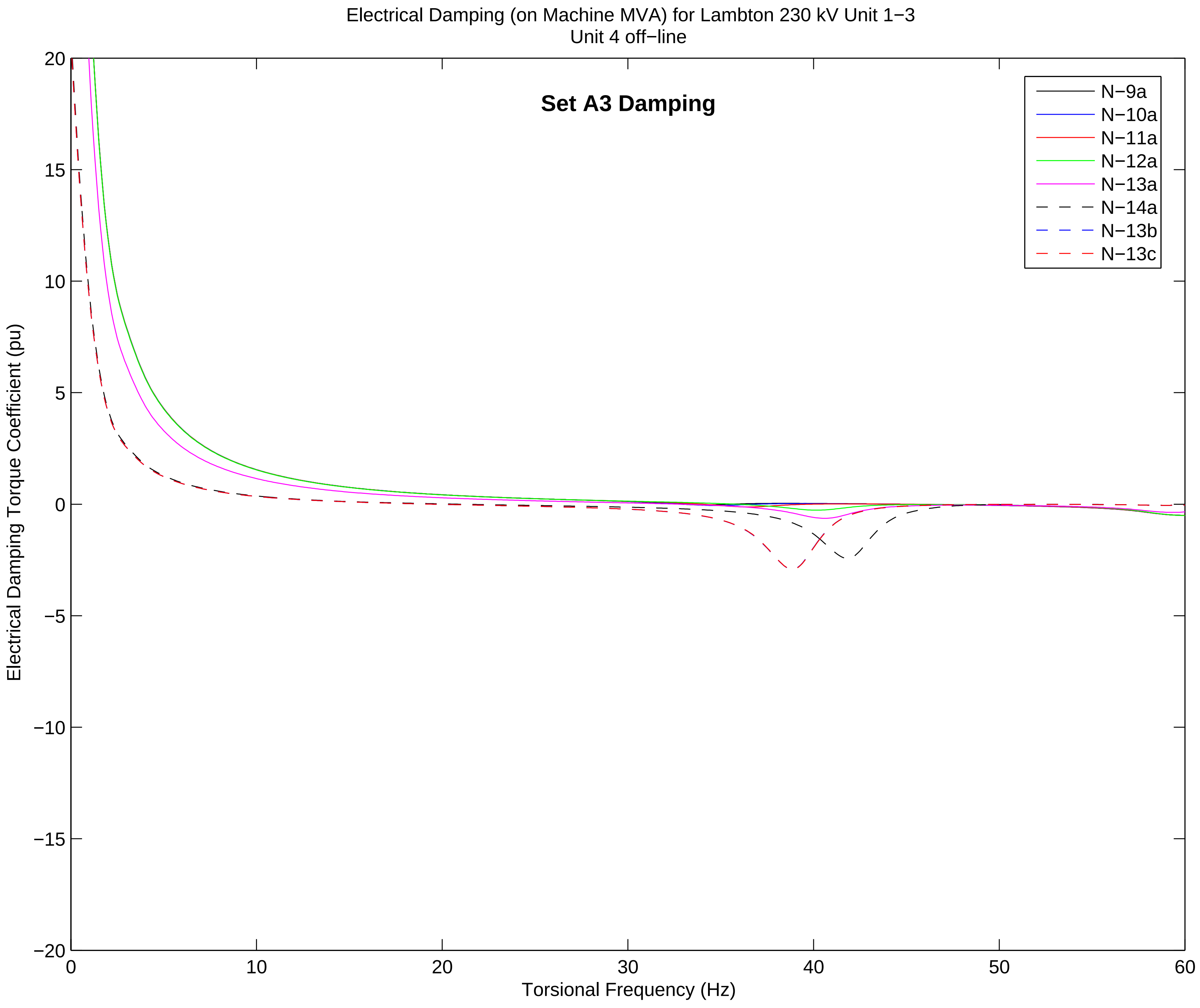

Electrical Damping (on Machine MVA) for Lambton 230 kV Units 1−2
Units 3−4 off−line
Set A2 Damping
N−9a
N−10a
N−11a
N−12a
N−13a
N−14a
N−13b
N−13c
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

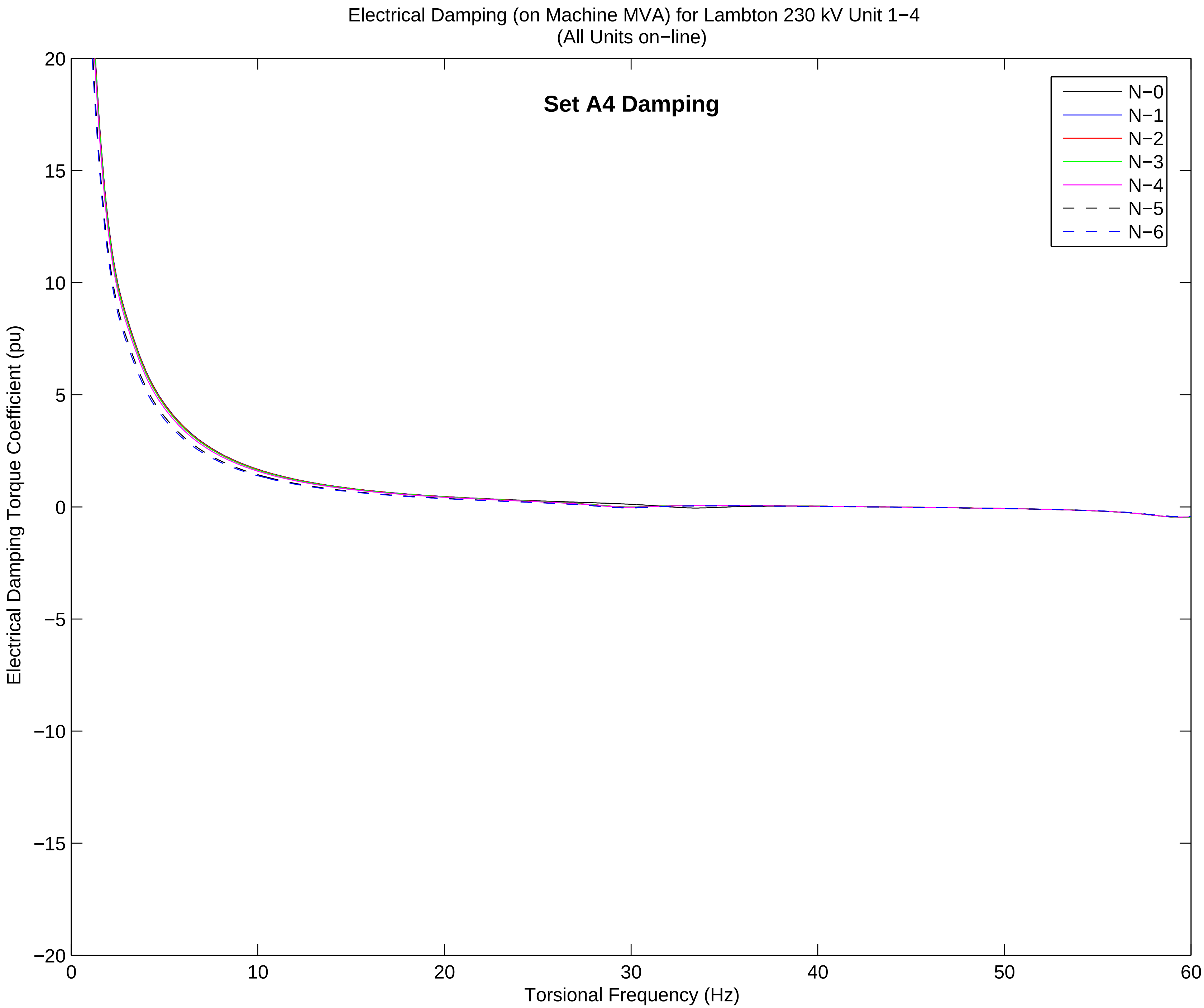

Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1−3
Unit 4 off−line
Set A3 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

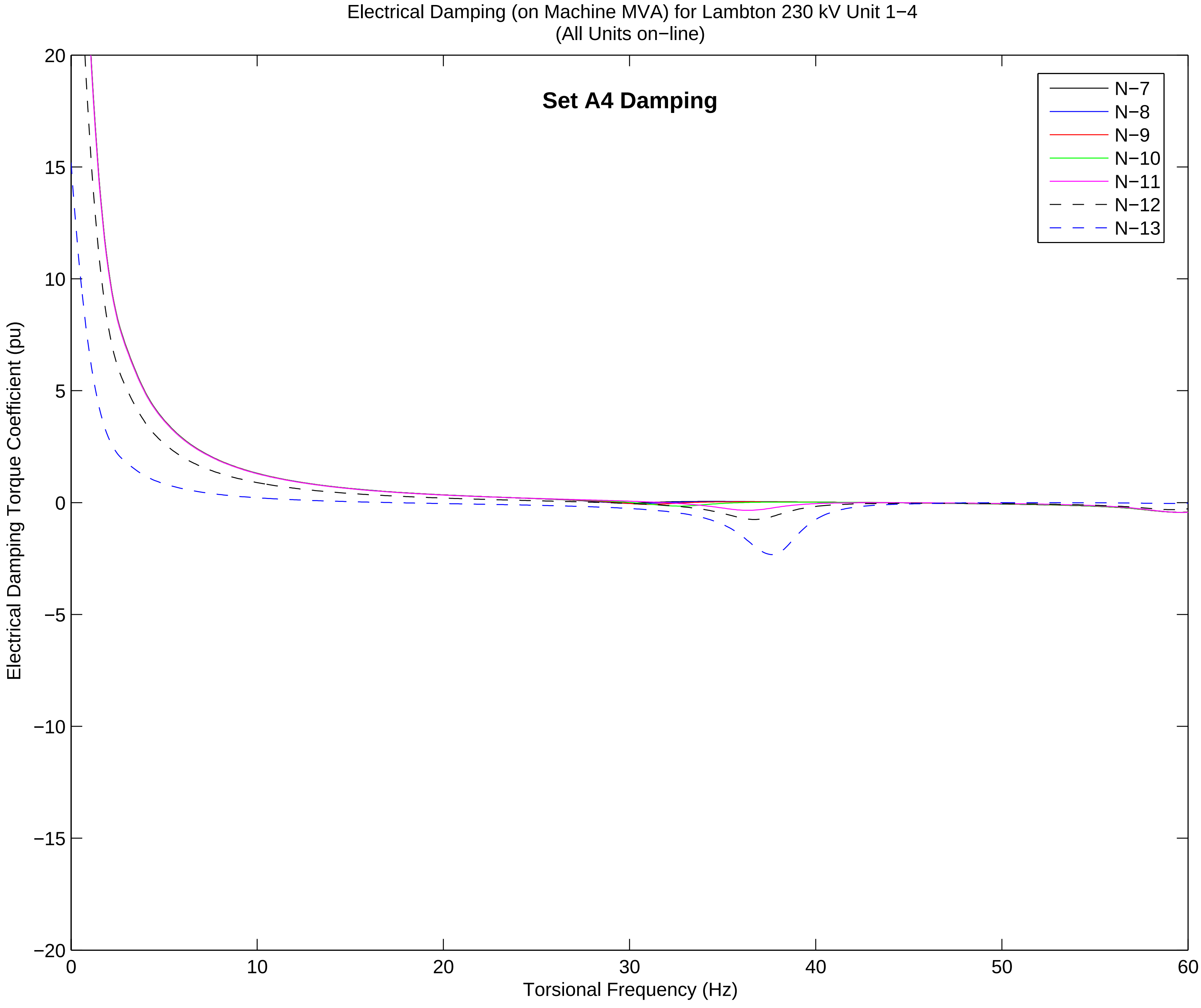


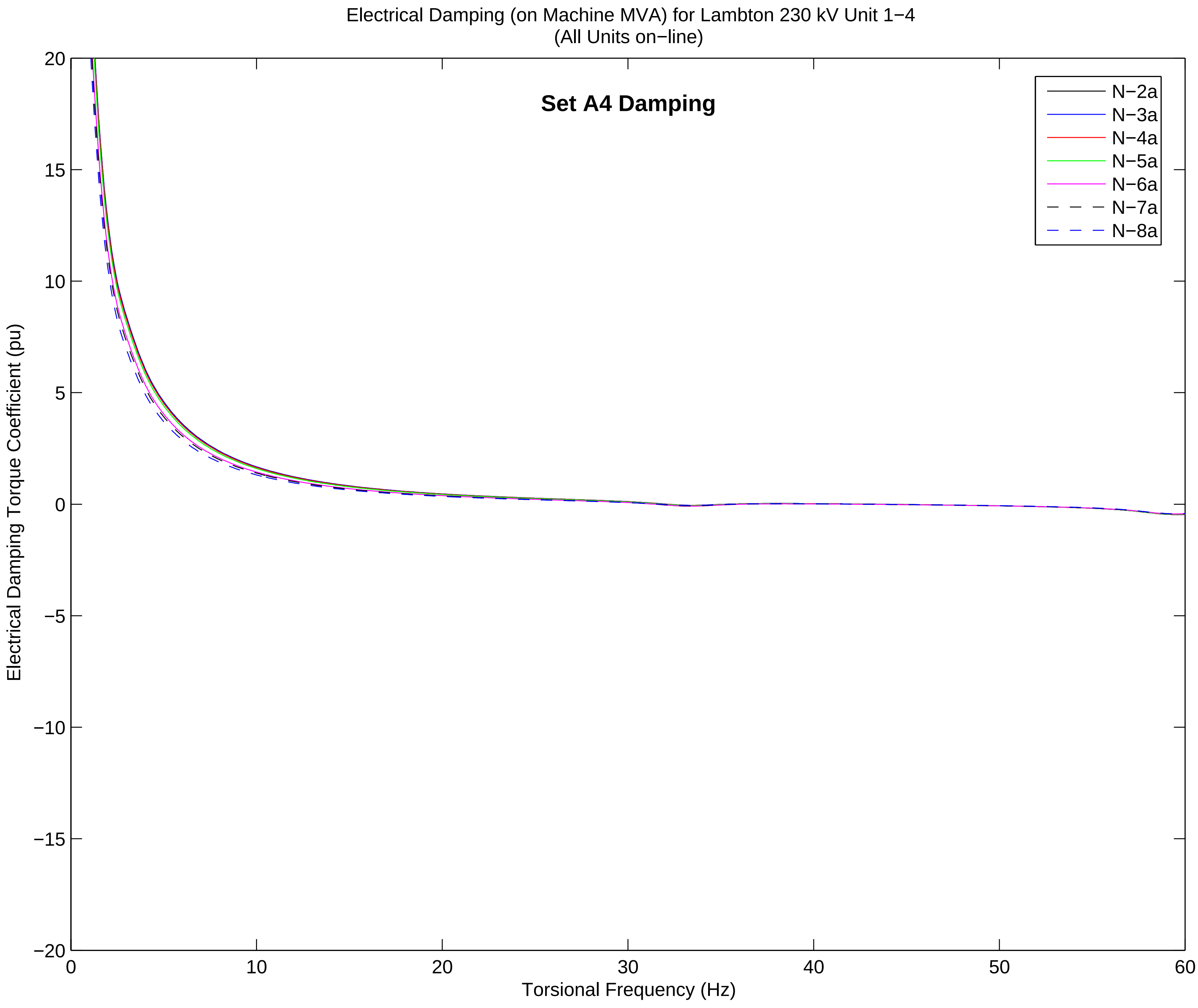
Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1−3
Unit 4 off−line
Set A3 Damping
N−7
N−8
N−9
N−10
N−11
N−12
N−13
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1−3
Unit 4 off−line
Set A3 Damping
N−2a
N−3a
N−4a
N−5a
N−6a
N−7a
N−8a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

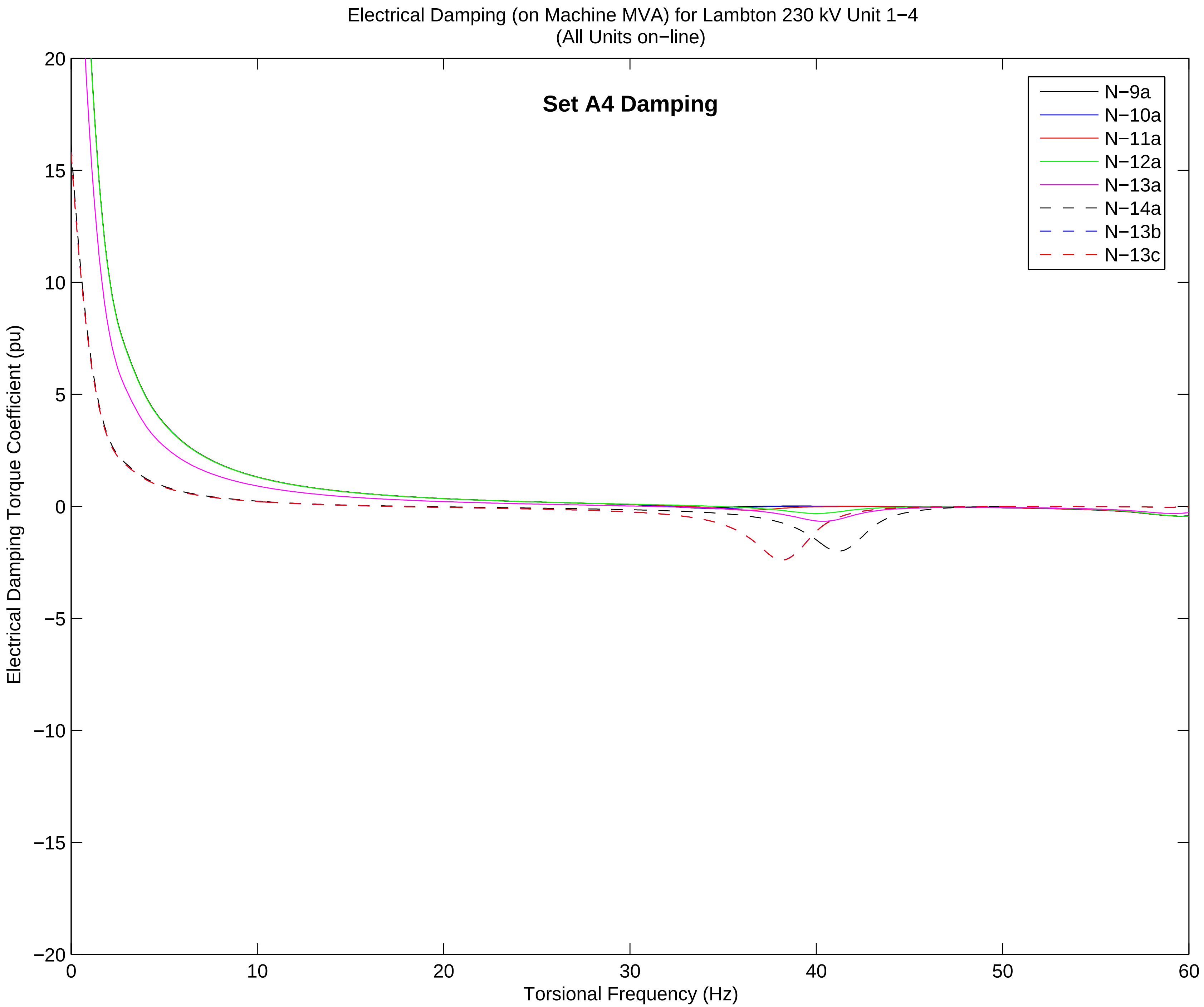

Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1−3
Unit 4 off−line
Set A3 Damping
N−9a
N−10a
N−11a
N−12a
N−13a
N−14a
N−13b
N−13c
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1−4
(All Units on−line)
Set A4 Damping
N−0
N−1
N−2
N−3
N−4
N−5
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

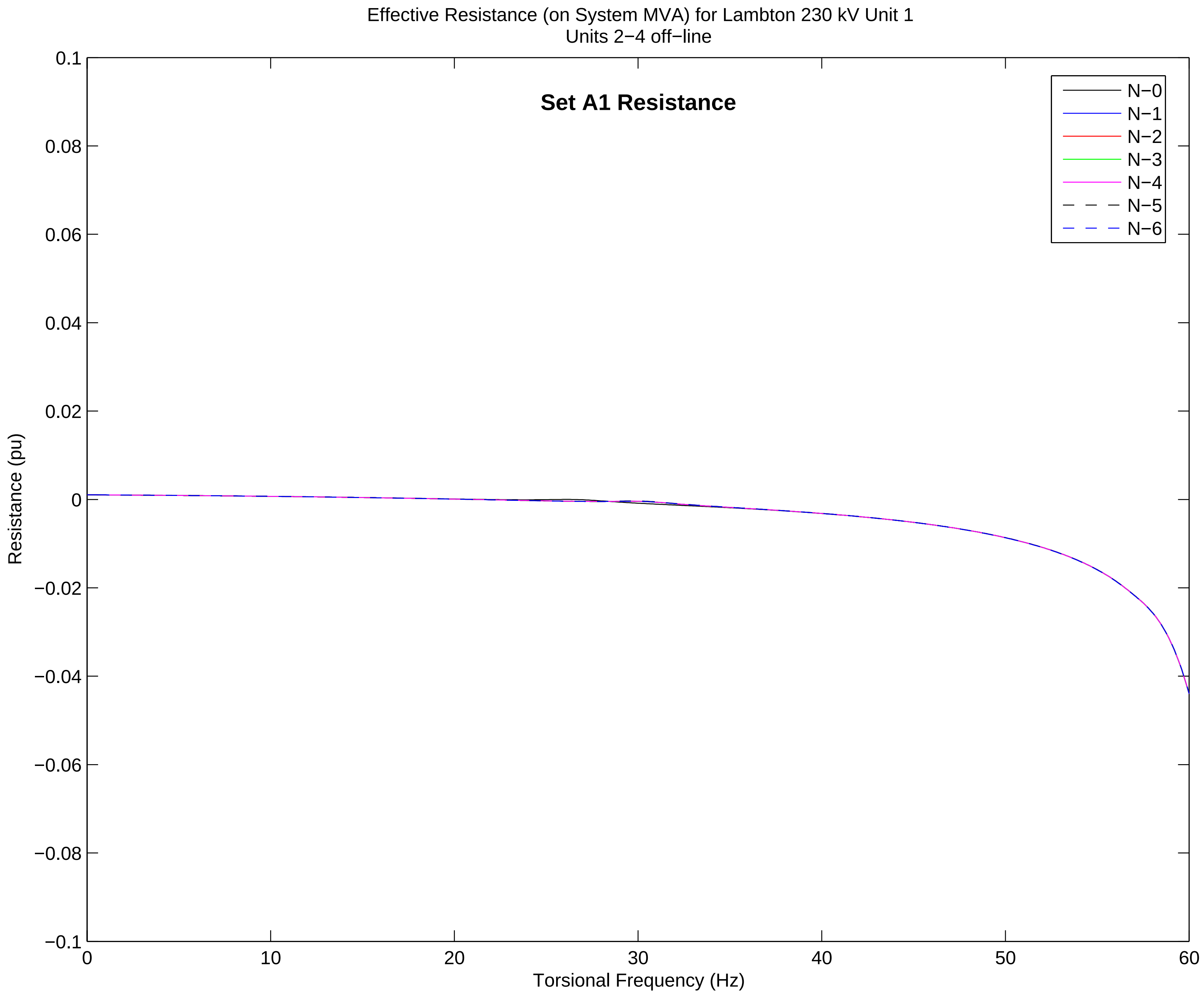

Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1−4
(All Units on−line)
Set A4 Damping
N−7
N−8
N−9
N−10
N−11
N−12
N−13
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

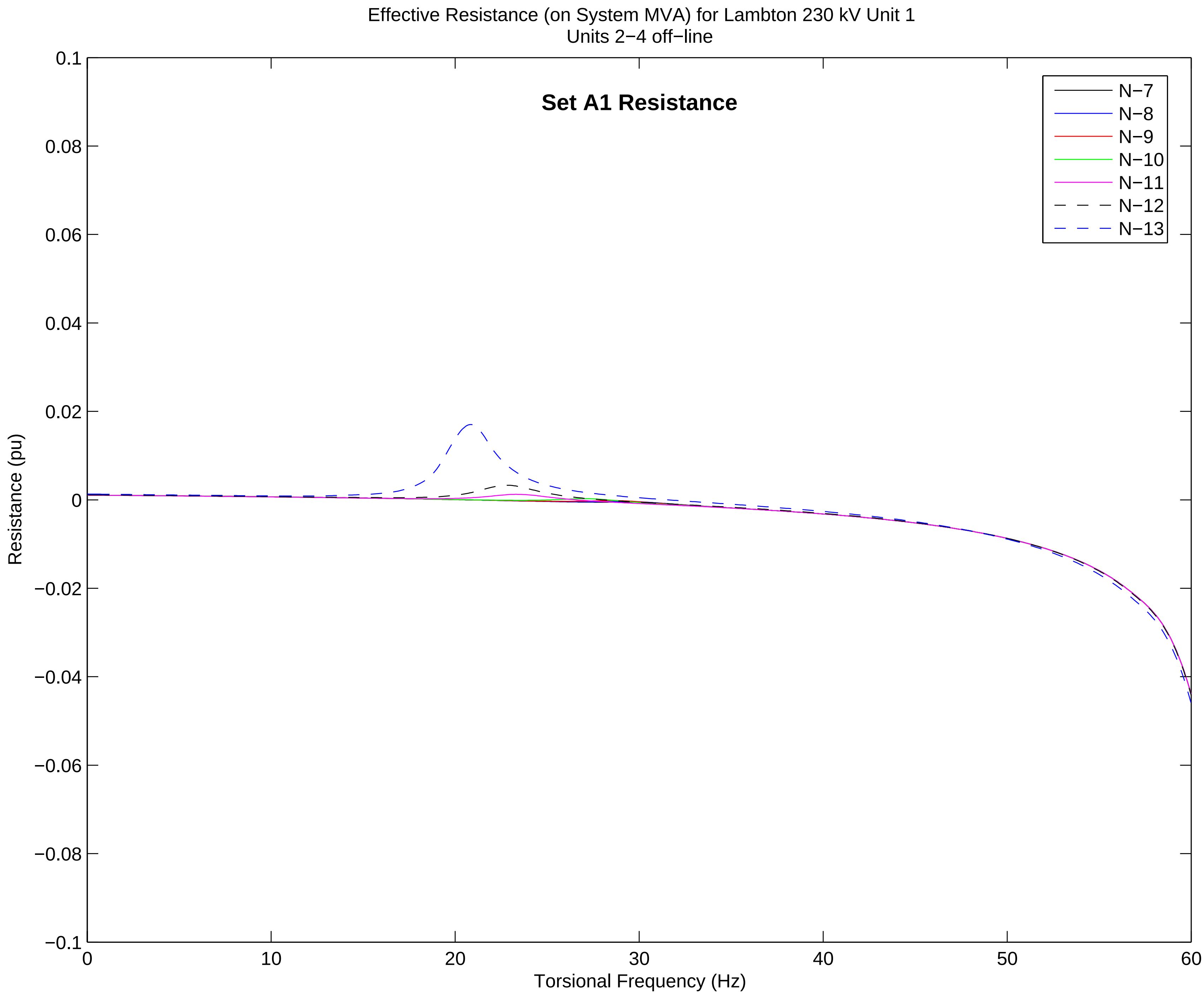


Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1−4
(All Units on−line)
Set A4 Damping
N−2a
N−3a
N−4a
N−5a
N−6a
N−7a
N−8a
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



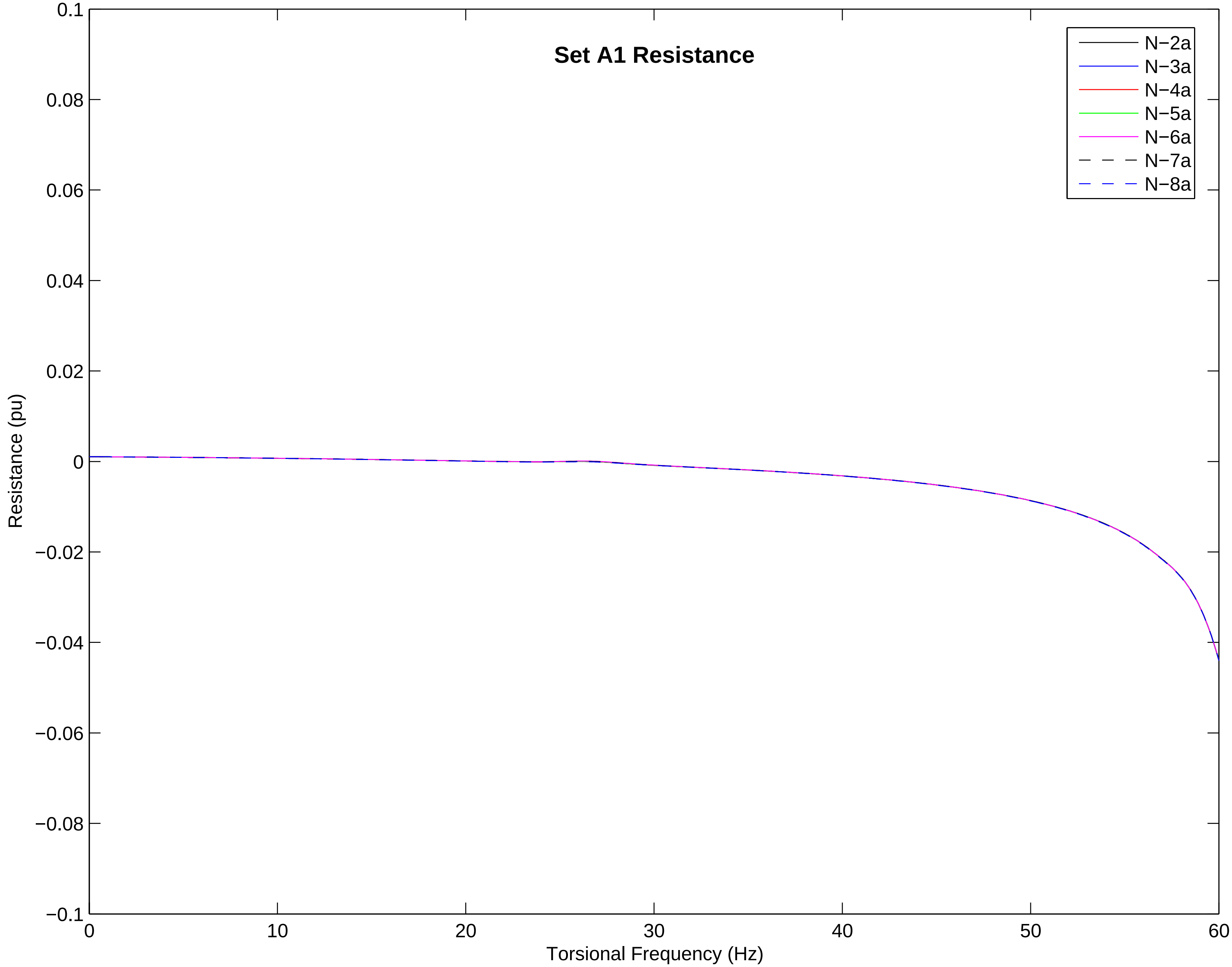
Electrical Damping (on Machine MVA) for Lambton 230 kV Unit 1−4
(All Units on−line)
Set A4 Damping
N−9a
N−10a
N−11a
N−12a
N−13a
N−14a
N−13b
N−13c
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

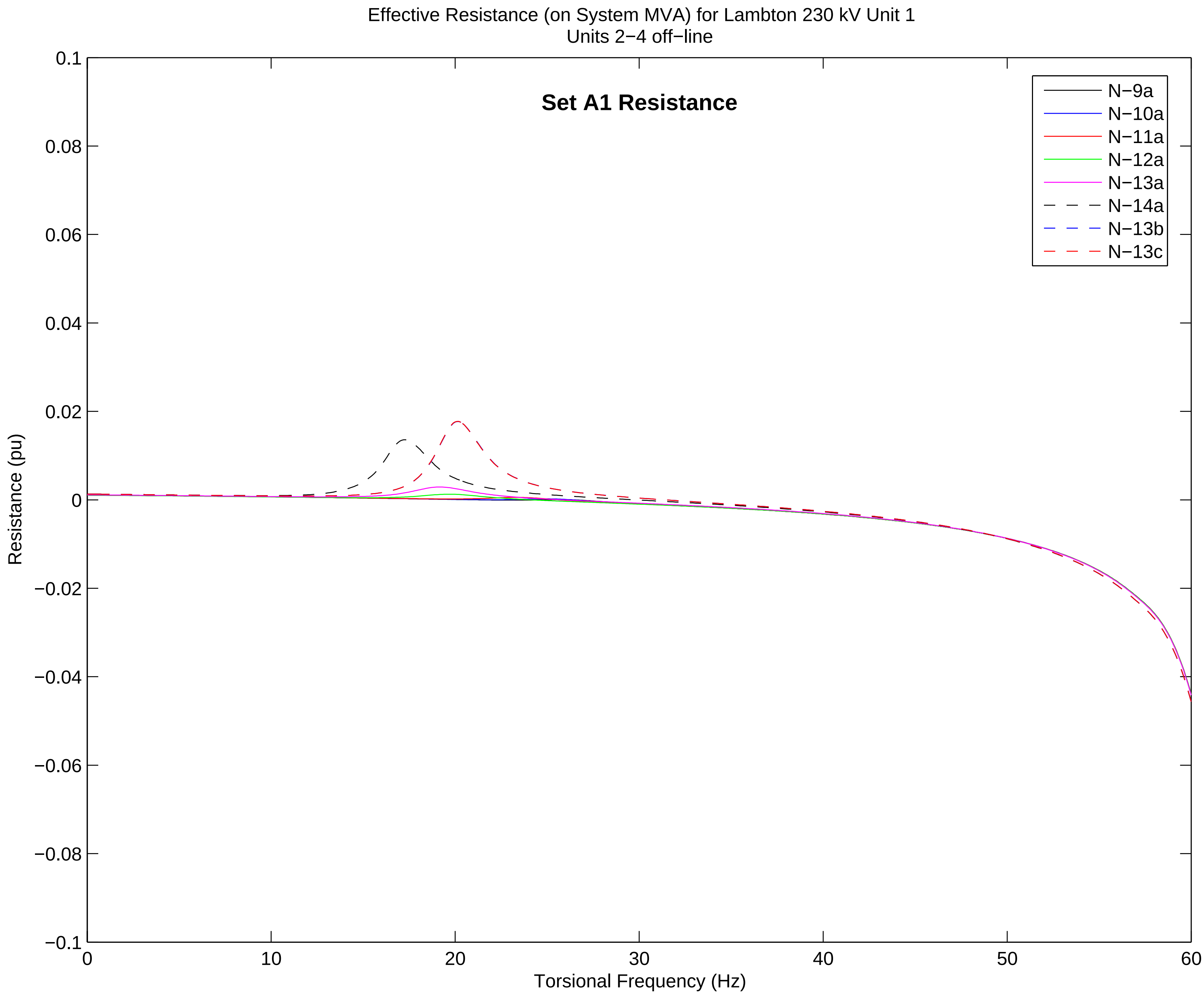

Effective Resistance (on System MVA) for Lambton 230 kV Unit 1
Units 2−4 off−line
Set A1 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

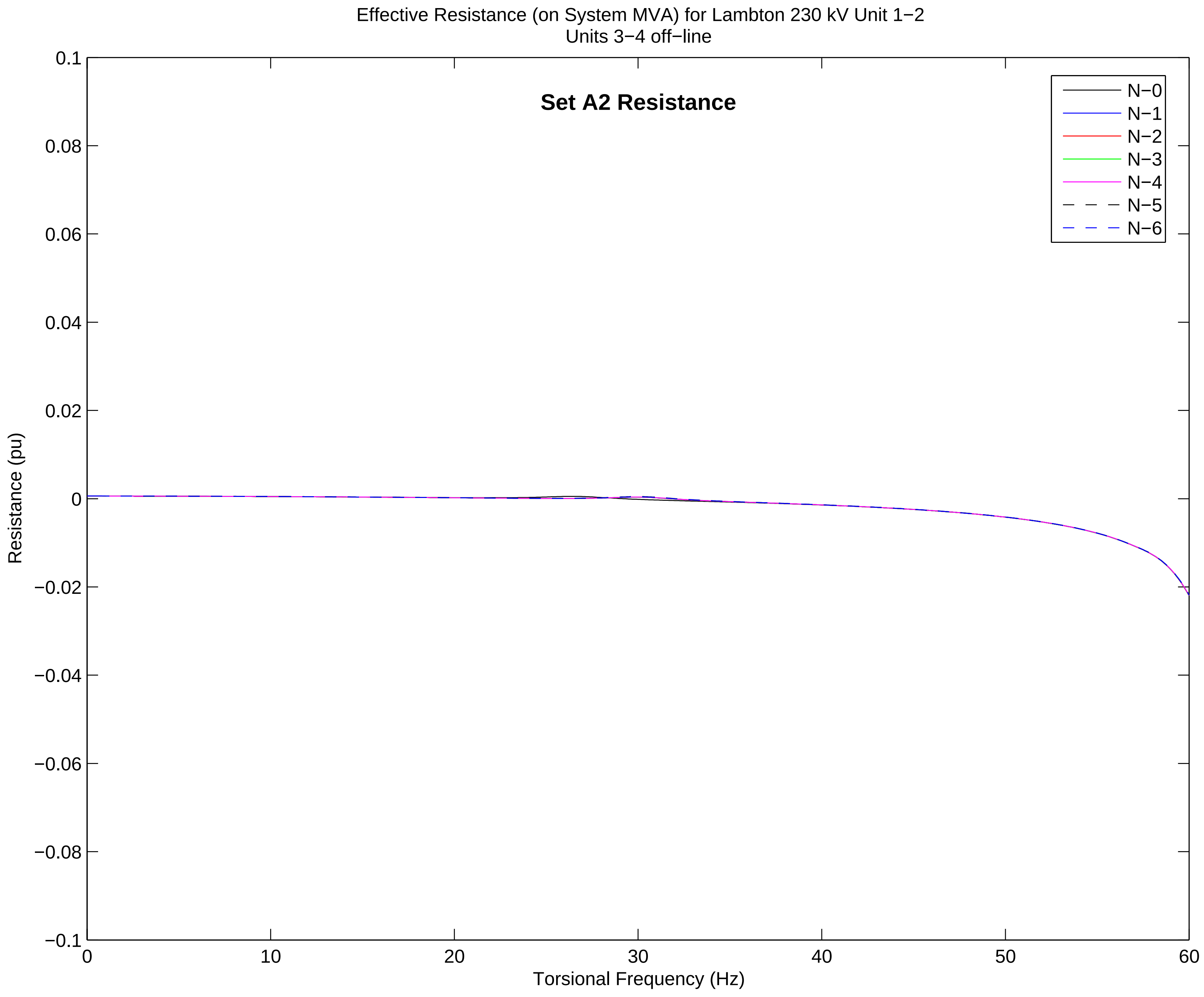


Effective Resistance (on System MVA) for Lambton 230 kV Unit 1
Units 2−4 off−line
Set A1 Resistance
N−7
N−8
N−9
N−10
N−11
N−12
N−13
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

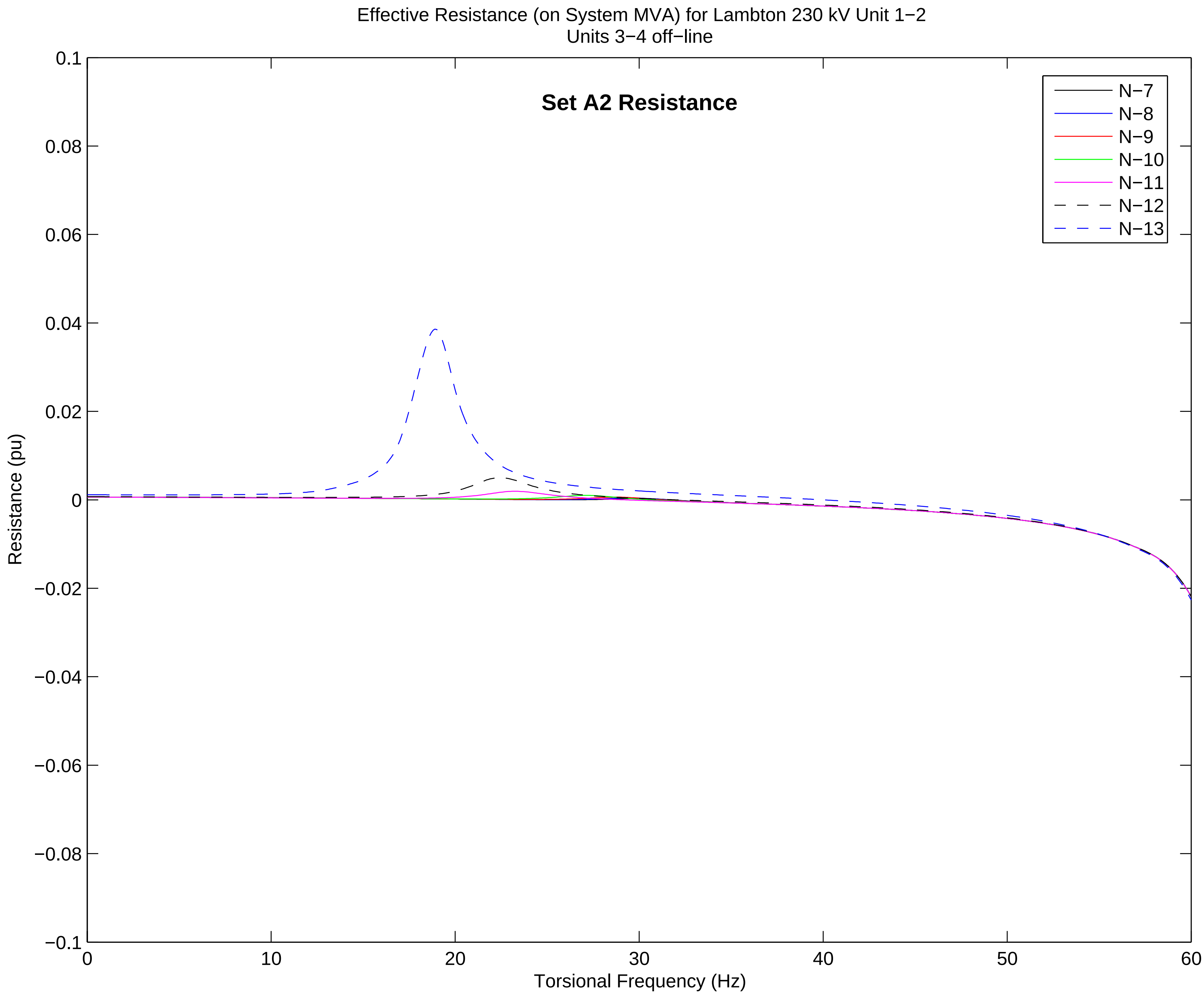
Effective Resistance (on System MVA) for Lambton 230 kV Unit 1
Units 2−4 off−line

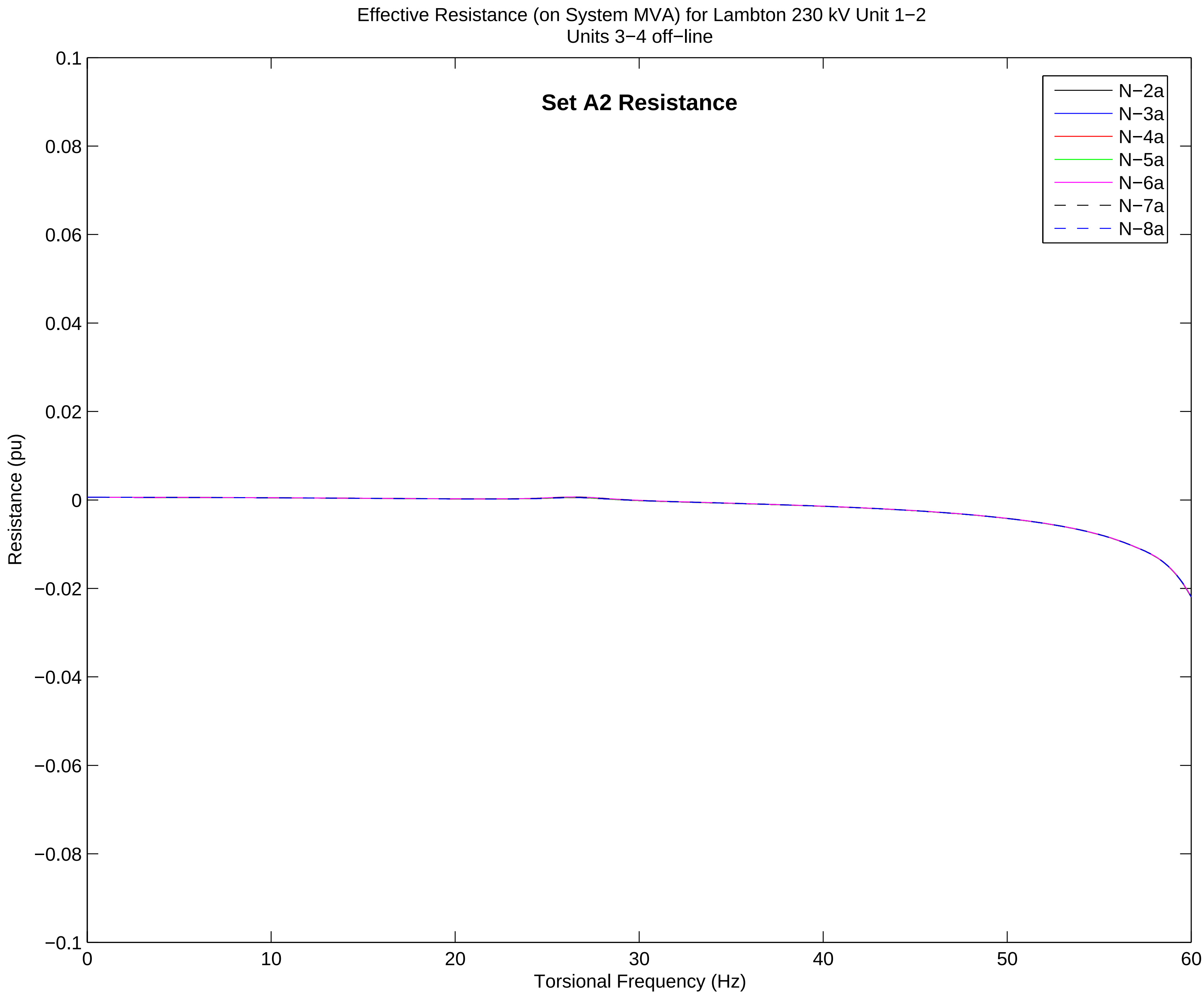



Effective Resistance (on System MVA) for Lambton 230 kV Unit 1
Units 2−4 off−line
Set A1 Resistance
N−9a
N−10a
N−11a
N−12a
N−13a
N−14a
N−13b
N−13c
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

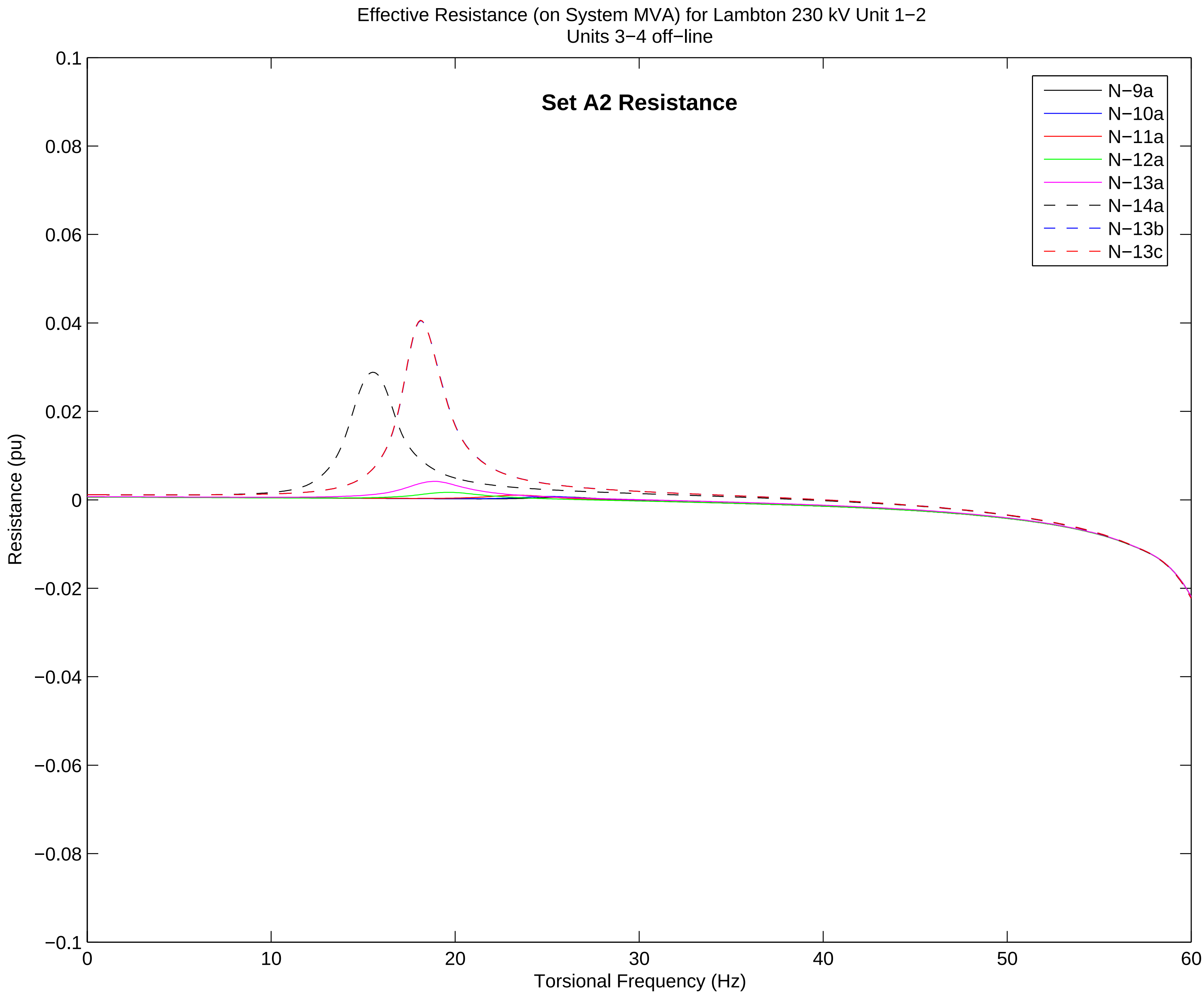


Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−2
Units 3−4 off−line
Set A2 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

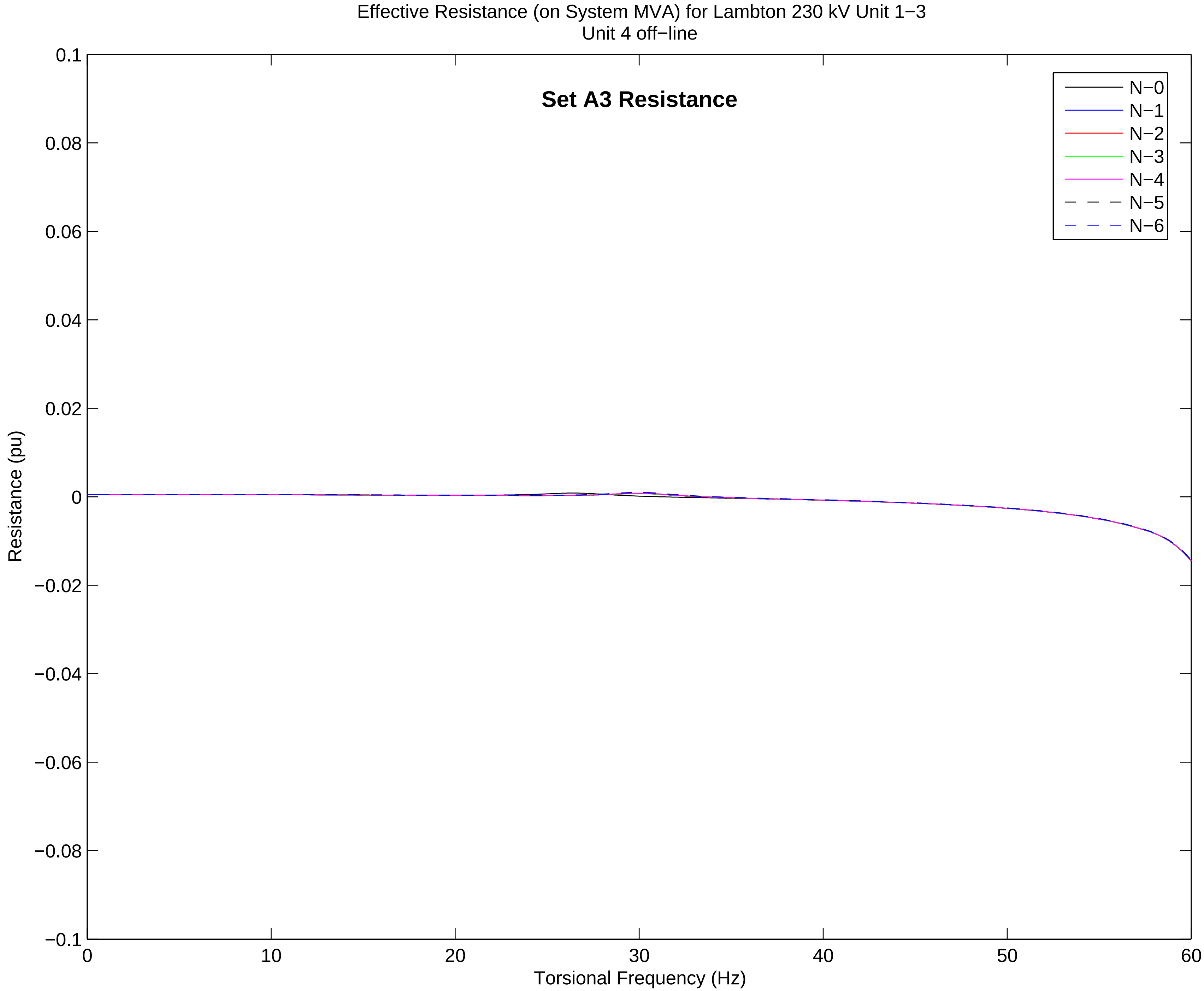

Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−2
Units 3−4 off−line
Set A2 Resistance
N−7
N−8
N−9
N−10
N−11
N−12
N−13
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

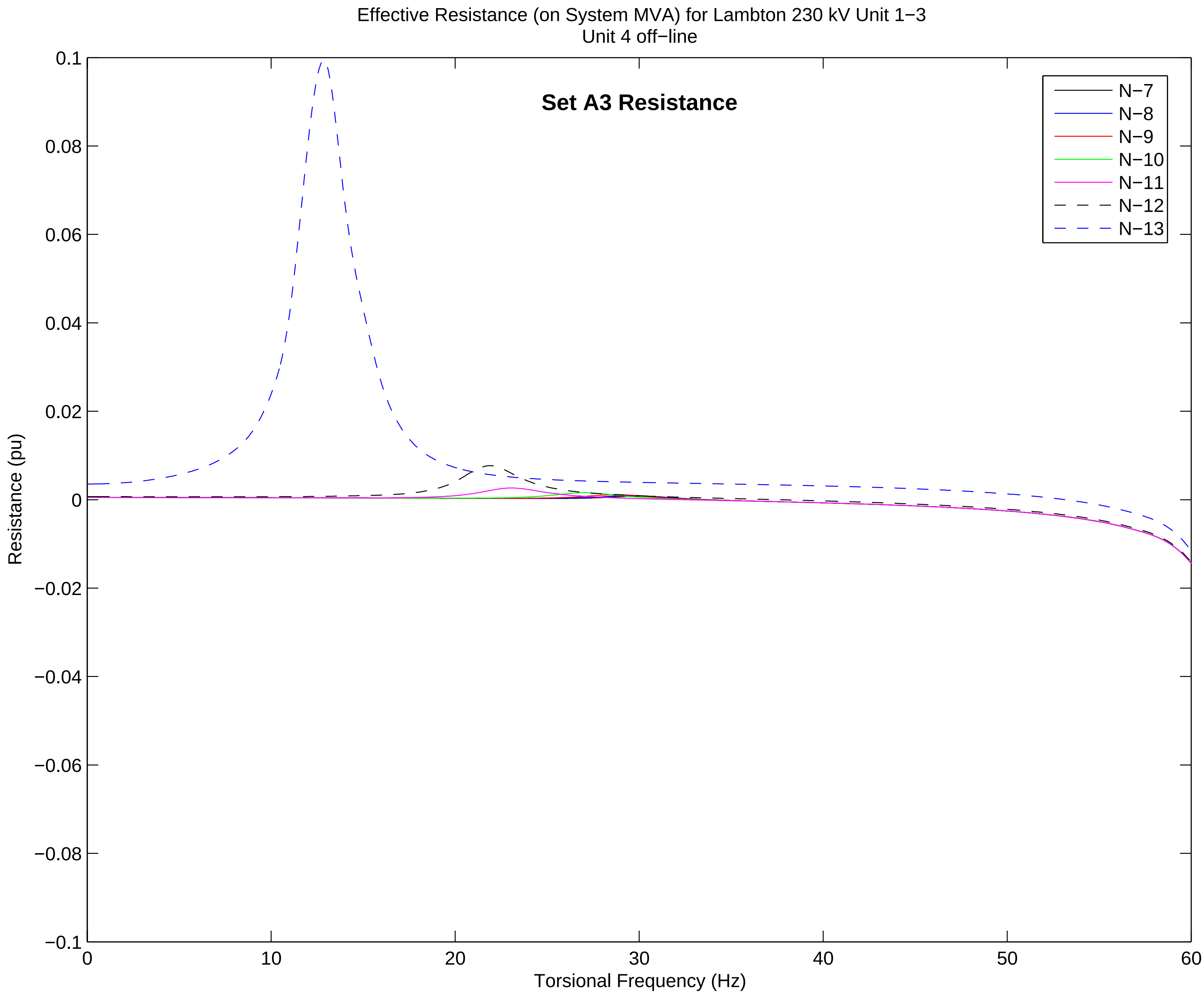


Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−2
Units 3−4 off−line
Set A2 Resistance
N−2a
N−3a
N−4a
N−5a
N−6a
N−7a
N−8a
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

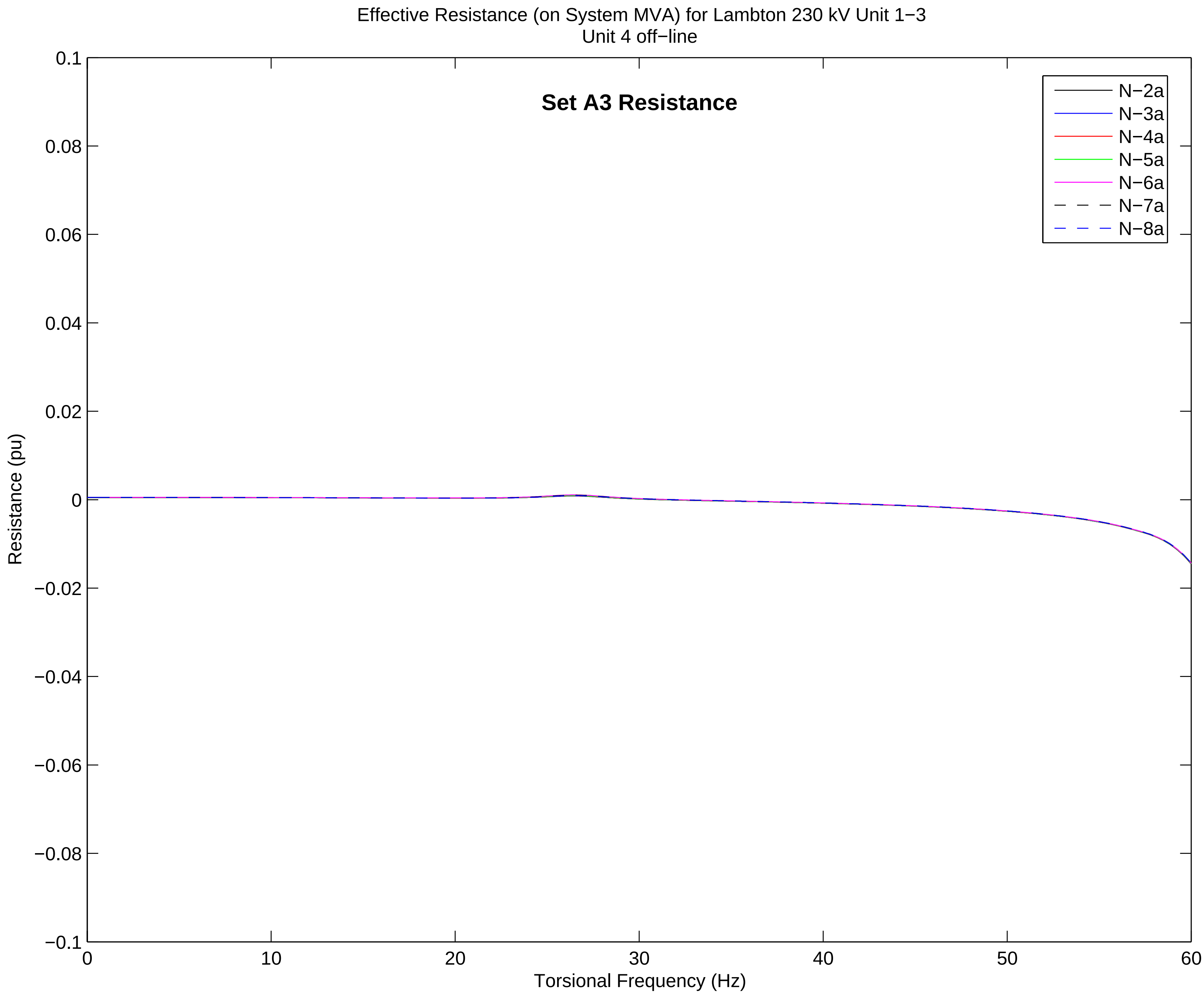


Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−2
Units 3−4 off−line
Set A2 Resistance
N−9a
N−10a
N−11a
N−12a
N−13a
N−14a
N−13b
N−13c
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

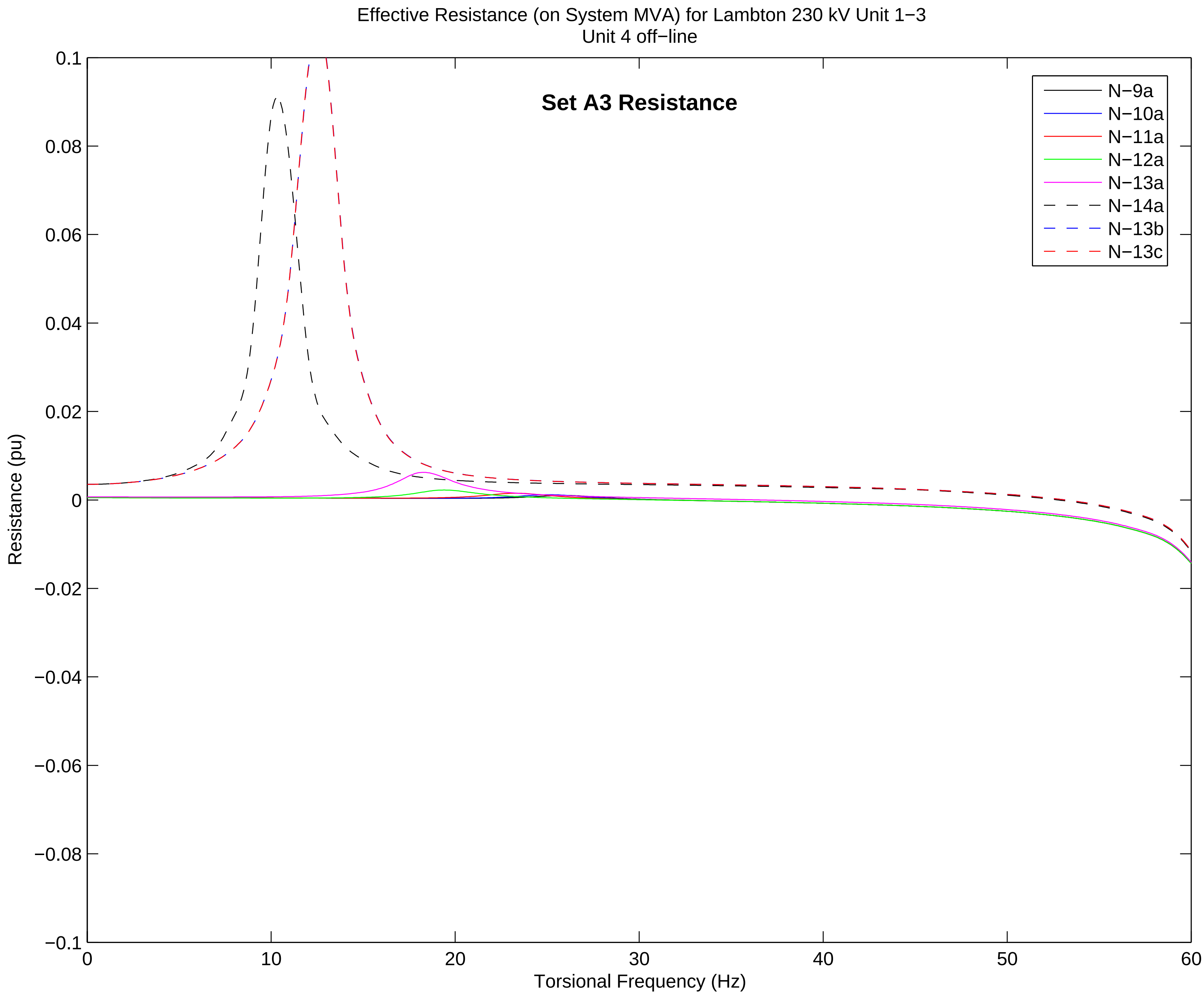

Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−3
Unit 4 off−line
Set A3 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



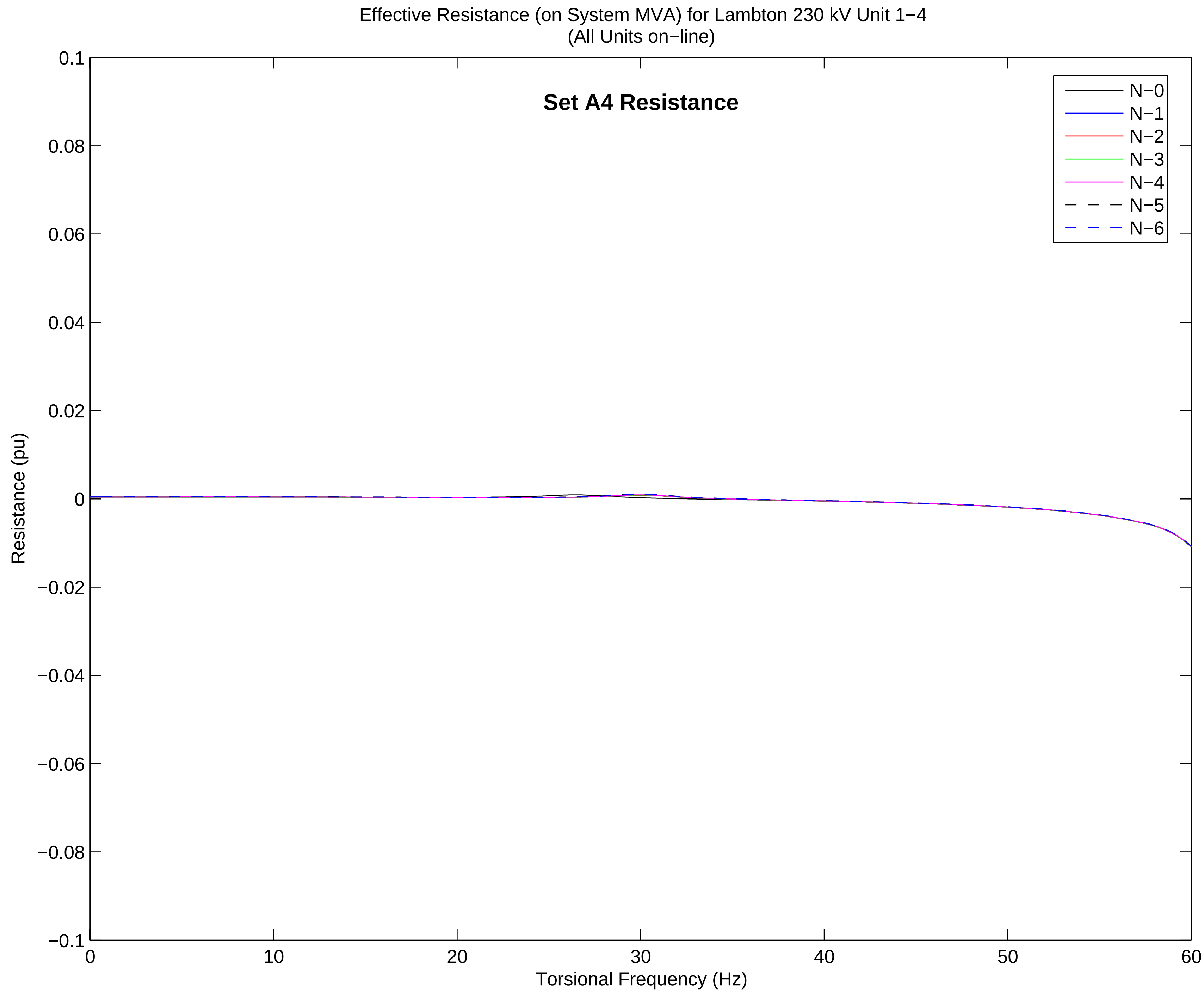
Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−3
Unit 4 off−line
Set A3 Resistance
N−7
N−8
N−9
N−10
N−11
N−12
N−13
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



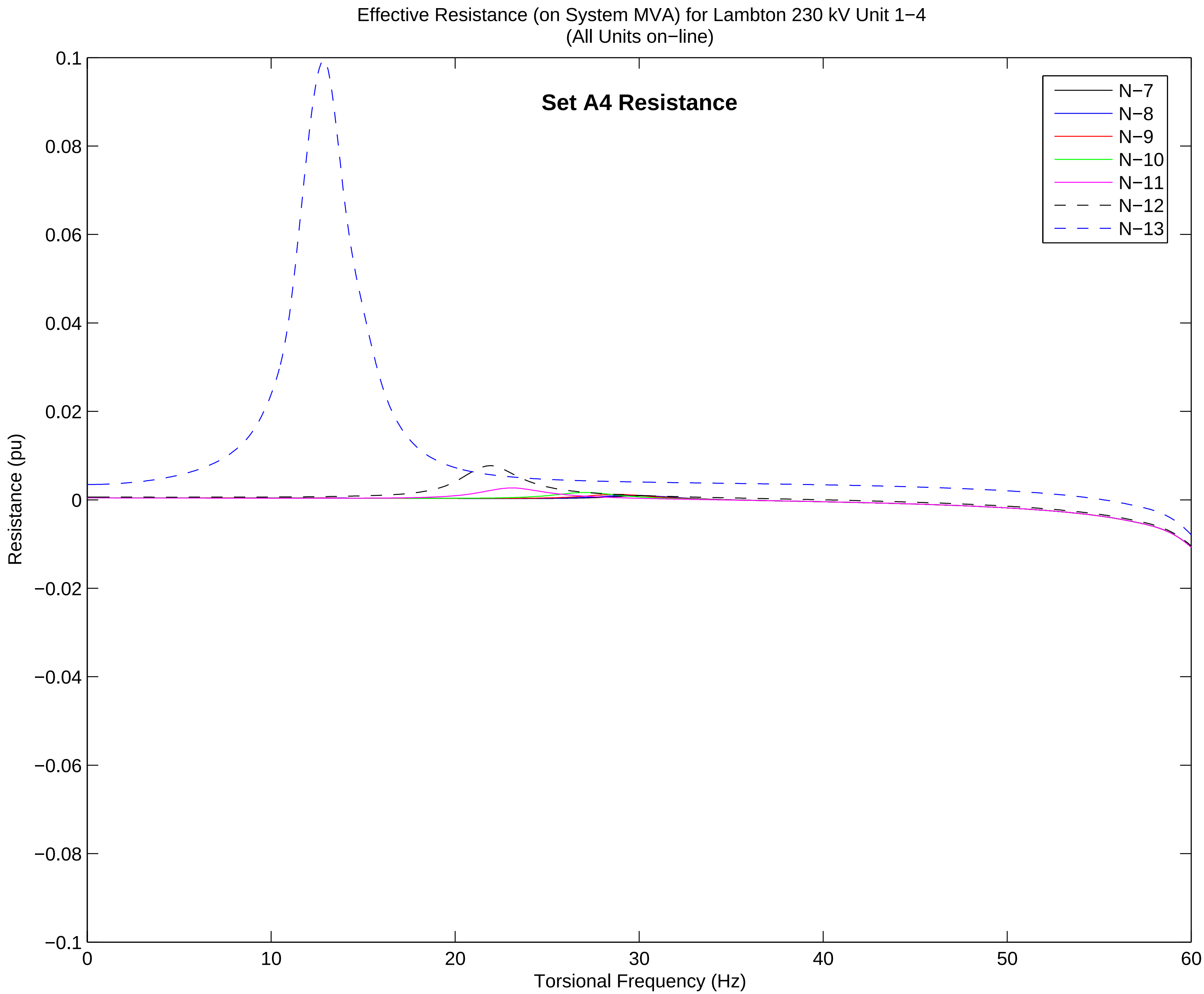
Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−3
Unit 4 off−line
Set A3 Resistance
N−2a
N−3a
N−4a
N−5a
N−6a
N−7a
N−8a
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

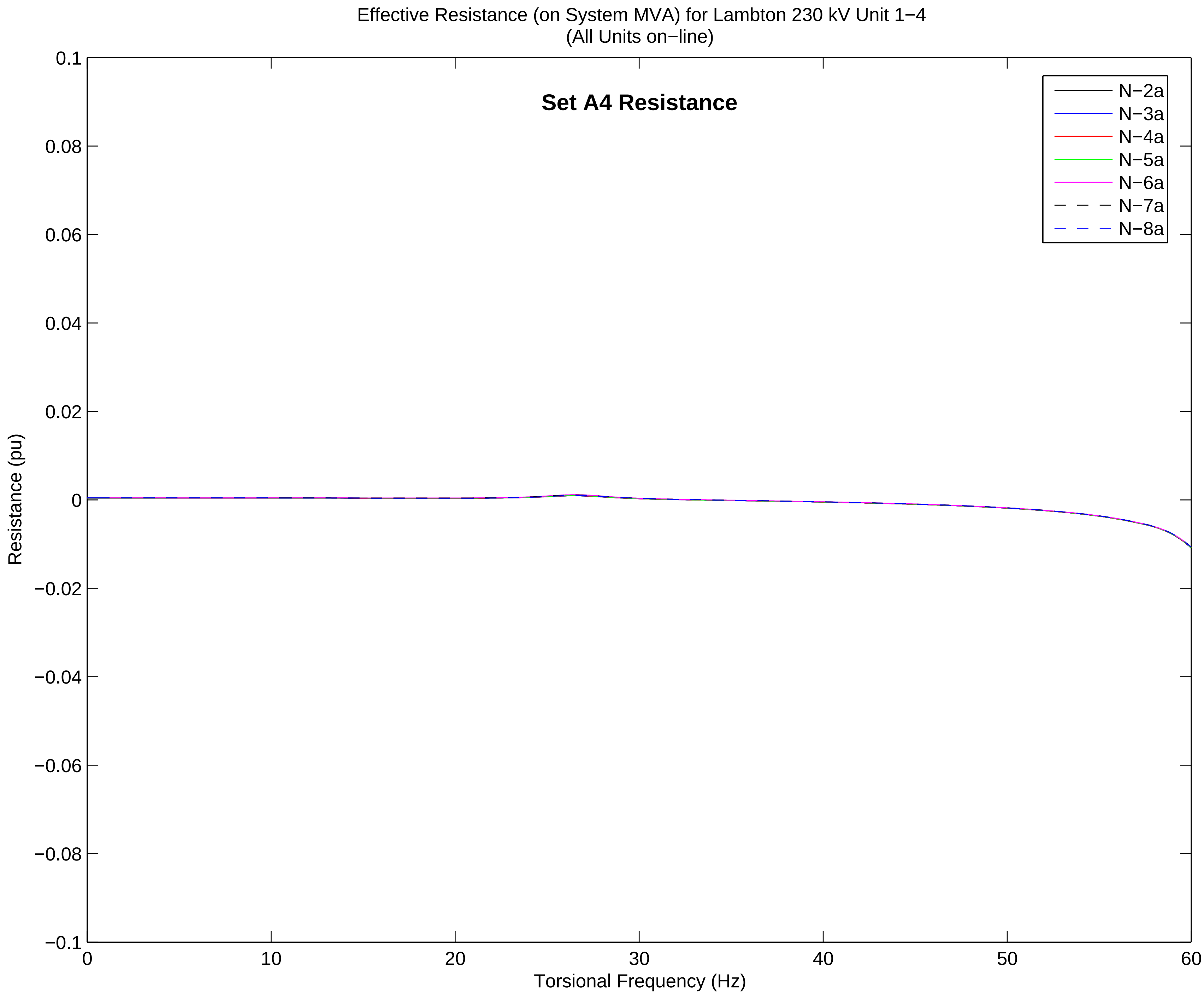


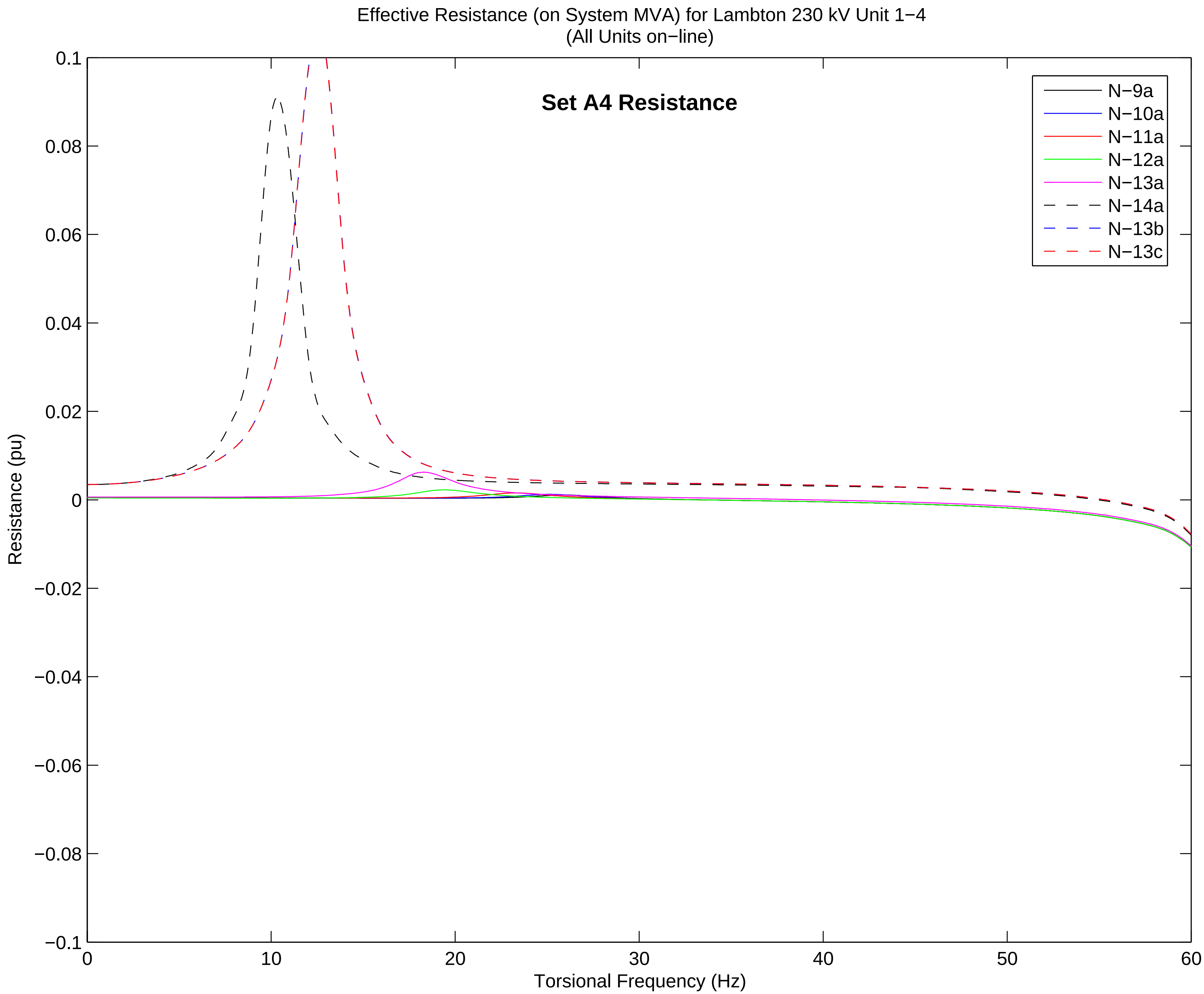
Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−3
Unit 4 off−line
Set A3 Resistance
N−9a
N−10a
N−11a
N−12a
N−13a
N−14a
N−13b
N−13c
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−4
(All Units on−line)
Set A4 Resistance
N−0
N−1
N−2
N−3
N−4
N−5
N−6
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−4
(All Units on−line)
Set A4 Resistance
N−7
N−8
N−9
N−10
N−11
N−12
N−13
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−4
(All Units on−line)
Set A4 Resistance
N−2a
N−3a
N−4a
N−5a
N−6a
N−7a
N−8a
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lambton 230 kV Unit 1−4
(All Units on−line)
Set A4 Resistance
N−9a
N−10a
N−11a
N−12a
N−13a
N−14a
N−13b
N−13c
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

APPENDIX G: Pickering Frequency Scan

Appendix G – Pickering Frequency Scan

This appendix contains 1) the electrical damping plots and 2) the effective resistance plots for the Pickering generators. The electrical damping plots are provided first, ordered by generator combination (Set ID) as identified in Table G-1 below. The effective resistance plots are then provided in the same order.

Table G-1: Bruce A Generator Combinations

Set ID	Group A				Group B			
	G1	G2	G5	G6*	G3	G4	G7	G8
A1	√							
A2	√	√						
A3	√	√	√					
B1					√			
B2					√	√		
B3					√	√	√	
B4					√	√	√	√

√ - indicates the generator is in-service

* - G6 ignored due to generator, bus and lines all removed from service in data set

Table G-2: Contingency Description

Contingency ID	Bowmanville - Cherrywood 500kV Line 1	Bowmanville - Cherrywood 500kV Line 2	Bowmanville - Cherrywood 500kV Line 3	Bowmanville - Cherrywood 500kV Line 4	CheryDk2 – Dobbin 230kV Line 1	CheryDk2 – H26CTieJ 230kV Line 1	CheryDk2 – EllesJC3 230kV Line 1	CheryDk2 – ScarJC14 230kV Line	CheryDk2 – AginJC20 230kV Line 1	CheryDk1 – ColumJ24 230kV Line 1	CheryDk1 – DuffinJ10 230kV Line 1	CheryDk1 – EllesJC2 230kV Line 1	CheryDk1 – Mark2J12 230kV Line 1	CheryDk1 – FchldC18 230kV Line 1
	For Generator Sets A1-A3													
N-0														
N-1	X													
N-2	X	X												
N-3	X	X	X											
N-4	X	X	X	X										
N-9	X	X	X	X	X	X	X	X	X					
N-14	X	X	X	X	X	X	X	X	X	X	X	X	X	X
N-27	See description below													
N-28	See description below													
N-41	See description below													

X – indicates the branch is out-of-service

(continued next page)

Table G-2: Contingency Description (continued)

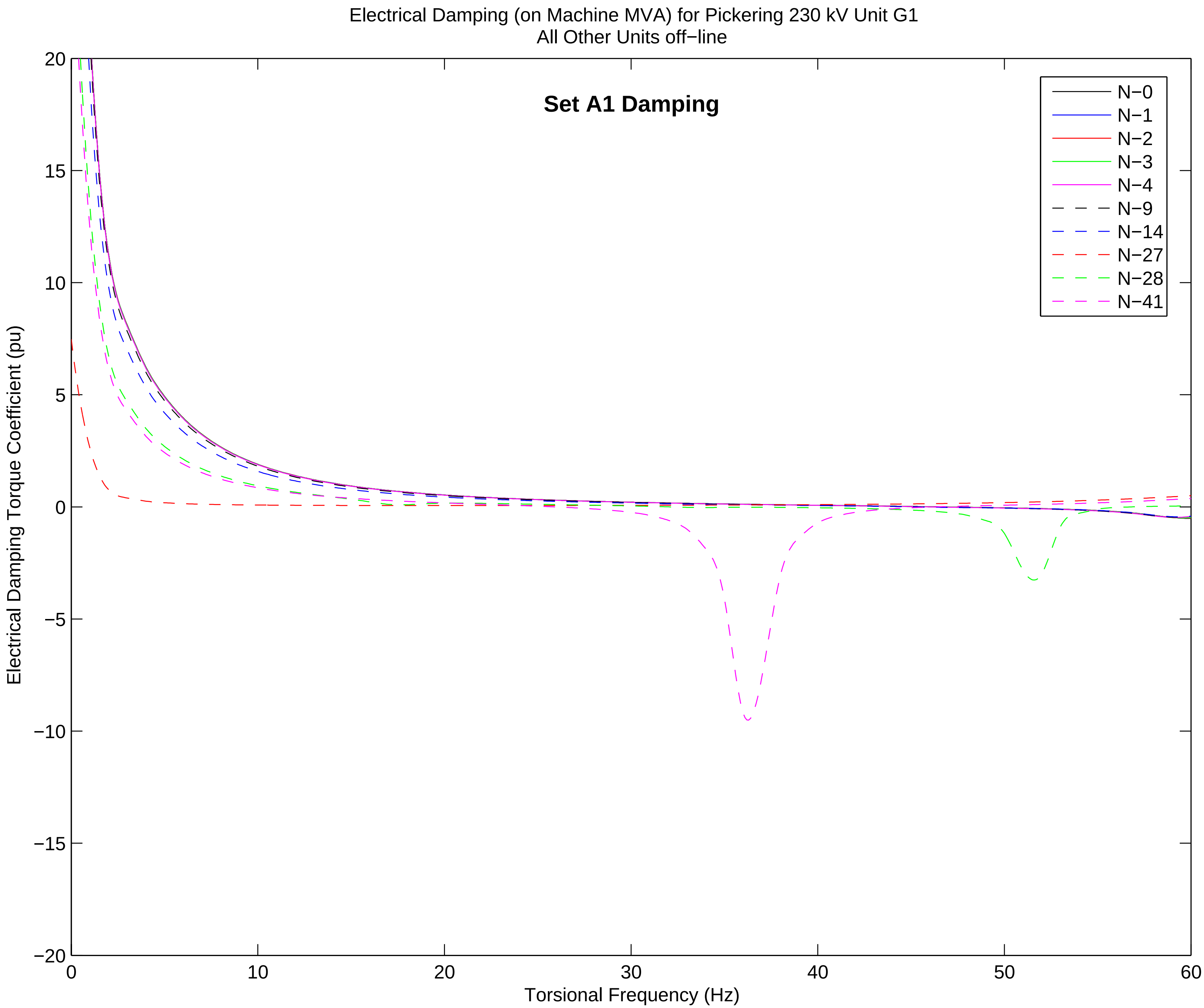
	Bowmanville - Cherrywood 500kV Line 1	Bowmanville - Cherrywood 500kV Line 2	Bowmanville - Cherrywood 500kV Line 3	Bowmanville - Cherrywood 500kV Line 4	CheryDk4 – Dobbin 230kV Line 1	CheryDk4 – DuffnJ28 230kV Line 1	CheryDk4 – Mark2J11 230kV Line 1	CheryDk4 –ScarJC17 230kV Line	CheryDk4 230kV/44kV Transformer T7	CheryDk4 230kV/44kV Transformer T8	CheryDk3 – B23CTieJ 230kV Line 1	CheryDk3 – Malv C4R 230kV Line 1	CheryDk3 – Malv C5R 230kV Line 1	CheryDk3 – Shep C15 230kV Line 1	CheryDk3 – WhitJM29 230kV Line 1
	For Generator Sets B1-B4														
N-0															
N-1	X														
N-2	X	X													
N-3	X	X	X												
N-4	X	X	X	X											
N-10	X	X	X	X	X	X	X	X	X	X					
N-15	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
N-28a	See Table G-3														
N-29	See Table G-3														
N-42	See Table G-3														

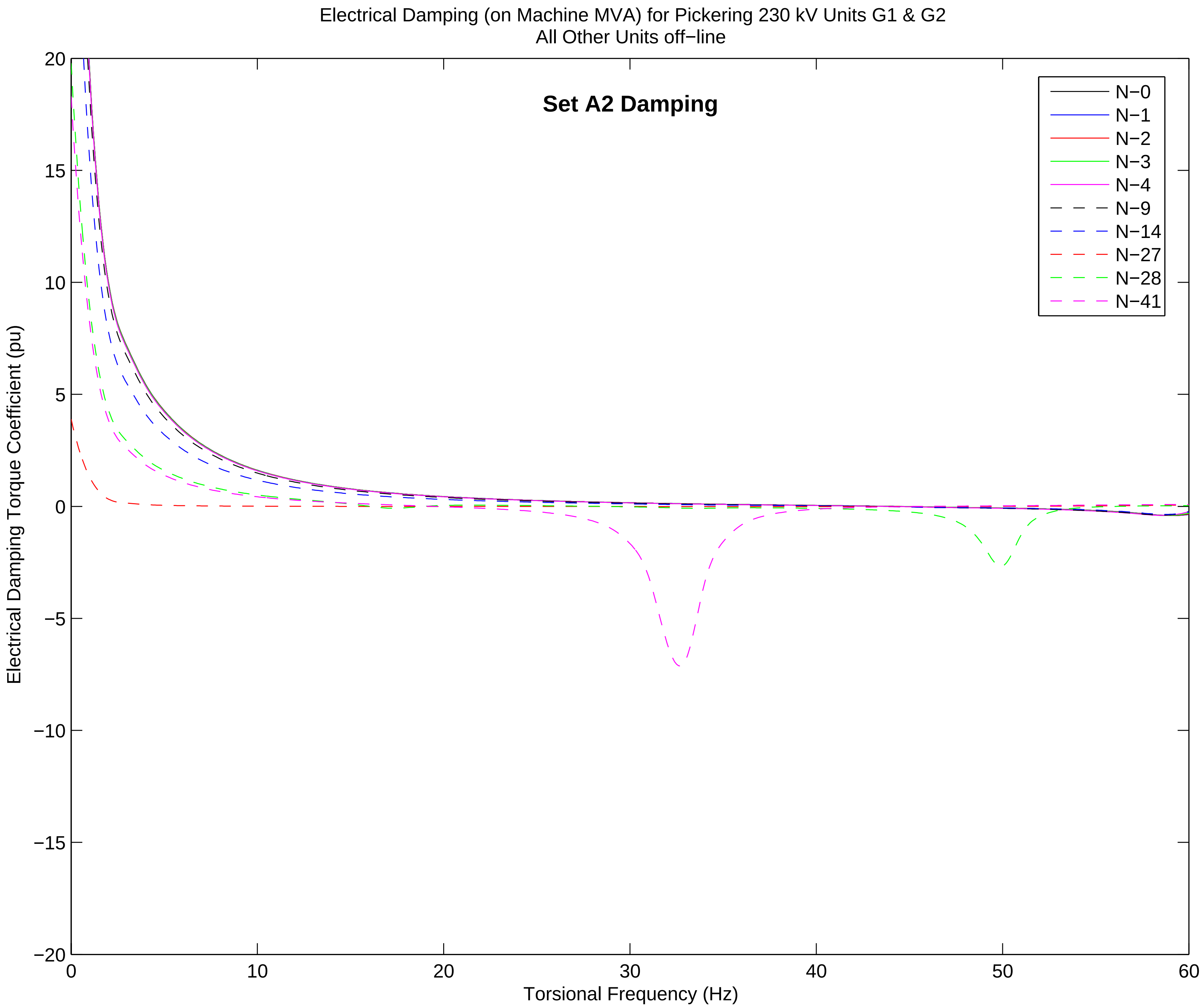
X – indicates the branch is out-of-service

Table G-3: Extensive Contingencies

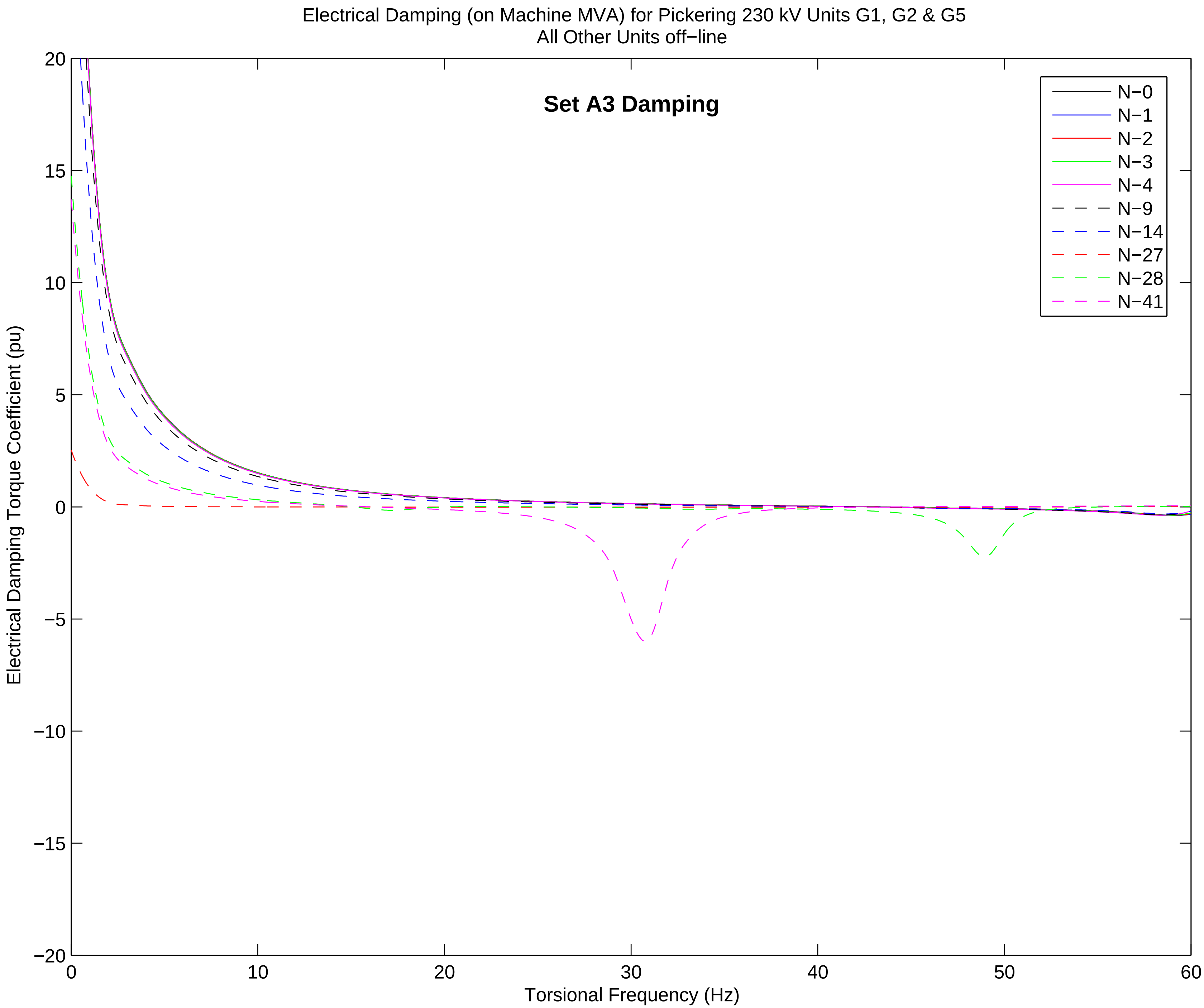
Element	Contingency					
	N-27	N-28	N-41	N-28a	N-29	N-42
Generator Sets Evaluated	A1 – A3			B1 – B4		
All of N-14 plus those below as indicated	X	X	X			
All of N-15 plus those below as indicated				X	X	X
Cherrywood 500/230kV Transformer 14	X	X	X	X	X	X
Cherrywood 500/230kV Transformer 15	X	X	X	X	X	X
Cherrywood 500/230kV Transformer 16	X	X	X	X	X	X
Cherrywood 500/230kV Transformer 17	X	X	X	X	X	X
Parkway 500kV/230kV/27.6kV Transformer	X	X	X	X	X	X
Clairville – Milton Bypass 500kV Line 1	X	X	X	X	X	X
Clairville – Milton Bypass 500kV Line 2	X	X	X	X	X	X
Clairville – Essa 500kV Line 1	X	X	X	X	X	X
Clairville – Essa 500kV Line 1	X	X	X	X	X	X
Clairville 500kV/230kV Transformer 13	X	X	X	X	X	X
Clairville 500kV/230kV Transformer 14	X	X	X	X	X	X
Clairville 500kV/230kV Transformer 15	X	X	X	X	X	X
Clairville 500kV/230kV Transformer 16	X	X	X	X	X	X
Clairville – Milton Line 1	X		X	X		X
Clairville – Milton Line 1	X			X		
Milton – Trafal72 500kV Line		X	X		X	X
Milton – Trafal73 500kV Line		X	X		X	X
Milton – Midd8185 500kV Line		X	X		X	X
Milton – Bruce B Series Cap			X			X
Midd8086-Middldk1 500kV/230kV Transformer T3			X			X
Midd8185-Middldk2 500kV/230kV Transformer T6			X			X
Nanticoke 500kV/230kV Transformer T11			X			X
Nanticoke 500kV/230kV Transformer T12			X			X
Nanticoke 500kV/22kV Transformer T54			X			X
Nanticoke 500kV/22kV Transformer T55			X			X
Nanticoke 500kV/22kV Transformer T56			X			X
Nanticoke 500kV/22kV Transformer T57			X			X
Longwood 500kV/230kV/27.6kV Transformer T11			X			X
Longwood 500kV/230kV/27.6kV Transformer T12			X			X
Longwood 500kV/230kV/27.6kV Transformer T13			X			X
Longwood 500kV/230kV/27.6kV Transformer T14			X			X
Longwood 500kV/230kV/27.6kV Transformer T15			X			X

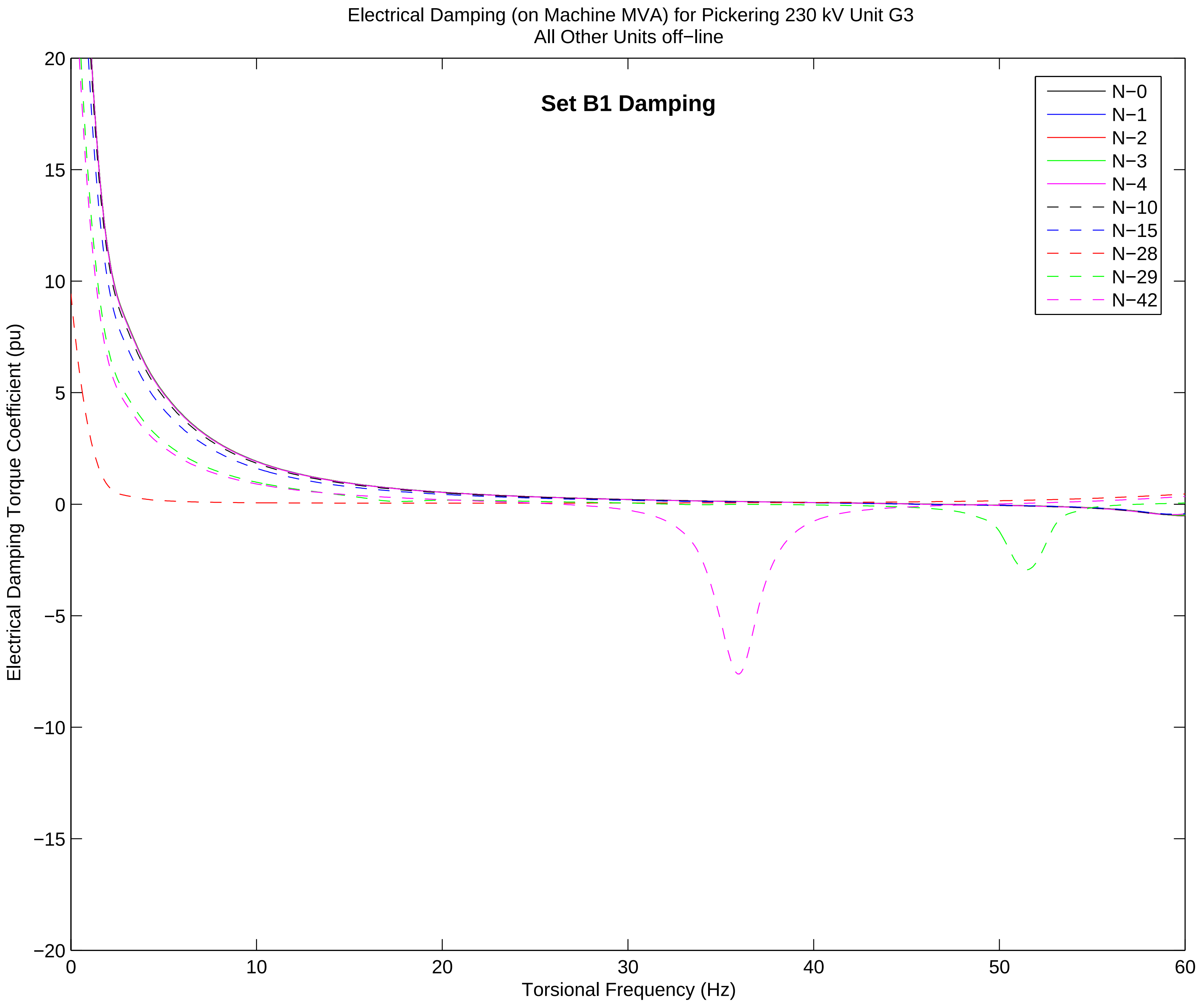
X – indicates the branch is out-of-service


Electrical Damping (on Machine MVA) for Pickering 230 kV Unit G1
All Other Units off−line
Set A1 Damping
N−0
N−1
N−2
N−3
N−4
N−9
N−14
N−27
N−28
N−41
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

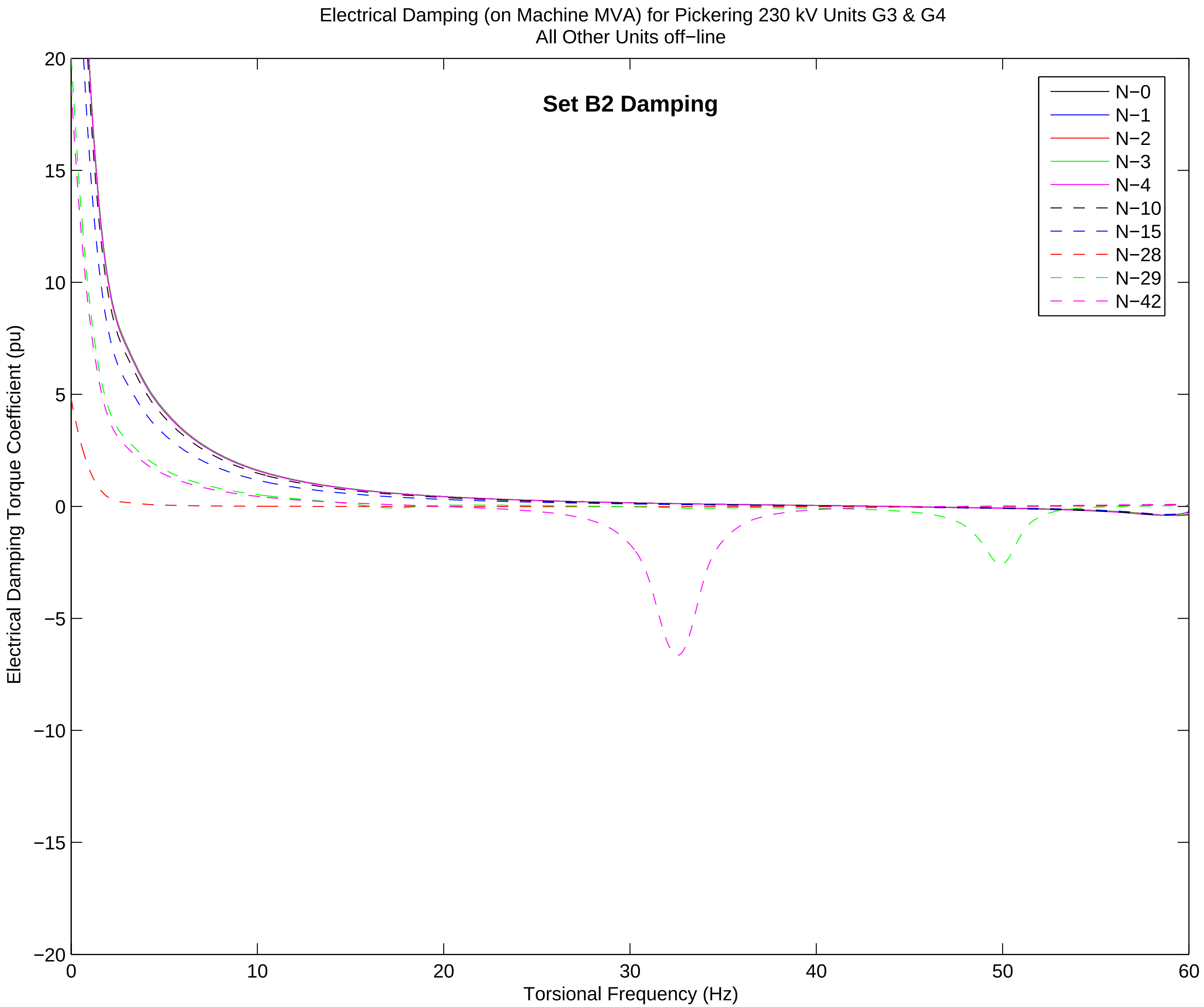


Electrical Damping (on Machine MVA) for Pickering 230 kV Units G1 & G2
All Other Units off−line
Set A2 Damping
N−0
N−1
N−2
N−3
N−4
N−9
N−14
N−27
N−28
N−41
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

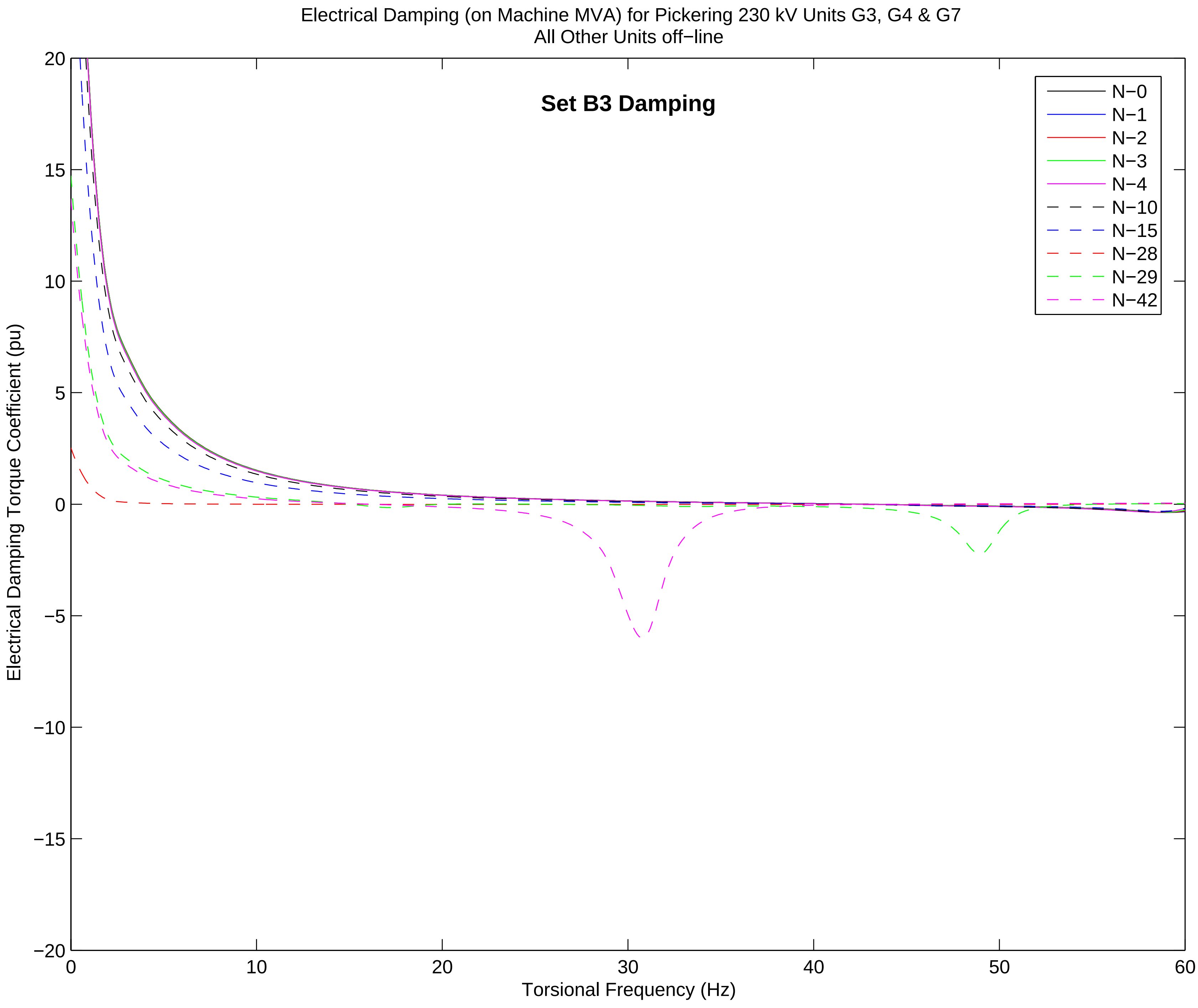

Electrical Damping (on Machine MVA) for Pickering 230 kV Units G1, G2 & G5
All Other Units off−line
Set A3 Damping
N−0
N−1
N−2
N−3
N−4
N−9
N−14
N−27
N−28
N−41
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



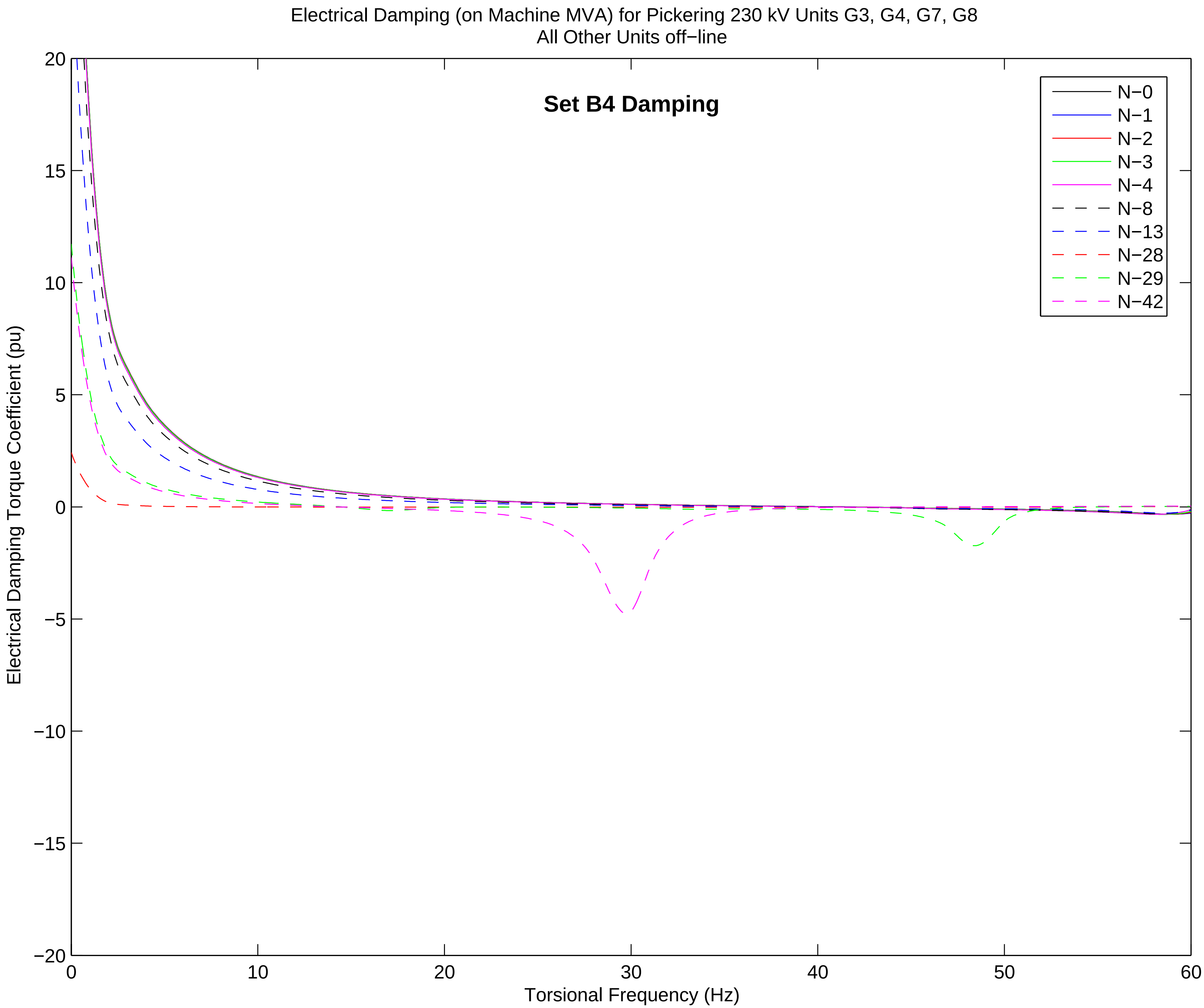
Electrical Damping (on Machine MVA) for Pickering 230 kV Unit G3
All Other Units off−line
Set B1 Damping
N−0
N−1
N−2
N−3
N−4
N−10
N−15
N−28
N−29
N−42
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



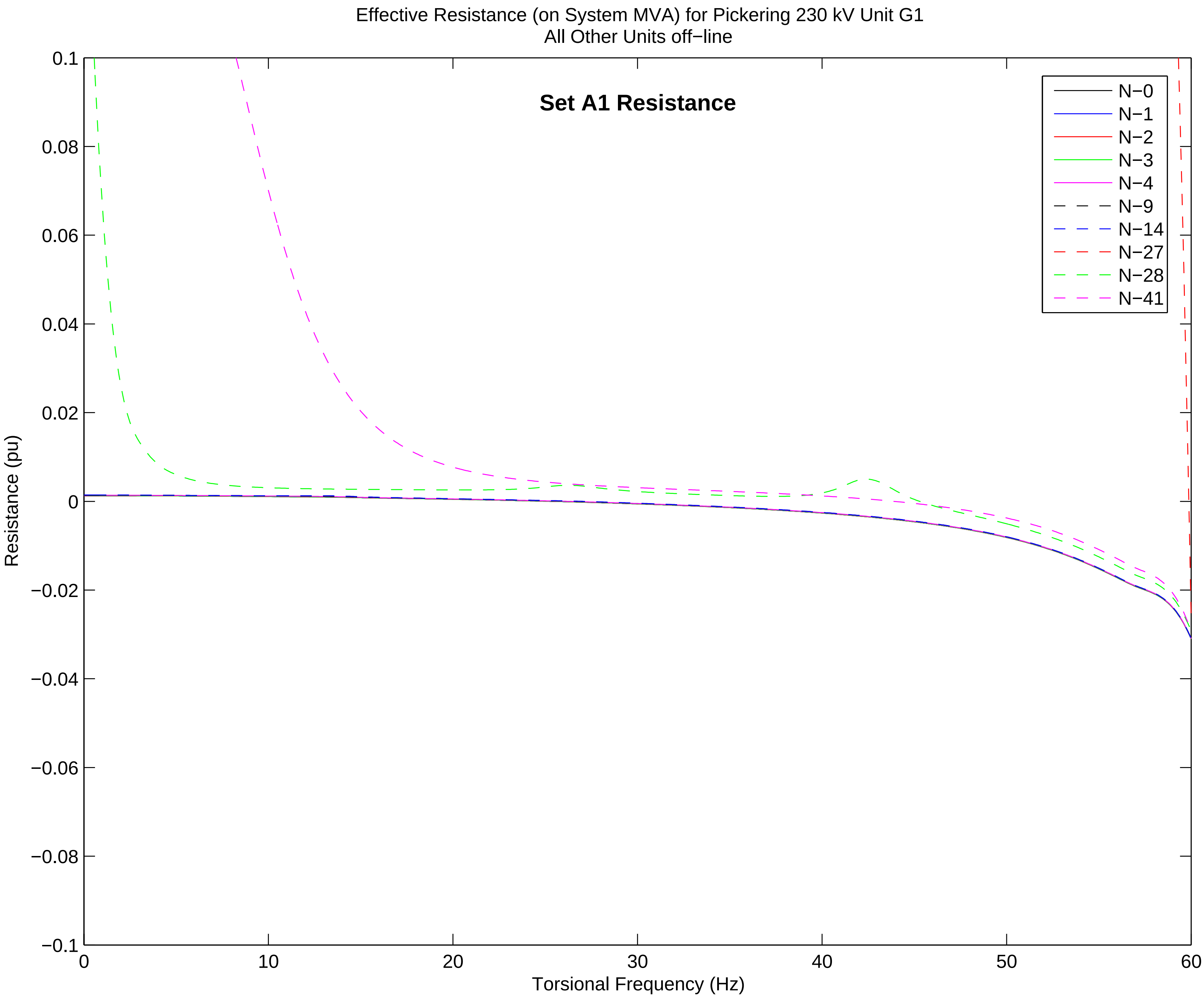
Electrical Damping (on Machine MVA) for Pickering 230 kV Units G3 & G4
All Other Units off−line
Set B2 Damping
N−0
N−1
N−2
N−3
N−4
N−10
N−15
N−28
N−29
N−42
Electrical Damping Torque Coefficient (pu)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)



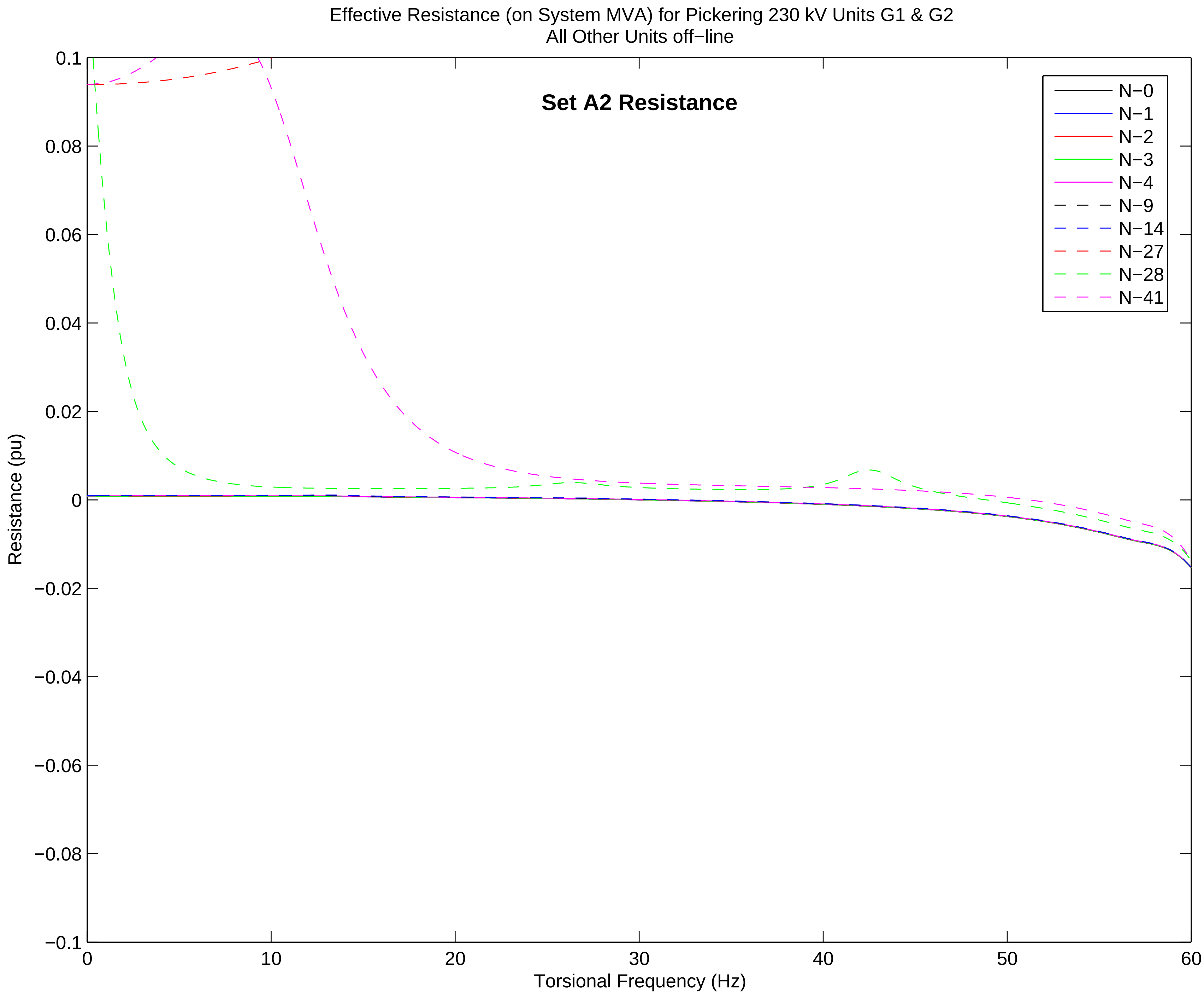
Electrical Damping (on Machine MVA) for Pickering 230 kV Units G3, G4 & G7
All Other Units off−line
Set B3 Damping
N−0
N−1
N−2
N−3
N−4
N−10
N−15
N−28
N−29
N−42
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



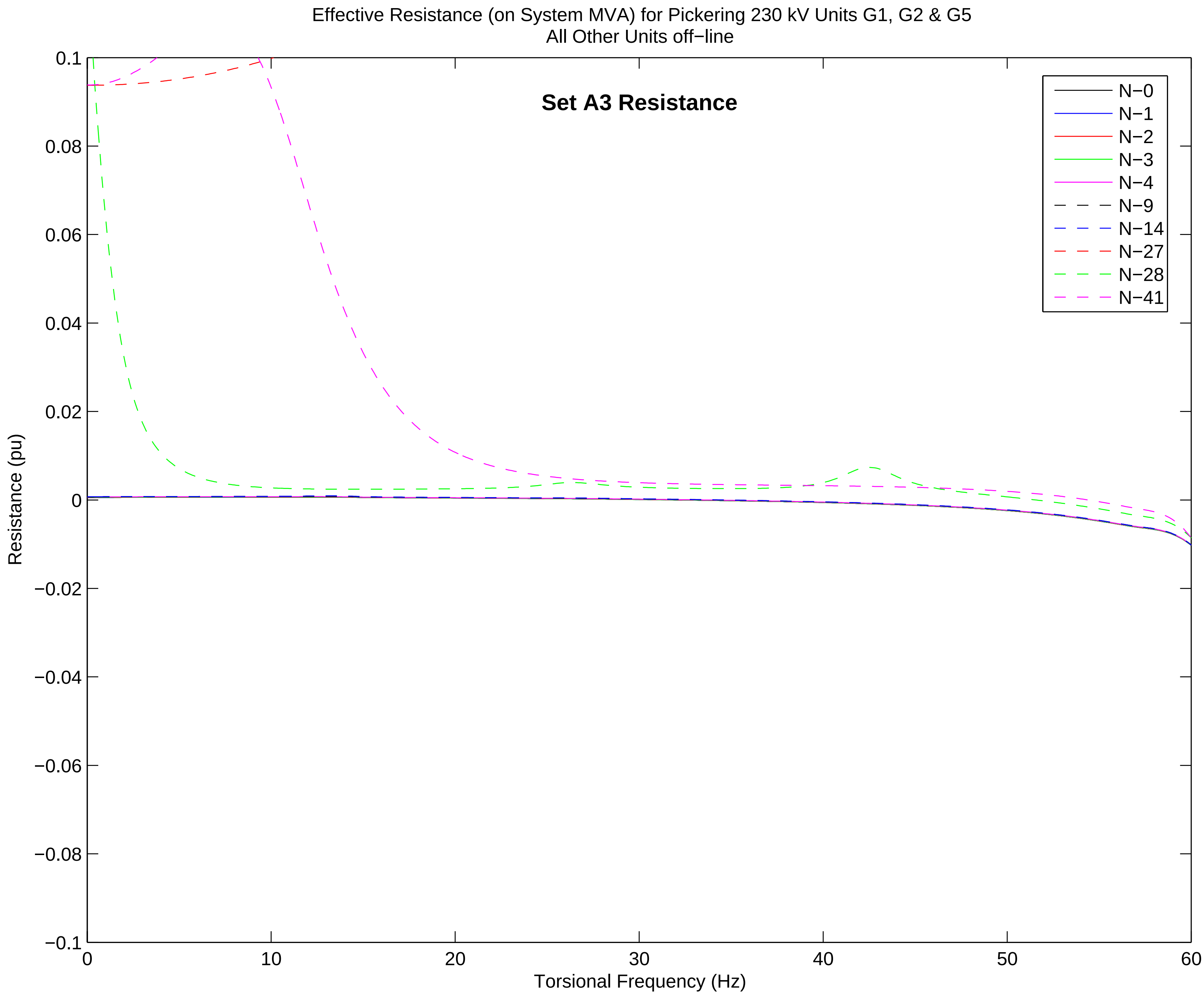
Electrical Damping (on Machine MVA) for Pickering 230 kV Units G3, G4, G7, G8
All Other Units off−line
Set B4 Damping
N−0
N−1
N−2
N−3
N−4
N−8
N−13
N−28
N−29
N−42
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



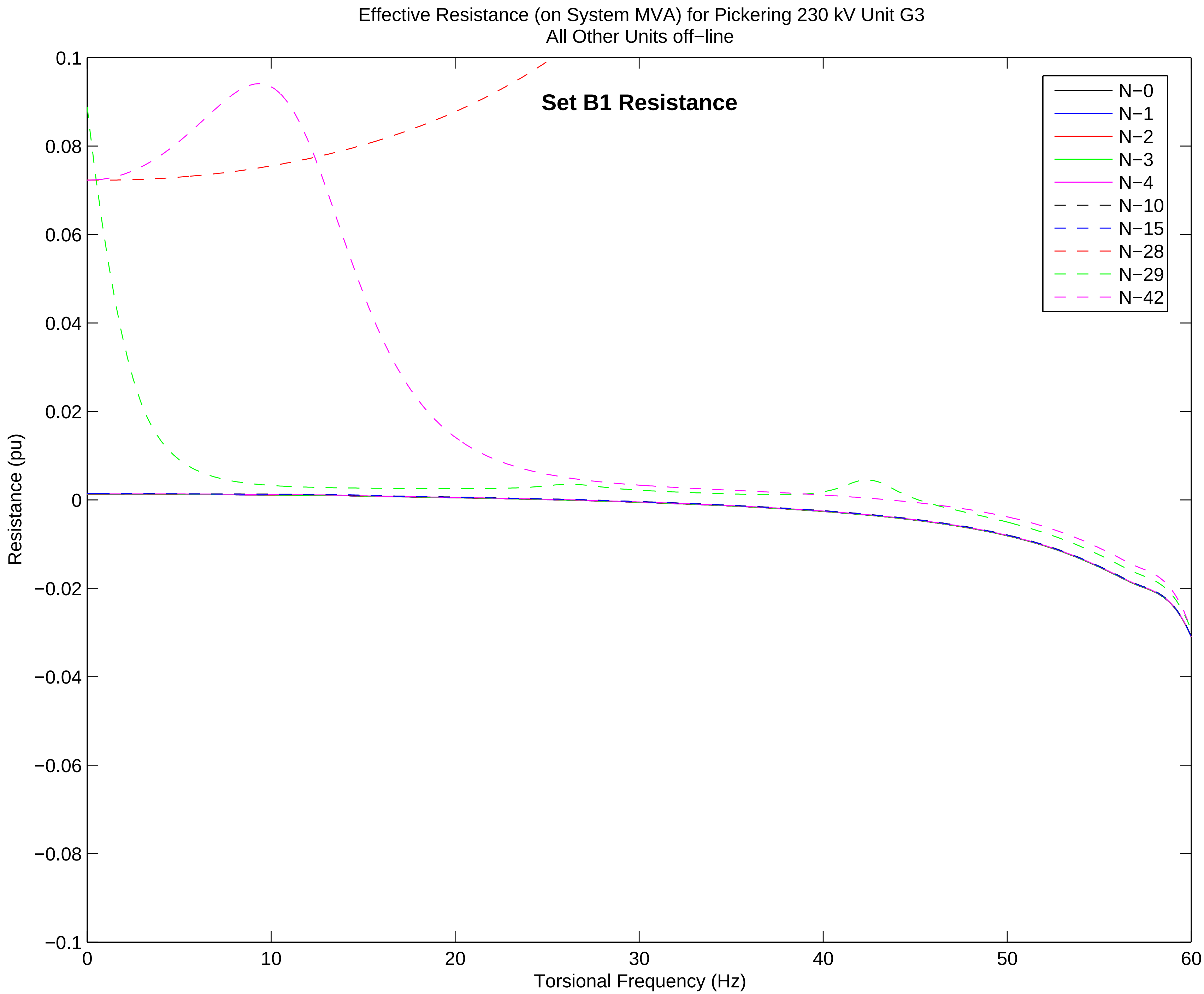
Effective Resistance (on System MVA) for Pickering 230 kV Unit G1
All Other Units off−line
Set A1 Resistance
N−0
N−1
N−2
N−3
N−4
N−9
N−14
N−27
N−28
N−41
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



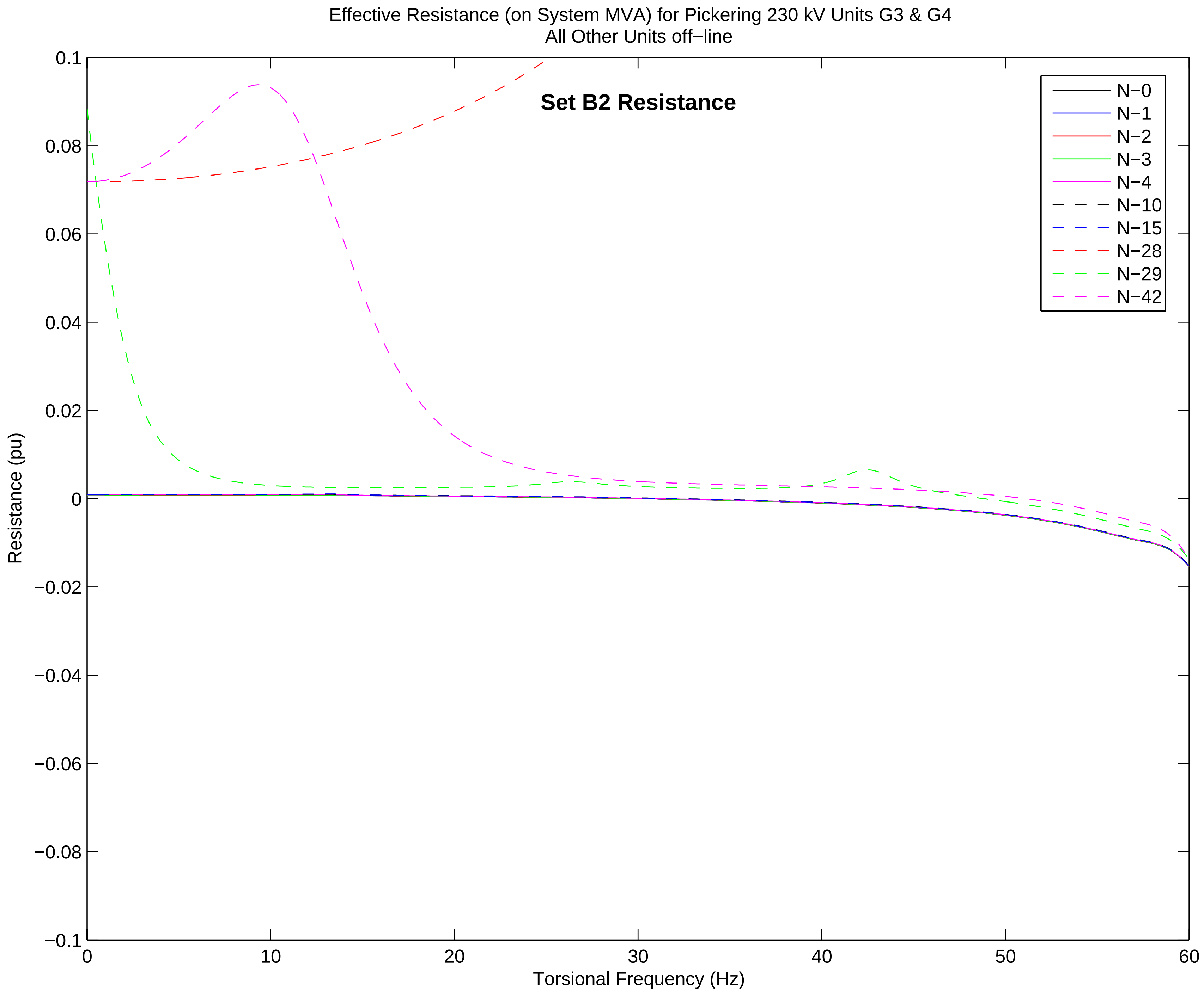
Effective Resistance (on System MVA) for Pickering 230 kV Units G1 & G2
All Other Units off−line
Set A2 Resistance
N−0
N−1
N−2
N−3
N−4
N−9
N−14
N−27
N−28
N−41
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

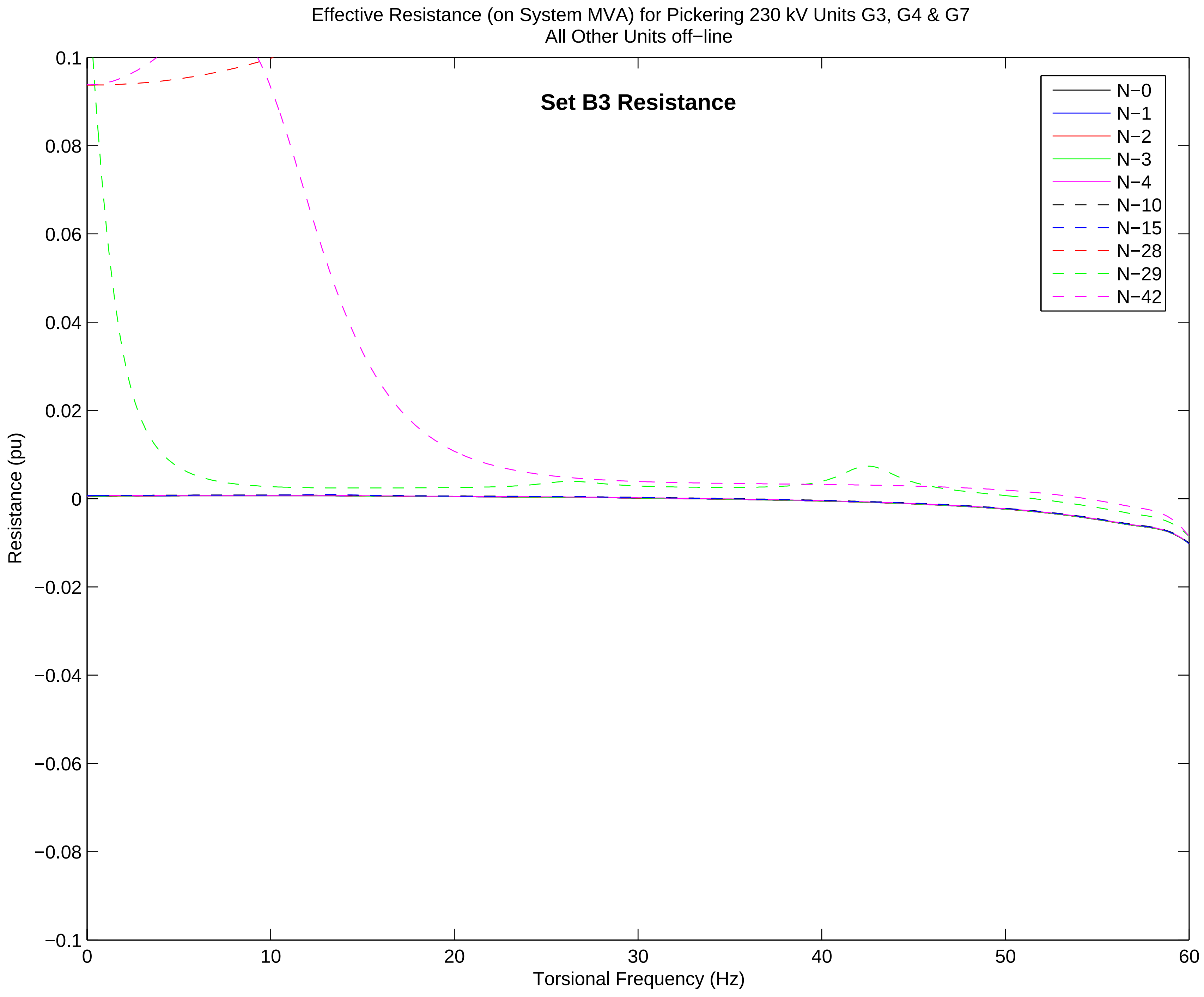


Effective Resistance (on System MVA) for Pickering 230 kV Units G1, G2 & G5
All Other Units off−line
Set A3 Resistance
N−0
N−1
N−2
N−3
N−4
N−9
N−14
N−27
N−28
N−41
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

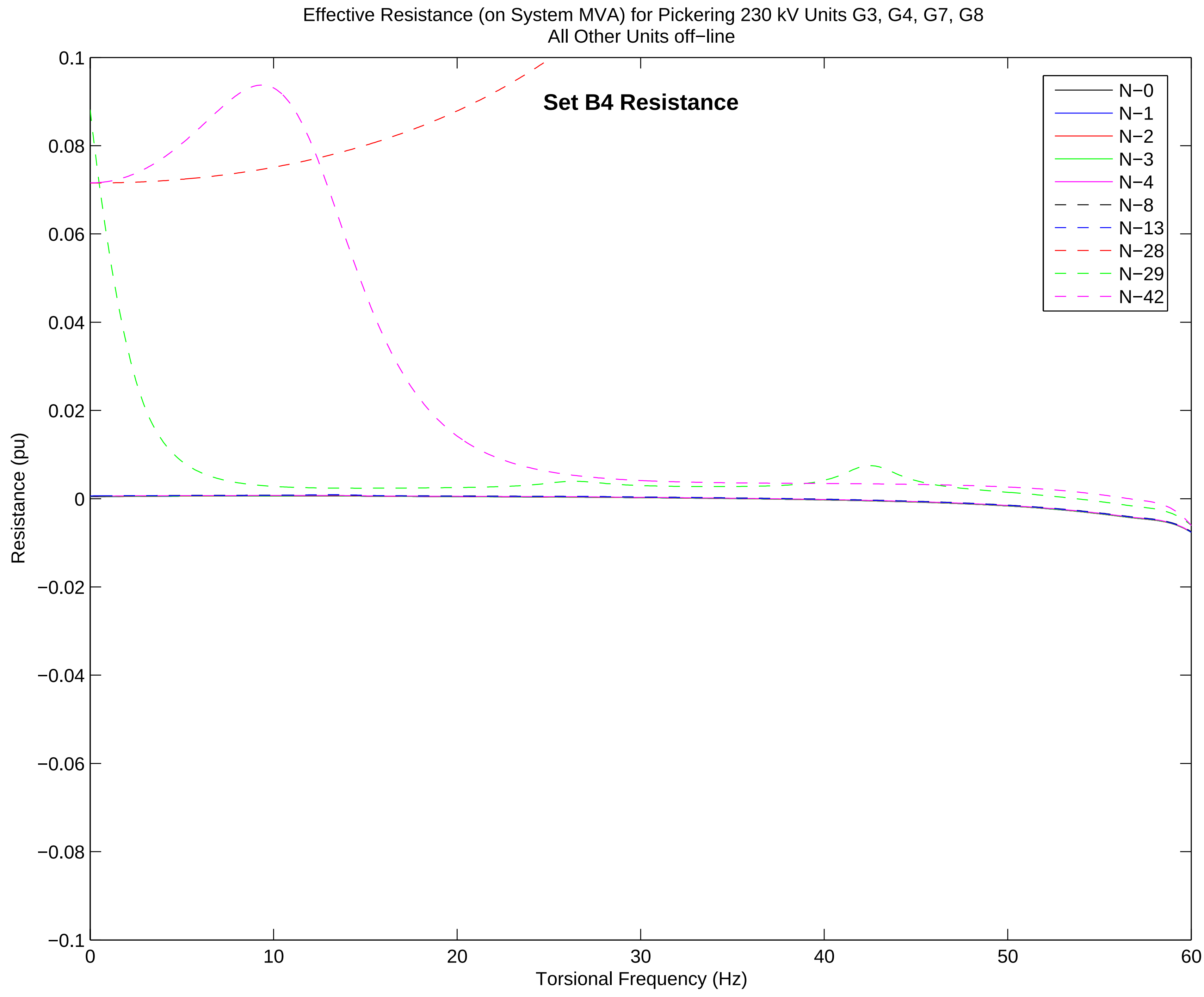


Effective Resistance (on System MVA) for Pickering 230 kV Unit G3
All Other Units off−line
Set B1 Resistance
N−0
N−1
N−2
N−3
N−4
N−10
N−15
N−28
N−29
N−42
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Pickering 230 kV Units G3 & G4
All Other Units off−line
Set B2 Resistance
N−0
N−1
N−2
N−3
N−4
N−10
N−15
N−28
N−29
N−42
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



Effective Resistance (on System MVA) for Pickering 230 kV Units G3, G4 & G7
All Other Units off−line
Set B3 Resistance
N−0
N−1
N−2
N−3
N−4
N−10
N−15
N−28
N−29
N−42
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Pickering 230 kV Units G3, G4, G7, G8
All Other Units off−line
Set B4 Resistance
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
N−0
N−1
N−2
N−3
N−4
N−8
N−13
N−28
N−29
N−42

APPENDIX H: Darlington Frequency Scan

Appendix H – Darlington

This appendix contains 1) the electrical damping plots and 2) the effective resistance plots for the Darlington generators. The electrical damping plots are provided first, ordered by generator combination (Set ID) as identified in Table H-1 below. The effective resistance plots are then provided in the same order.

Table H-1: Generator Combinations

	Darlington Generators			
Set ID	G1	G2	G3	G4
A1	√			
A2	√	√		
A3	√	√	√	
A4	√	√	√	√

√ - indicates the generator is in-service

Table H-2: Contingency Descriptions

Contingency ID	Lennox – Bowmanville 500kV Line 1	Lennox – Bowmanville 500kV Line 2	Lennox – Bowmanville 500kV Line 3	Lennox – Bowmanville 500kV Line 4	Bowmanville – Cherrywood 500kV Line 1	Bowmanville – Cherrywood 500kV Line 2	Bowmanville – Cherrywood 500kV Line 3	Bowmanville – Cherrywood 500kV Line 4
N-0								
N-1	X							
N-1a					X			
N-1b							X	
N-2	X	X						
N-2a	X				X			
N-2b	X						X	
N-2c					X	X		
N-2d					X		X	
N-2e							X	X
N-3	X	X	X					
N-3a	X	X			X			
N-3b	X	X					X	
N-3c	X				X	X		
N-3d	X				X		X	
N-3e	X						X	X
N-3f					X	X	X	
N-3g					X		X	X

(continued below)

Table H-2: Contingency Descriptions (continued)

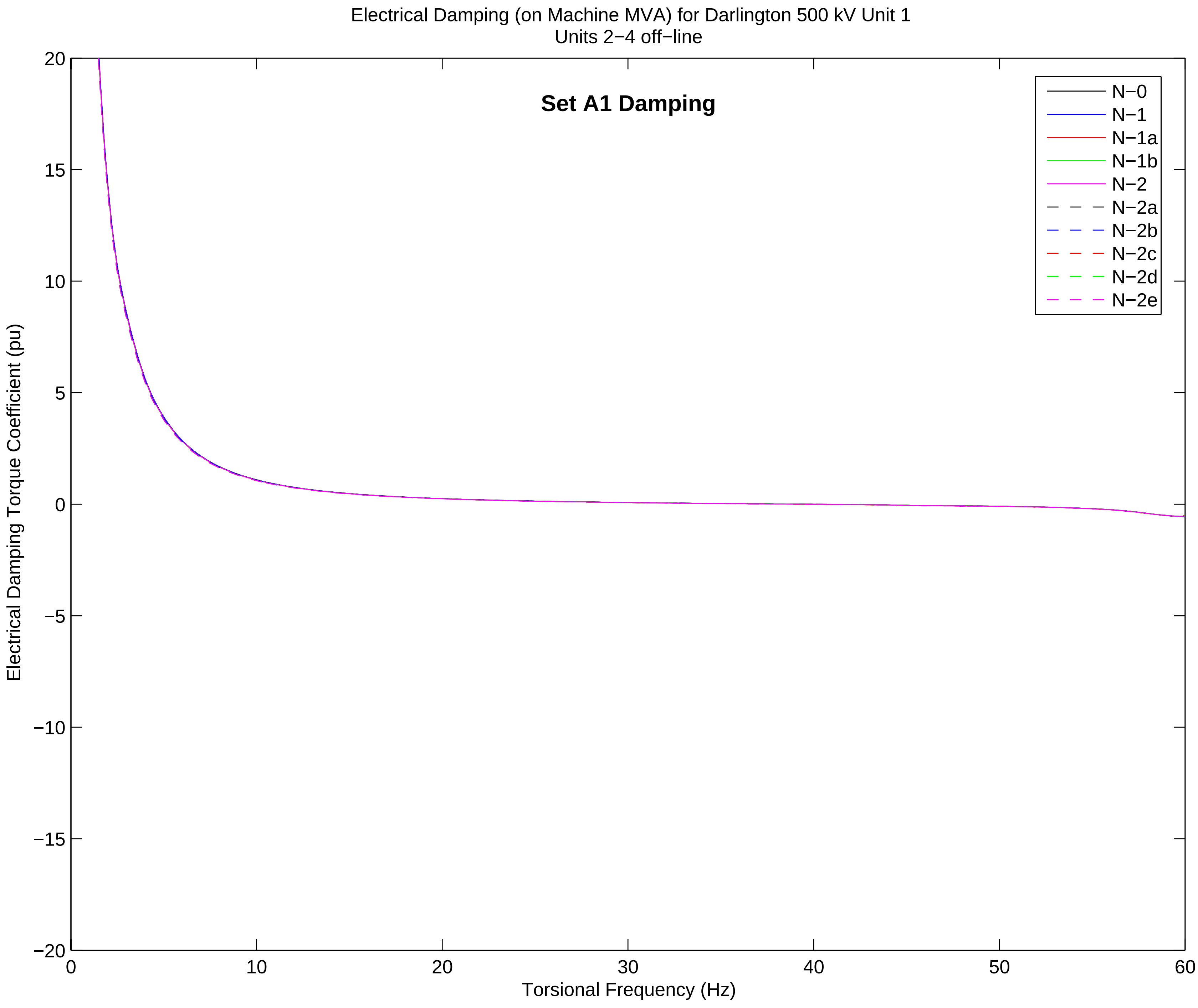
Contingency ID	Lennox – Bowmanville 500kV Line 1	Lennox – Bowmanville 500kV Line 2	Lennox – Bowmanville 500kV Line 3	Lennox – Bowmanville 500kV Line 4	Bowmanville – Cherrywood 500kV Line 1	Bowmanville – Cherrywood 500kV Line 2	Bowmanville – Cherrywood 500kV Line 3	Bowmanville – Cherrywood 500kV Line 4
N-4	X	X	X	X				
N-4a	X	X	X		X			
N-4b	X	X	X				X	
N-4c	X	X			X	X		
N-4d	X	X			X		X	
N-4e	X	X					X	X
N-4f	X				X	X	X	
N-4g	X				X		X	X
N-19	See Table H-3							
N-20	See Table H-3							
N-33	See Table H-3							

X – indicates the branch is out-of-service

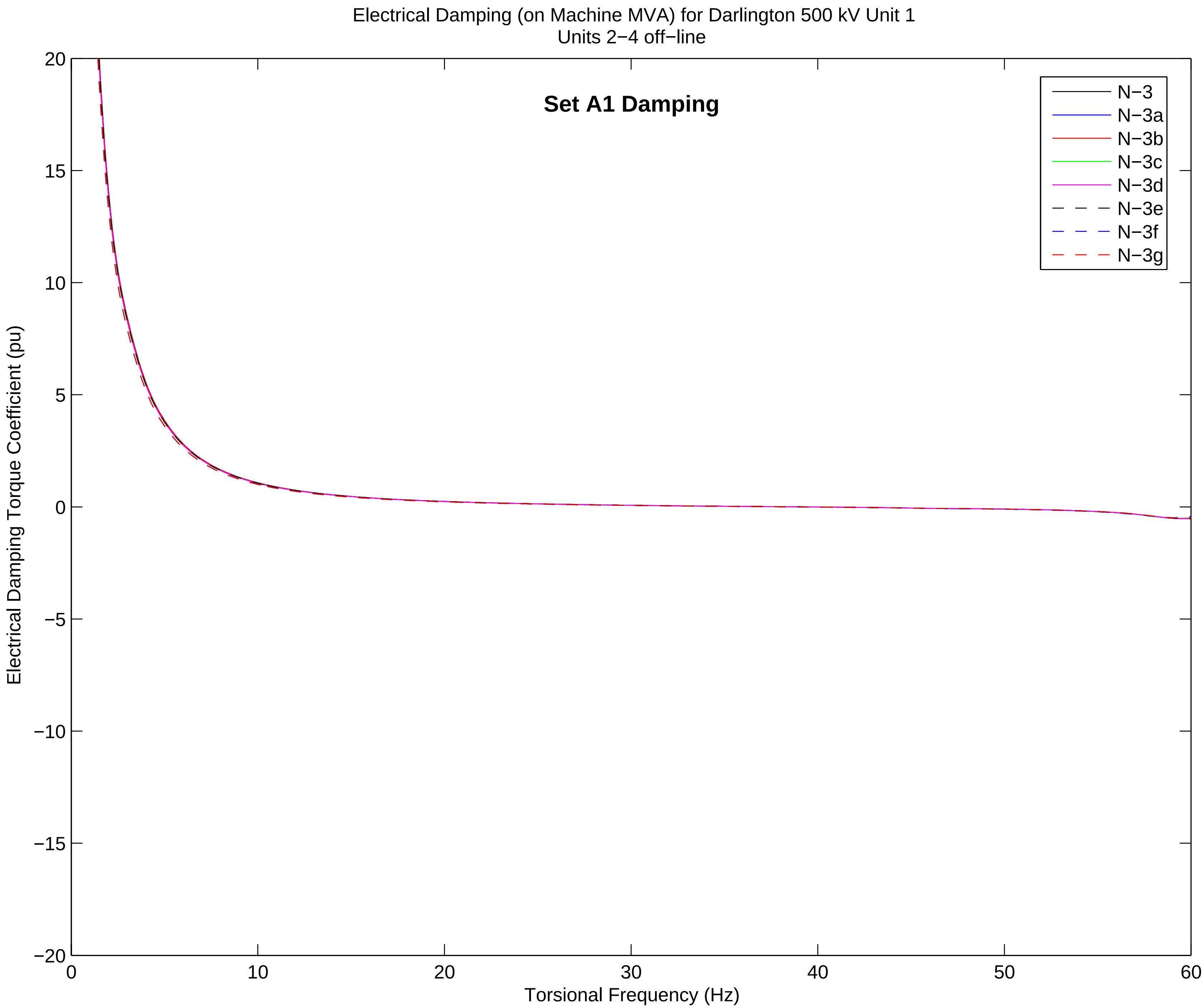
Table H-3: Extensive Contingencies

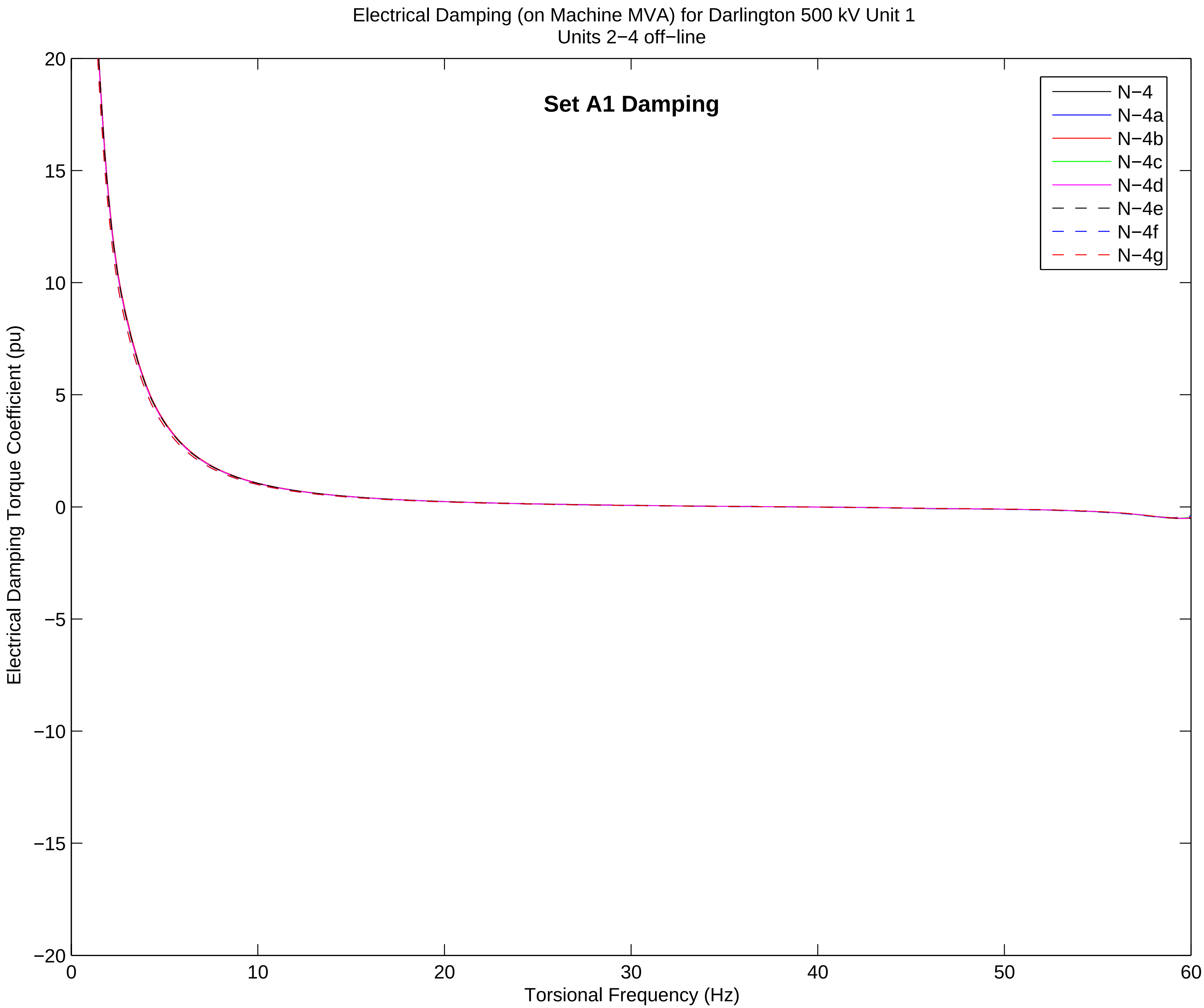
Element	Contingency		
	N-19	N-20	N-33
Lennox – Bowmanville 500kV Line 1	X	X	X
Lennox – Bowmanville 500kV Line 2	X	X	X
Lennox – Bowmanville 500kV Line 3	X	X	X
Lennox – Bowmanville 500kV Line 4	X	X	X
Cherrywood 500/230kV Transformer 14	X	X	X
Cherrywood 500/230kV Transformer 15	X	X	X
Cherrywood 500/230kV Transformer 16	X	X	X
Cherrywood 500/230kV Transformer 17	X	X	X
Parkway 500kV/230kV/27.6kV Transformer	X	X	X
Clairville – Milton Bypass 500kV Line 1	X	X	
Clairville – Milton Bypass 500kV Line 2	X	X	X
Clairville – Essa 500kV Line 1	X	X	X
Clairville – Essa 500kV Line 1	X	X	X
Clairville 500kV/230kV Transformer 13	X	X	X
Clairville 500kV/230kV Transformer 14	X	X	X
Clairville 500kV/230kV Transformer 15	X	X	X
Clairville 500kV/230kV Transformer 16	X	X	X
Clairville – Milton Line 1	X		
Clairville – Milton Line 1	X		
Milton – Trafal72 500kV Line		X	X
Milton – Trafal73 500kV Line		X	X
Milton – Midd8185 500kV Line		X	X
Milton – Bruce B Series Cap			X
Midd8086-Middldk1 500kV/230kV Transformer T3			X
Midd8185-Middldk2 500kV/230kV Transformer T6			X
Nanticoke 500kV/230kV Transformer T11			X
Nanticoke 500kV/230kV Transformer T12			X
Nanticoke 500kV/22kV Transformer T54			X
Nanticoke 500kV/22kV Transformer T55			X
Nanticoke 500kV/22kV Transformer T56			X
Nanticoke 500kV/22kV Transformer T57			X
Longwood 500kV/230kV/27.6kV Transformer T11			X
Longwood 500kV/230kV/27.6kV Transformer T12			X
Longwood 500kV/230kV/27.6kV Transformer T13			X
Longwood 500kV/230kV/27.6kV Transformer T14			X
Longwood 500kV/230kV/27.6kV Transformer T15			X

X – indicates the branch is out-of-service

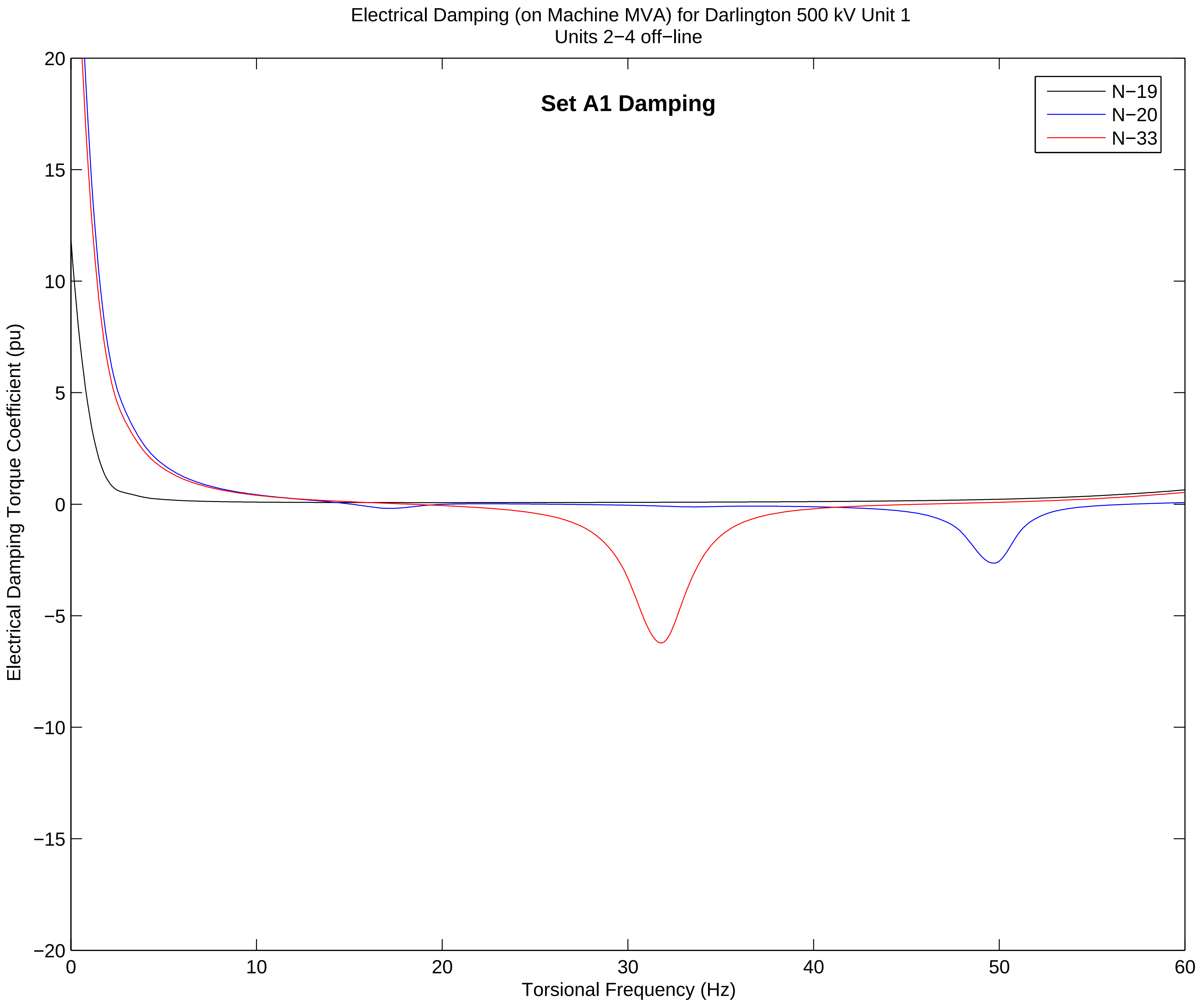


Electrical Damping (on Machine MVA) for Darlington 500 kV Unit 1
Units 2−4 off−line
Set A1 Damping
N−0
N−1
N−1a
N−1b
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

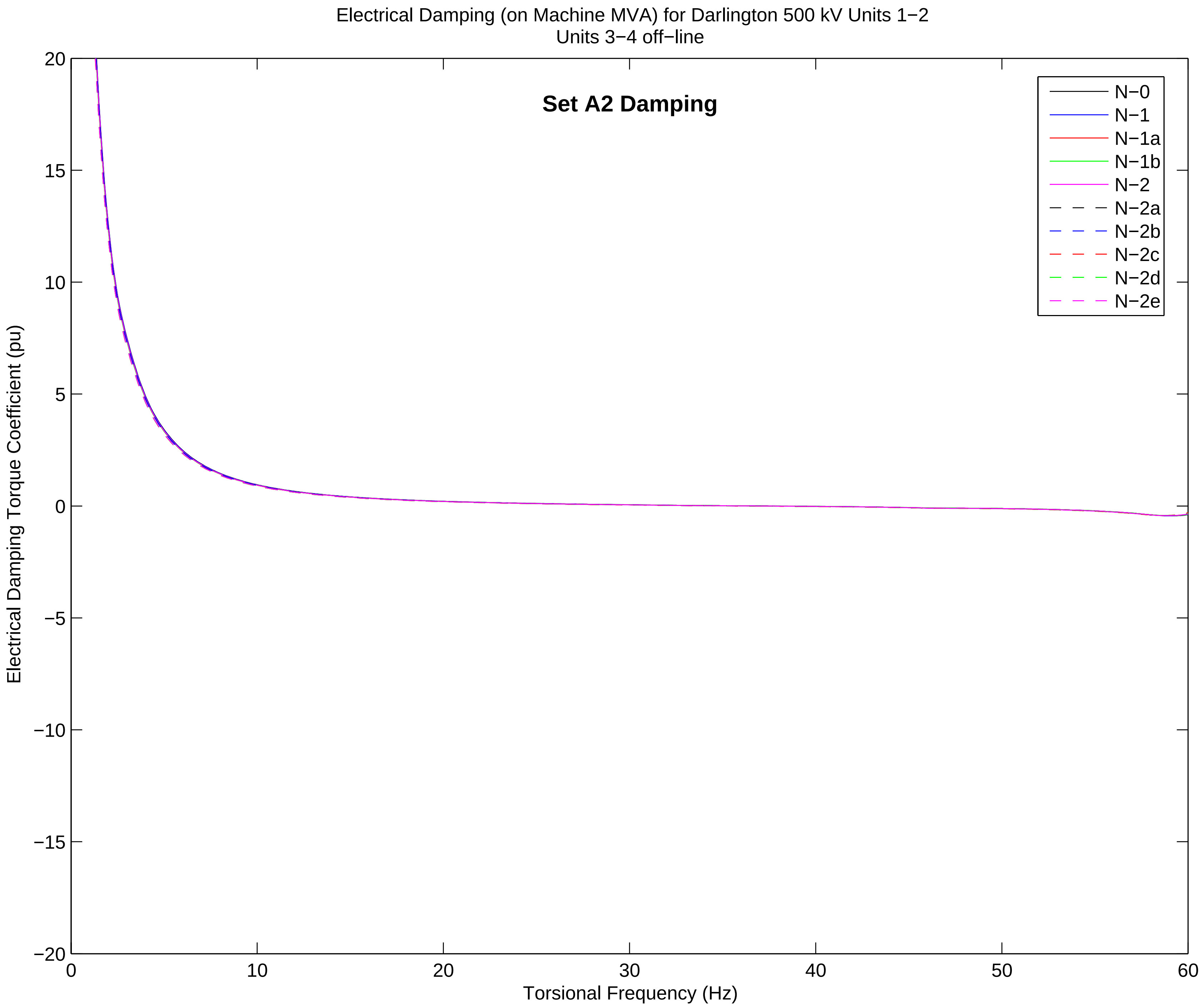

Electrical Damping (on Machine MVA) for Darlington 500 kV Unit 1
Units 2−4 off−line
Set A1 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



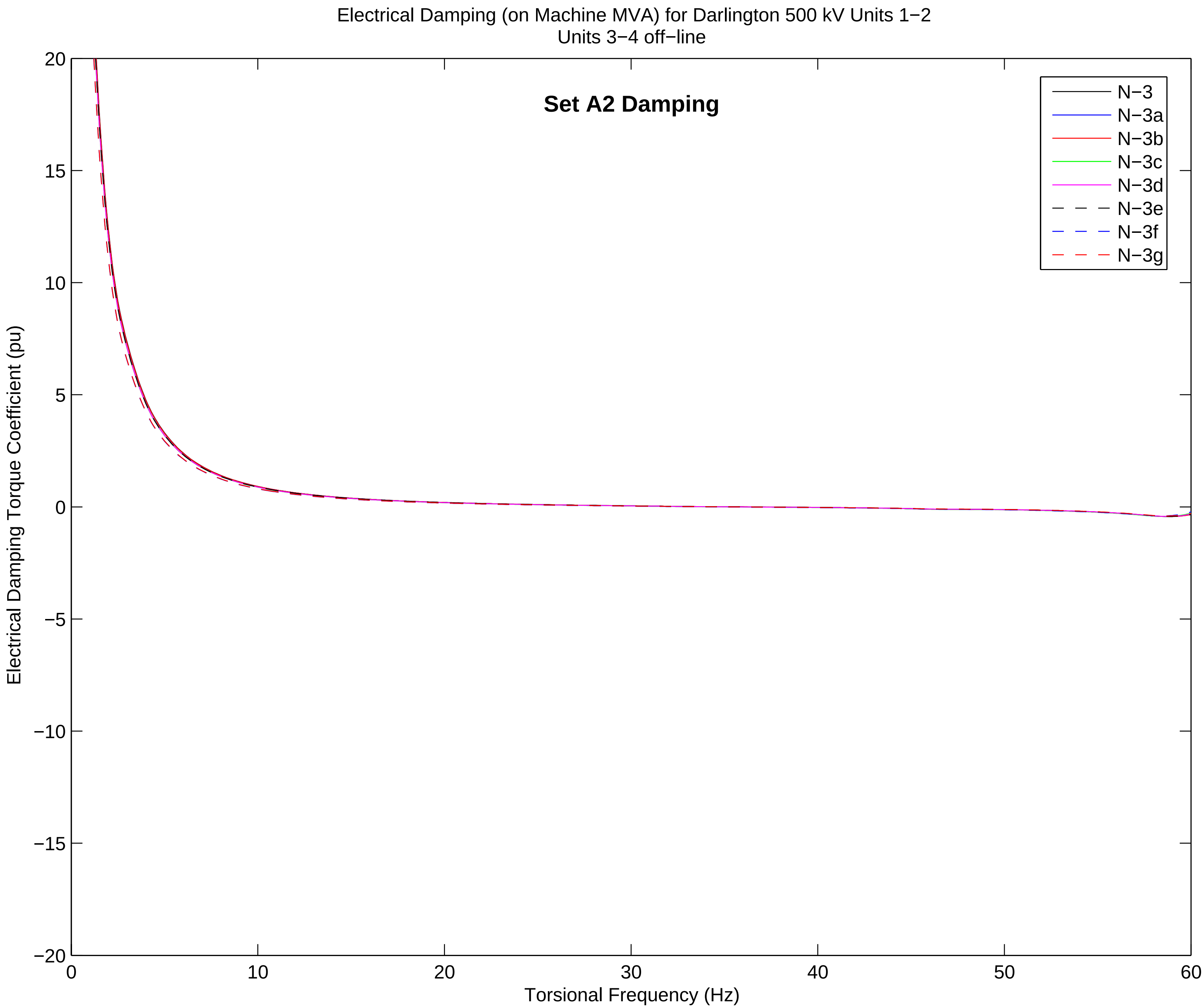
Electrical Damping (on Machine MVA) for Darlington 500 kV Unit 1
Units 2−4 off−line
Set A1 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



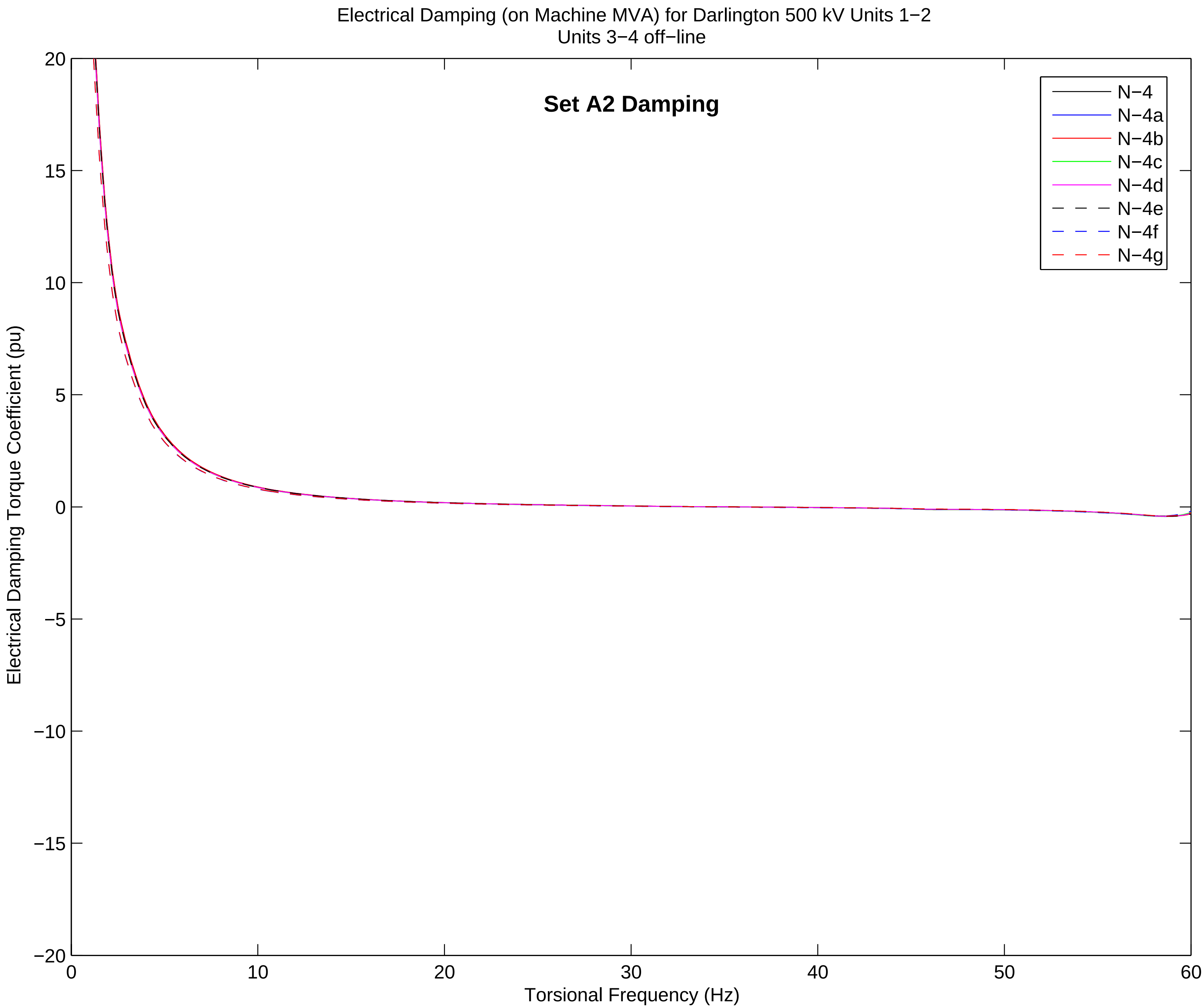
Electrical Damping (on Machine MVA) for Darlington 500 kV Unit 1
Units 2−4 off−line
Set A1 Damping
N−19
N−20
N−33
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)
Electrical Damping Torque Coefficient (pu)

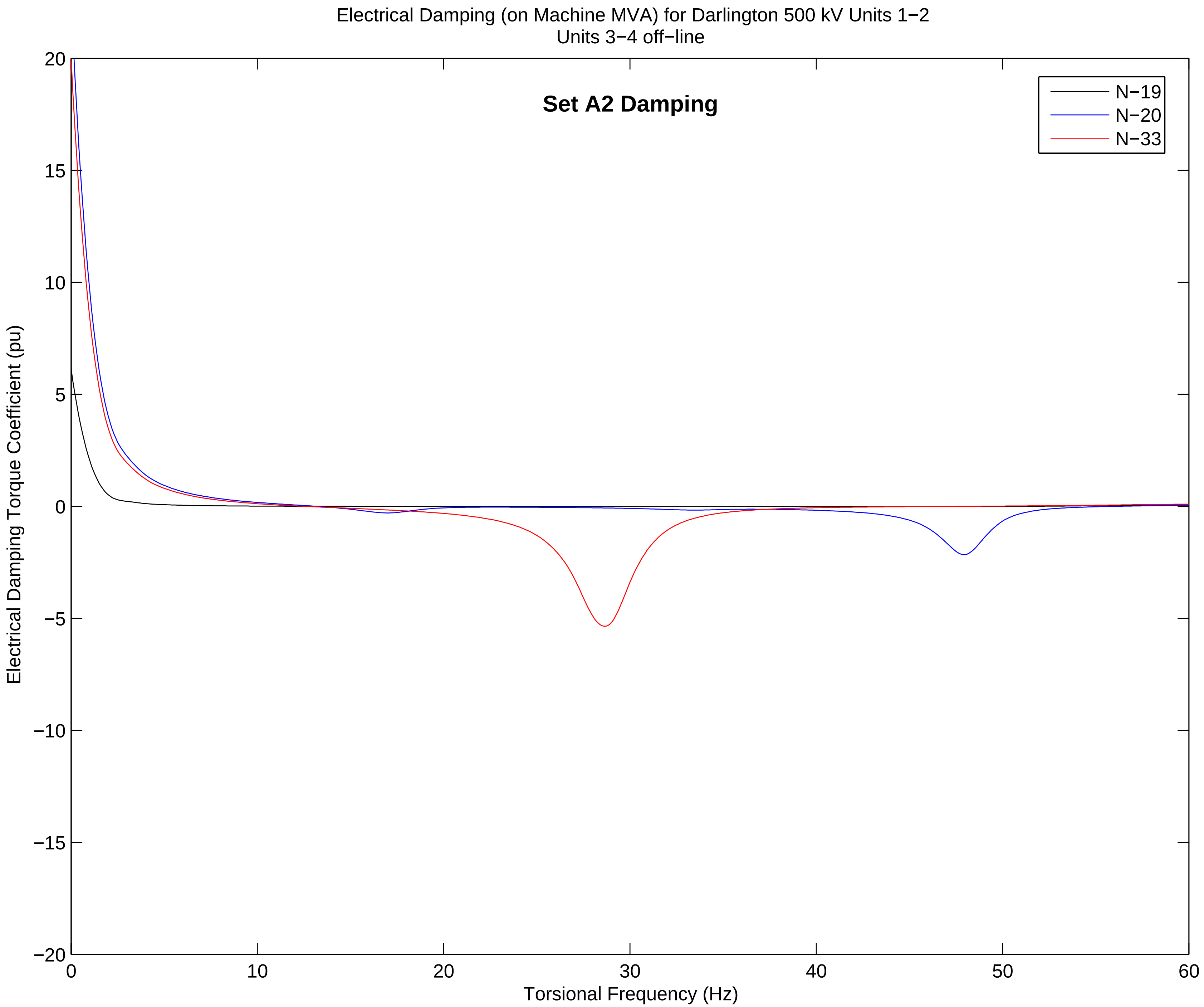


Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−2
Units 3−4 off−line
Set A2 Damping
N−0
N−1
N−1a
N−1b
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
20
15
10
5
0
−5
−10
−15
−20
Electrical Damping Torque Coefficient (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

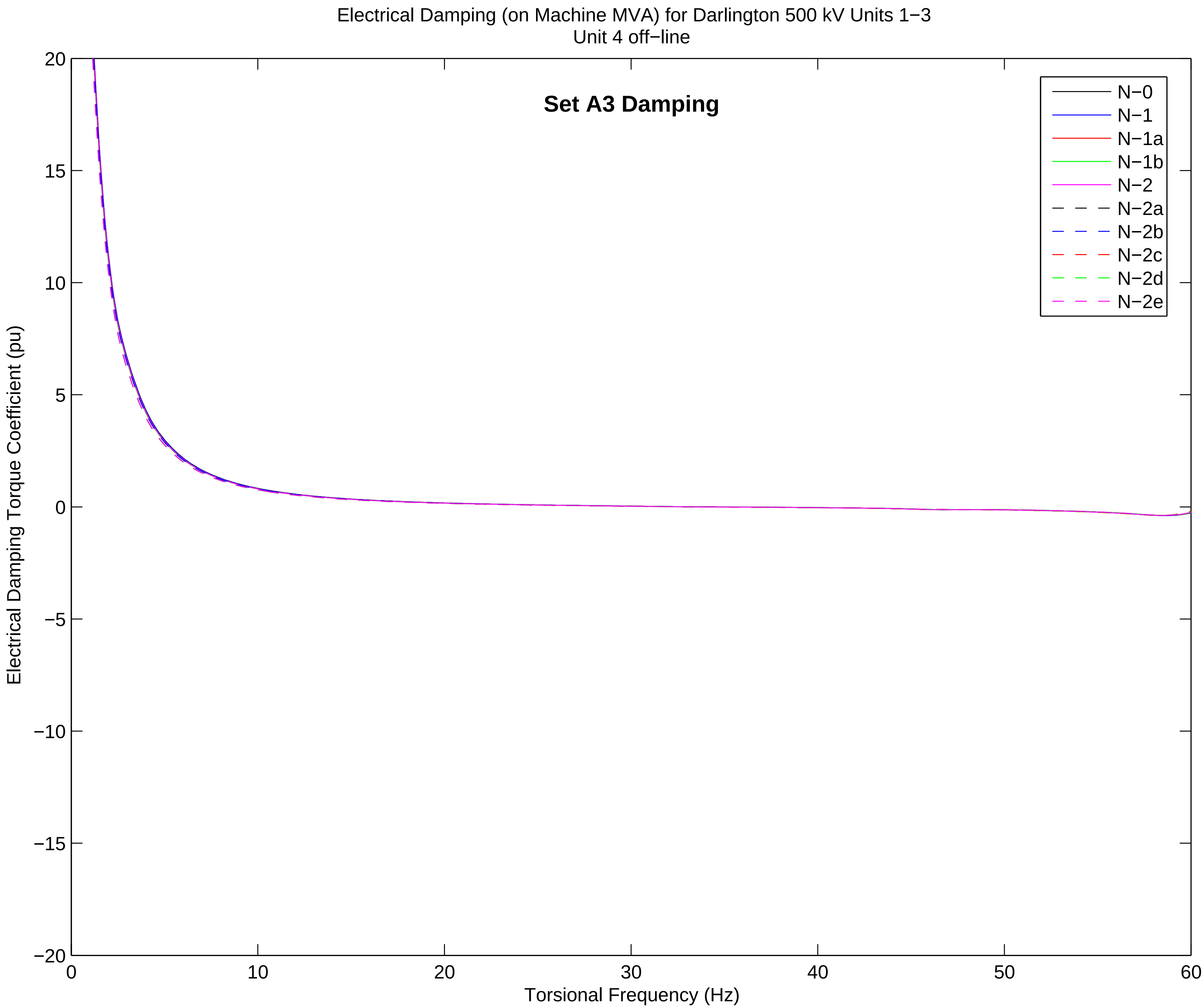


Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−2
Units 3−4 off−line
Set A2 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

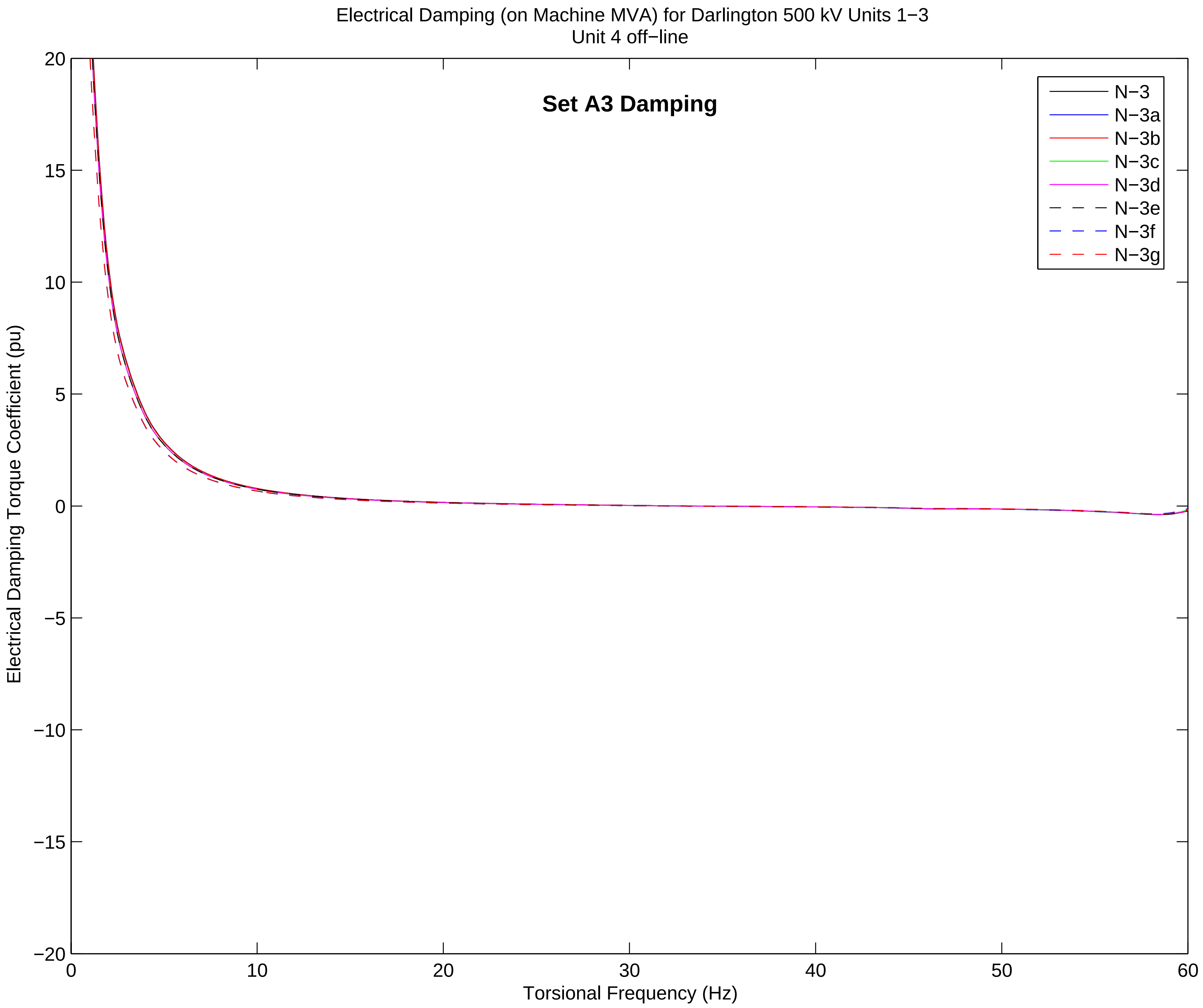

Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−2
Units 3−4 off−line
Set A2 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



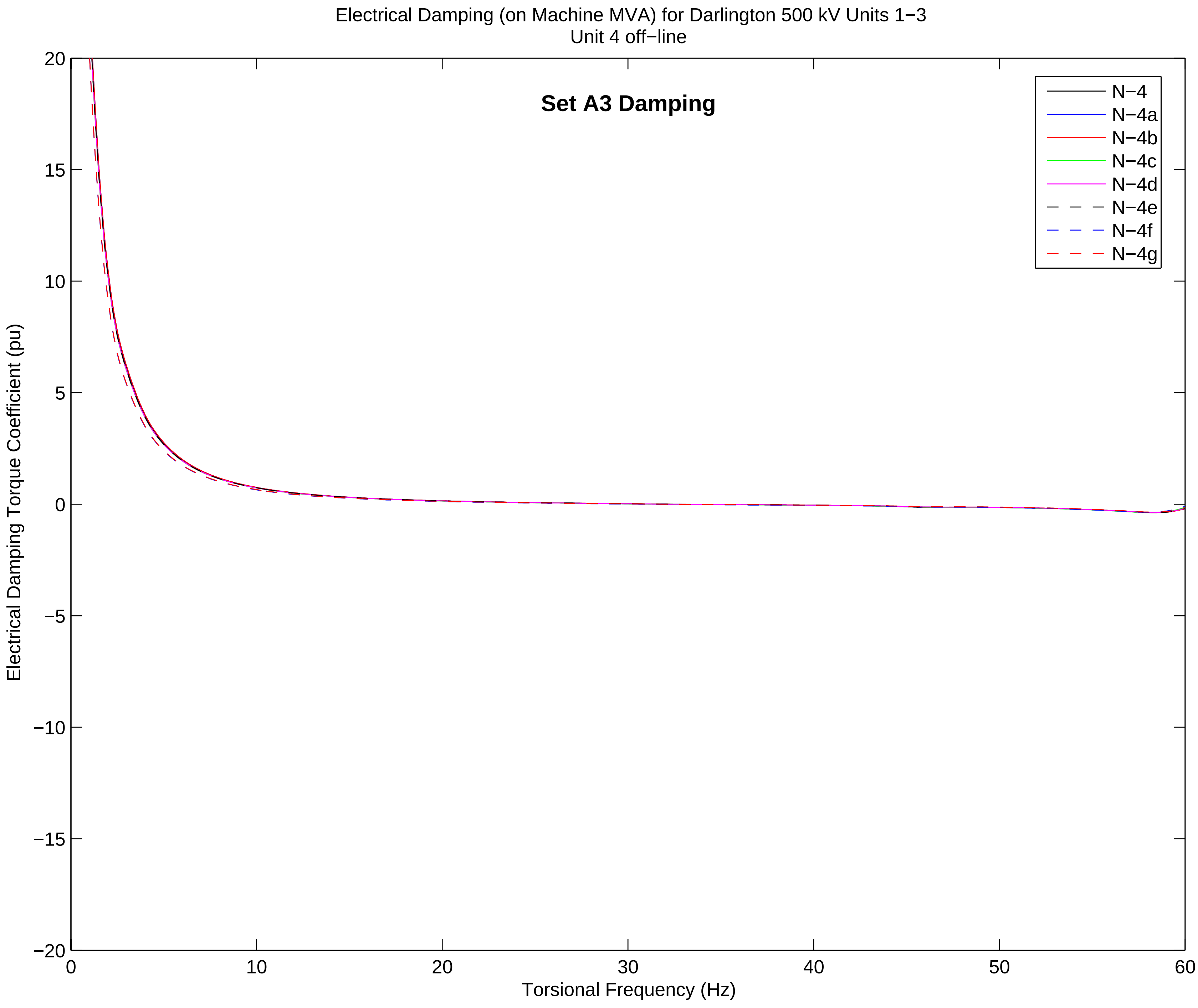
Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−2
Units 3−4 off−line
Set A2 Damping
N−19
N−20
N−33
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)
Electrical Damping Torque Coefficient (pu)



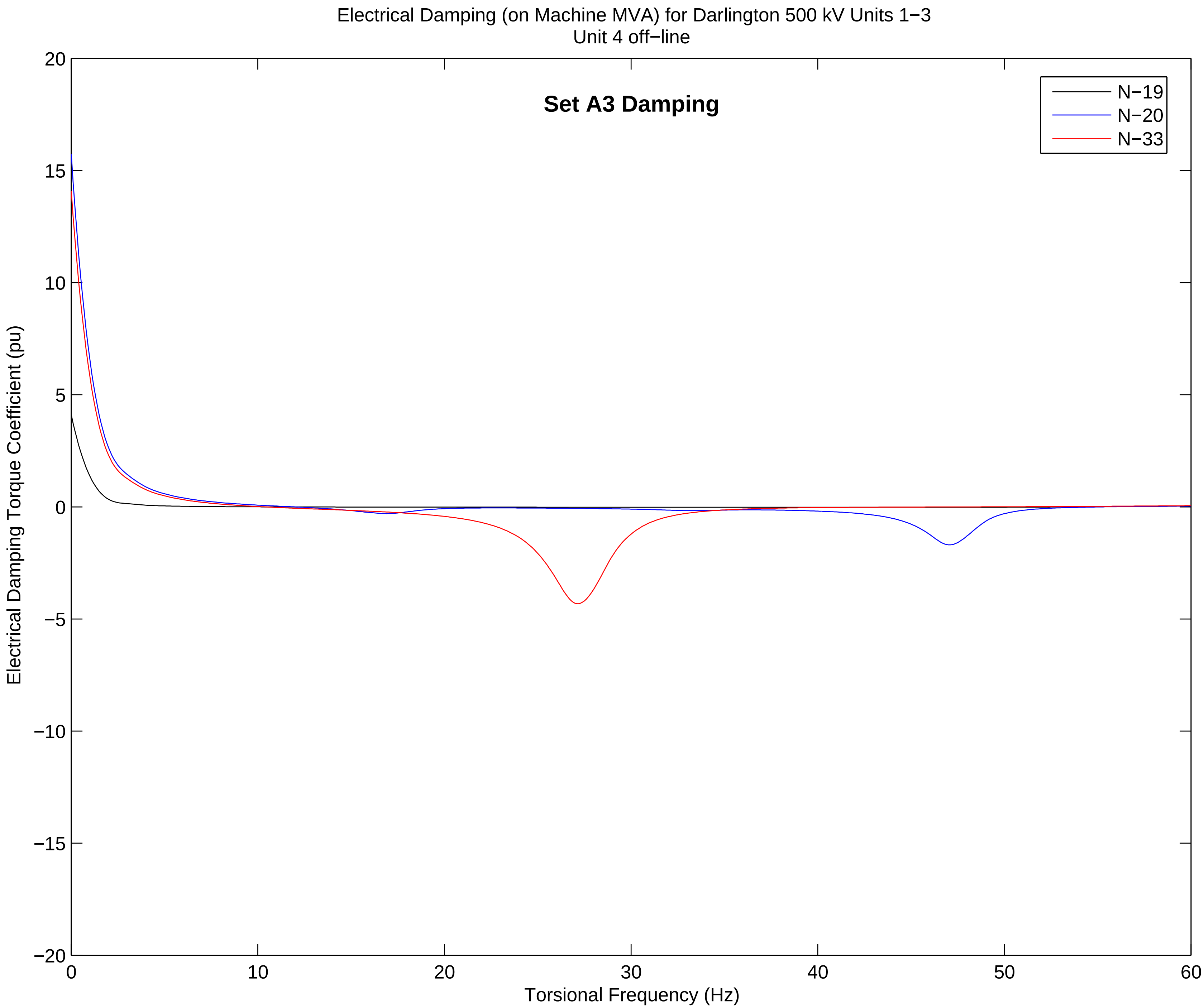
Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−3
Unit 4 off−line
Set A3 Damping
N−0
N−1
N−1a
N−1b
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

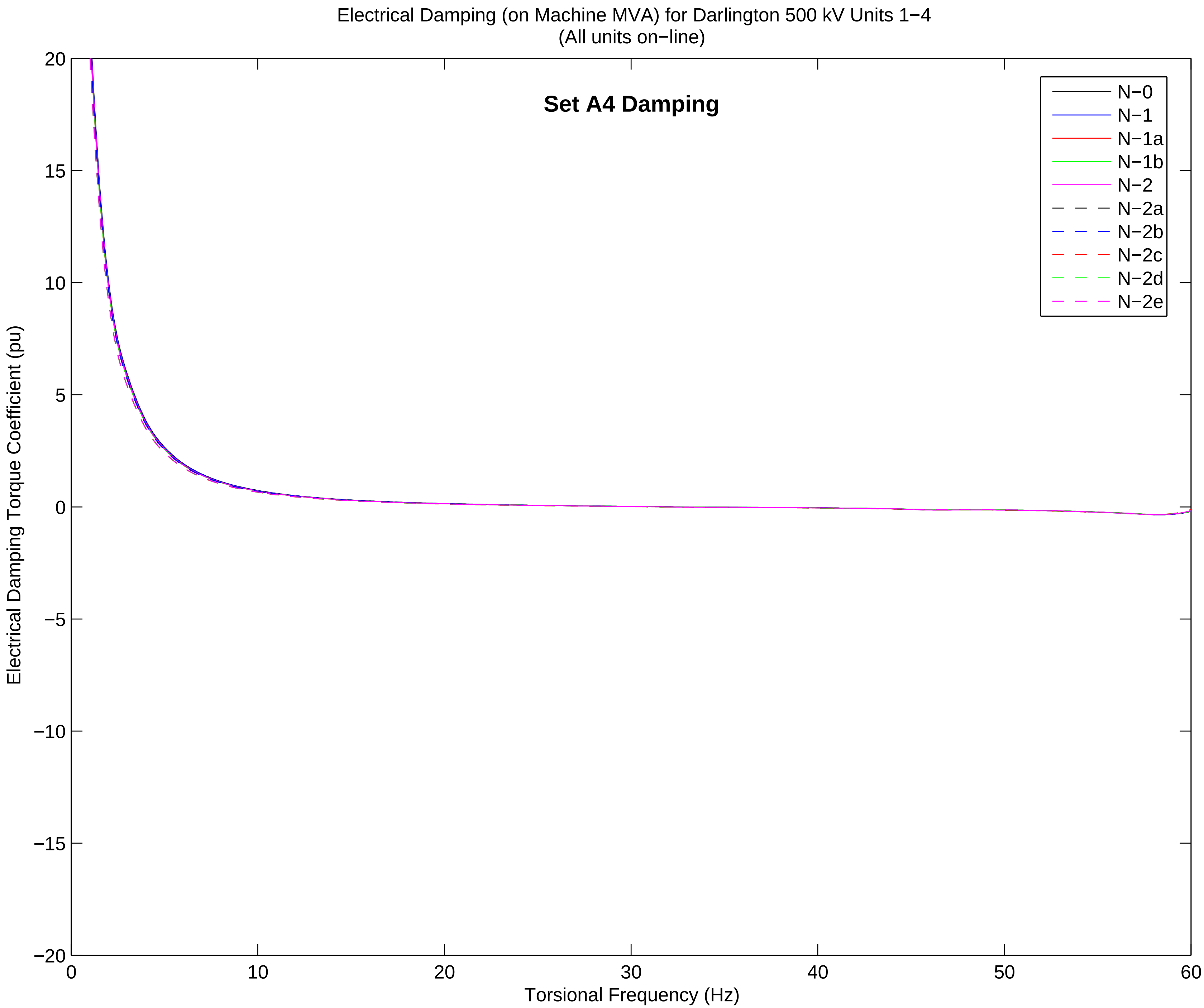


Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−3
Unit 4 off−line
Set A3 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



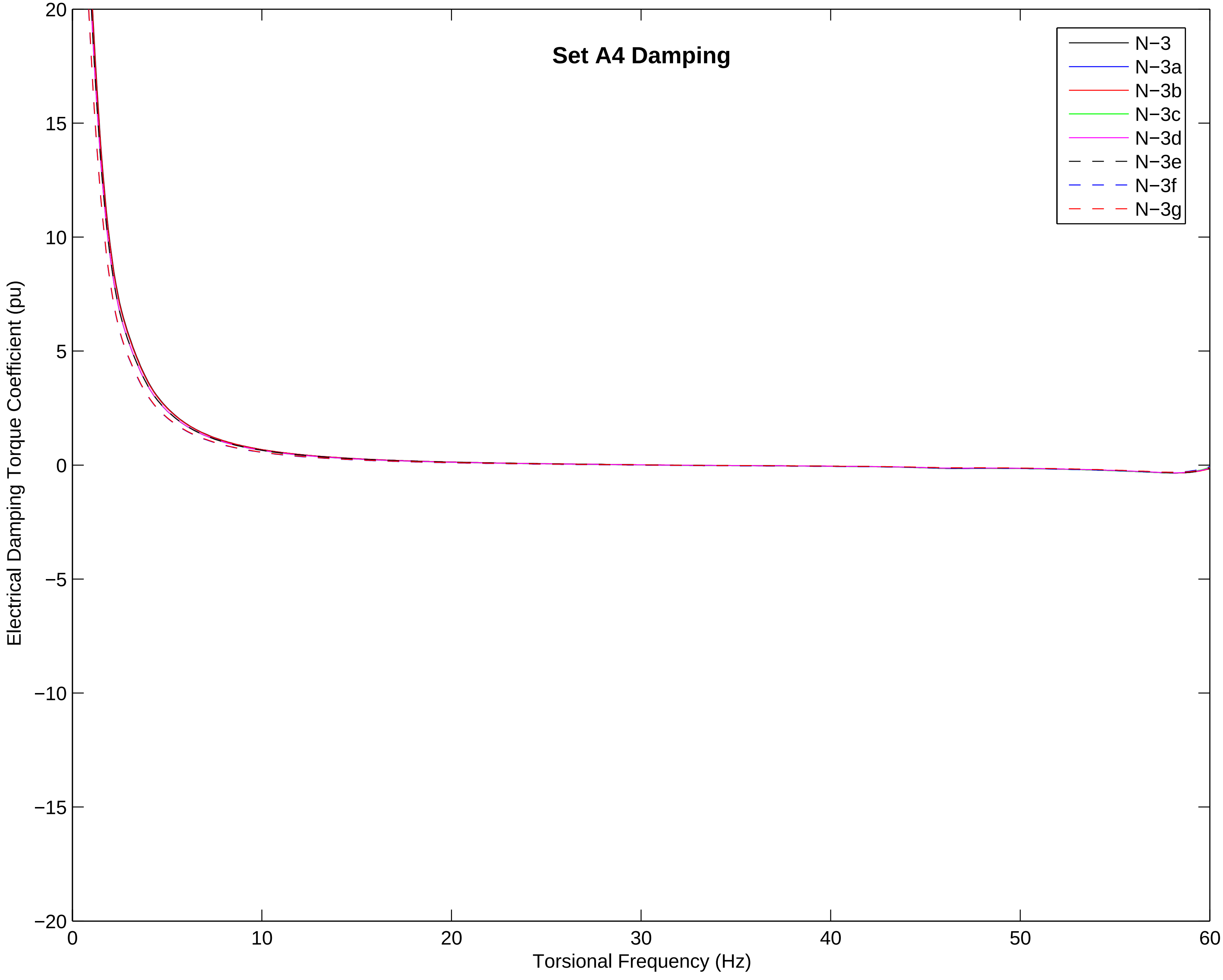
Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−3
Unit 4 off−line
Set A3 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

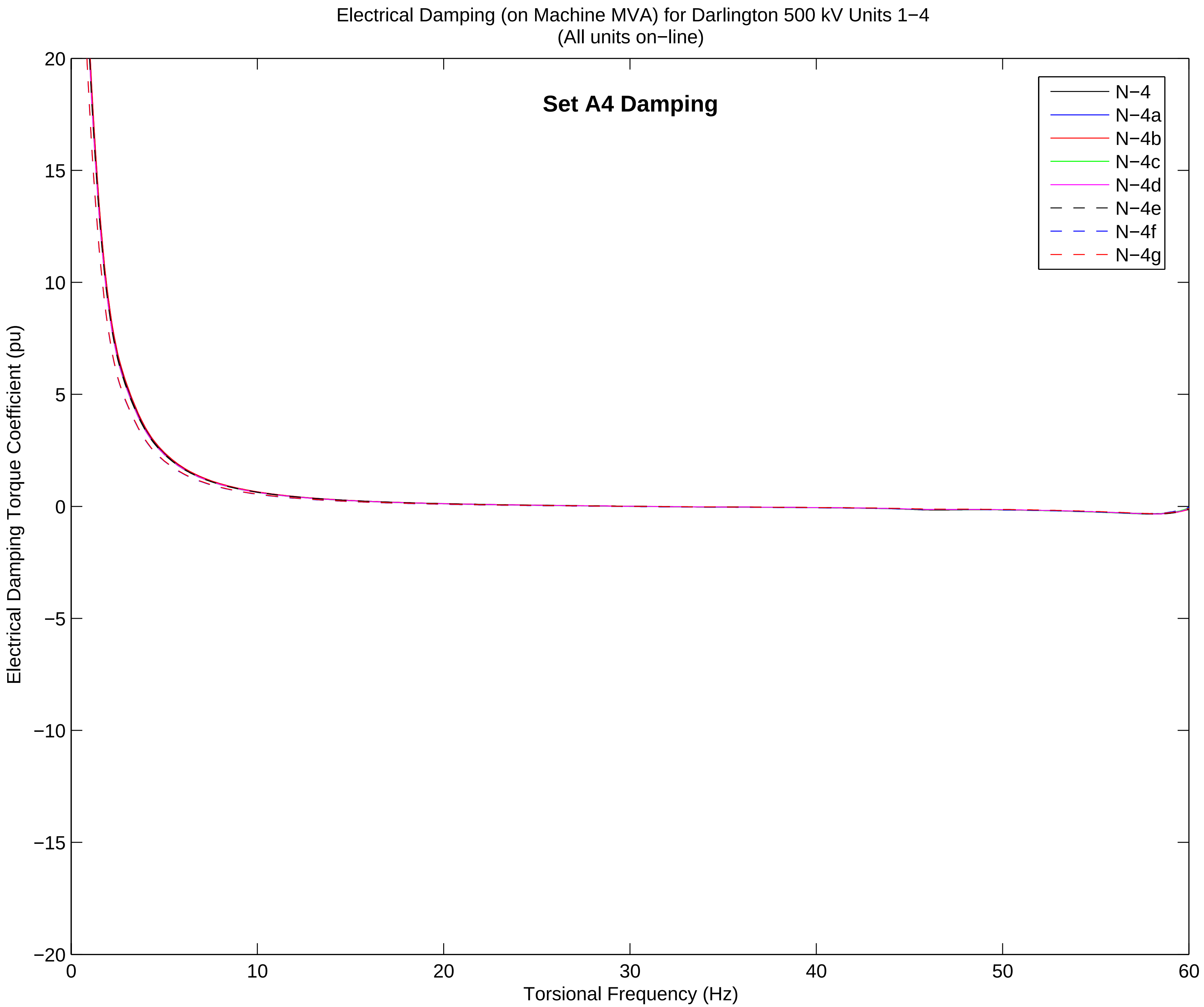

Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−3
Unit 4 off−line
Set A3 Damping
N−19
N−20
N−33
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



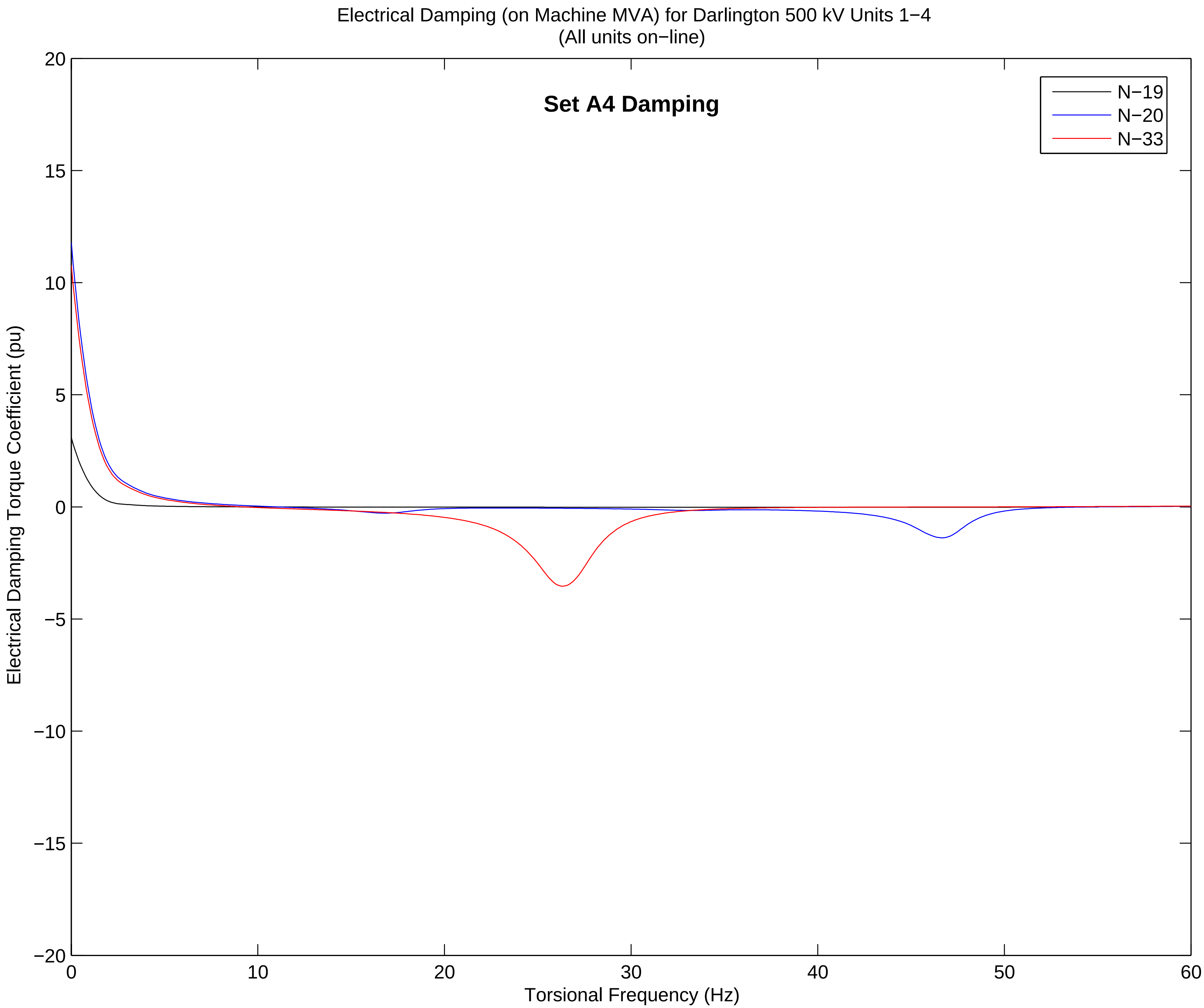
Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−4
(All units on−line)
Set A4 Damping
N−0
N−1
N−1a
N−1b
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

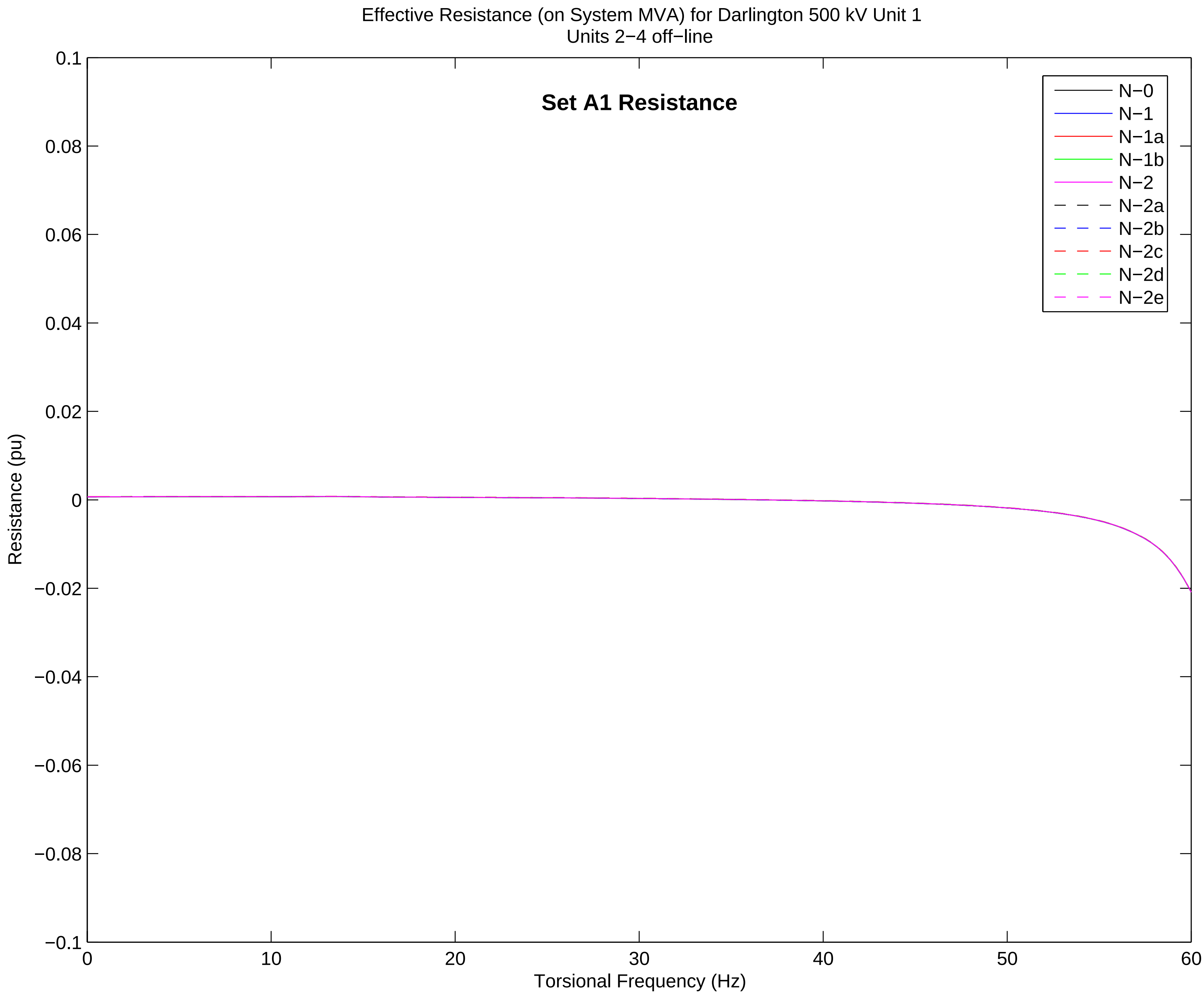
Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−4
(All units on−line)



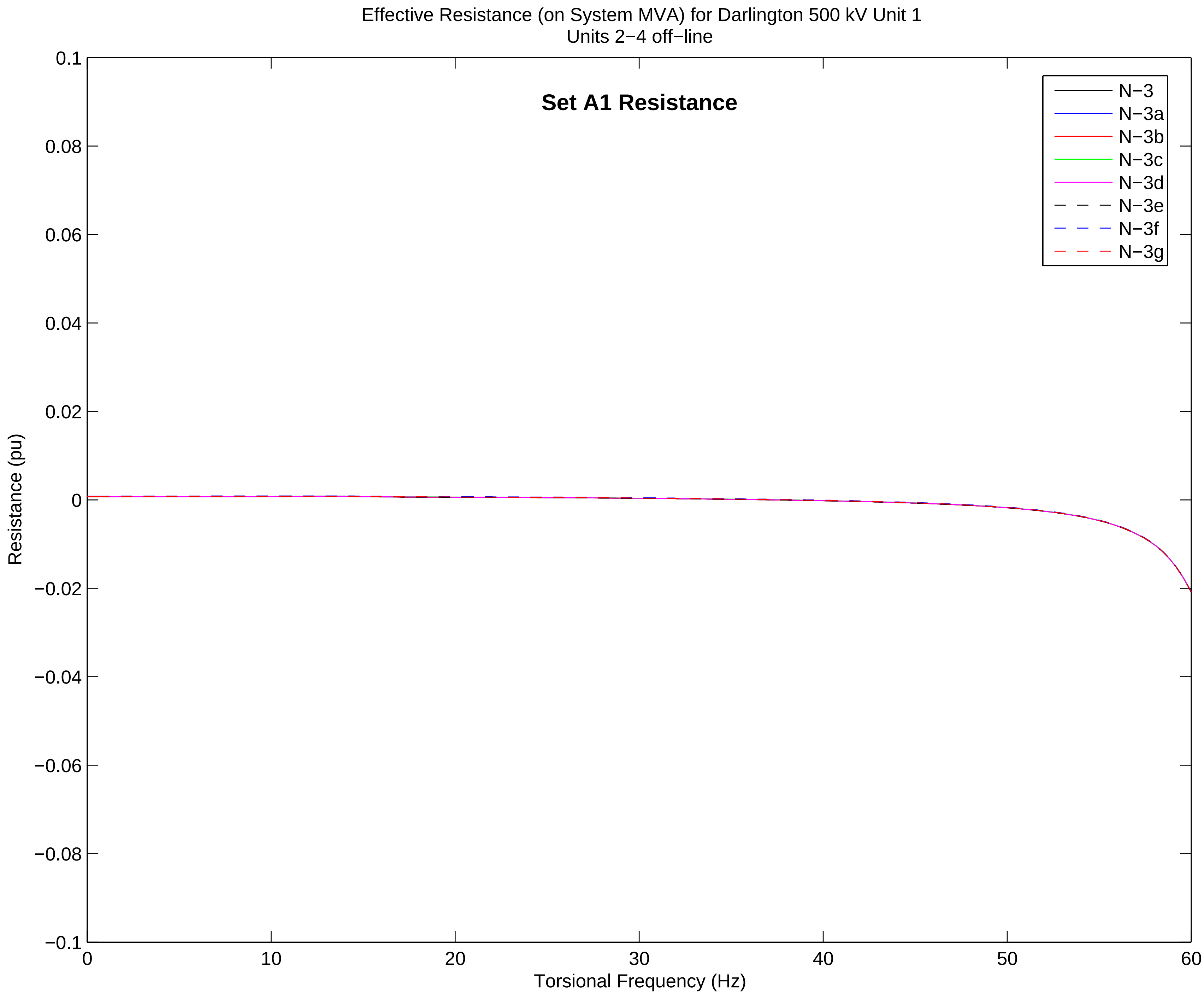


Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−4
(All units on−line)
Set A4 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)
Electrical Damping Torque Coefficient (pu)

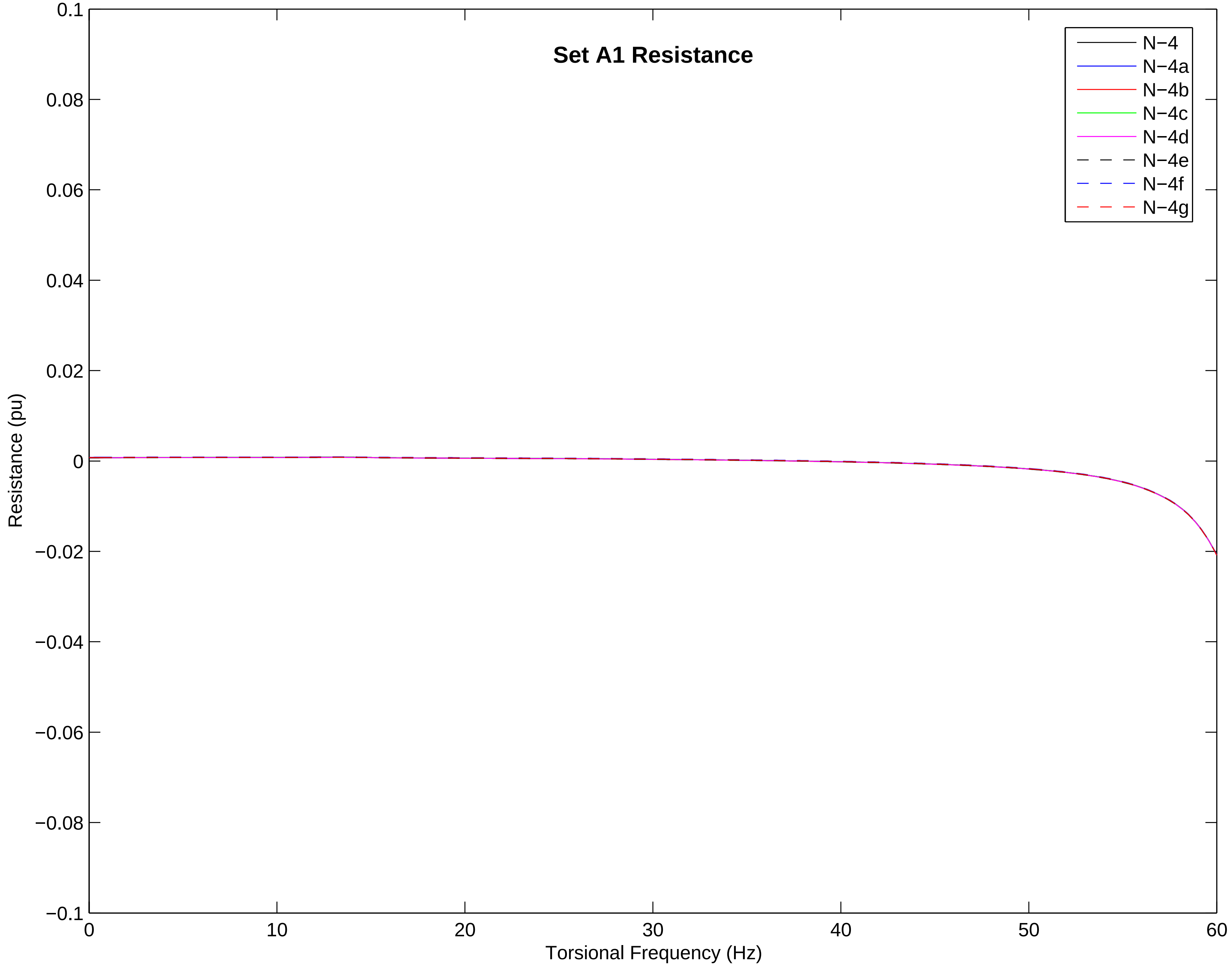

Electrical Damping (on Machine MVA) for Darlington 500 kV Units 1−4
(All units on−line)
Set A4 Damping
N−19
N−20
N−33
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

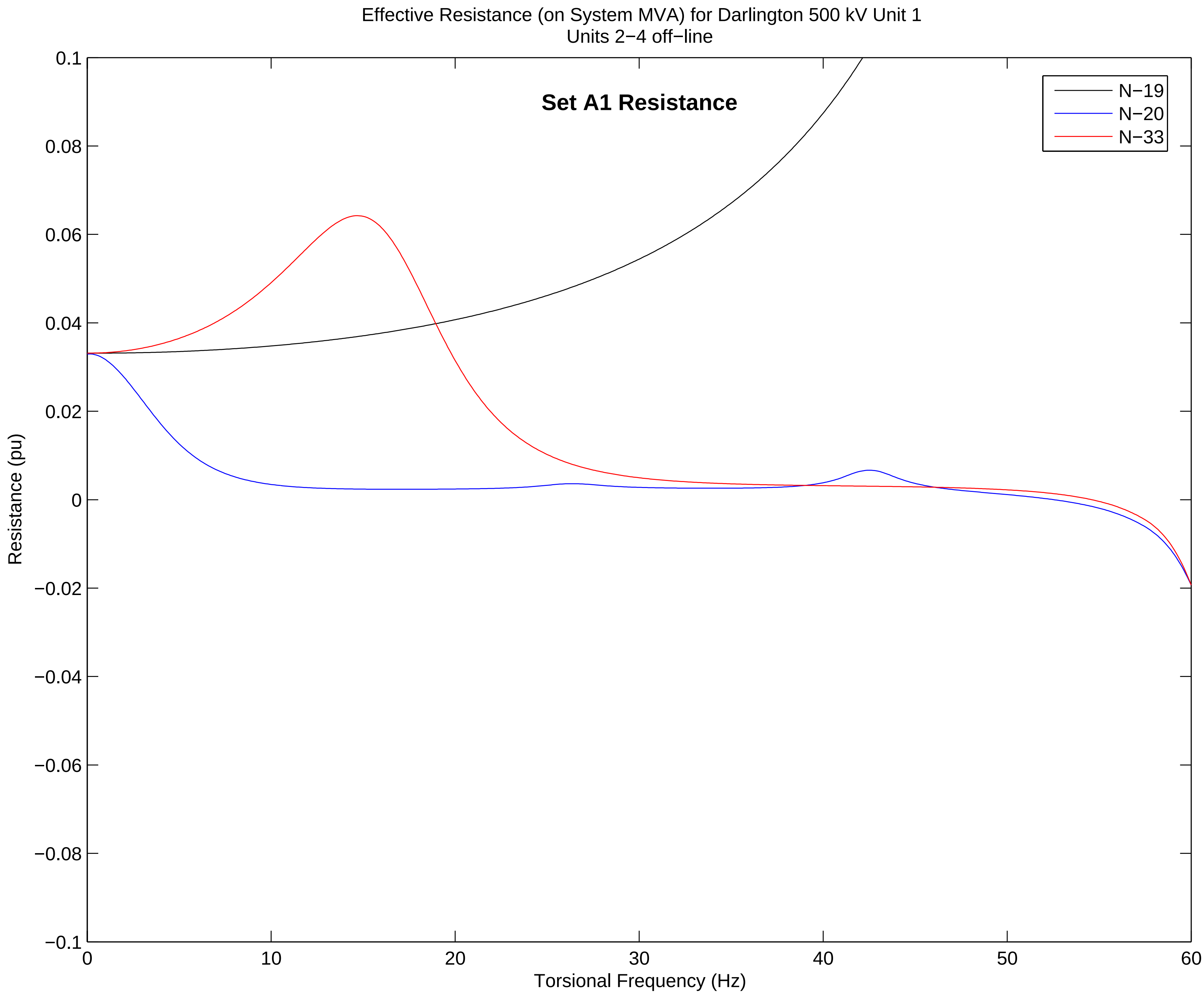


Effective Resistance (on System MVA) for Darlington 500 kV Unit 1
Units 2−4 off−line
Set A1 Resistance
N−0
N−1
N−1a
N−1b
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

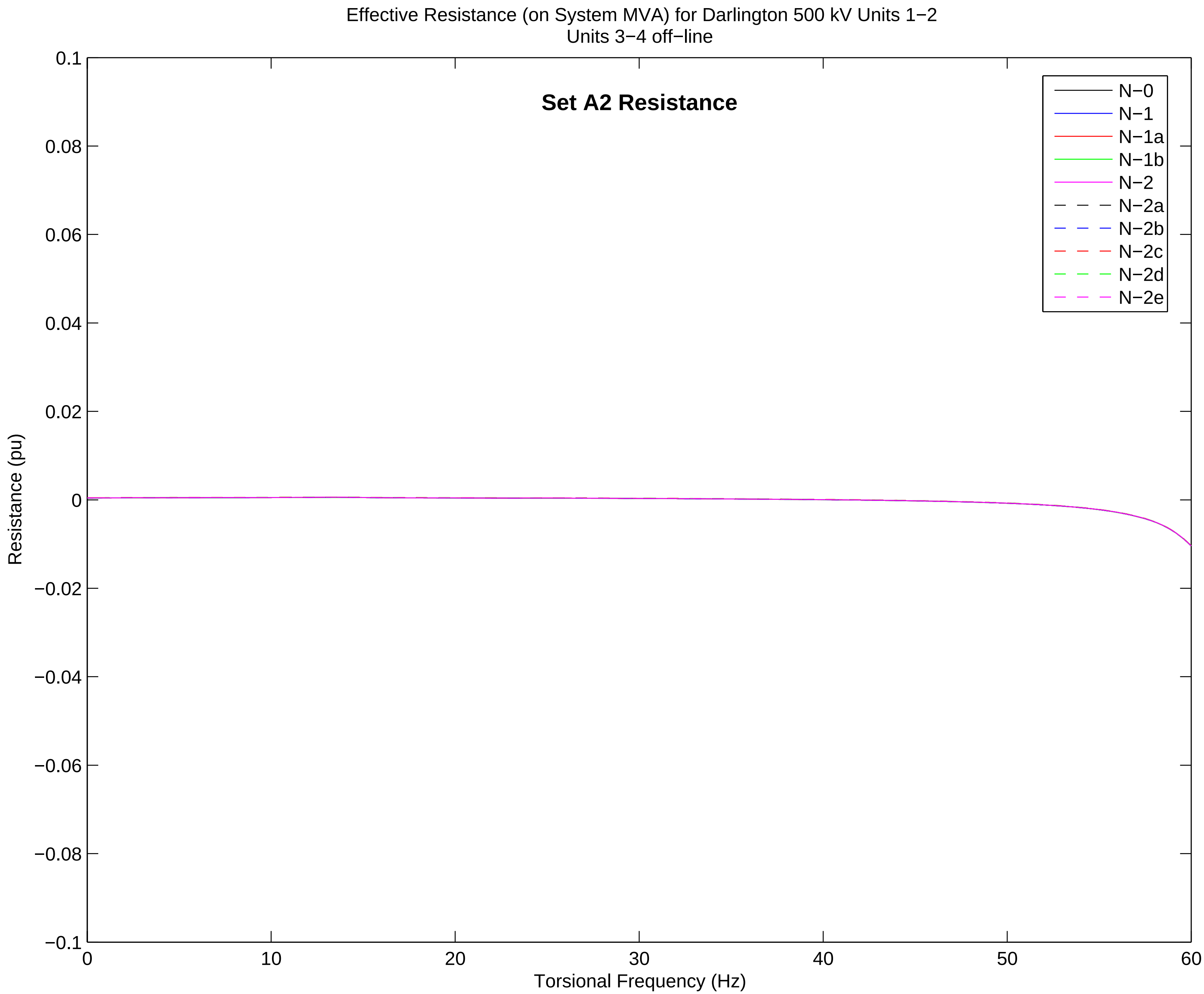

Effective Resistance (on System MVA) for Darlington 500 kV Unit 1
Units 2−4 off−line
Set A1 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

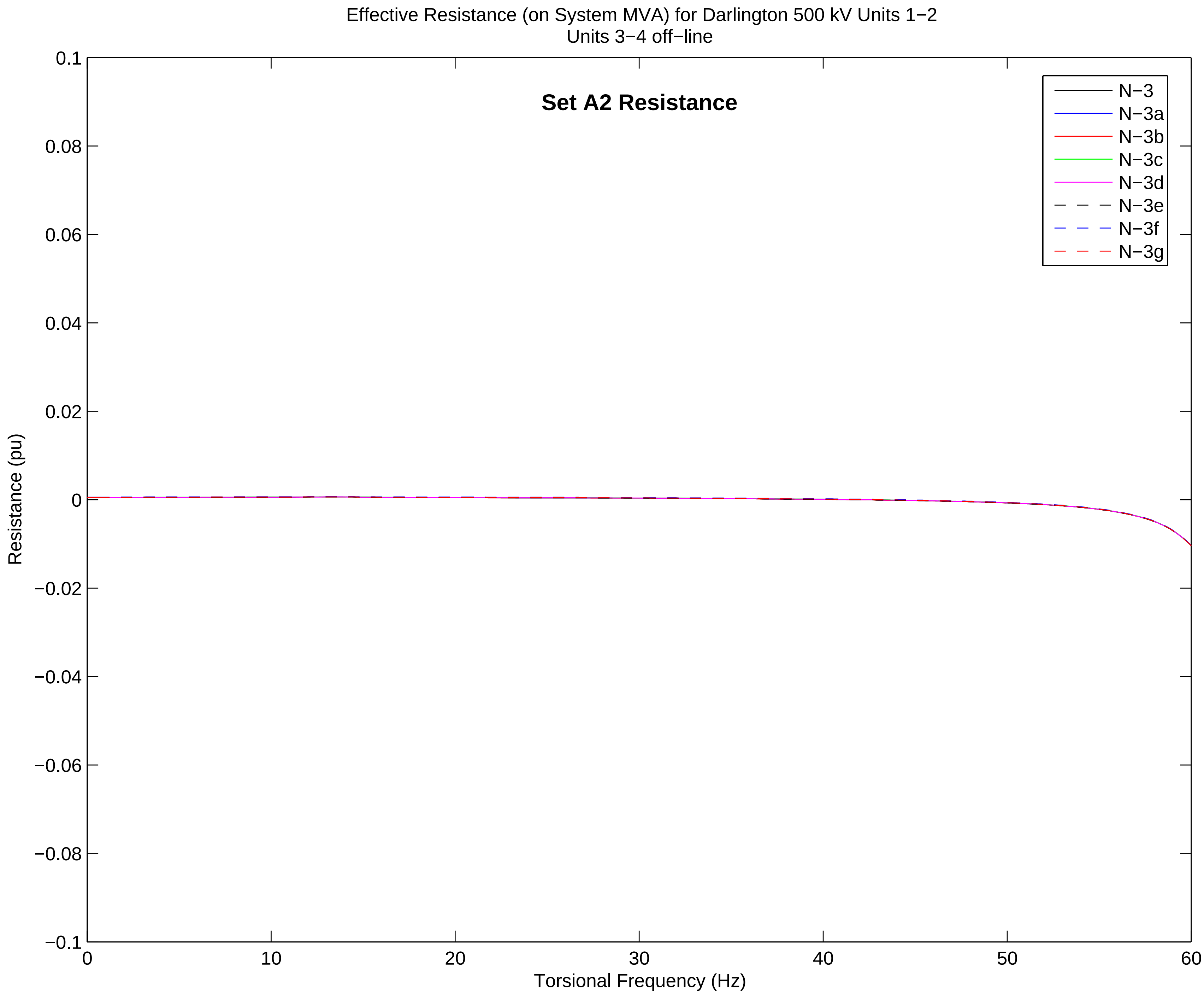
Effective Resistance (on System MVA) for Darlington 500 kV Unit 1
Units 2−4 off−line

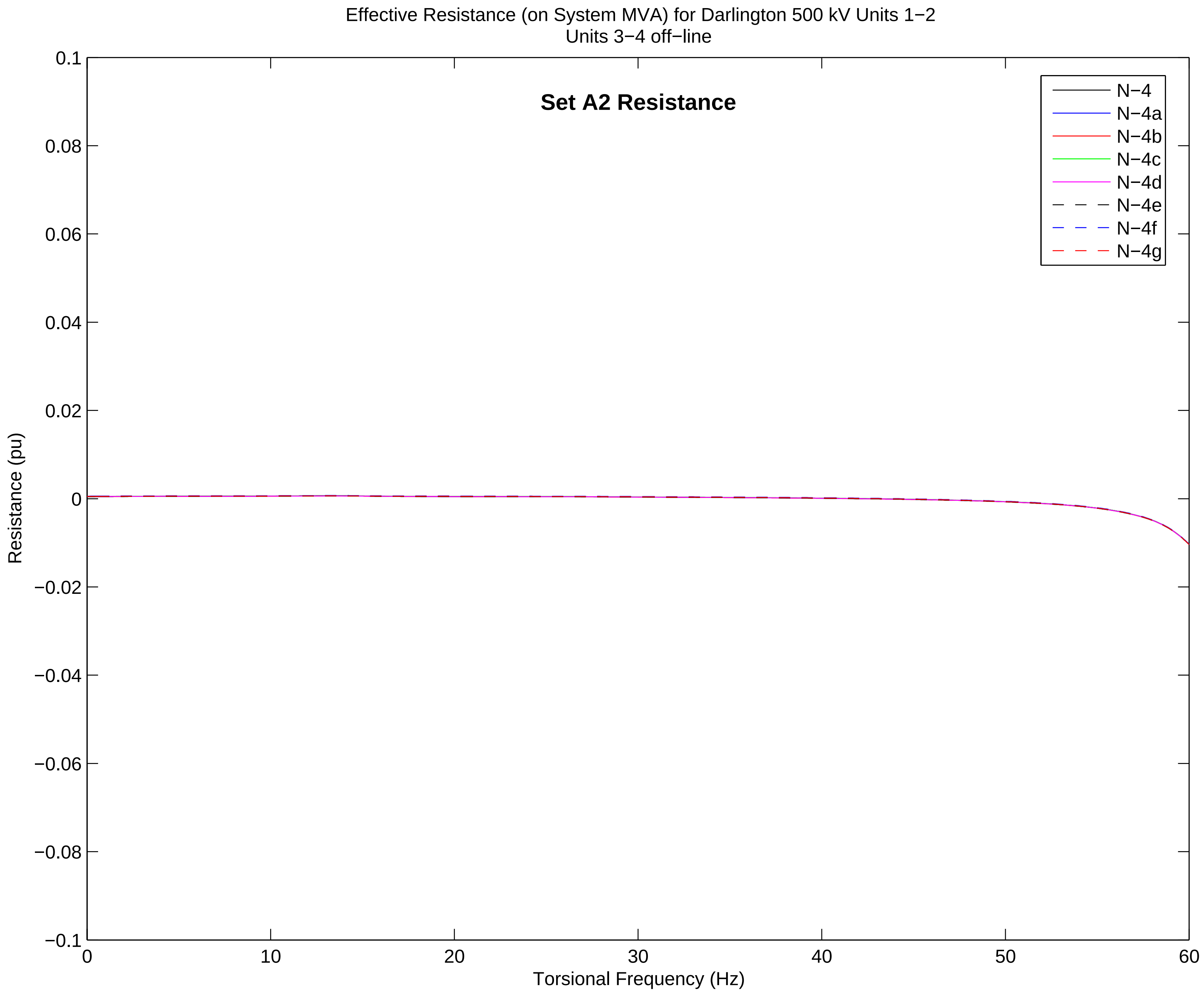




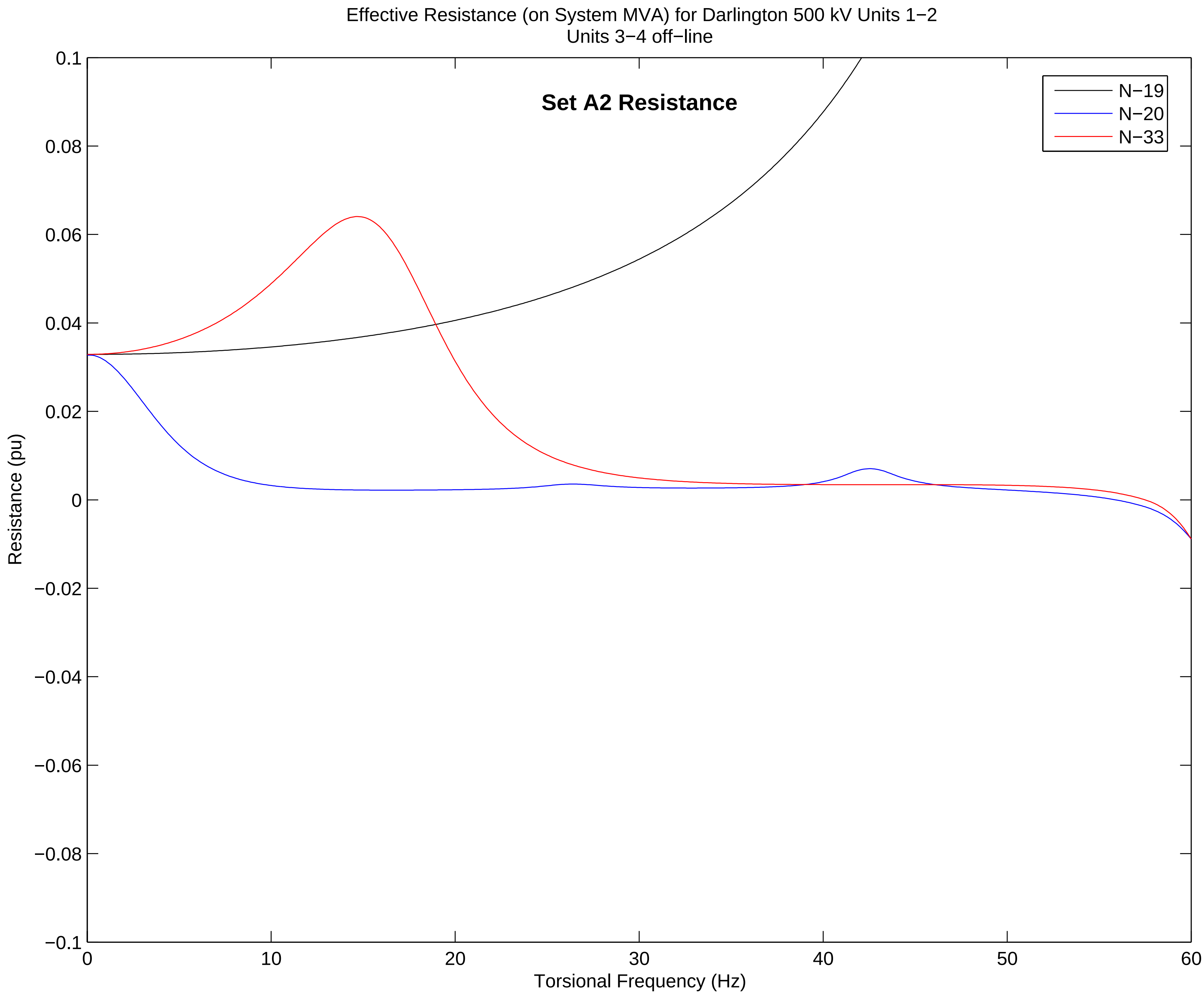
Effective Resistance (on System MVA) for Darlington 500 kV Unit 1
Units 2−4 off−line
Set A1 Resistance
N−19
N−20
N−33
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

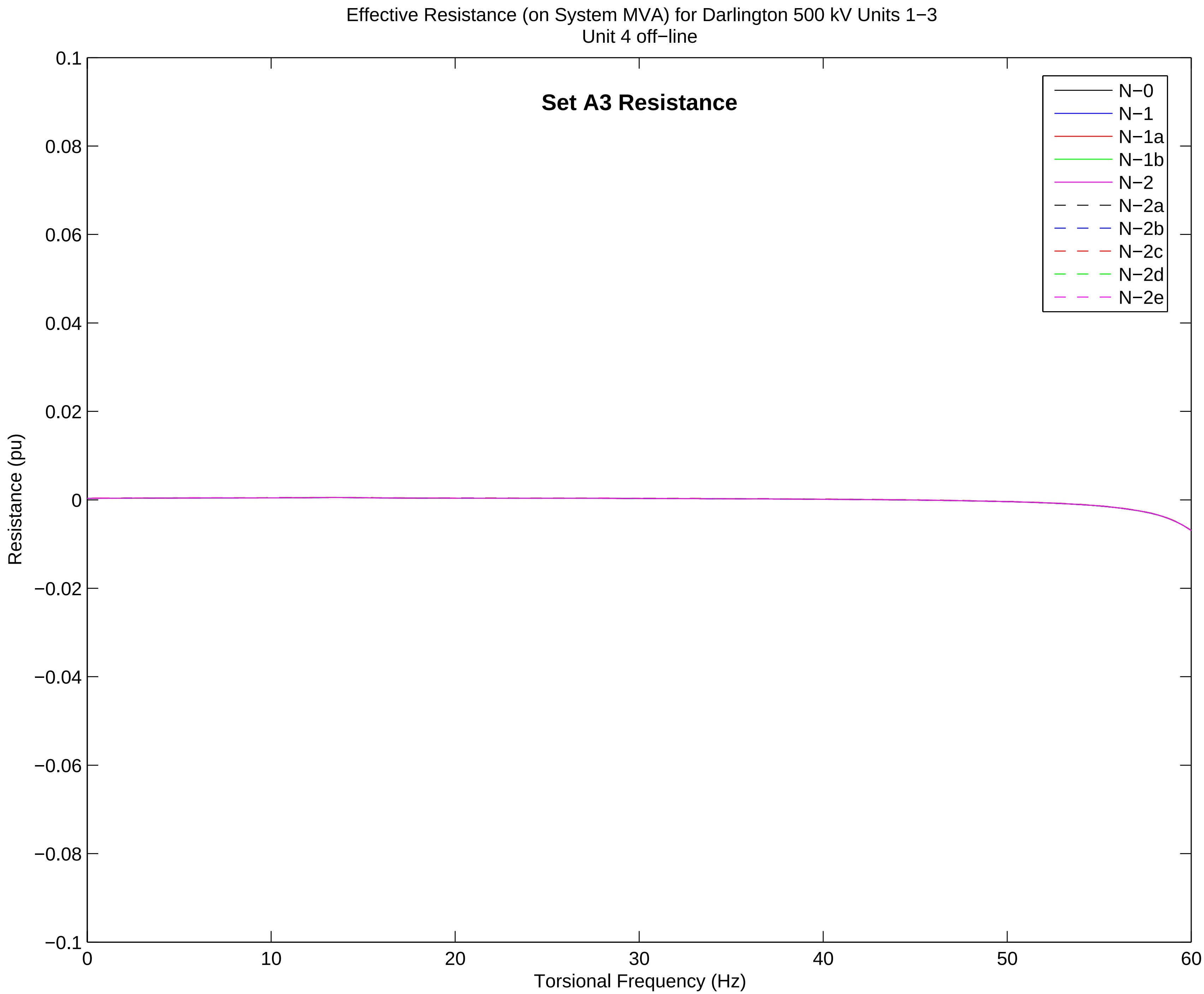

Effective Resistance (on System MVA) for Darlington 500 kV Units 1−2
Units 3−4 off−line
Set A2 Resistance
N−0
N−1
N−1a
N−1b
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Darlington 500 kV Units 1−2
Units 3−4 off−line
Set A2 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

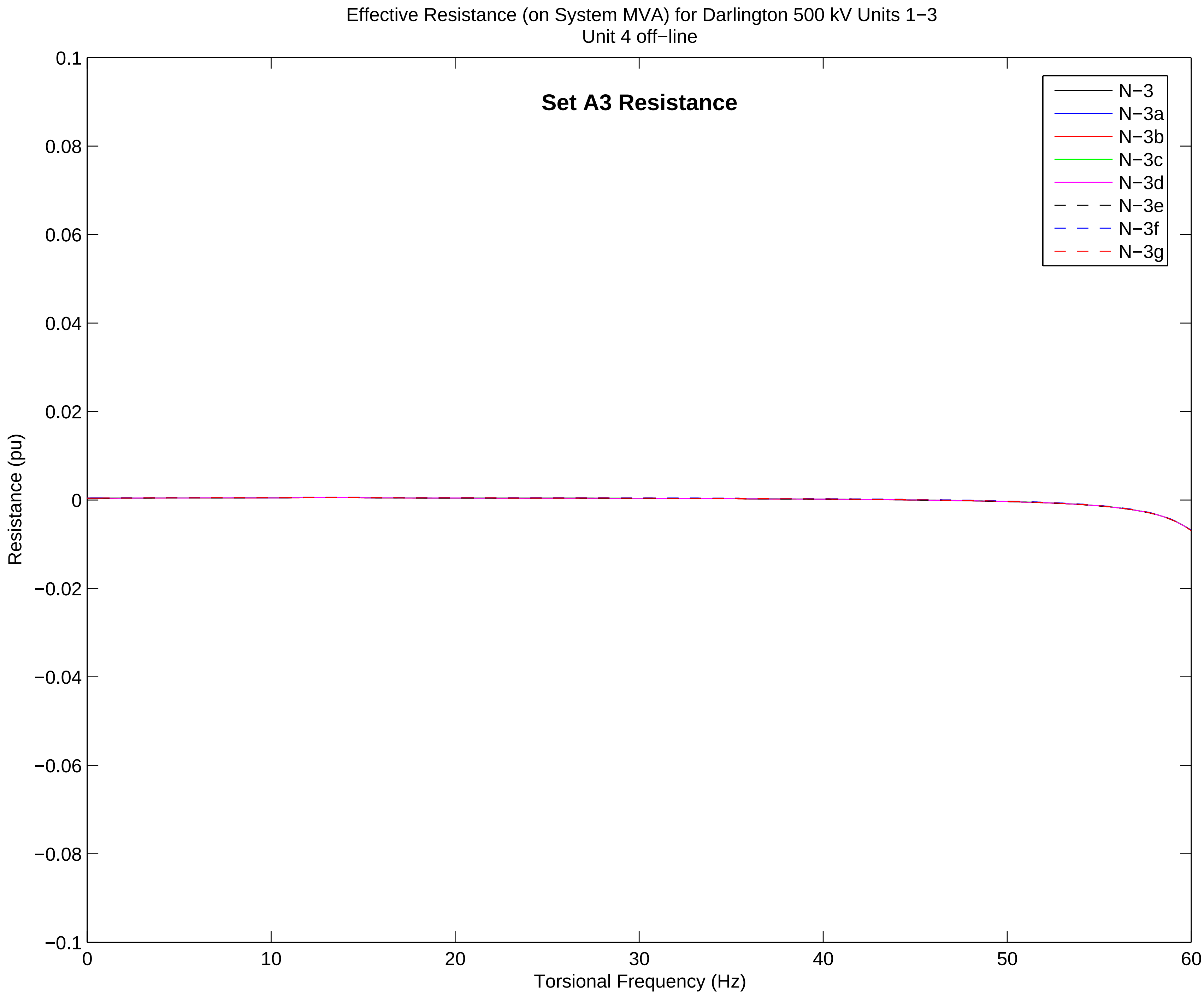


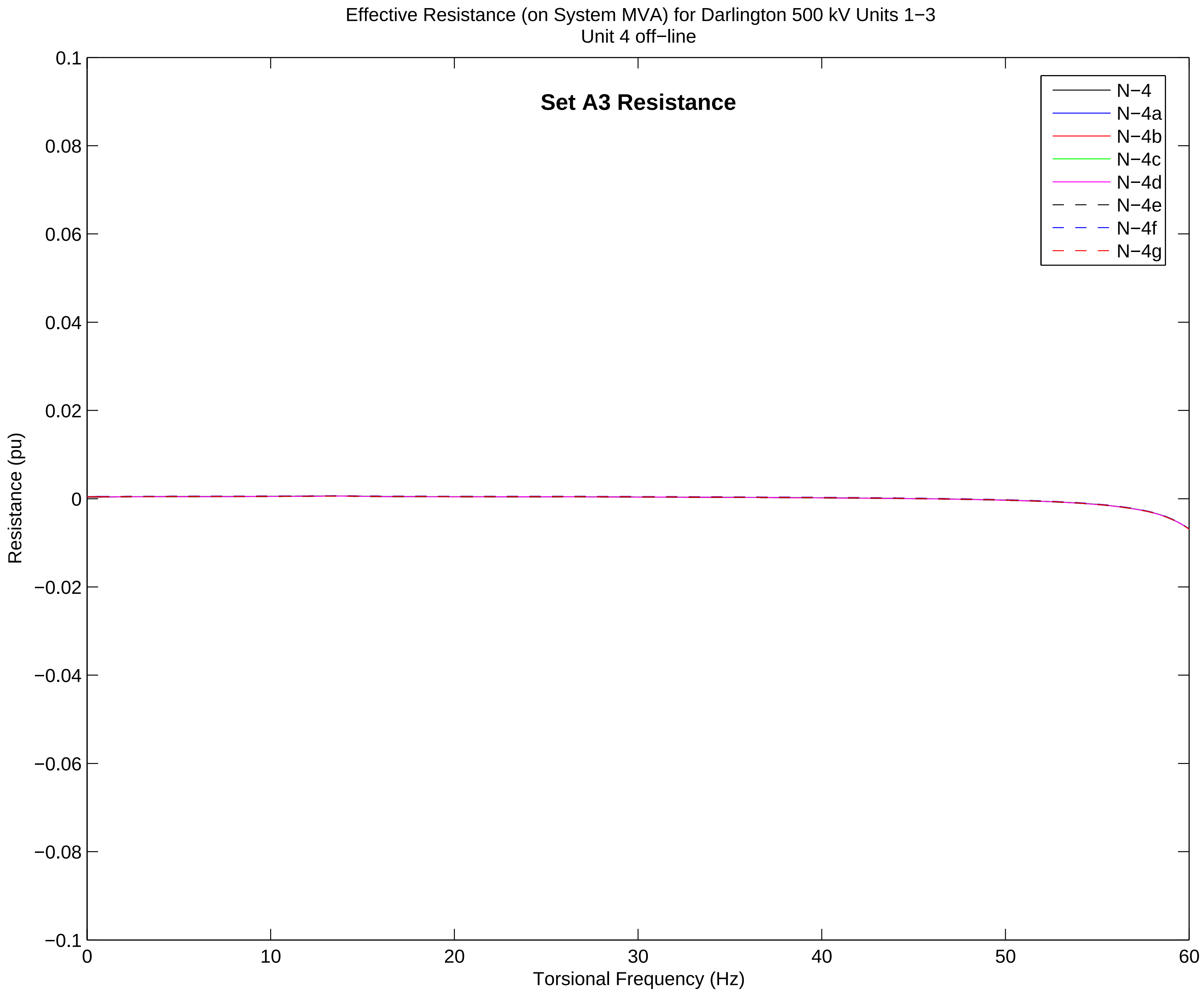
Effective Resistance (on System MVA) for Darlington 500 kV Units 1−2
Units 3−4 off−line
Set A2 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Darlington 500 kV Units 1−2
Units 3−4 off−line
Set A2 Resistance
N−19
N−20
N−33
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

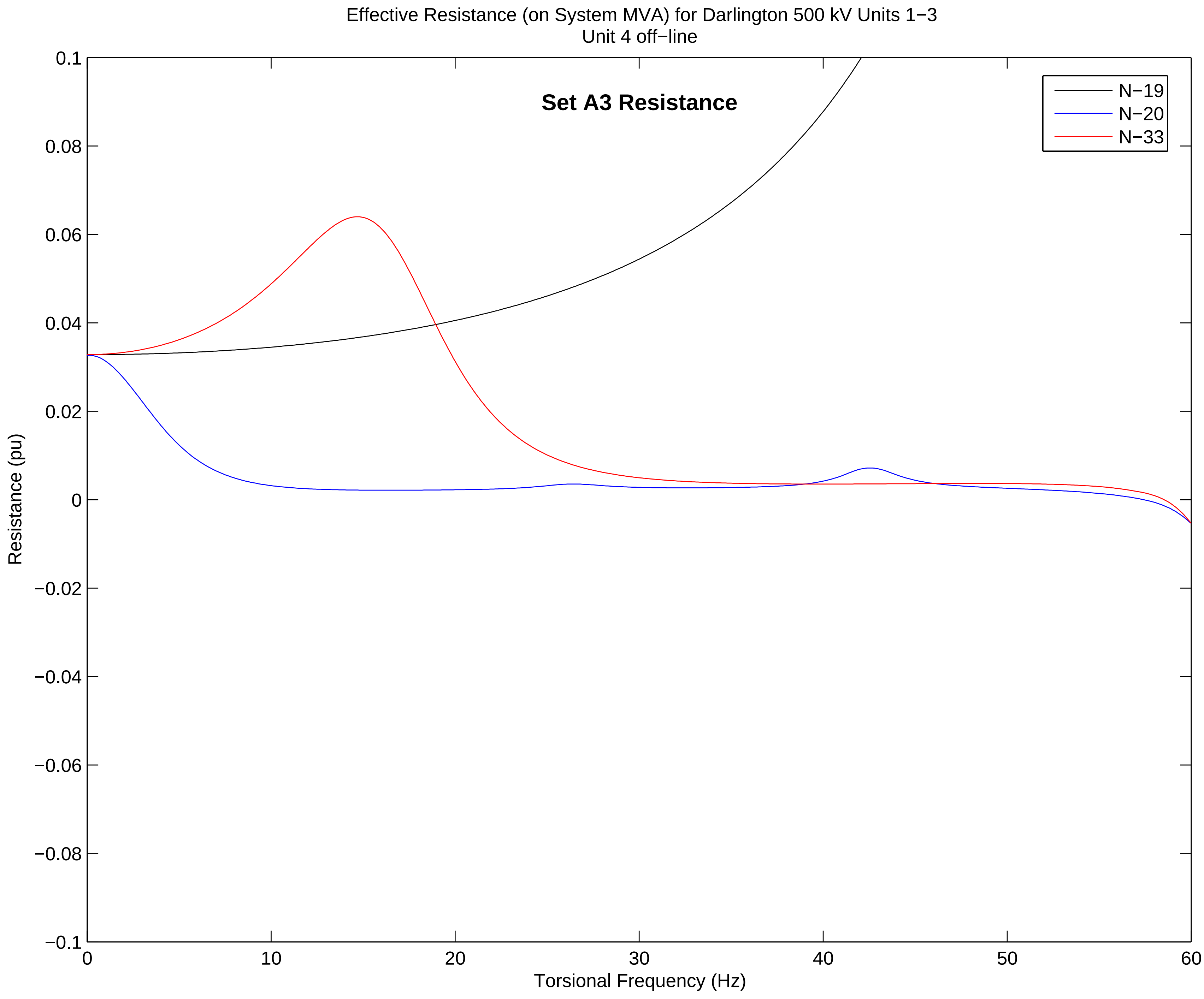


Effective Resistance (on System MVA) for Darlington 500 kV Units 1−3
Unit 4 off−line
Set A3 Resistance
N−0
N−1
N−1a
N−1b
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

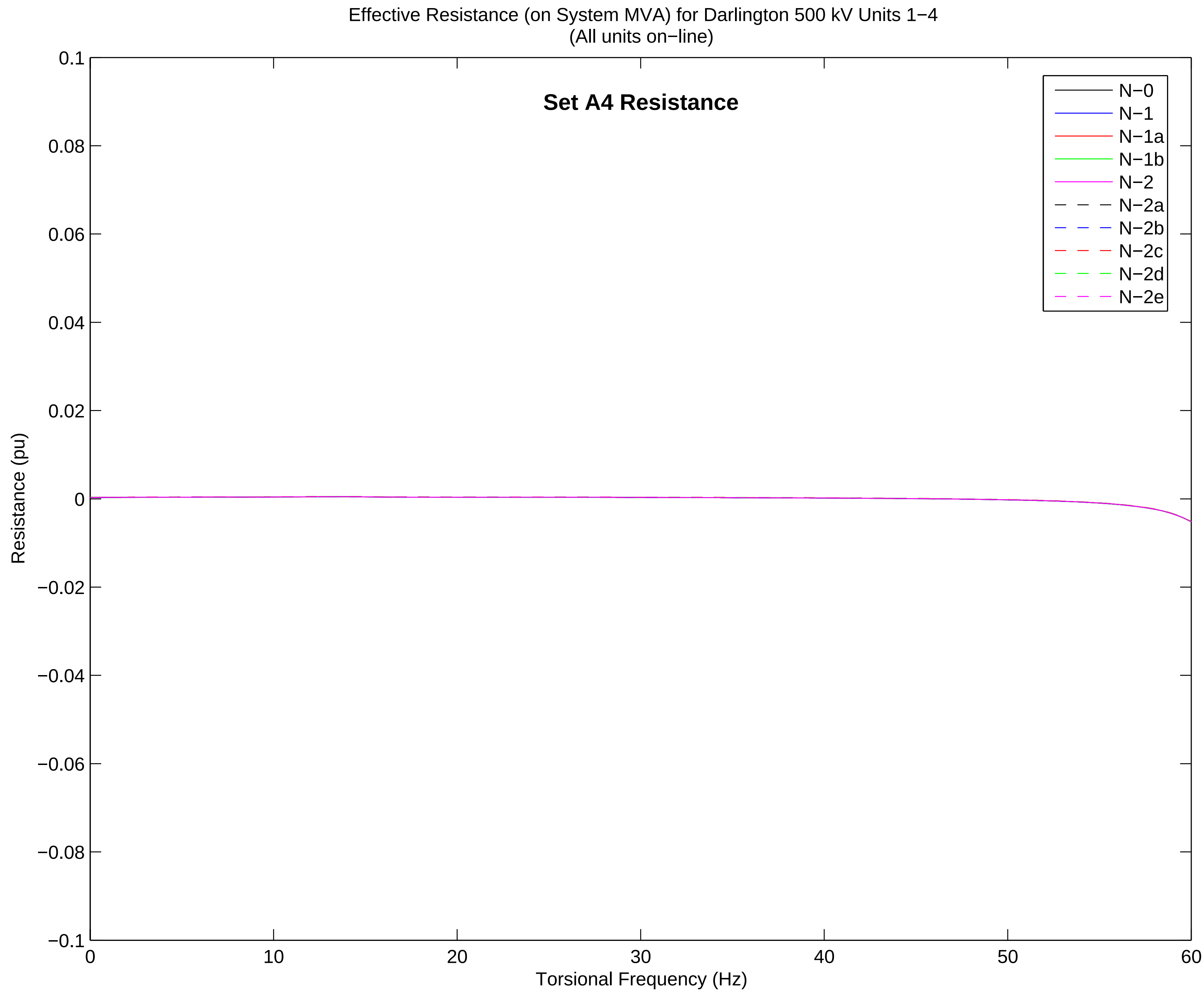

Effective Resistance (on System MVA) for Darlington 500 kV Units 1−3
Unit 4 off−line
Set A3 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



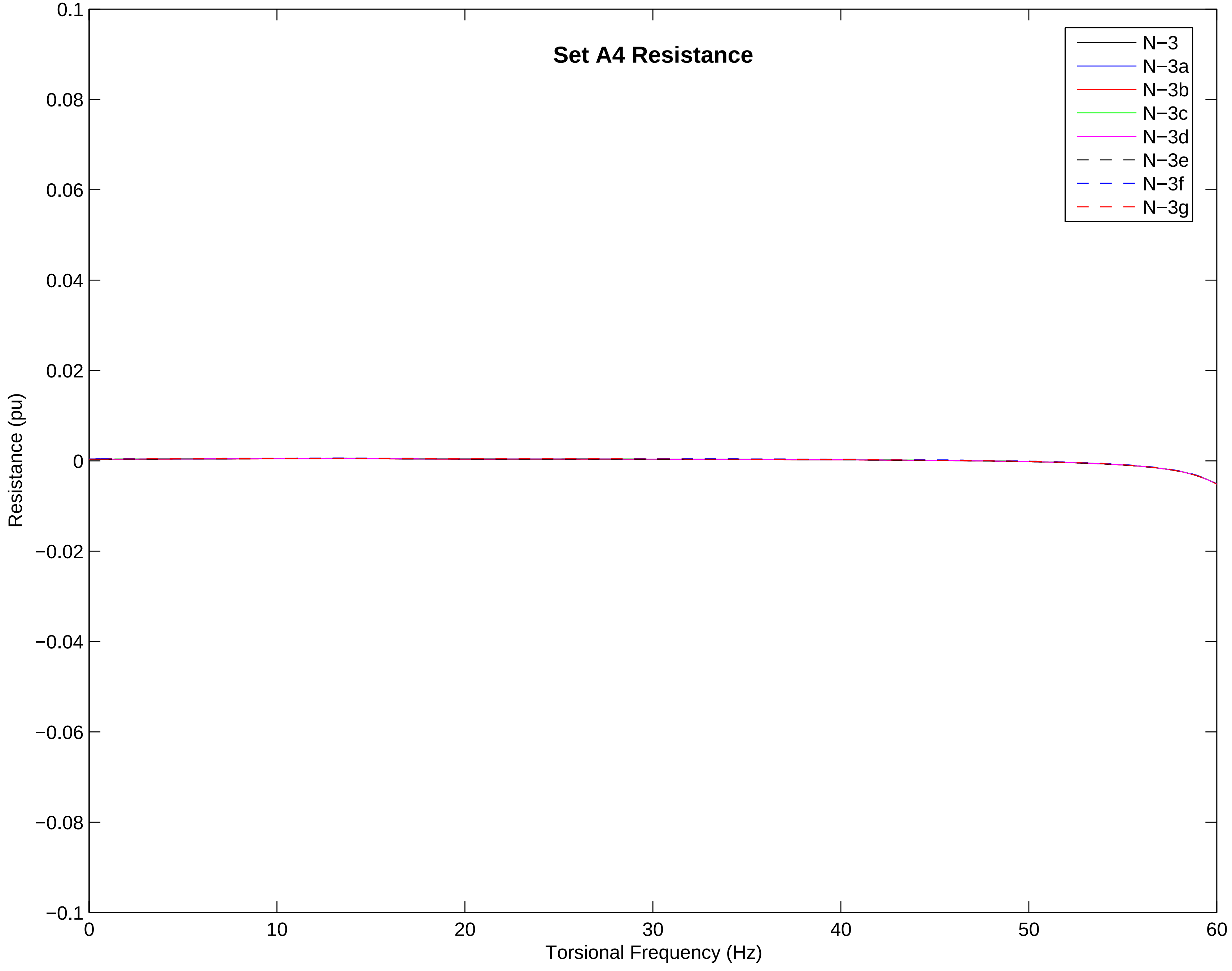
Effective Resistance (on System MVA) for Darlington 500 kV Units 1−3
Unit 4 off−line
Set A3 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

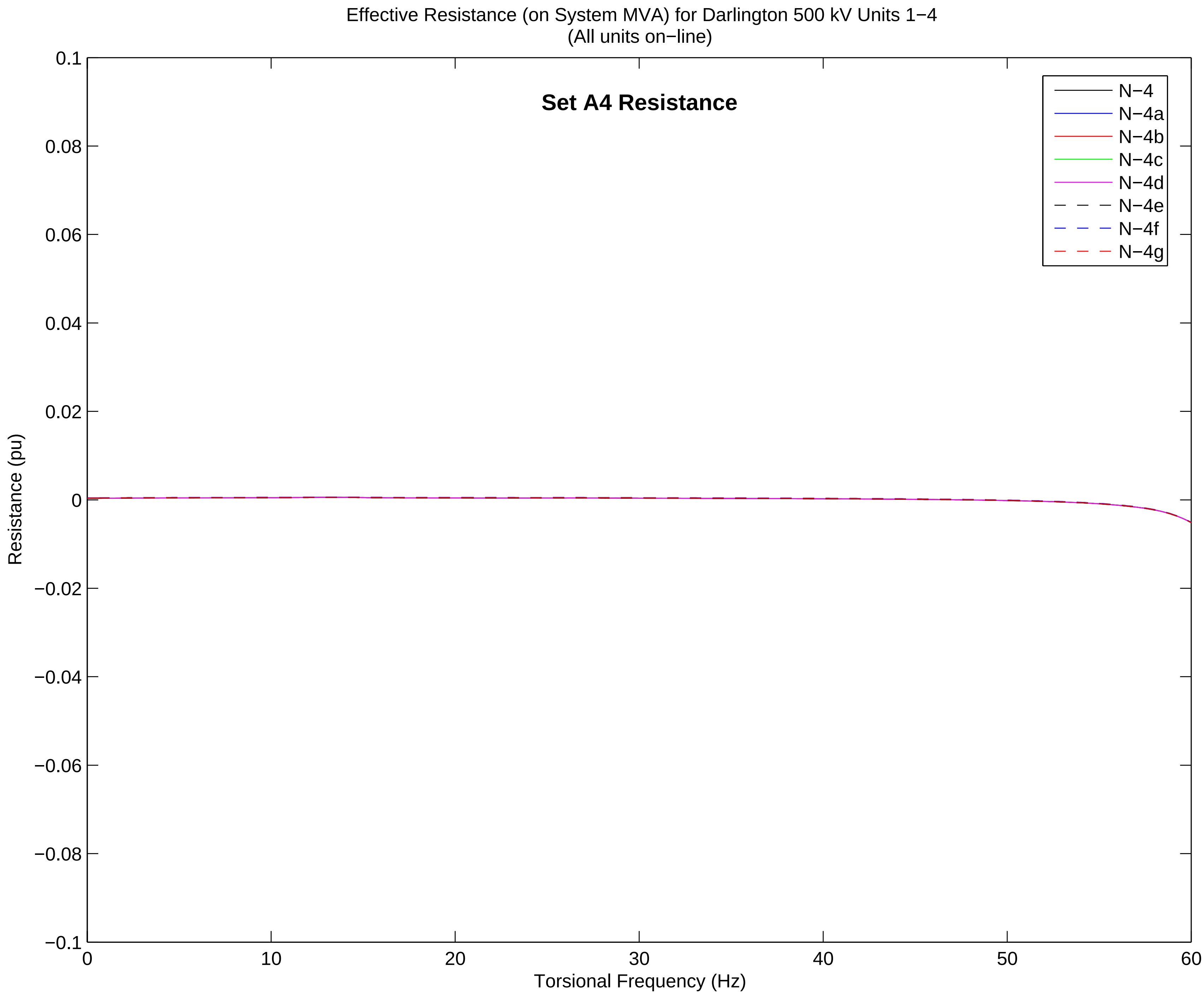


Effective Resistance (on System MVA) for Darlington 500 kV Units 1−3
Unit 4 off−line
Set A3 Resistance
N−19
N−20
N−33
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

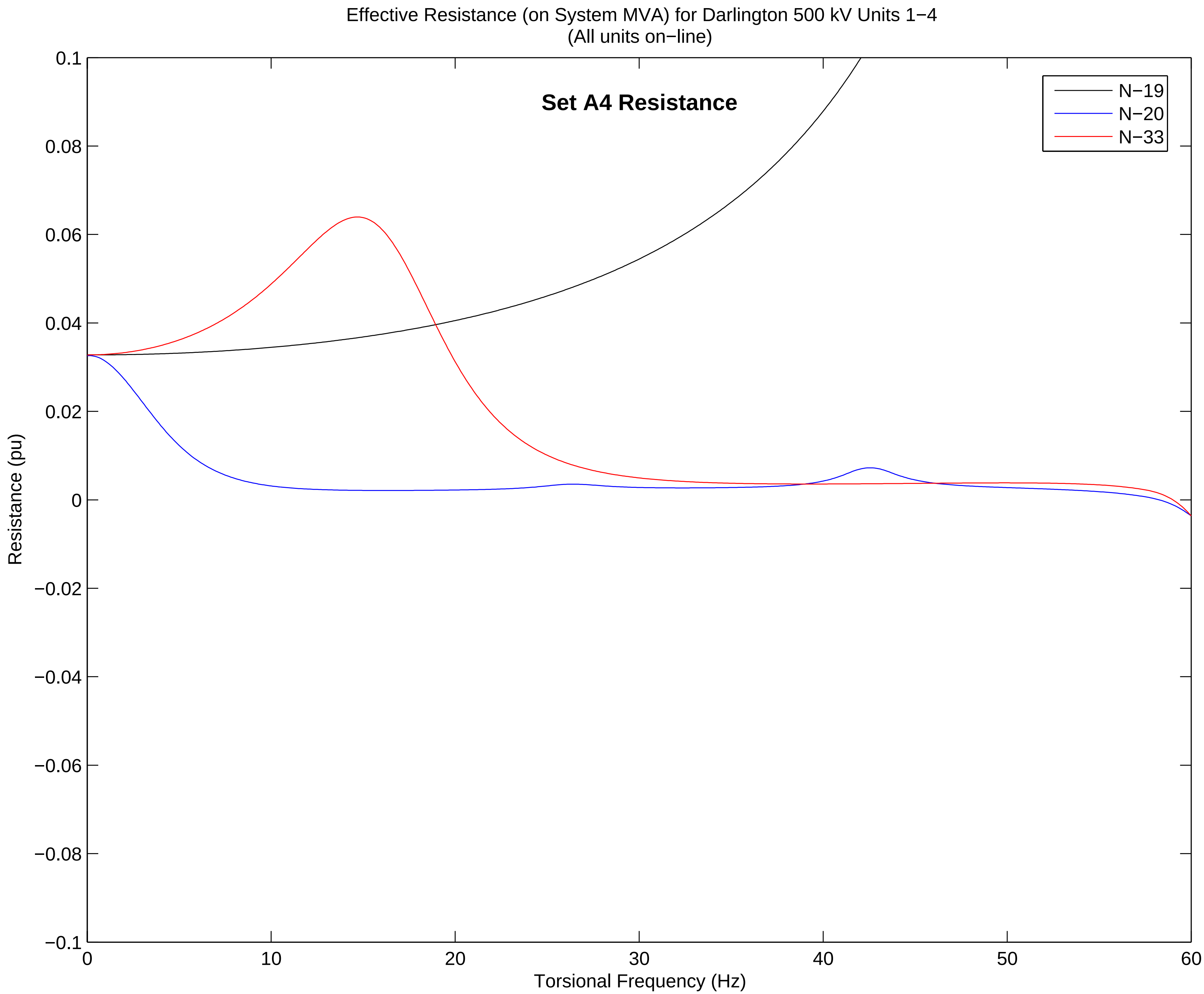

Effective Resistance (on System MVA) for Darlington 500 kV Units 1−4
(All units on−line)
Set A4 Resistance
N−0
N−1
N−1a
N−1b
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

Effective Resistance (on System MVA) for Darlington 500 kV Units 1−4
(All units on−line)





Effective Resistance (on System MVA) for Darlington 500 kV Units 1−4
(All units on−line)
Set A4 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Darlington 500 kV Units 1−4
(All units on−line)
Set A4 Resistance
N−19
N−20
N−33
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

APPENDIX I: Lennox Frequency Scan

Appendix I – Lennox

This appendix contains 1) the electrical damping plots and 2) the effective resistance plots for the Lennox generators. The electrical damping plots are provided first, ordered by generator combination (Set ID) as identified in Table I-1 below. The effective resistance plots are then provided in the same order.

Table I-1: Generator Combinations

Set ID	500kV Generators		230kV Generators	
	G3	G4	G1	G2
A1		√		
A2	√	√		
B1			√	
B2			√	√
C1		√	√	
C2		√	√	√
C3	√	√	√	
C4	√	√	√	√
D1		√	√	
D2		√	√	√
D3	√	√	√	
D4	√	√	√	√

√ - indicates the generator is in-service

Table I-2: Contingency Descriptions

Contingency ID	Lennox 500kV/230kV/27.6kV Transformer 51	Lennox 500kV/230kV/27.6kV Transformer 52	Lennox – Bowmanville 500kV Line 1	Lennox – Bowmanville 500kV Line 2	Lennox – Bowmanville 500kV Line 3	Lennox – Bowmanville 500kV Line 4	Hawthorn – Lennox 500kV Line 1	Hawthorn – Lennox 500kV Line 2	Catar X3 – Lennox 230kV Line 1	Lennox – LafarJX1 230kV Line 1	Lennox – LafarJX2 230kV Line 1	Lennox – WestBkX4 230kV Line 1
N-0												
N-1	X											
N-2	X	X										
N-2a	X		X									
N-2b	X						X					
N-2c	X								X			
N-2d	X									X		
N-2e	X										X	
N-2f	X											X
N-3	X	X	X									
N-3a	X	X					X					
N-3b	X	X							X			
N-3c	X	X								X		
N-3d	X	X									X	
N-3e	X	X										X
N-3f	X		X	X								
N-3g	X		X				X					

(continued next page)

Table I-2: Contingency Descriptions (continued)

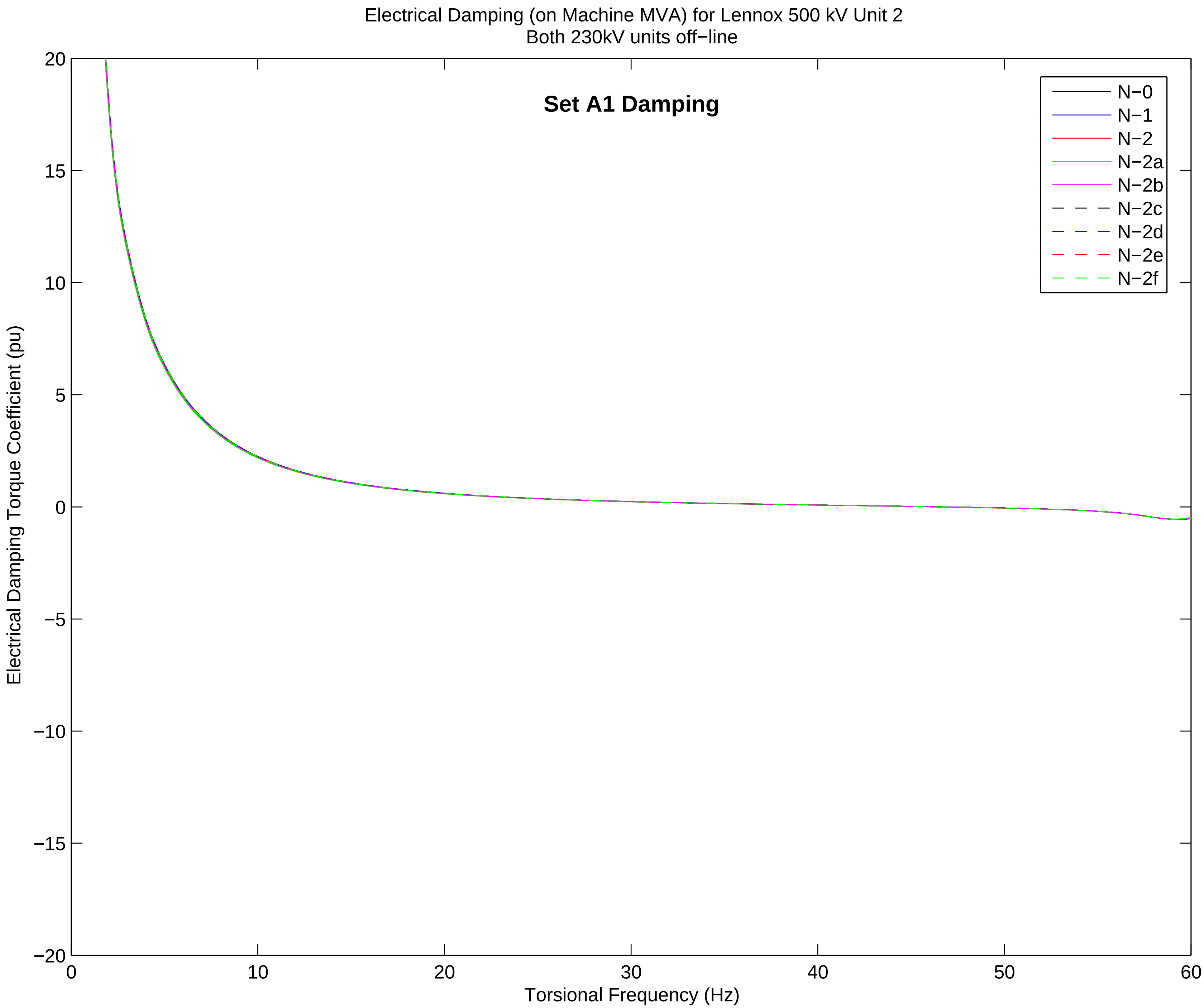
Contingency ID	Lennox 500kV/230kV/27.6kV Transformer 51	Lennox 500kV/230kV/27.6kV Transformer 52	Lennox – Bowmanville 500kV Line 1	Lennox – Bowmanville 500kV Line 2	Lennox – Bowmanville 500kV Line 3	Lennox – Bowmanville 500kV Line 4	Hawthorn – Lennox 500kV Line 1	Hawthorn – Lennox 500kV Line 2	Catar X3 – Lennox 230kV Line 1	Lennox – LafarJX1 230kV Line 1	Lennox – LafarJX2 230kV Line 1	Lennox – WestBkX4 230kV Line 1
N-3h	X		X						X			
N-3i	X									X		
N-3j	X										X	
N-3k	X											X
N-3l	X						X	X				
N-3m	X						X		X			
N-3n	X						X			X		
N-3o	X						X				X	
N-3p	X						X					X
N-3q	X								X	X		
N-3r	X								X		X	
N-3s	X								X			X
N-3t	X									X	X	
N-3u	X									X		X
N-3v	X										X	X
N-4	X	X	X	X								
N-4a	X	X	X				X					
N-4b	X	X					X	X				
N-4c	X	X							X	X		
N-4d	X	X							X		X	
N-4e	X	X							X			X
N-4f	X	X								X	X	
N-4g	X	X								X		X
N-4h	X	X									X	X
N-5	X	X	X	X	X							
N-5a	X	X	X				X	X				
N-6	X	X	X	X	X	X						
N-23	See Table I-3											
N-24	See Table I-3											
N-25	See Table I-3											
N-26	See Table I-3											
N-37	See Table I-3											

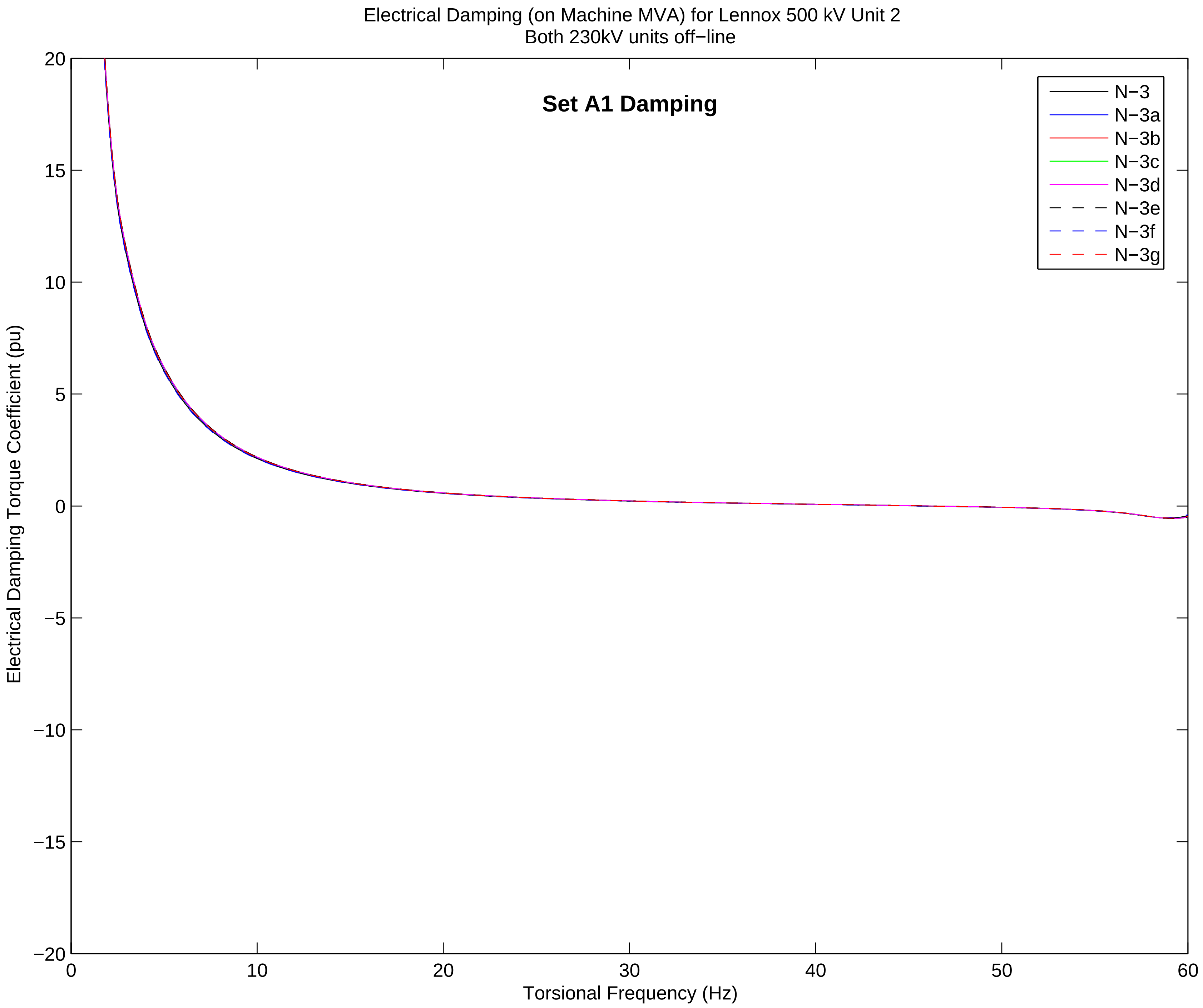
X – indicates the branch is out-of-service

Table I-3: Extensive Contingencies

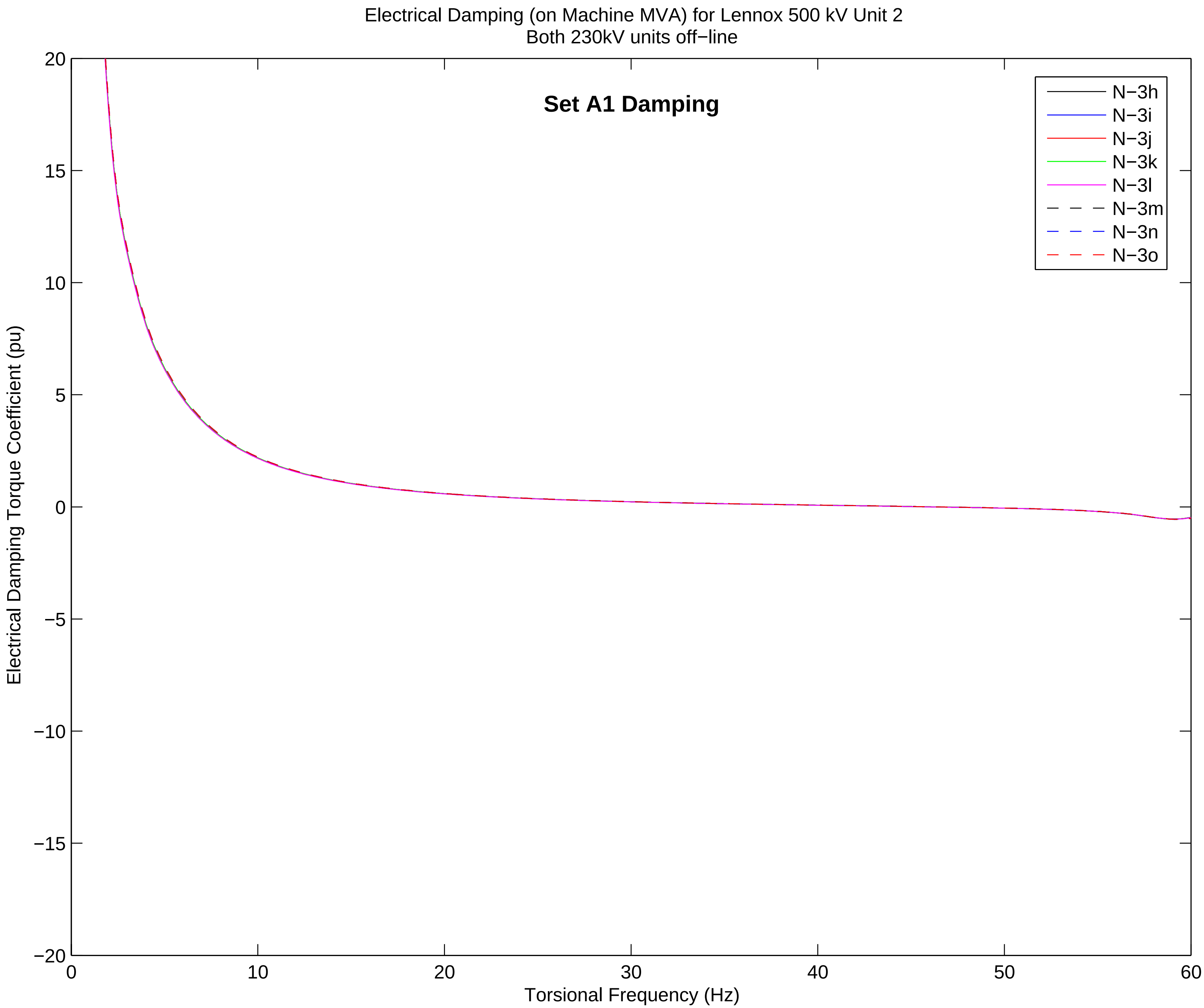
Element	Contingency				
	N-23	N-24	N-25	N-26	N-37
Generator Sets Evaluated	B1-B2 C1-C4 D1-D4	B1-B2 C1-C4 D1-D4	A1-A2	A1-A2	All
Lennox 500kV/230kV Transformer 51			X	X	X
Lennox 500kV/230kV Transformer 52			X	X	X
Hawthorn – Lennox 500kV Line 1	X	X	X	X	X
Hawthorn – Lennox 500kV Line 2	X	X	X	X	X
Bowmanville – Darlington 500kV Line 1	X	X	X	X	X
Bowmanville – Darlington 500kV Line 2	X	X	X	X	X
Bowmanville – Darlington 500kV Line 3	X	X	X	X	X
Bowmanville – Darlington 500kV Line 4	X	X	X	X	X
Cherrywood 500/230kV Transformer 14	X	X	X	X	X
Cherrywood 500/230kV Transformer 15	X	X	X	X	X
Cherrywood 500/230kV Transformer 16	X	X	X	X	X
Cherrywood 500/230kV Transformer 17	X	X	X	X	X
Parkway 500kV/230kV/27.6kV Transformer	X	X	X	X	X
Clairville – Milton Bypass 500kV Line 1	X	X	X	X	X
Clairville – Milton Bypass 500kV Line 2	X	X	X	X	X
Clairville – Essa 500kV Line 1	X	X	X	X	X
Clairville – Essa 500kV Line 1	X	X	X	X	X
Clairville 500kV/230kV Transformer 13	X	X	X	X	X
Clairville 500kV/230kV Transformer 14	X	X	X	X	X
Clairville 500kV/230kV Transformer 15	X	X	X	X	X
Clairville 500kV/230kV Transformer 16	X	X	X	X	X
Clairville – Milton Line 1	X		X		X
Clairville – Milton Line 1	X		X		
Milton – Trafal72 500kV Line		X		X	X
Milton – Trafal73 500kV Line		X		X	X
Milton – Midd8185 500kV Line		X		X	X
Milton – Bruce B Series Cap					X
Midd8086-Middldk1 500kV/230kV Transformer T3					X
Midd8185-Middldk2 500kV/230kV Transformer T6					X
Nanticoke 500kV/230kV Transformer T11					X
Nanticoke 500kV/230kV Transformer T12					X
Nanticoke 500kV/22kV Transformer T54					X
Nanticoke 500kV/22kV Transformer T55					X
Nanticoke 500kV/22kV Transformer T56					X
Nanticoke 500kV/22kV Transformer T57					X
Longwood 500kV/230kV/27.6kV Transformer T11					X
Longwood 500kV/230kV/27.6kV Transformer T12					X
Longwood 500kV/230kV/27.6kV Transformer T13					X
Longwood 500kV/230kV/27.6kV Transformer T14					X
Longwood 500kV/230kV/27.6kV Transformer T15					X

X – indicates the branch is out-of-service

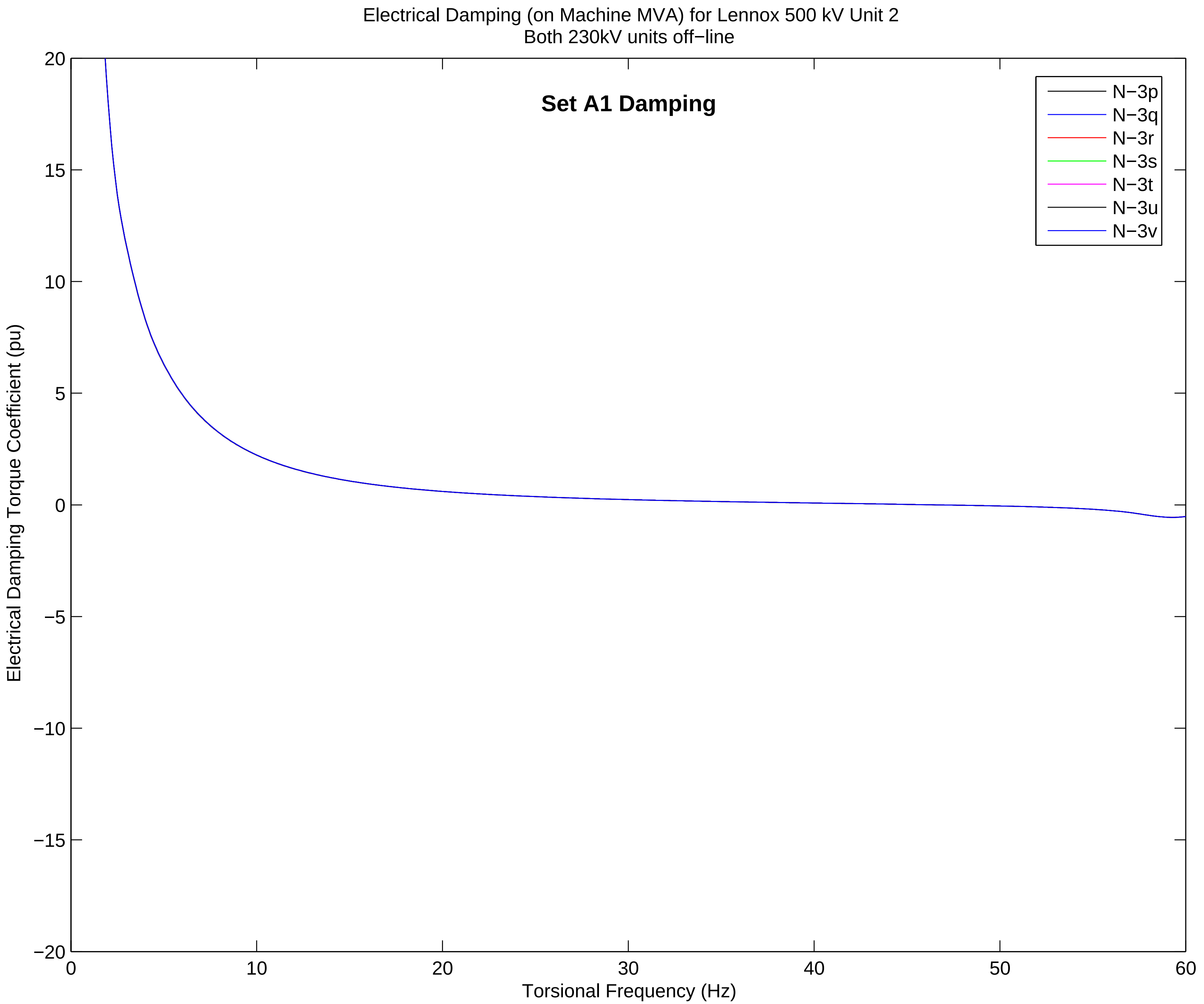

Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)
Electrical Damping Torque Coefficient (pu)



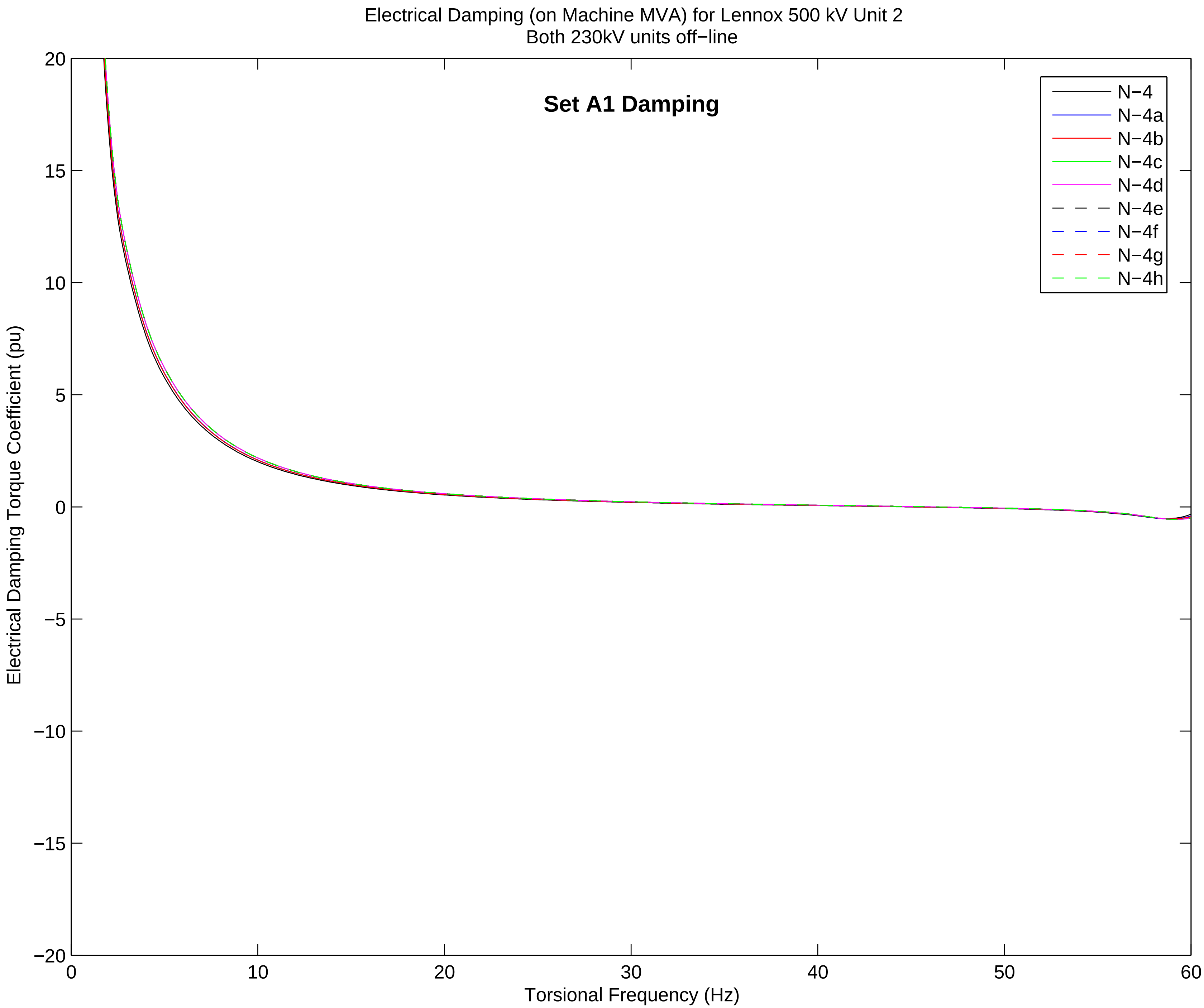
Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
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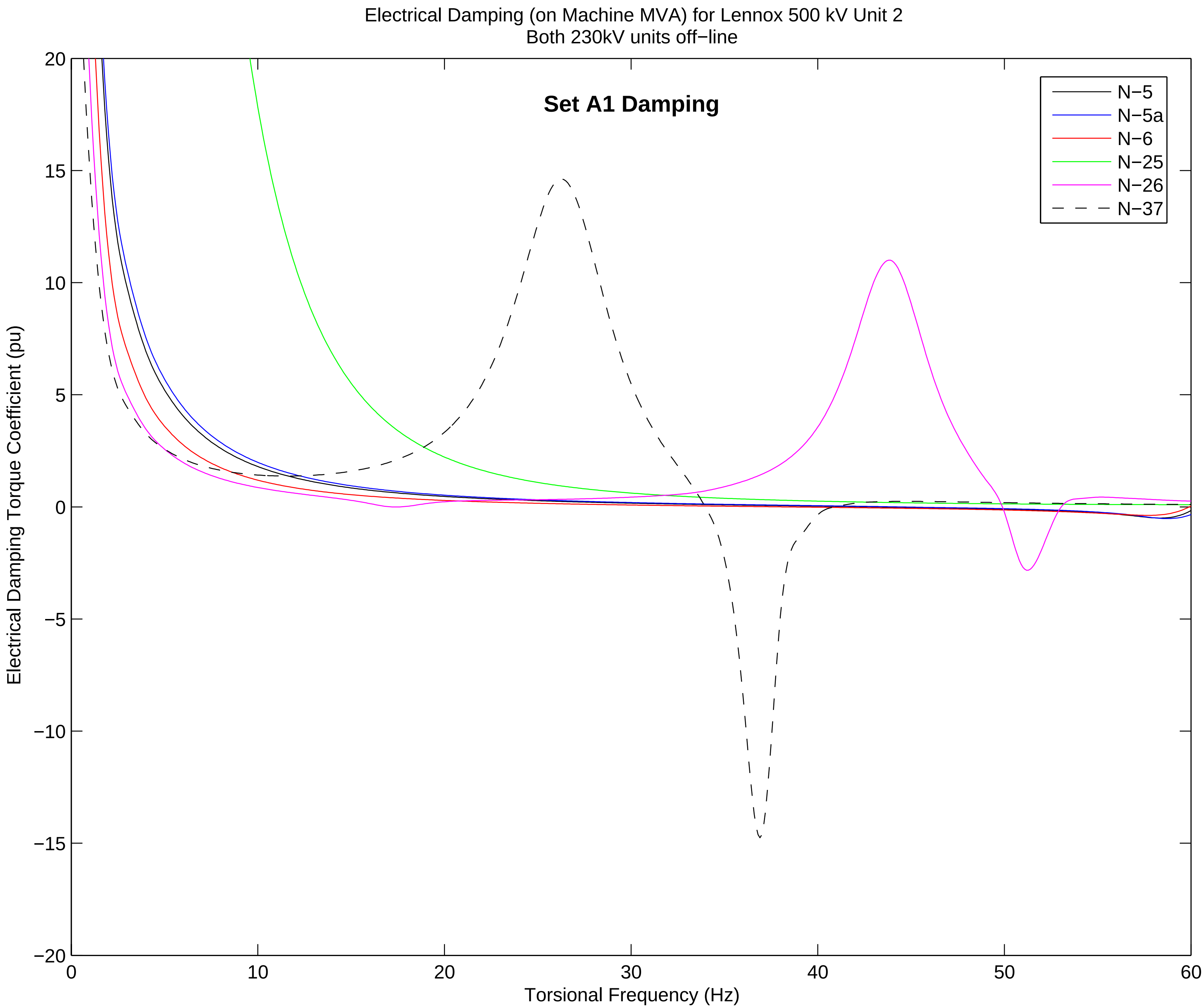
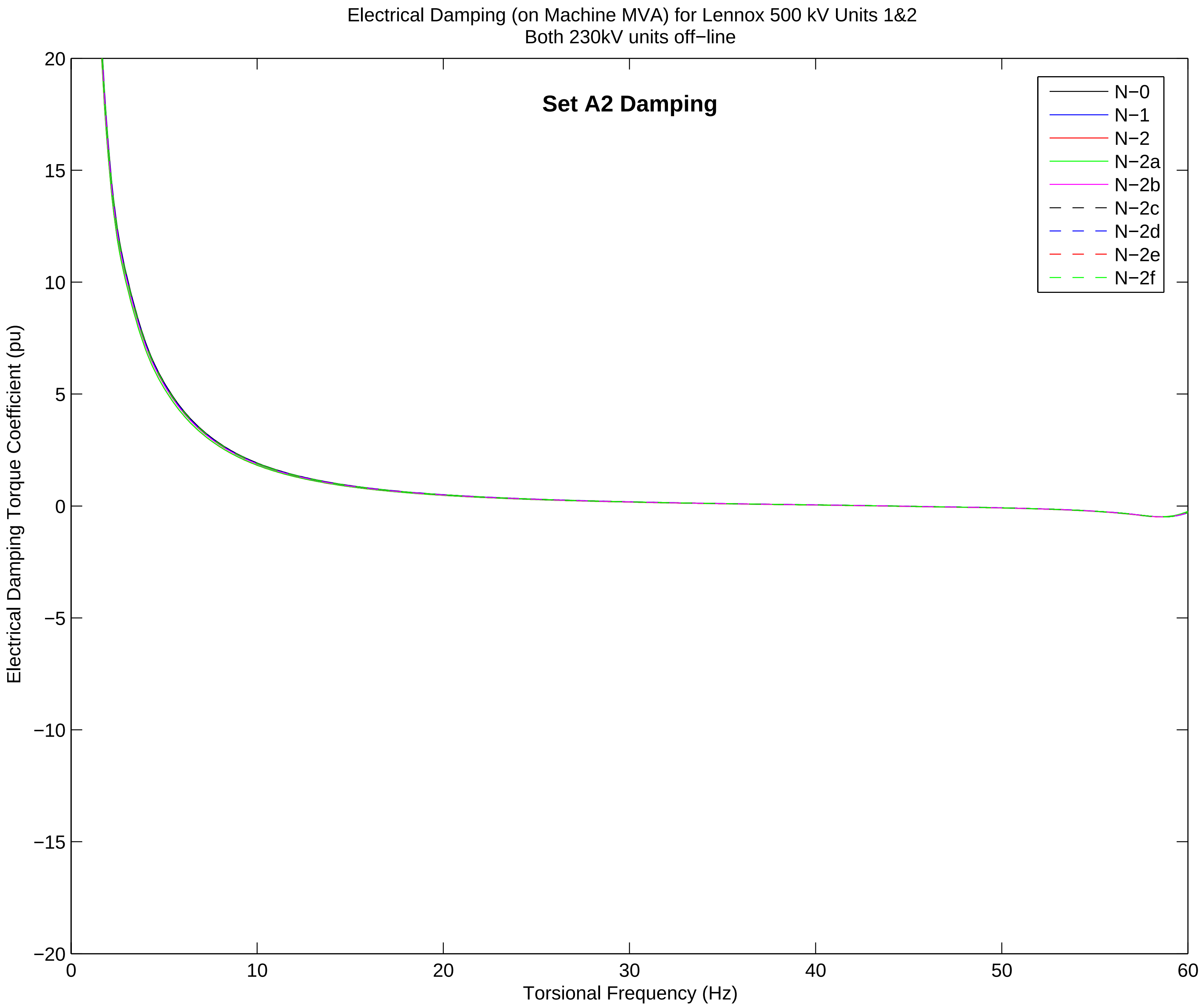
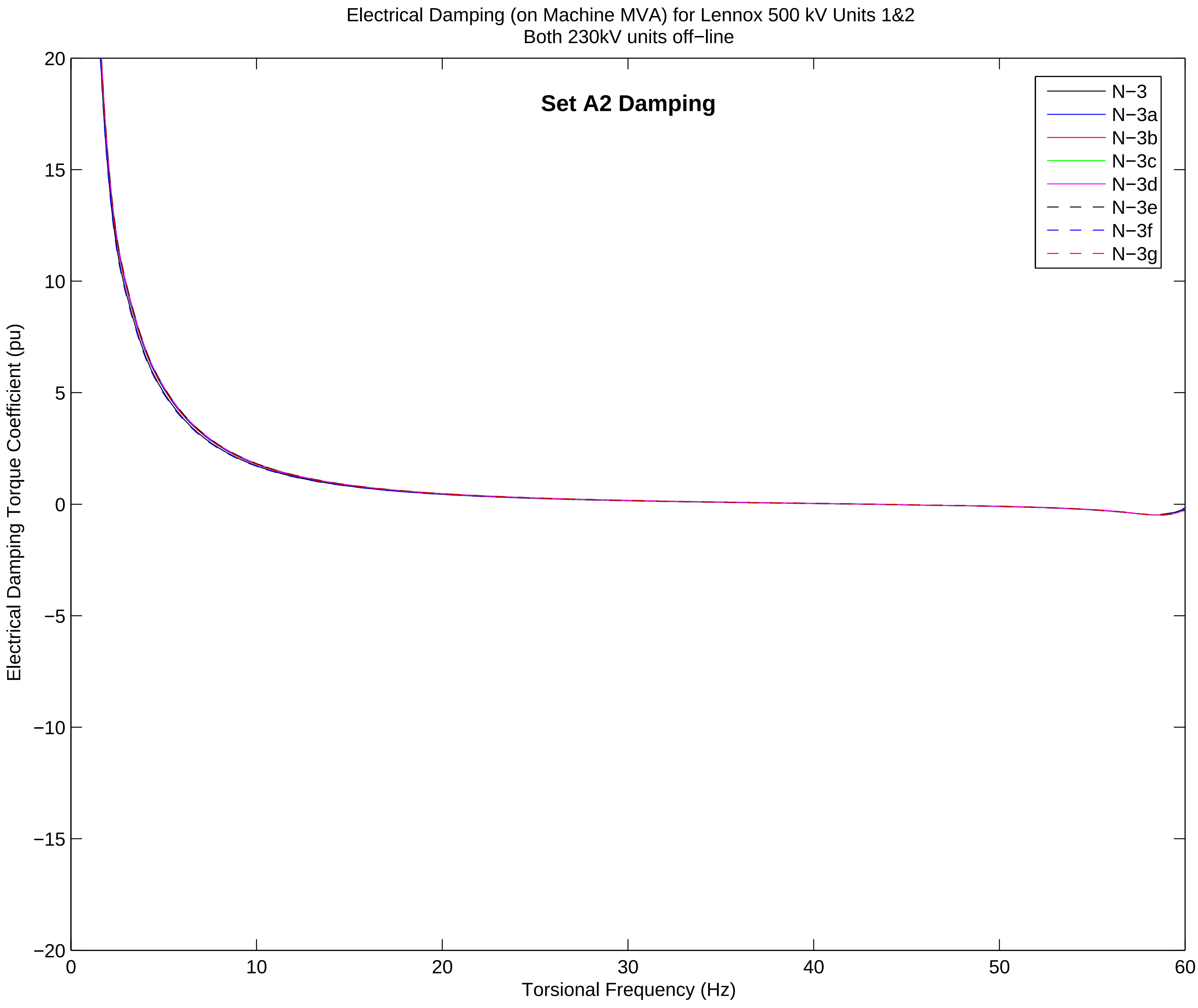
50
60


Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Damping
N−5
N−5a
N−6
N−25
N−26
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
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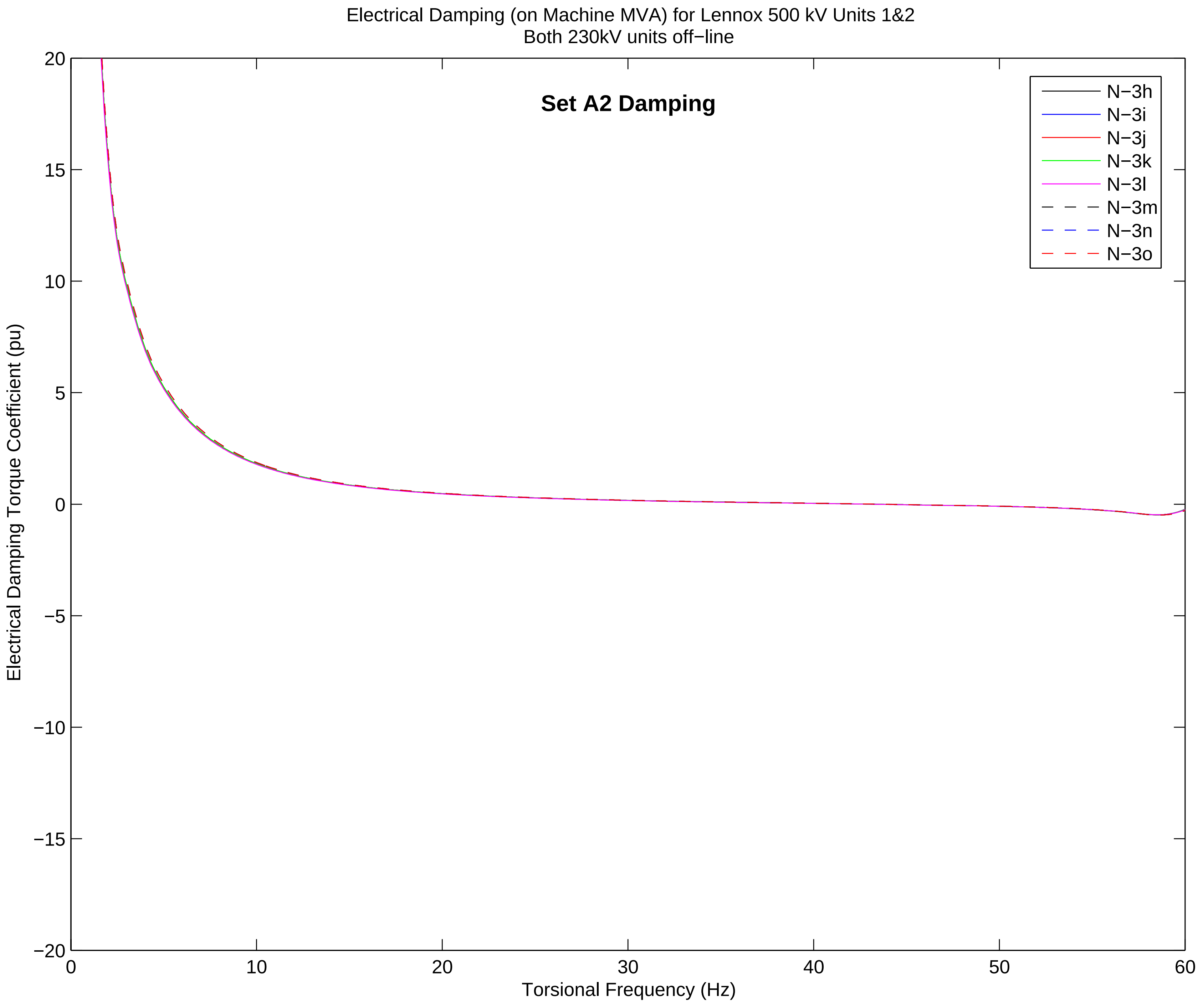
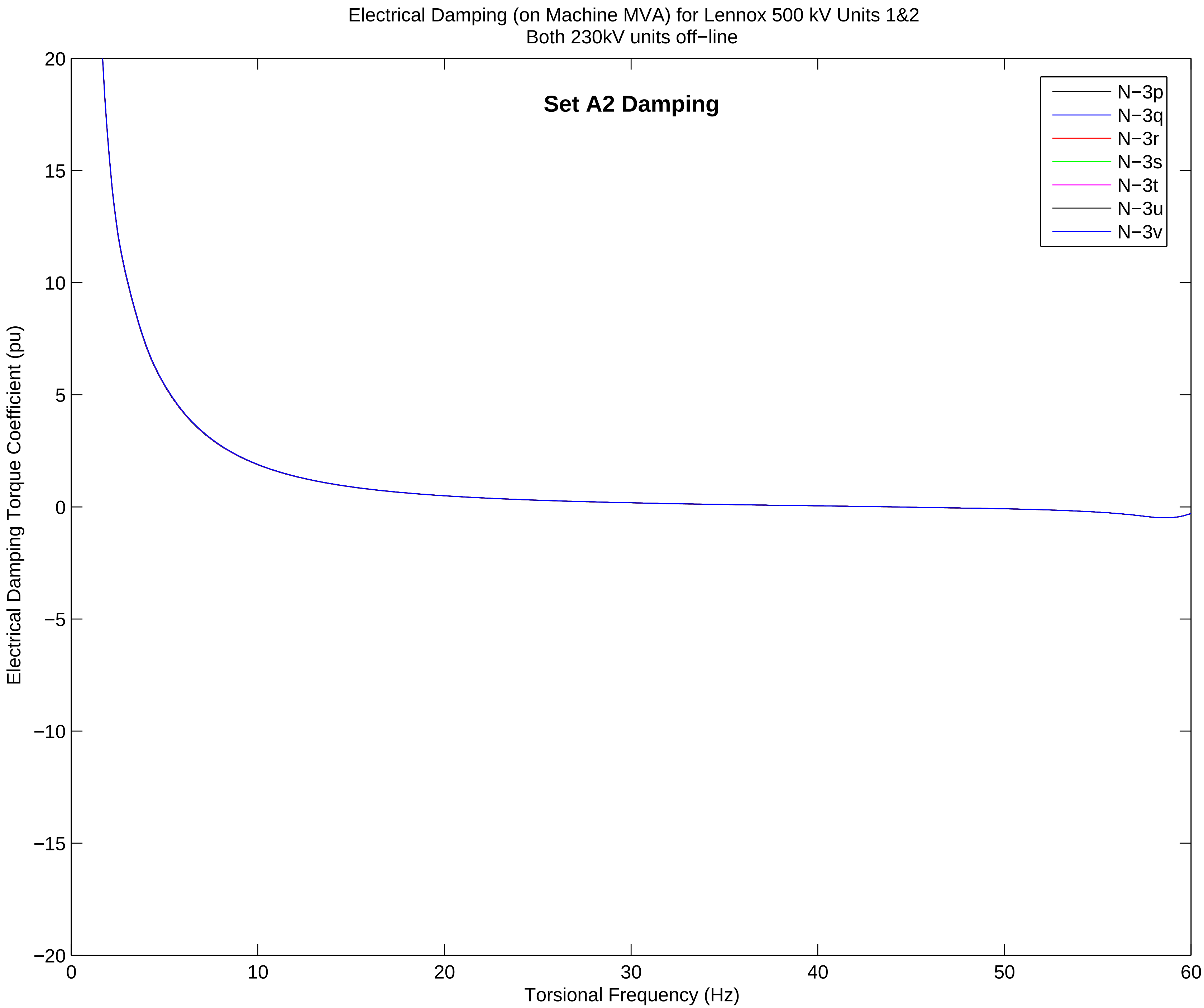
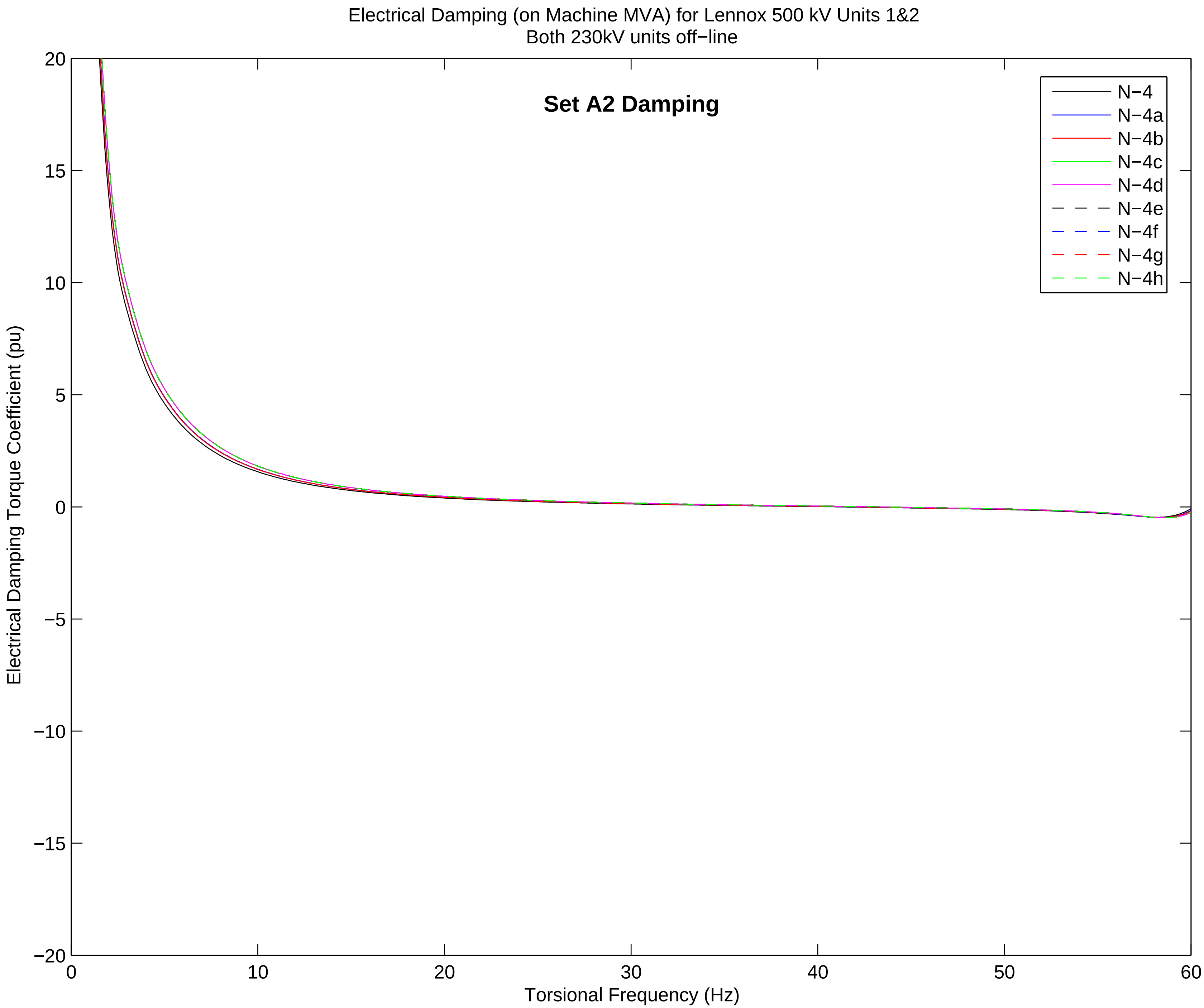
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
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−5
−10
−15
−20
0
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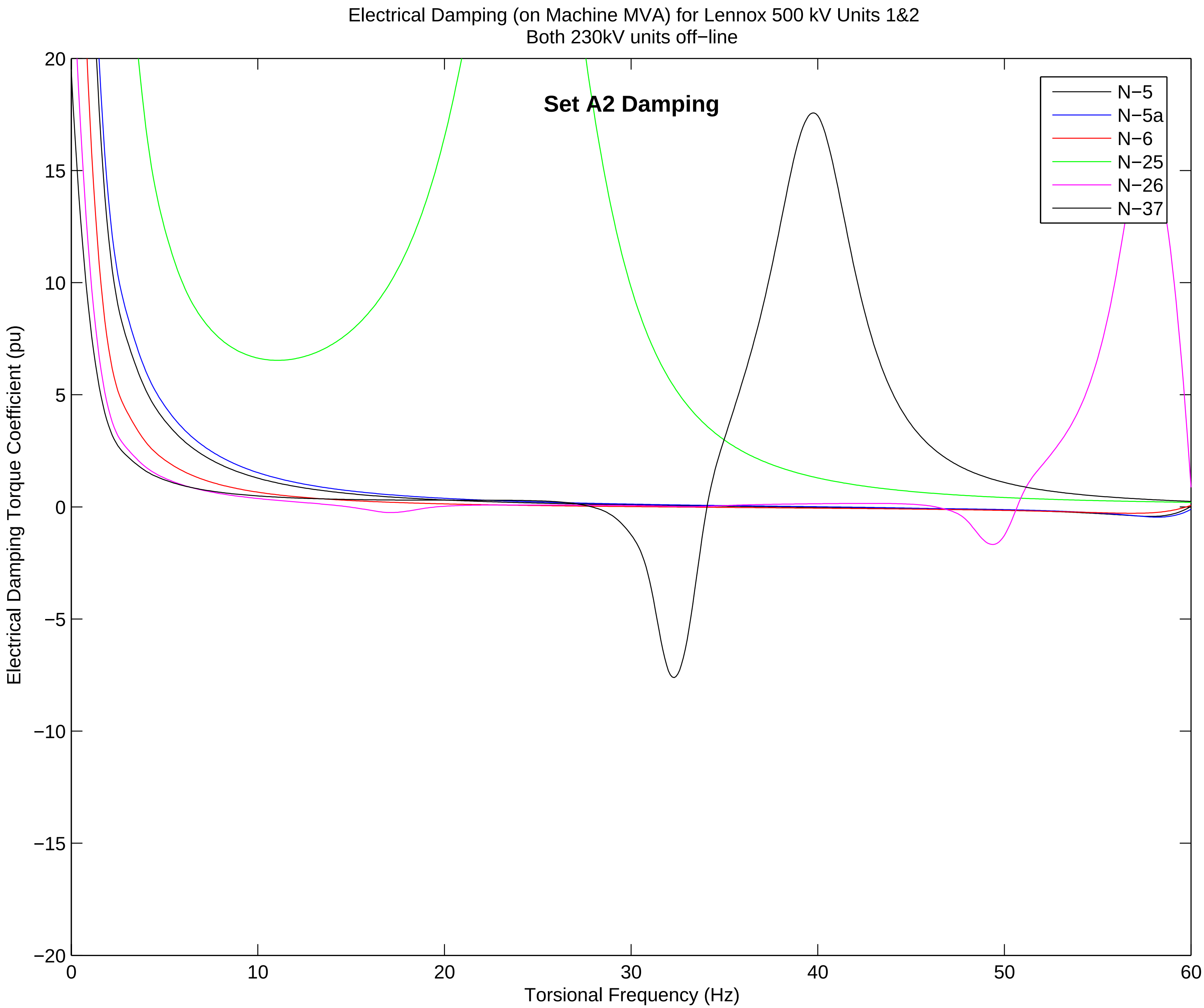
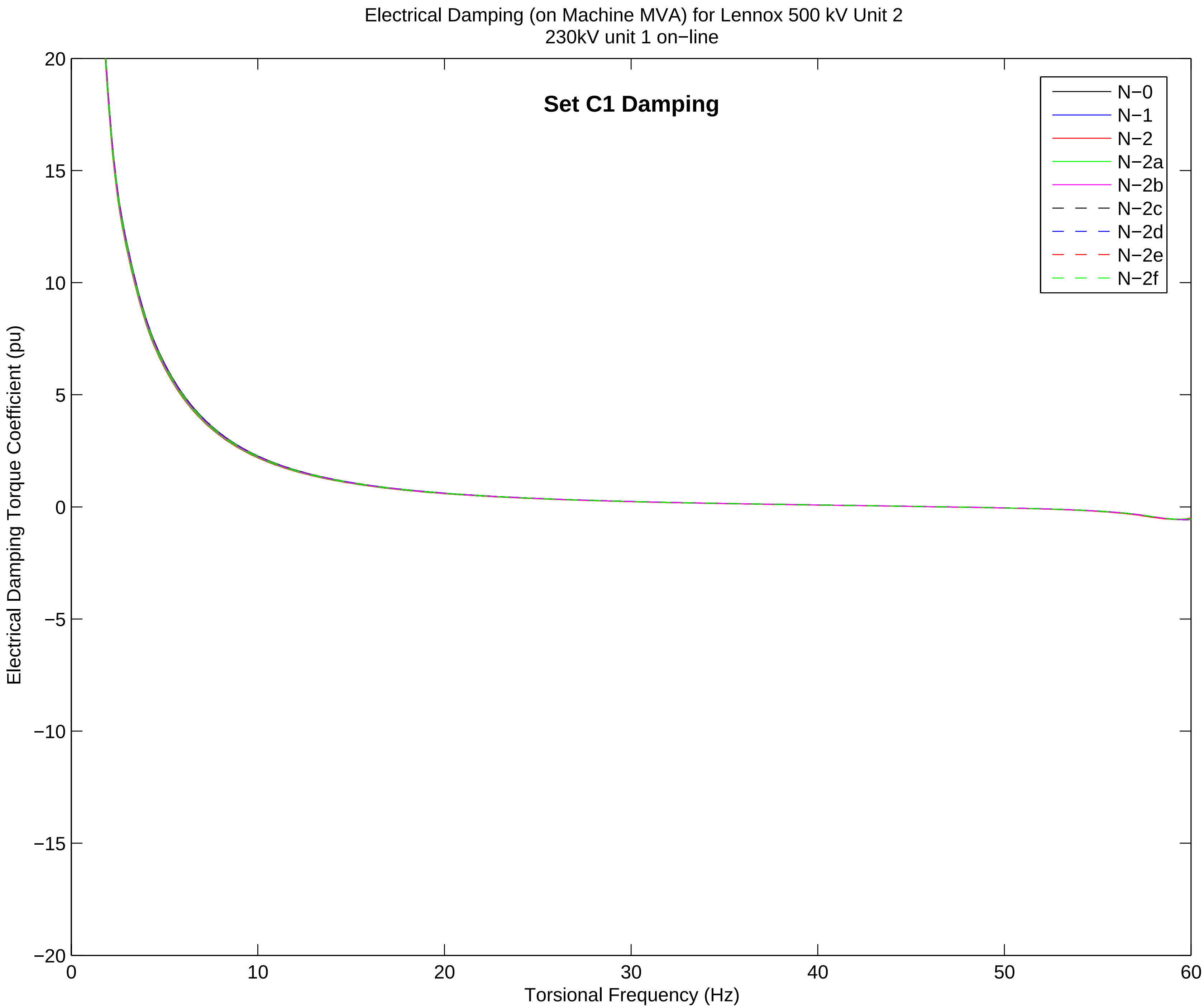
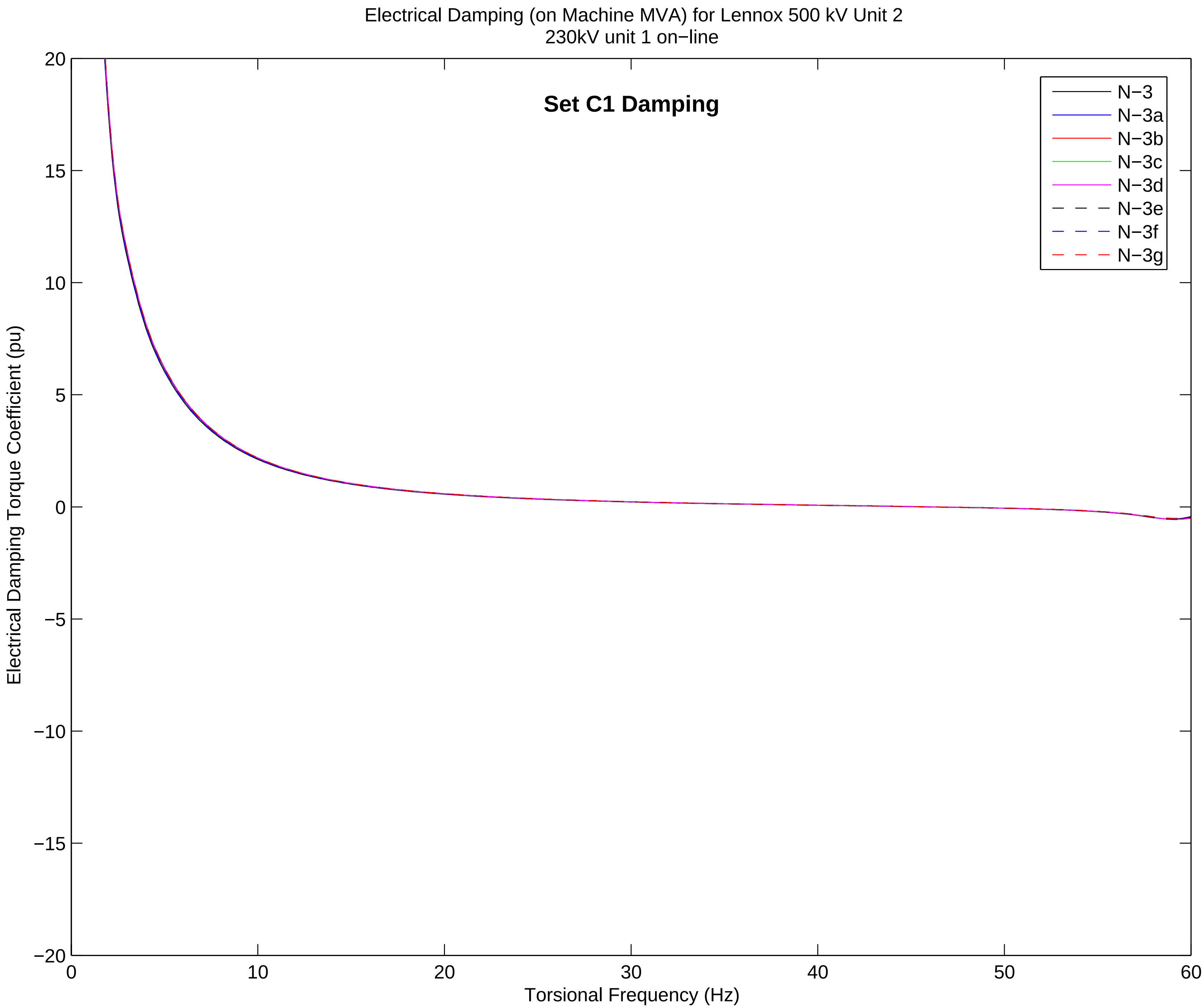

Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Damping
N−5
N−5a
N−6
N−25
N−26
N−37
Electrical Damping Torque Coefficient (pu)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
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−10
−15
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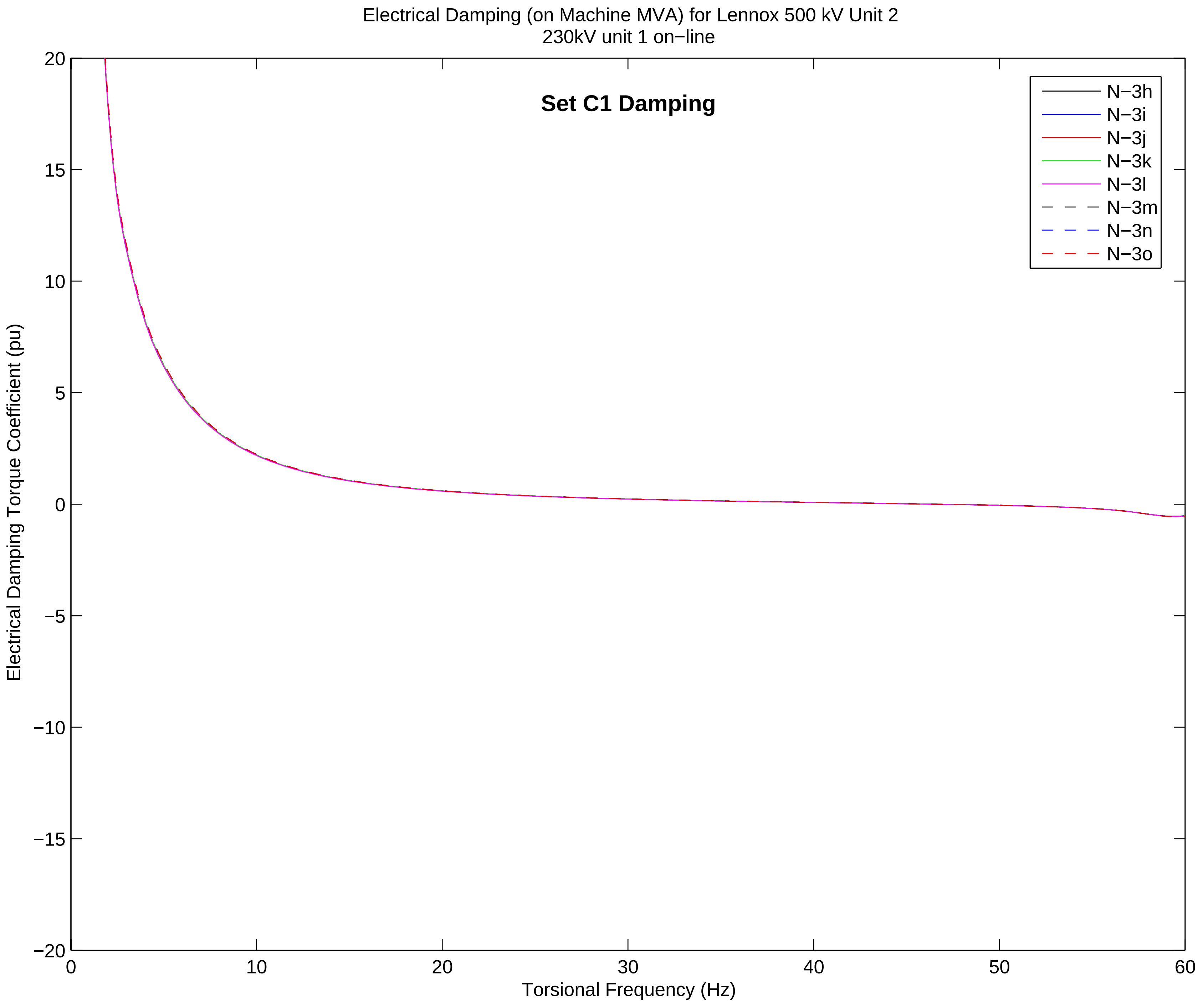

Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
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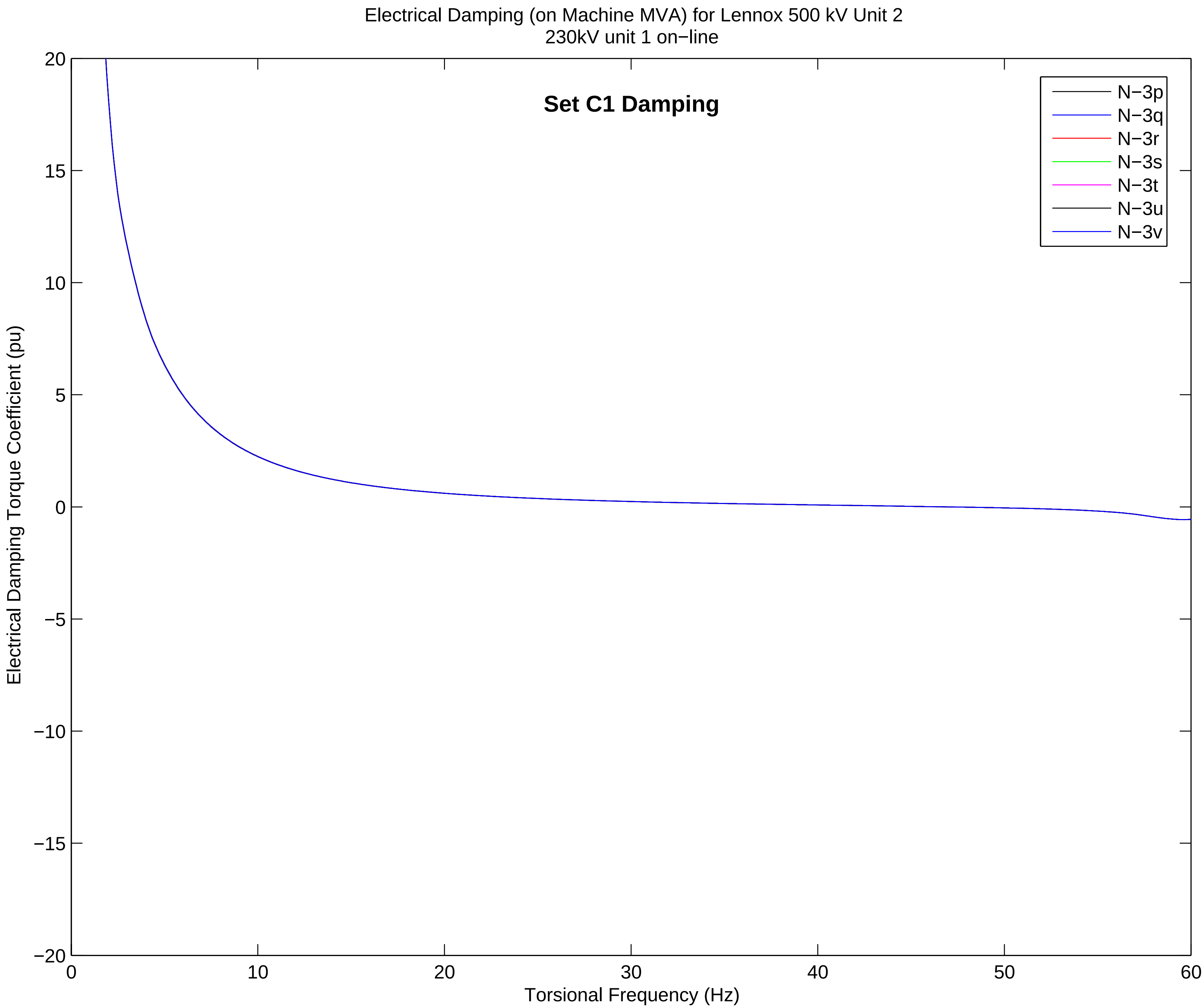

Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
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0
−5
−10
−15
−20
0
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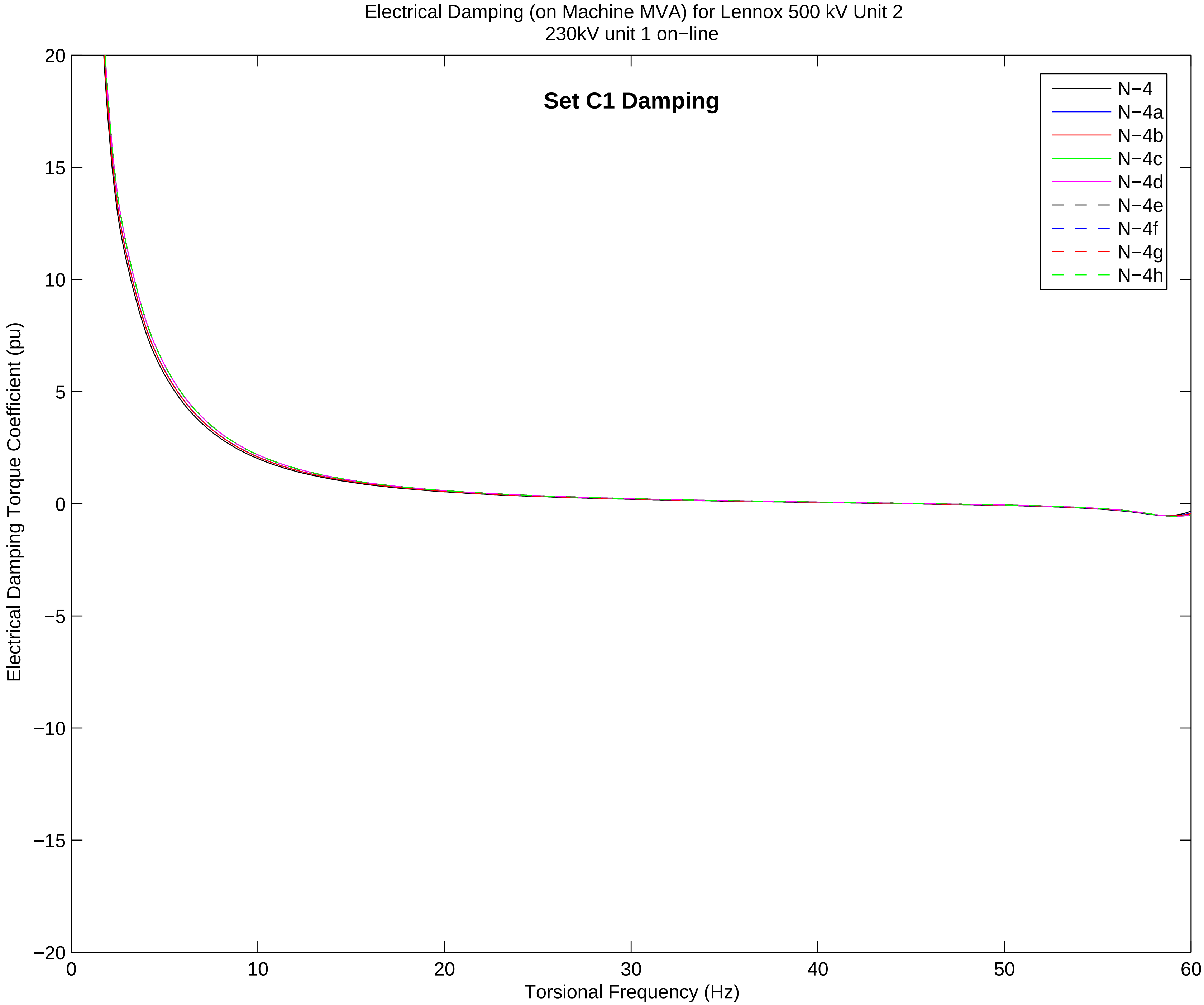
Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
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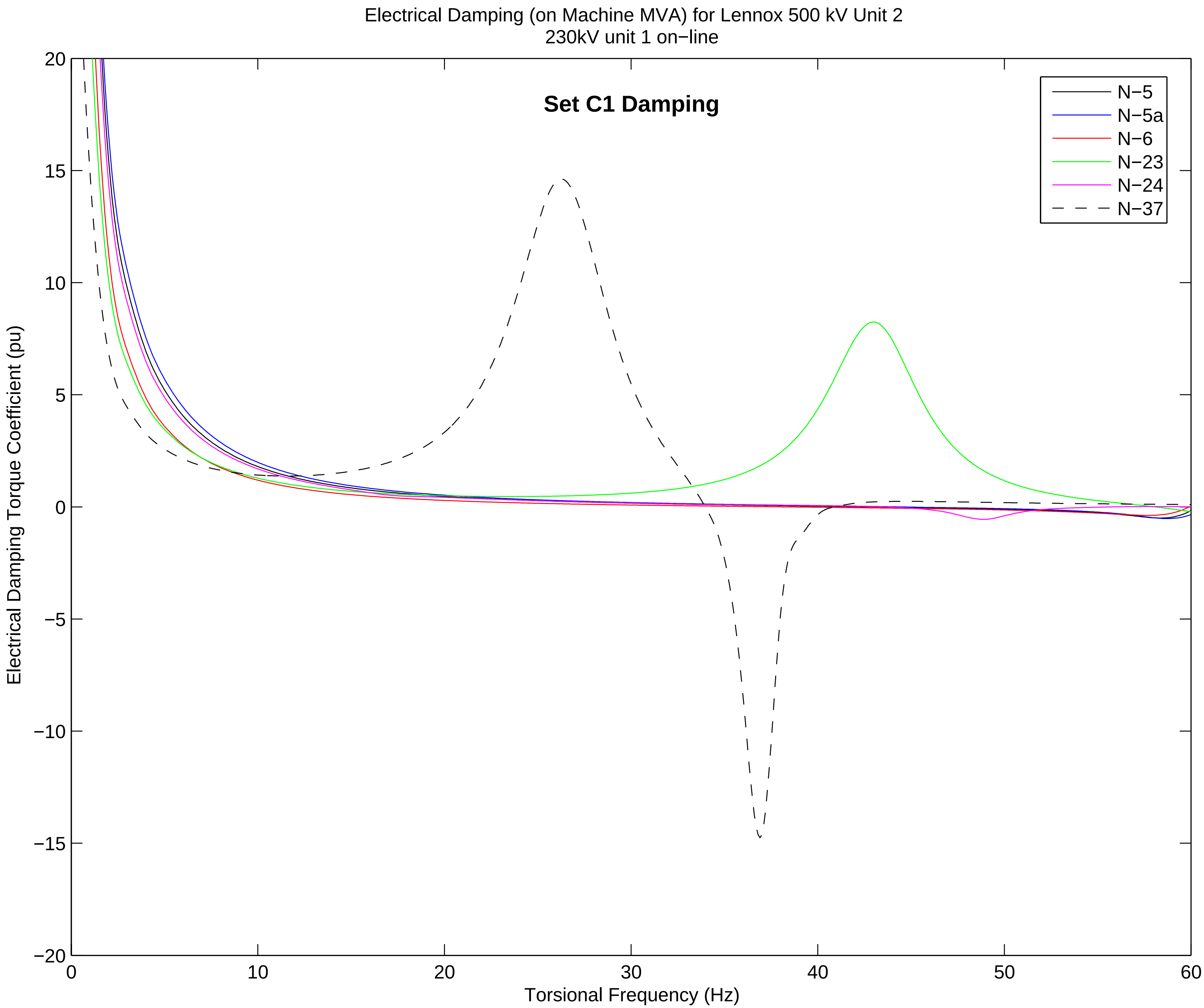
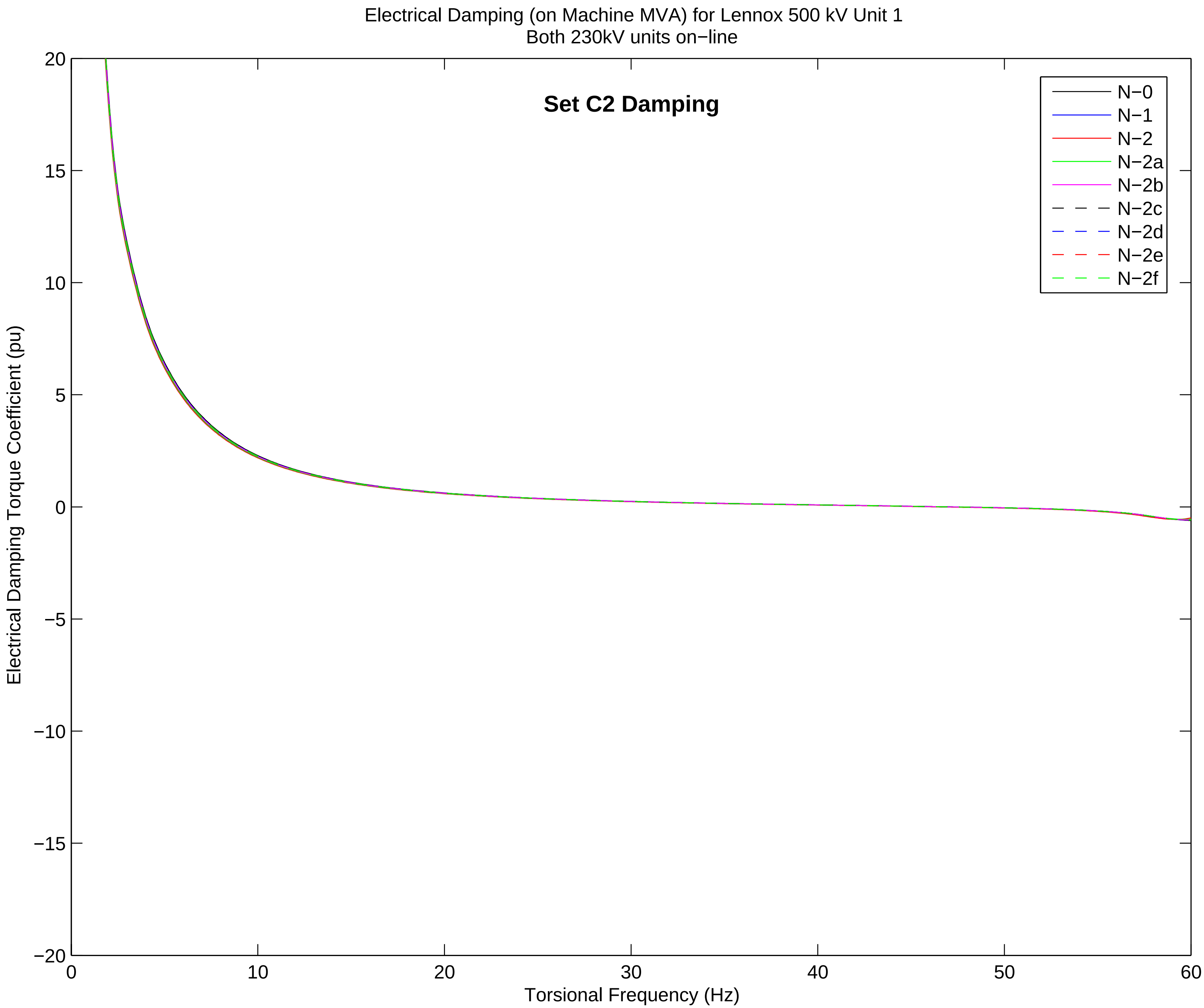
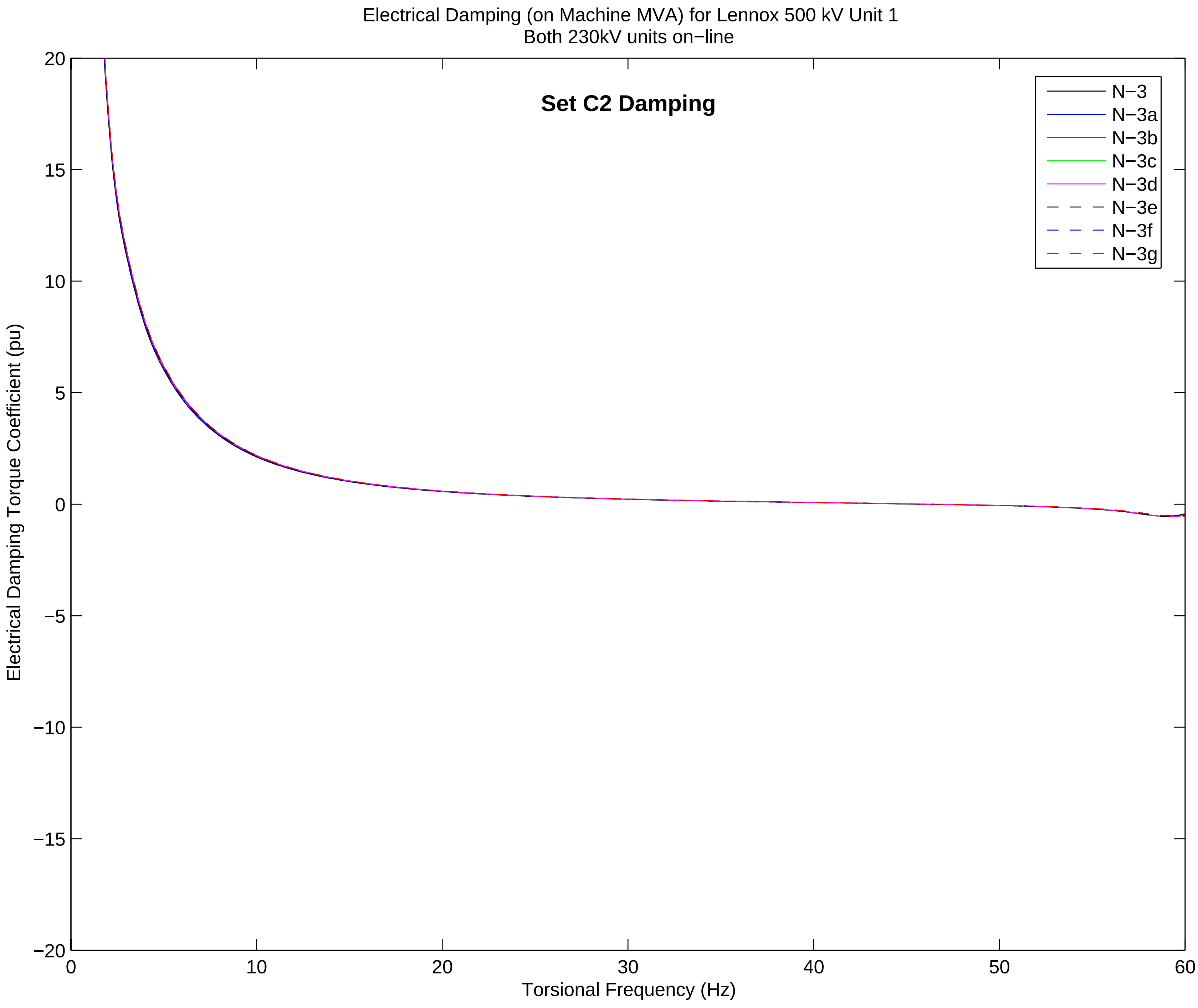


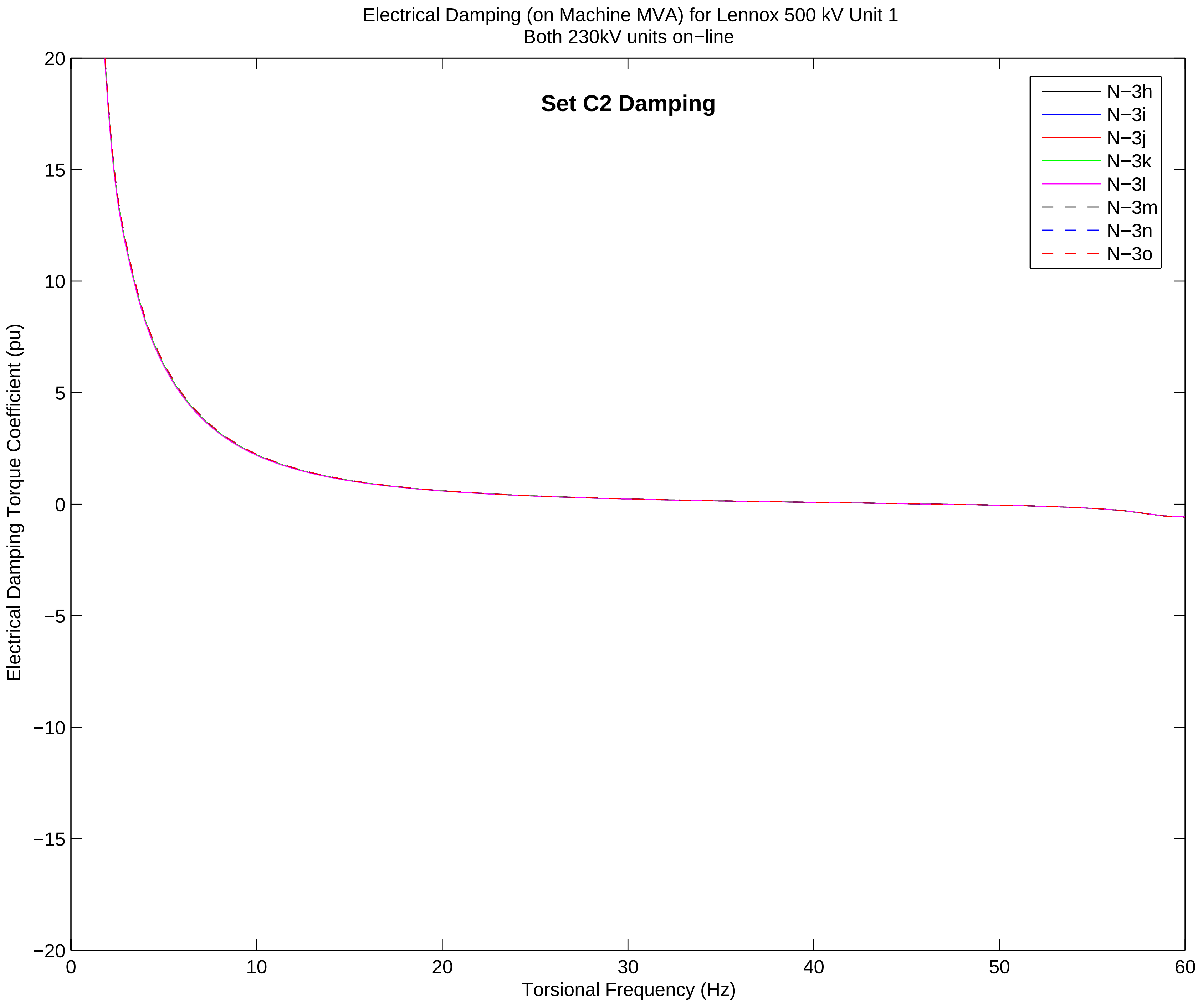
Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

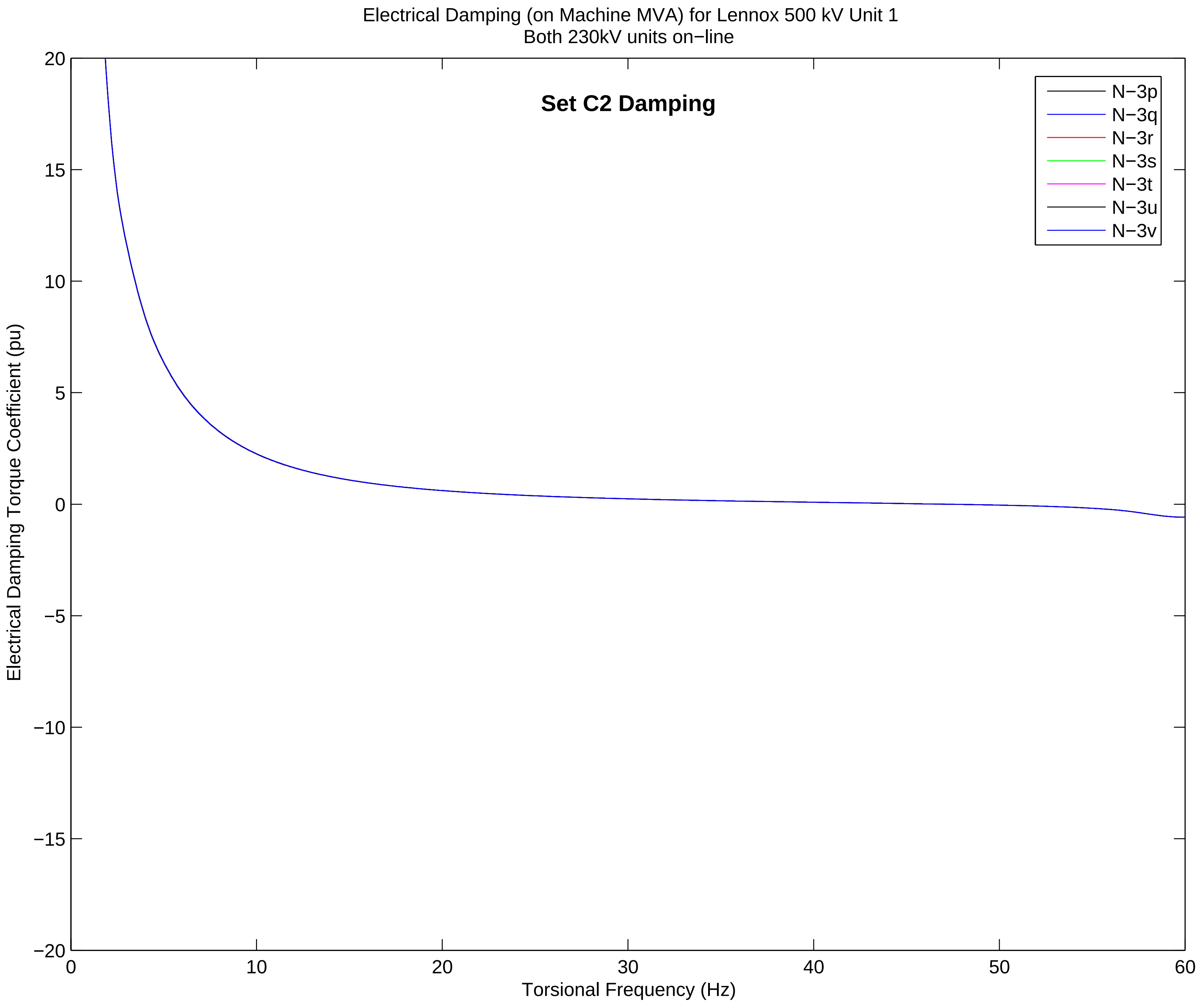


Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

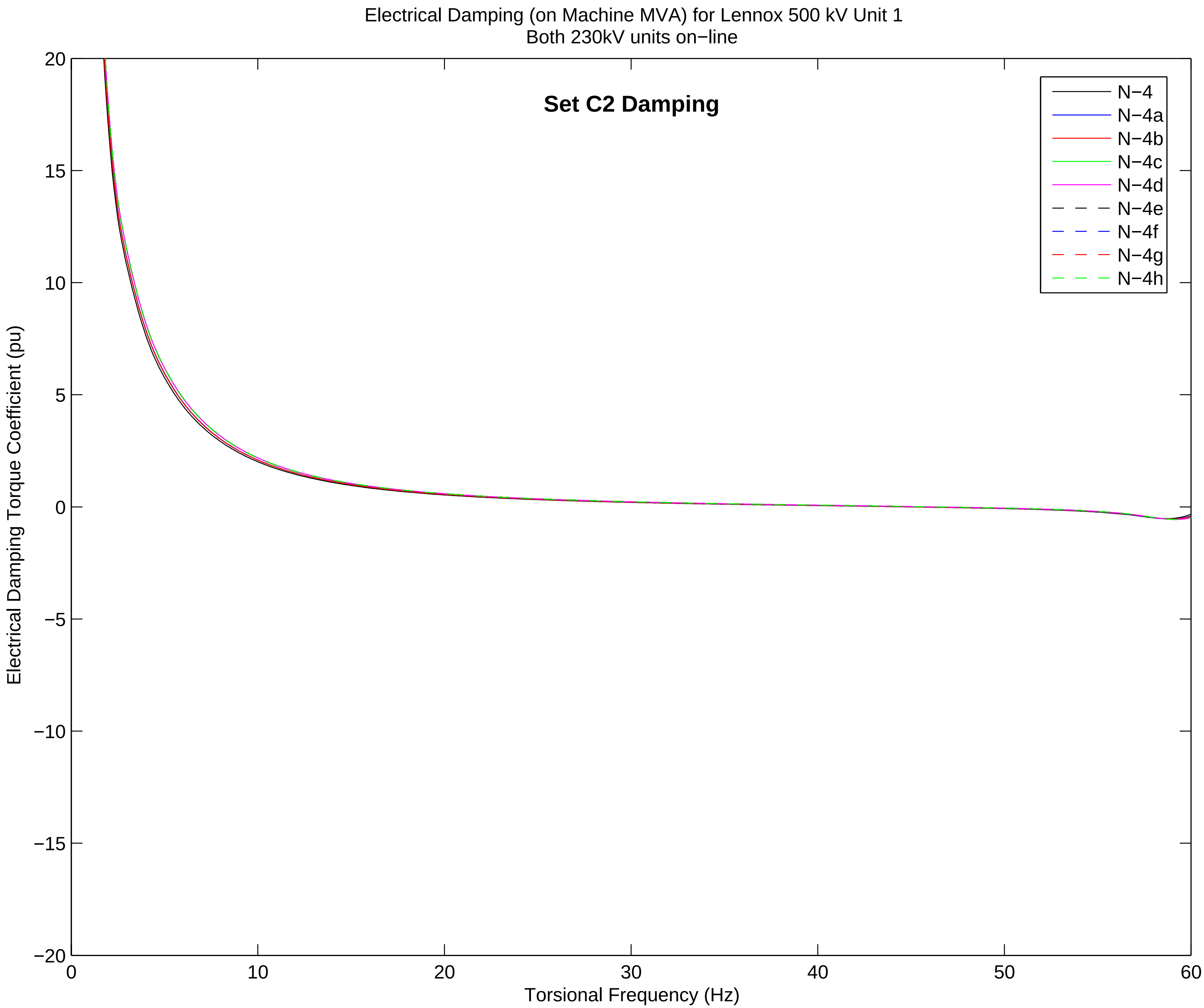


Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

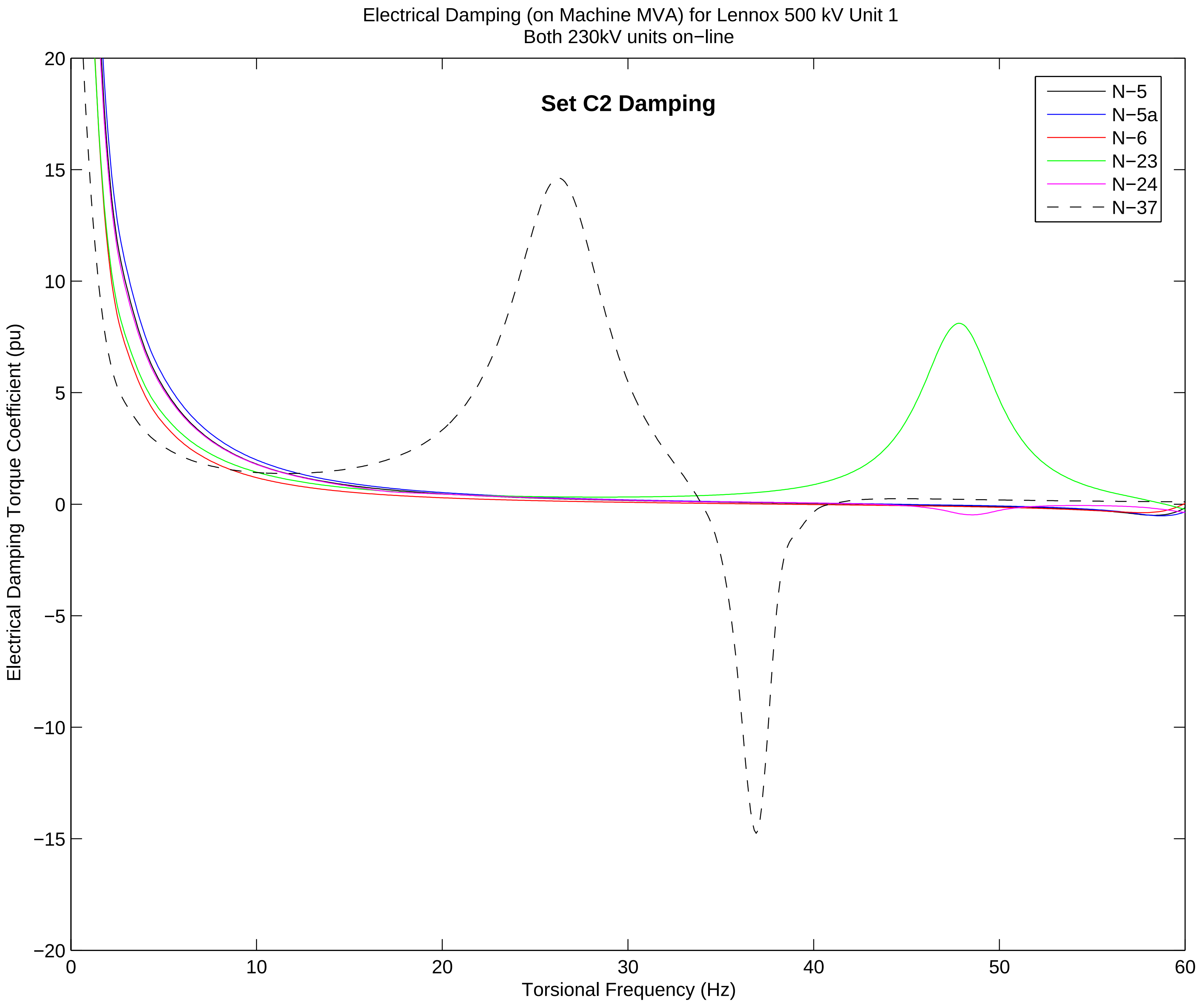

Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

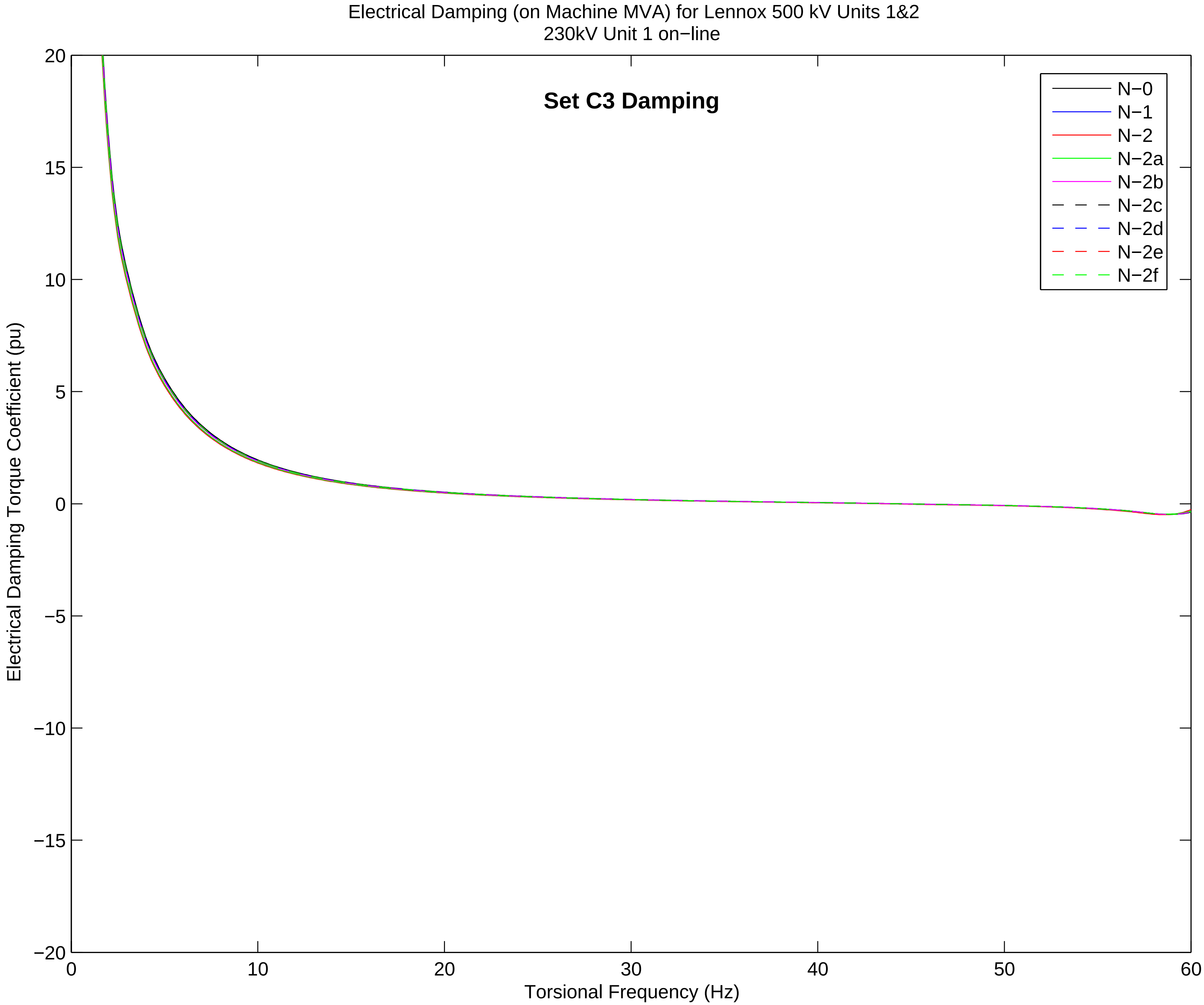


Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

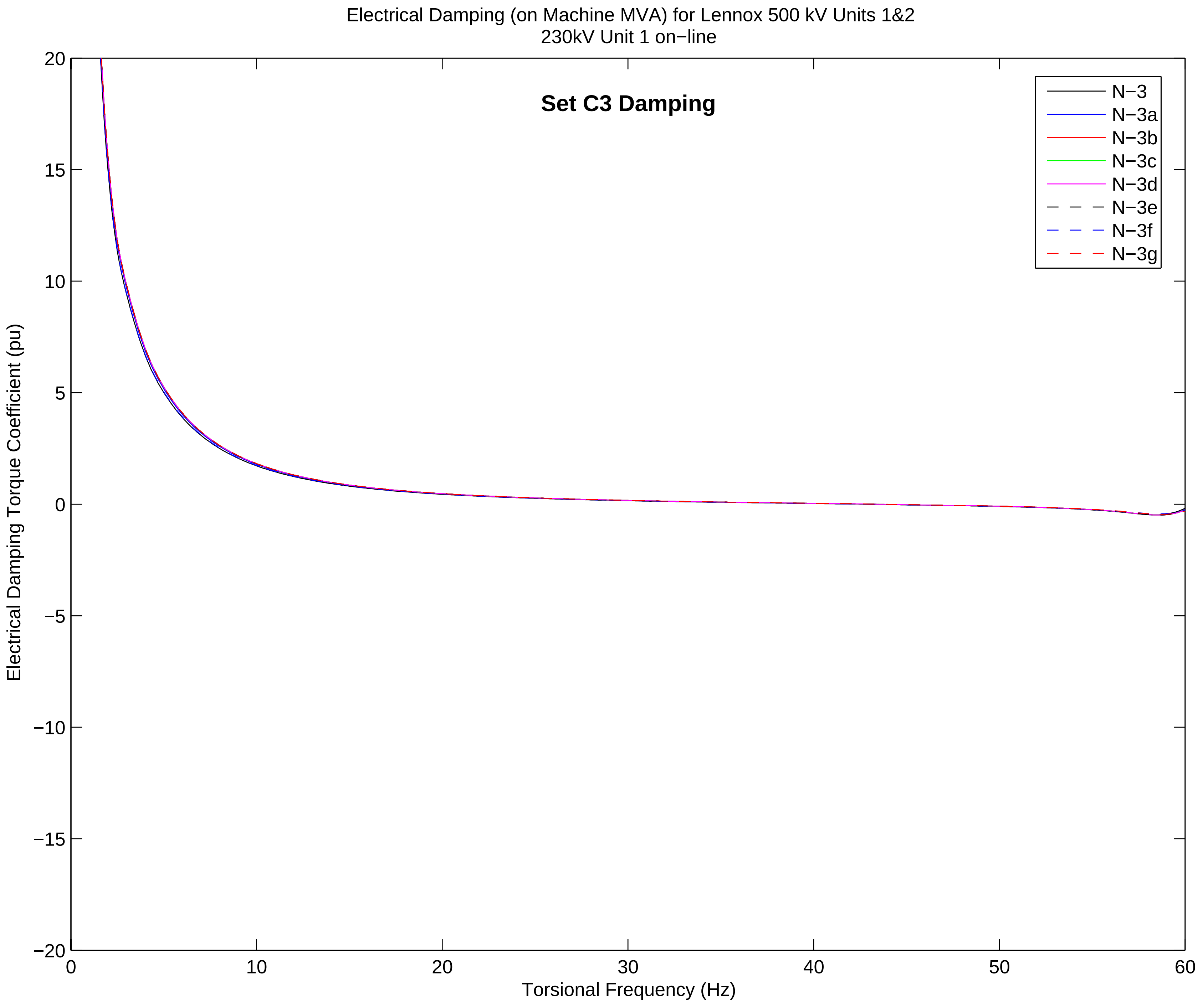


Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

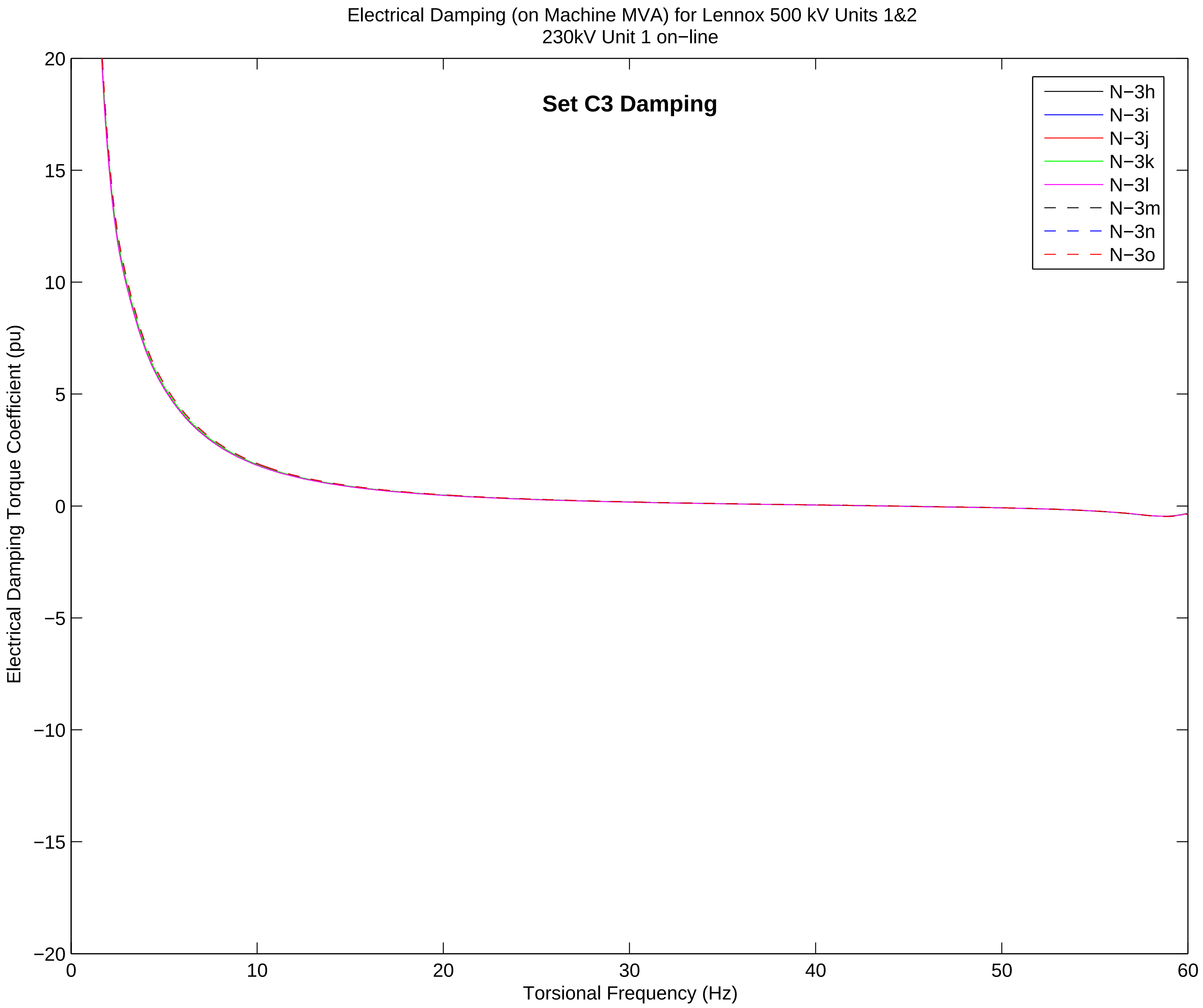

Electrical Damping (on Machine MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

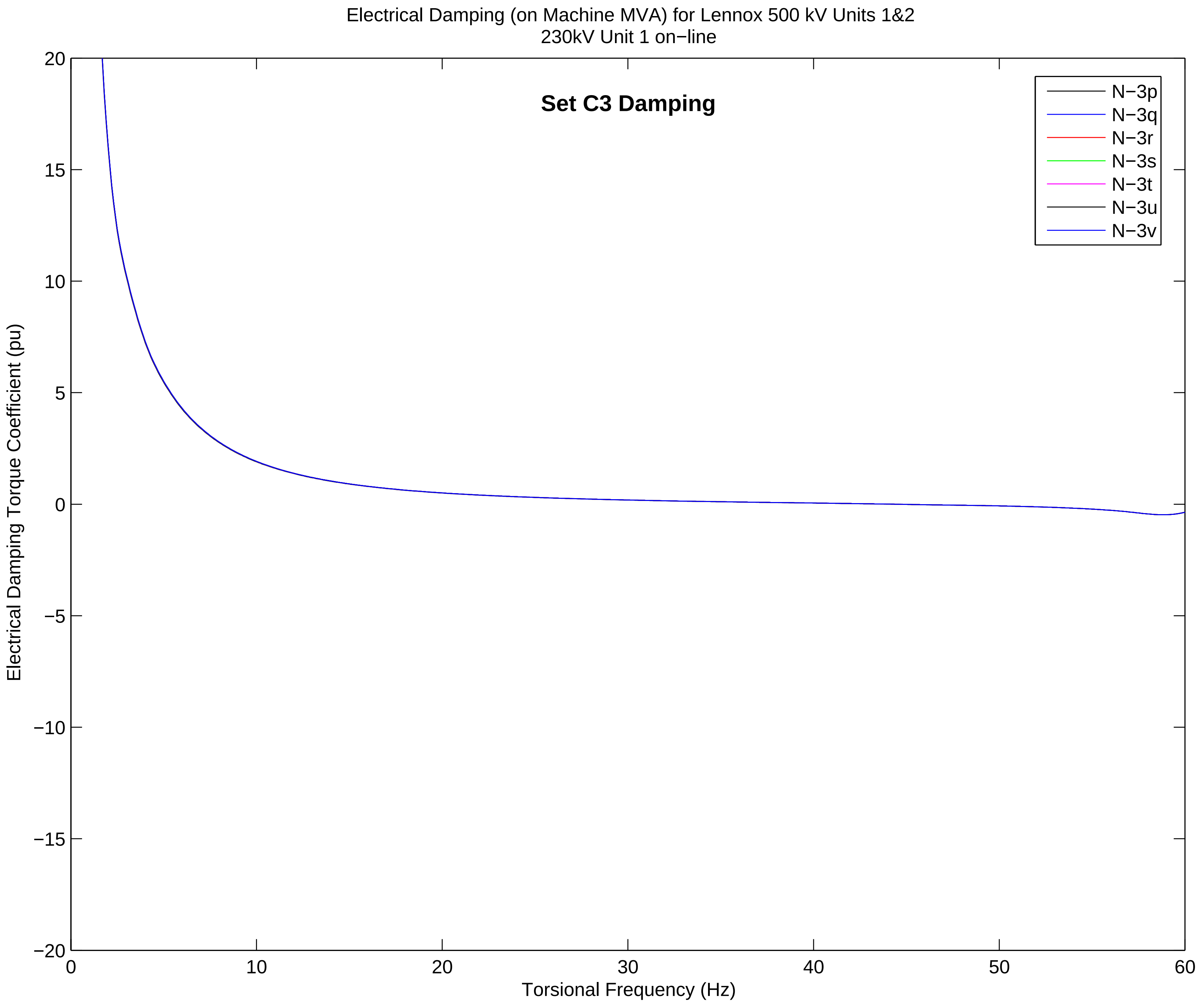


Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

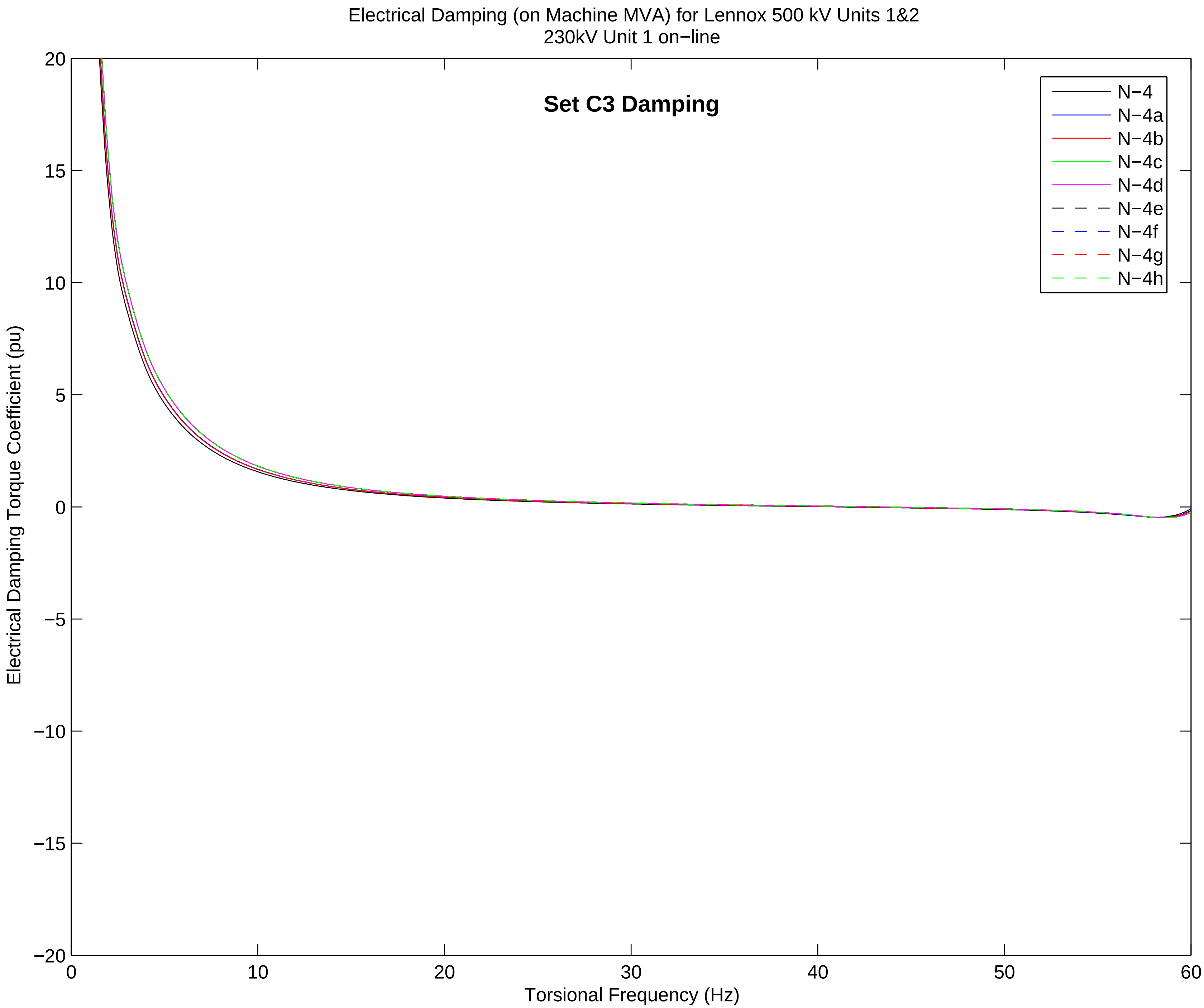


Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

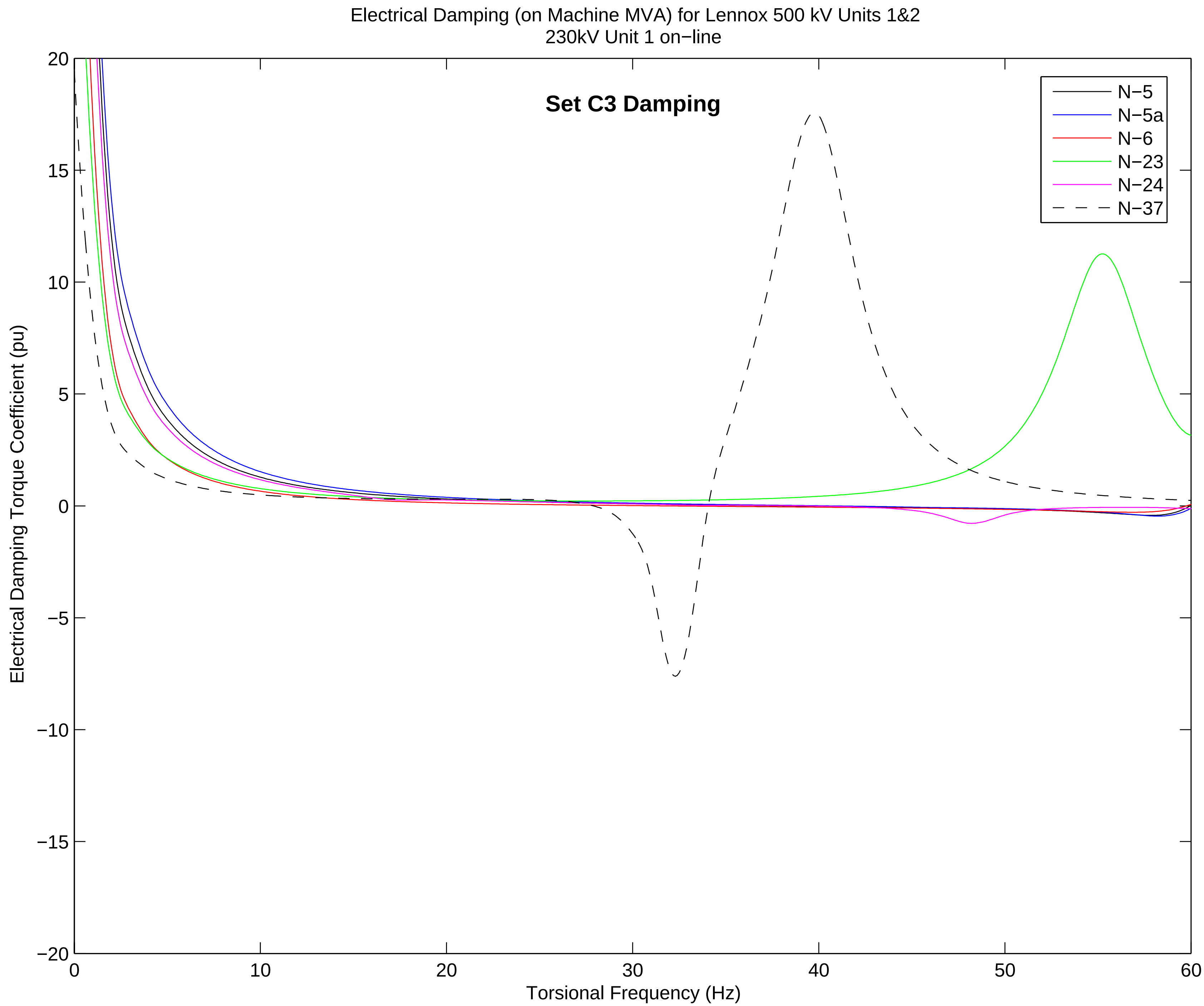

Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



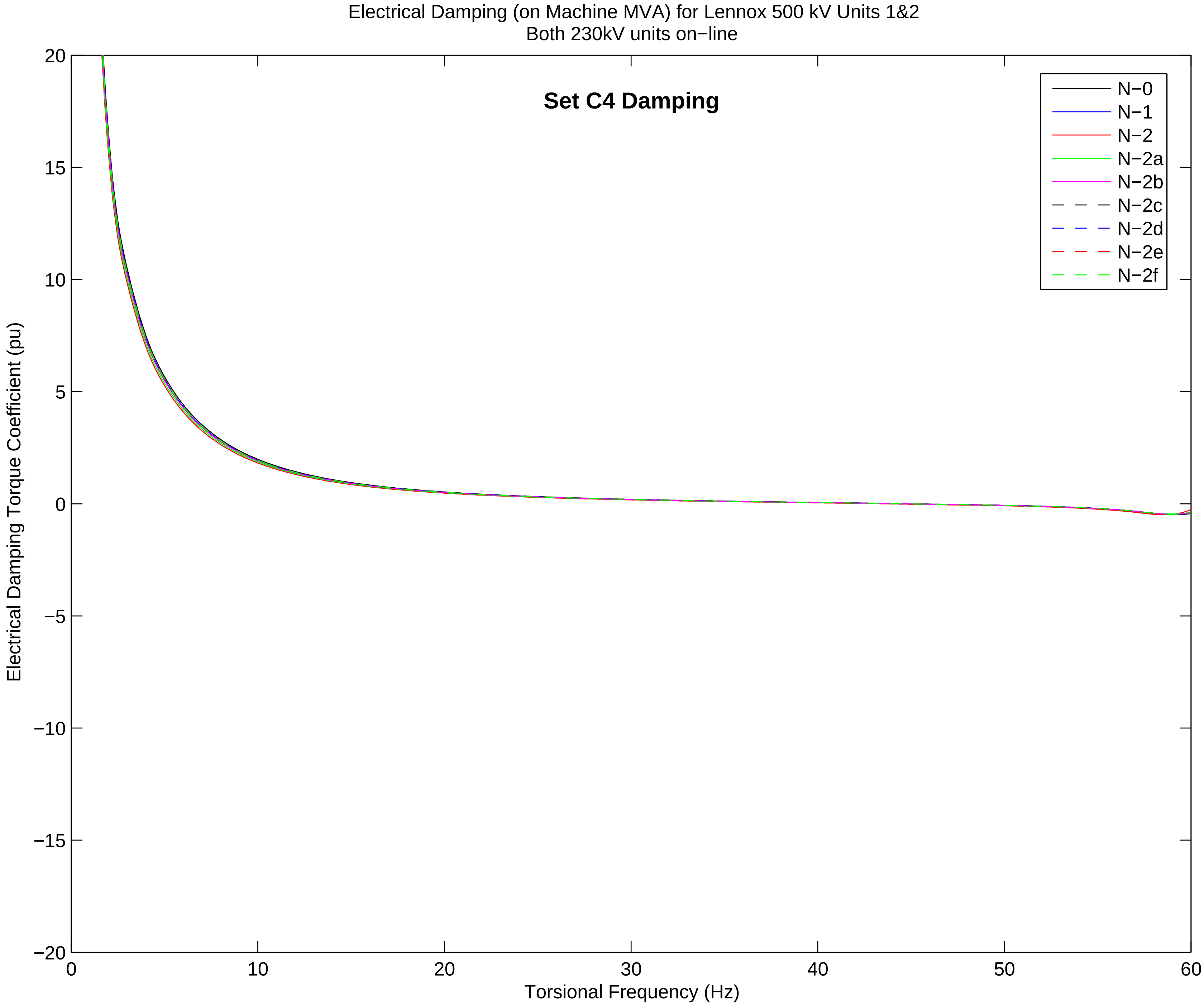
Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



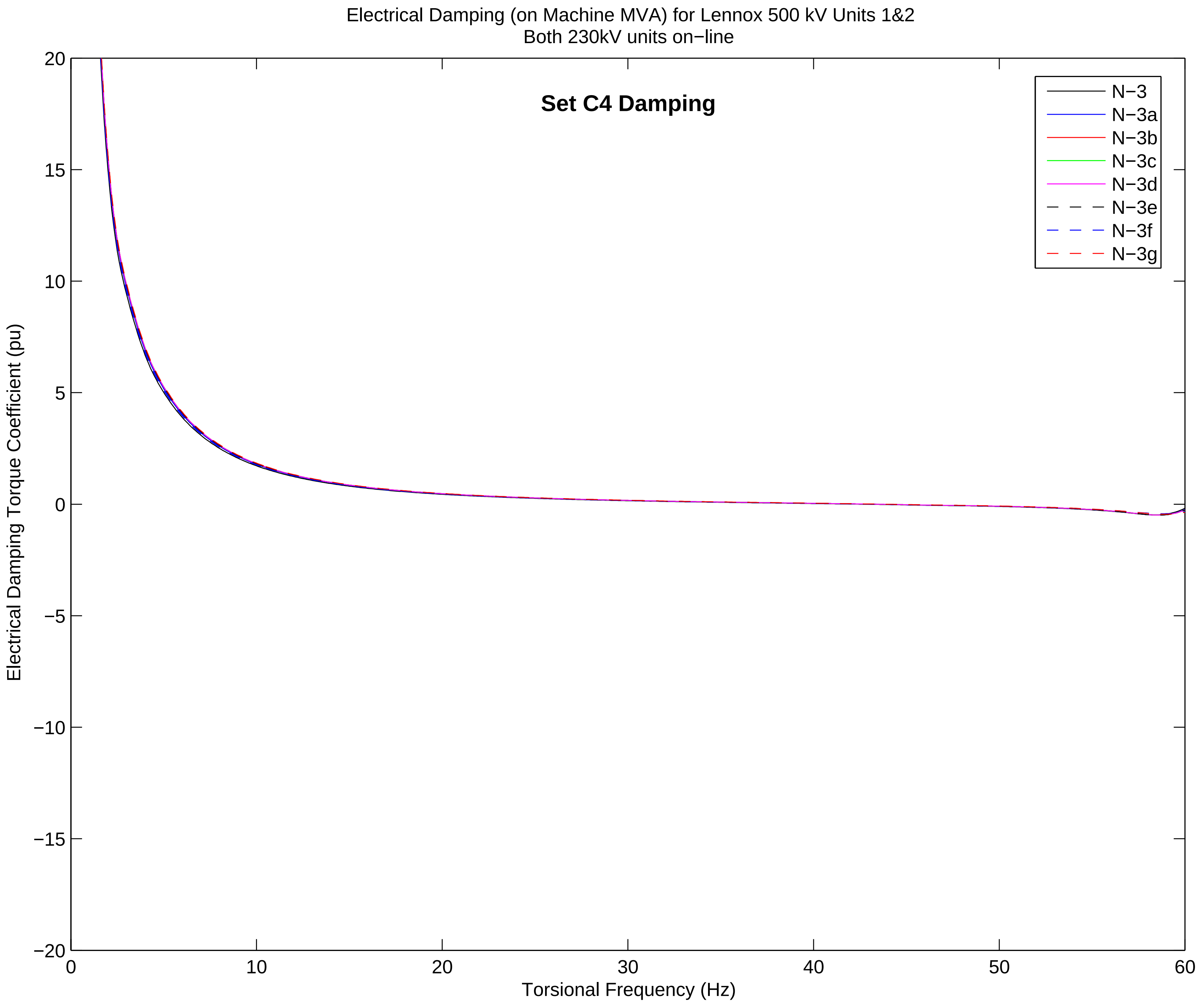
Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)
Electrical Damping Torque Coefficient (pu)



Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
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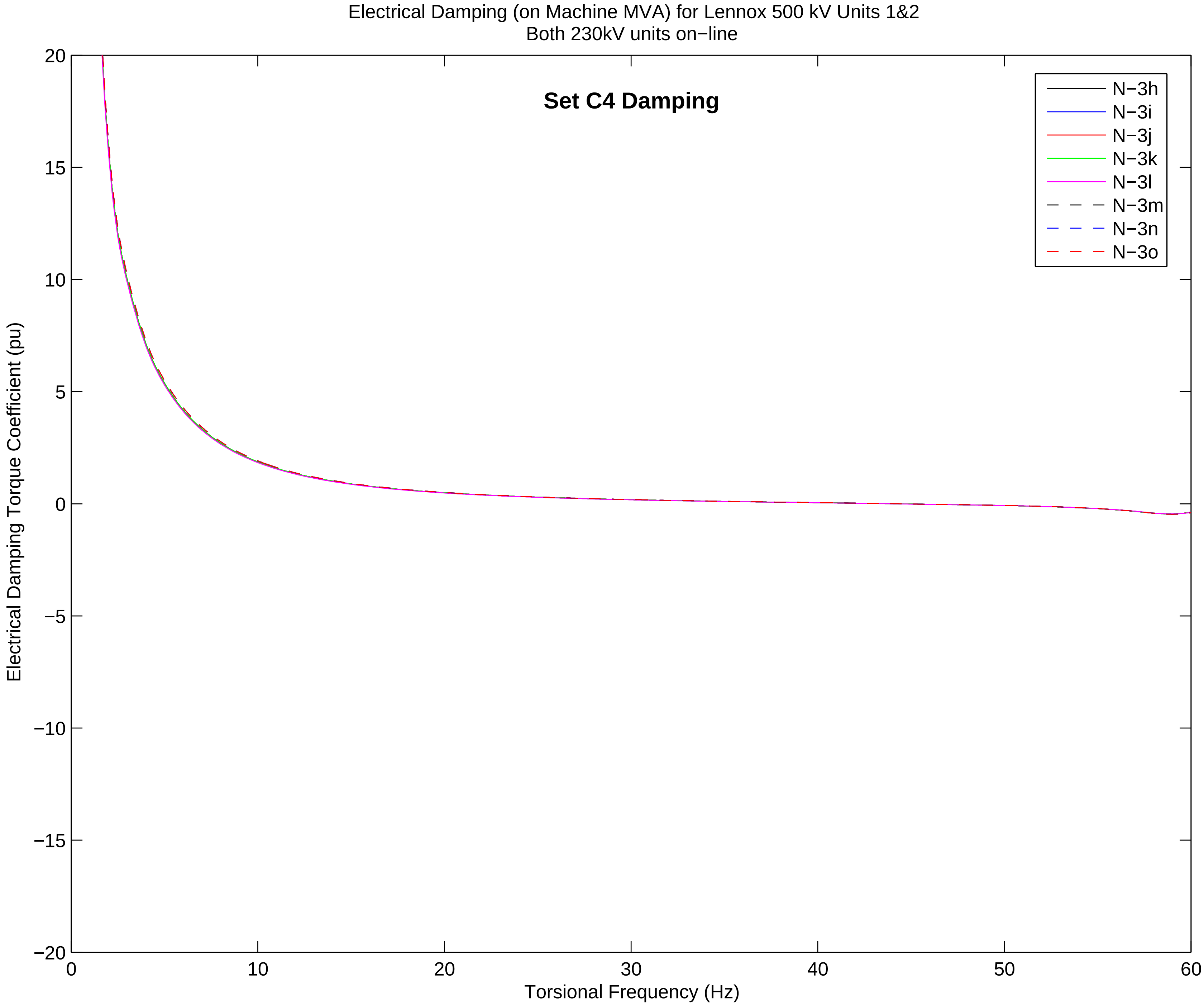
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
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5
0
−5
−10
−15
−20
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10
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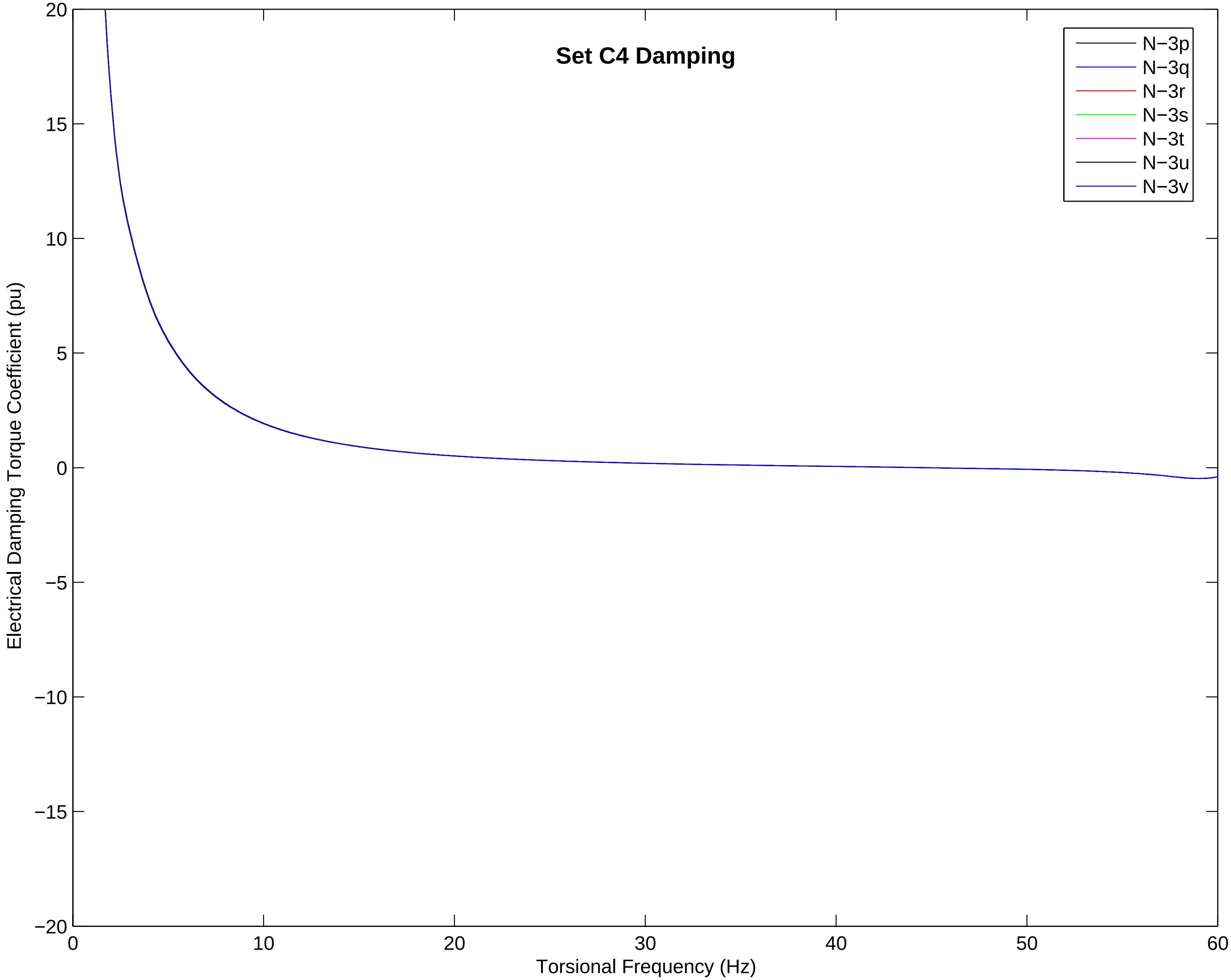
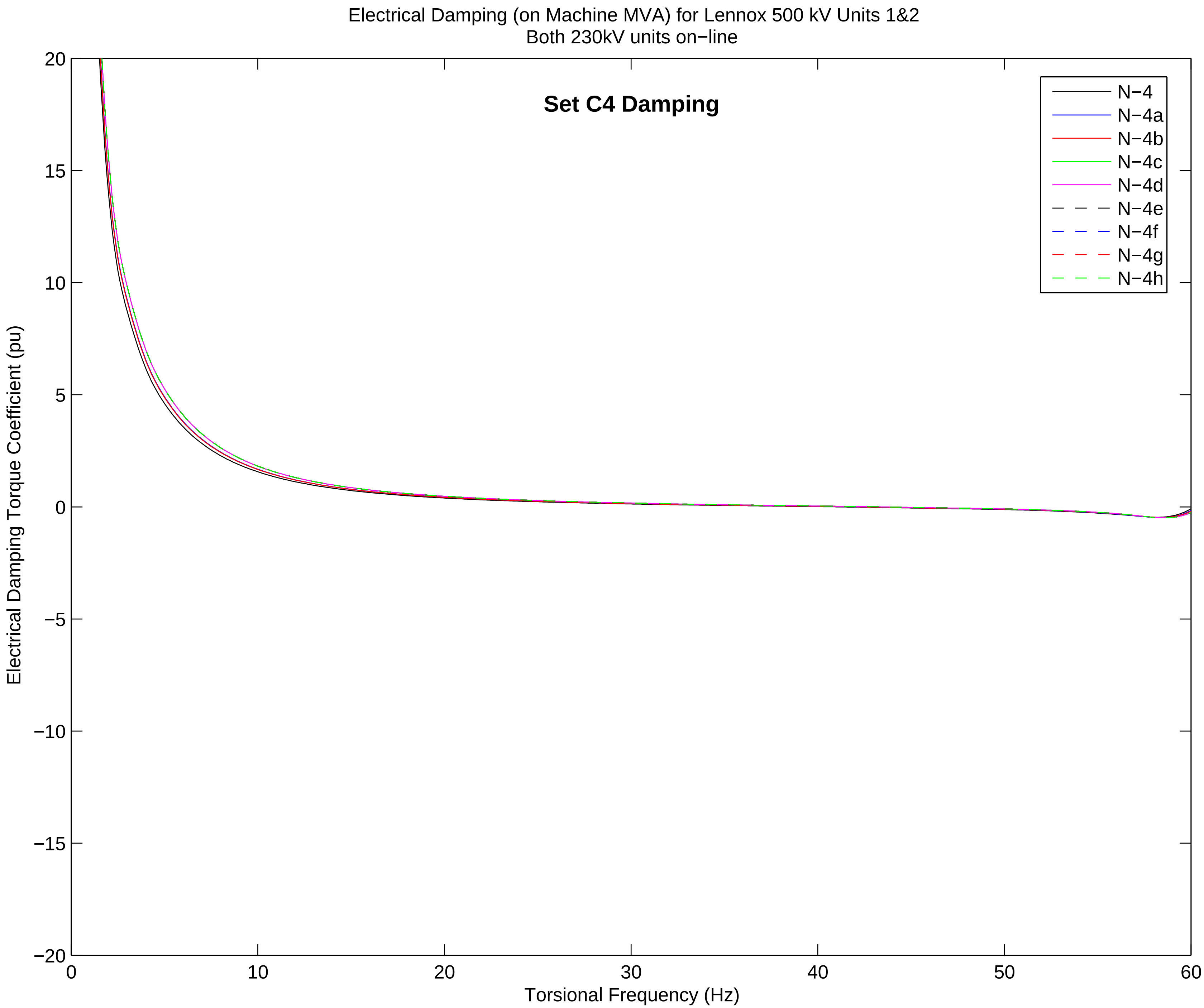
60

Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line




Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
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−5
−10
−15
−20
0
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20
30
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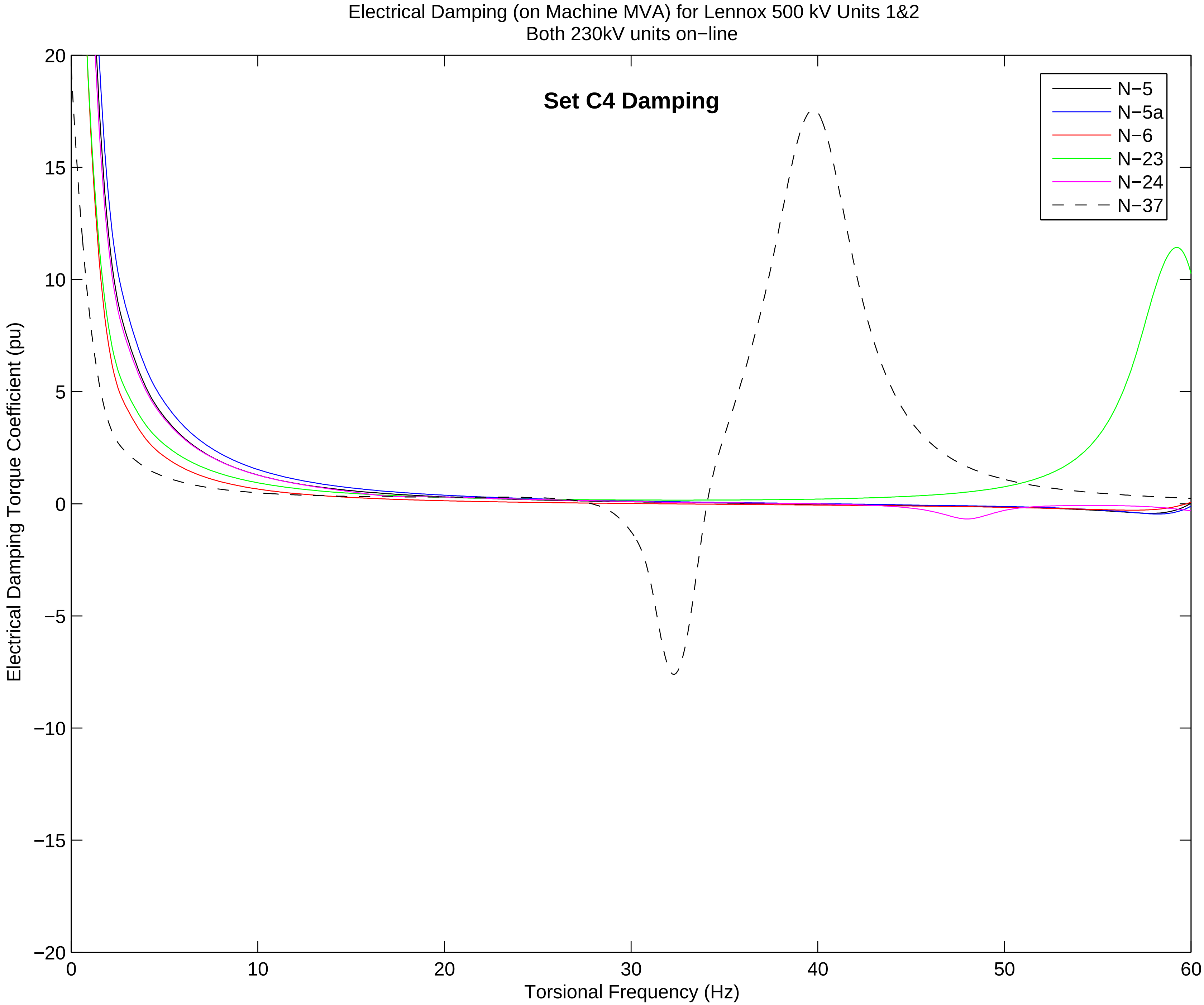
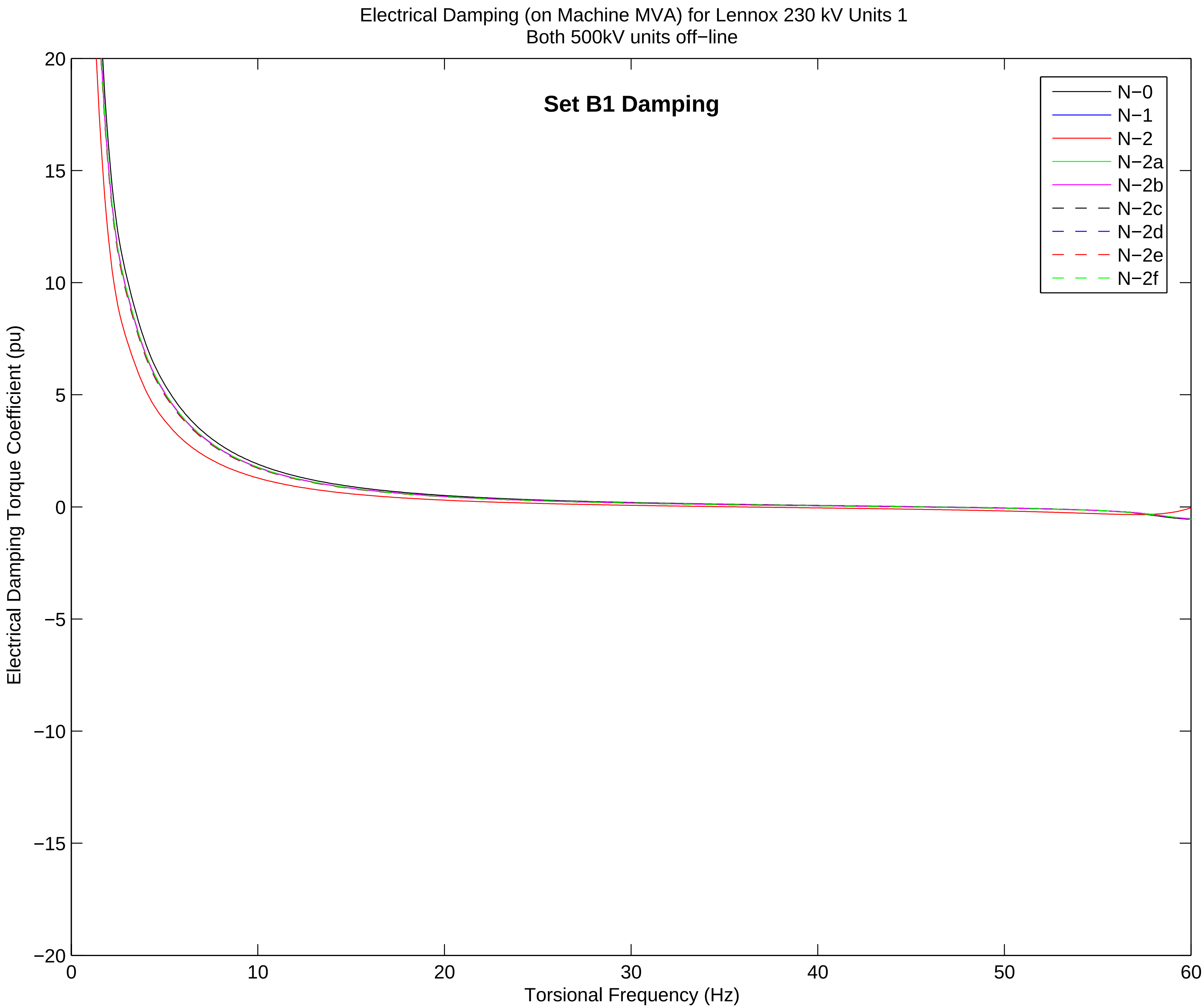
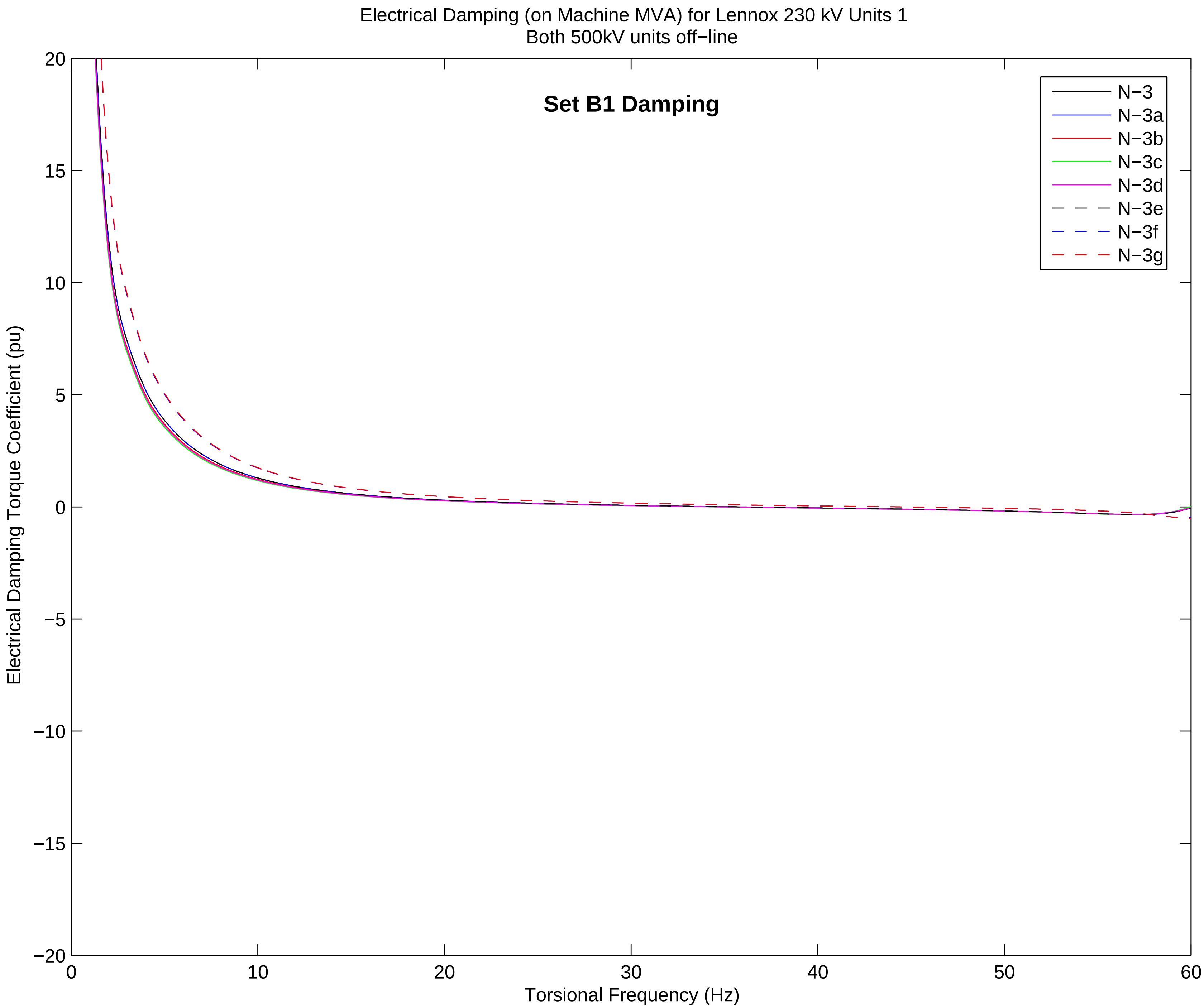
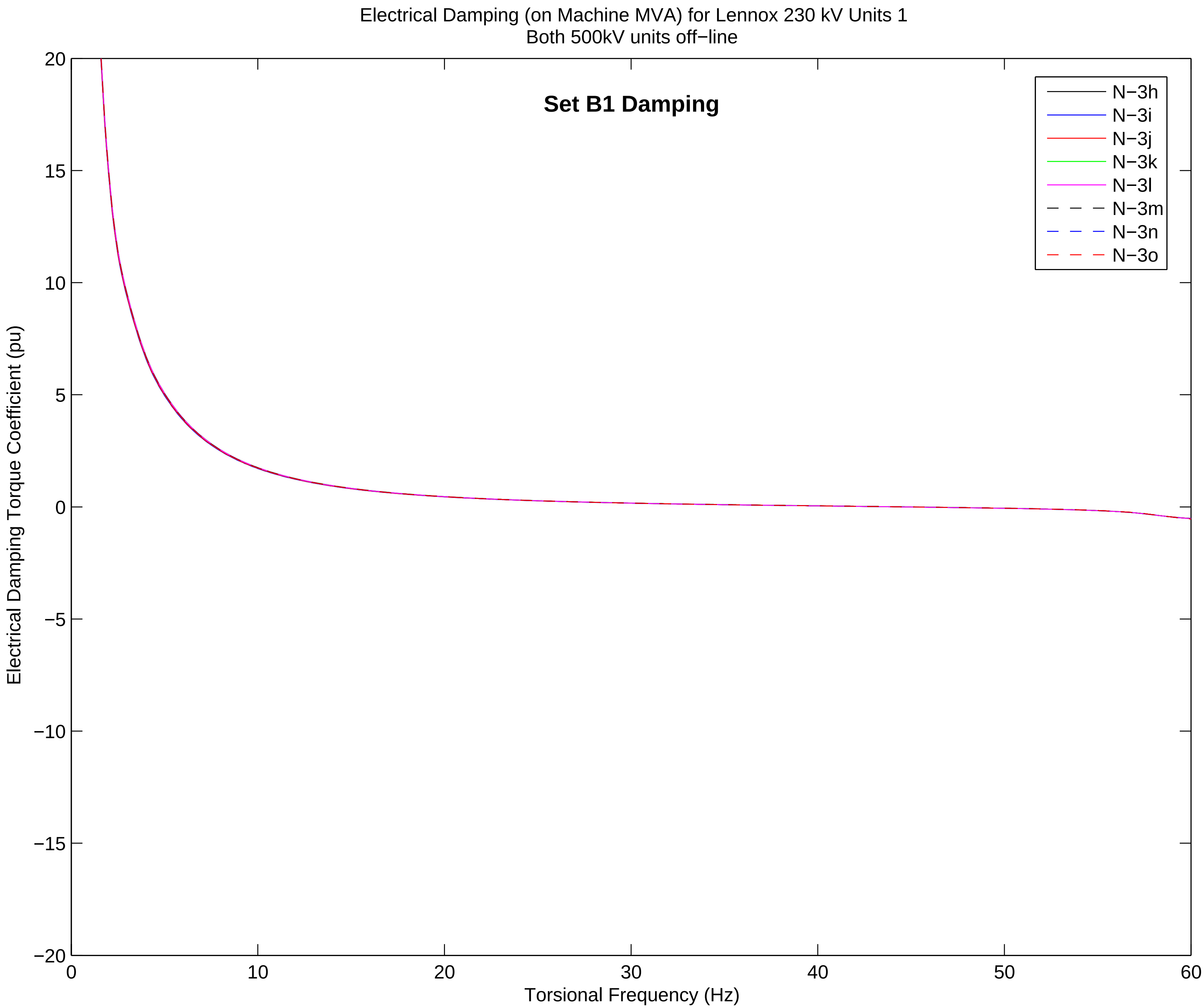


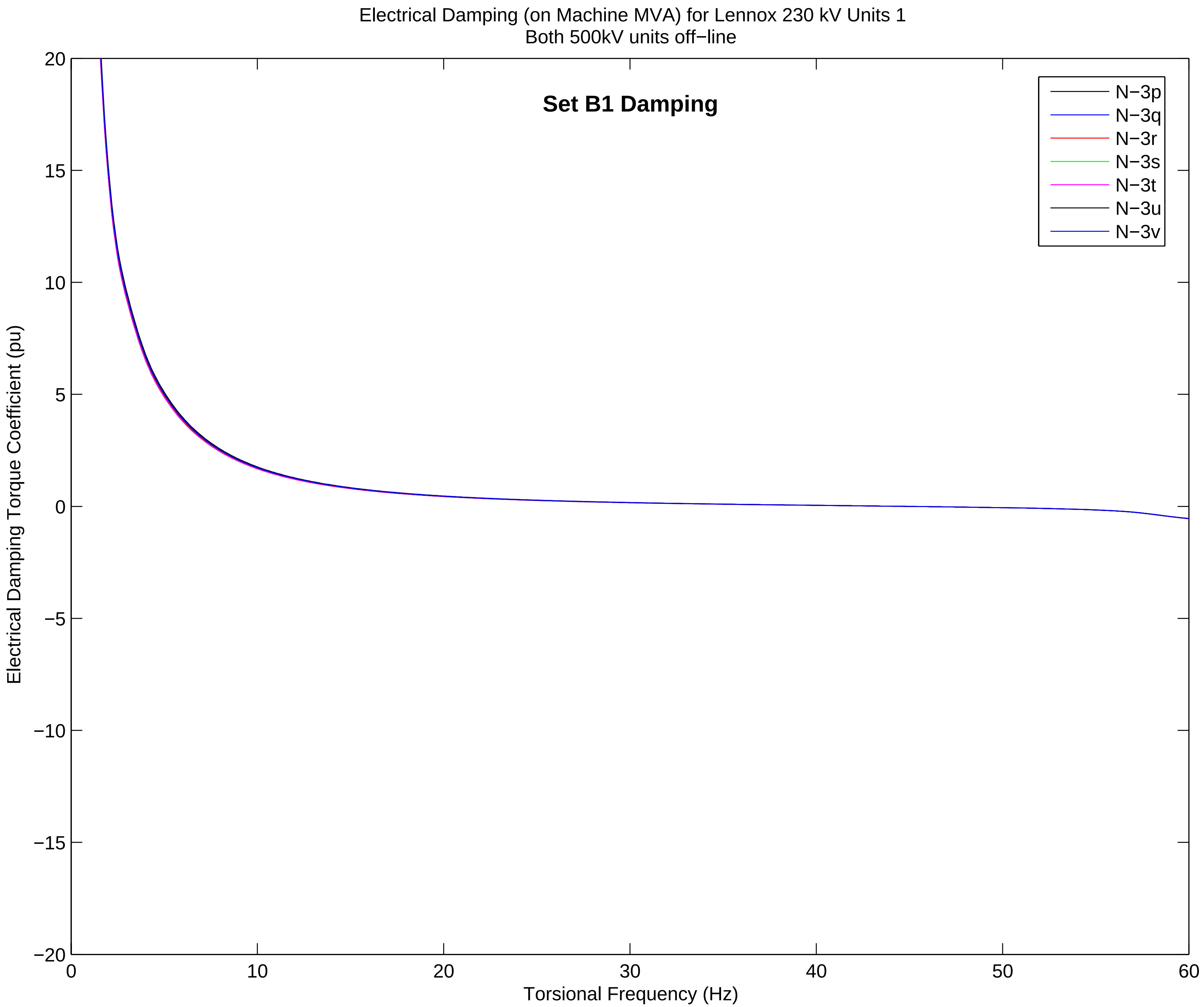
Electrical Damping (on Machine MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
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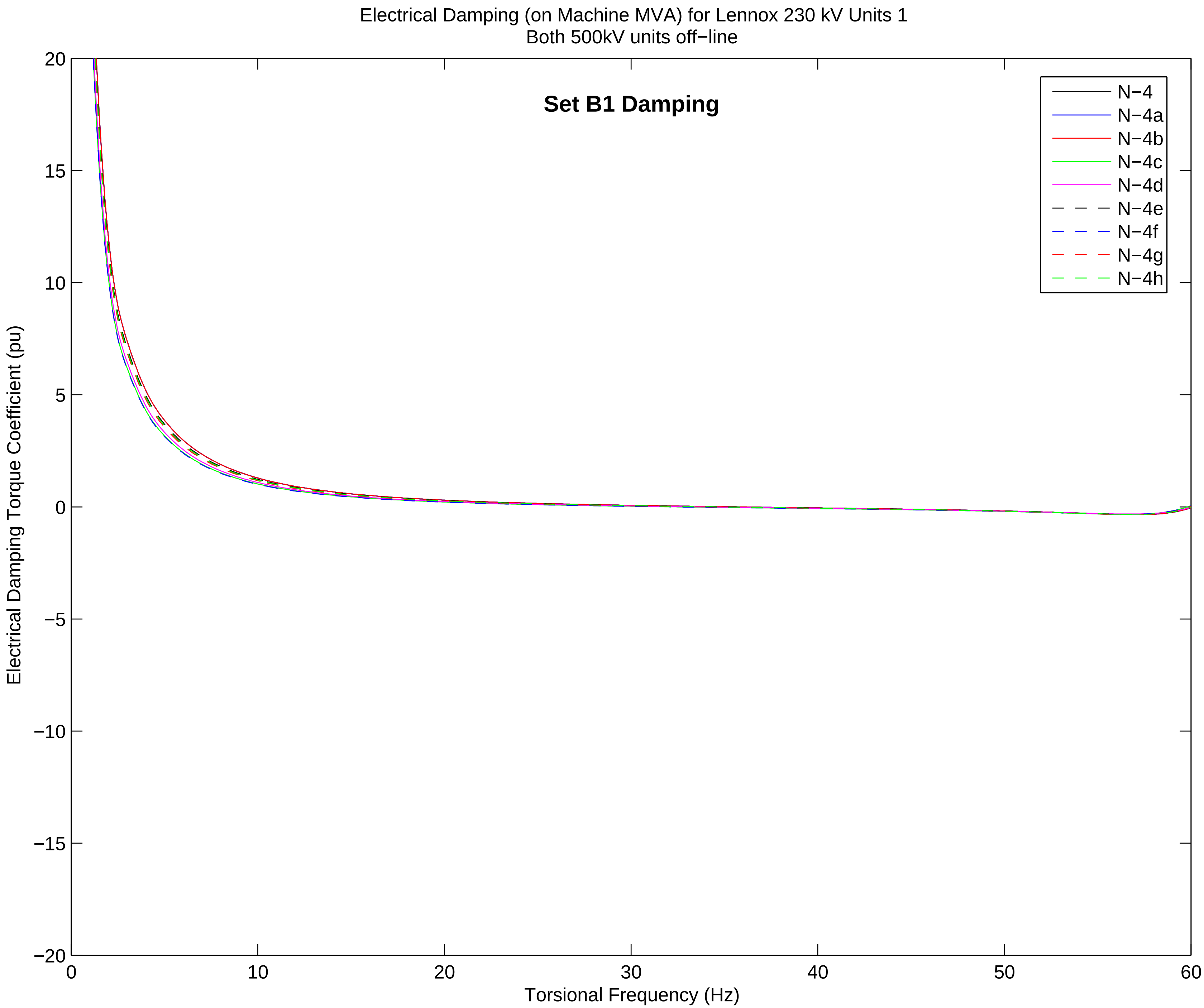
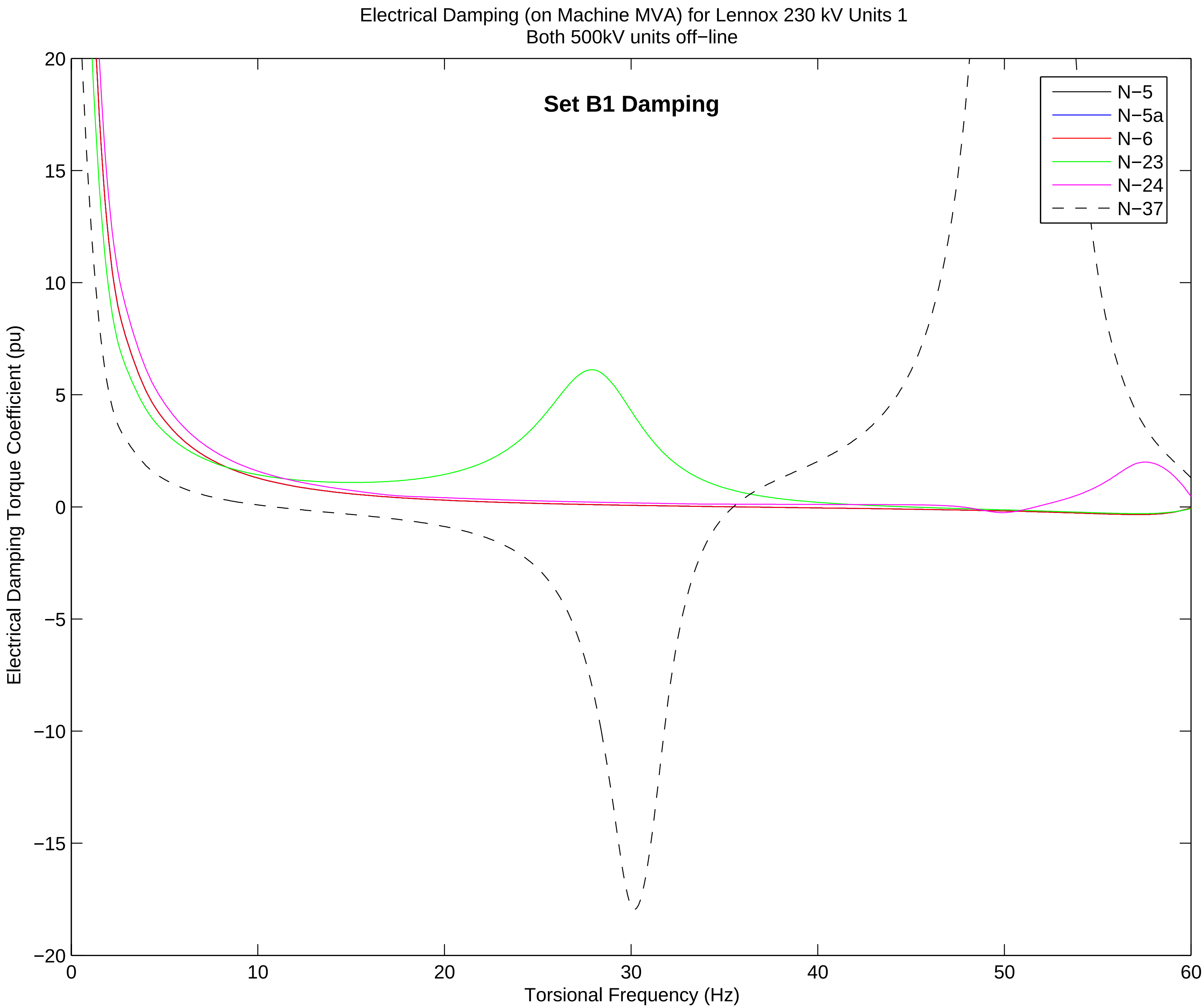
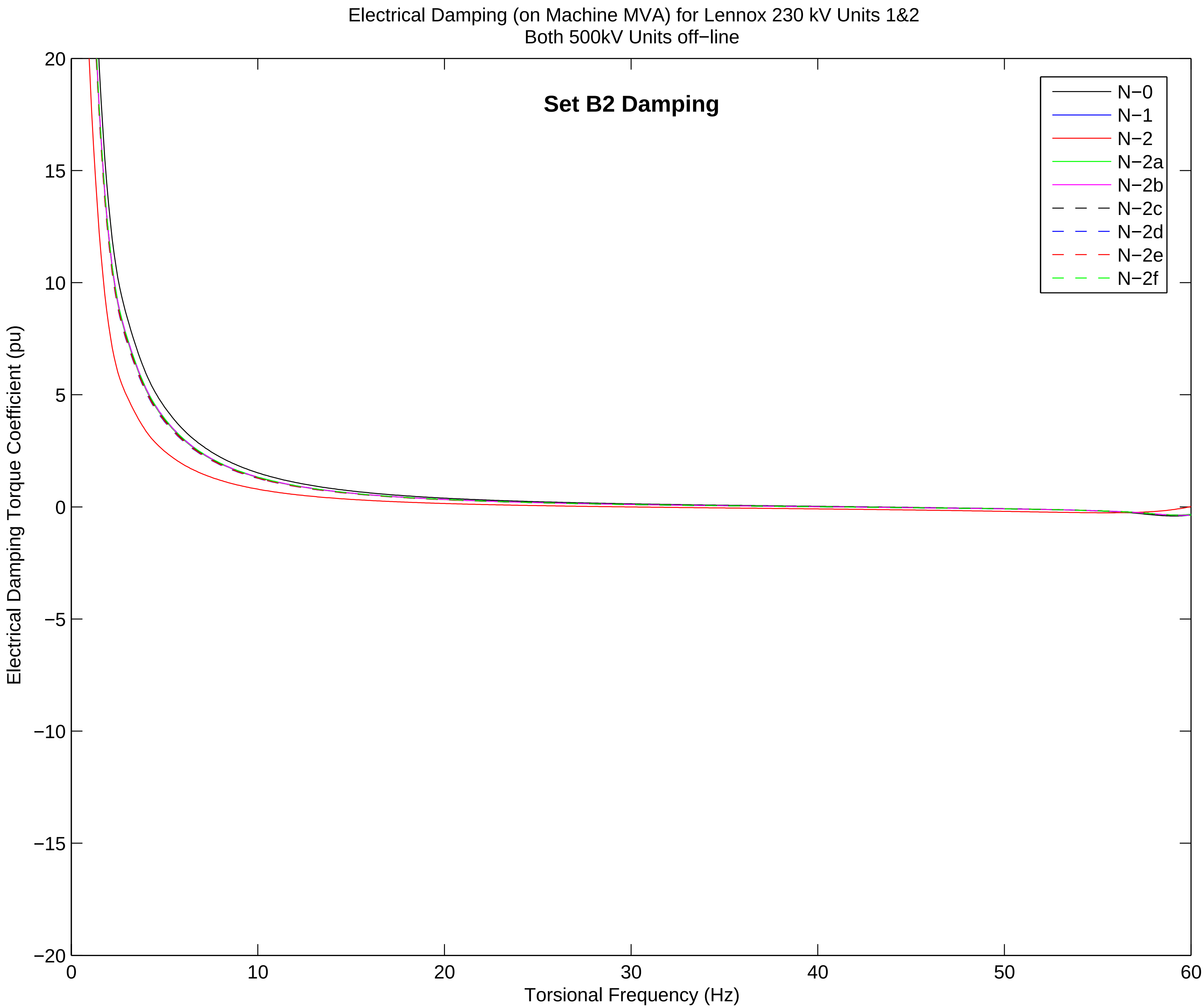
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

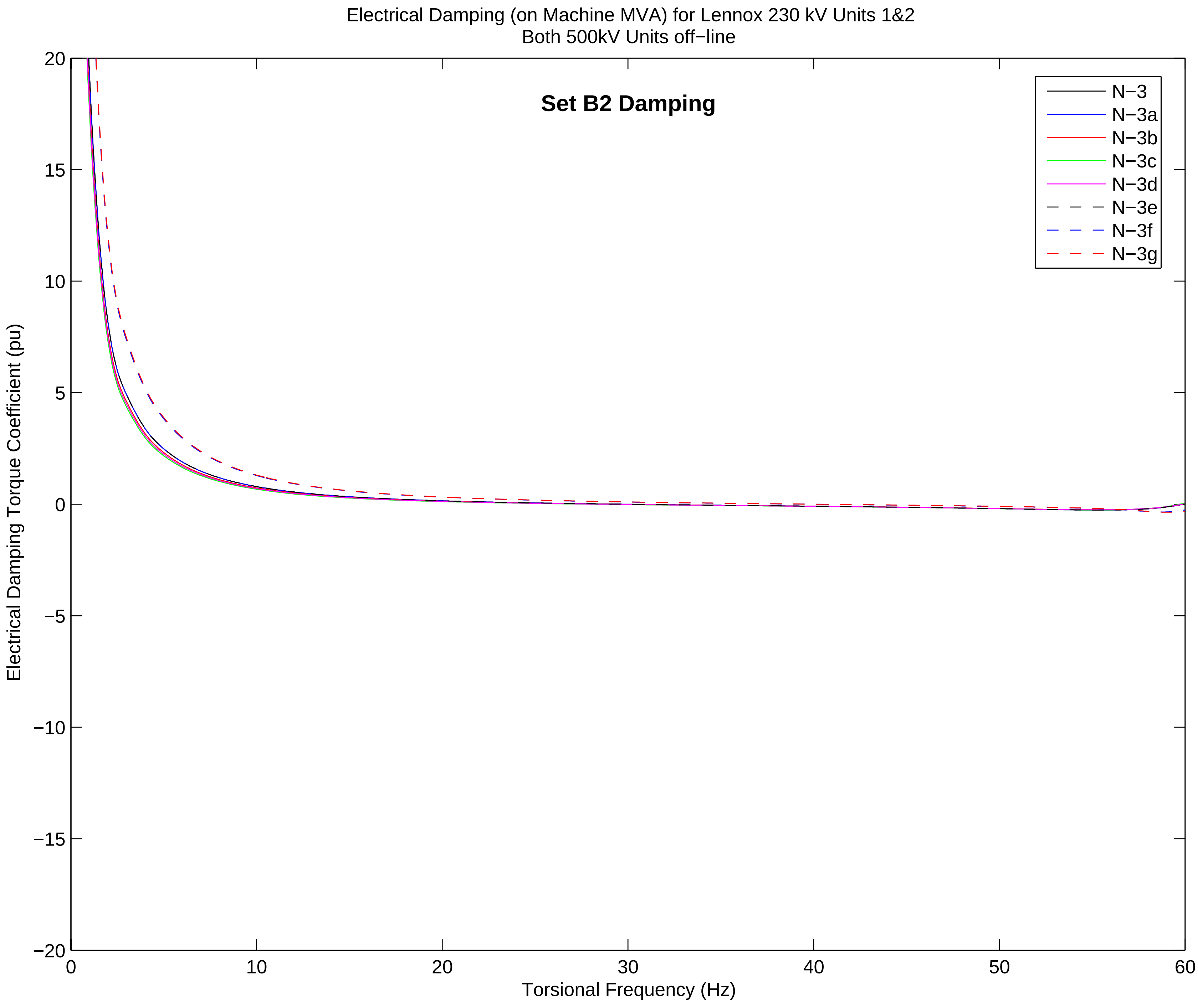


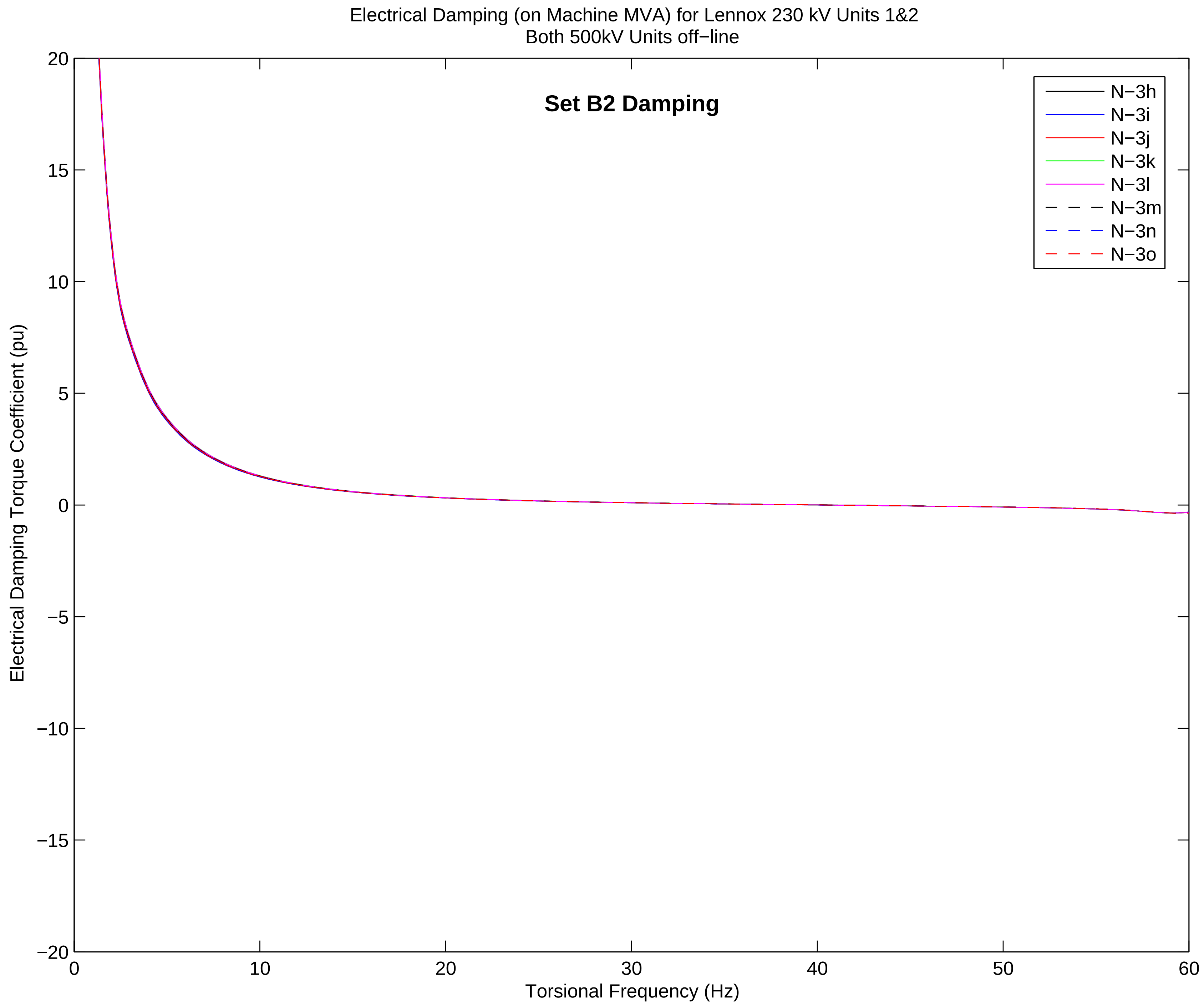
Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

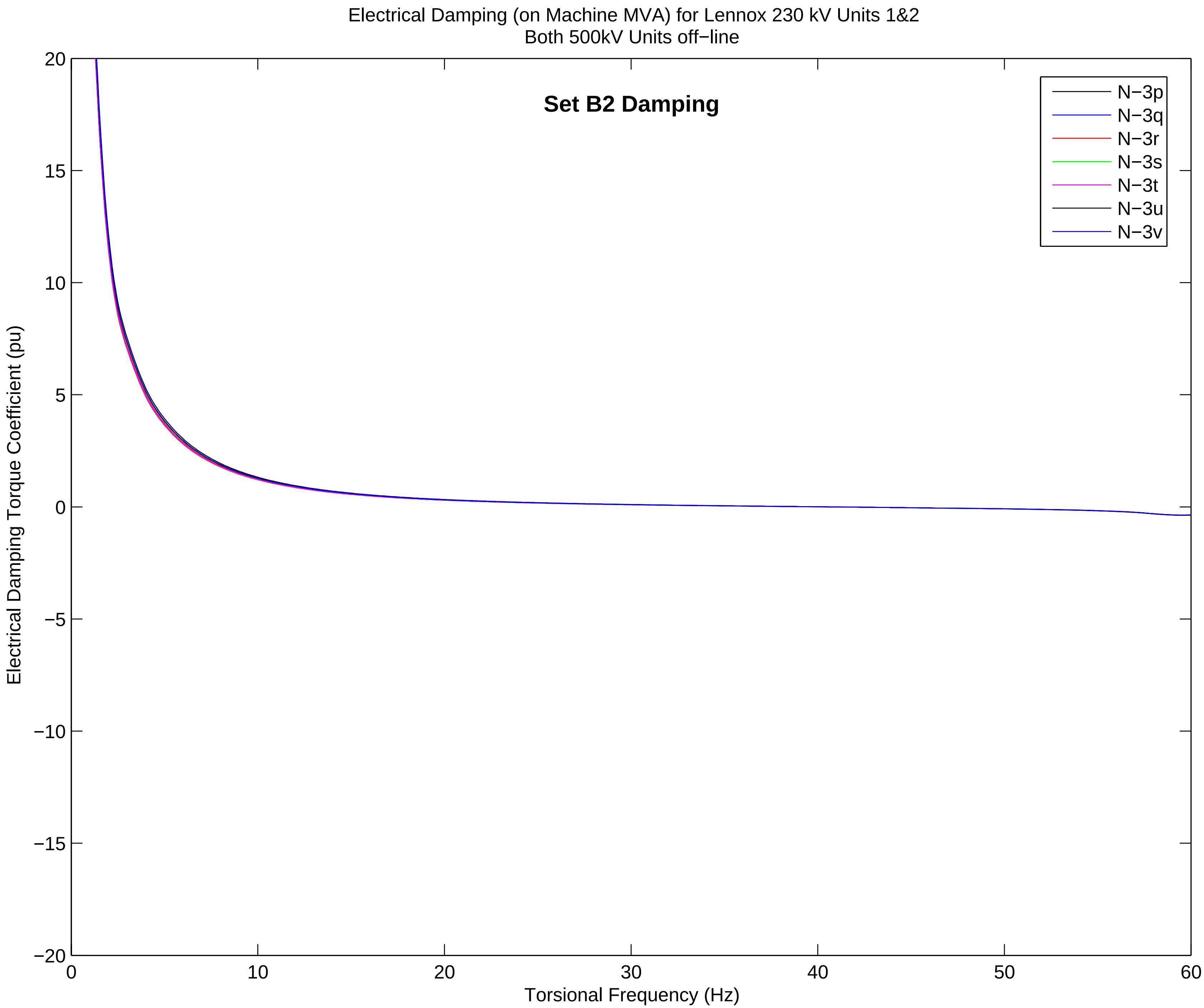


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

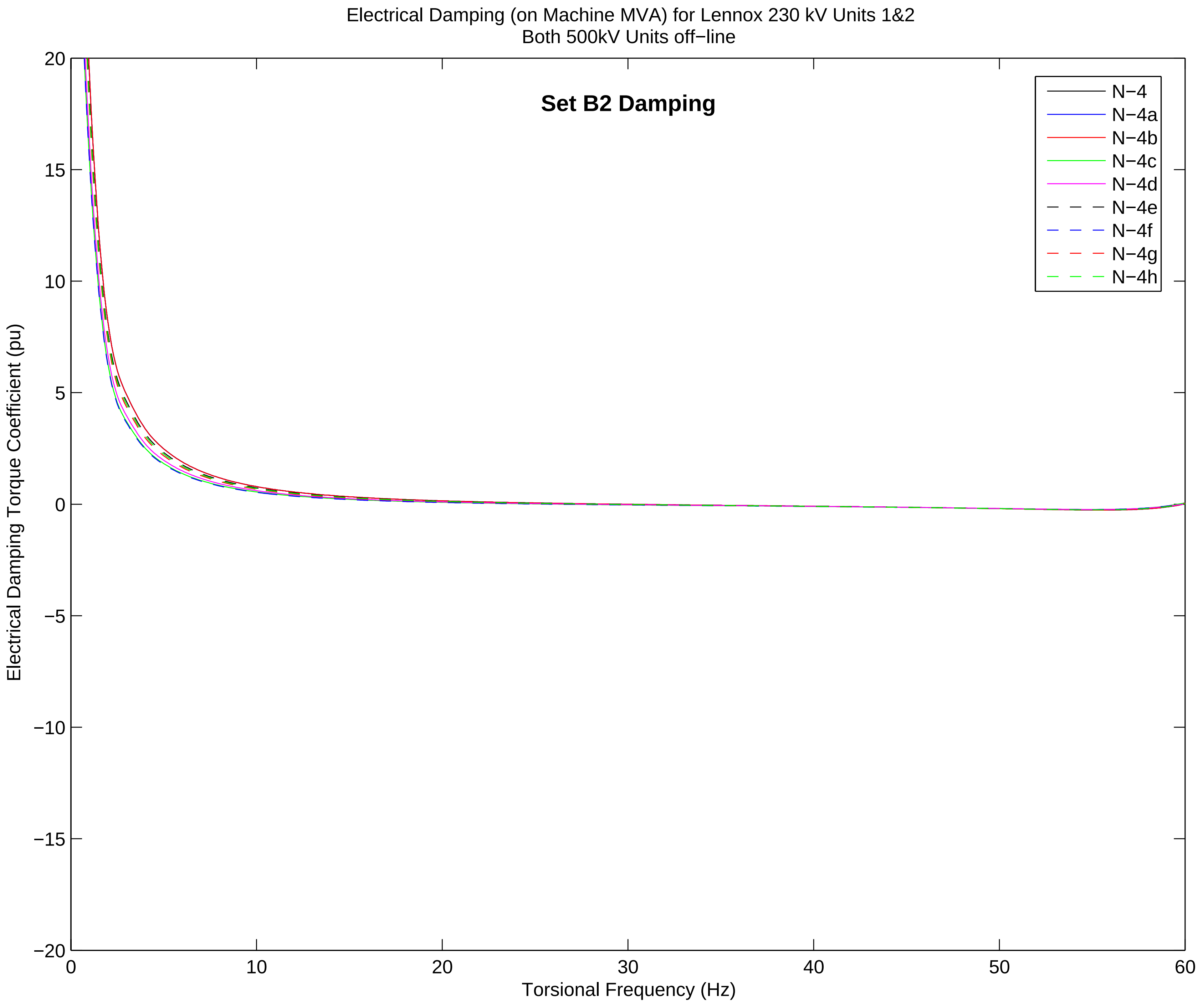

Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

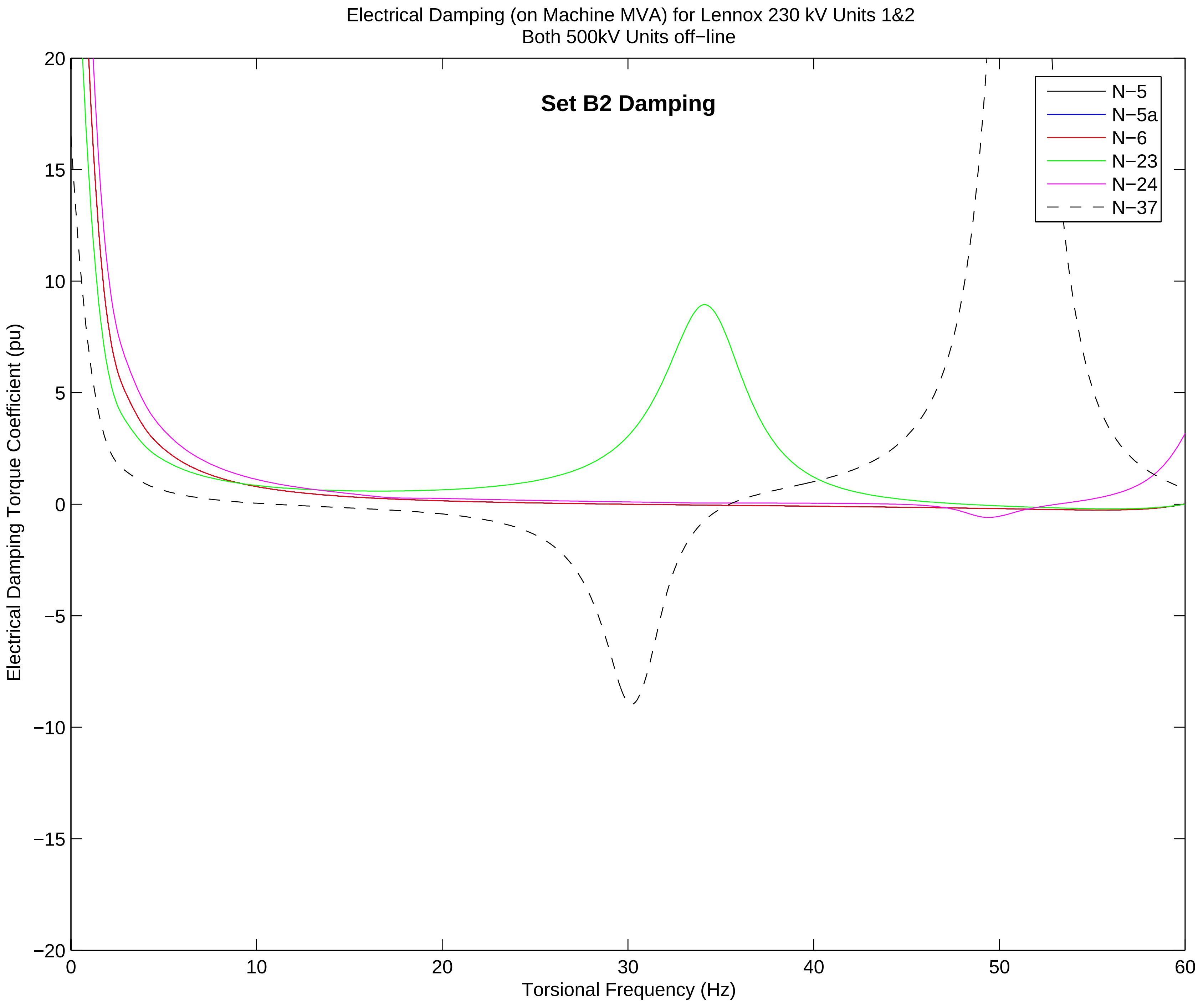


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

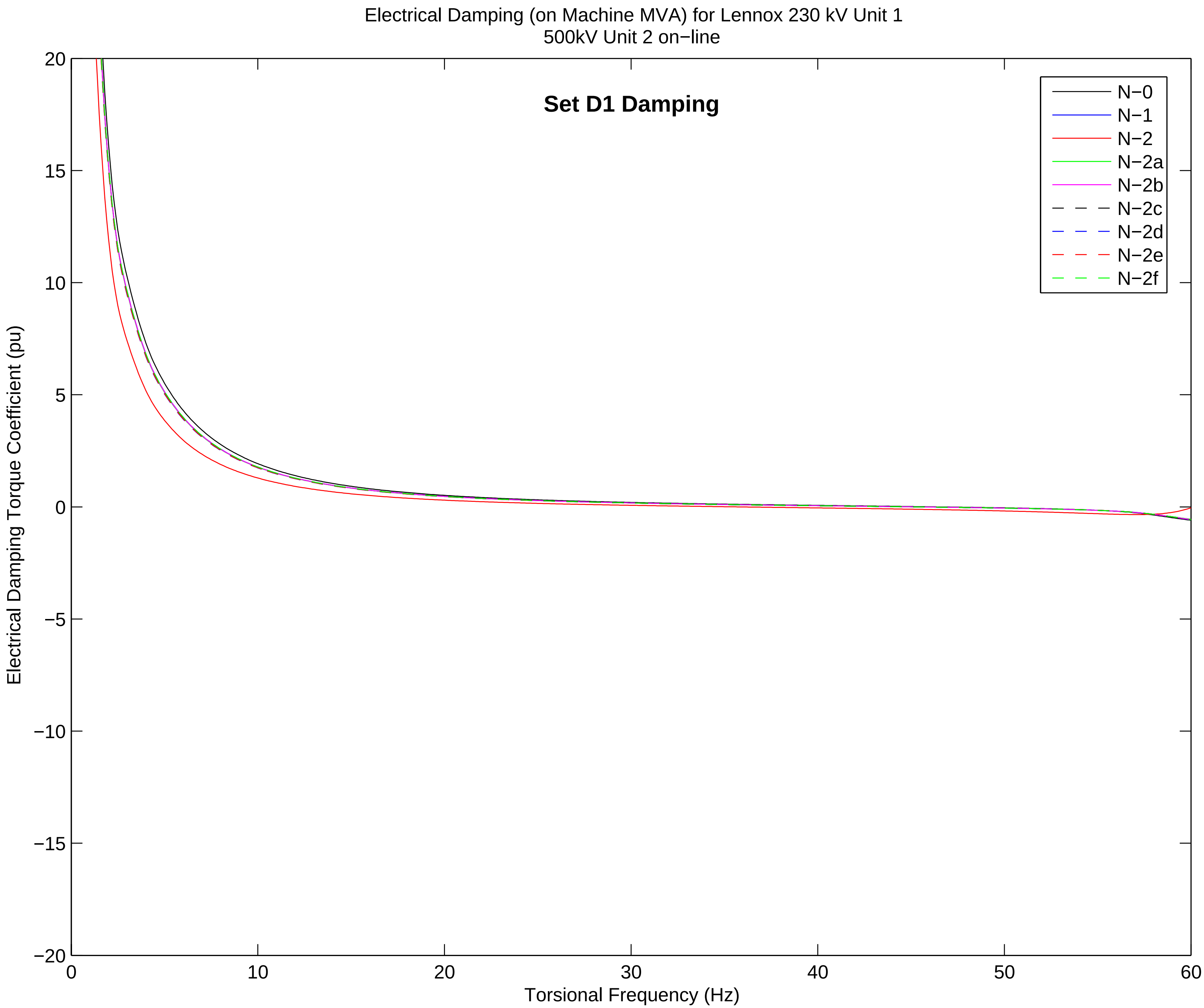


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

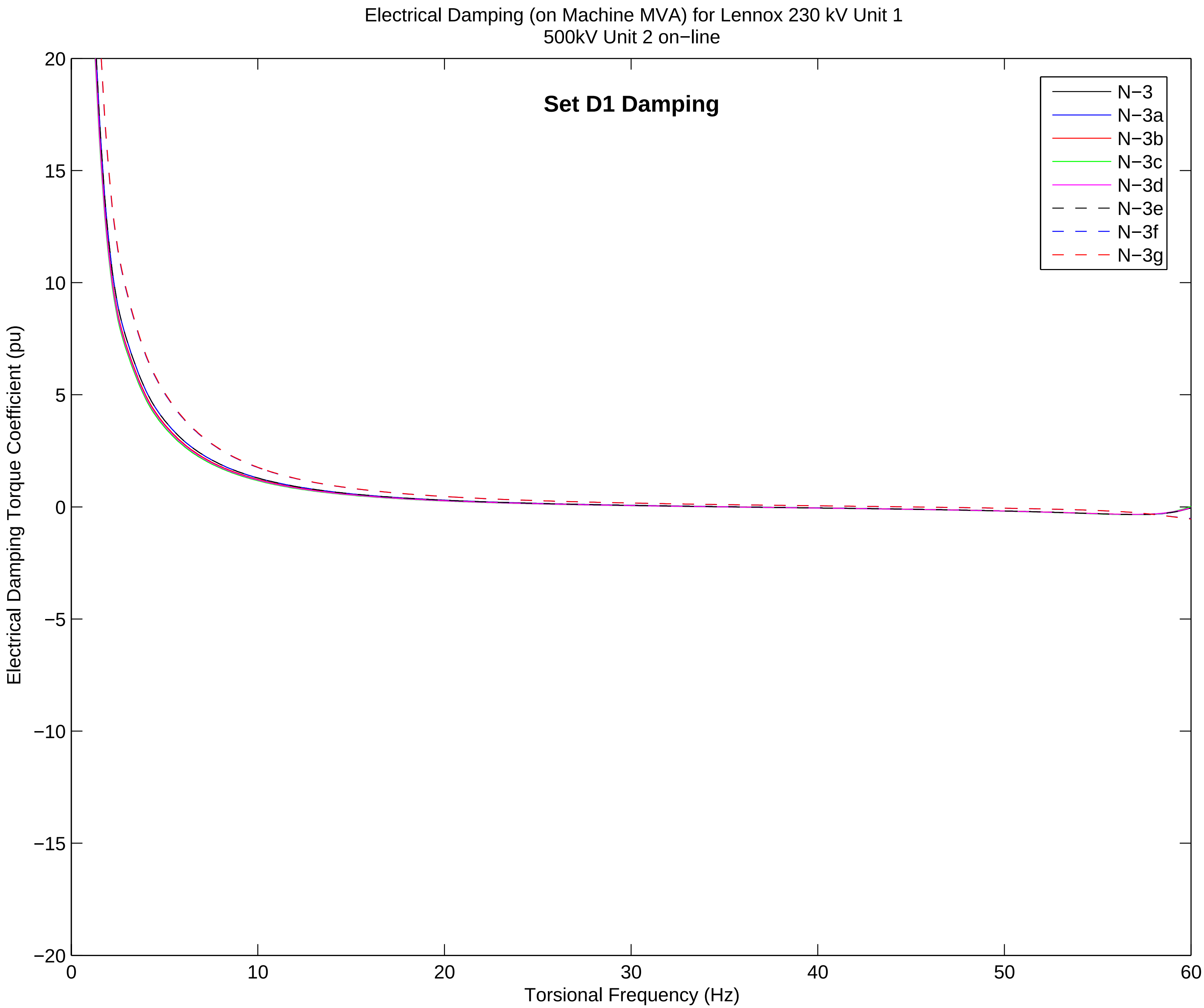

Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



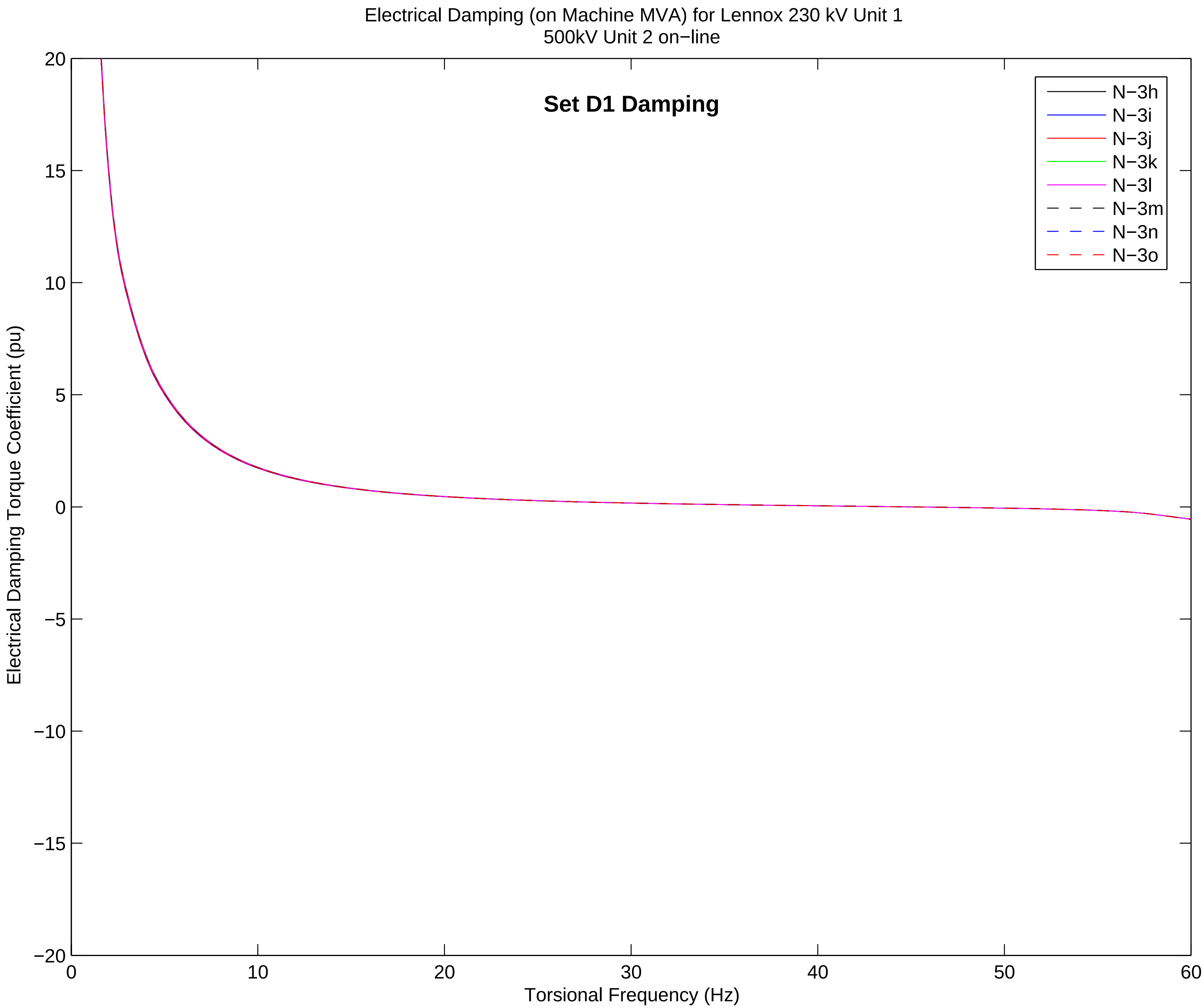
Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



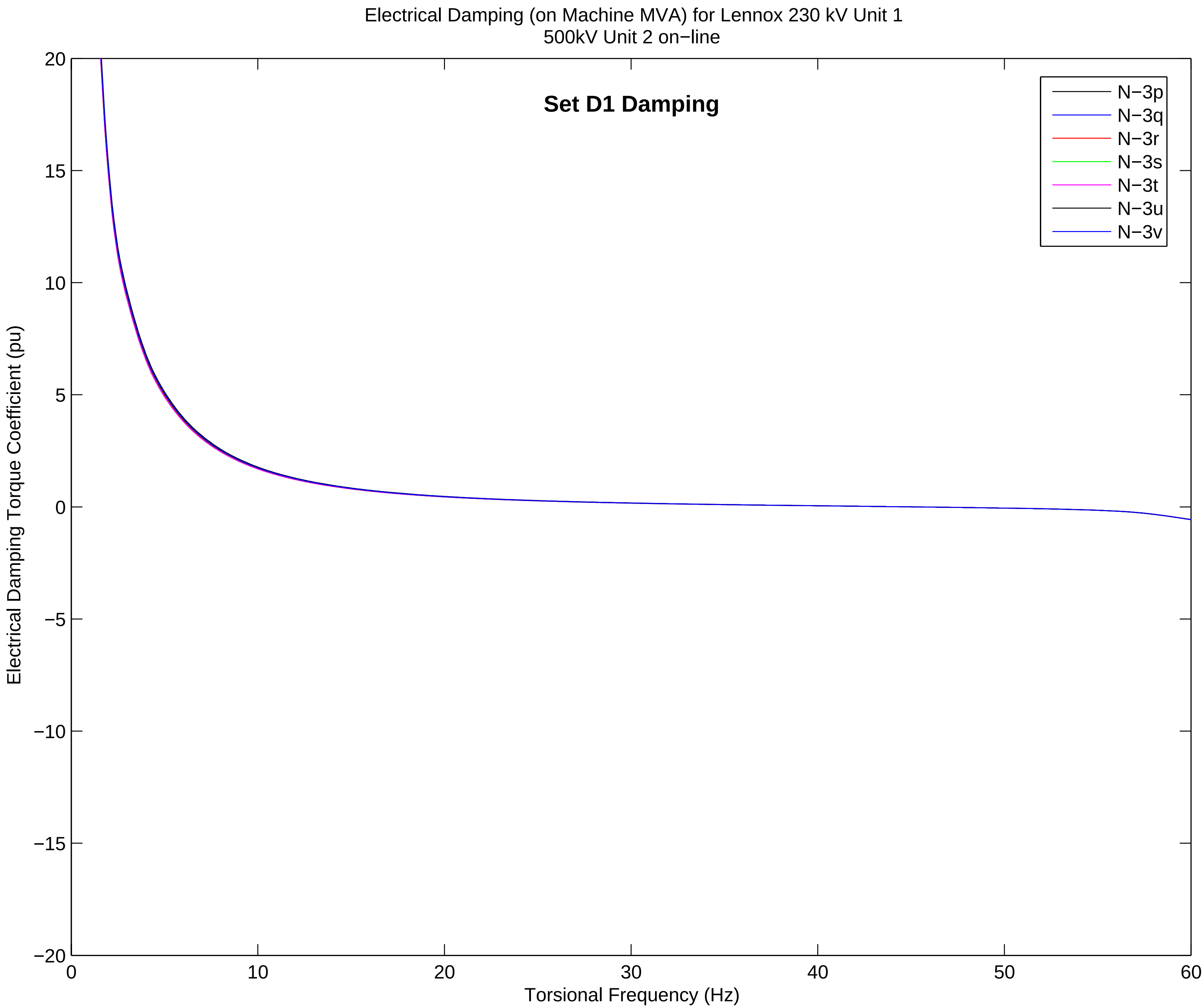
Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

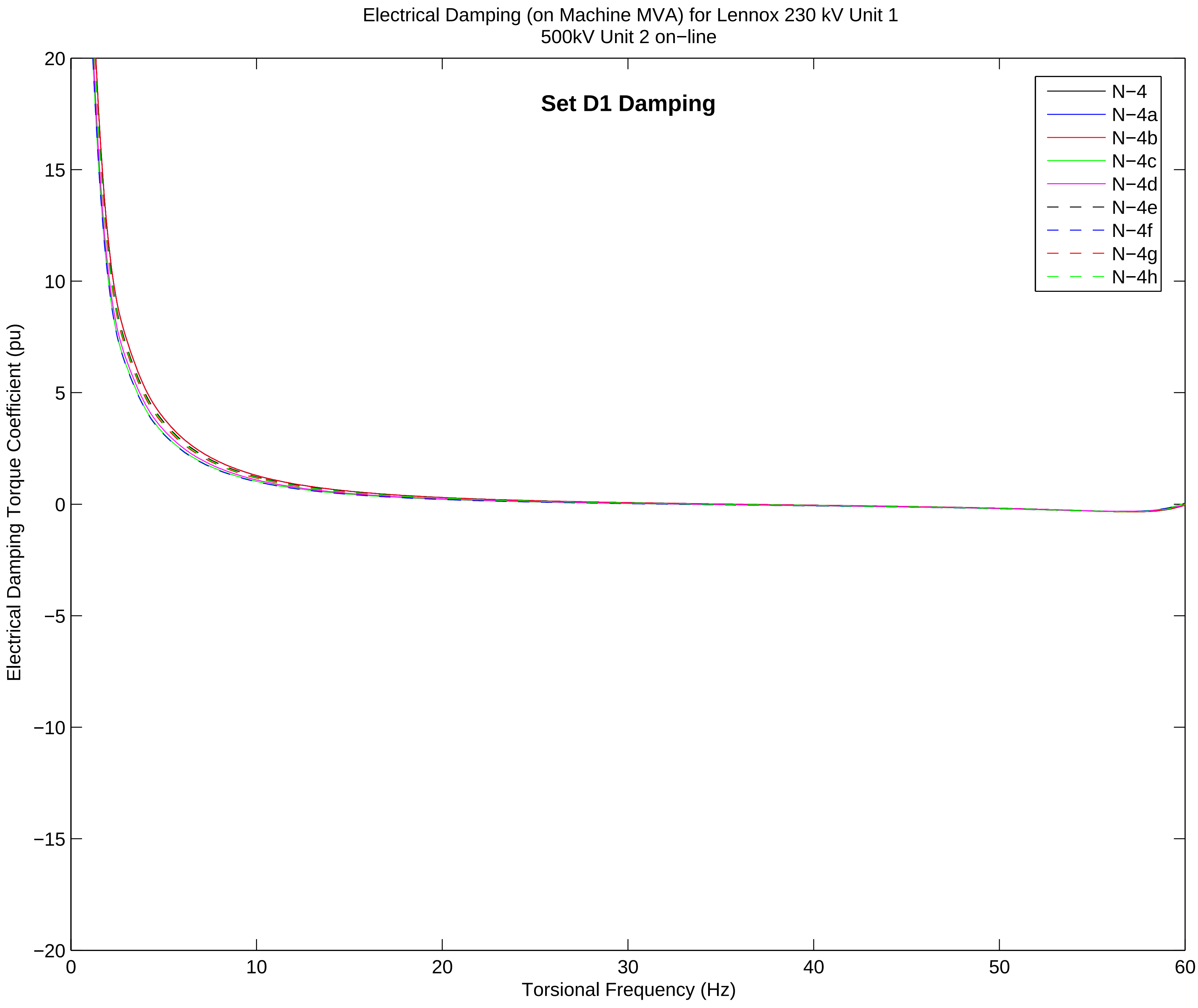


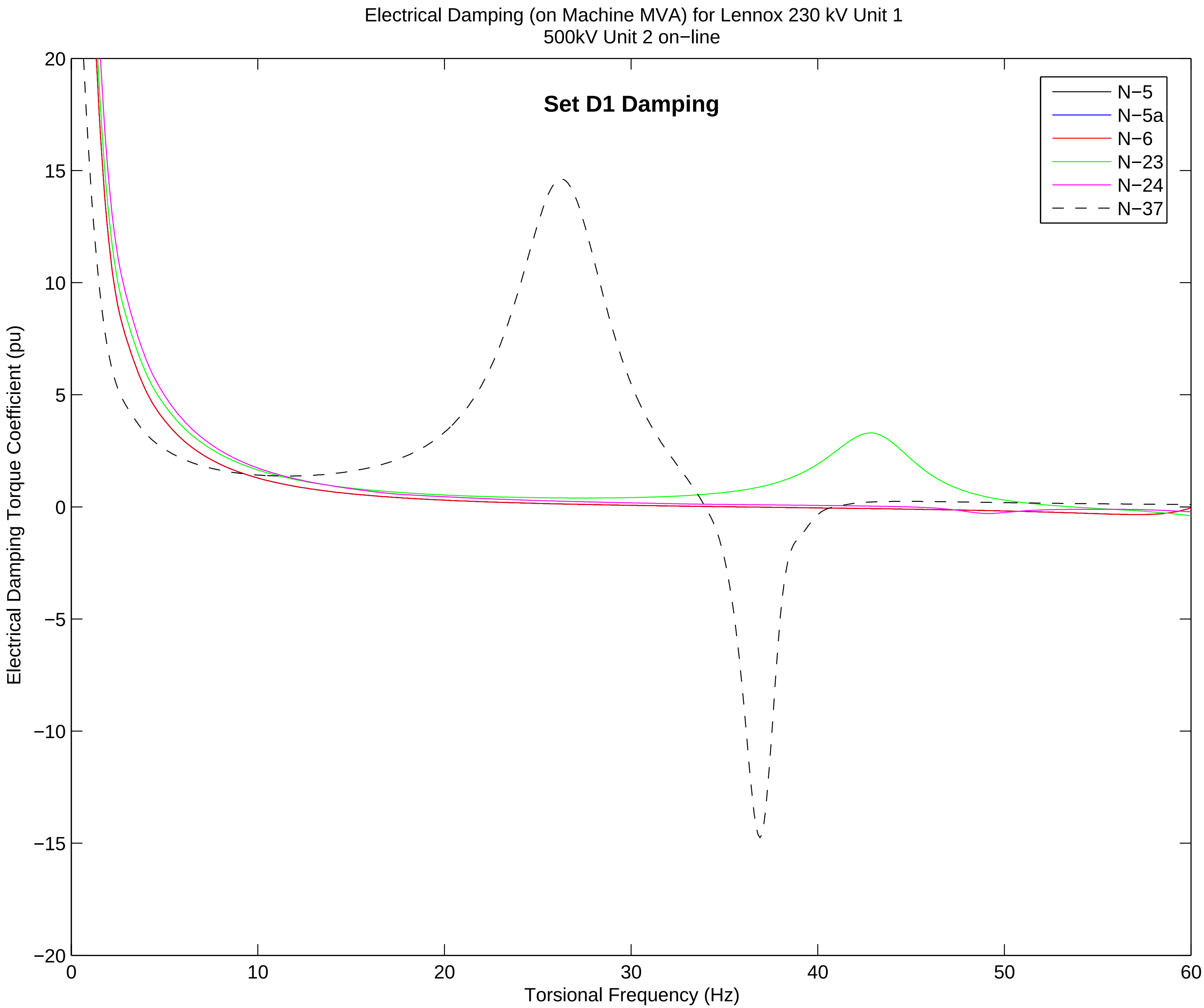
Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

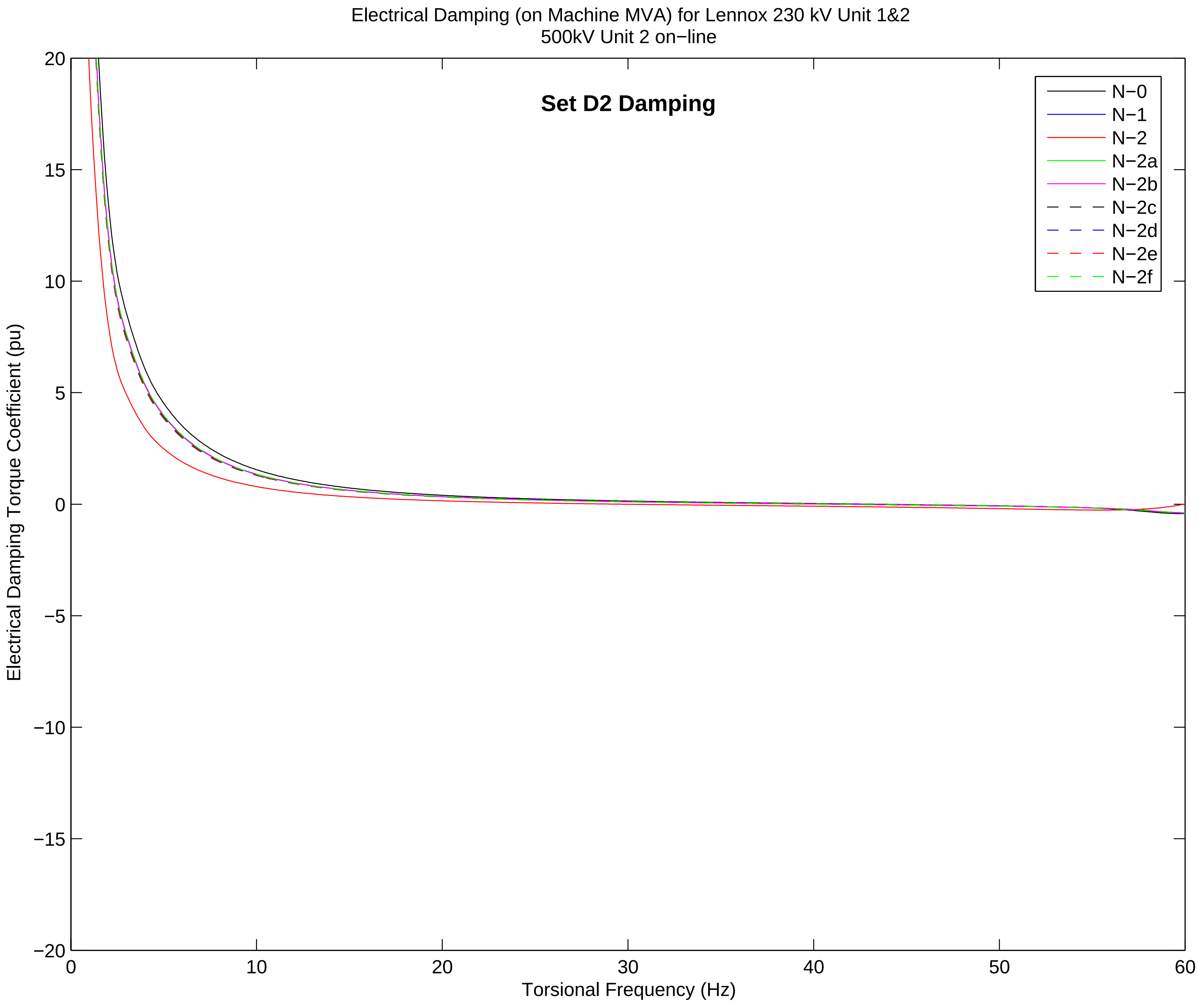


Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

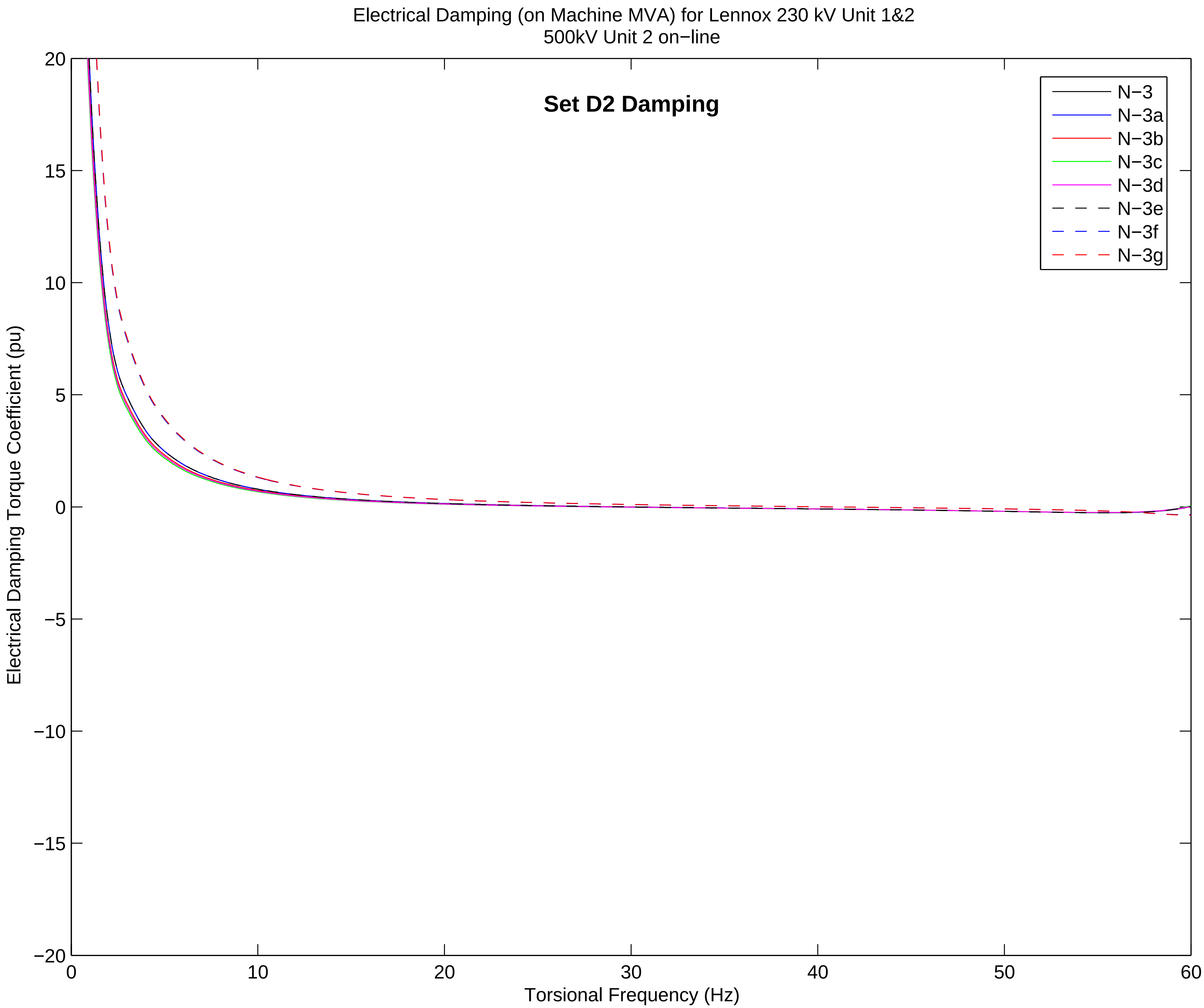

Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)

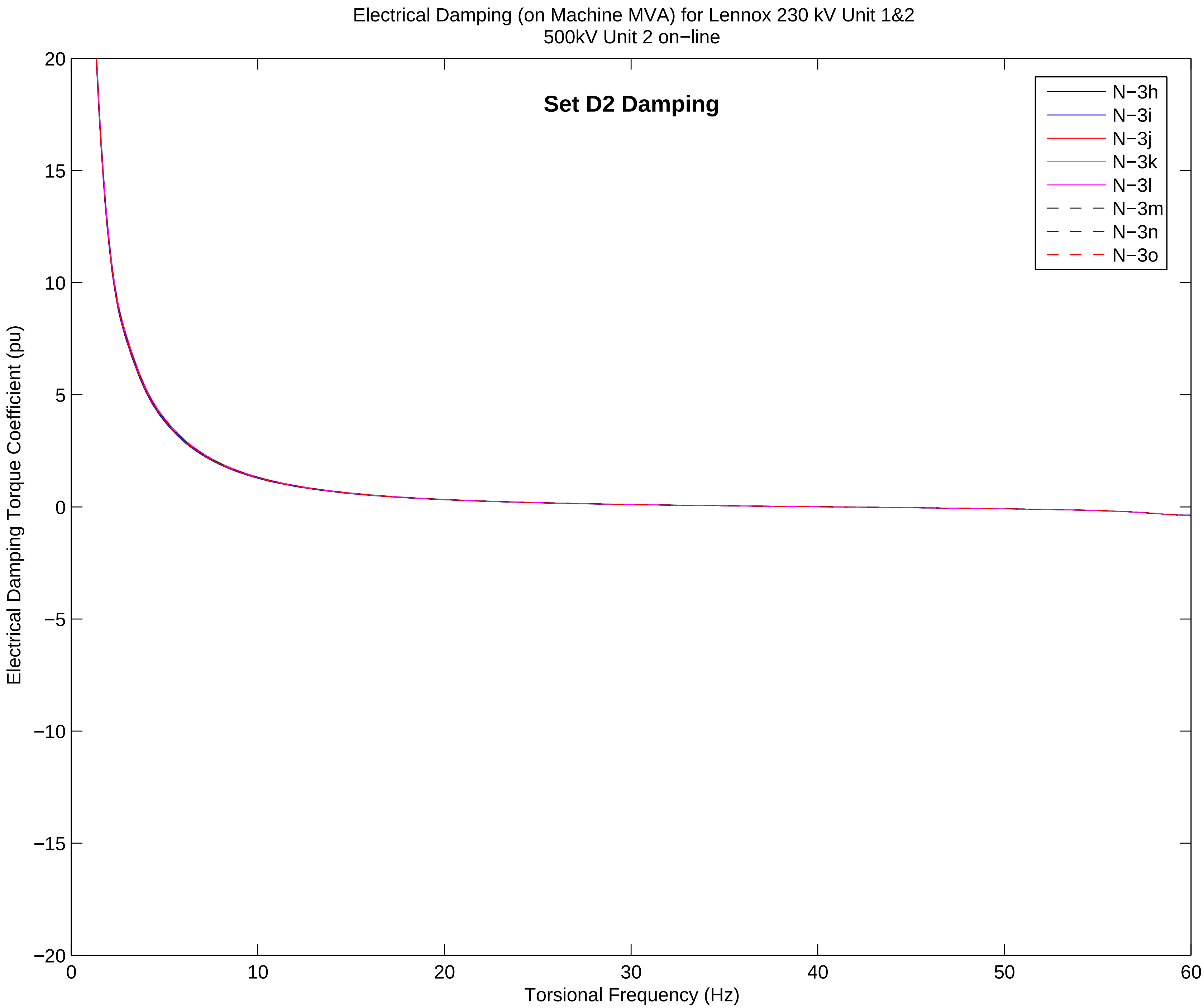

Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



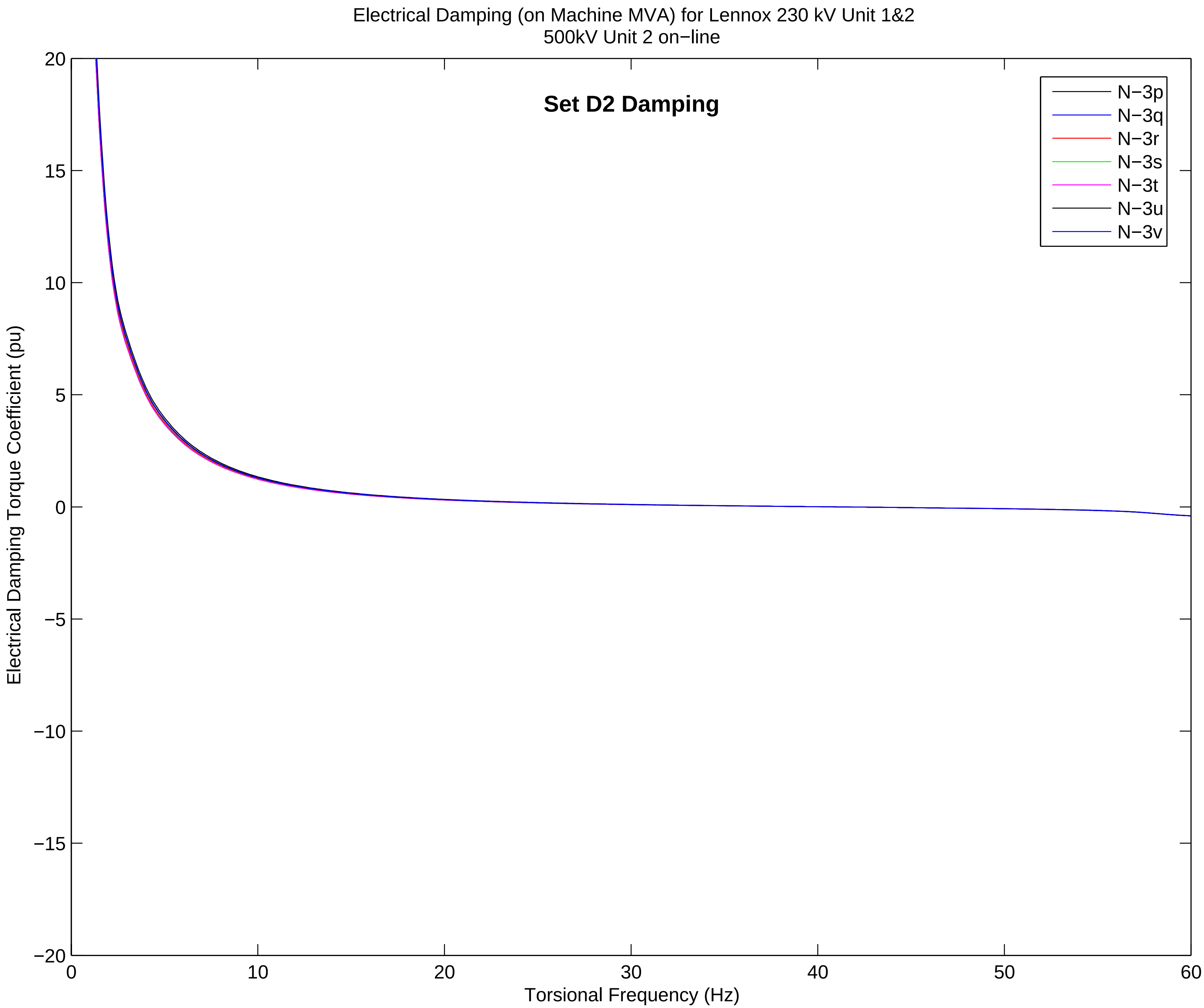
Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)

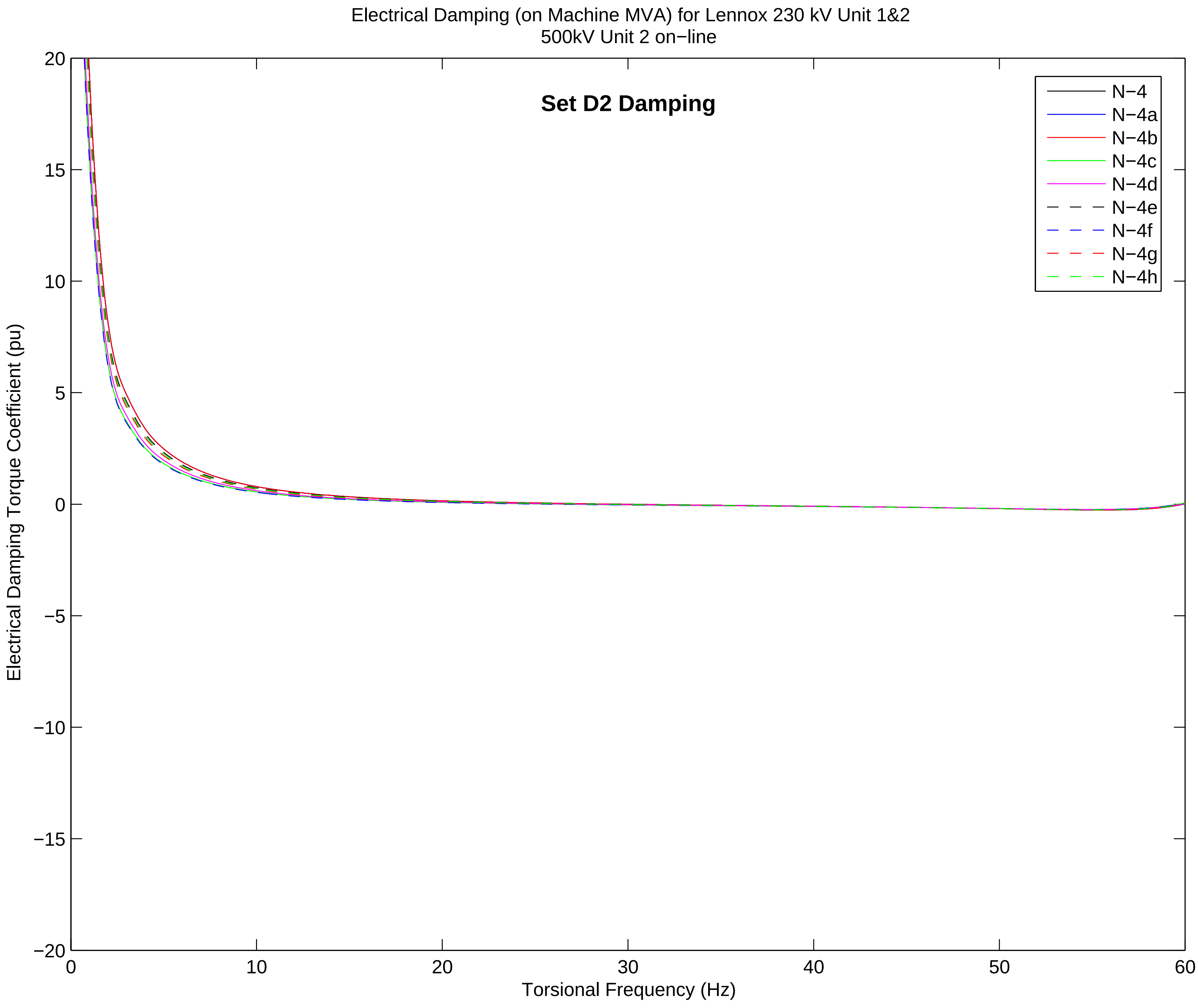


Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)

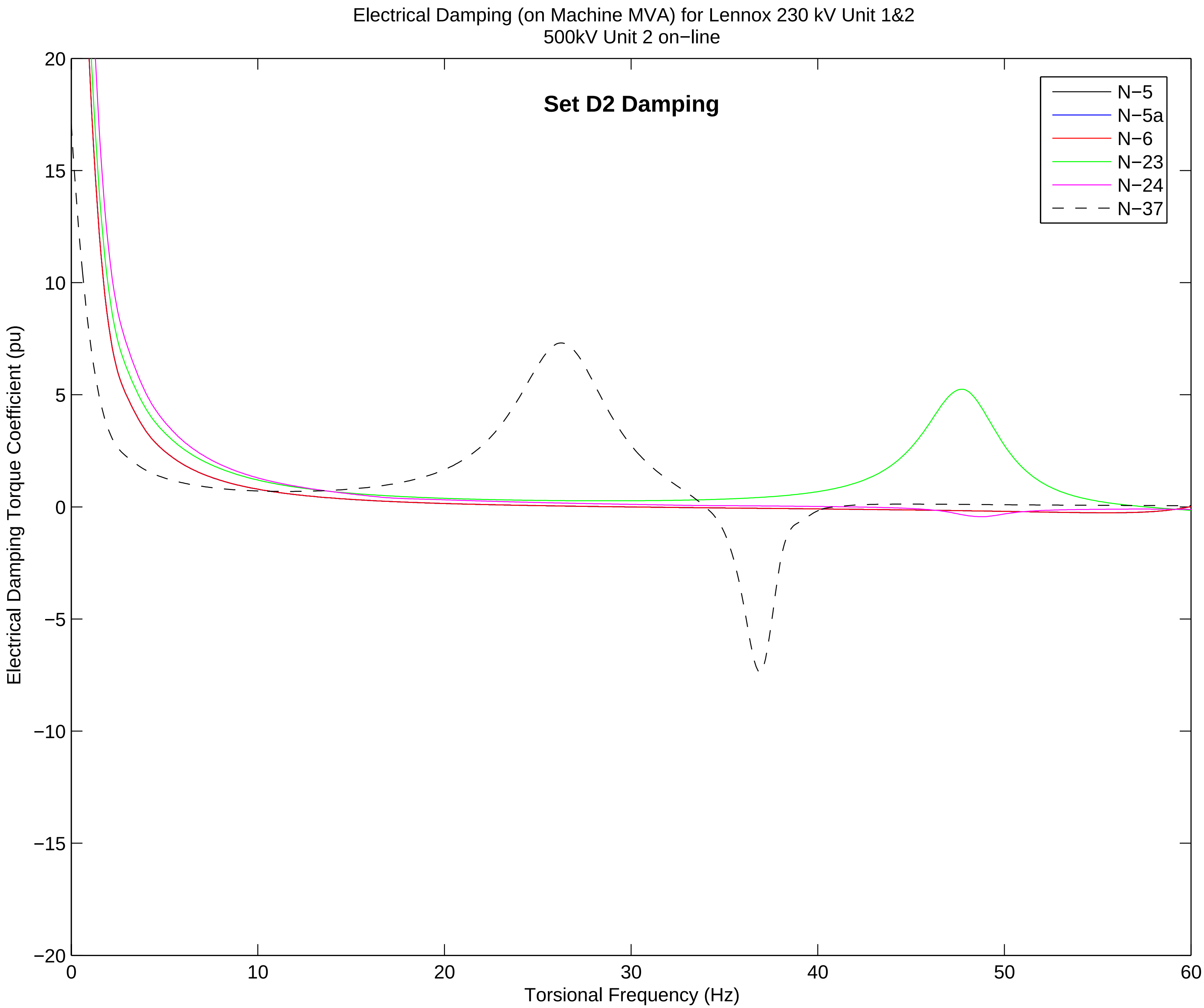


Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

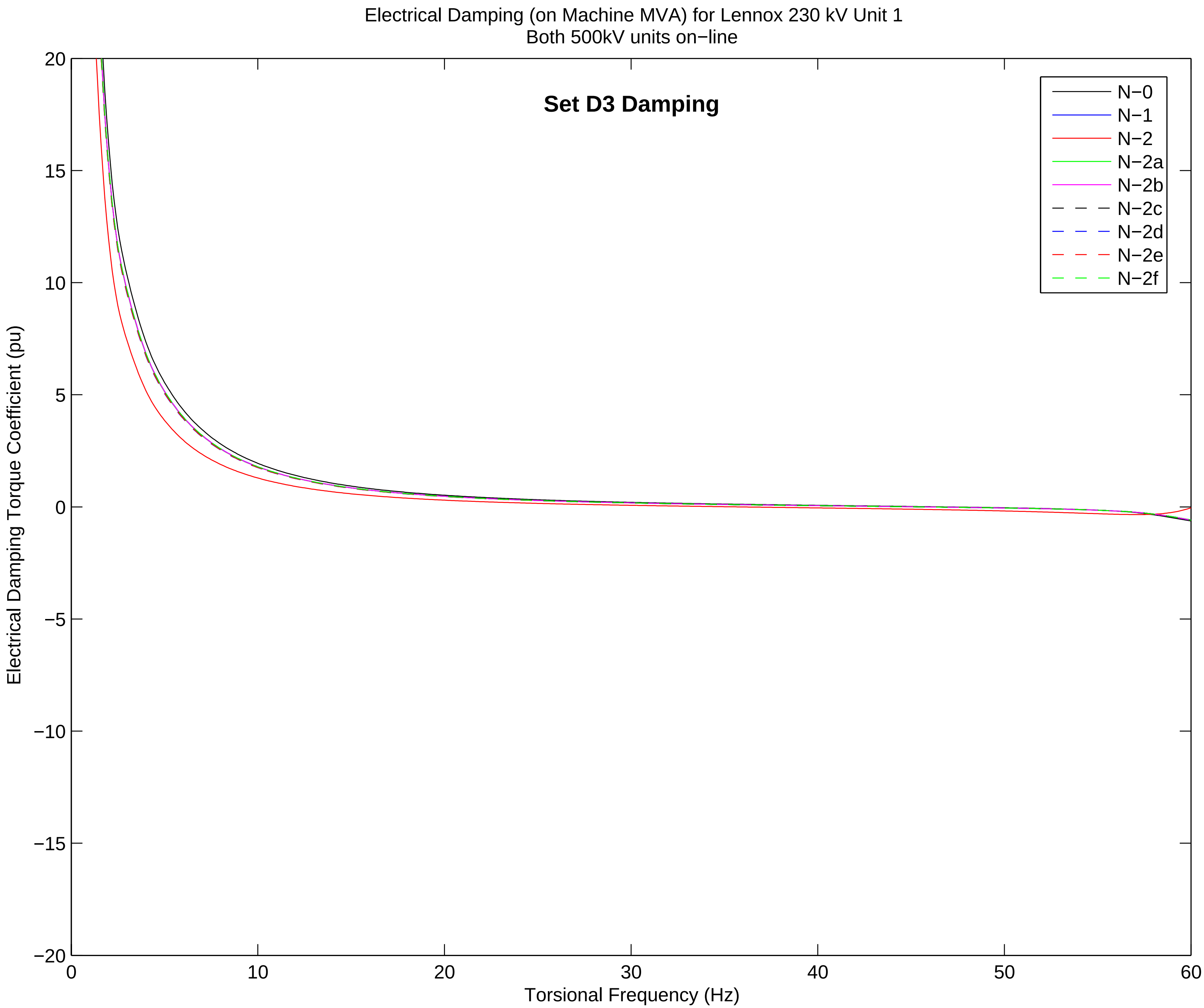

Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

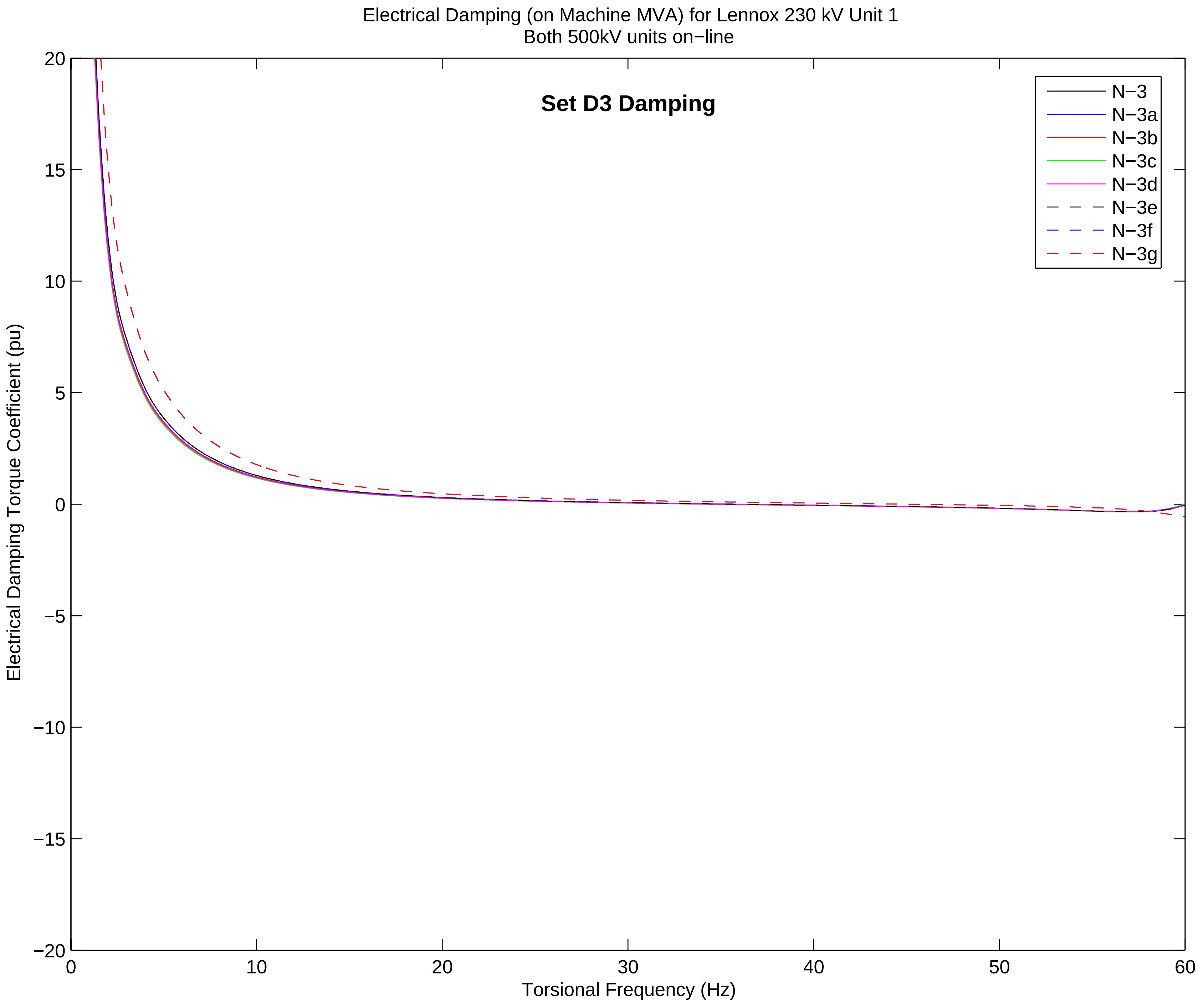


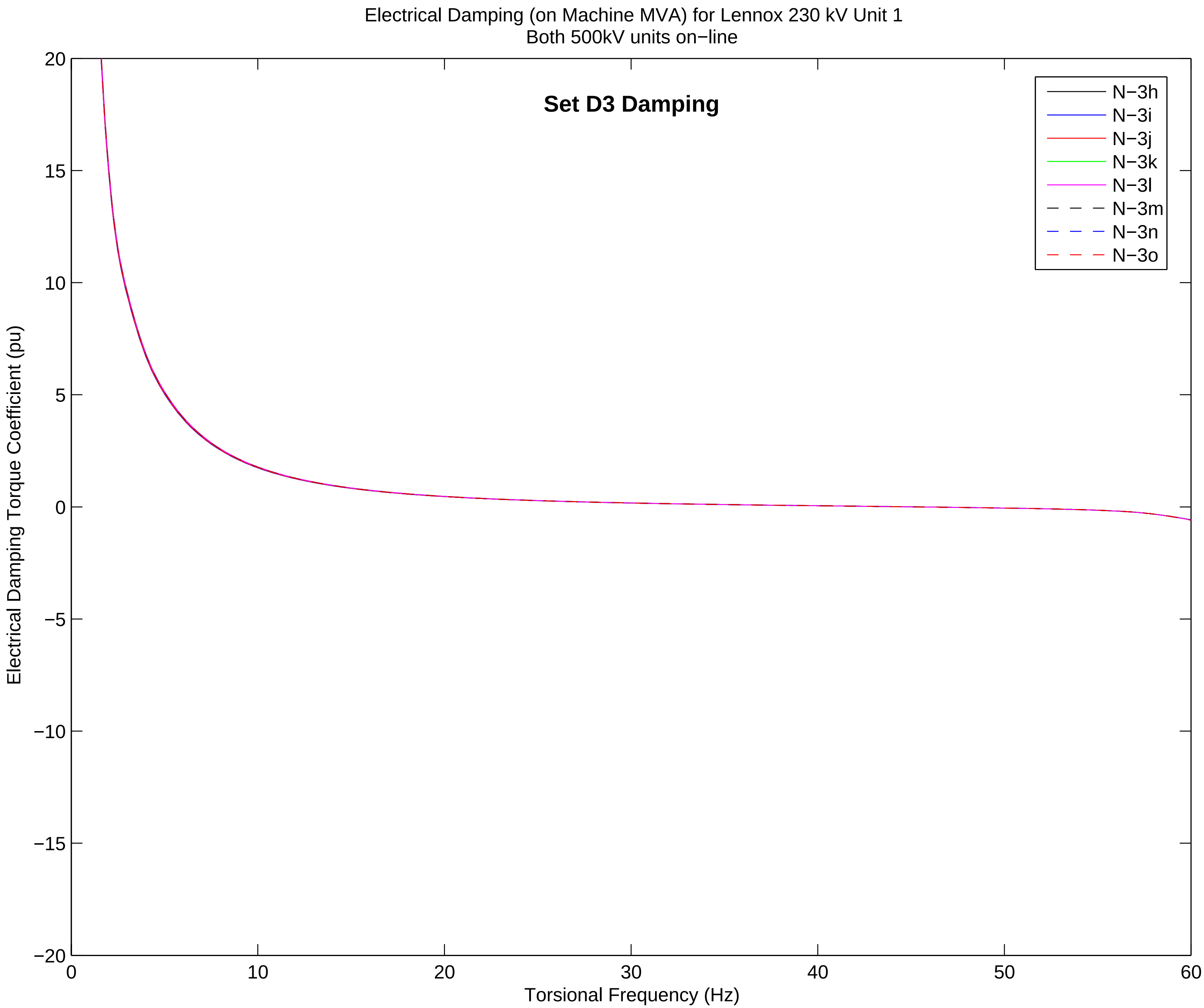
Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

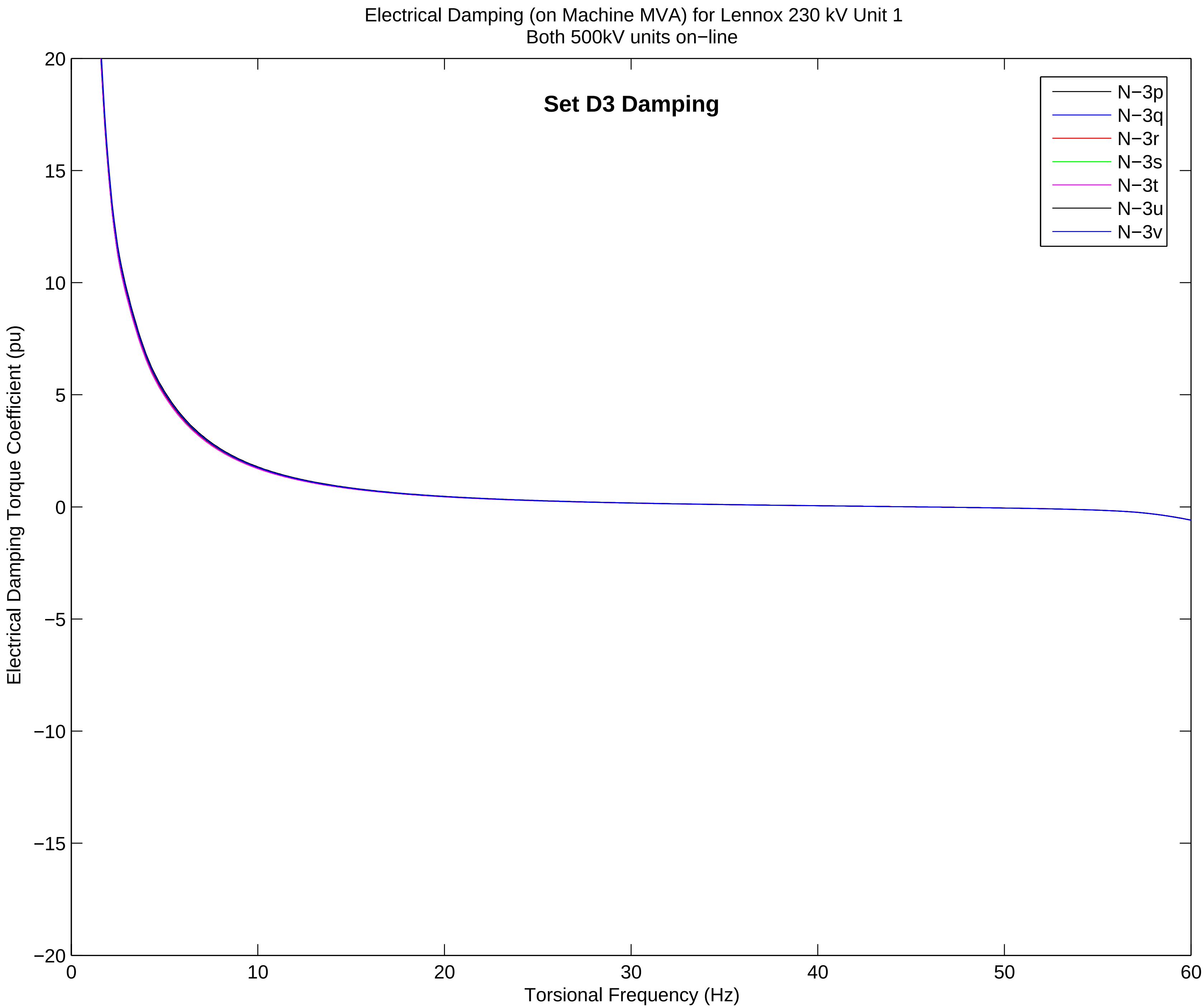


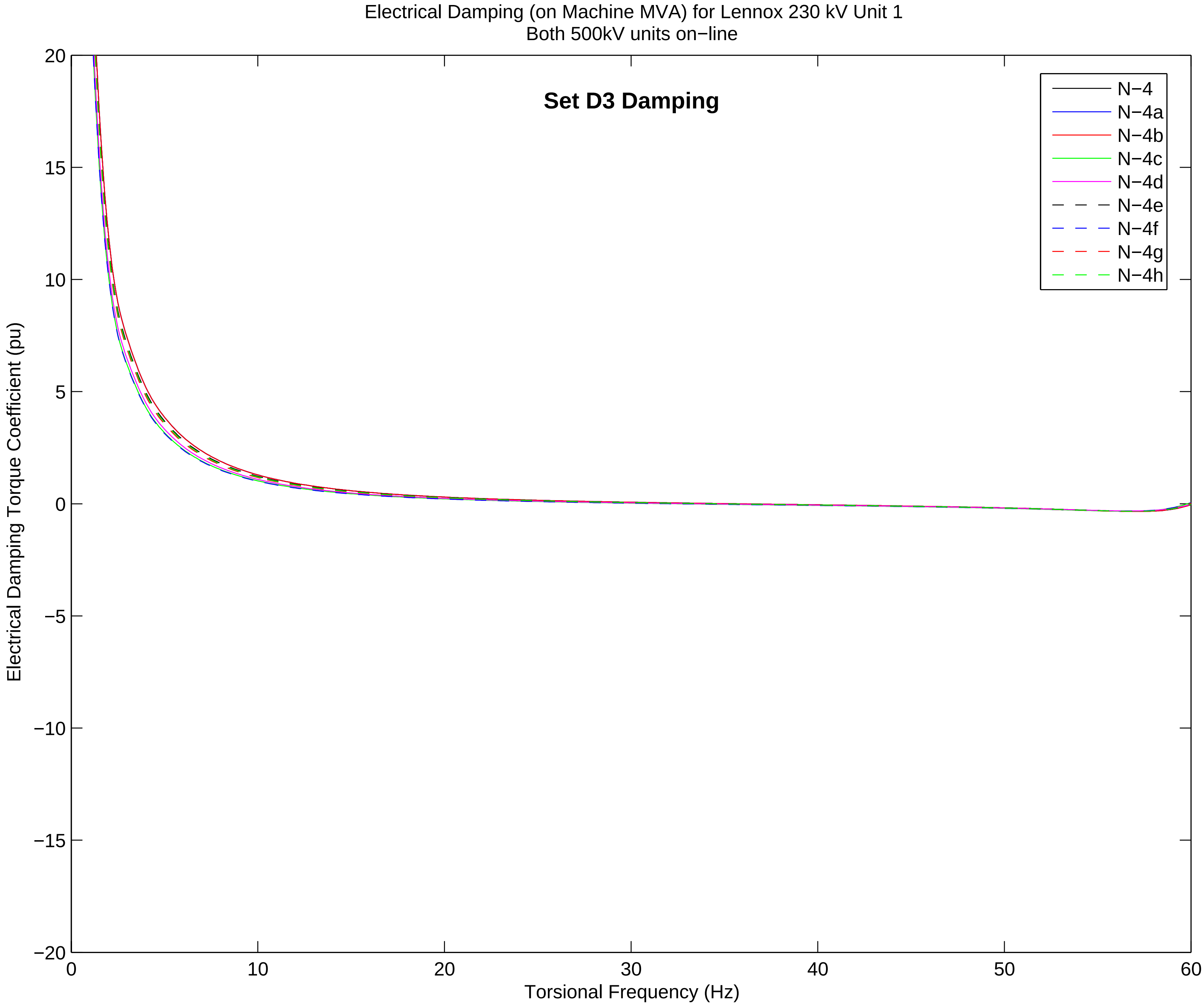
Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

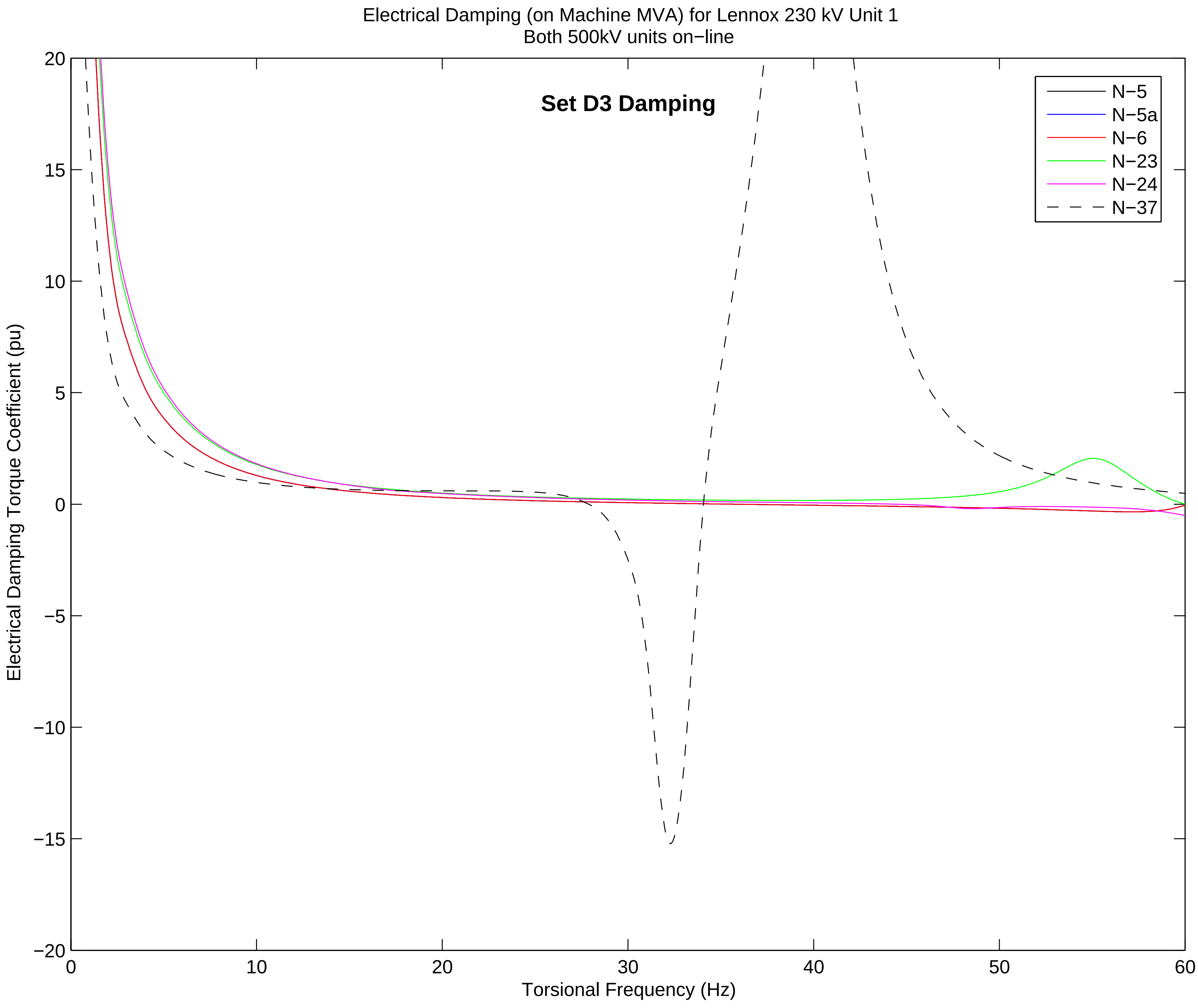

Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

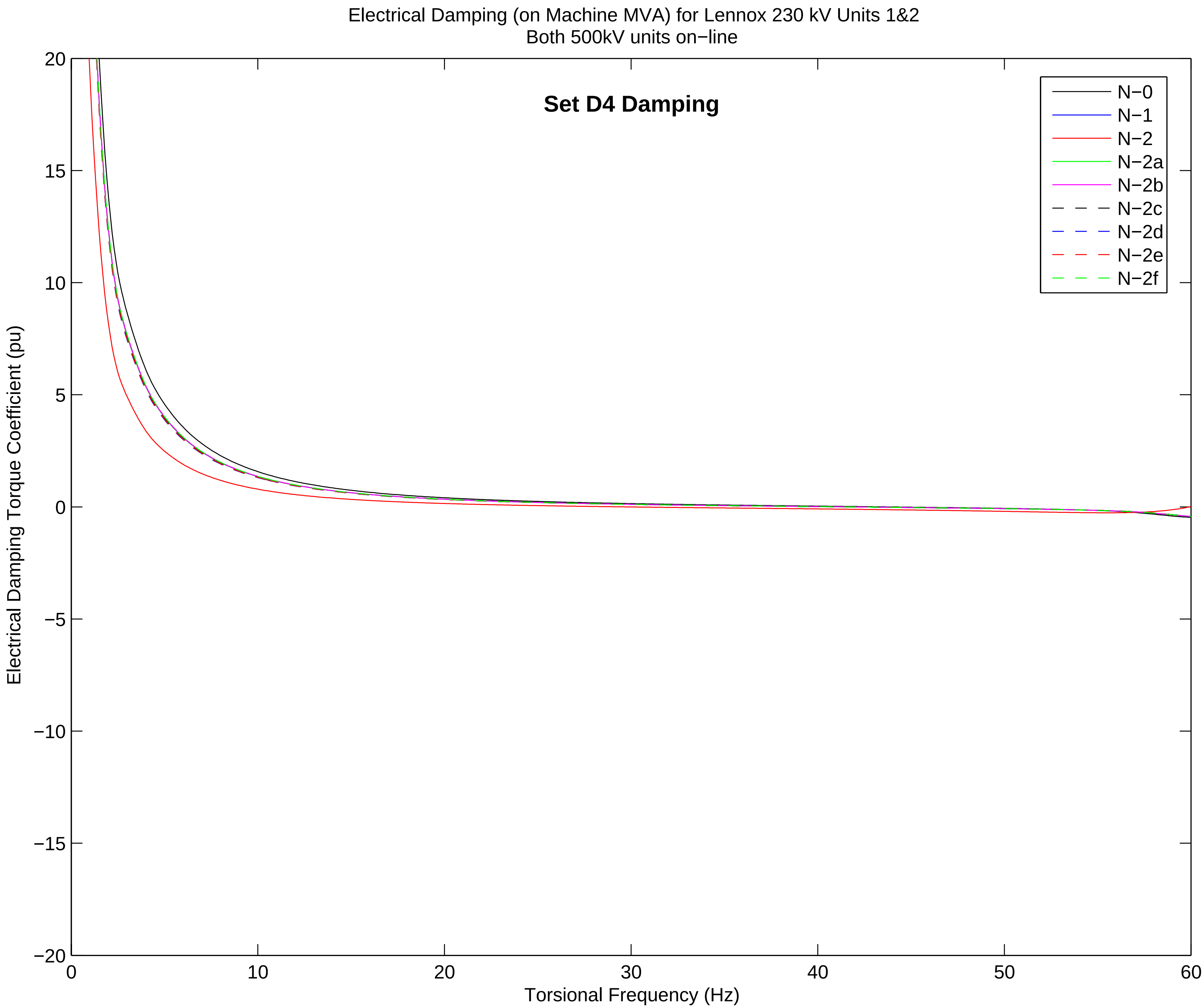

Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



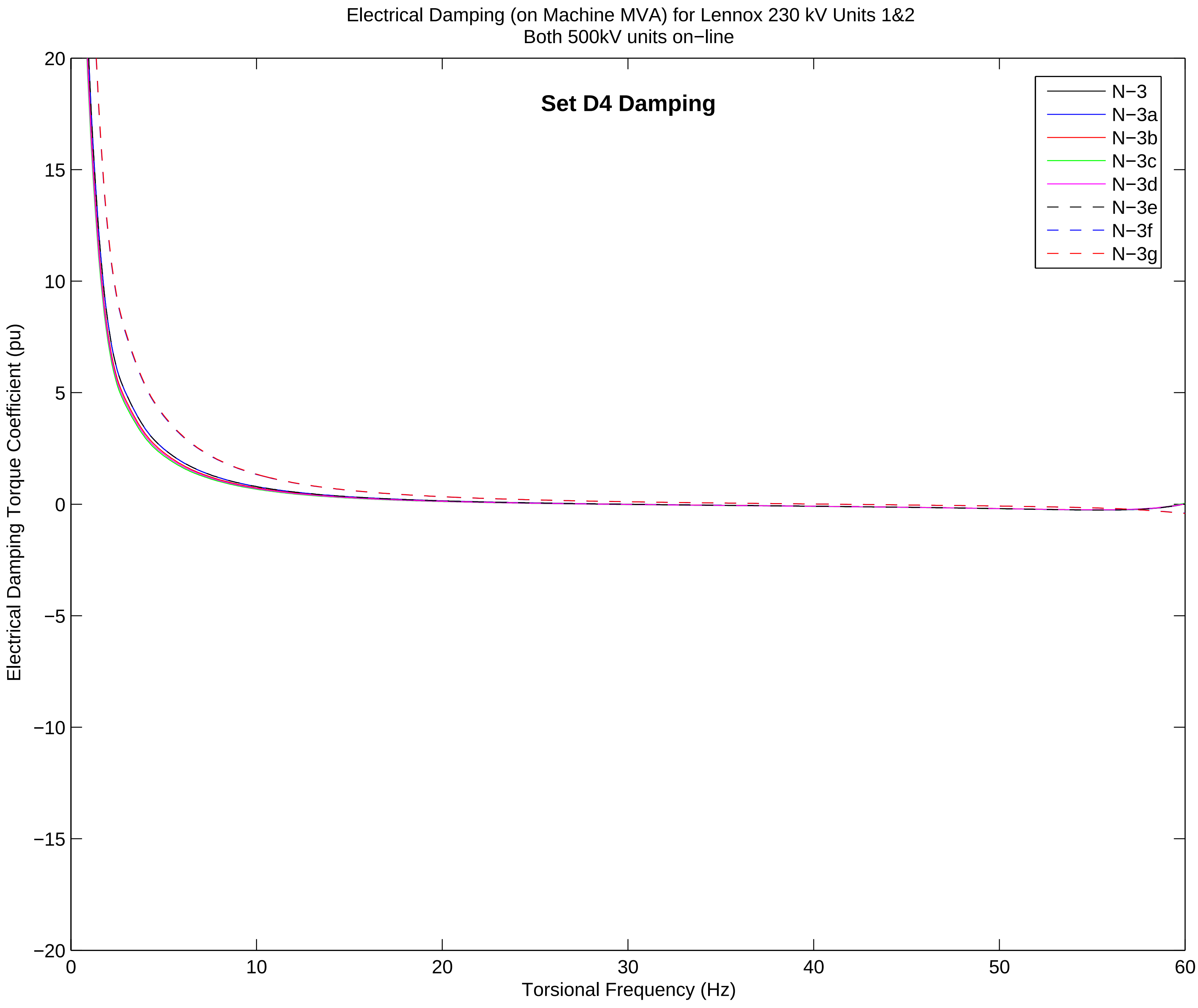
Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)



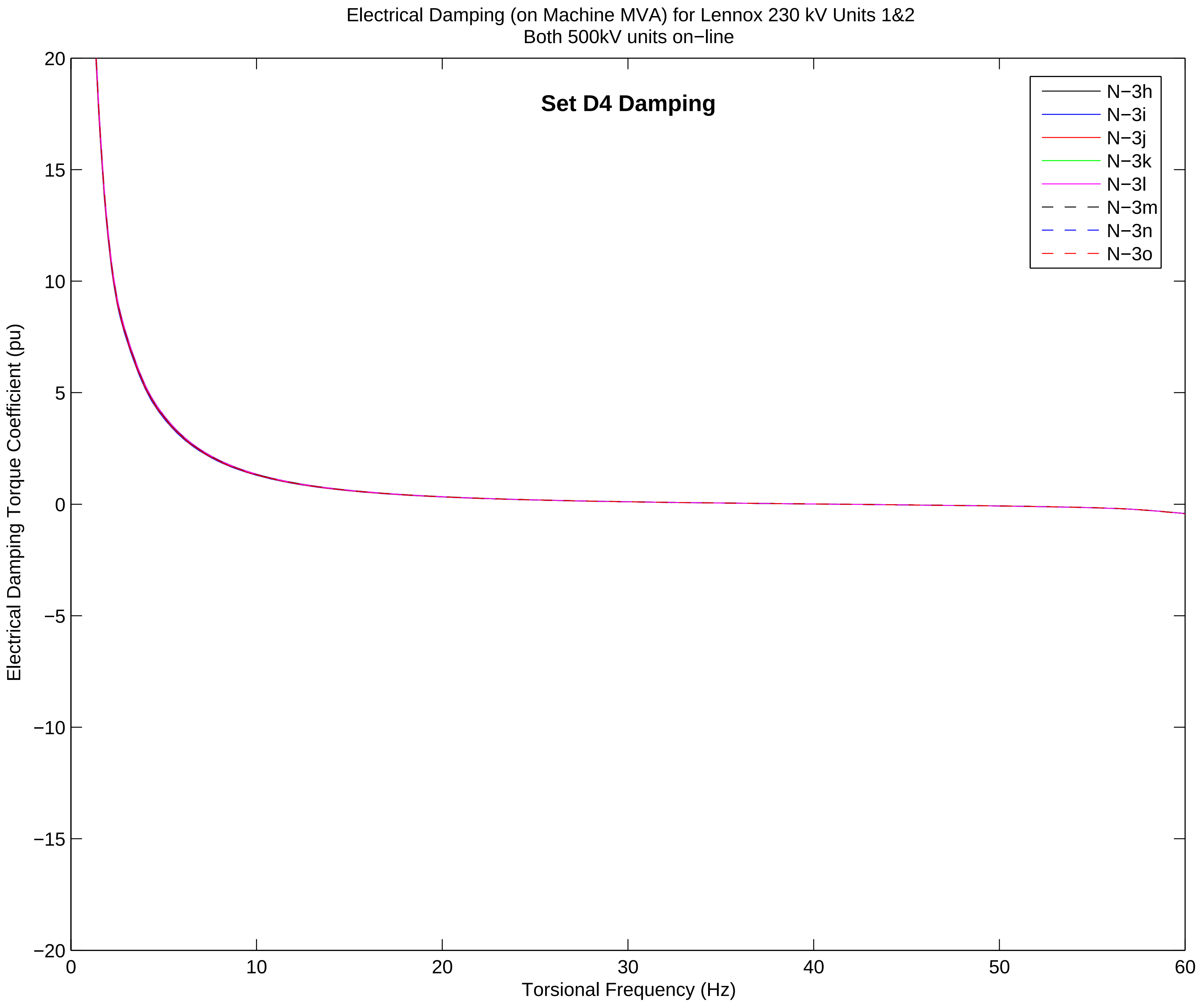
Electrical Damping (on Machine MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)

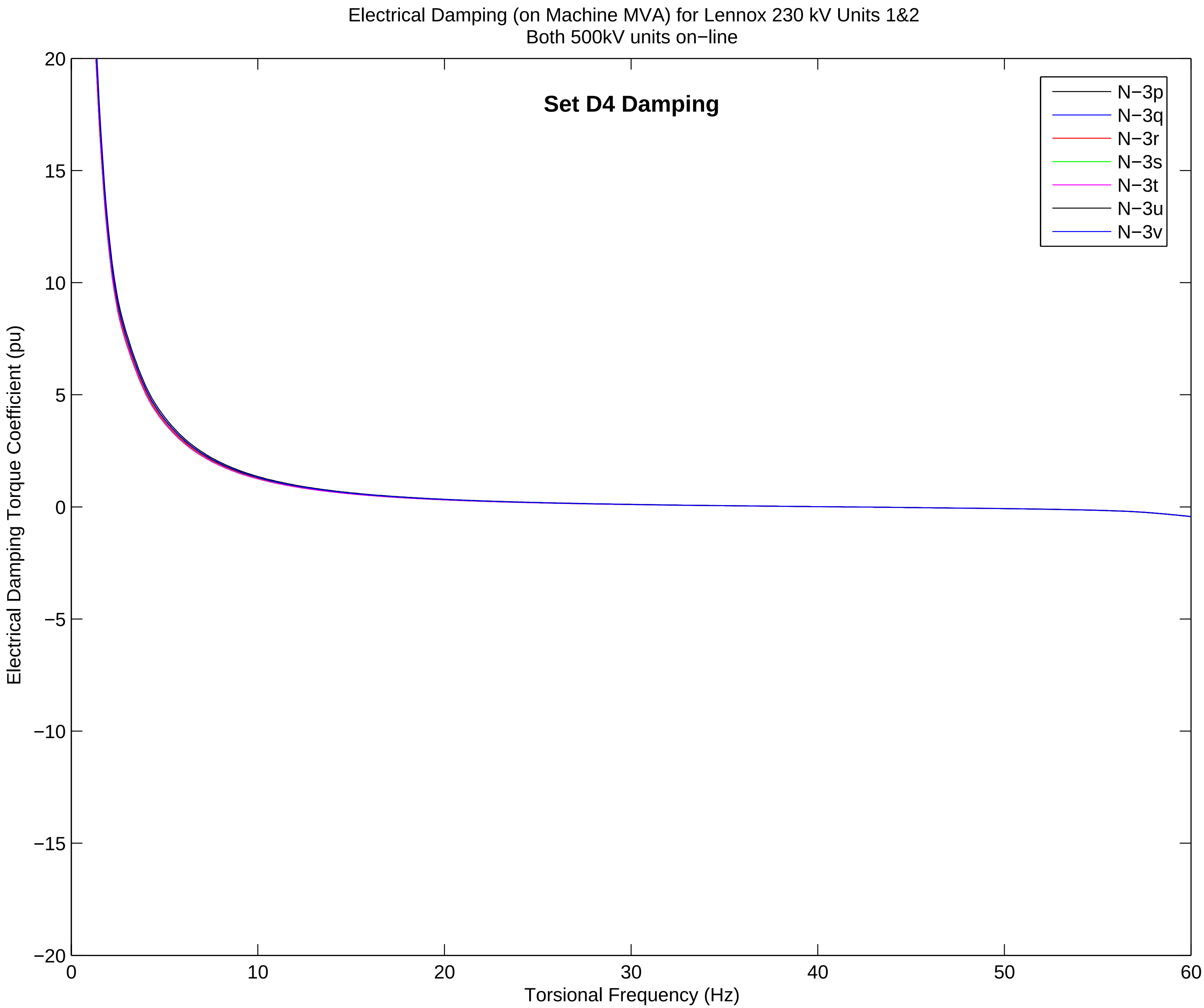


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Damping
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

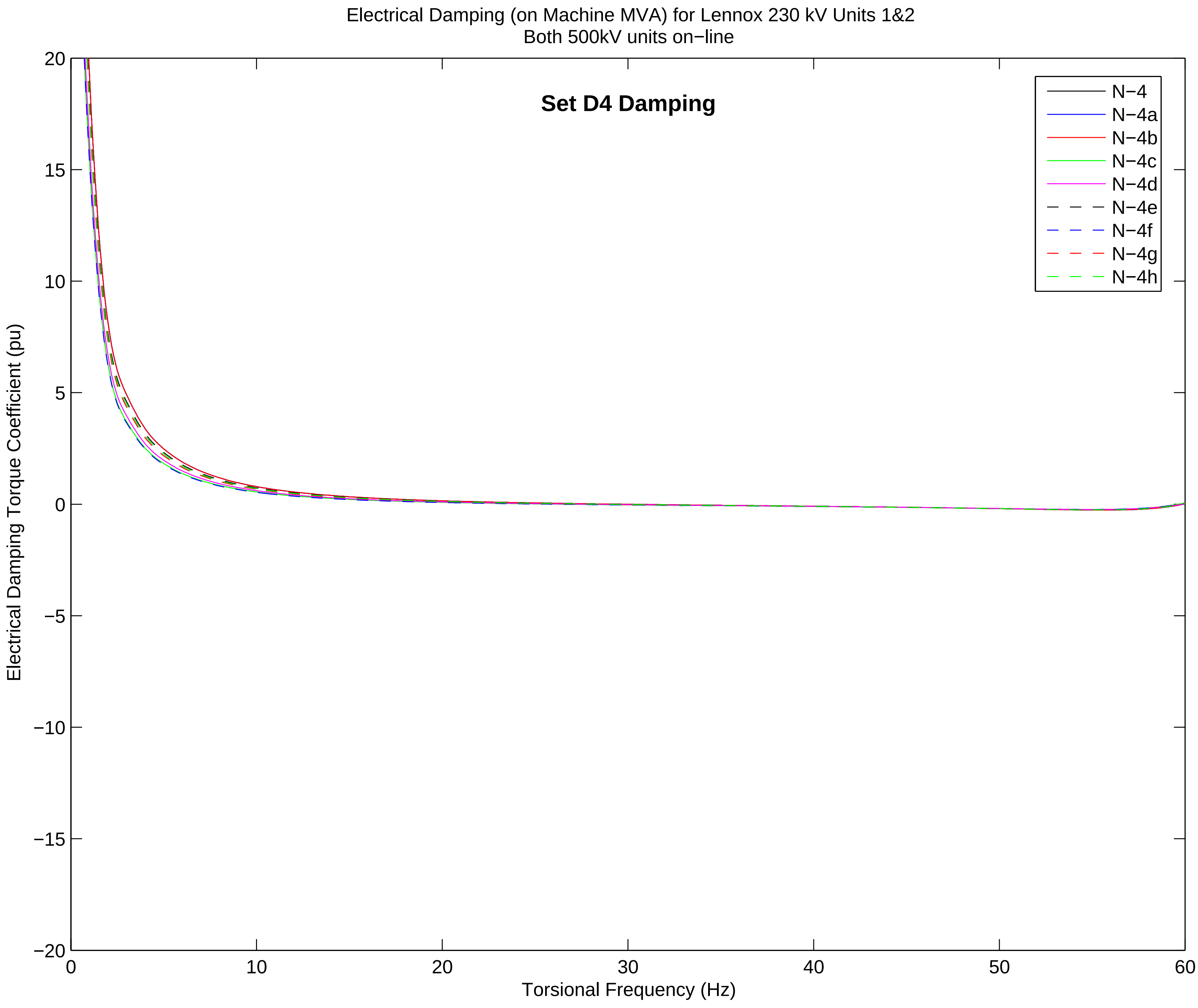


Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Damping
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)

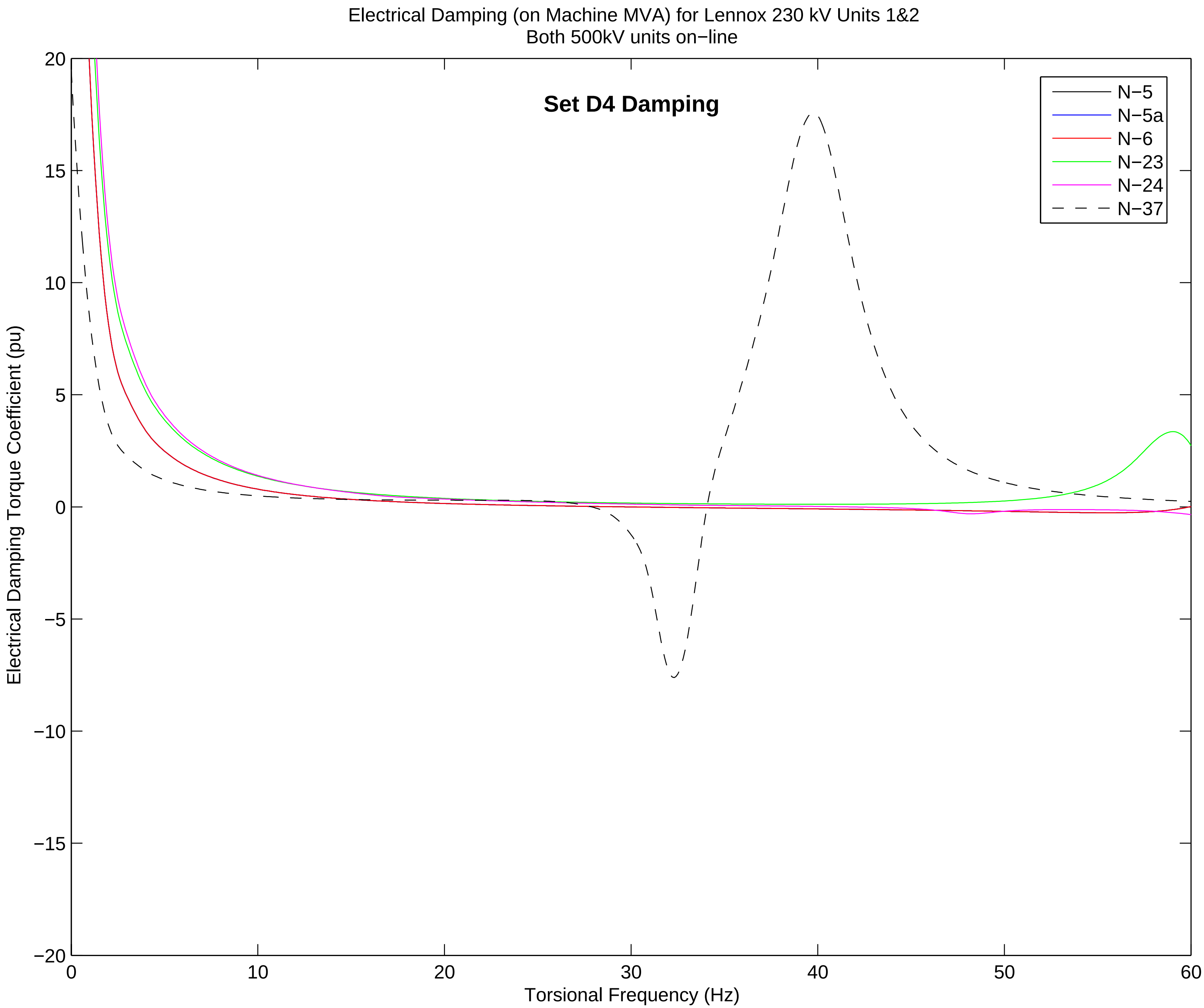

Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Damping
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



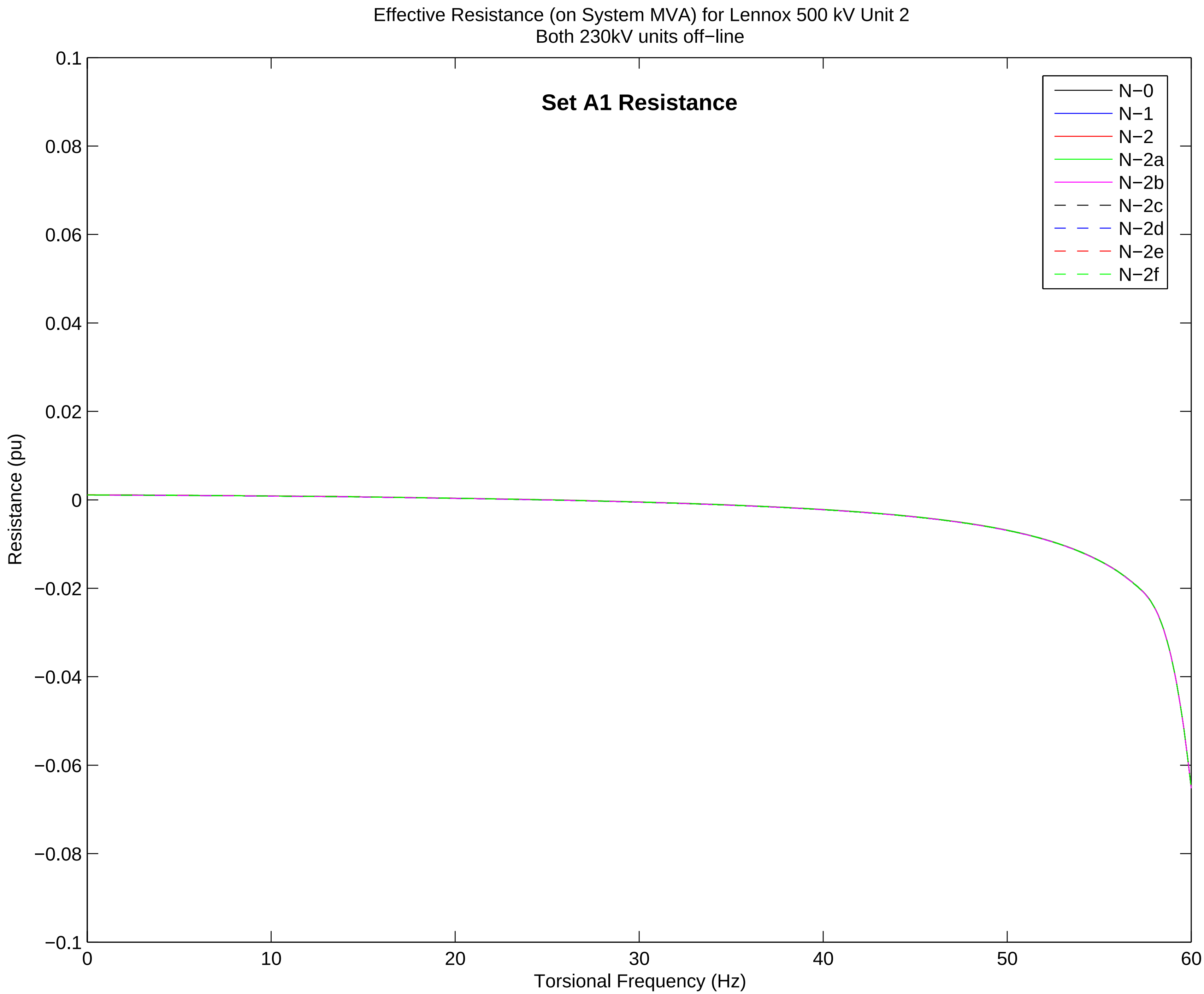
Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Damping
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



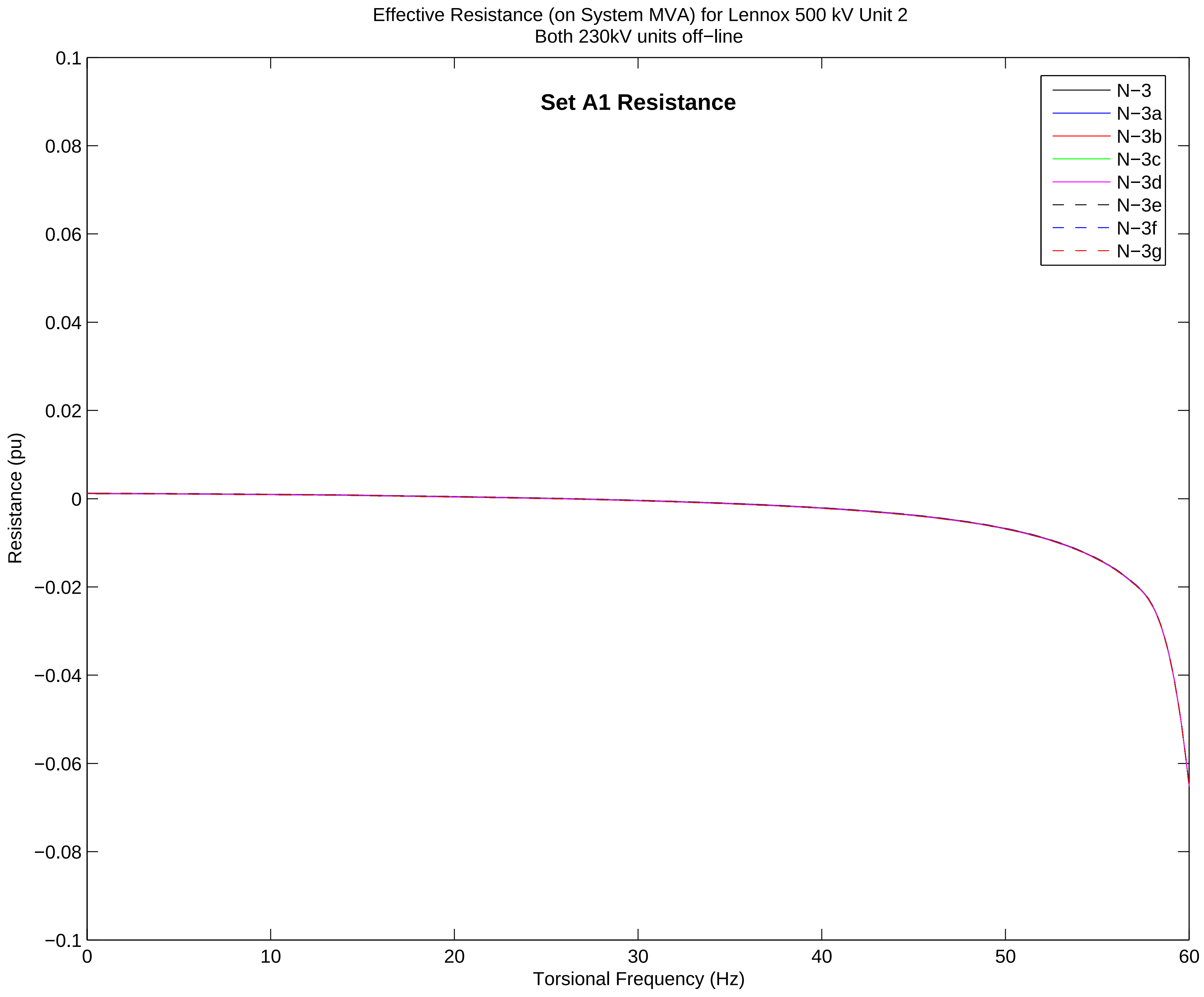
Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Damping
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

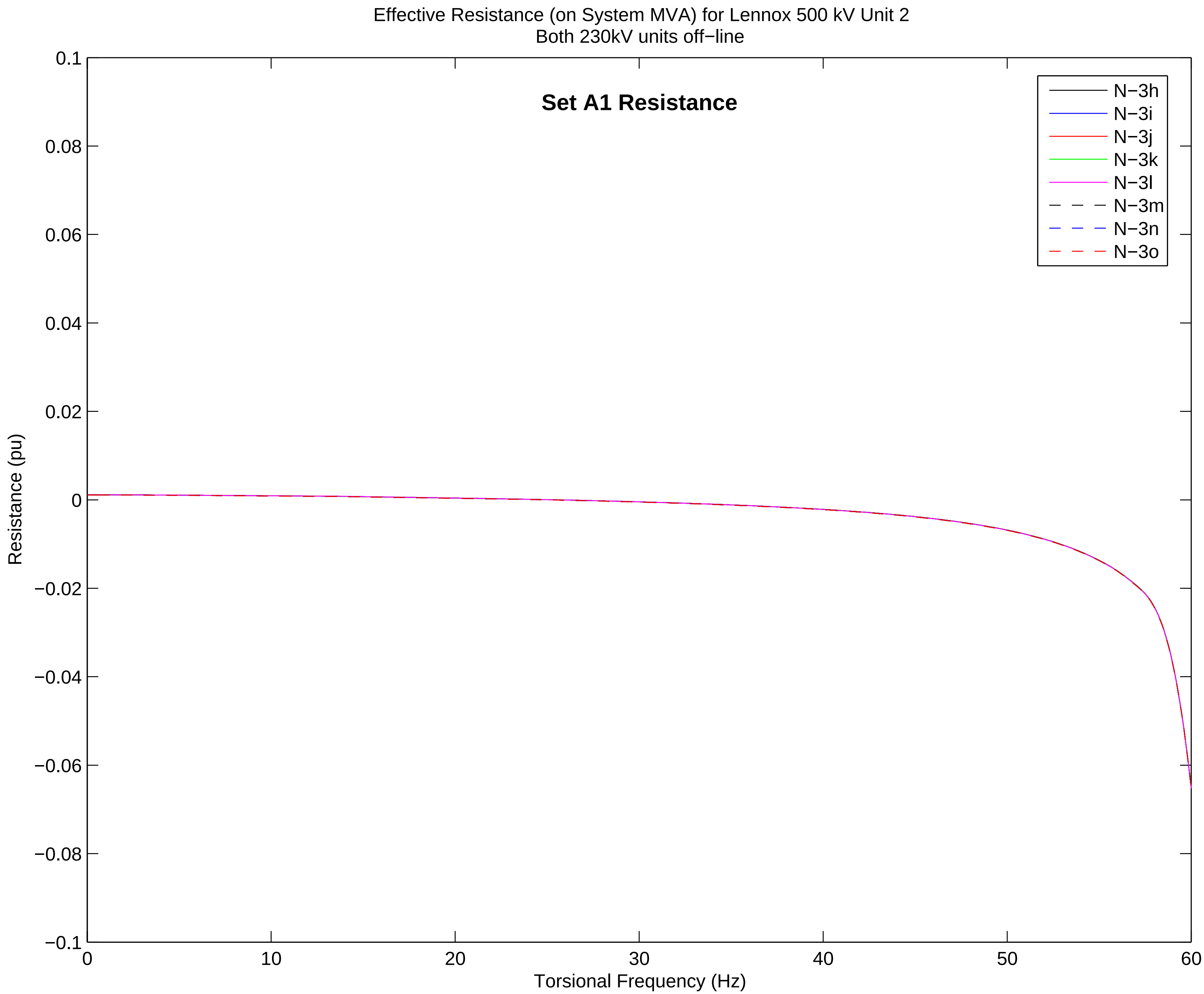


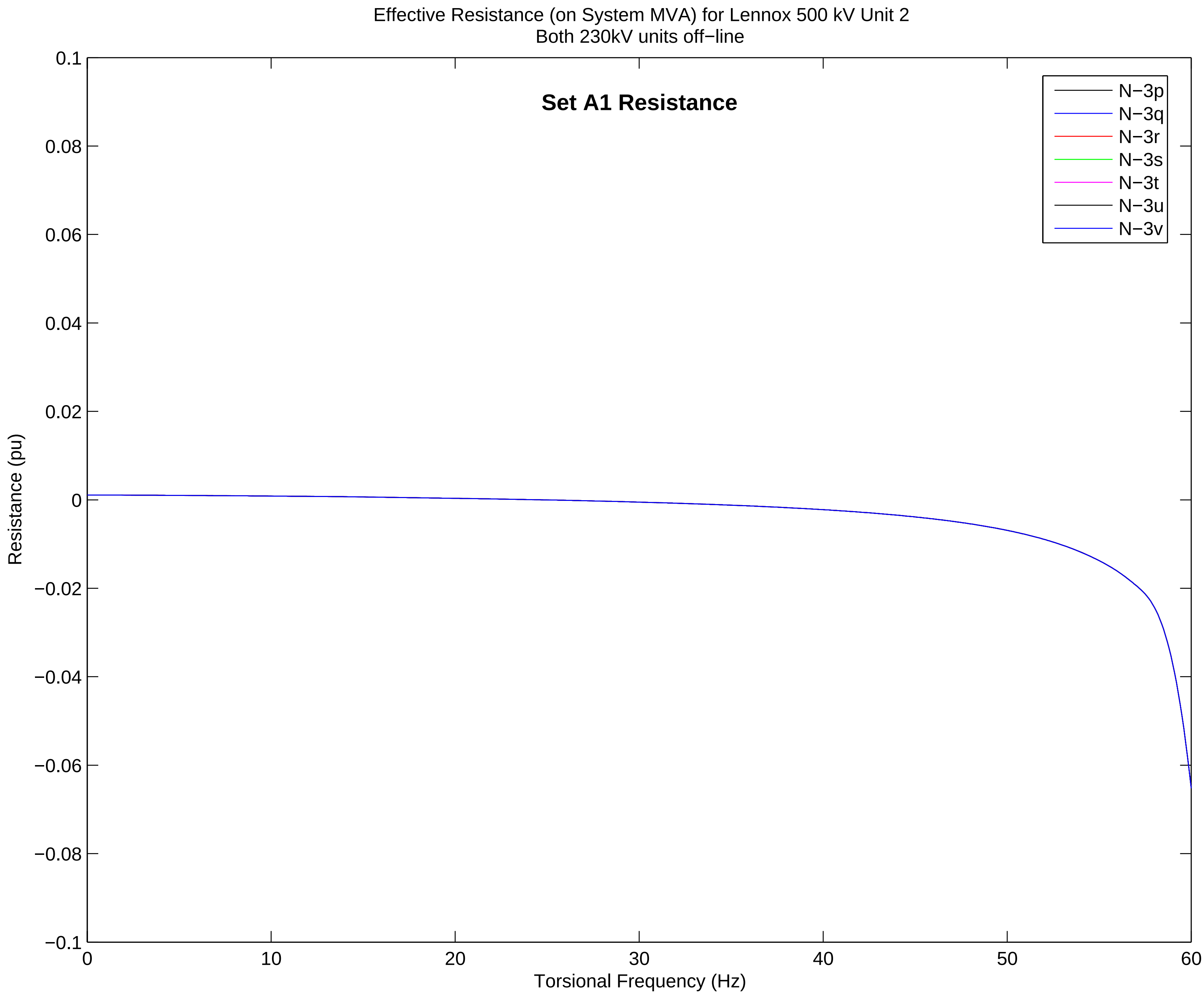
Electrical Damping (on Machine MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Damping
N−5
N−5a
N−6
N−23
N−24
N−37
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



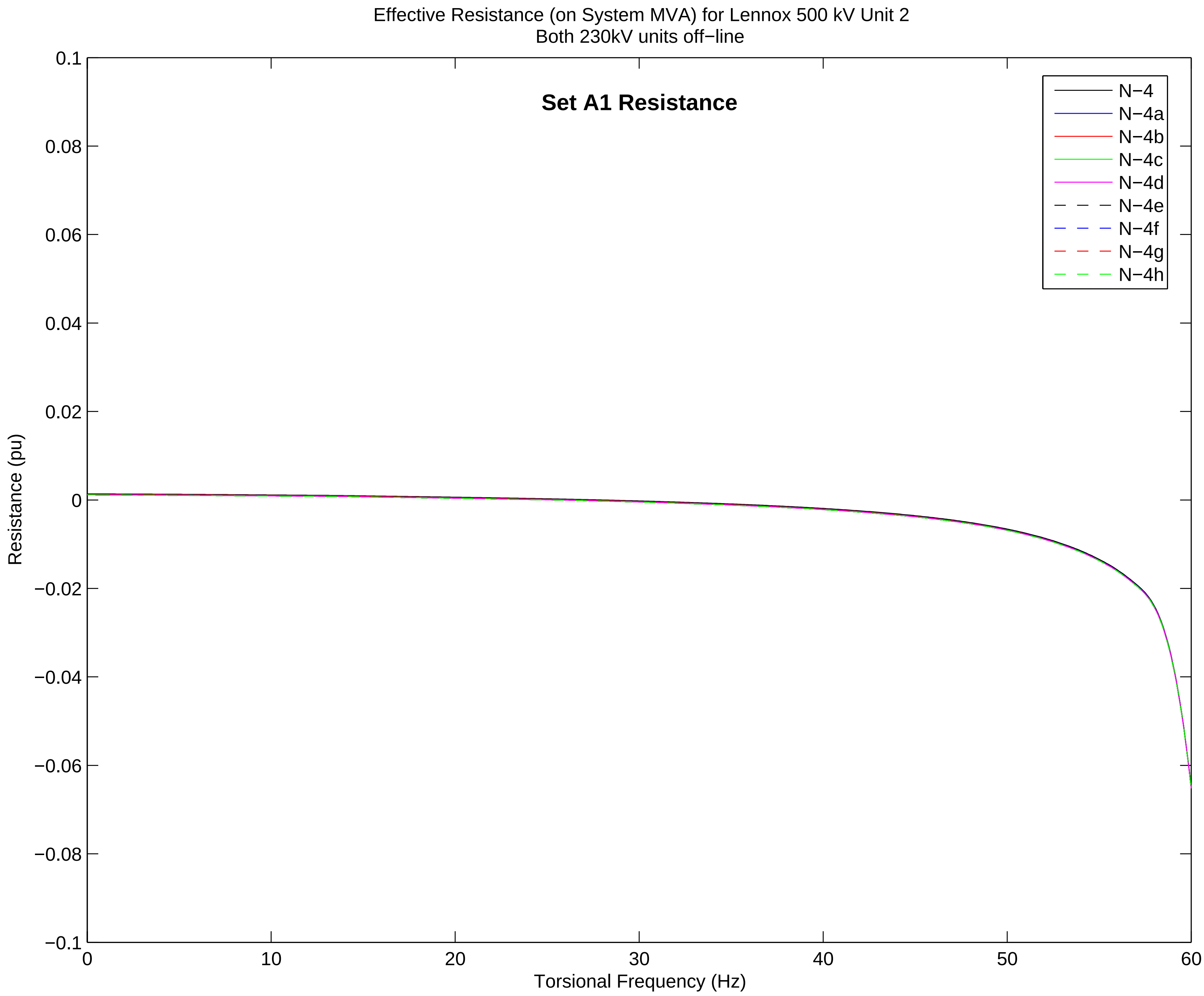
Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

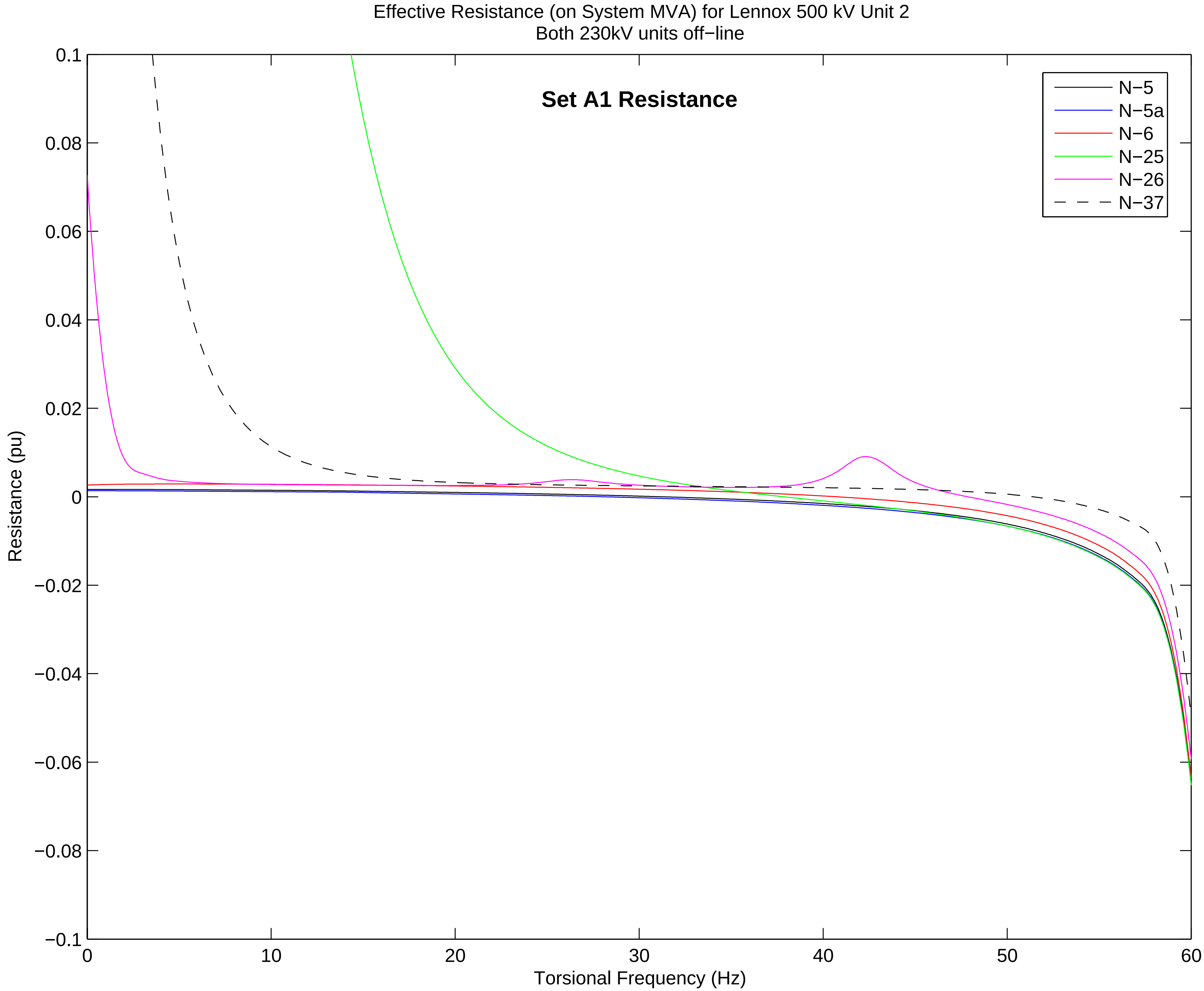

Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

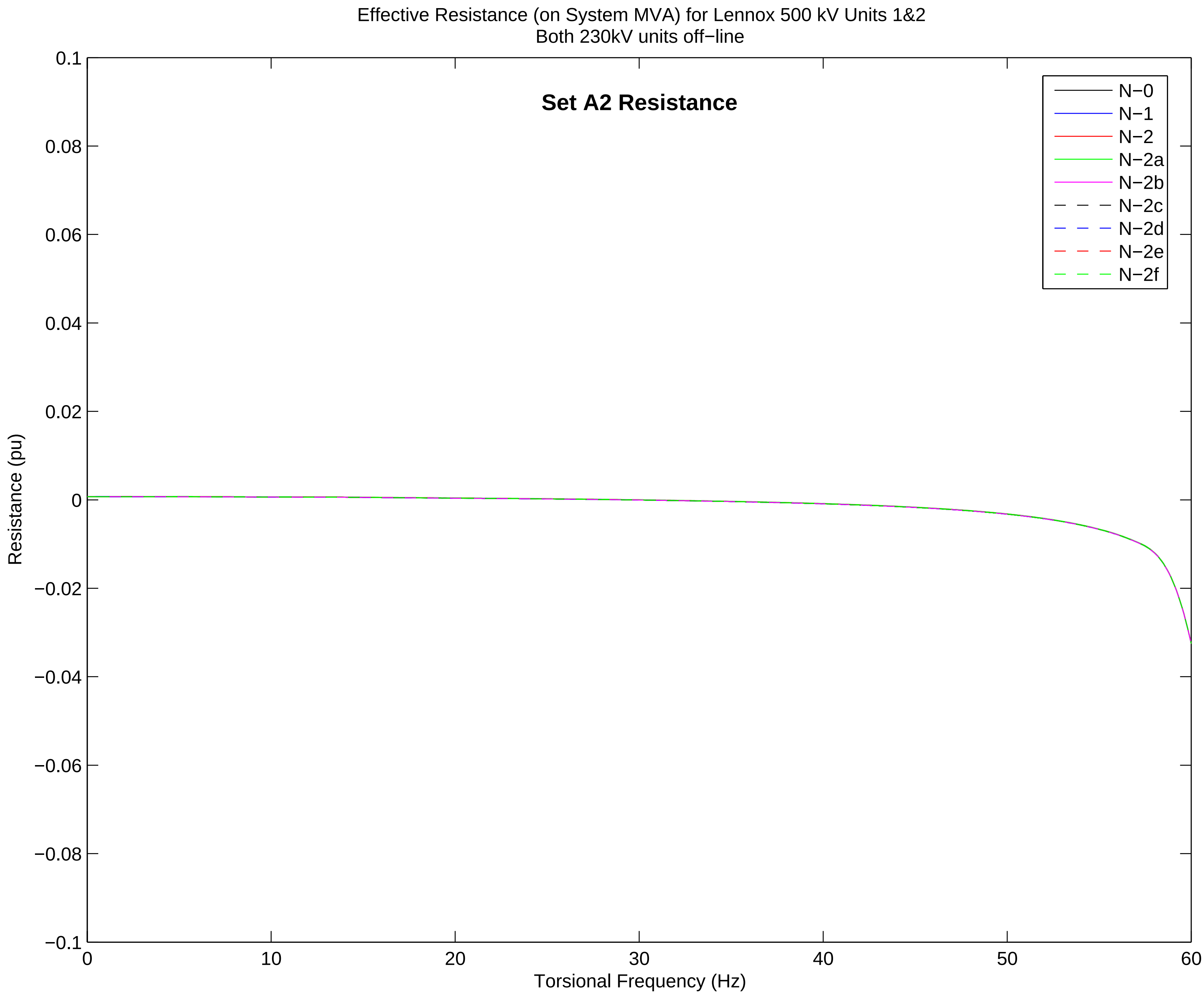

Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



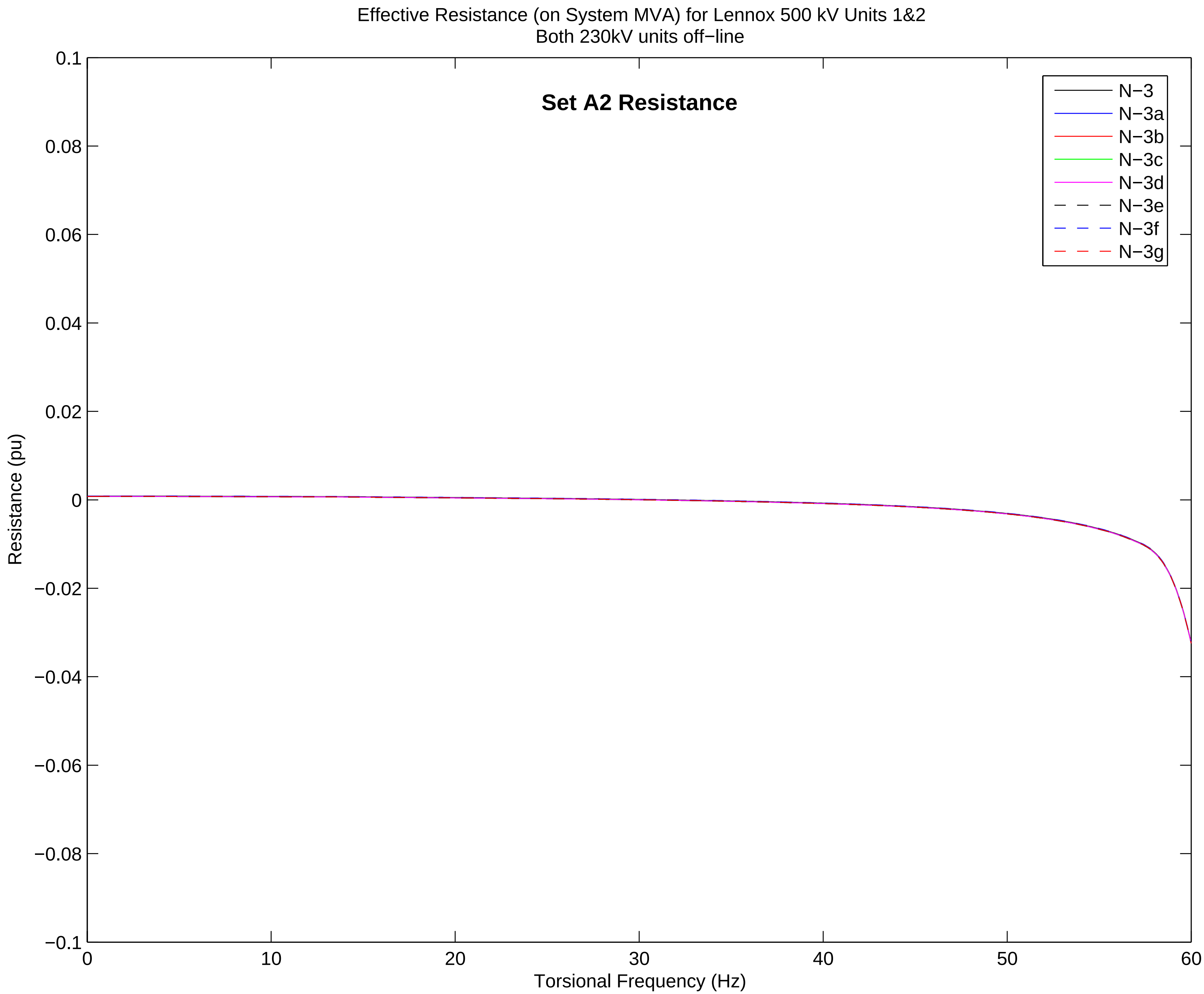
Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

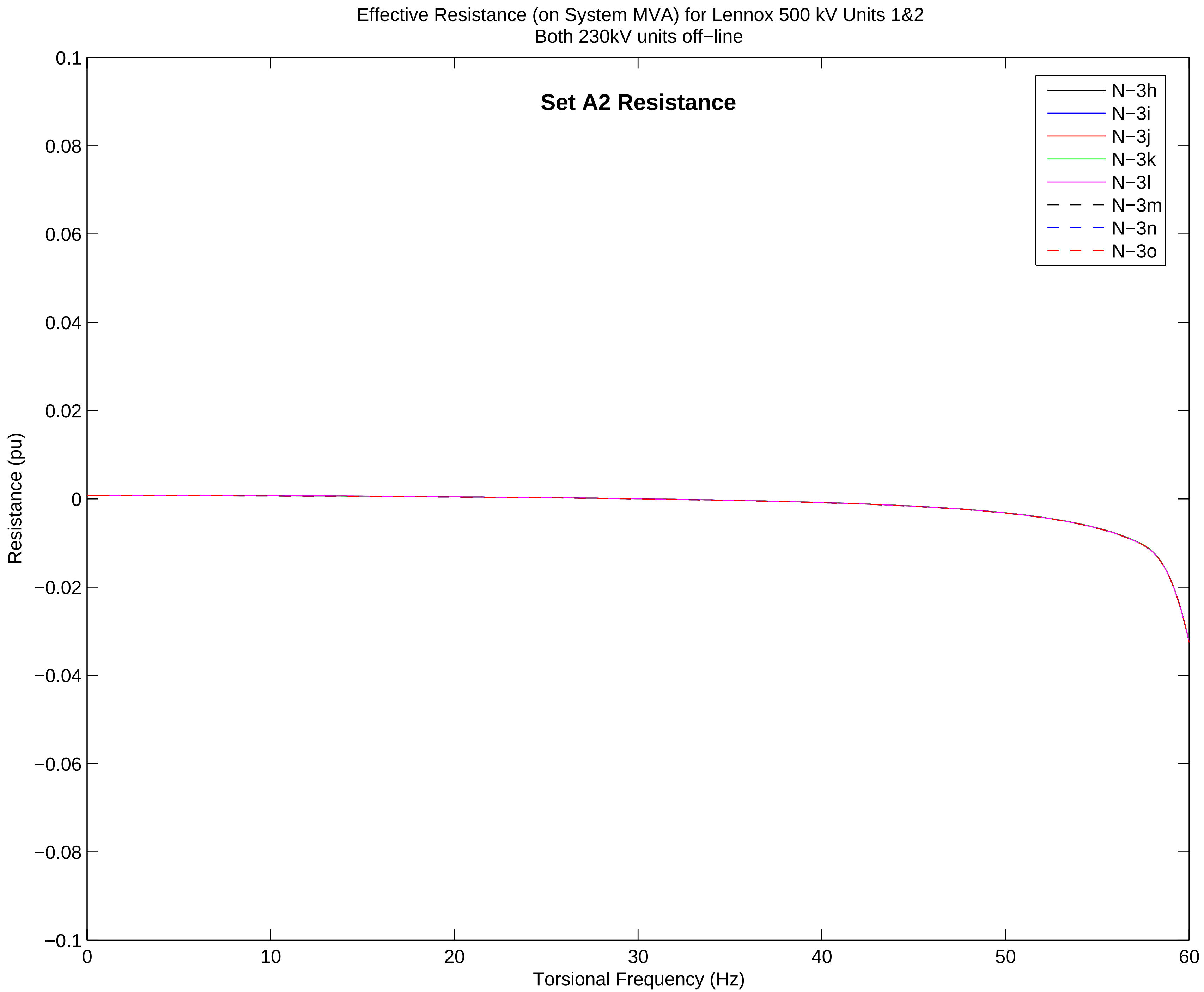

Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
Both 230kV units off−line
Set A1 Resistance
N−5
N−5a
N−6
N−25
N−26
N−37
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



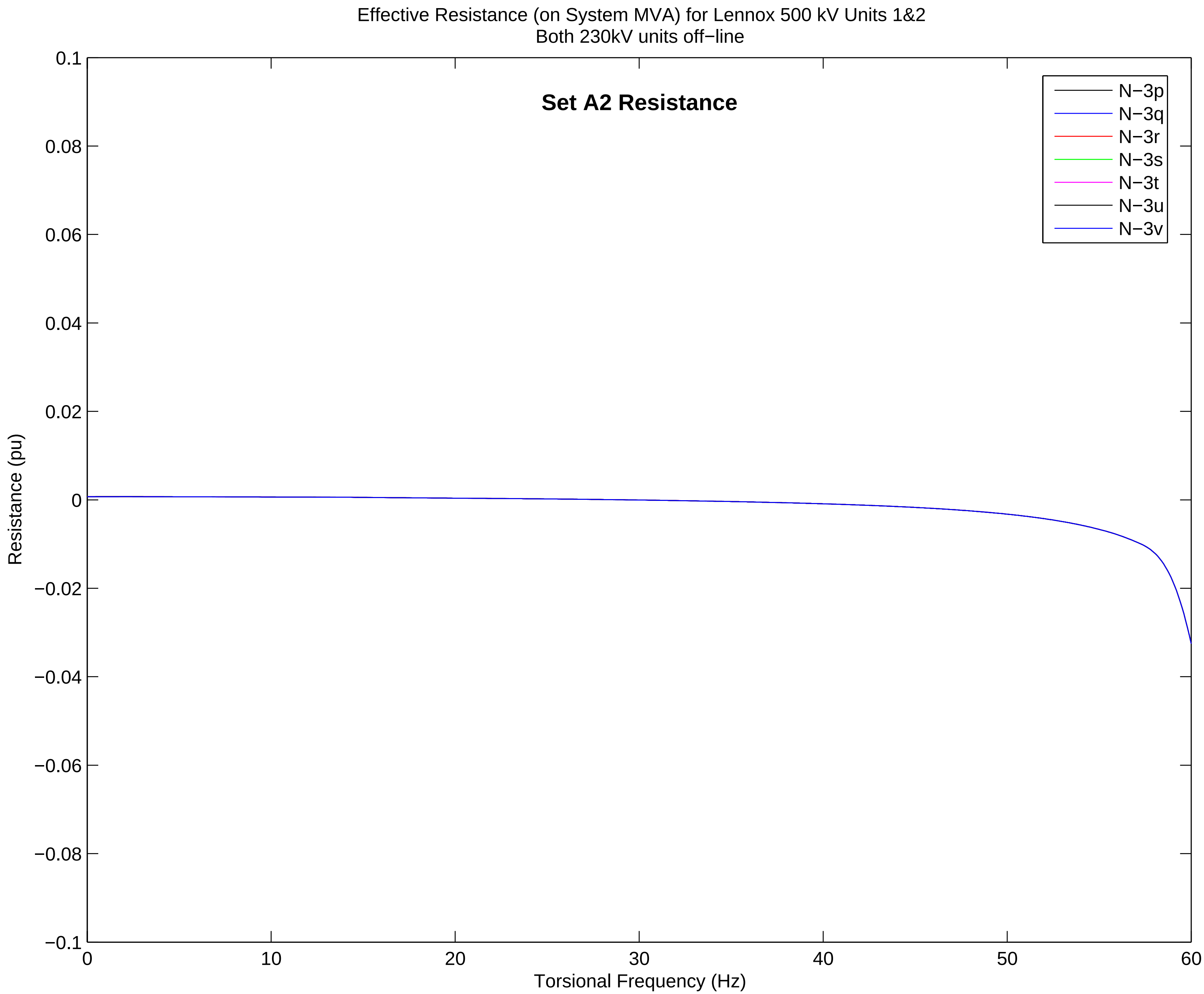
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



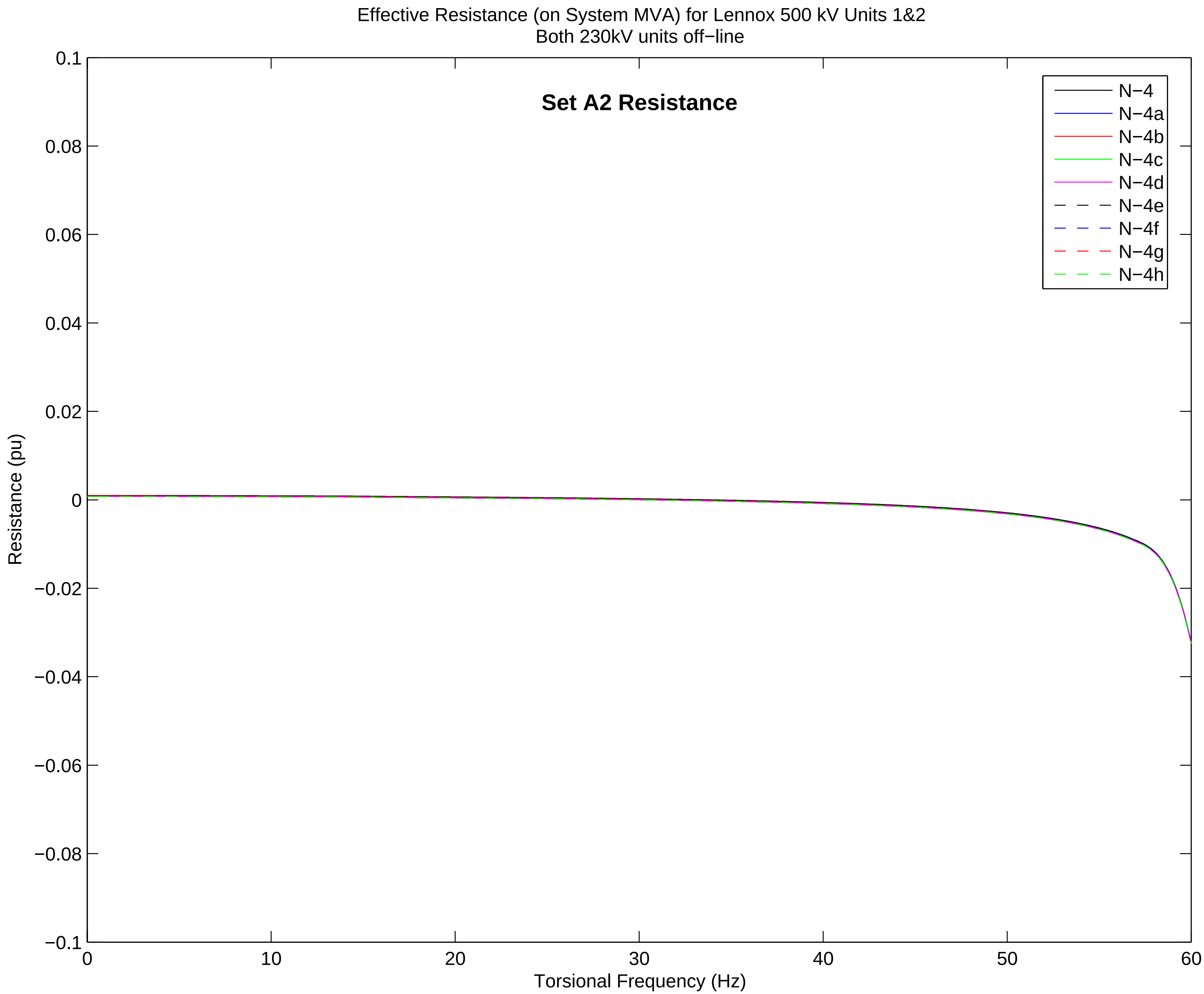
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



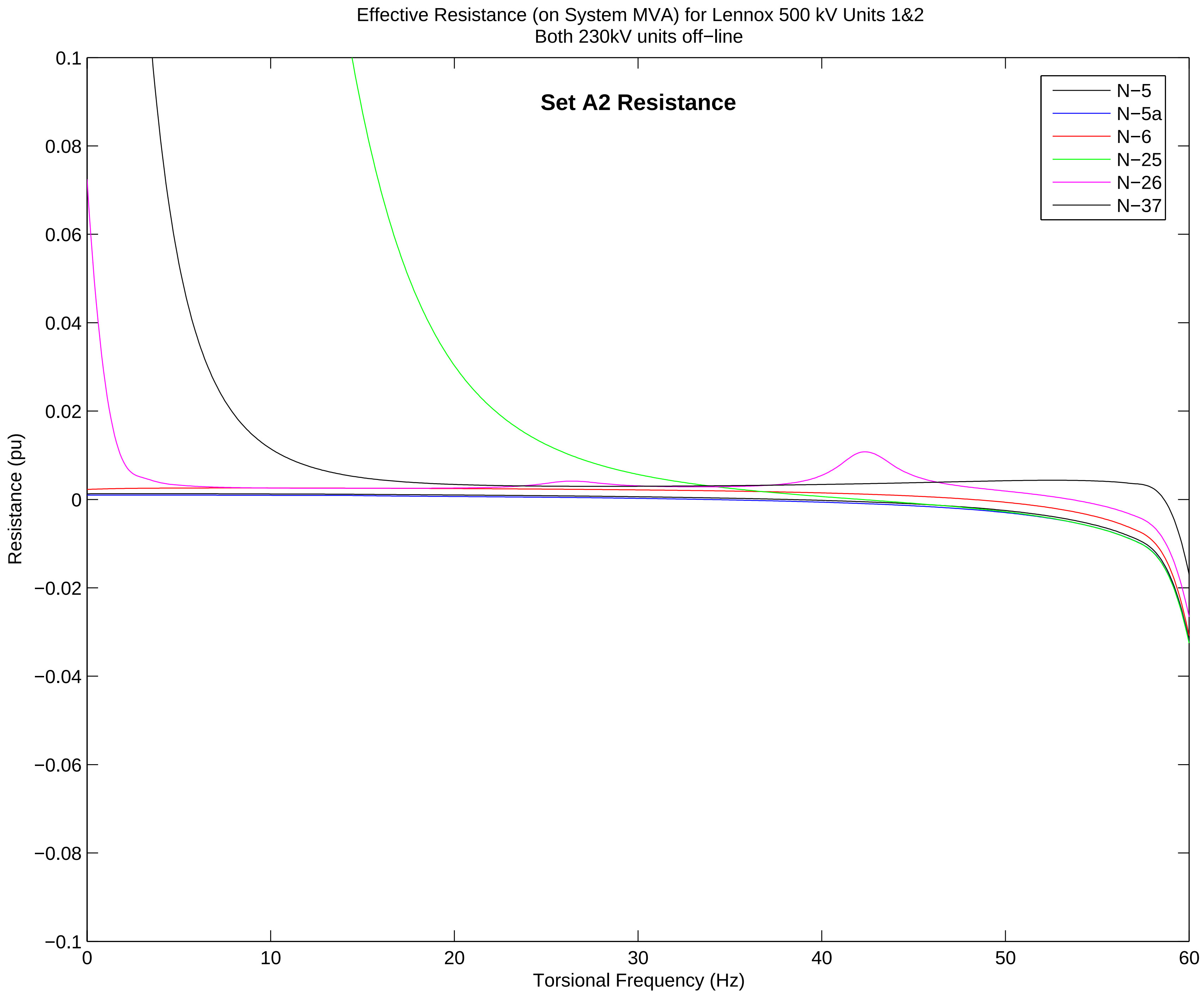
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



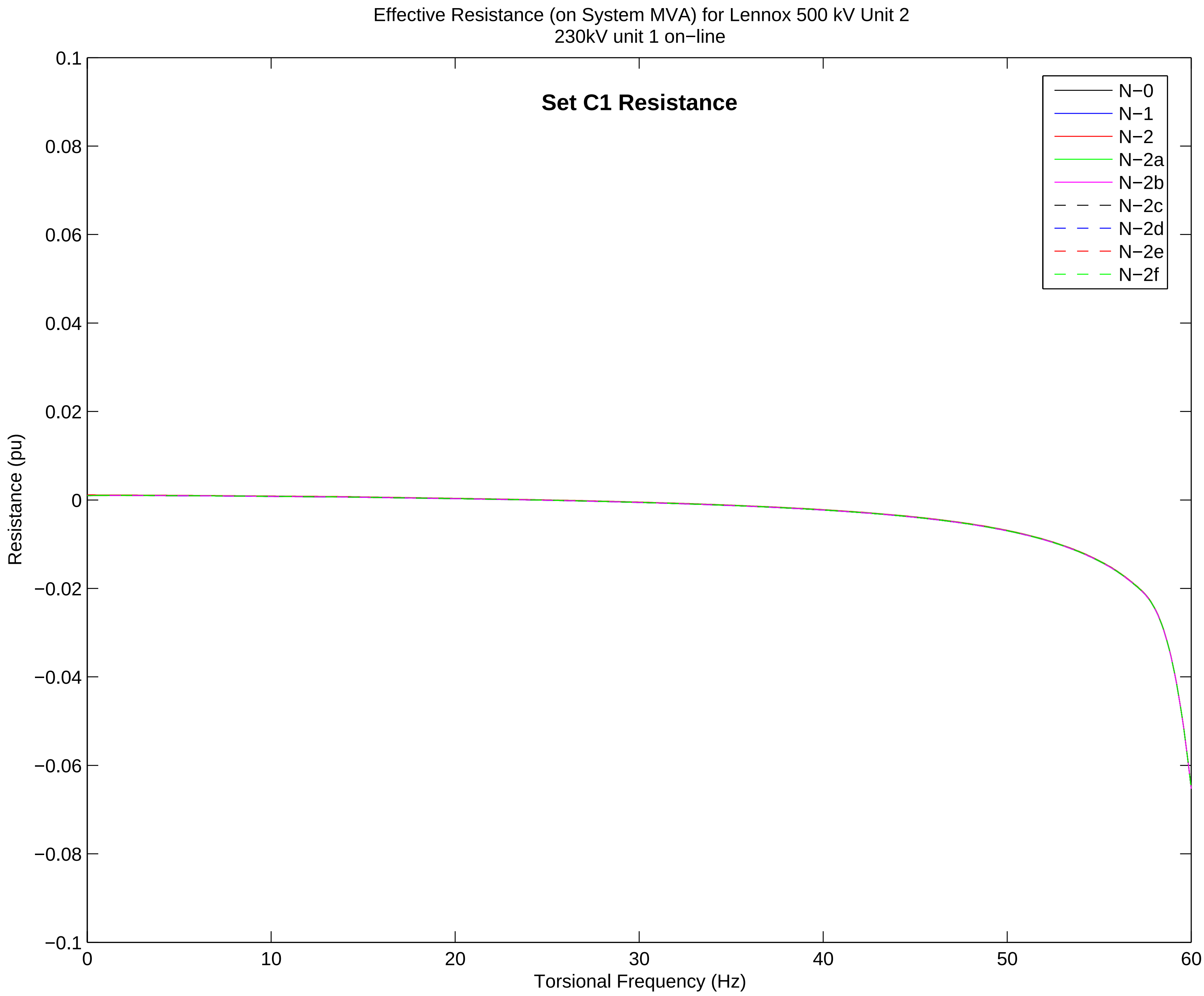
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

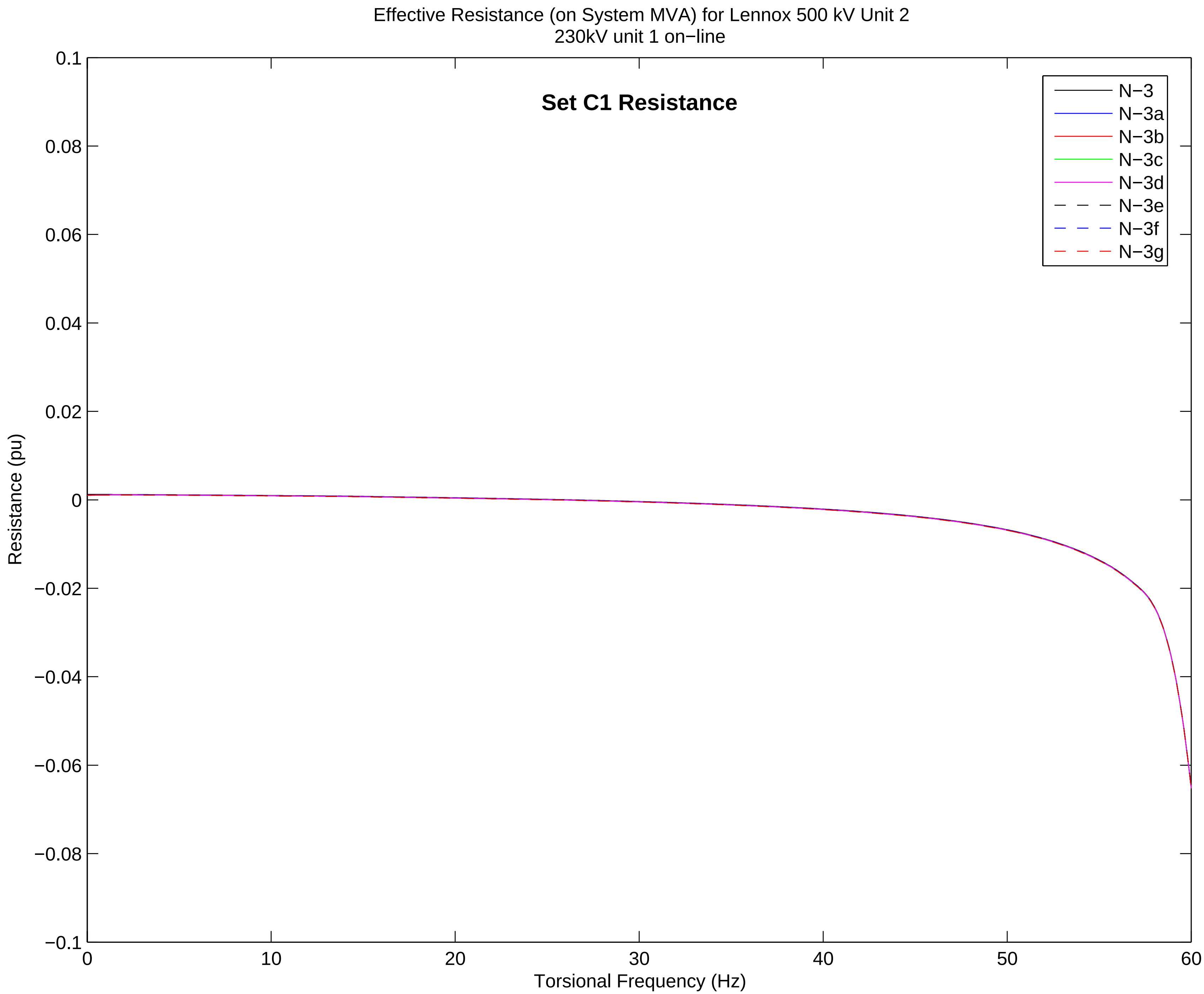


Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

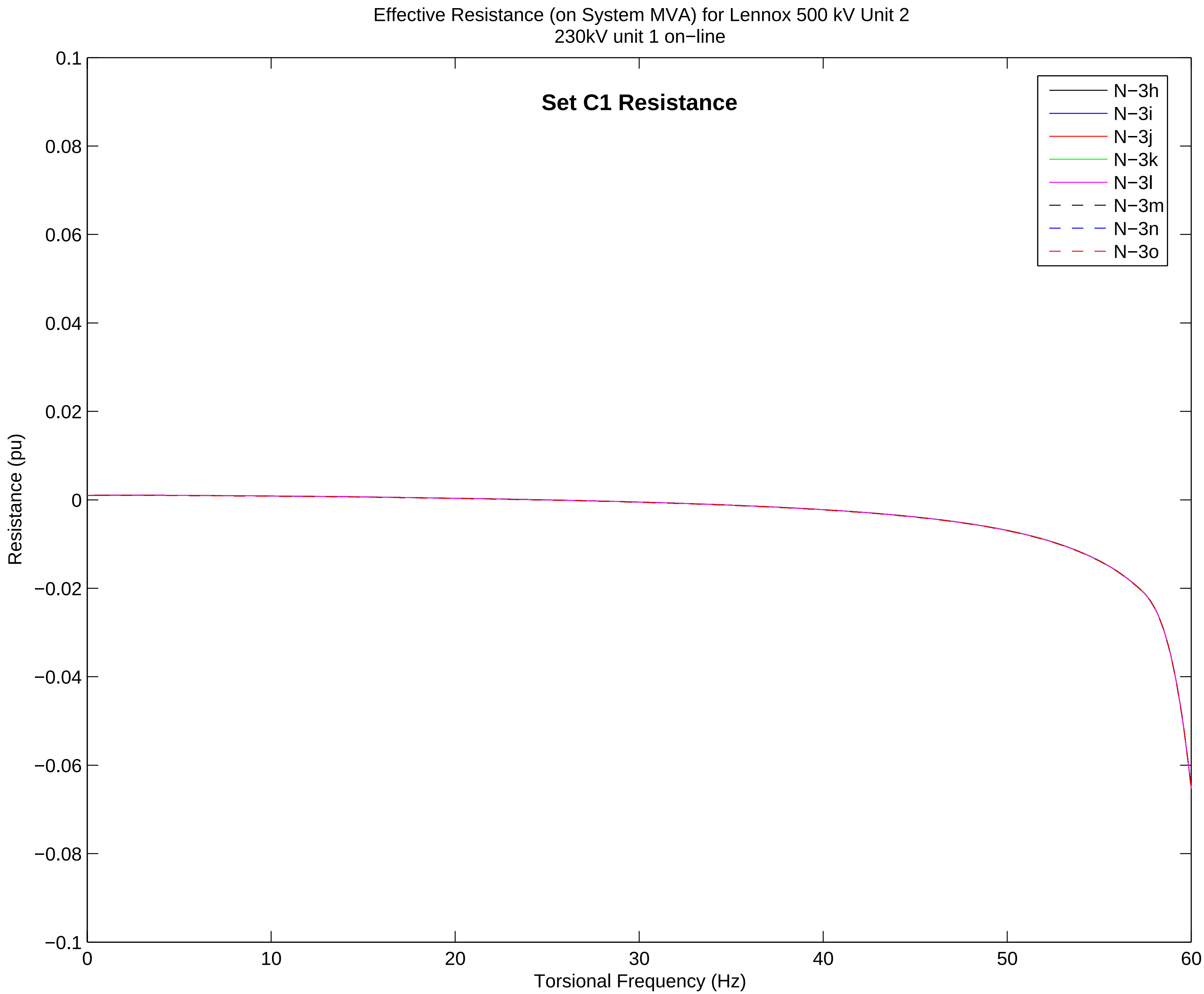


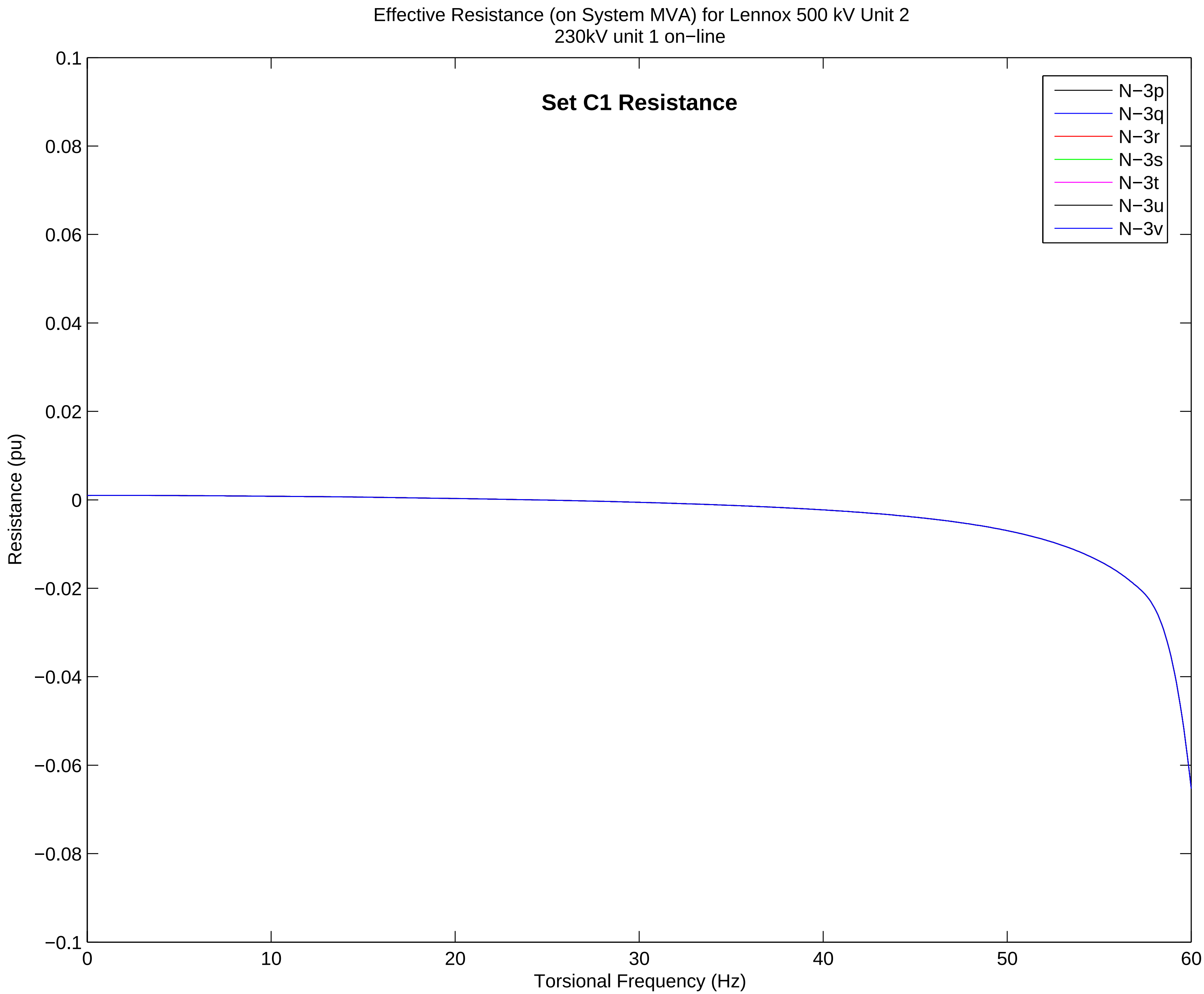
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units off−line
Set A2 Resistance
N−5
N−5a
N−6
N−25
N−26
N−37
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

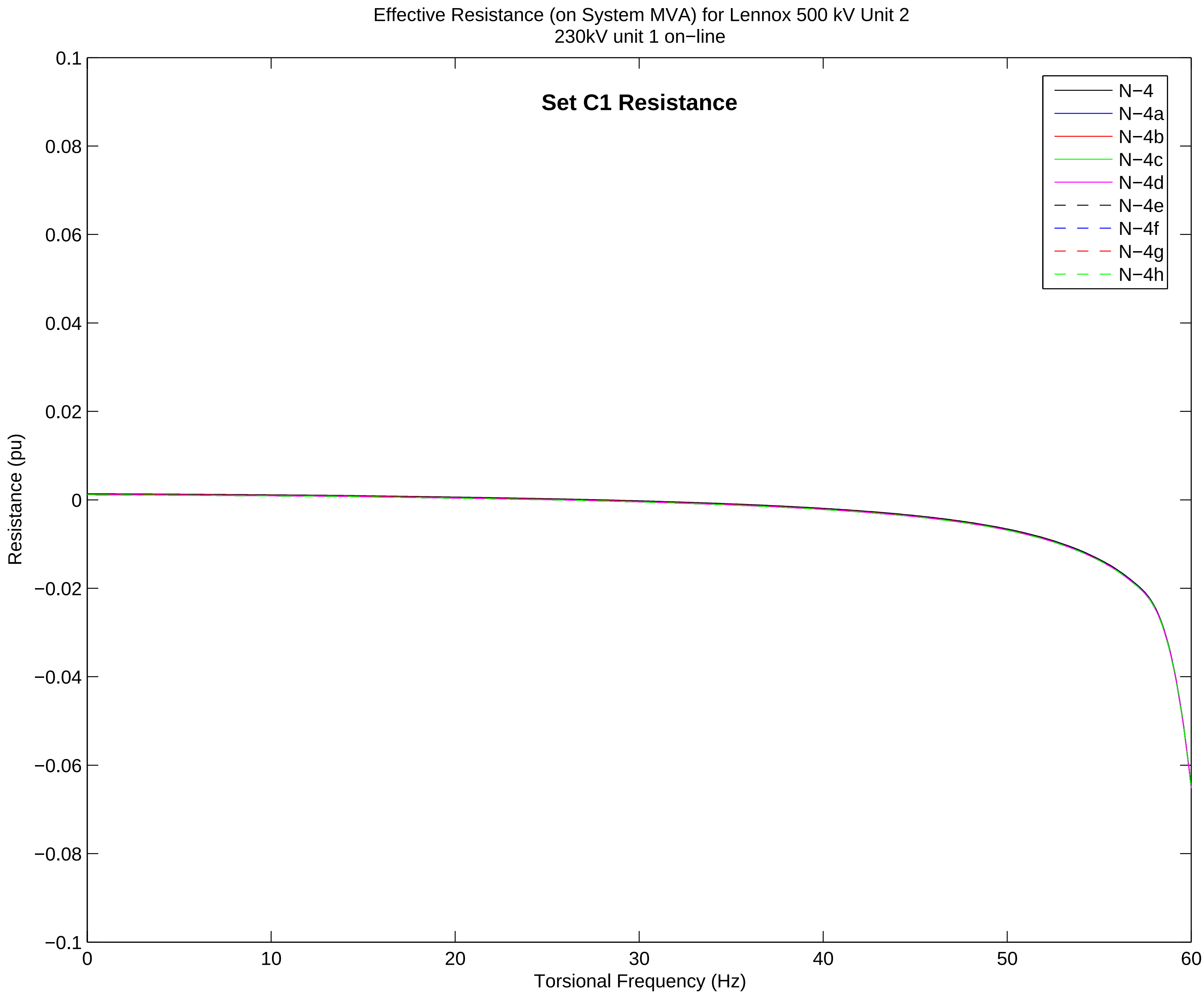

Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



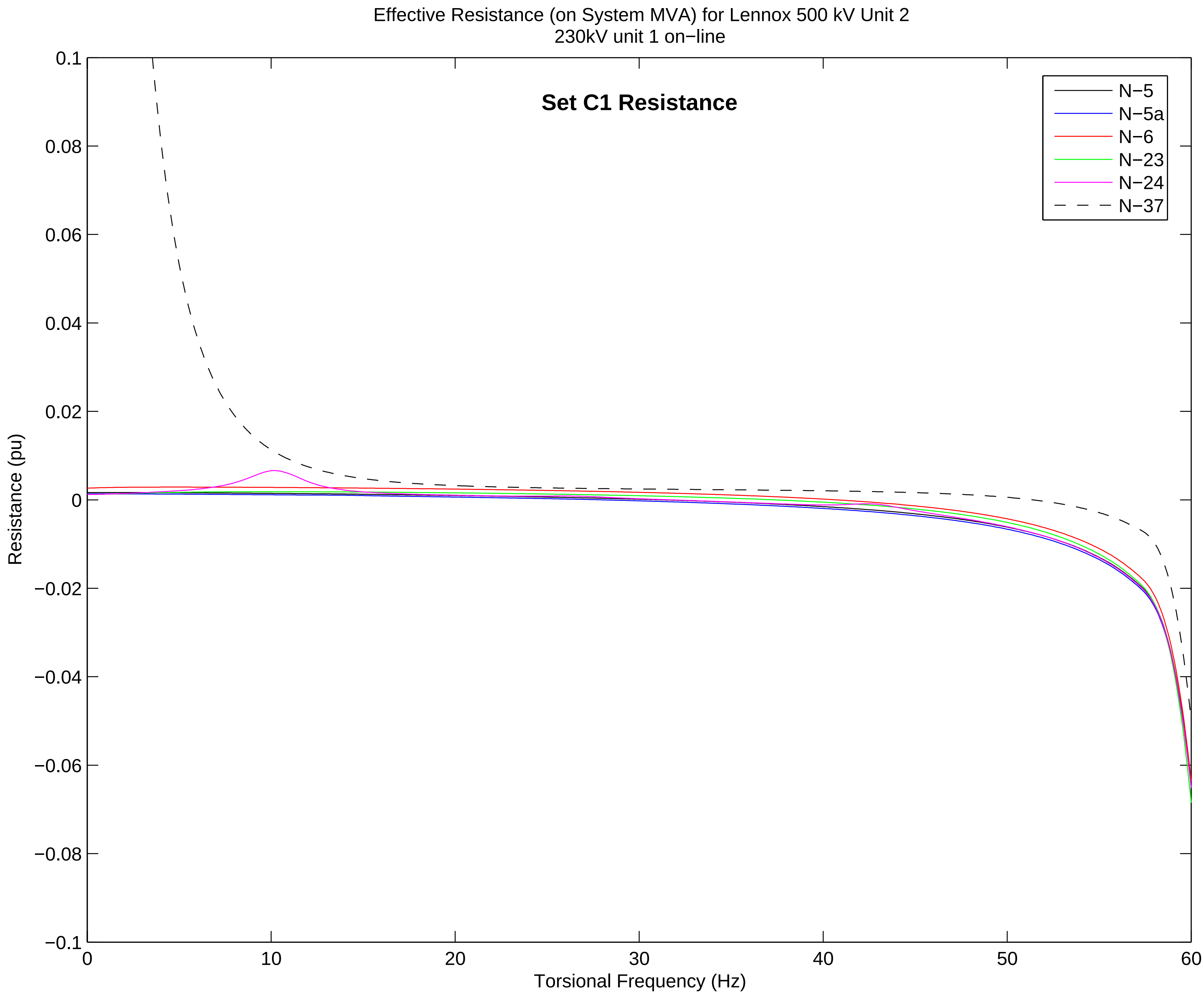
Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

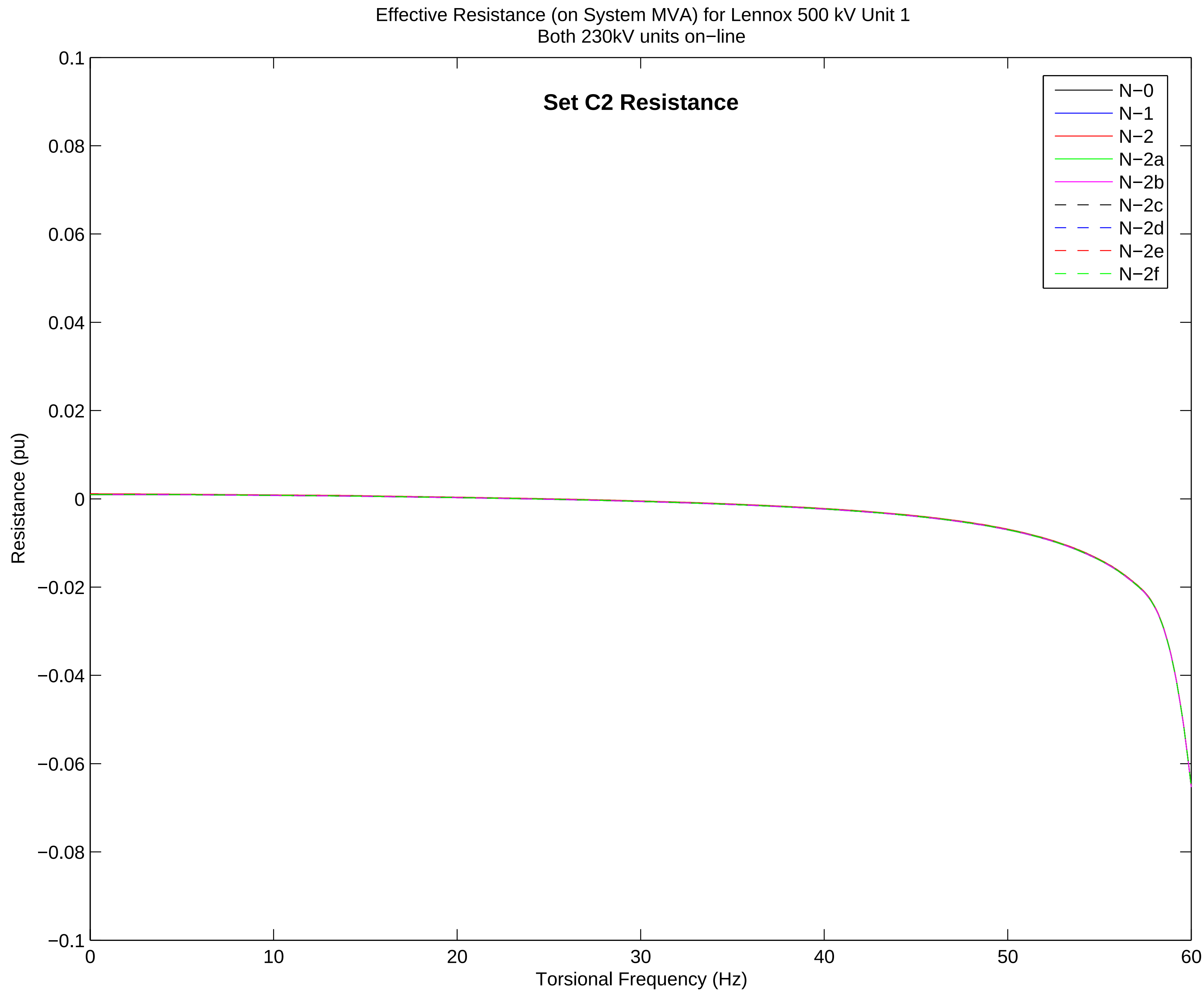

Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



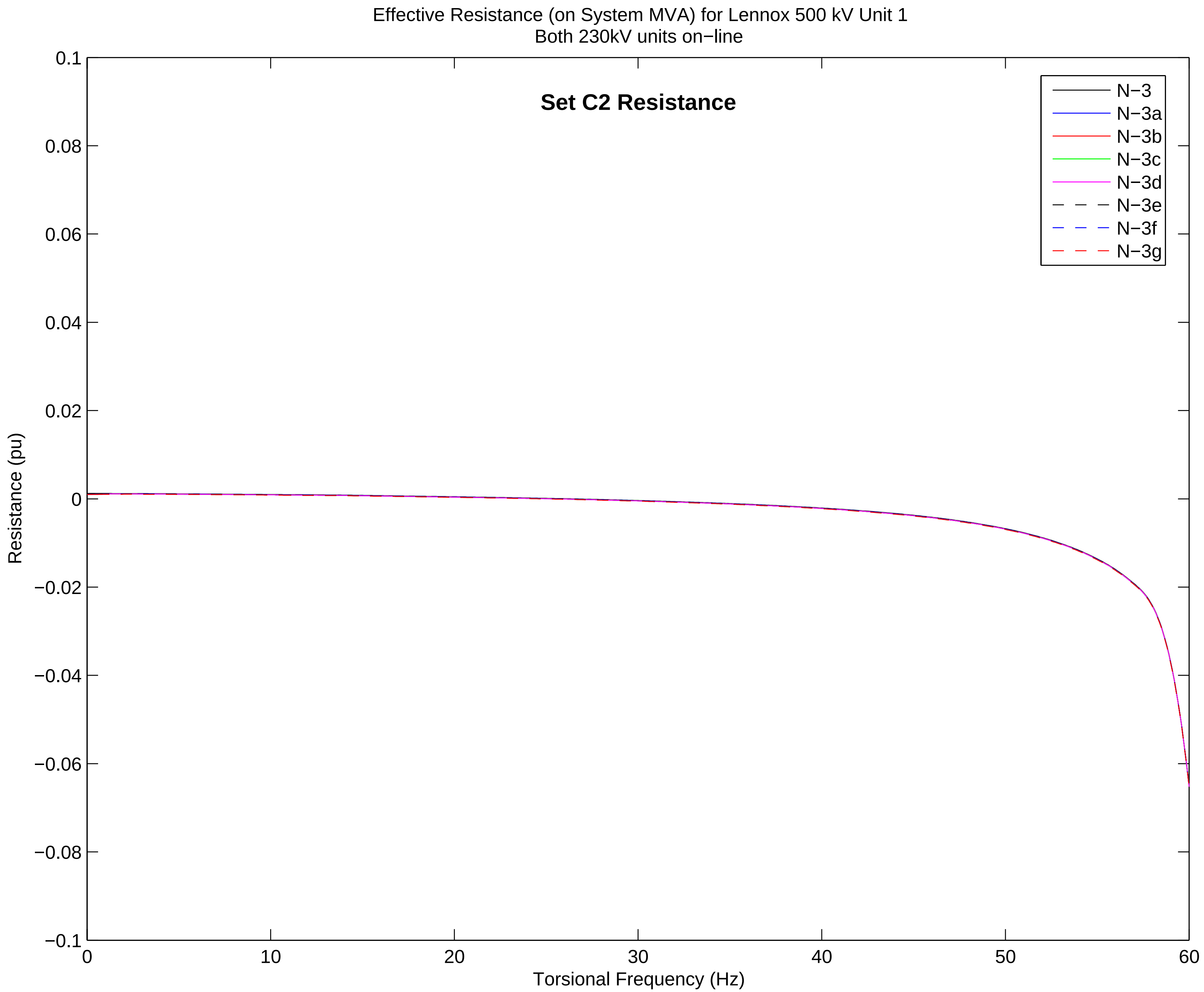
Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



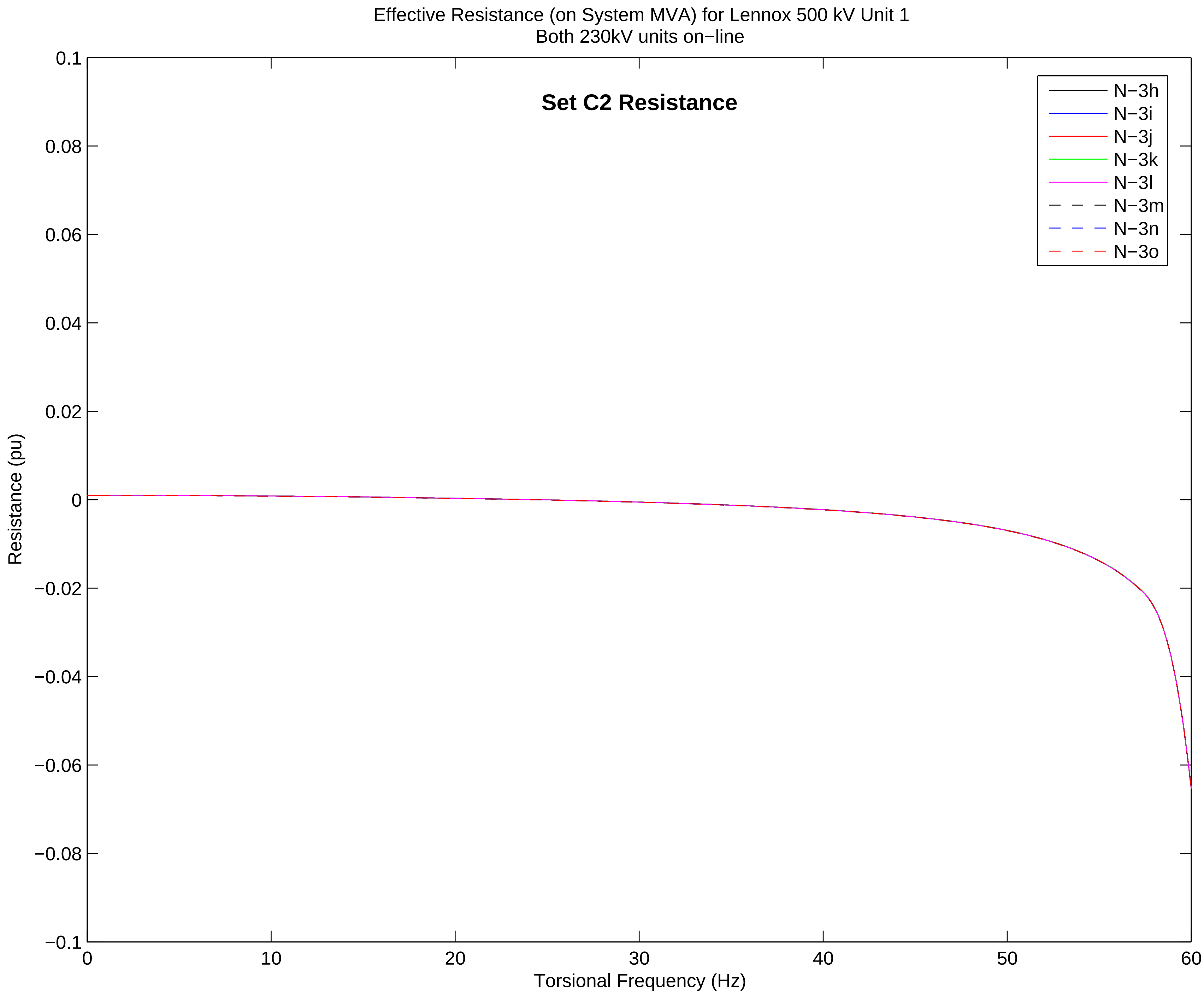
Effective Resistance (on System MVA) for Lennox 500 kV Unit 2
230kV unit 1 on−line
Set C1 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



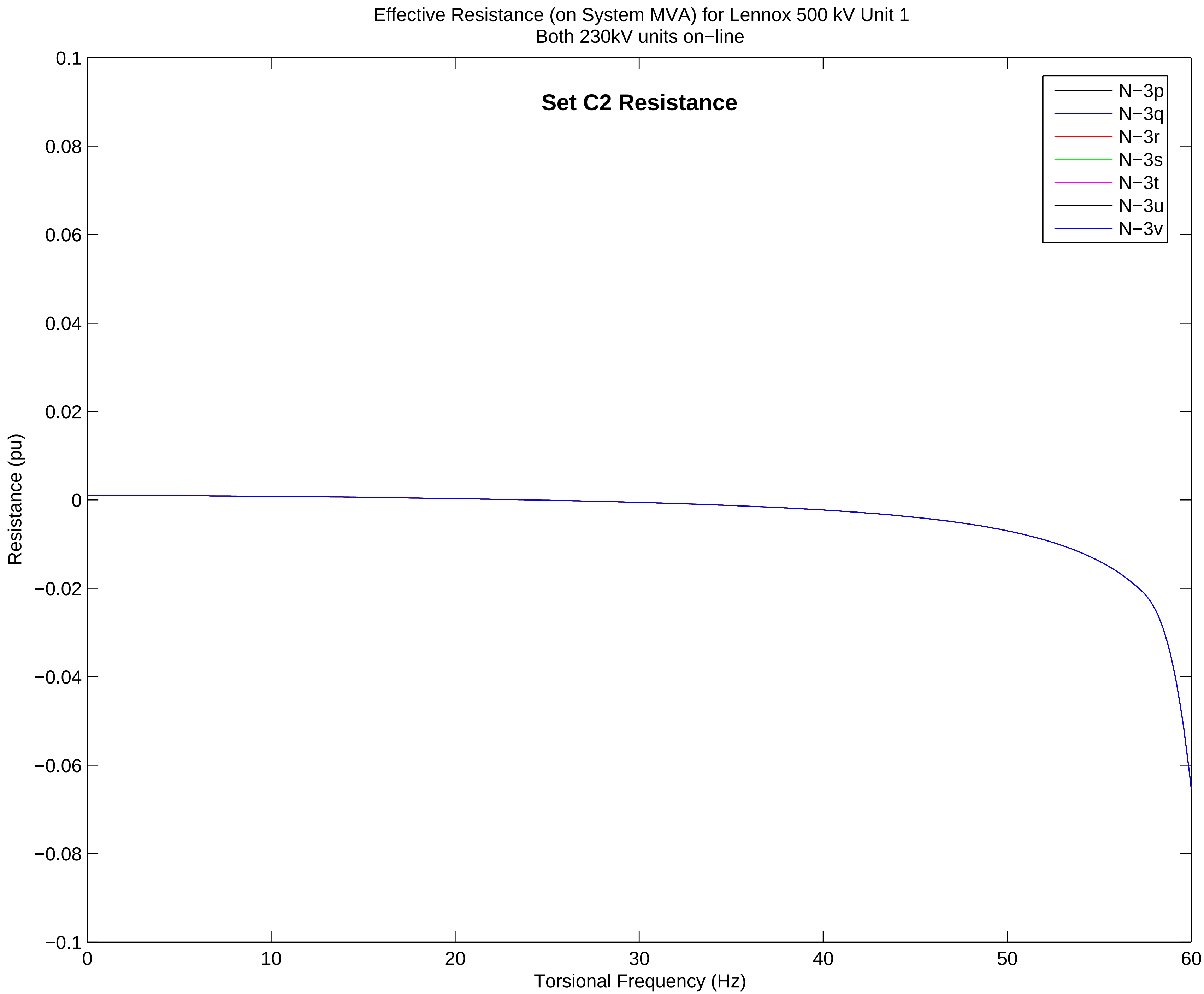
Effective Resistance (on System MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

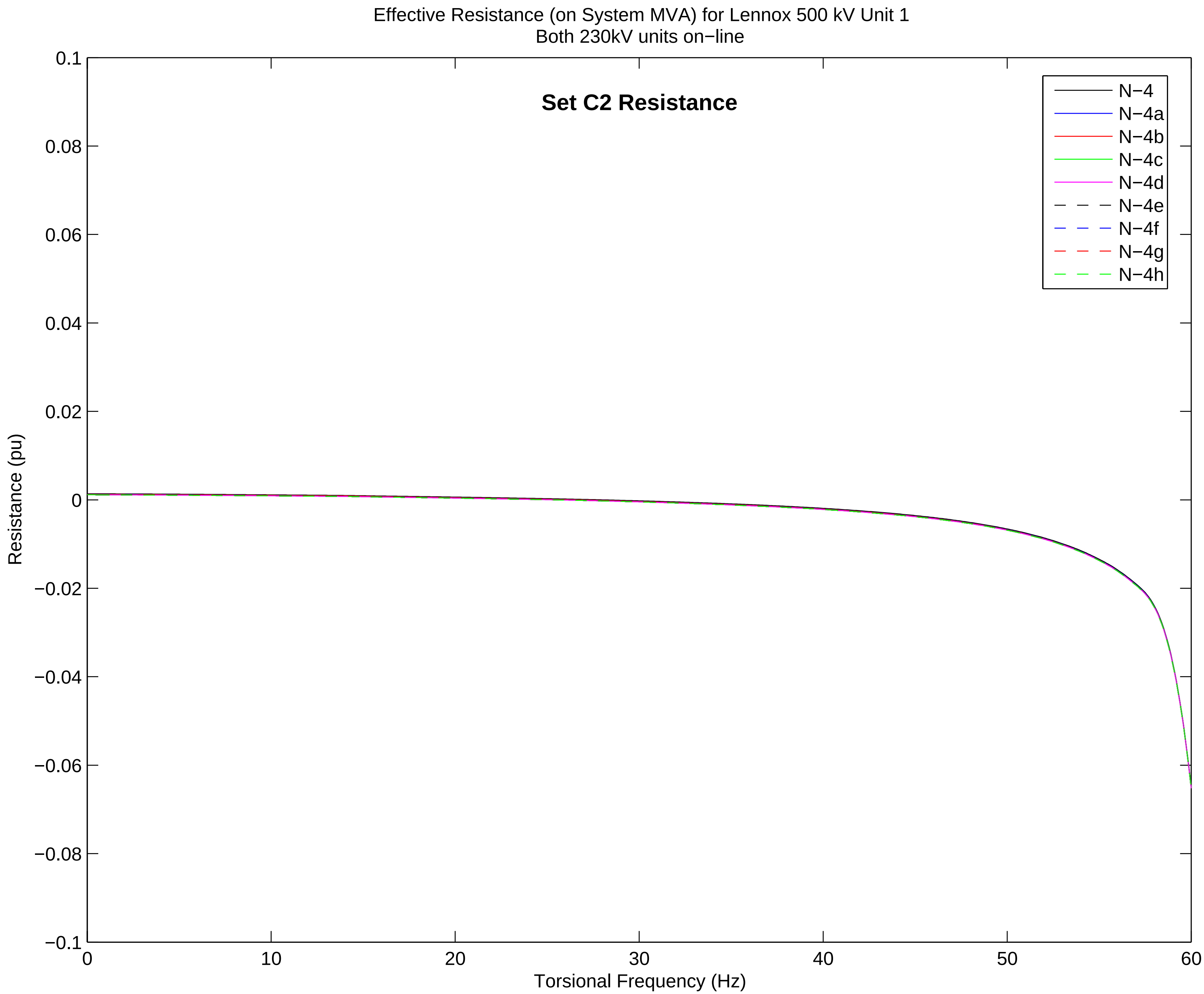


Effective Resistance (on System MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

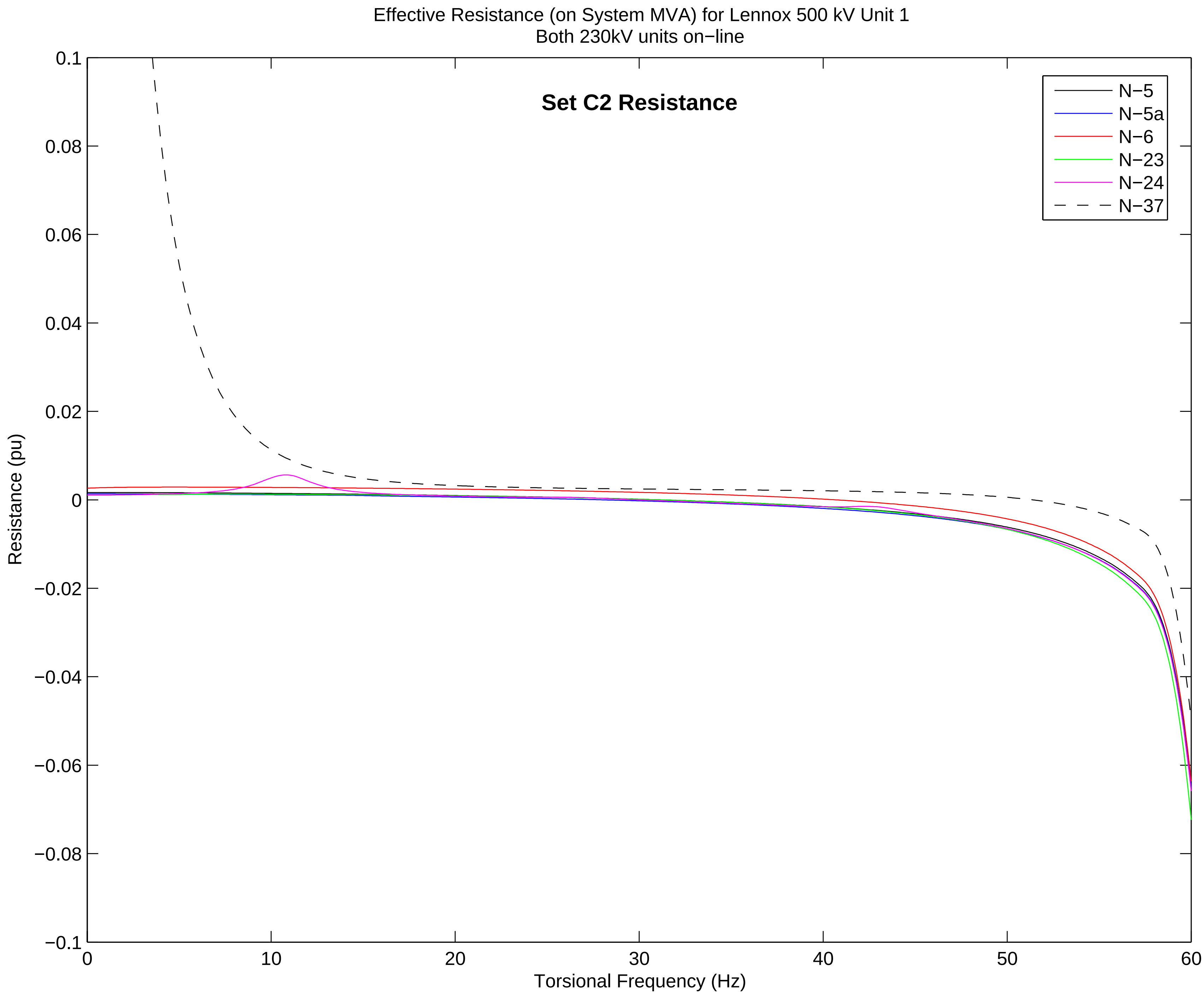


Effective Resistance (on System MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

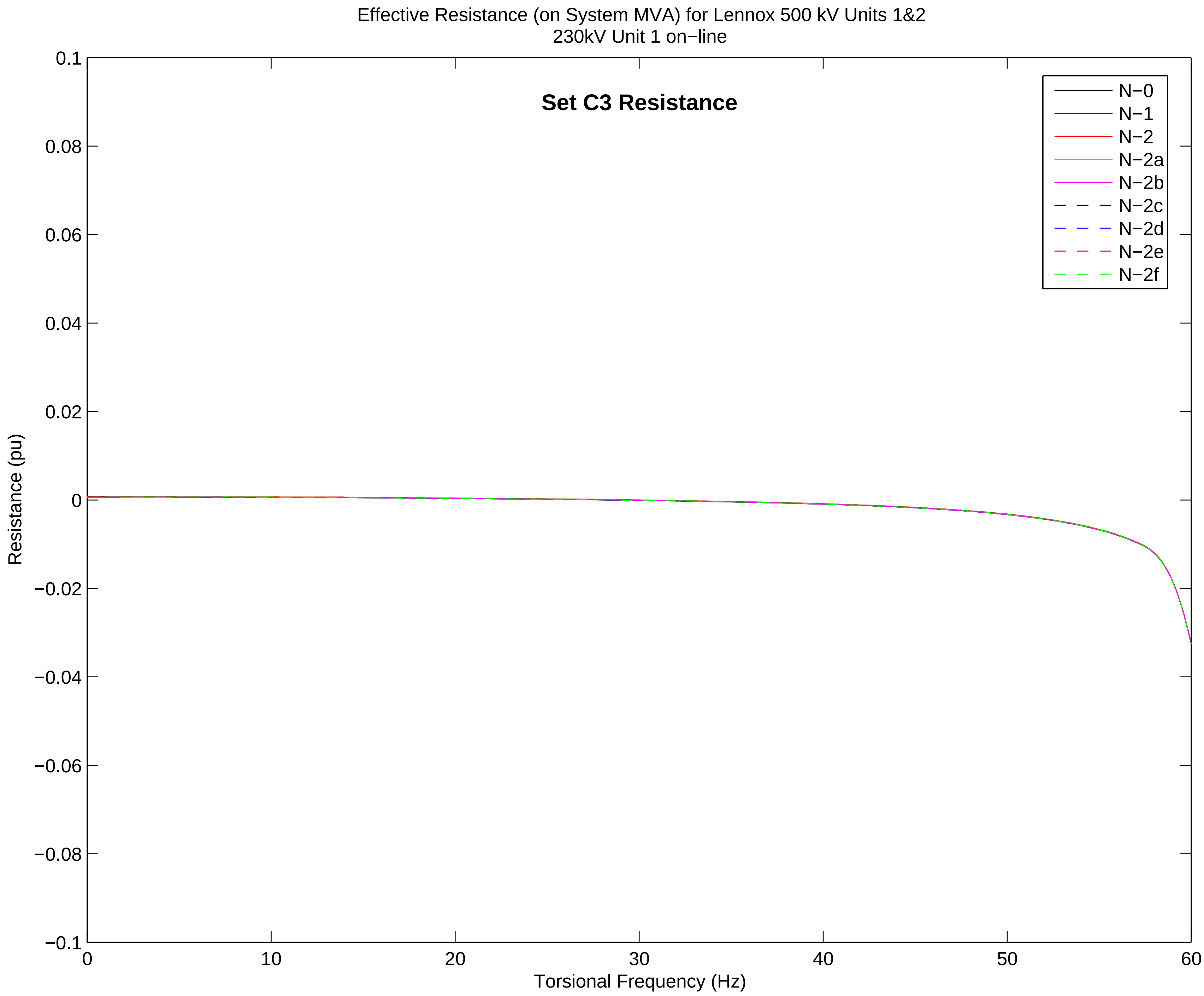

Effective Resistance (on System MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



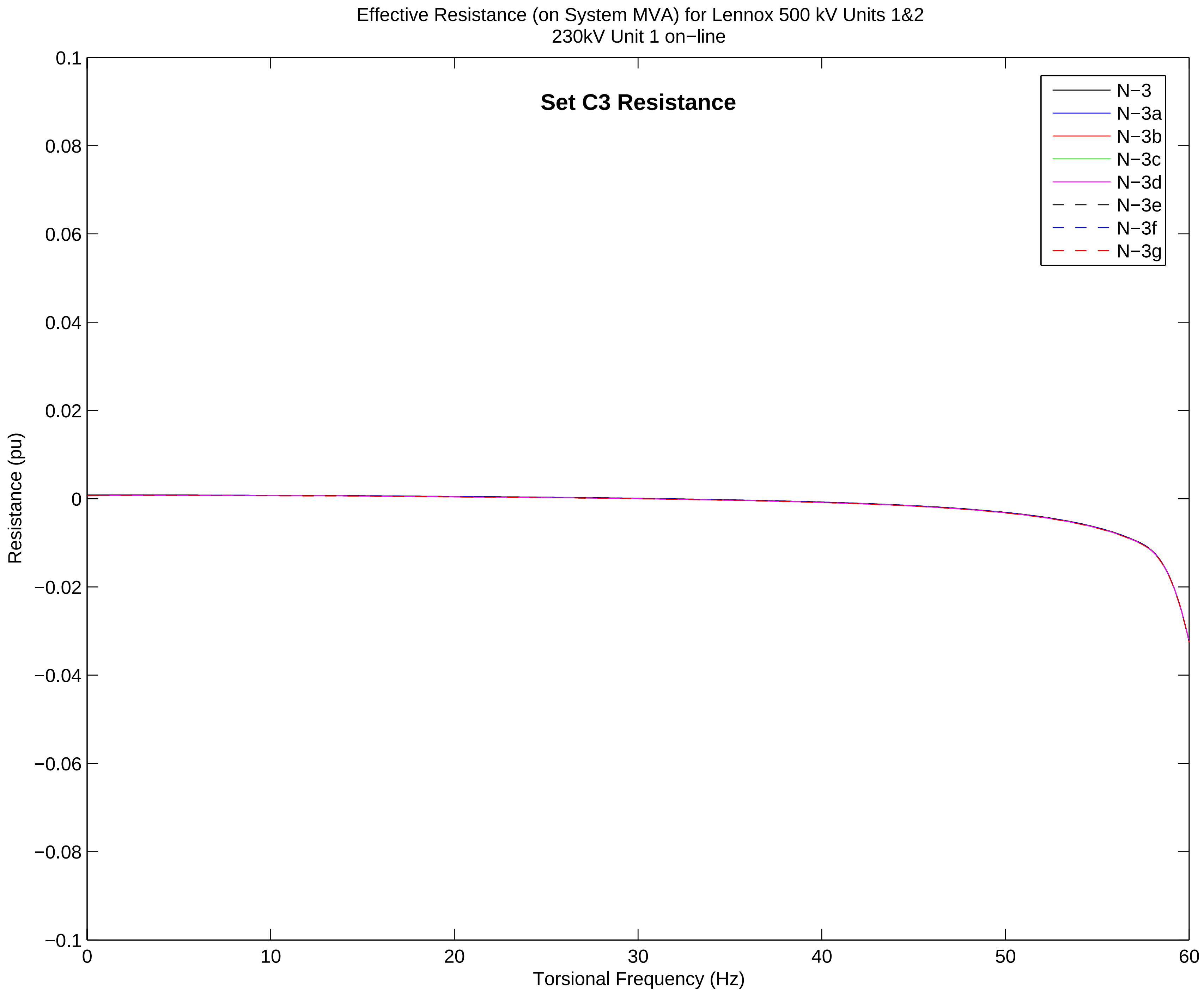
Effective Resistance (on System MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



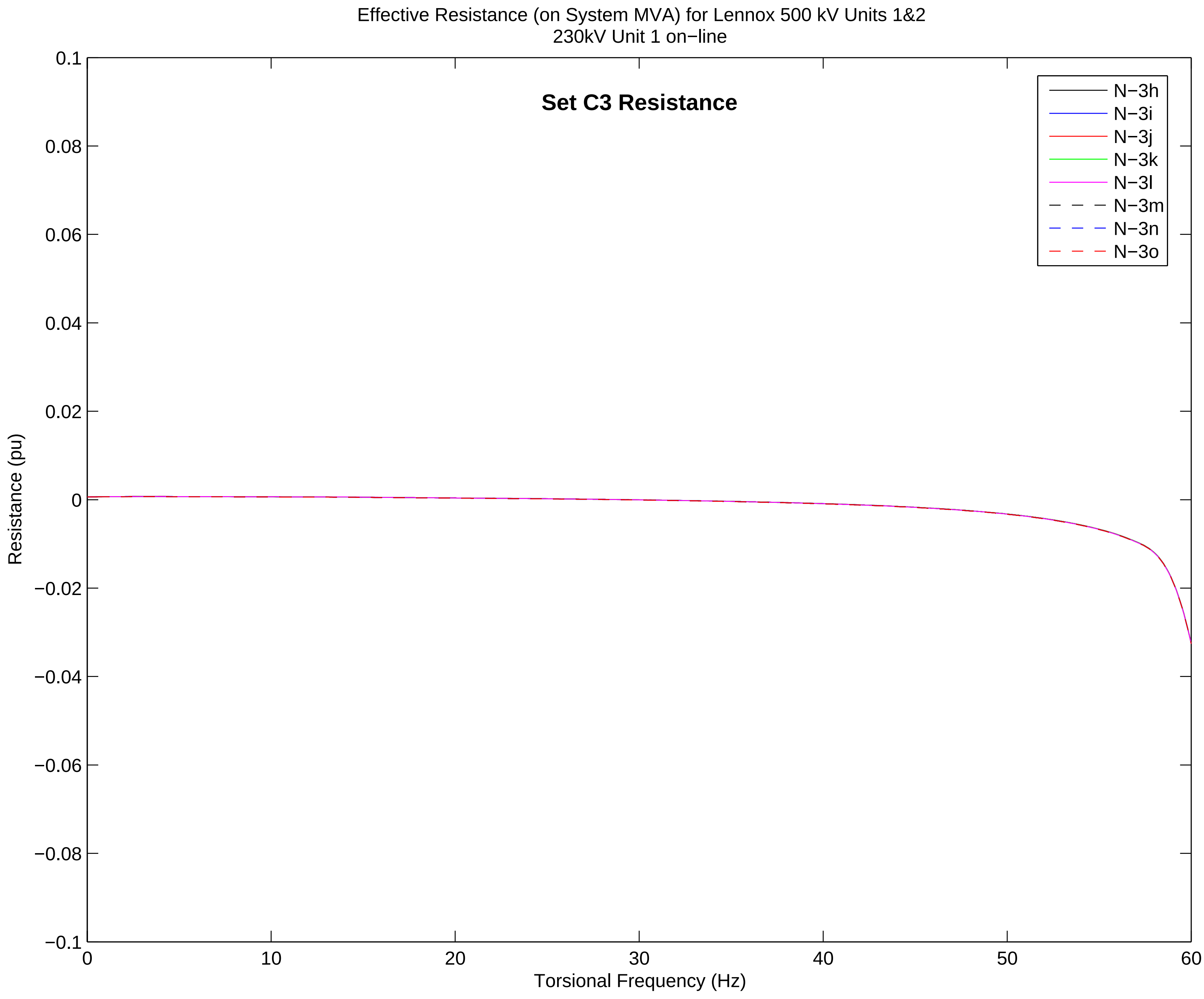
Effective Resistance (on System MVA) for Lennox 500 kV Unit 1
Both 230kV units on−line
Set C2 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



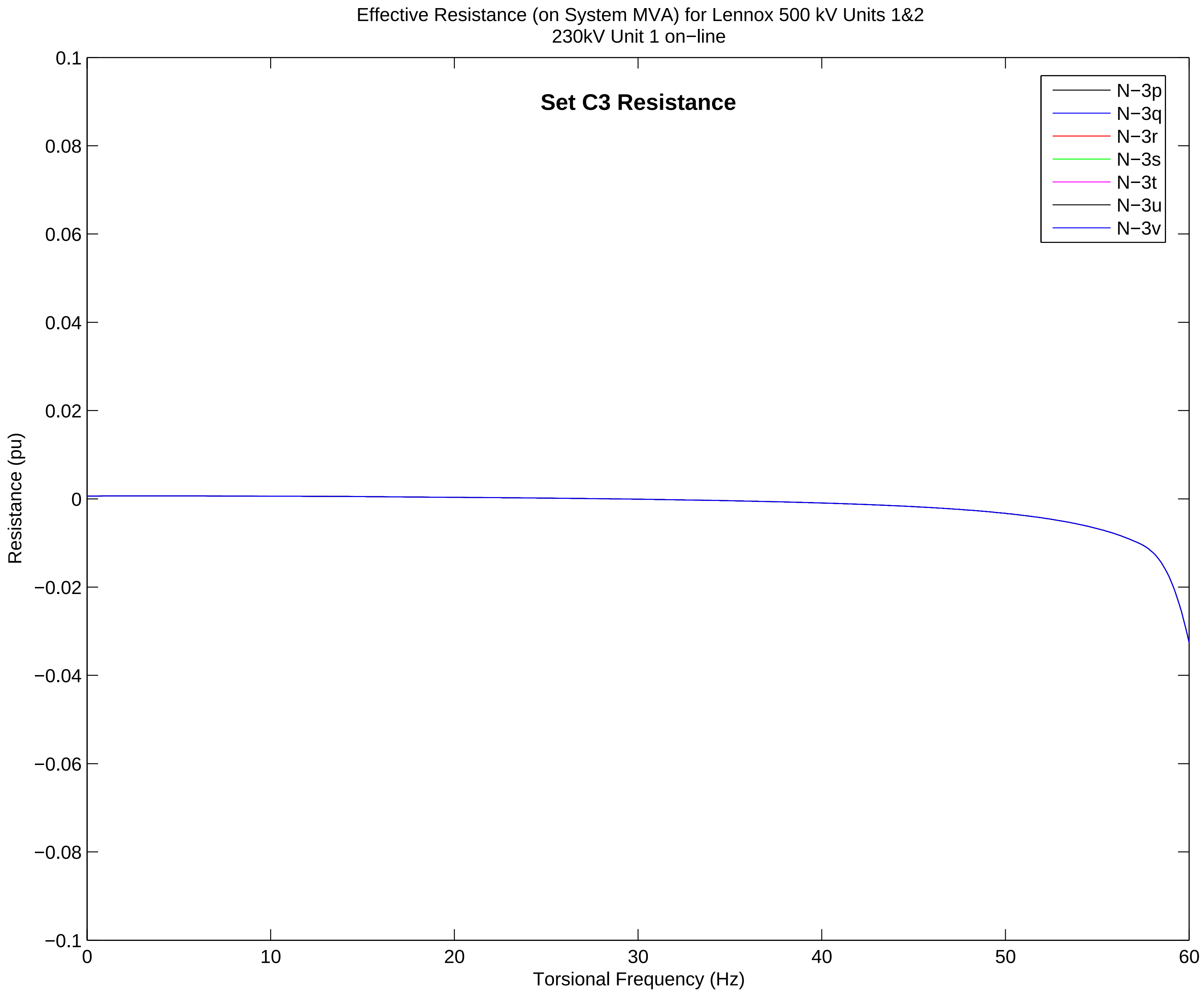
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

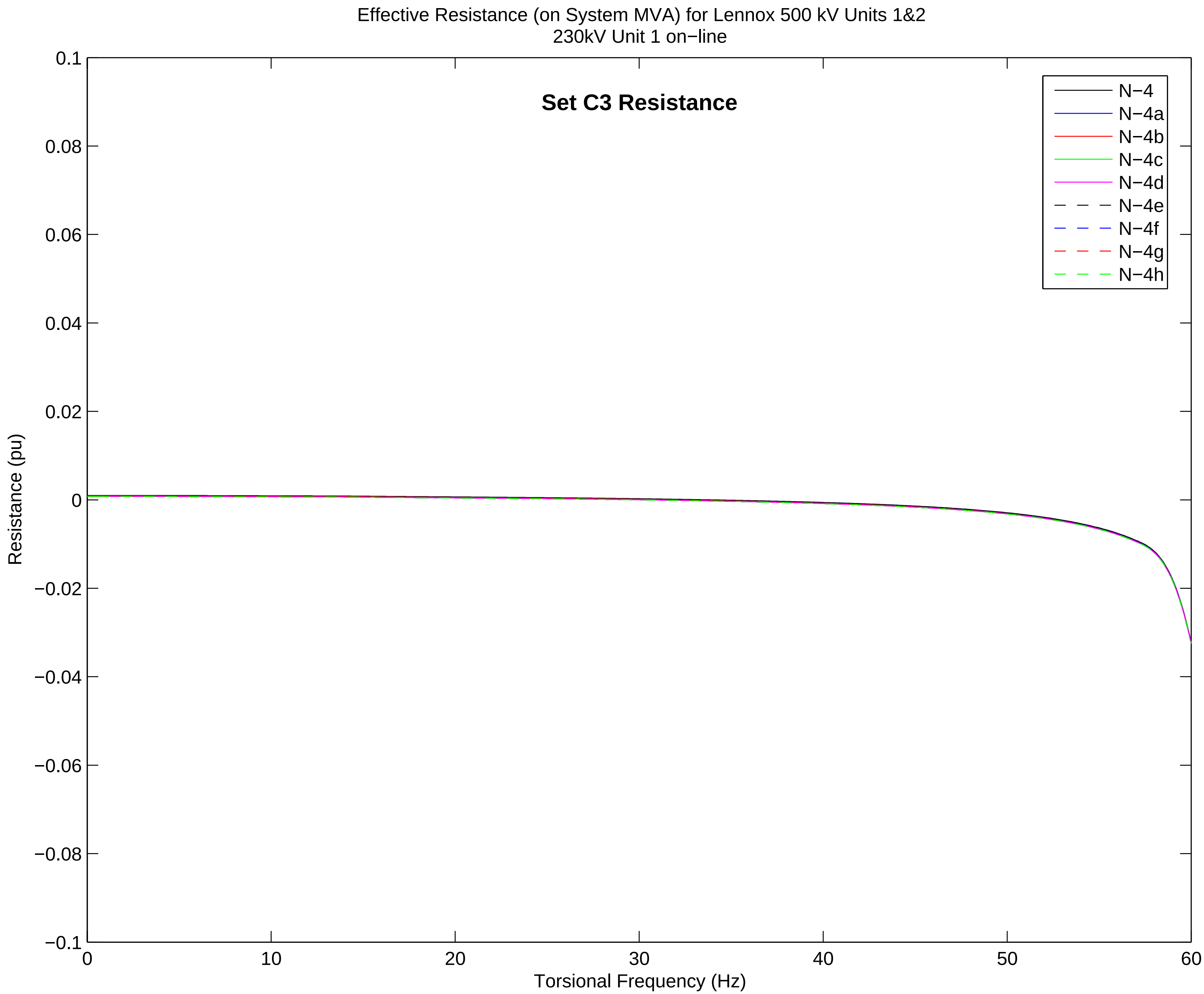


Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

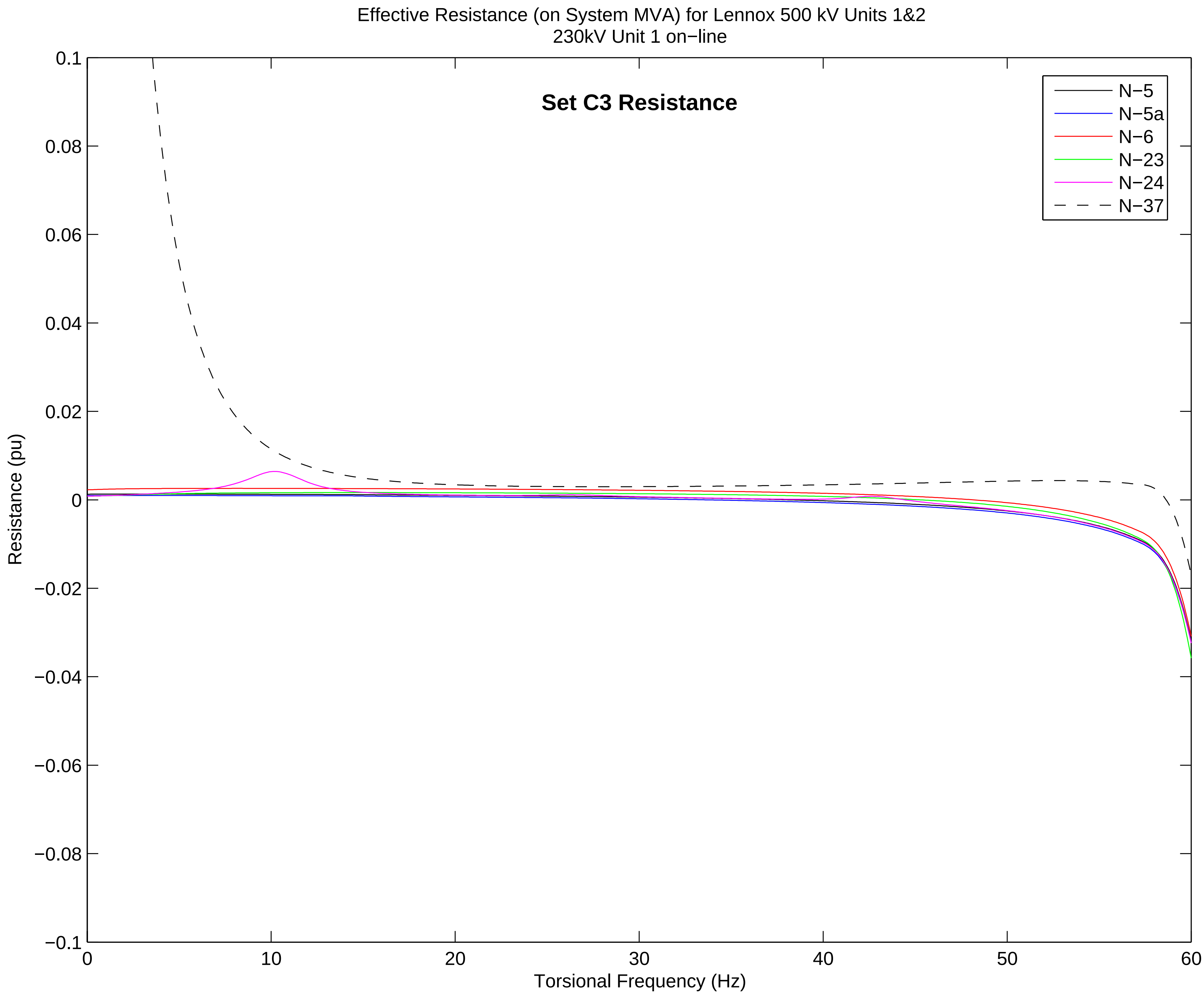


Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

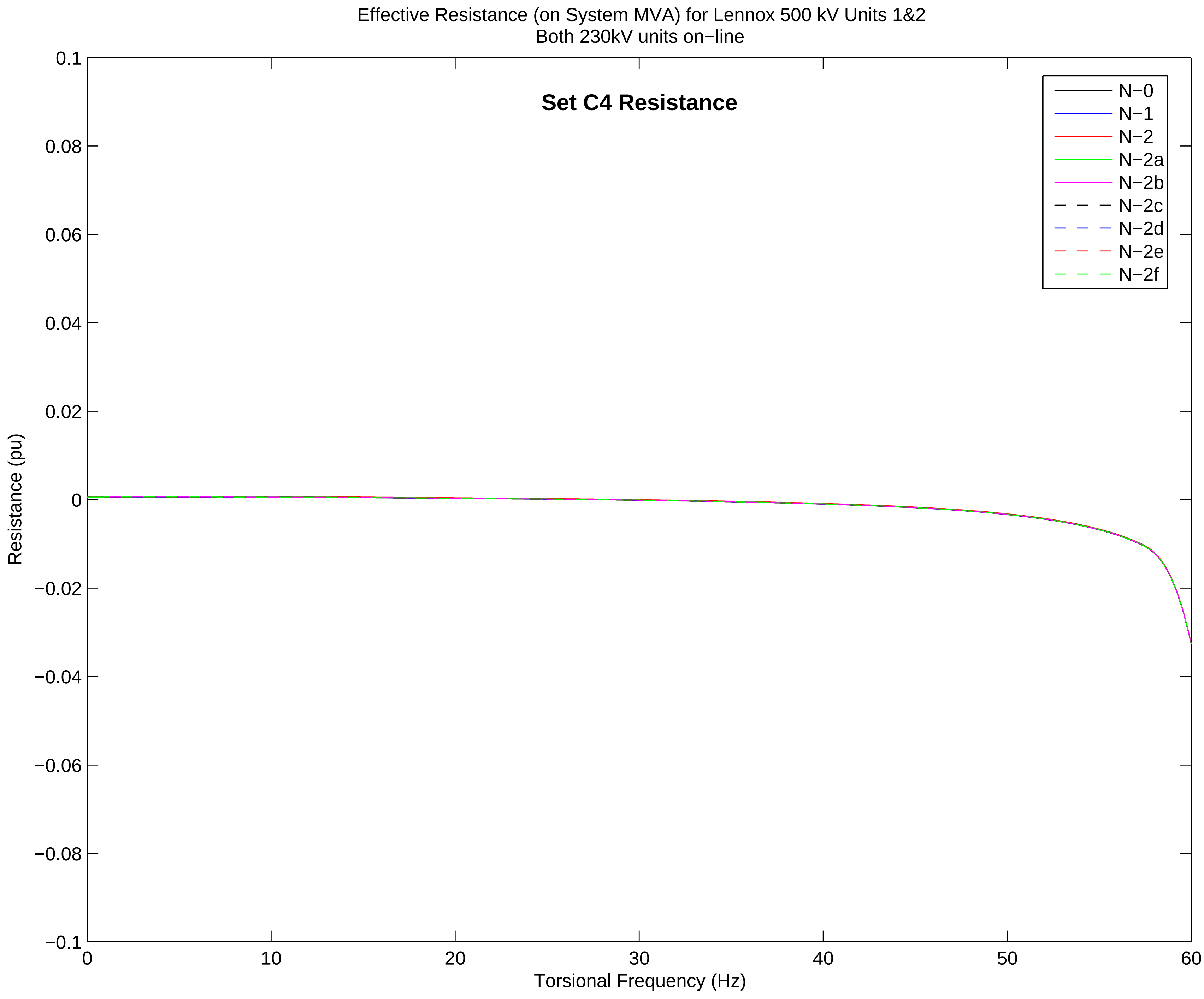

Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



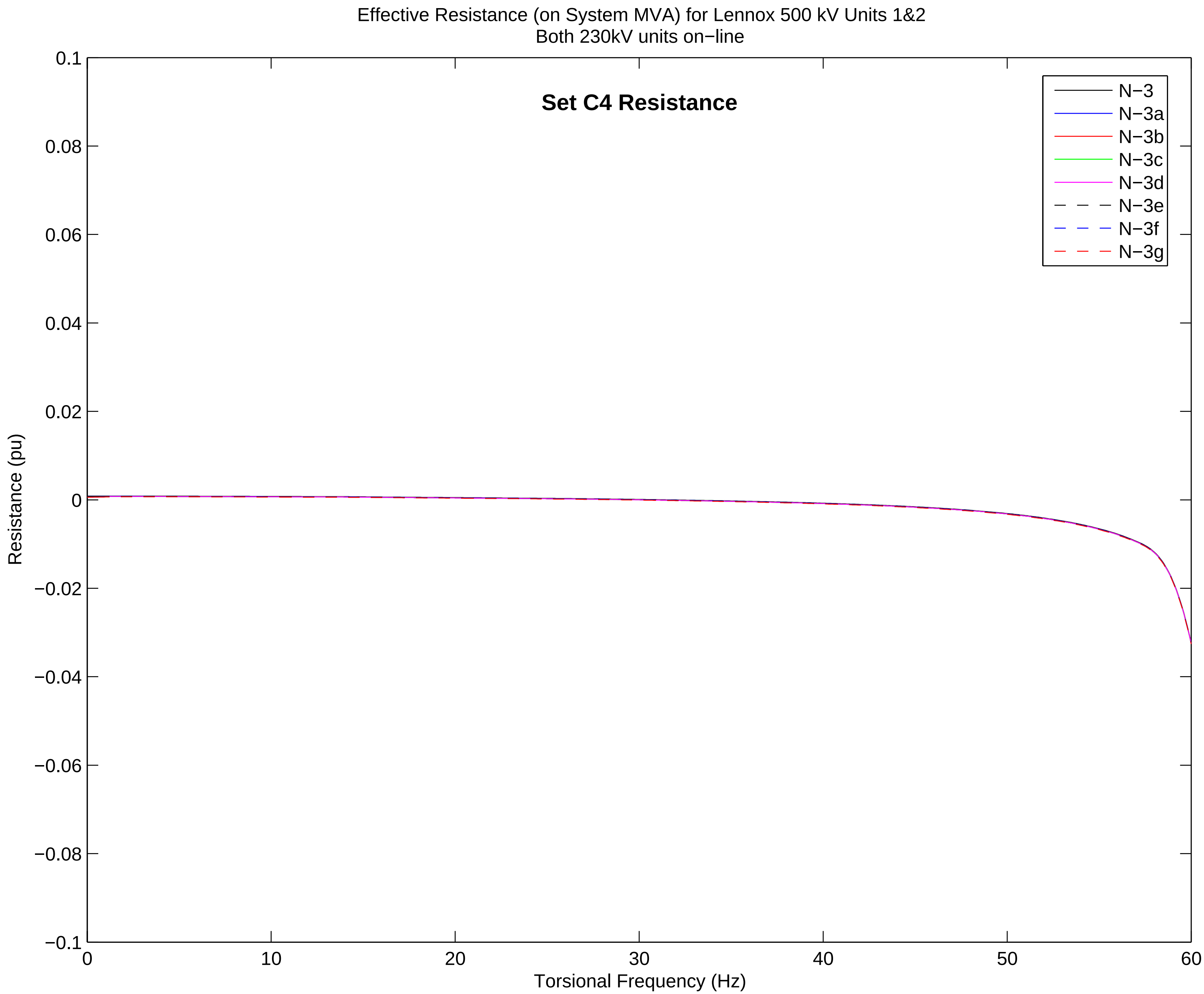
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



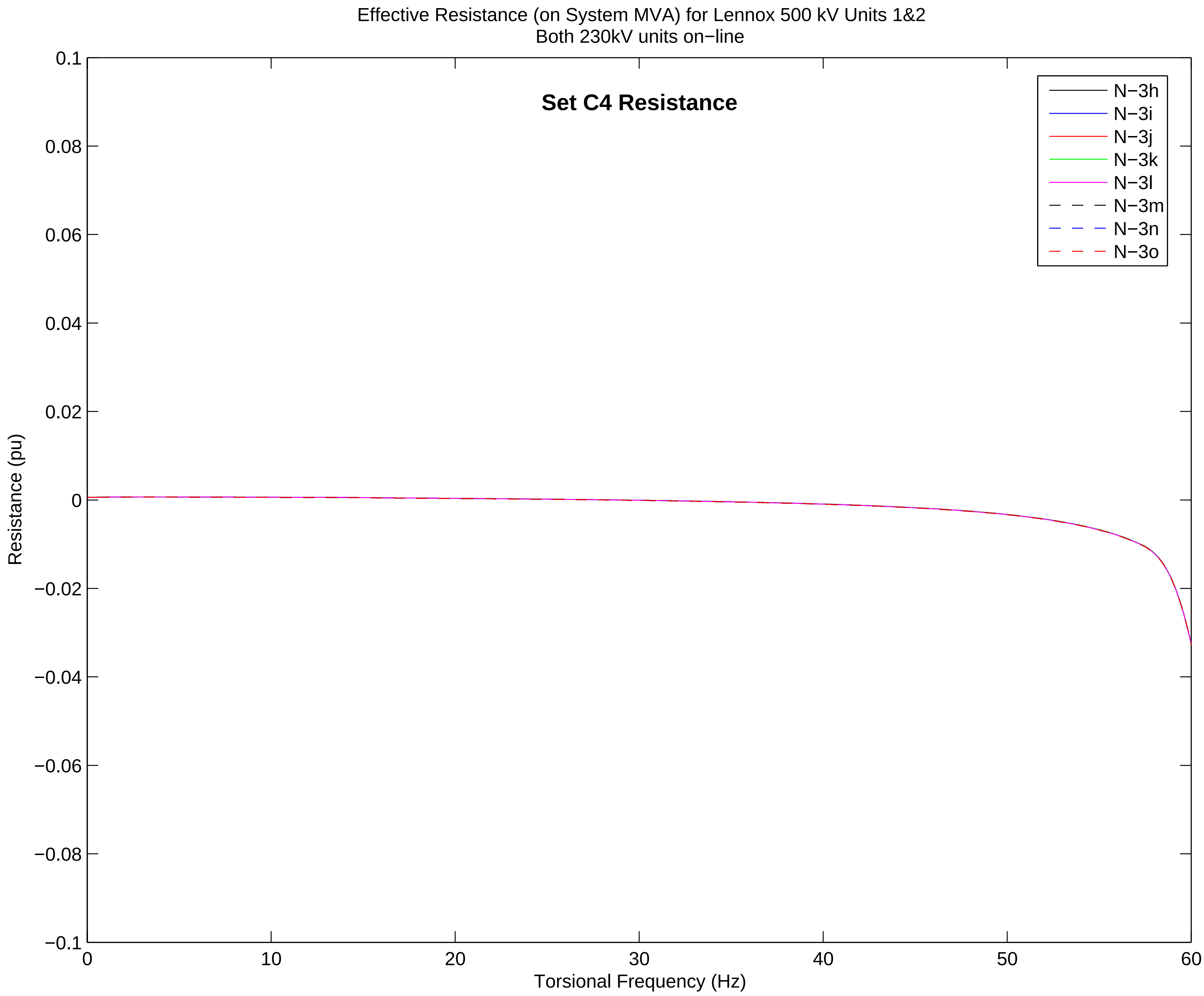
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
230kV Unit 1 on−line
Set C3 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



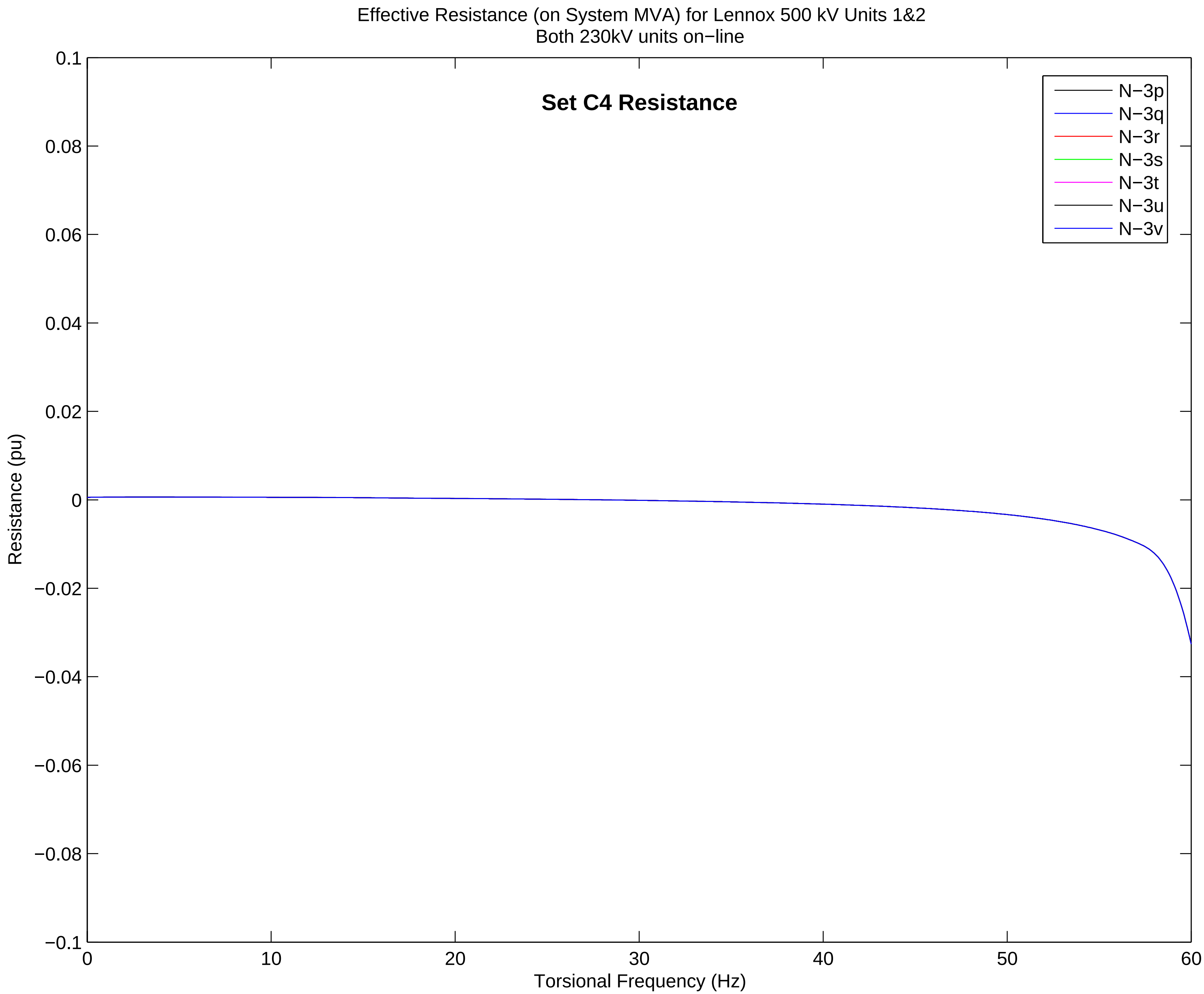
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



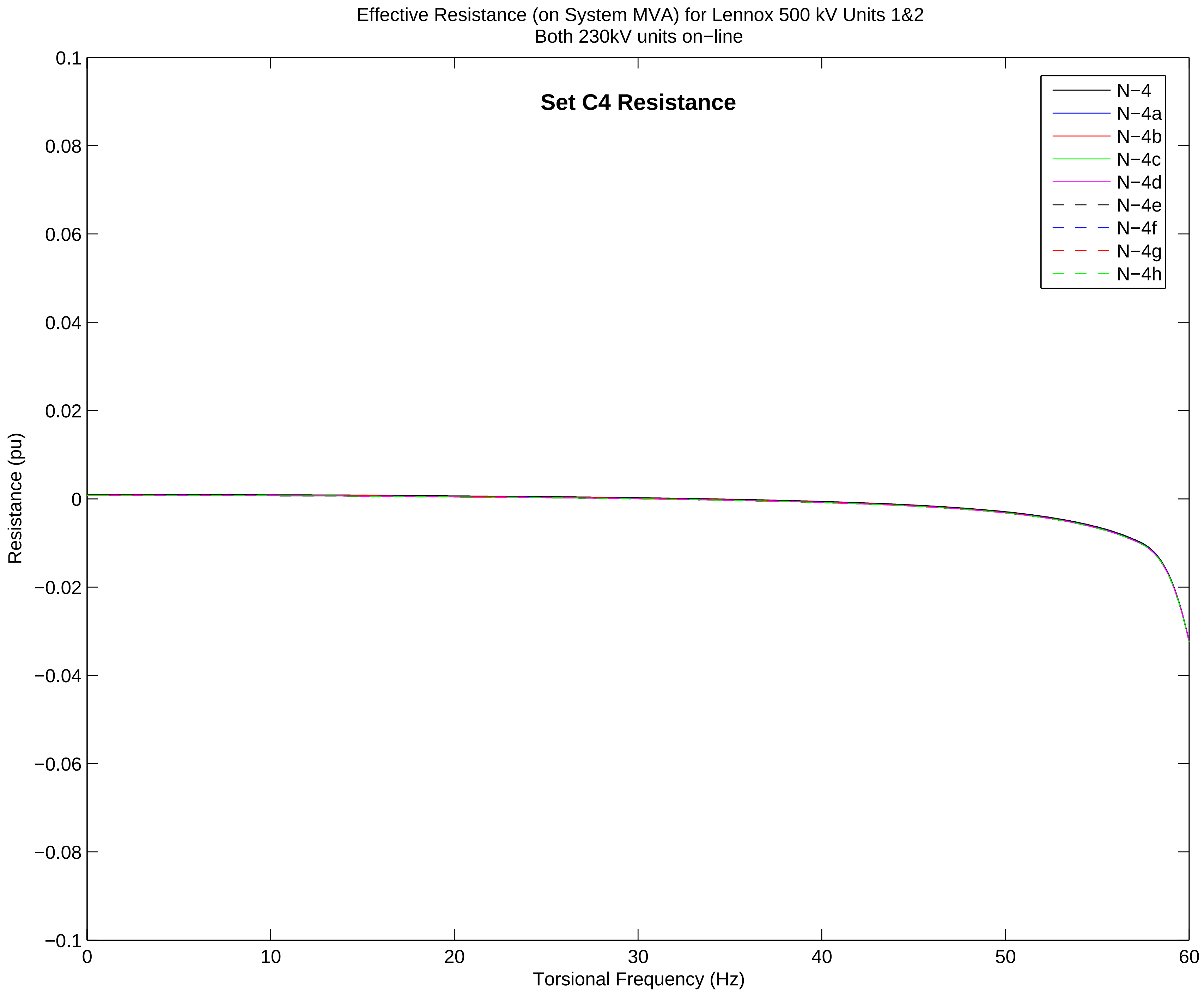
Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

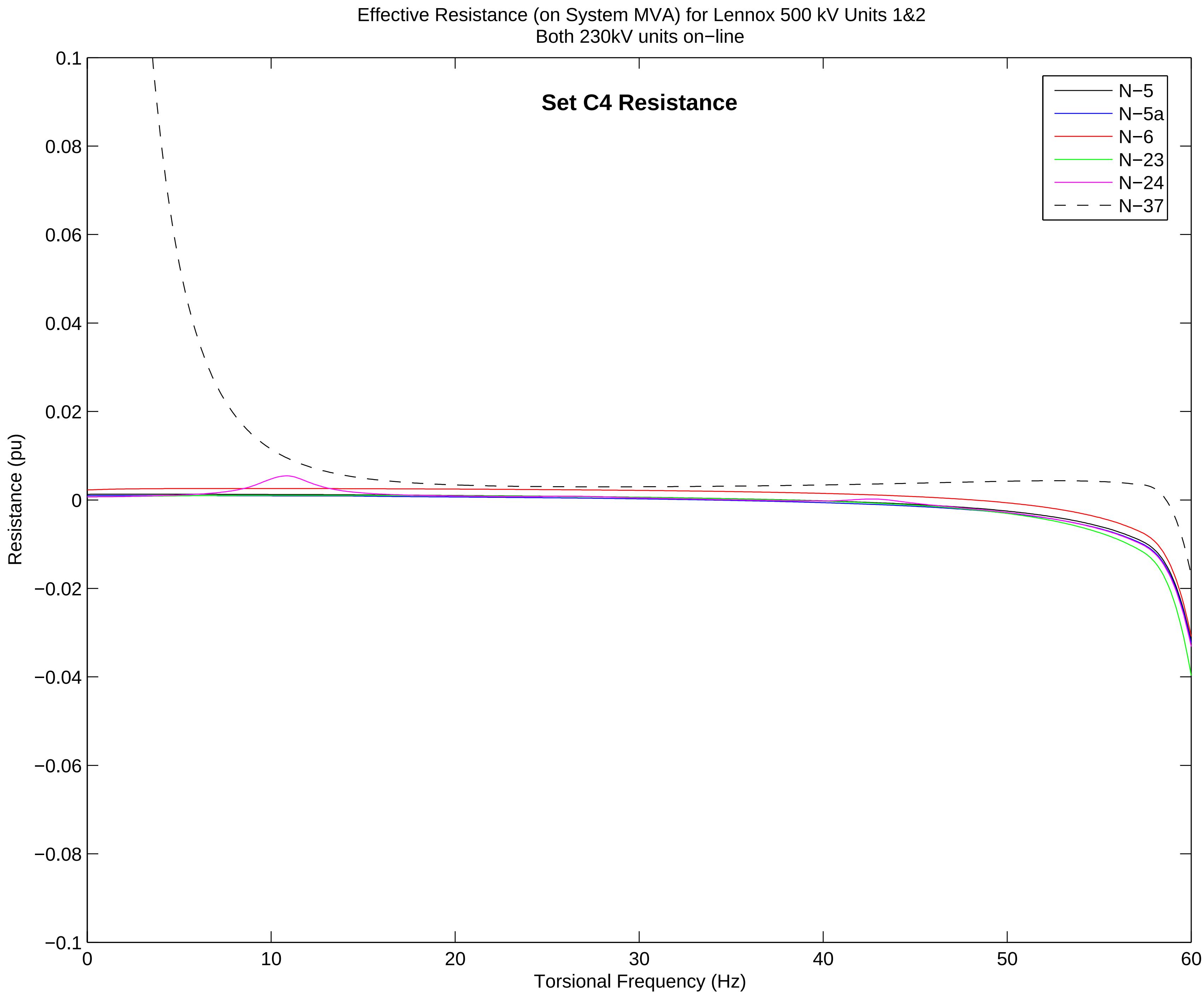


Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

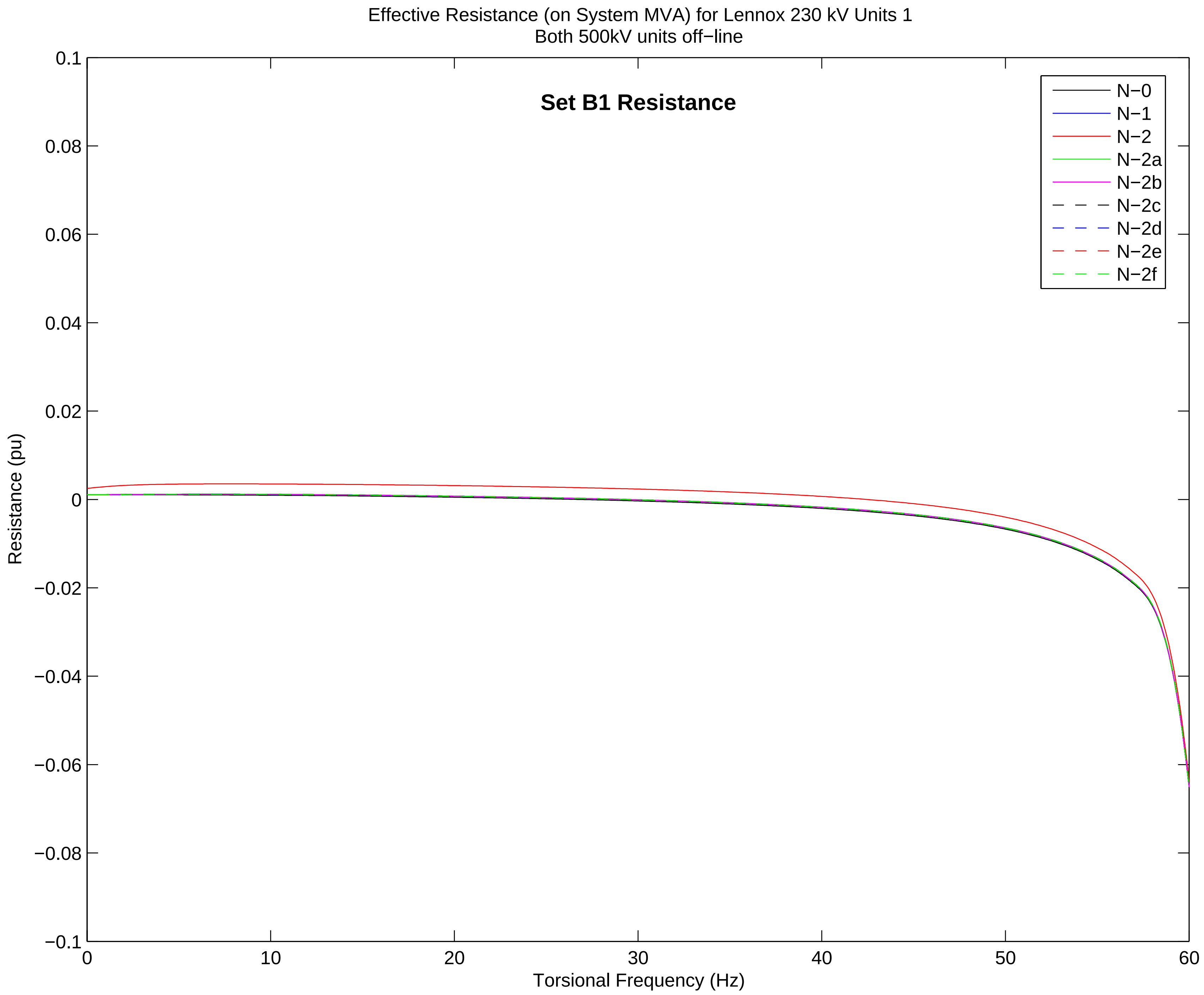


Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

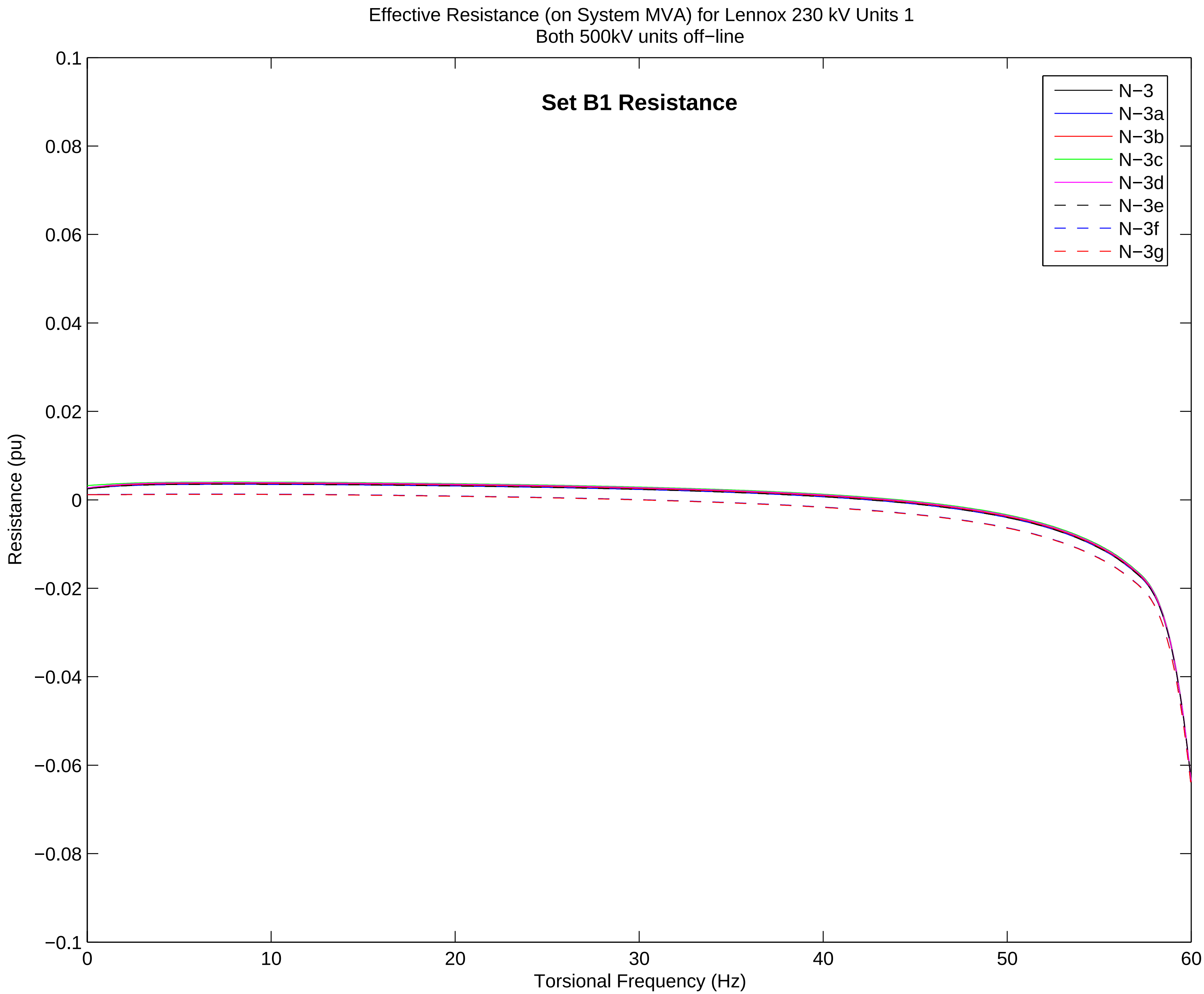

Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

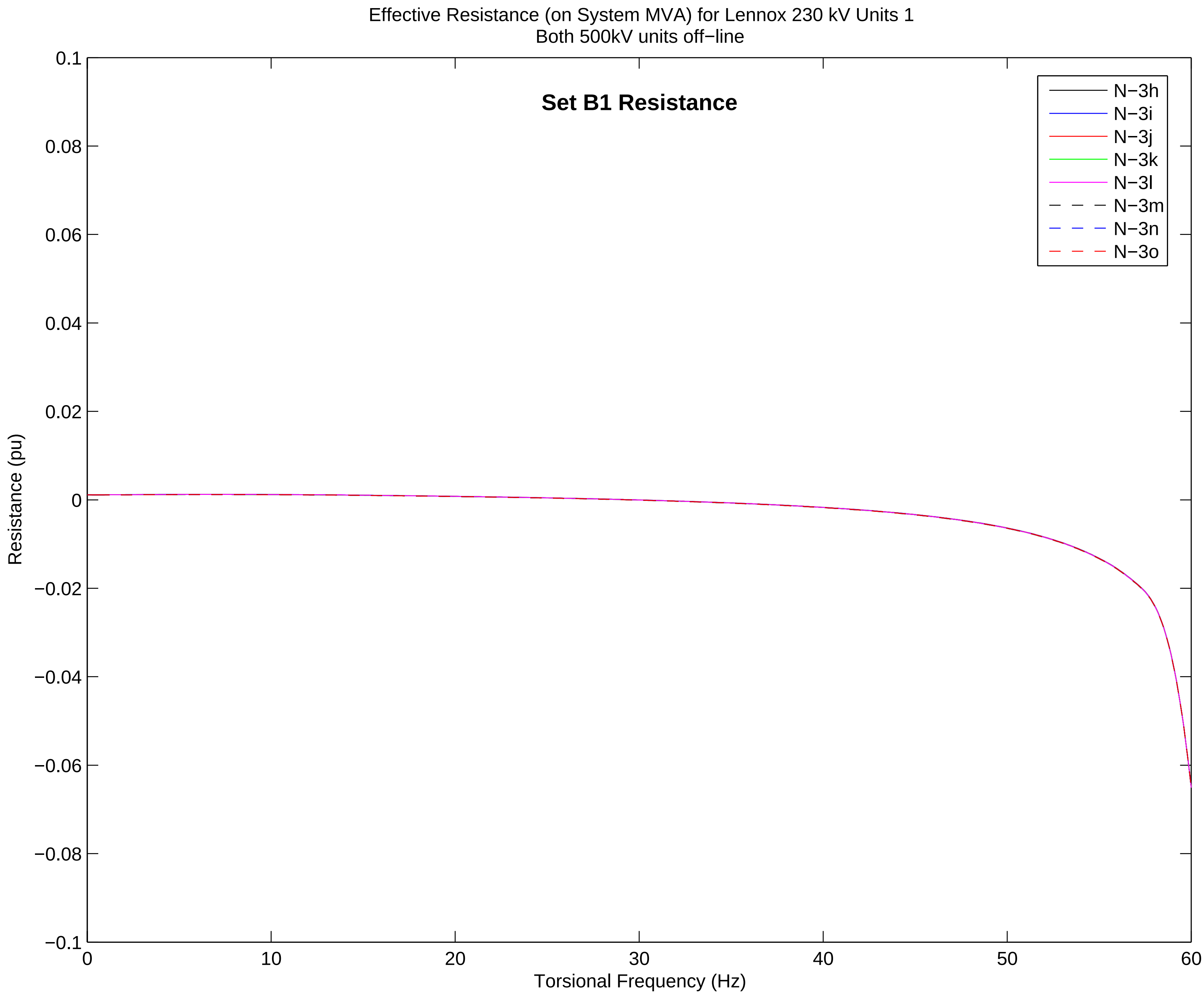


Effective Resistance (on System MVA) for Lennox 500 kV Units 1&2
Both 230kV units on−line
Set C4 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

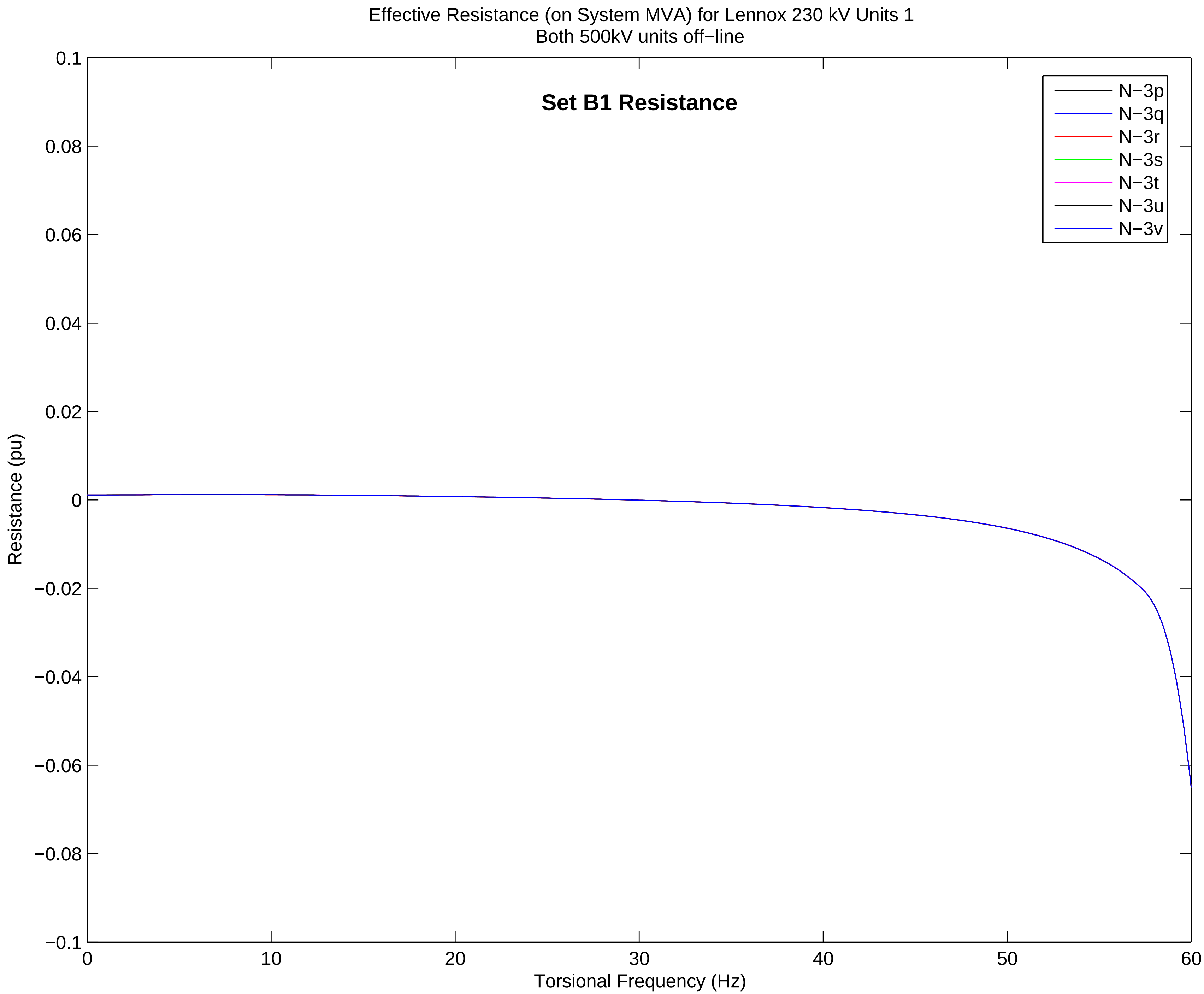


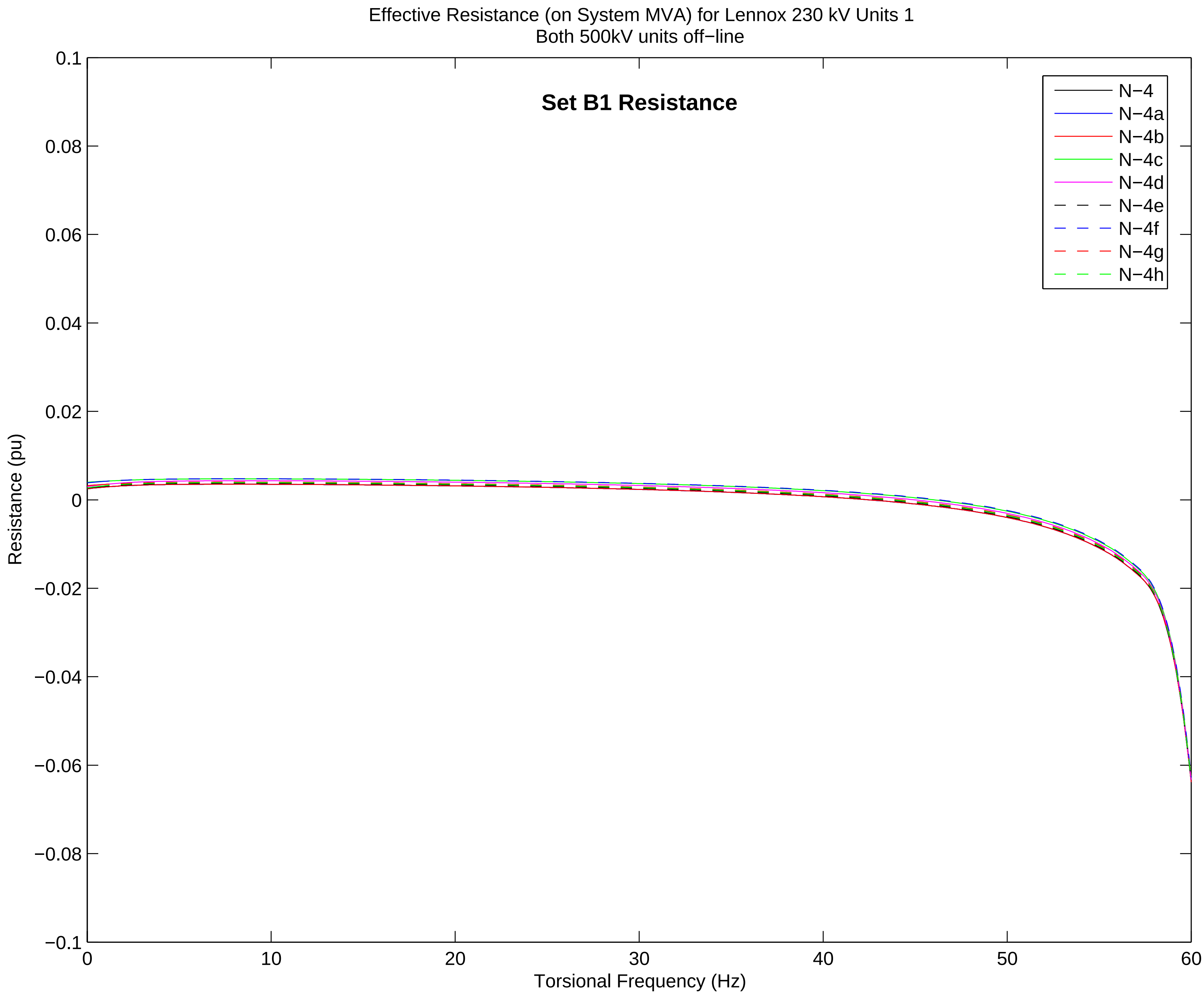
Effective Resistance (on System MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

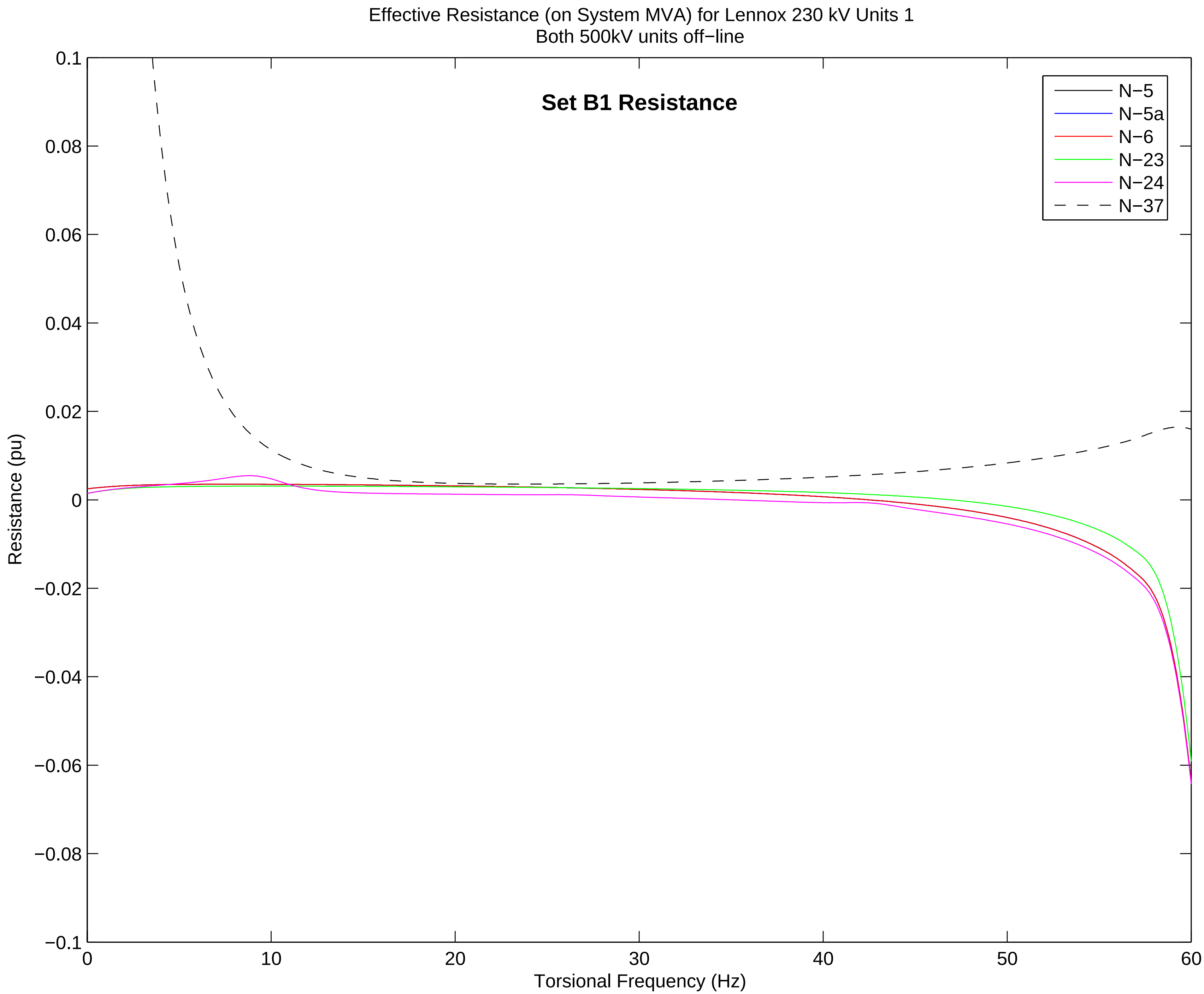


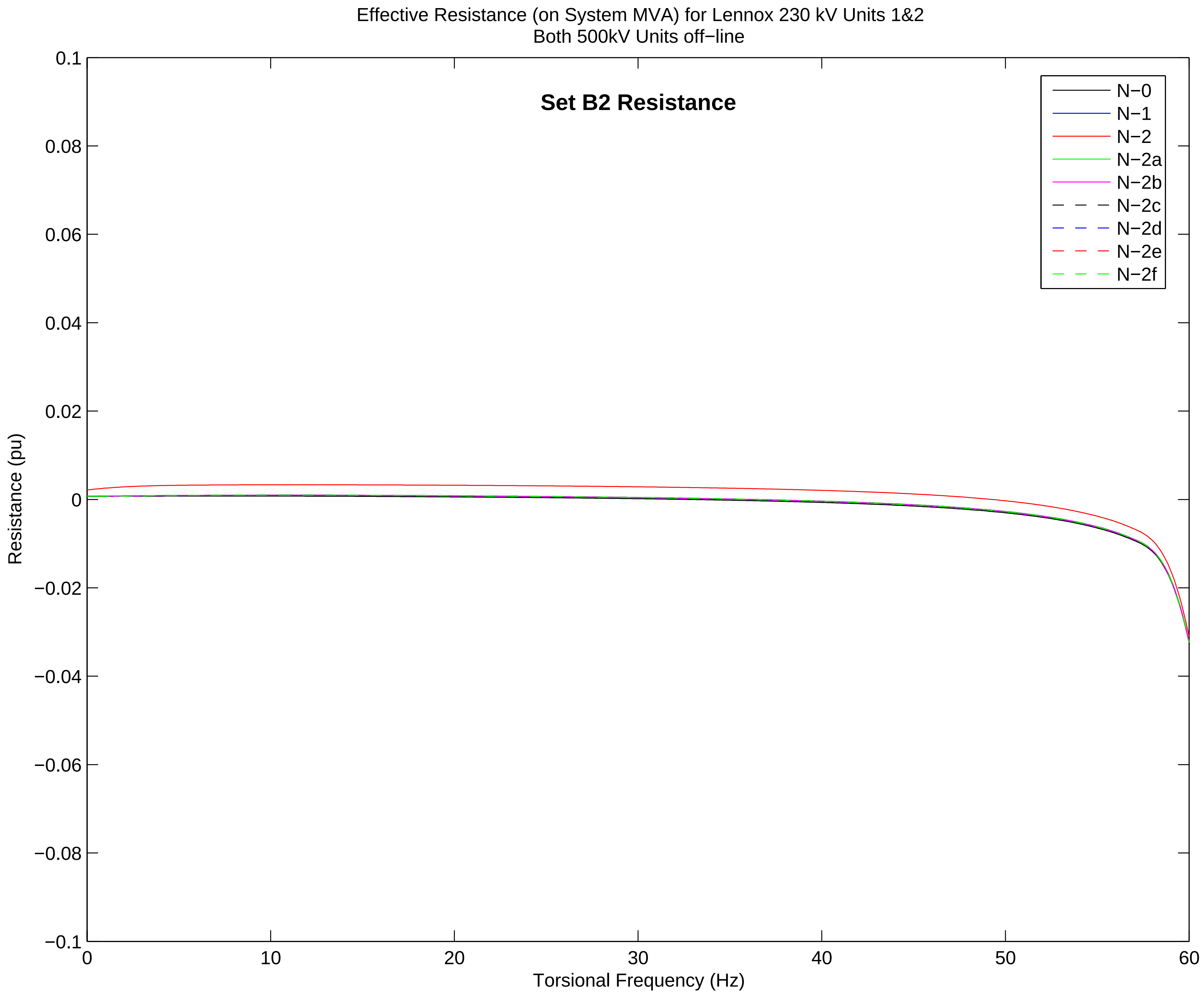
Effective Resistance (on System MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

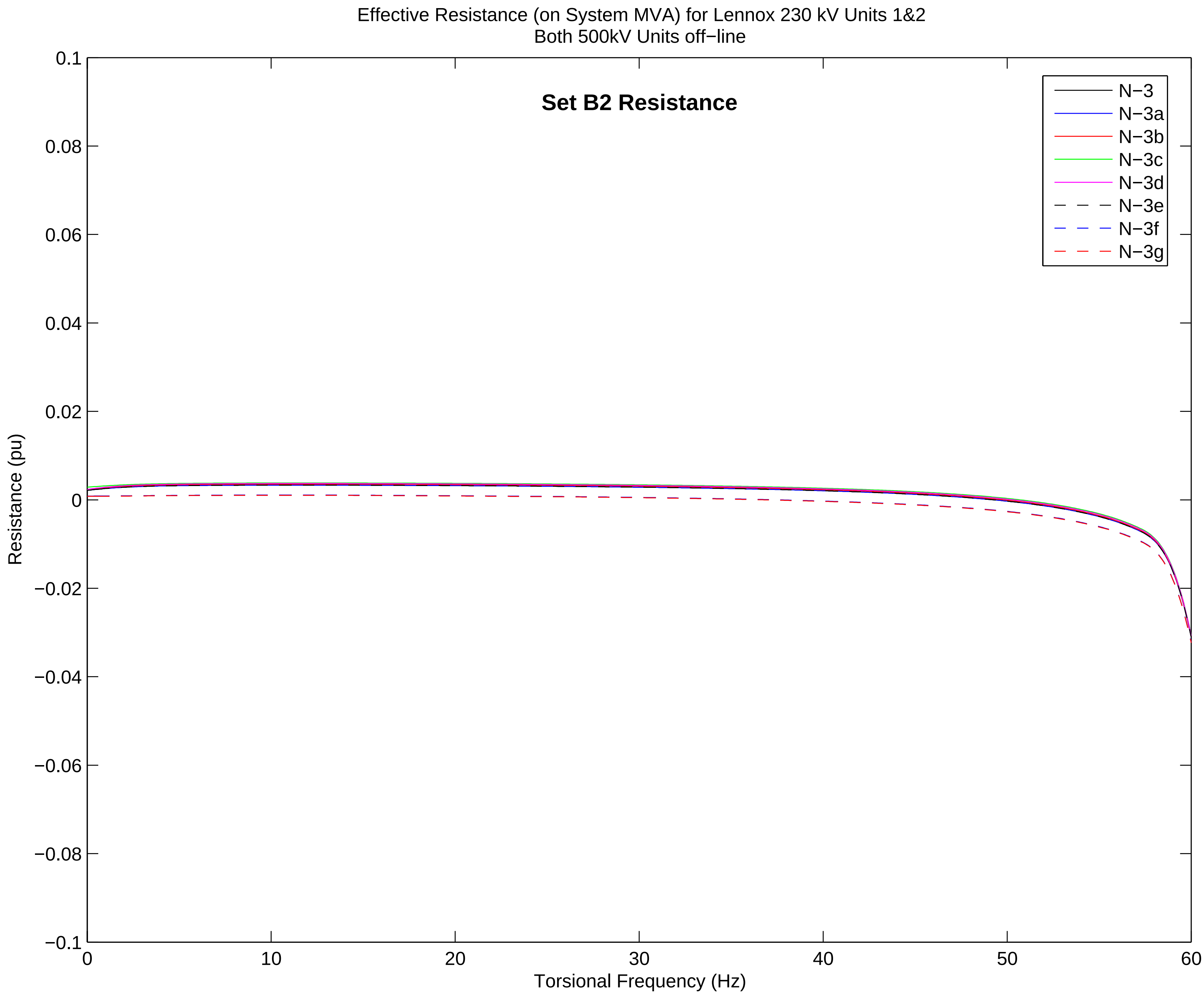


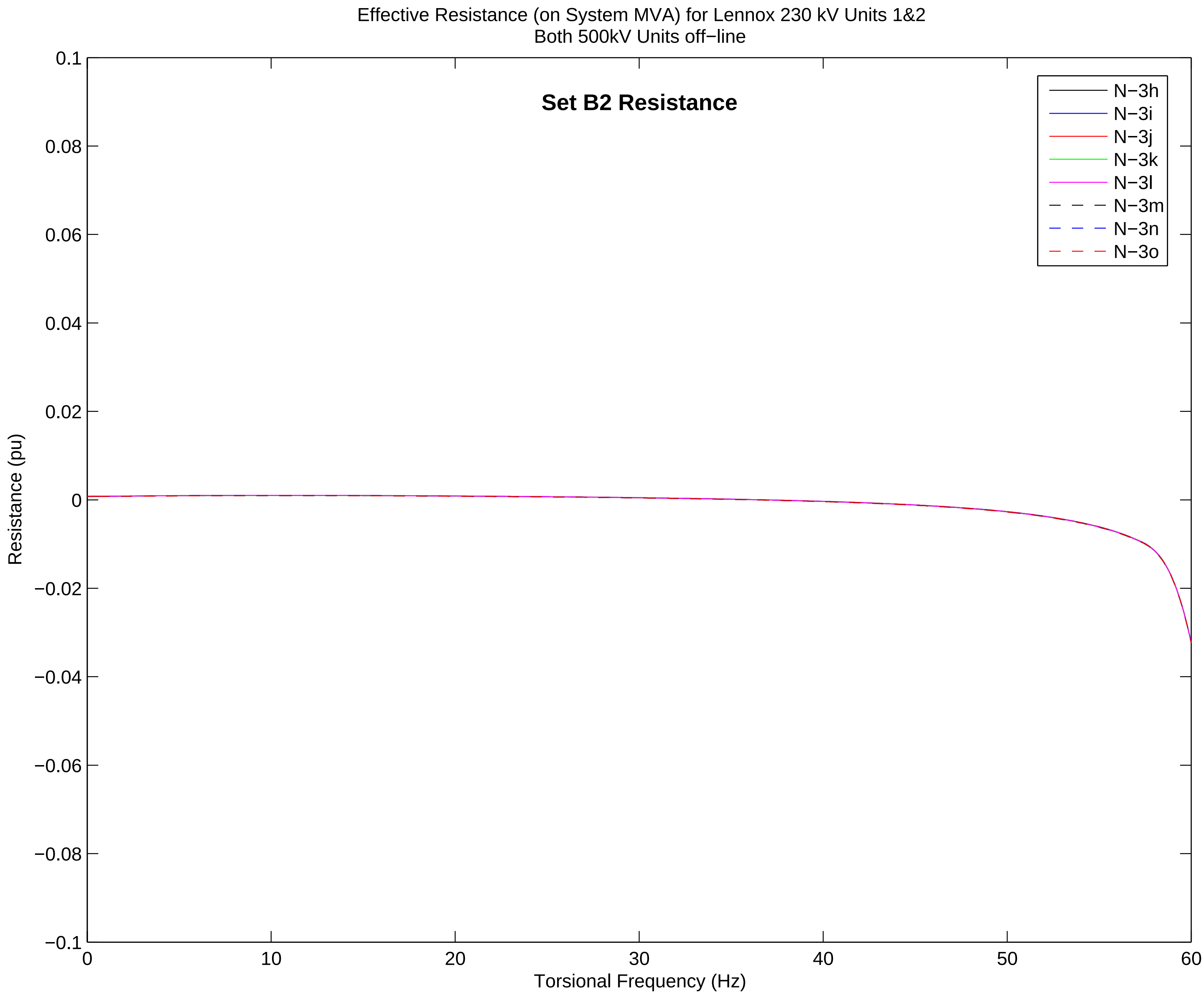
Effective Resistance (on System MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

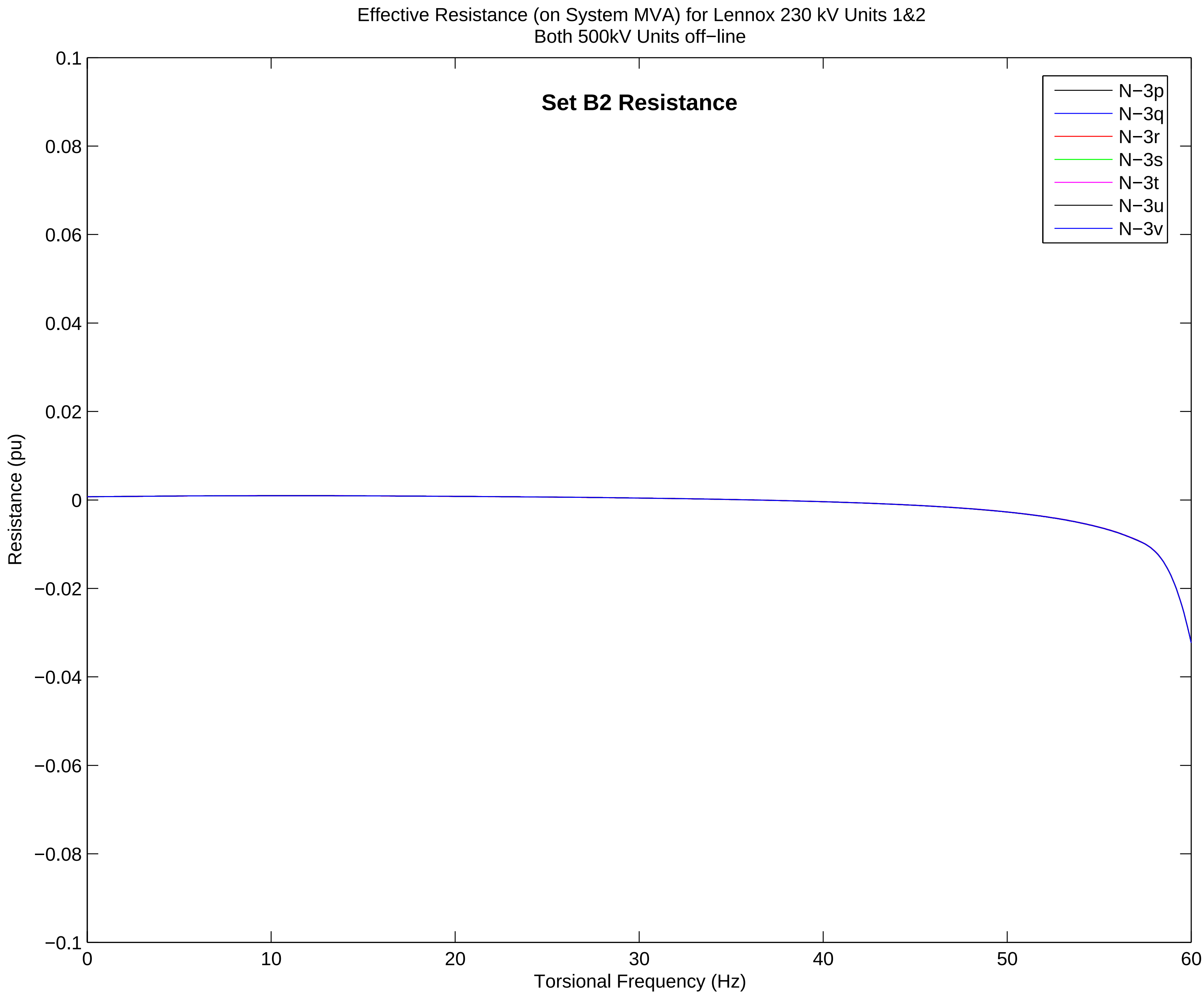

Effective Resistance (on System MVA) for Lennox 230 kV Units 1
Both 500kV units off−line
Set B1 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

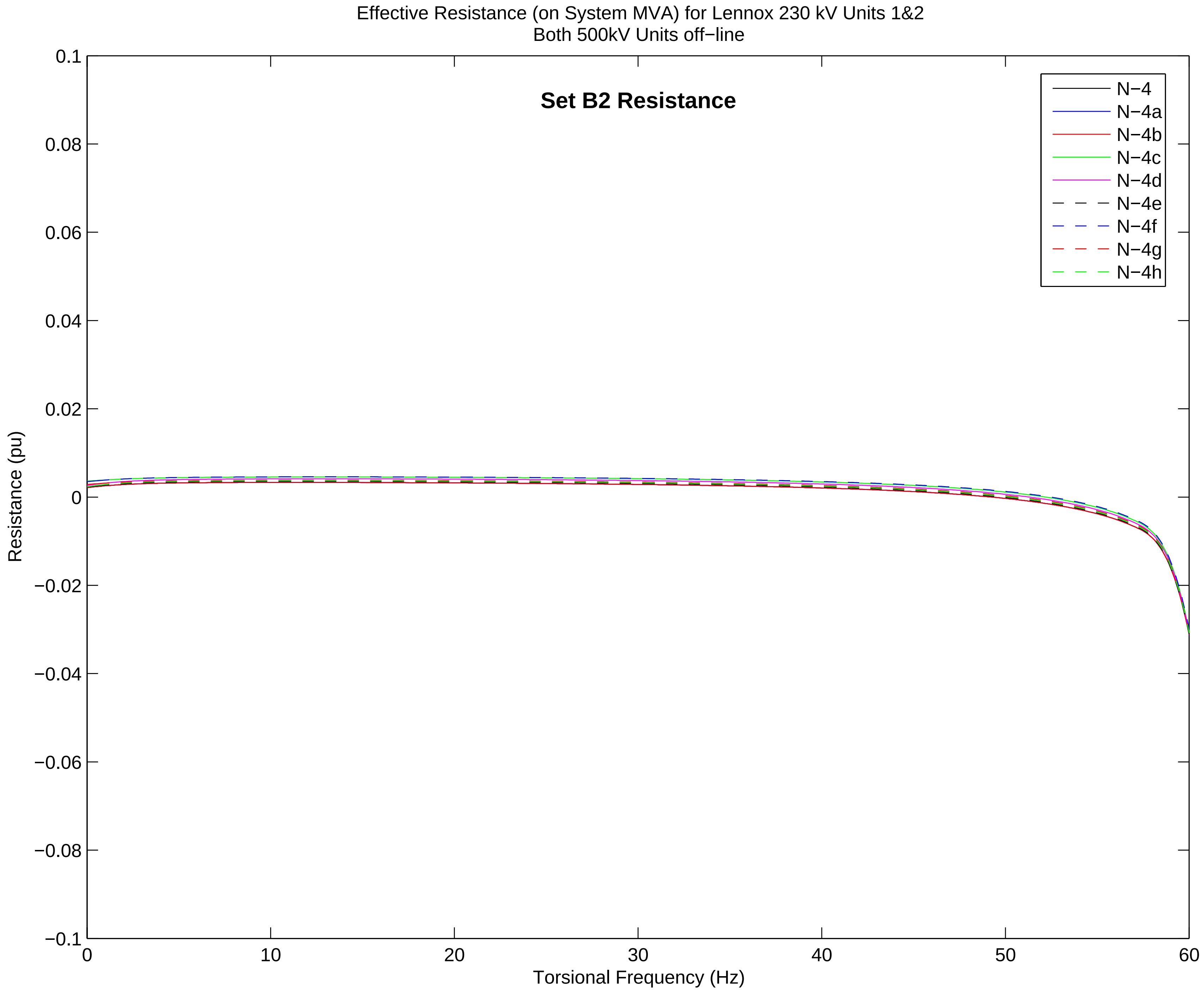


Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

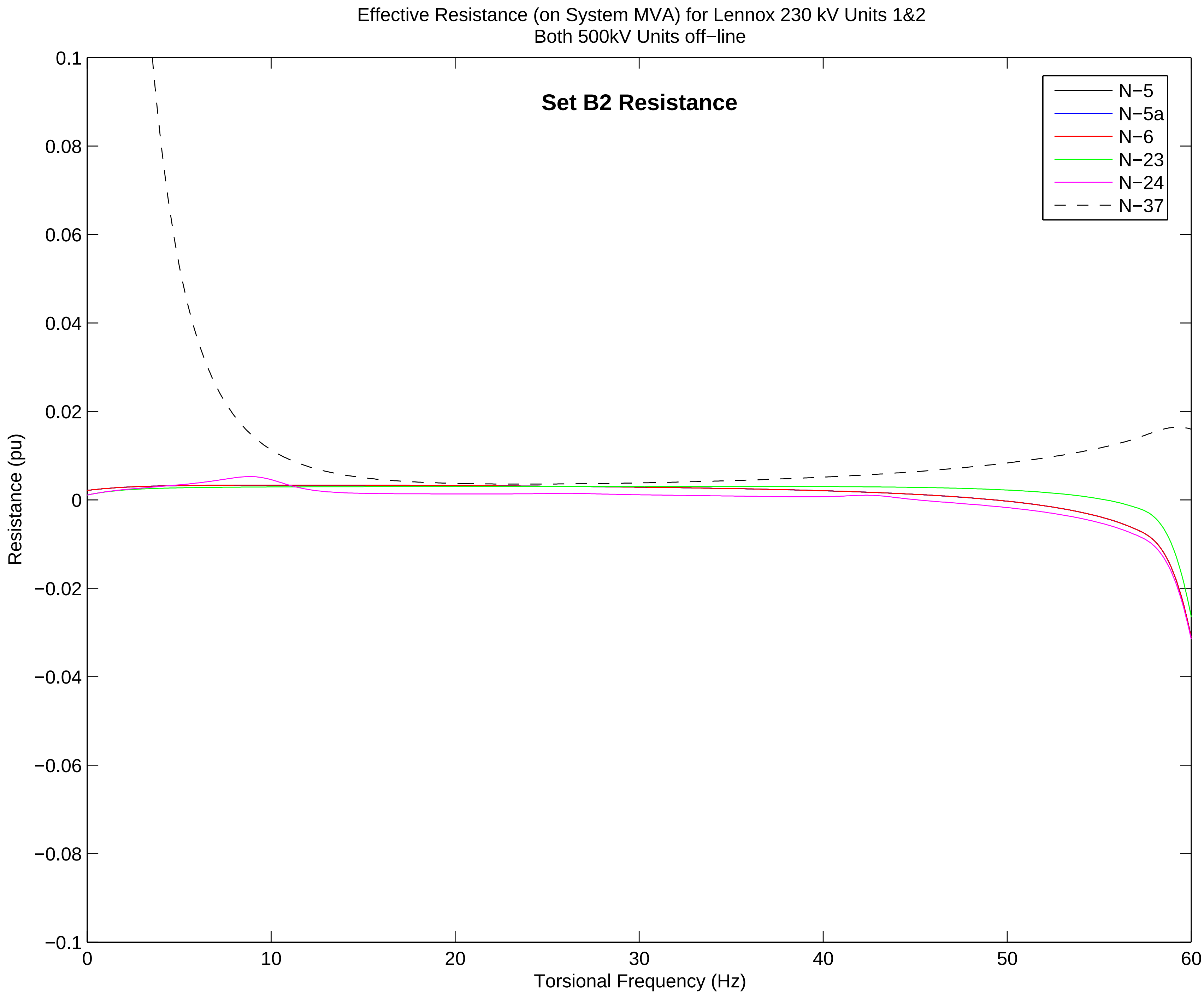

Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

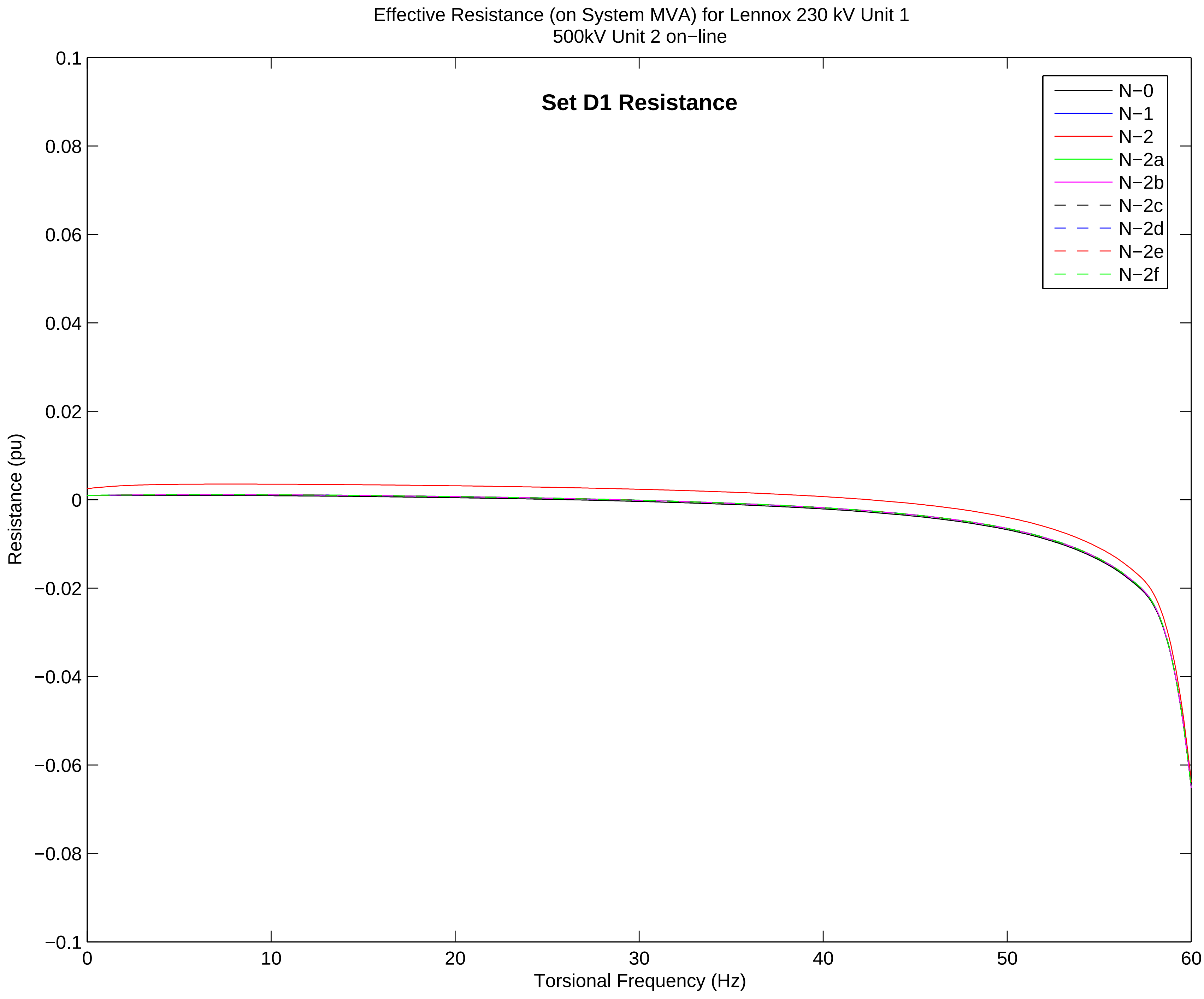

Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

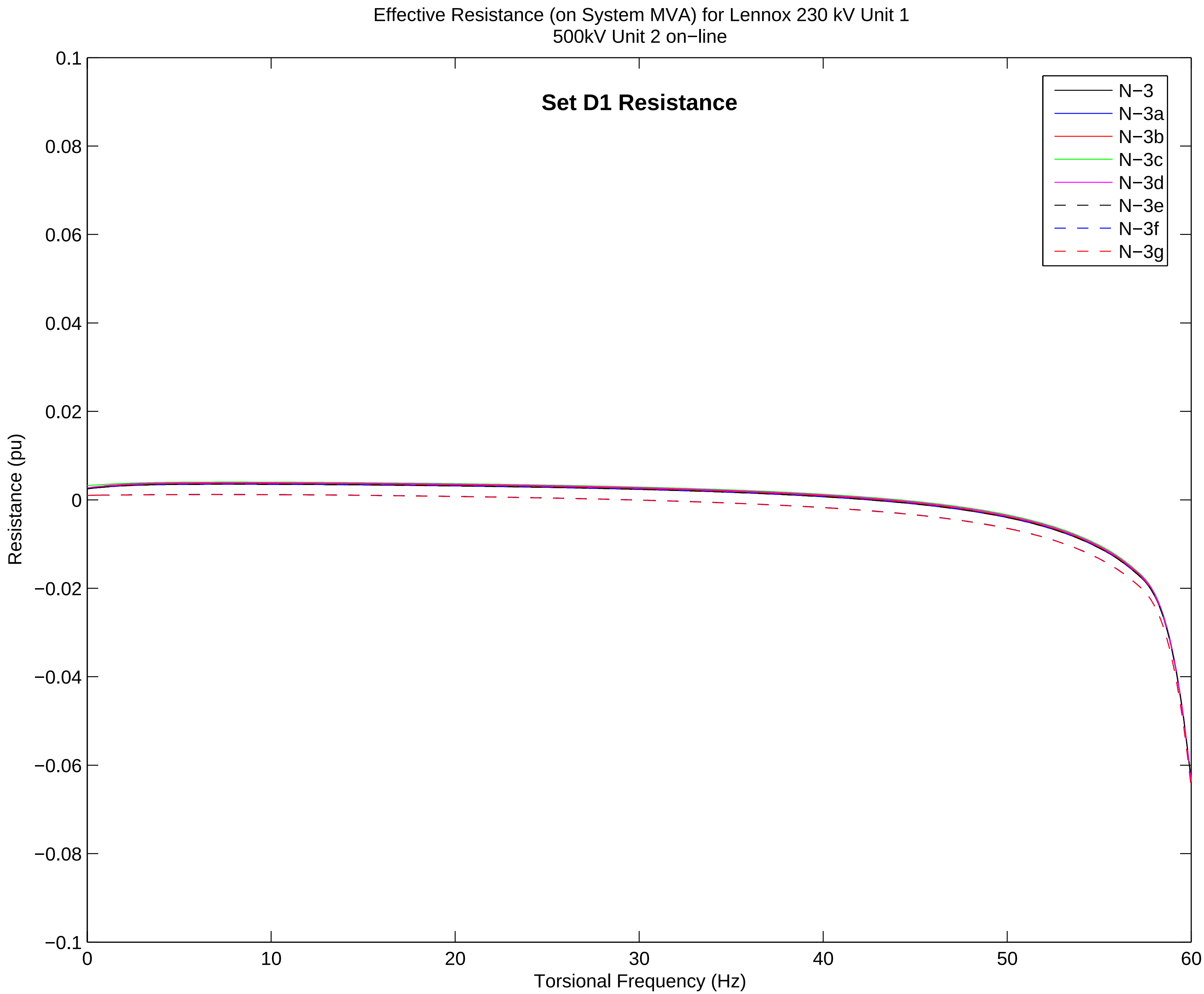


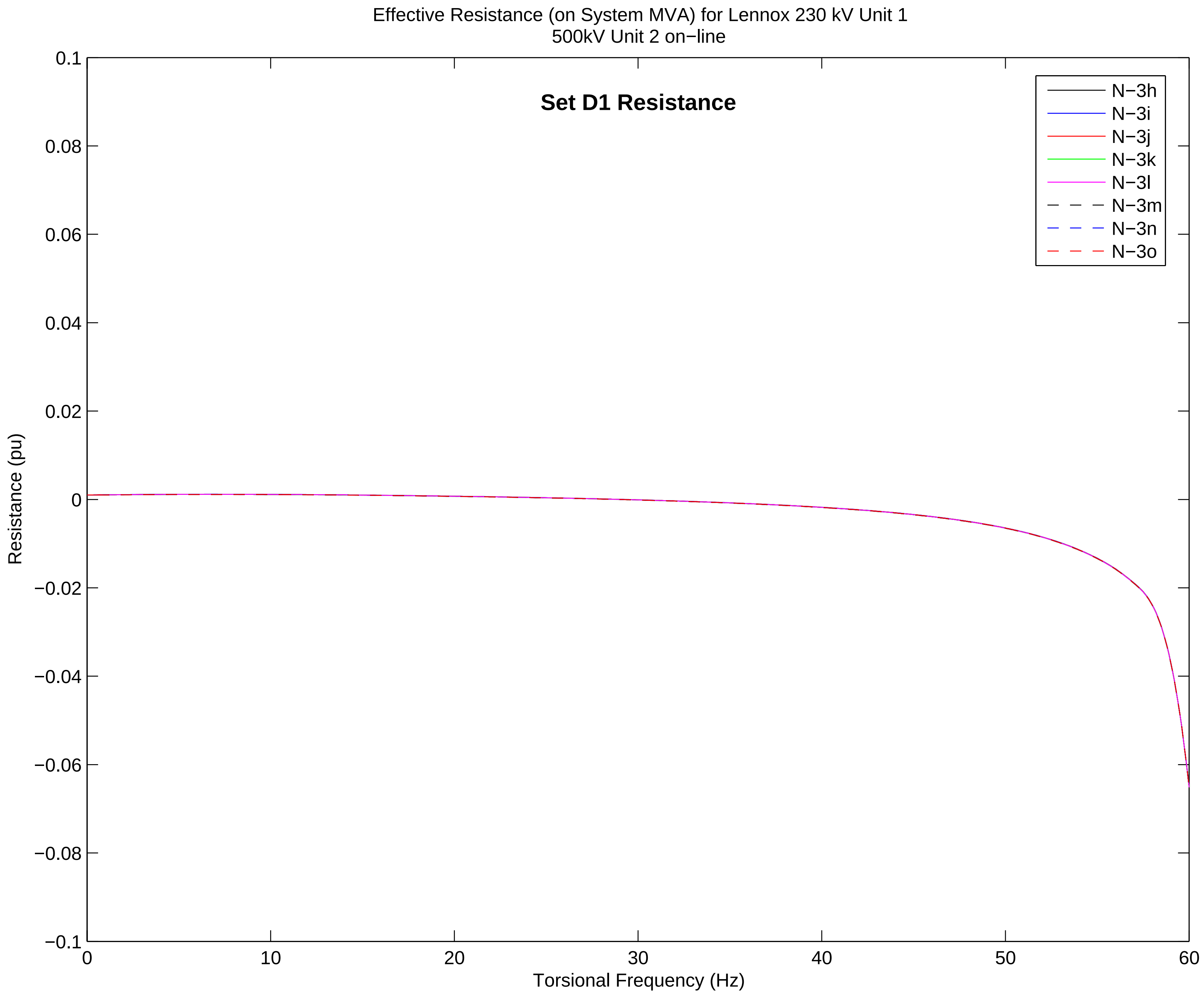
Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

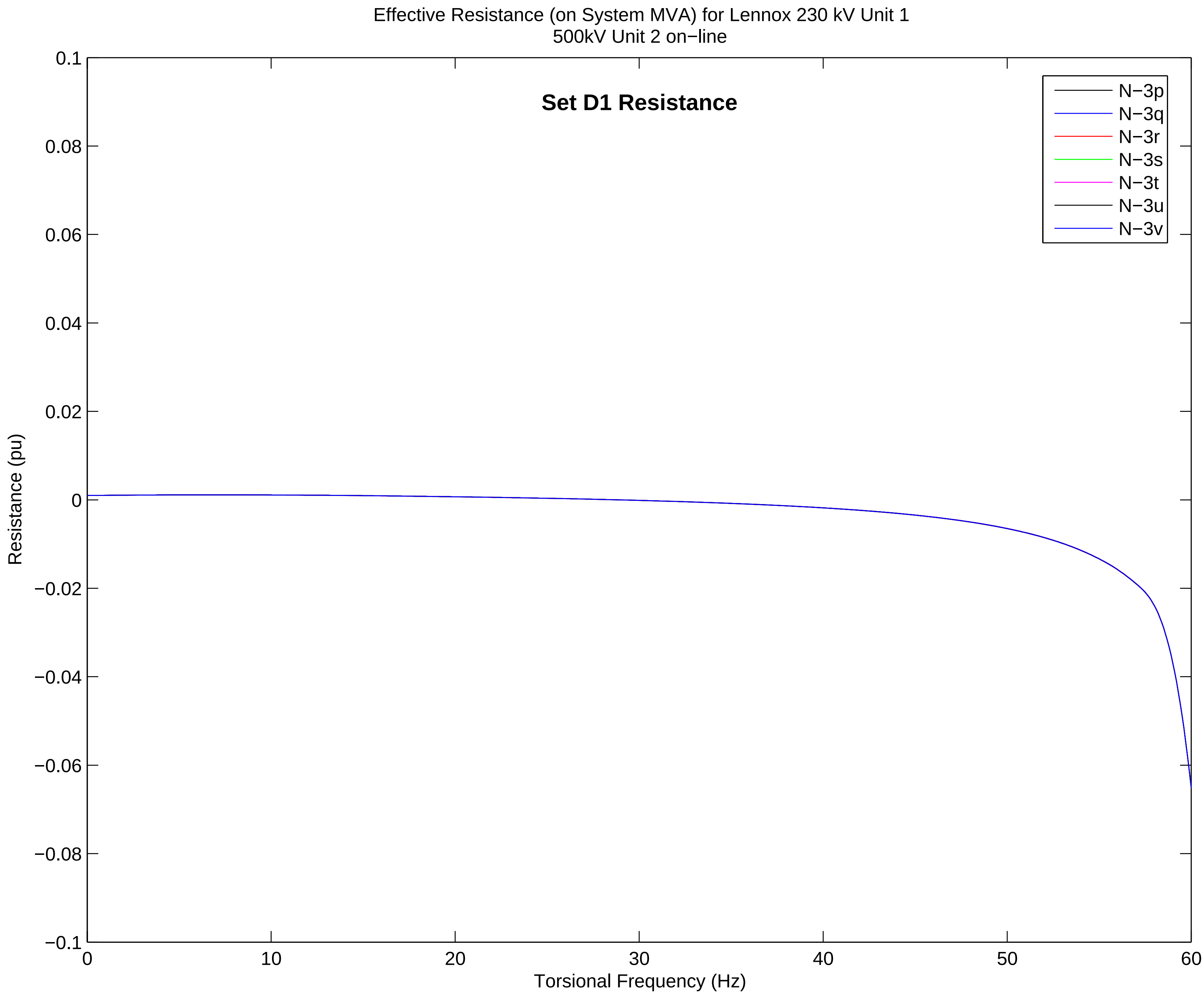


Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV Units off−line
Set B2 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

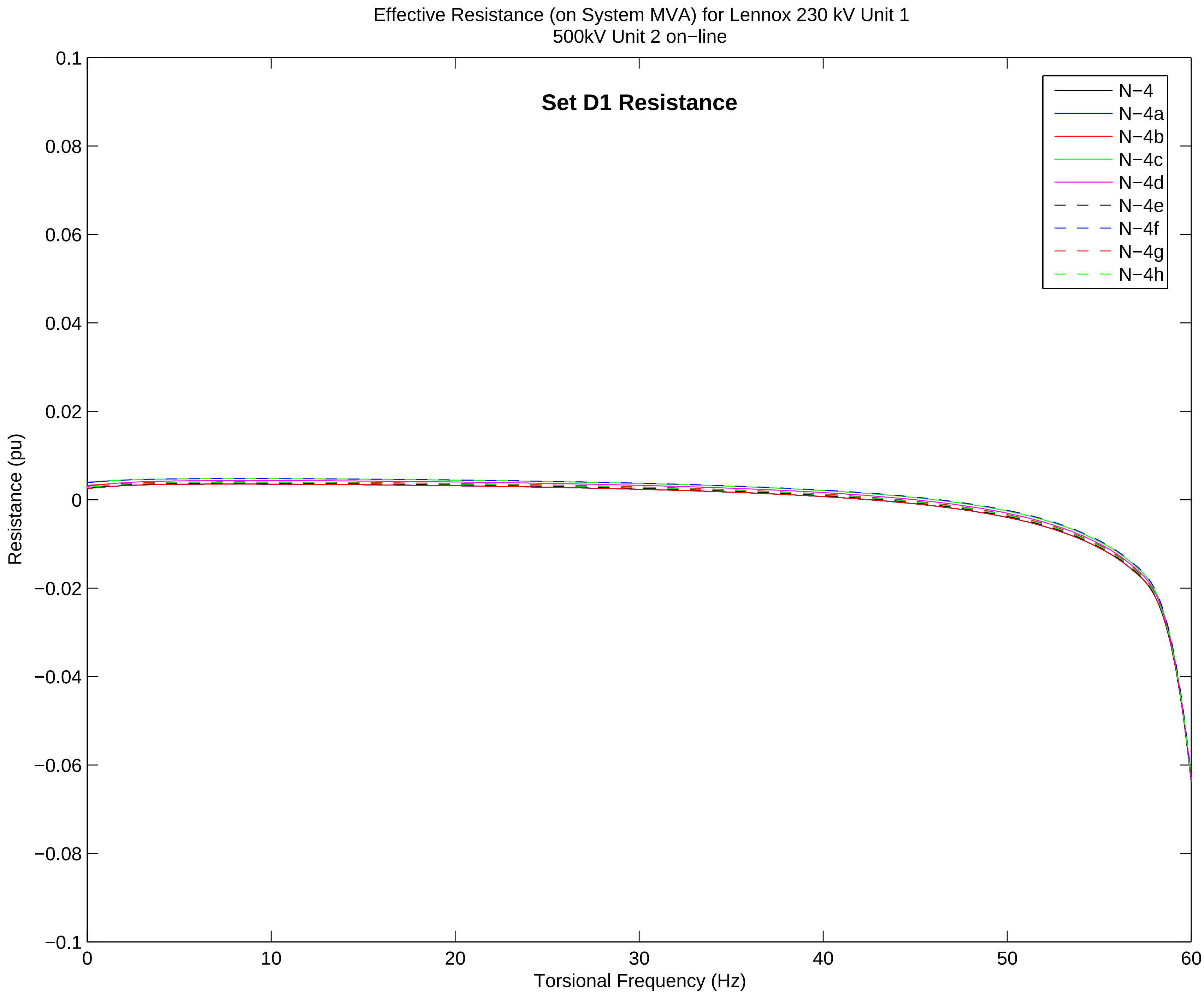

Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Torsional Frequency (Hz)
0
10
20
30
40
50
60

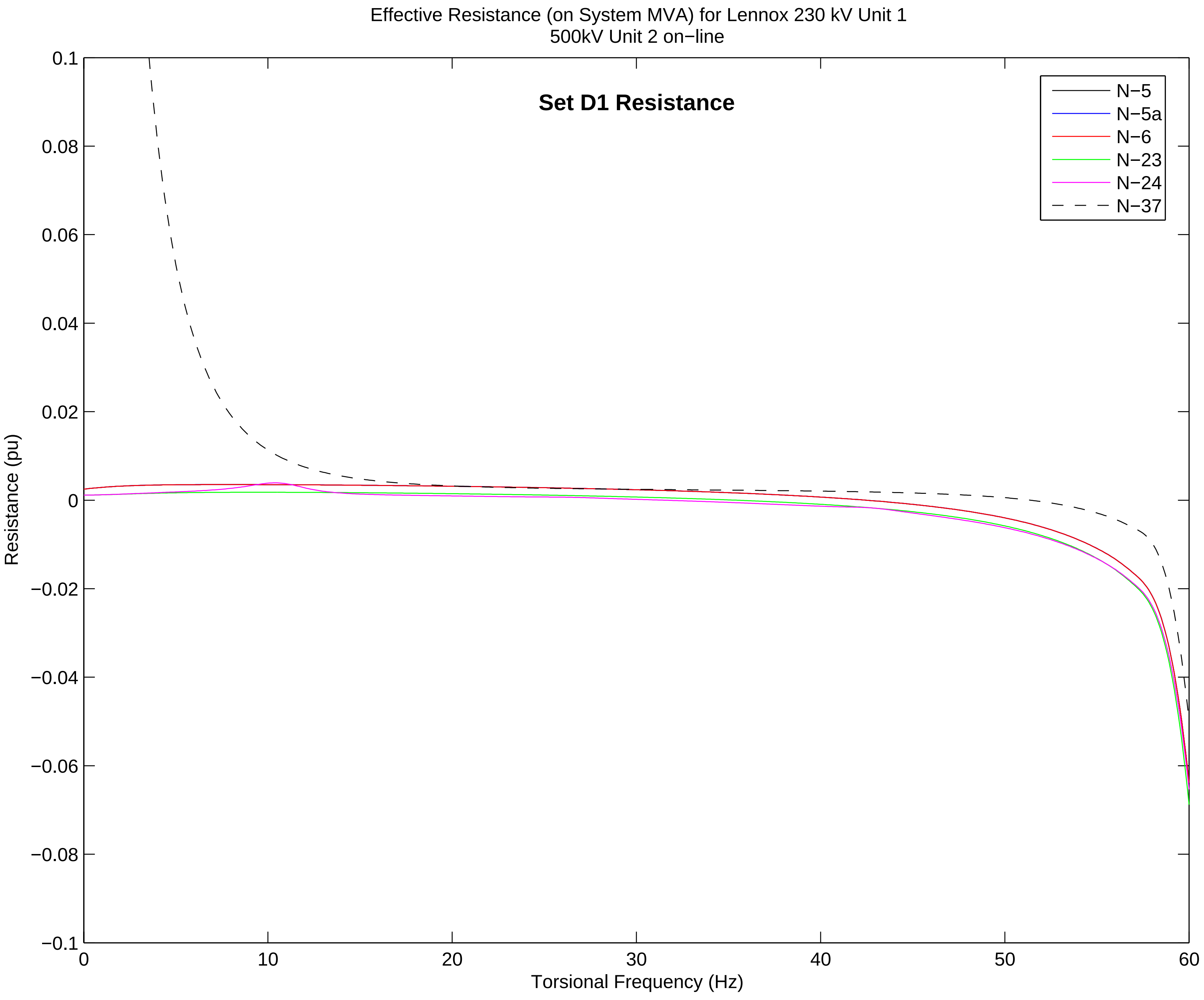

Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

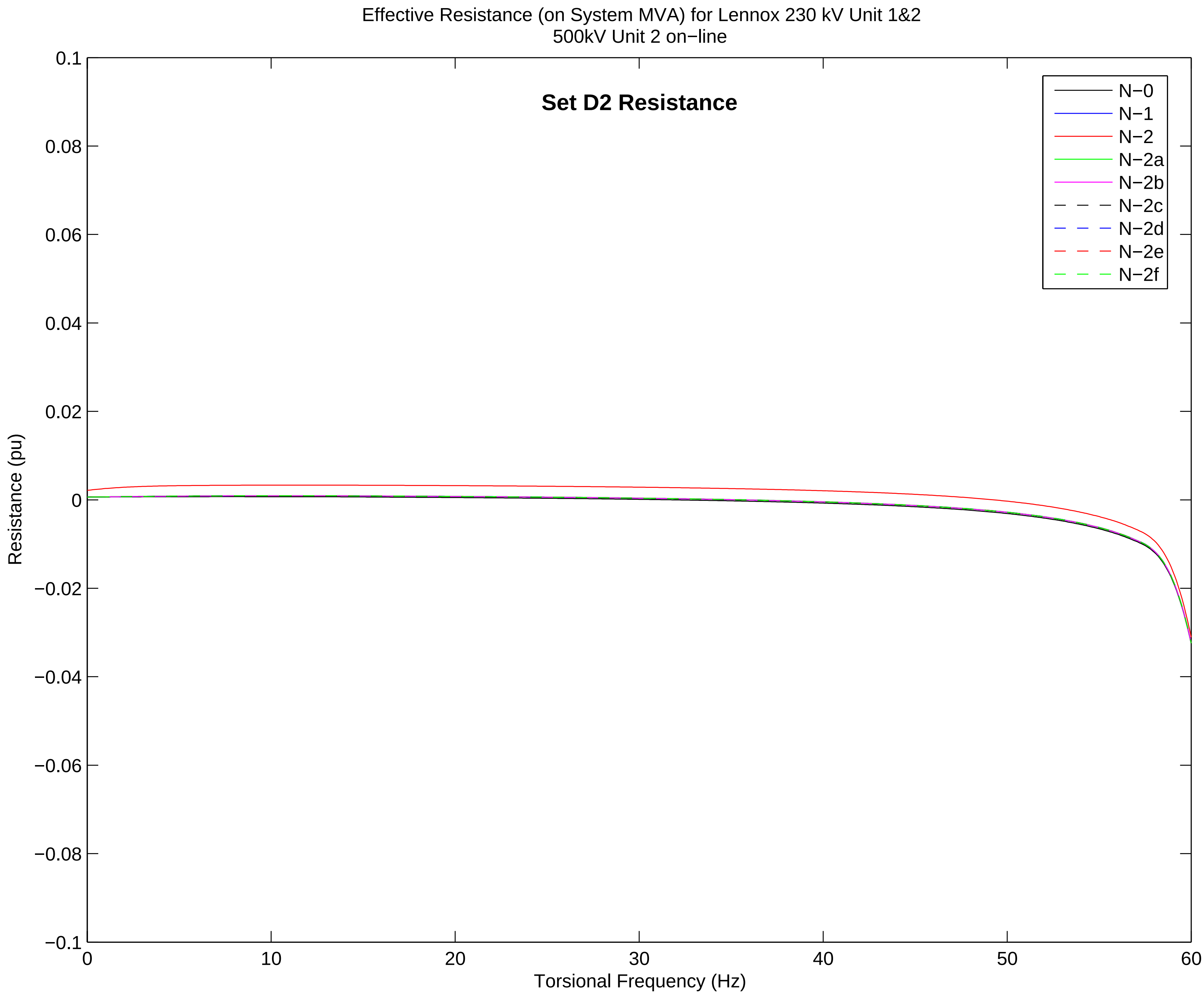


Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

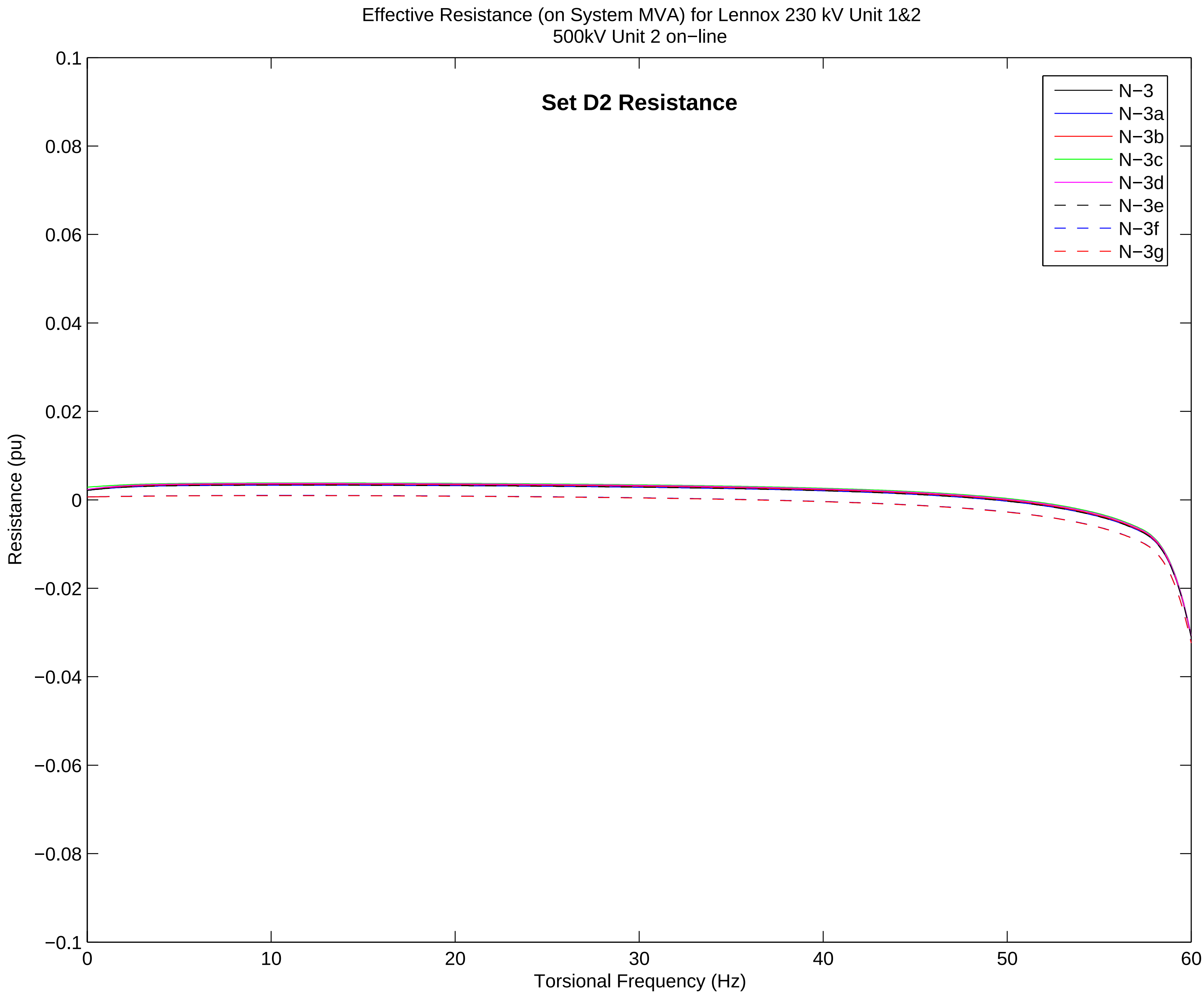

Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

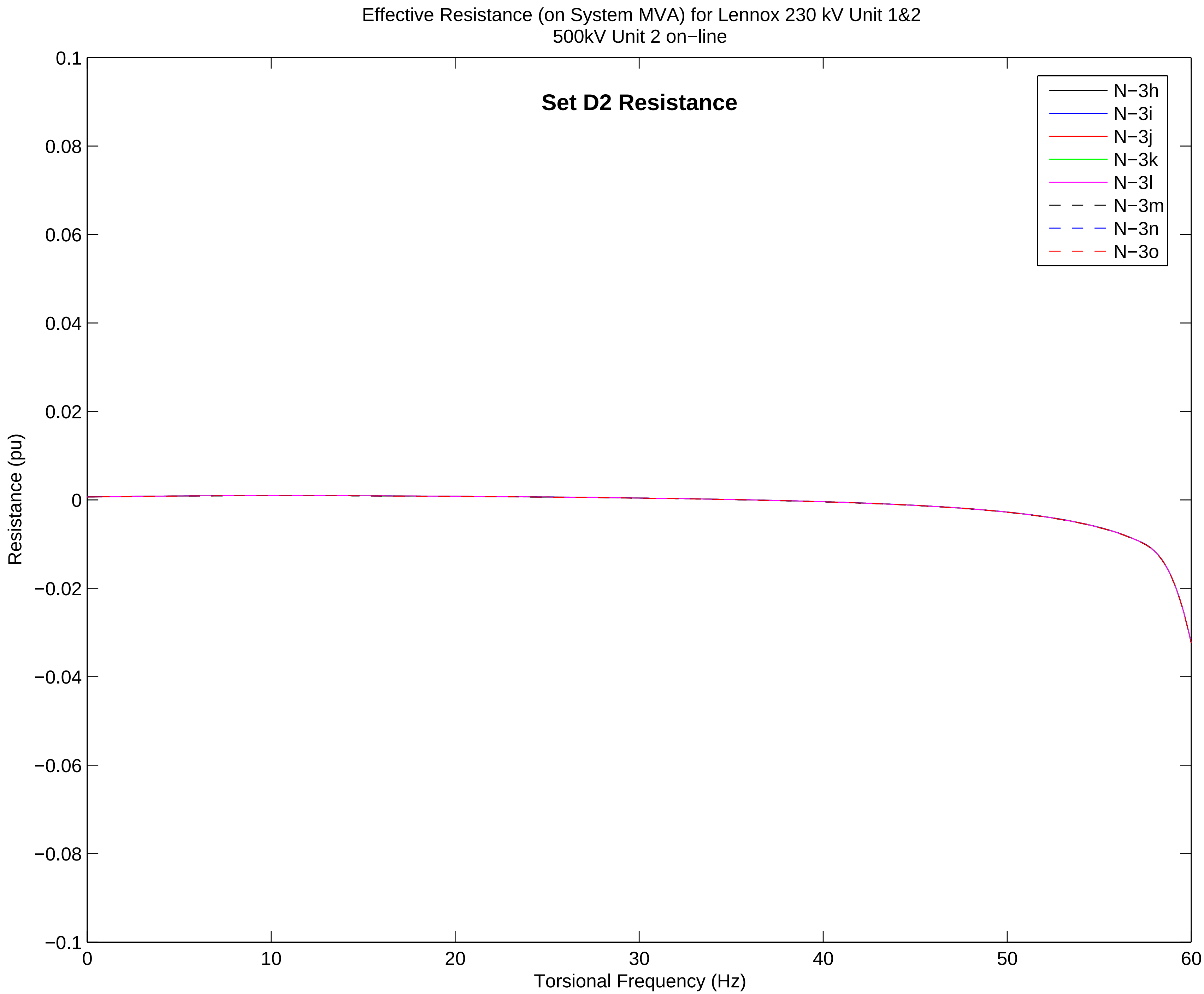


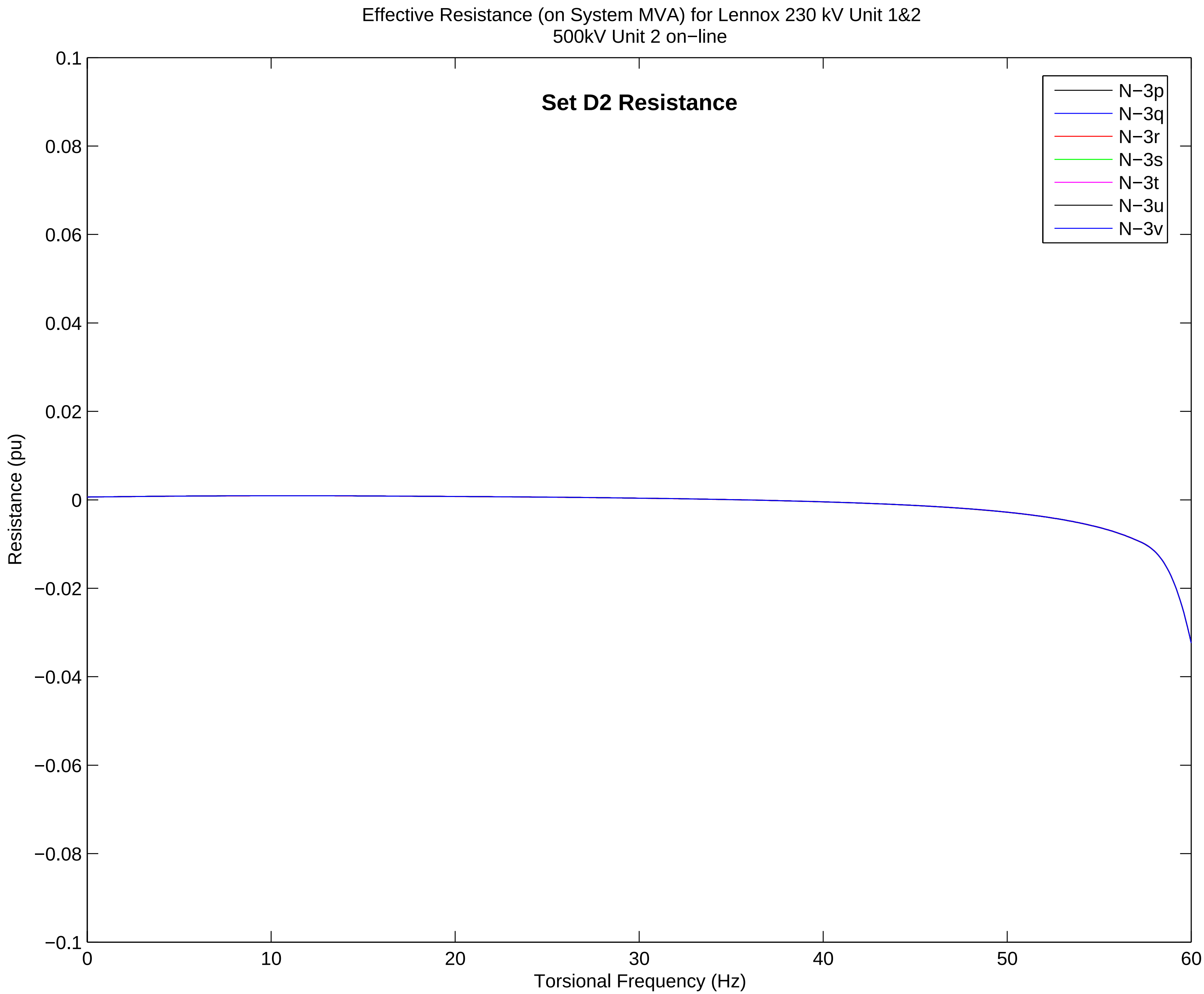
Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
500kV Unit 2 on−line
Set D1 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

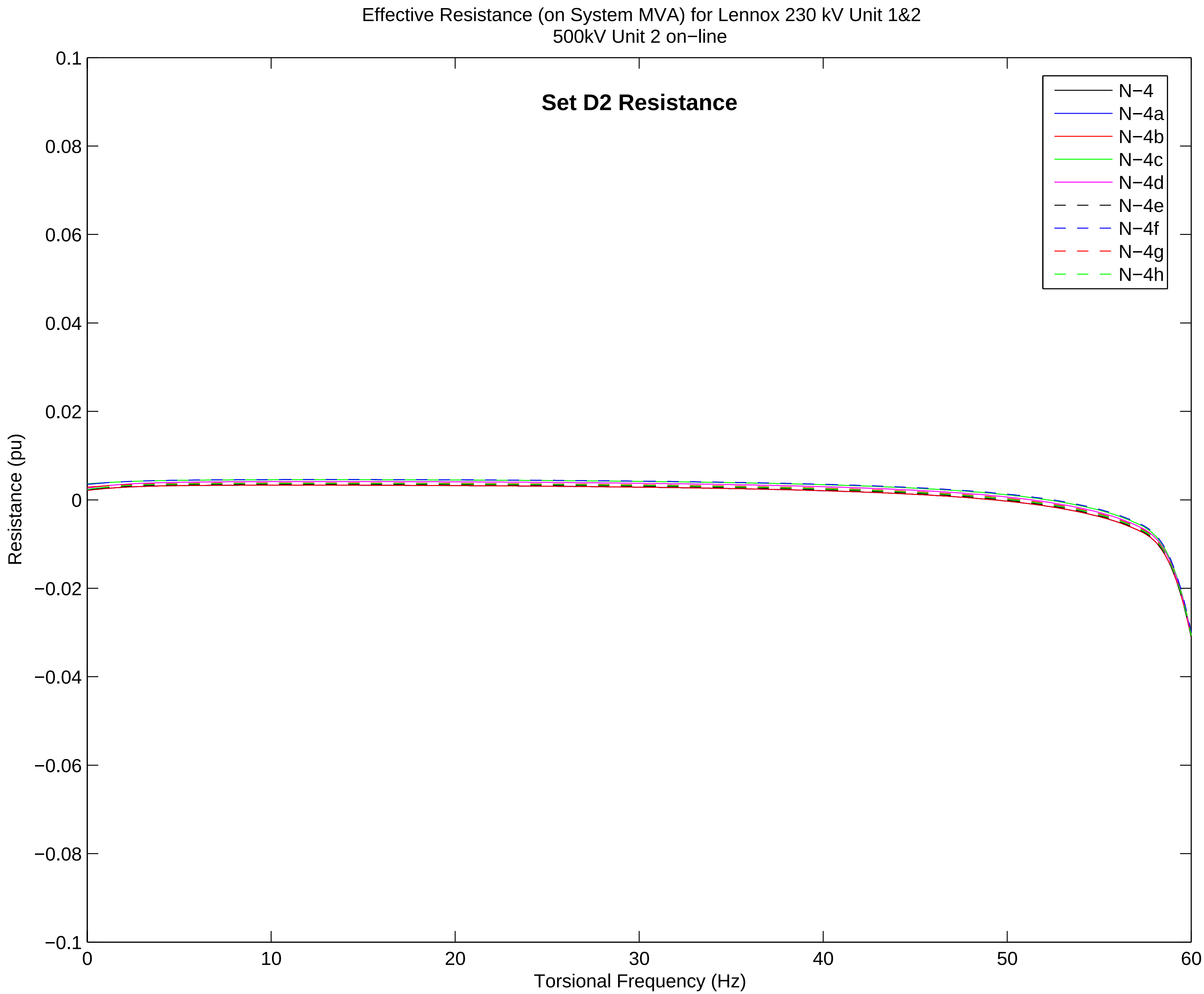


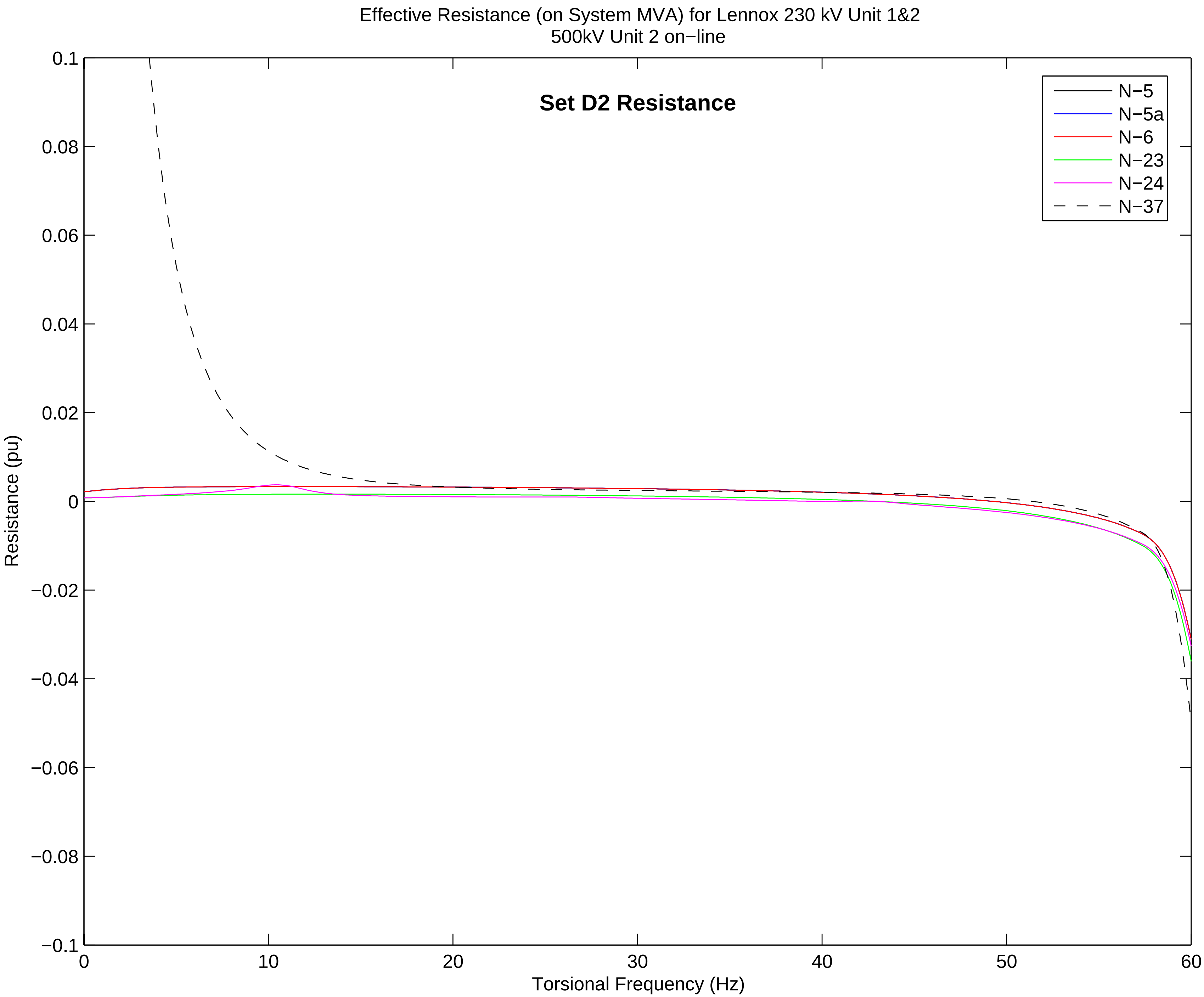
Effective Resistance (on System MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

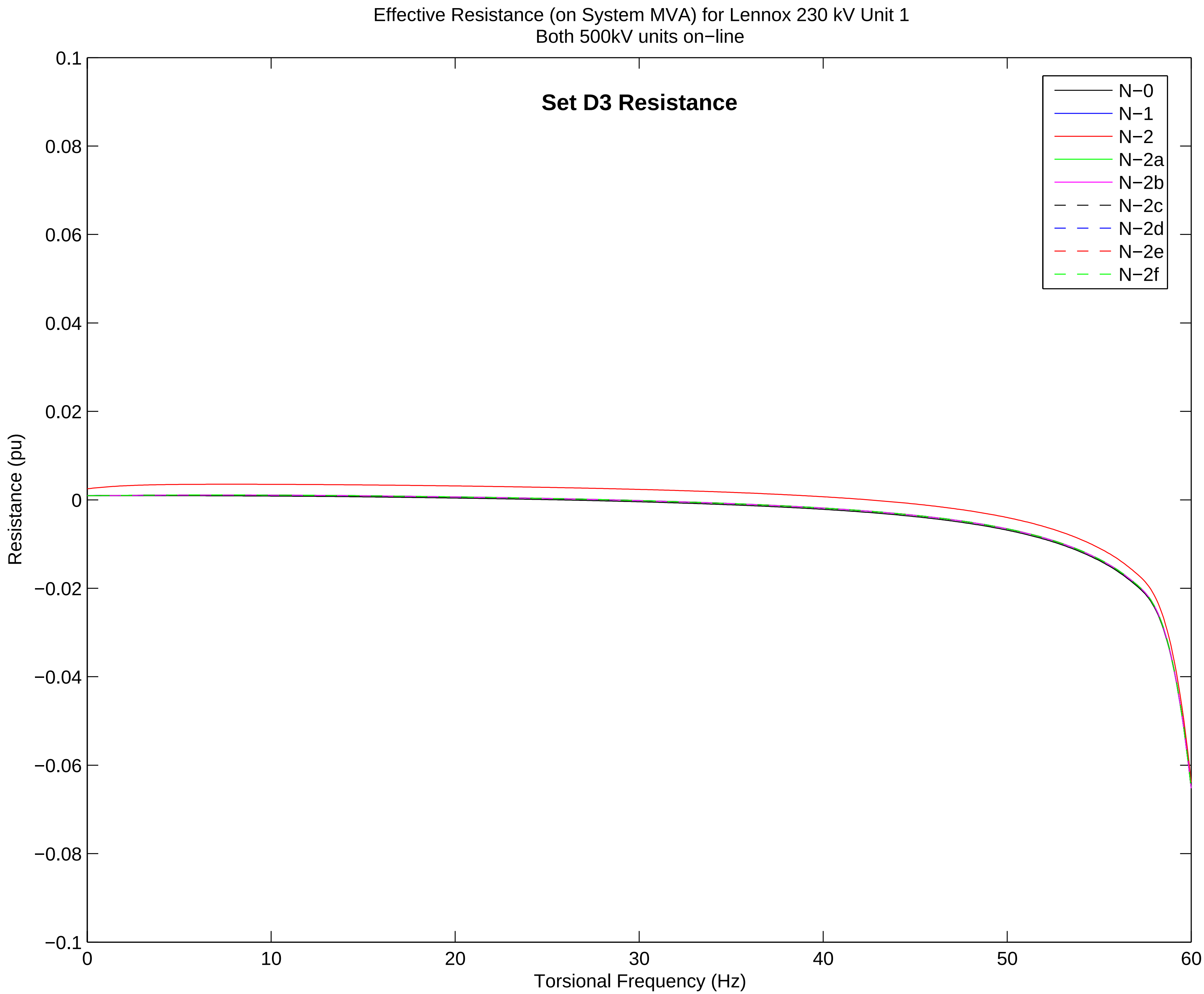

Effective Resistance (on System MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

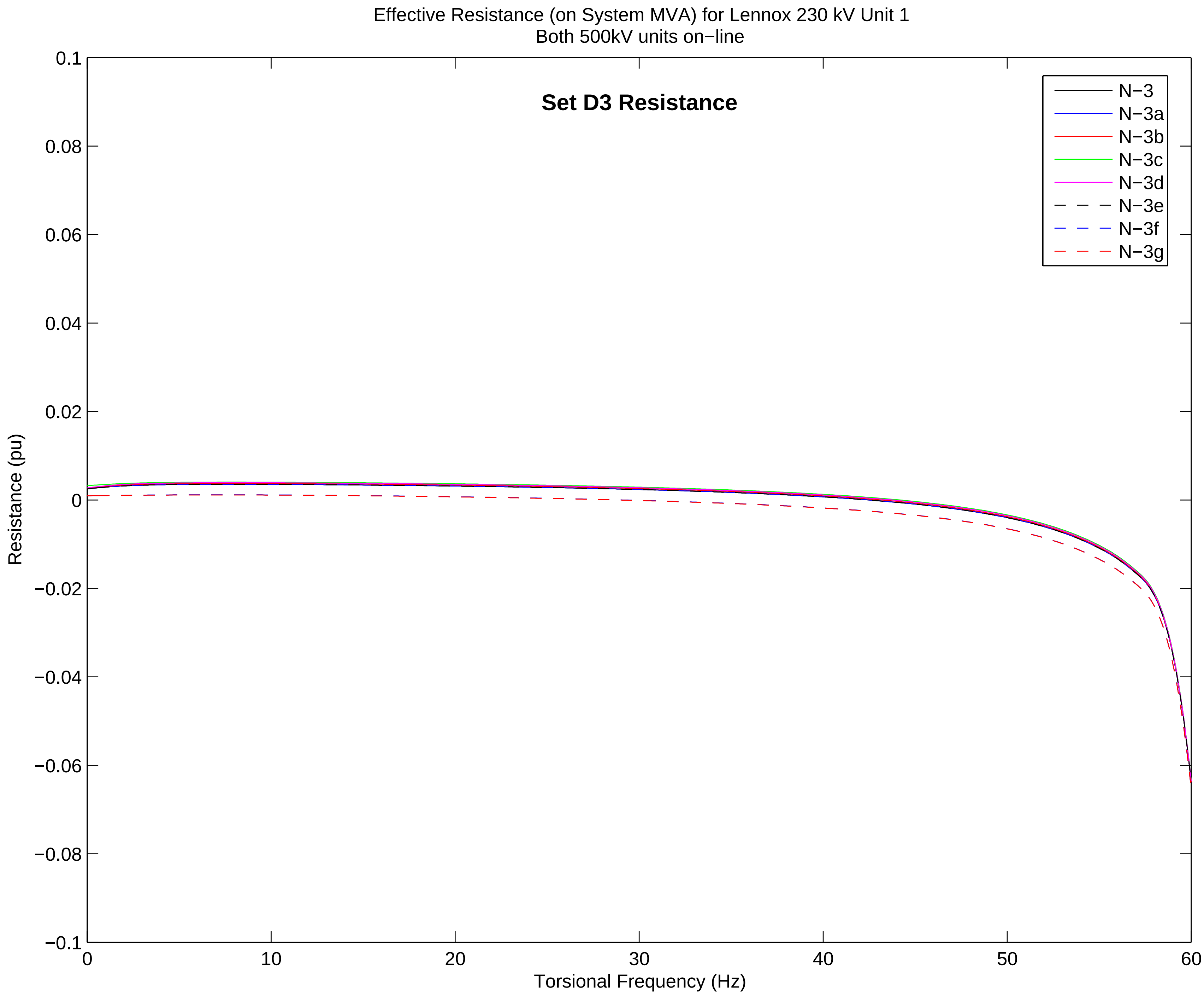

Effective Resistance (on System MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

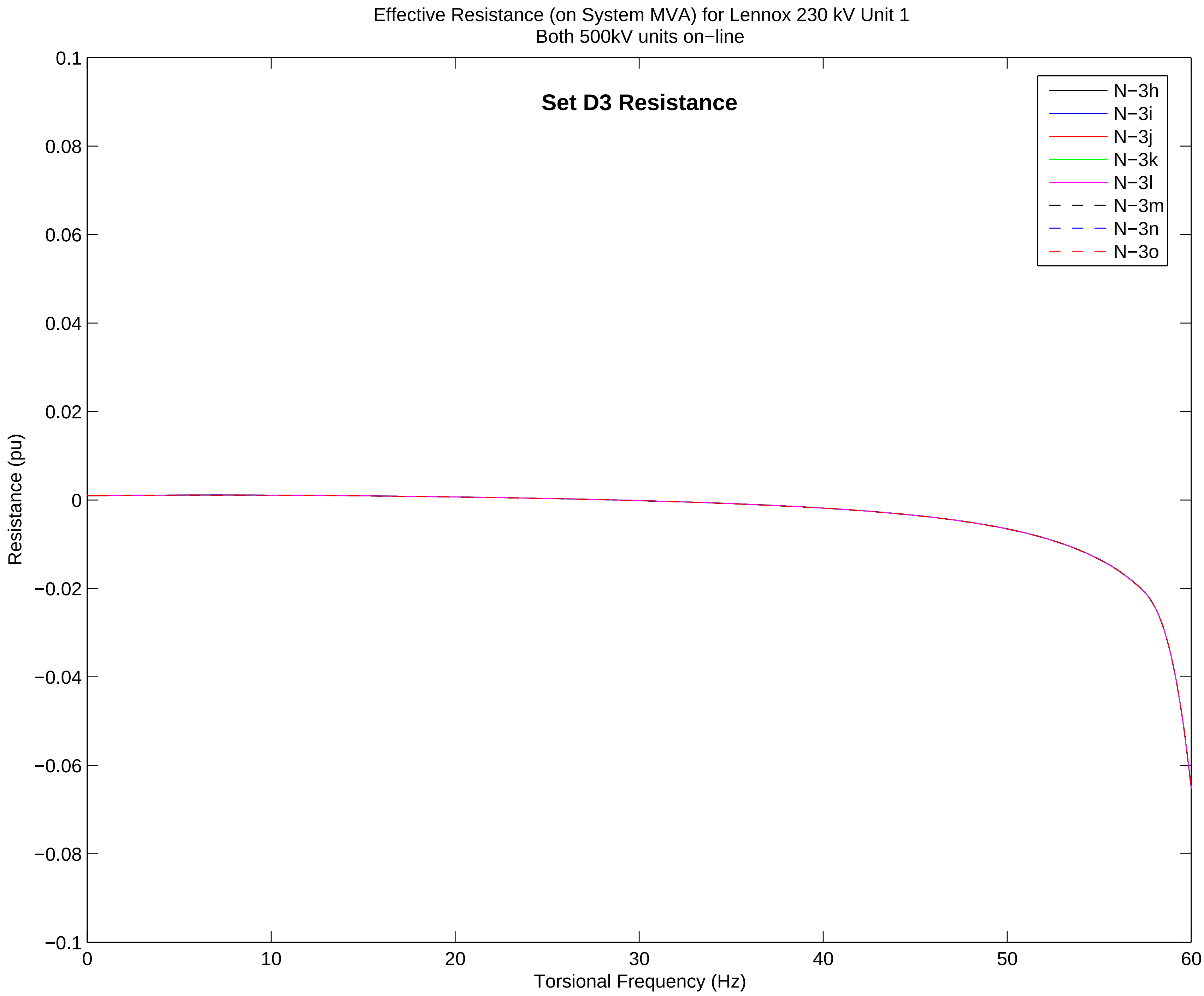

Effective Resistance (on System MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lennox 230 kV Unit 1&2
500kV Unit 2 on−line
Set D2 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

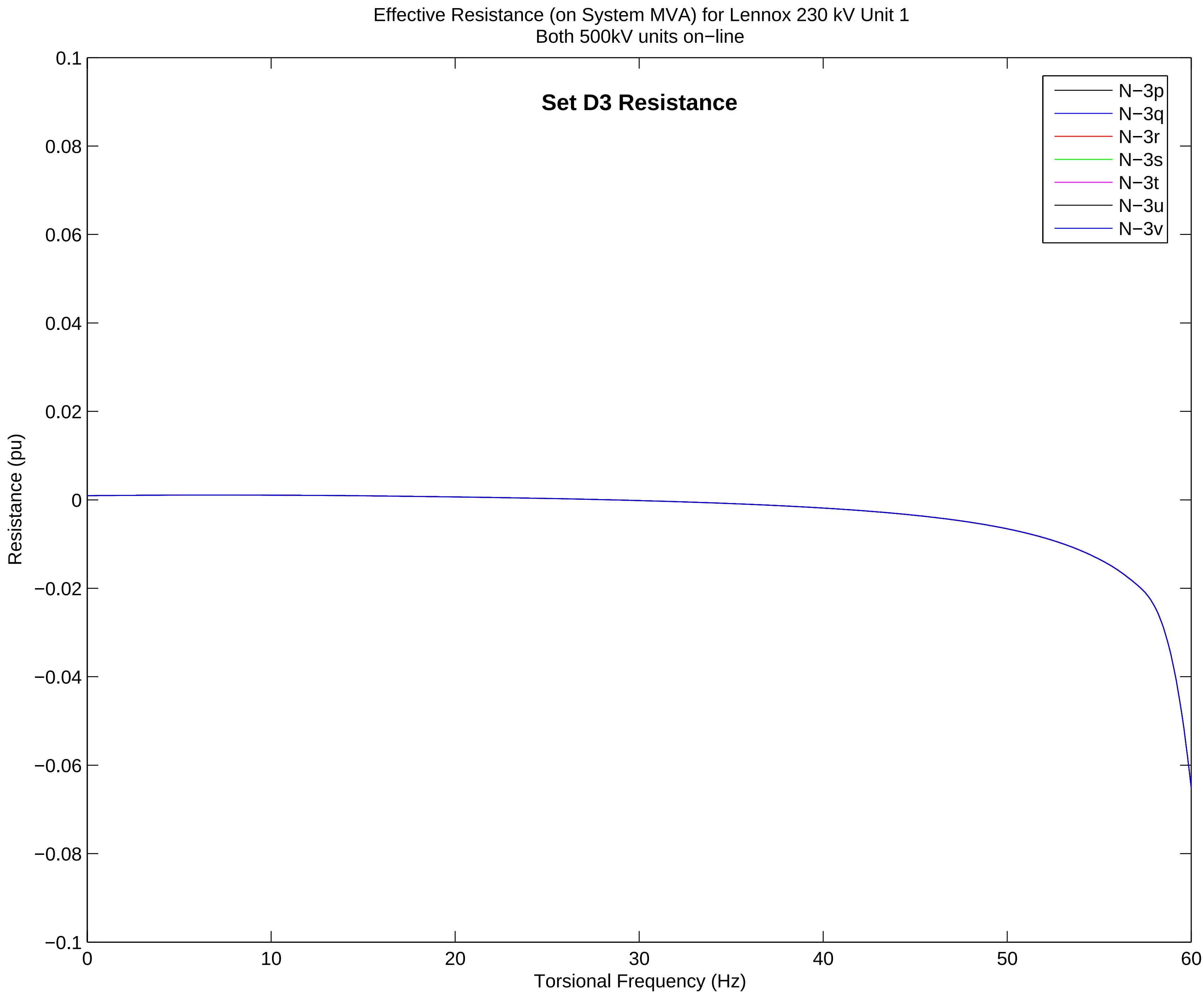


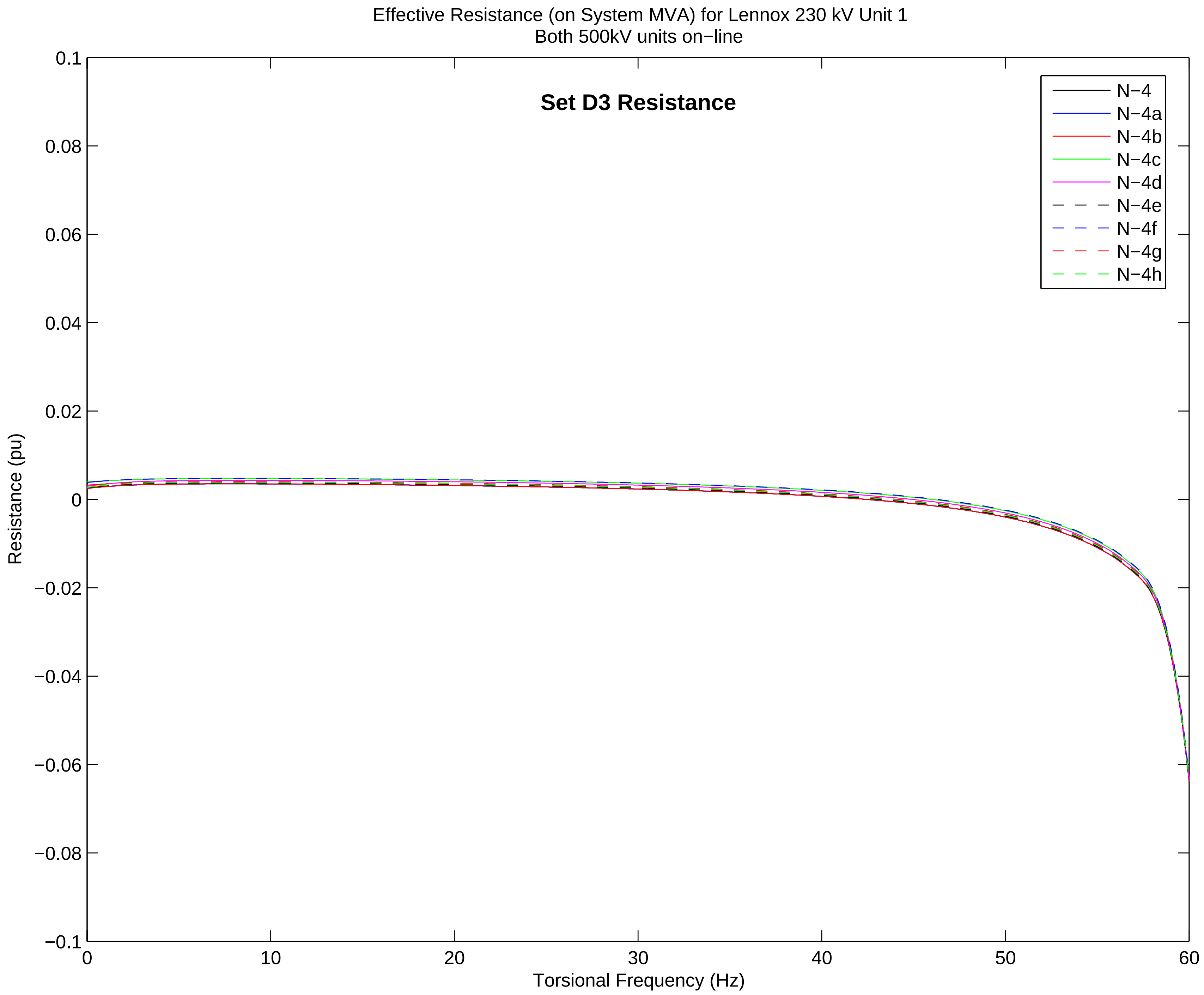
Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Torsional Frequency (Hz)
0
10
20
30
40
50
60


Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

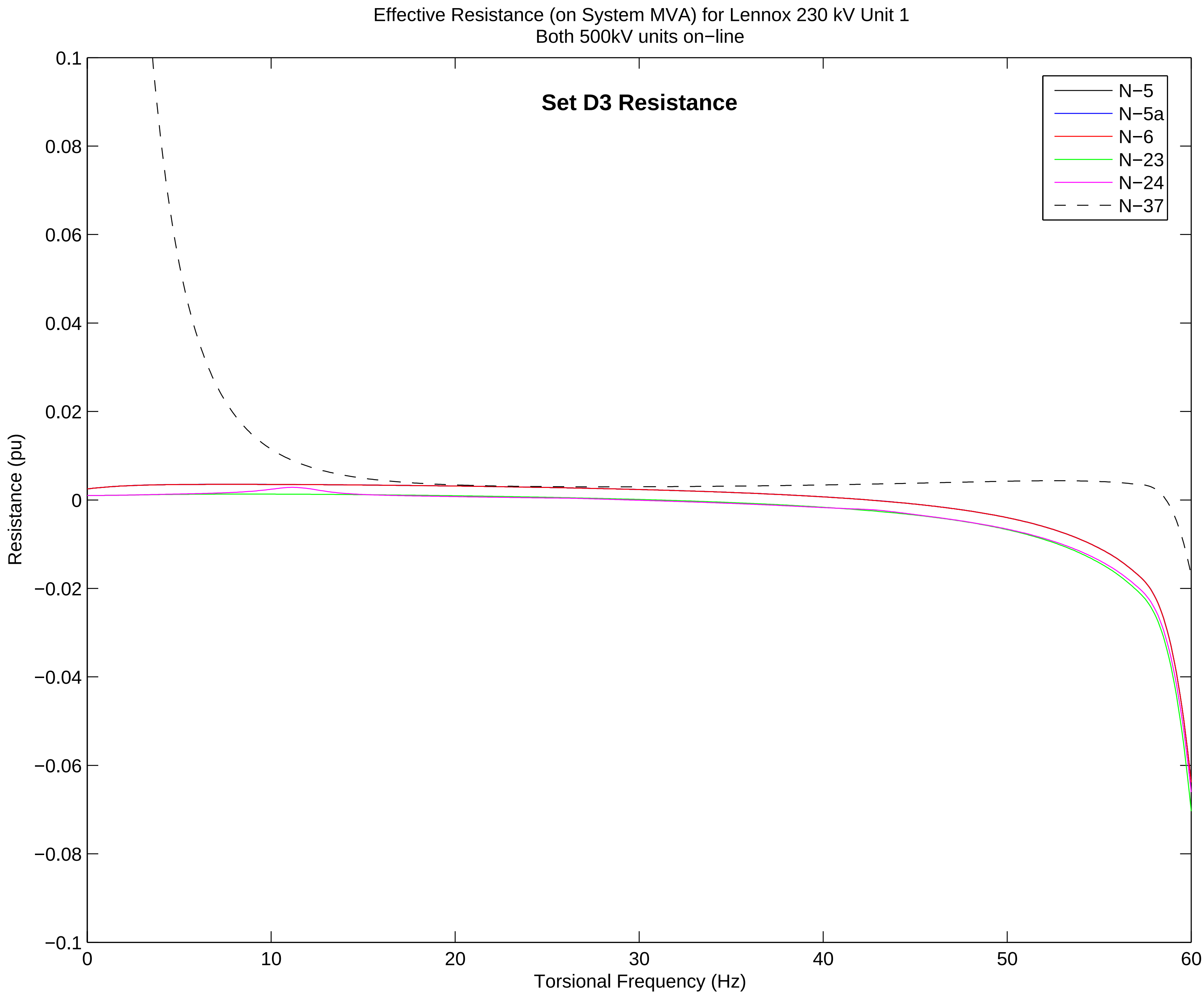


Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60

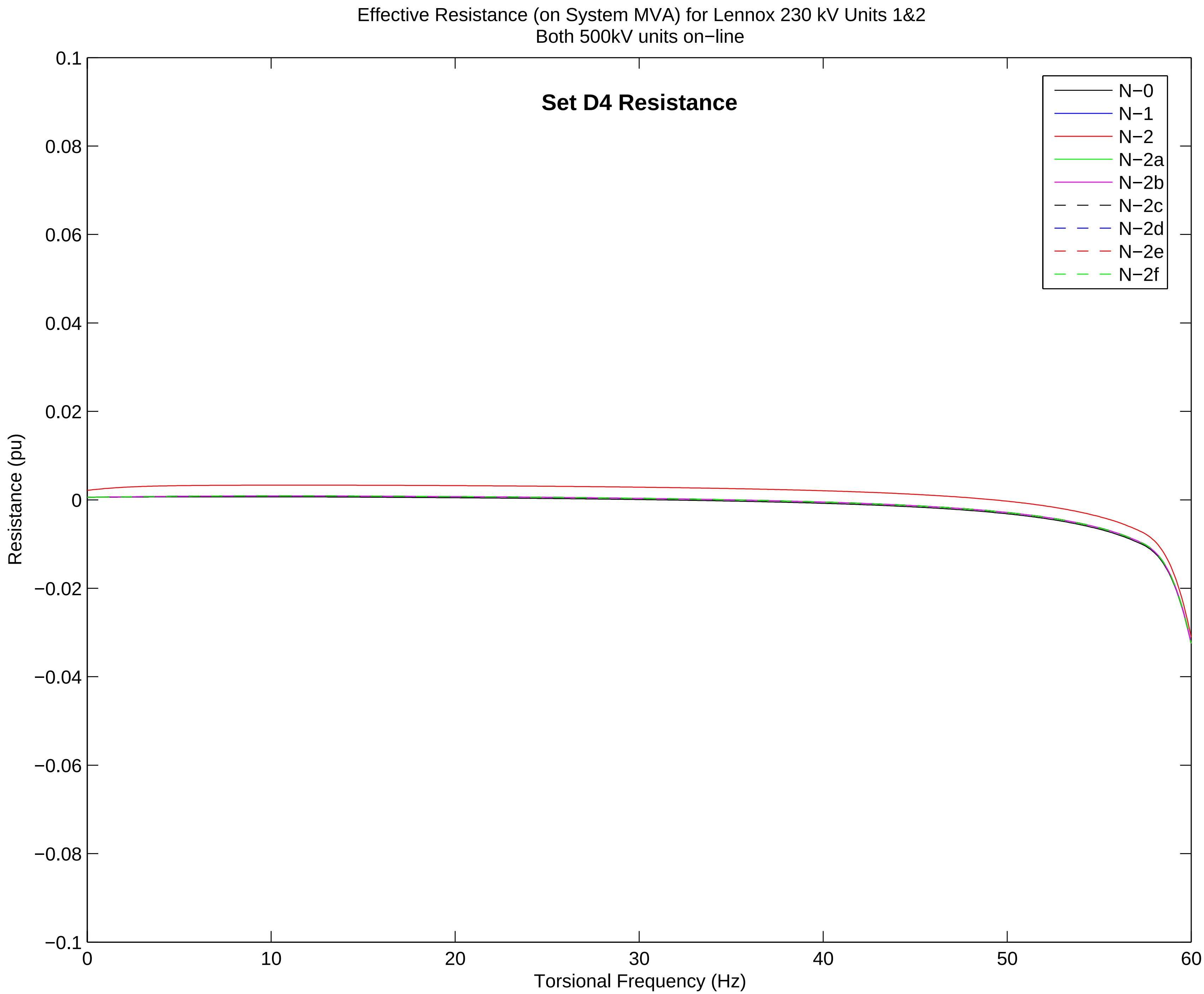

Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



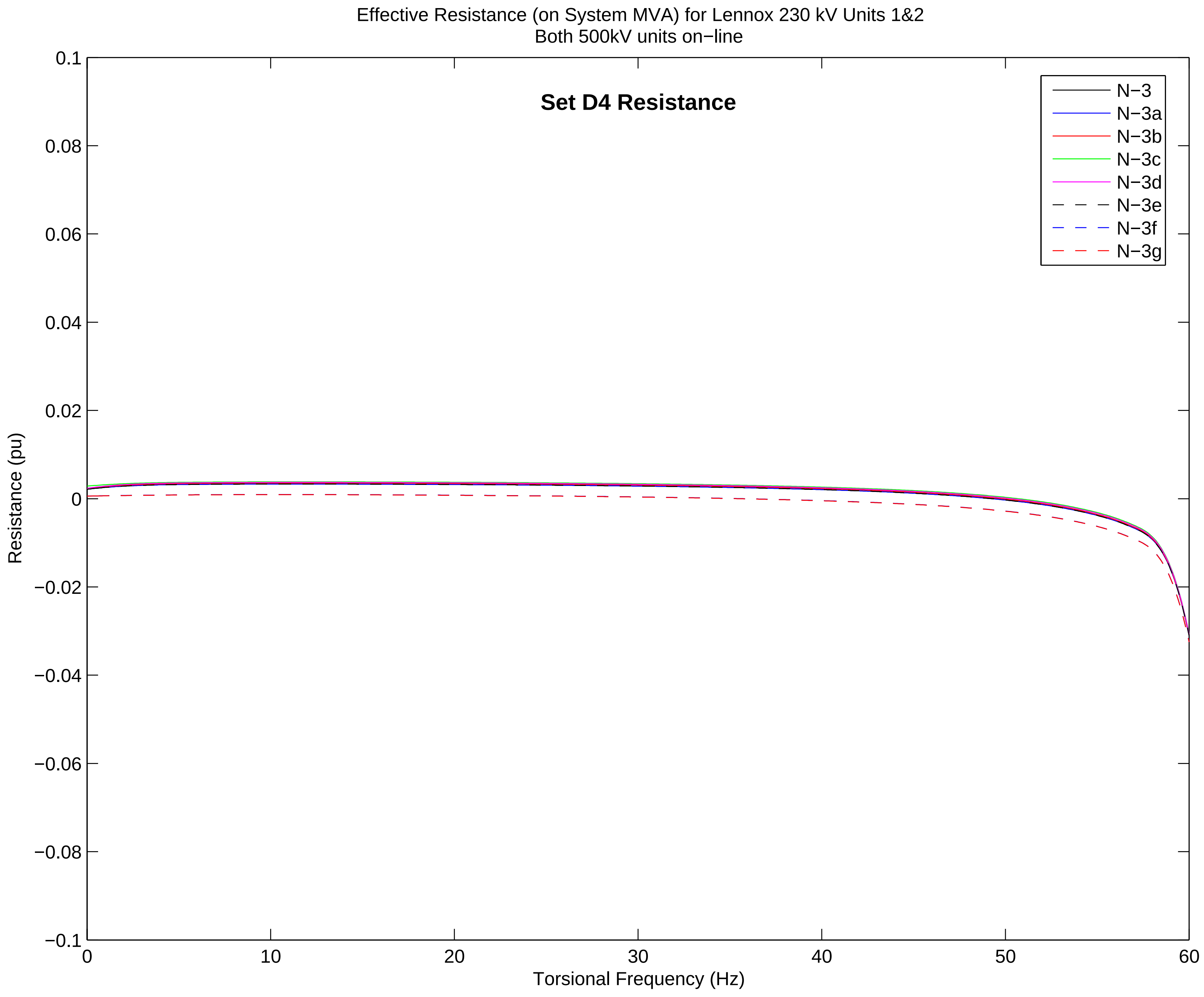
Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



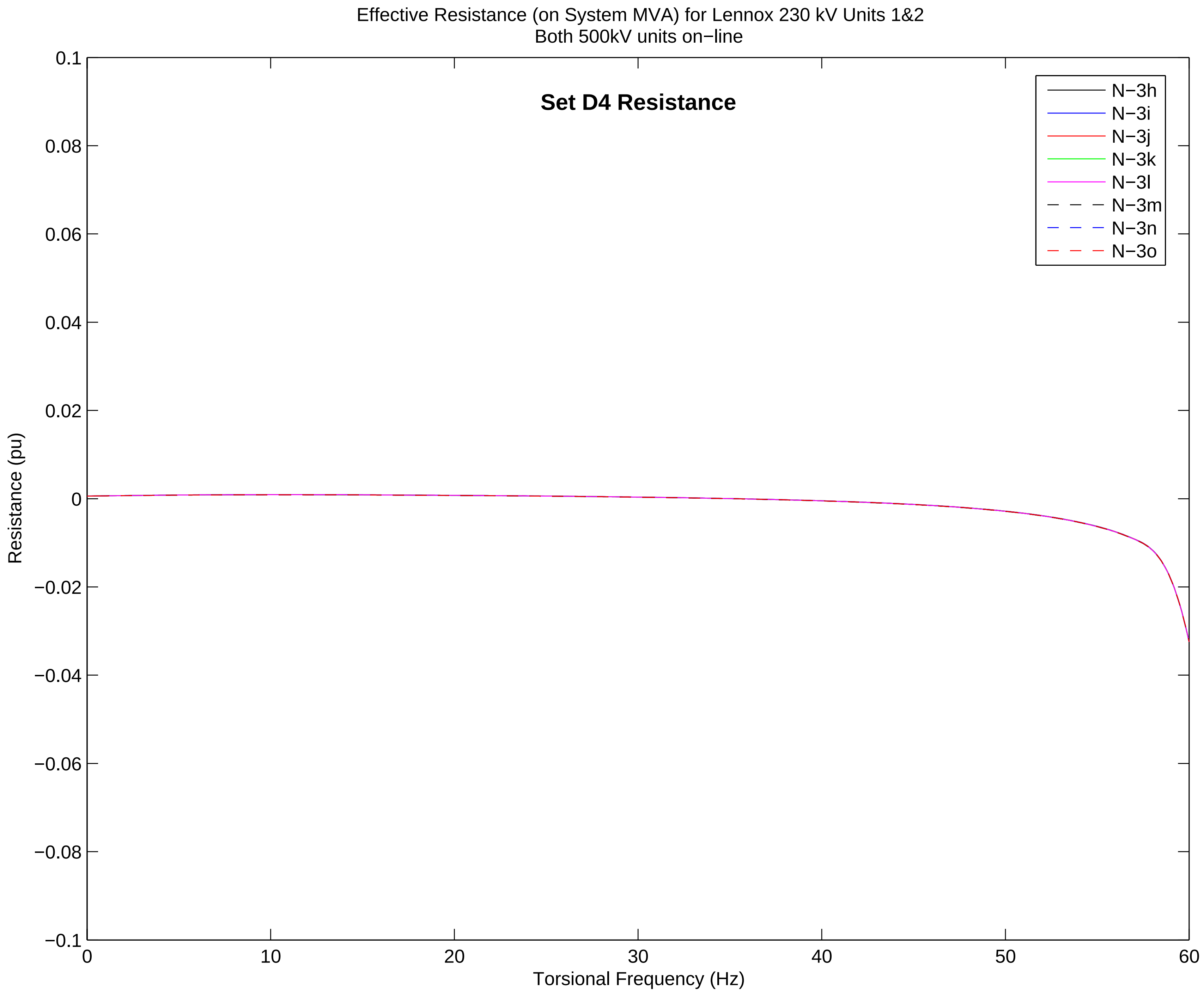
Effective Resistance (on System MVA) for Lennox 230 kV Unit 1
Both 500kV units on−line
Set D3 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
Resistance (pu)
Torsional Frequency (Hz)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60



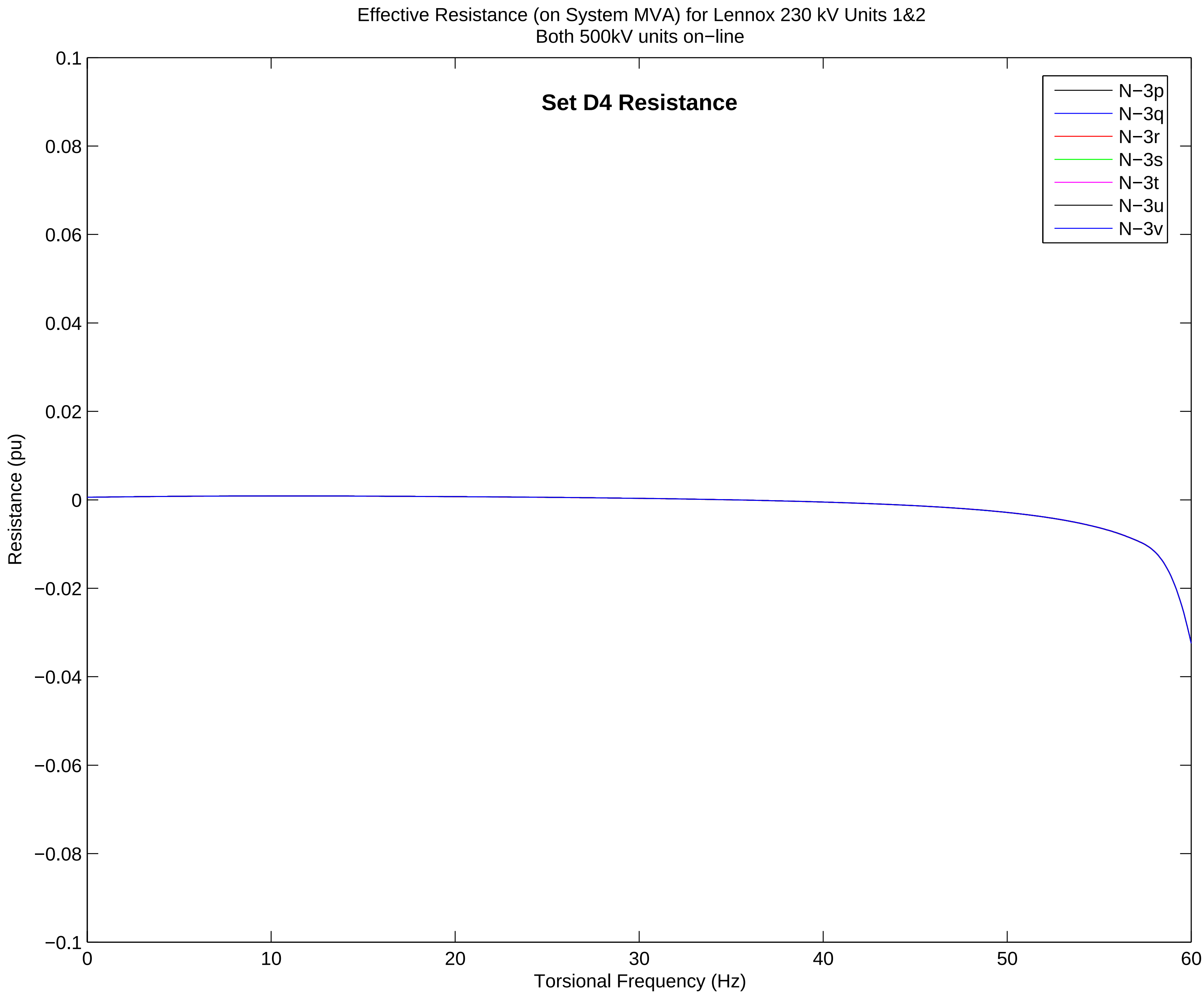
Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Resistance
N−0
N−1
N−2
N−2a
N−2b
N−2c
N−2d
N−2e
N−2f
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



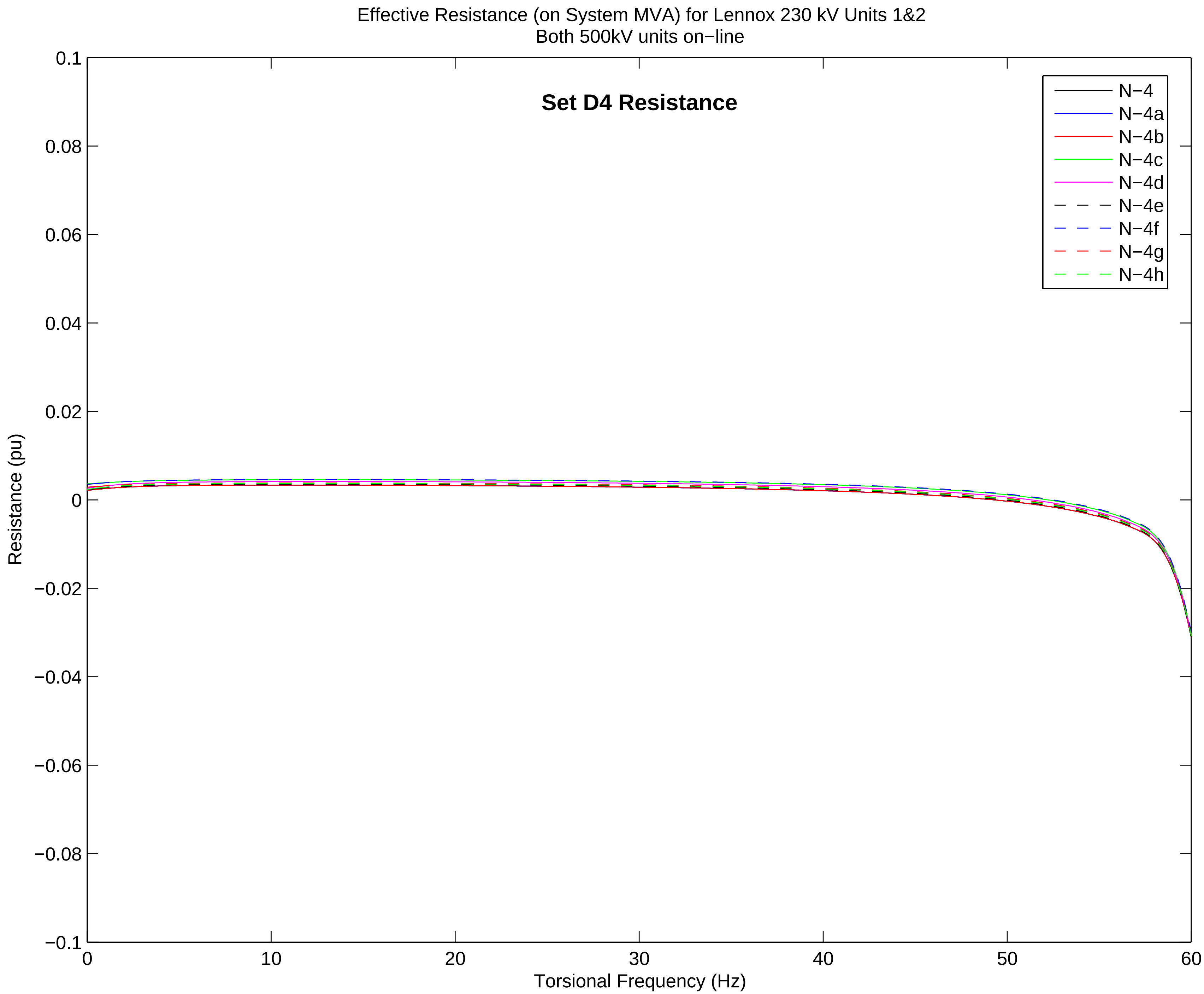
Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Resistance
N−3
N−3a
N−3b
N−3c
N−3d
N−3e
N−3f
N−3g
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)

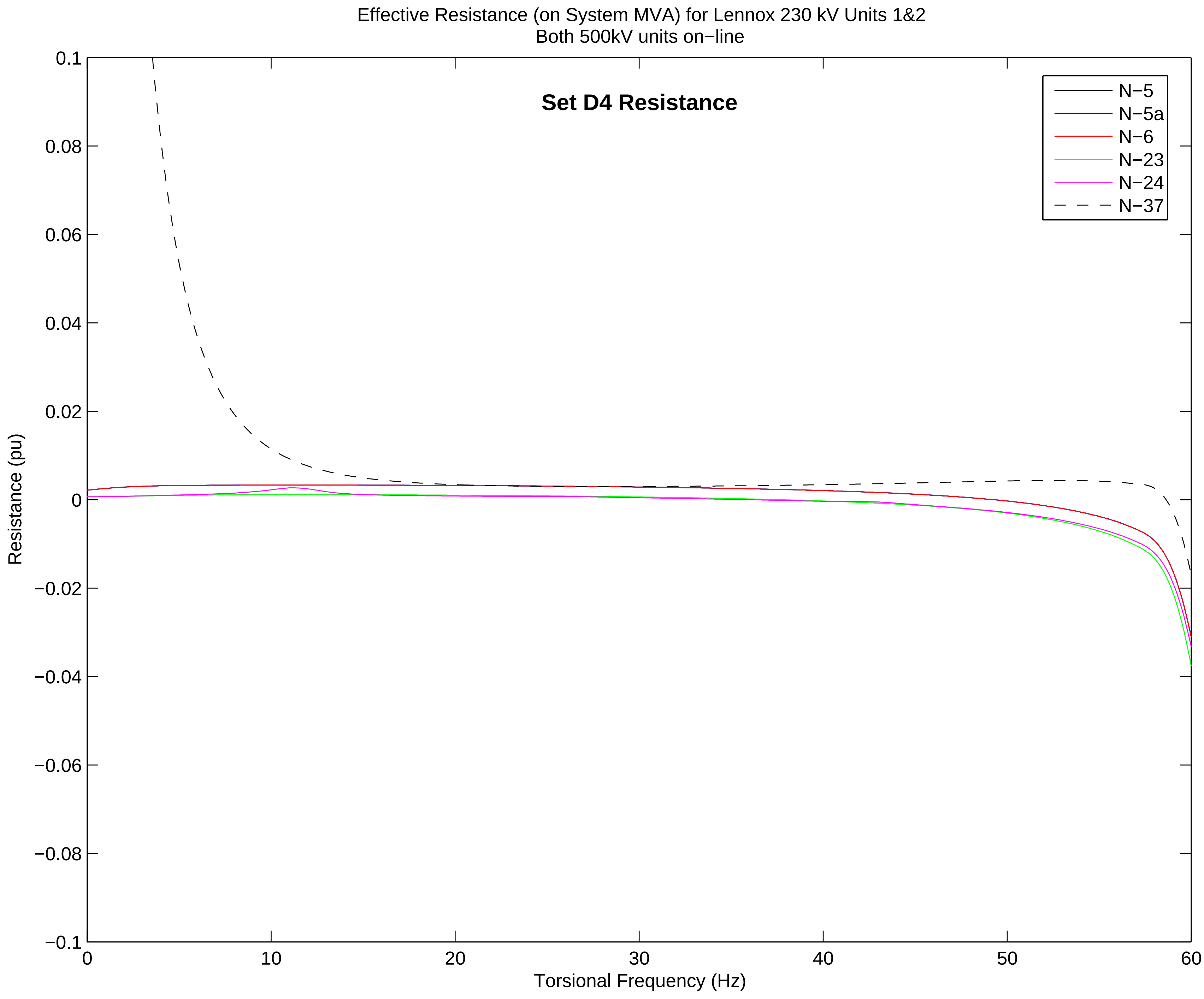


Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Resistance
N−3h
N−3i
N−3j
N−3k
N−3l
N−3m
N−3n
N−3o
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Resistance
N−3p
N−3q
N−3r
N−3s
N−3t
N−3u
N−3v
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
Resistance (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)


Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Resistance
N−4
N−4a
N−4b
N−4c
N−4d
N−4e
N−4f
N−4g
N−4h
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)



Effective Resistance (on System MVA) for Lennox 230 kV Units 1&2
Both 500kV units on−line
Set D4 Resistance
N−5
N−5a
N−6
N−23
N−24
N−37
Resistance (pu)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
0
10
20
30
40
50
60
Torsional Frequency (Hz)

APPENDIX J: 3-D Damping Plots for Nanticoke 500 kV Units

(Note: Z – axis on plots do not have the same scale)

<u>15.1 Hz Mode:</u>

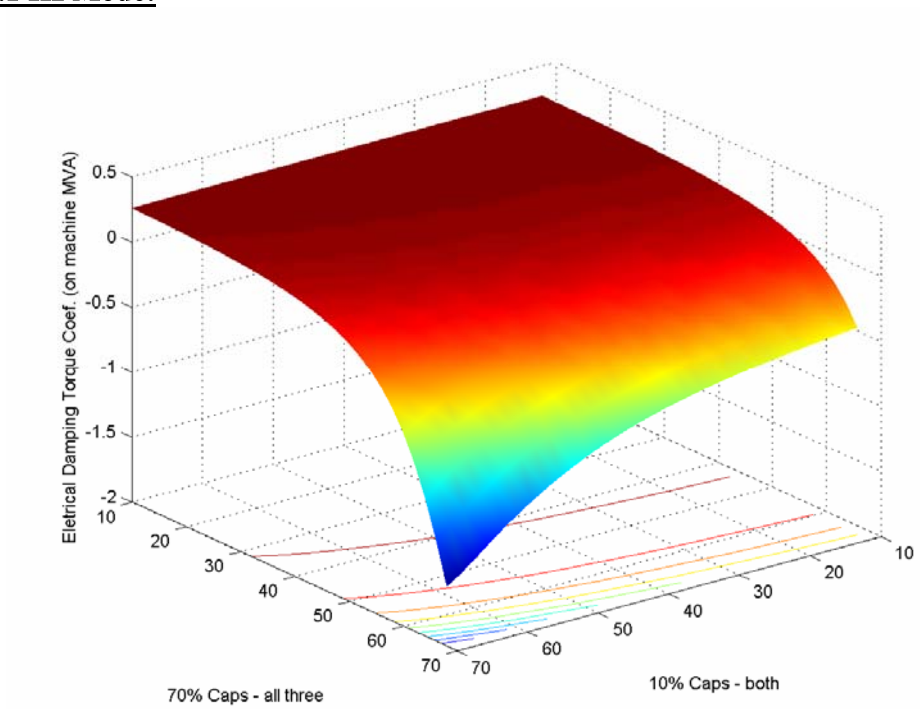


Figure J-1: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 15.1 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged.

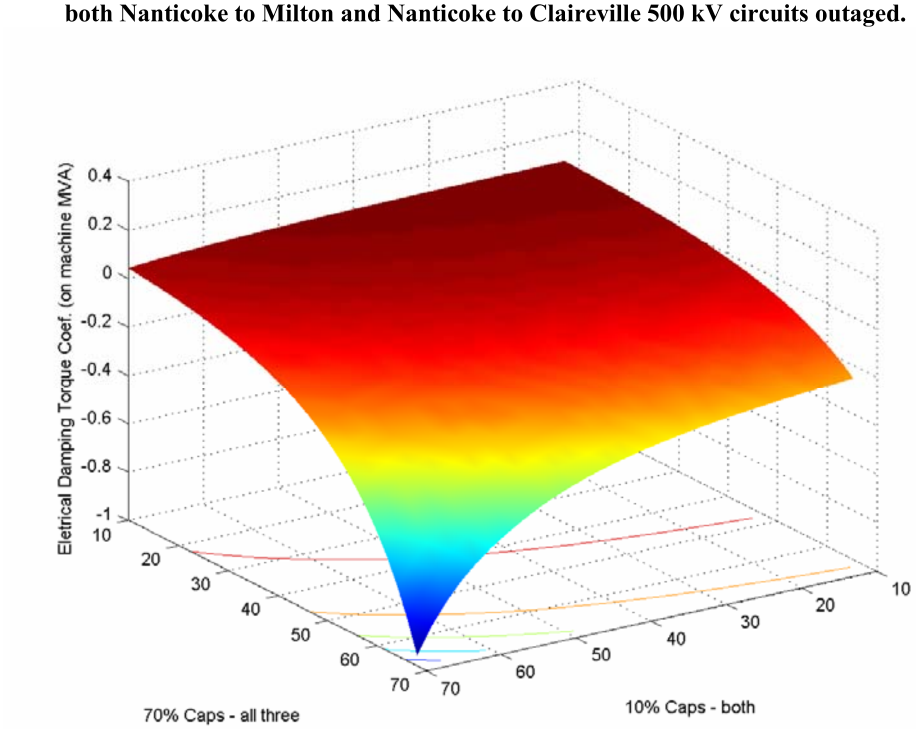


Figure J-2: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 15.1 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

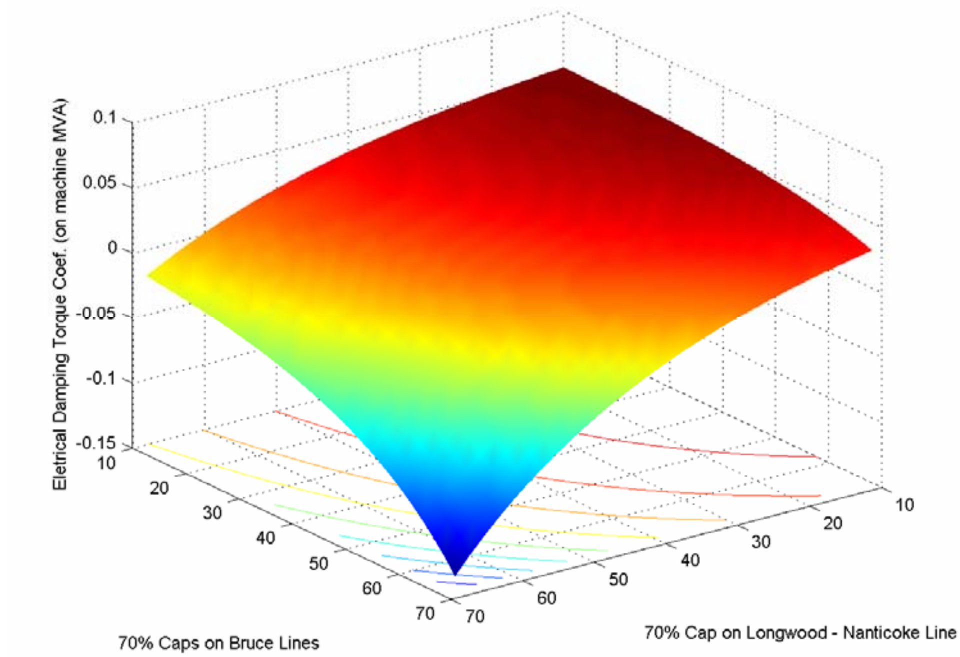


Figure J-3: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 15.1 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

28.8 Hz Mode:

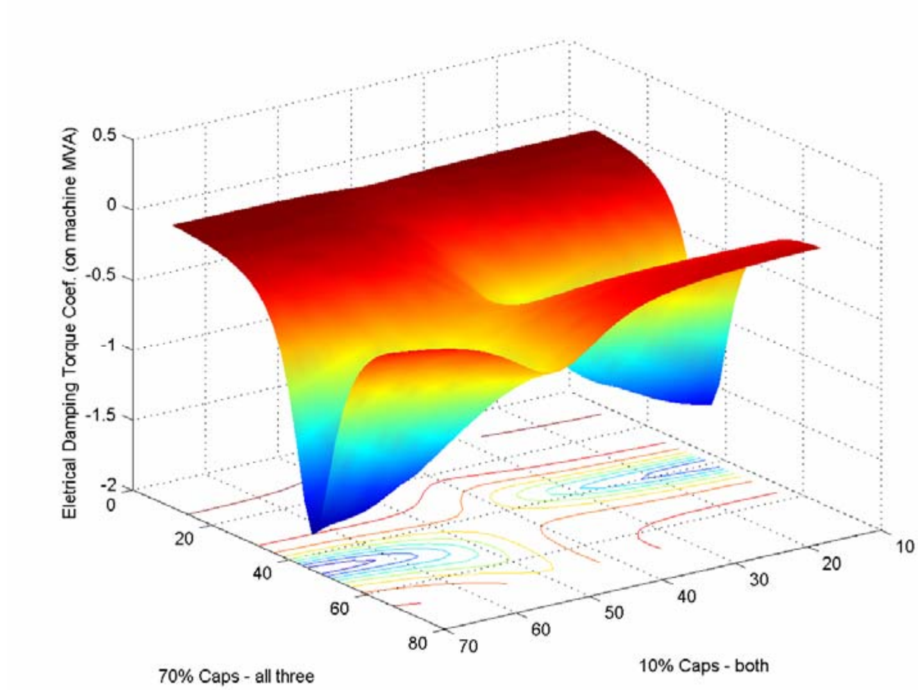


Figure J-4: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 28.8 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged.

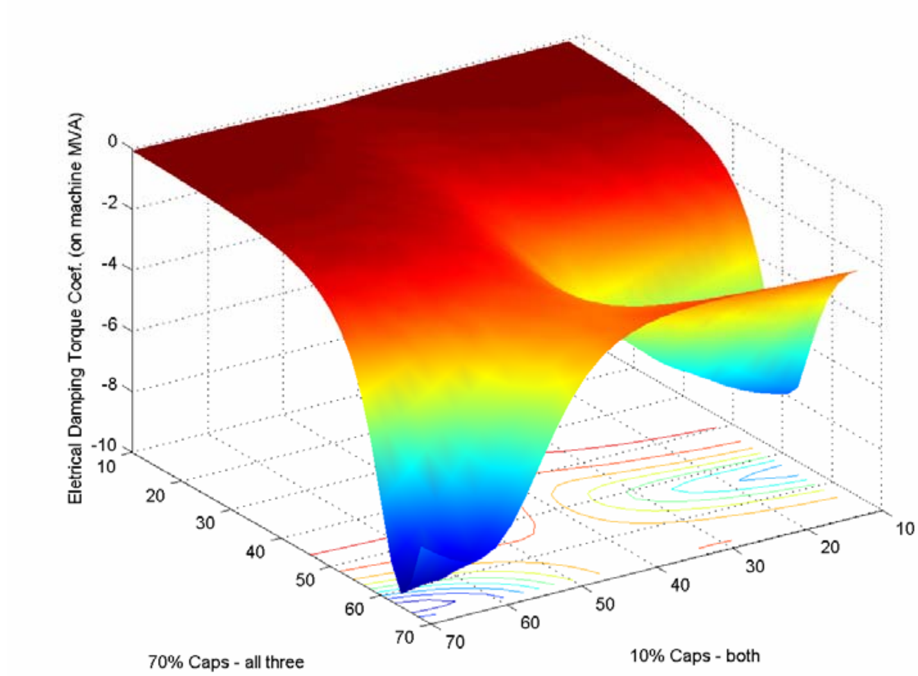


Figure J-5: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 28.8 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

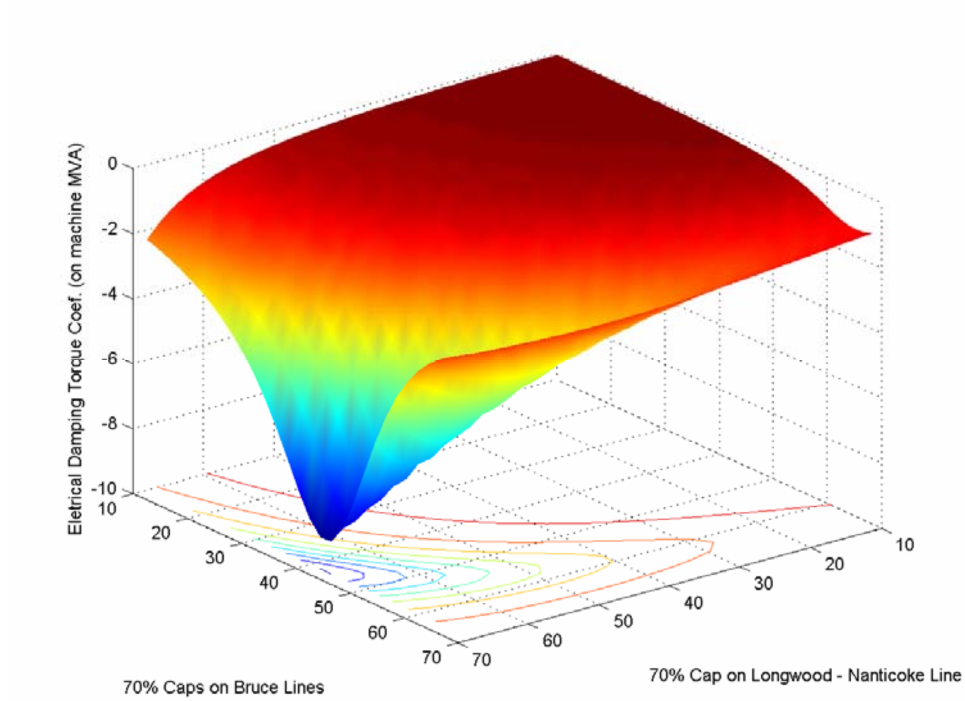


Figure J-6: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 28.8 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

35.3 Hz Mode:

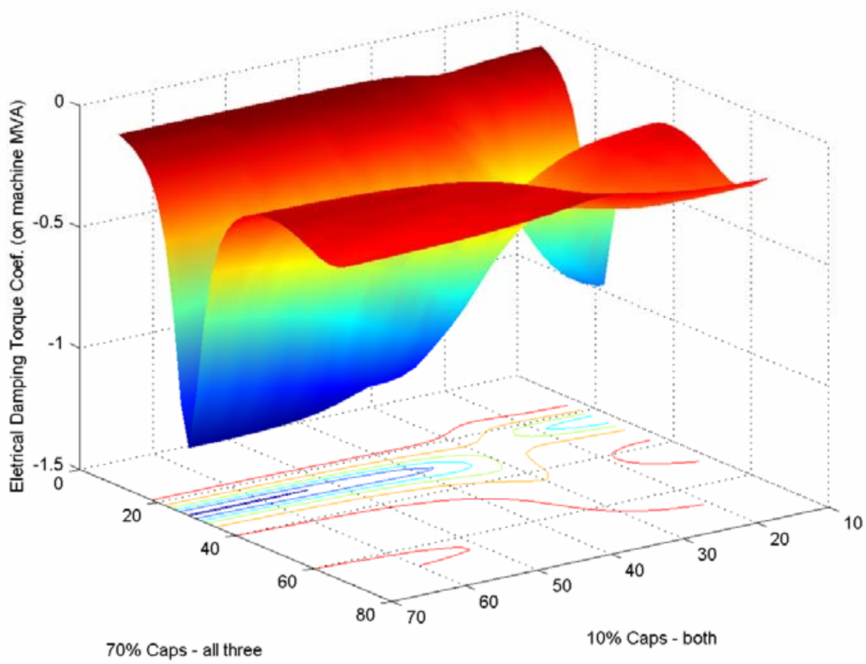


Figure J-7: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 35.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged.

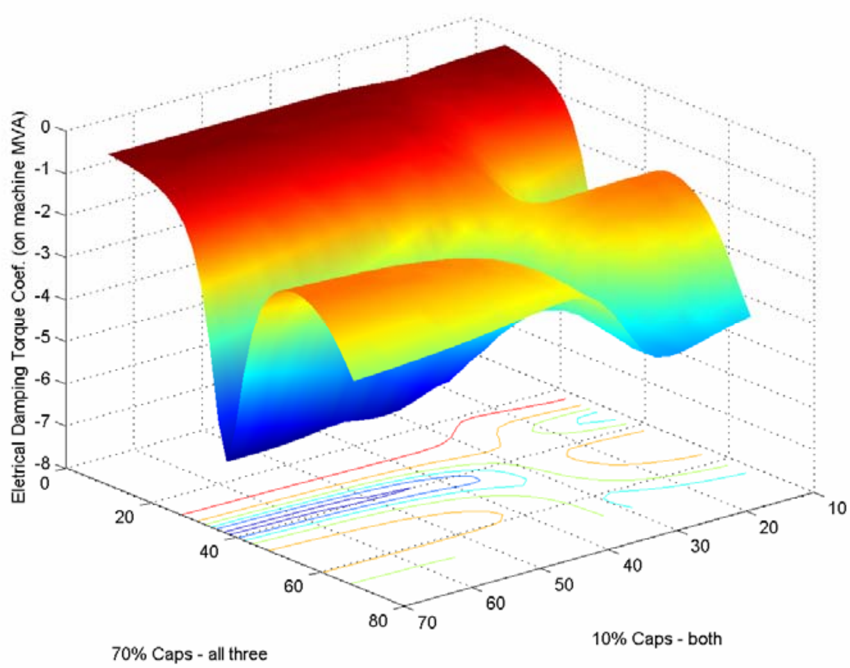


Figure J-8: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 35.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

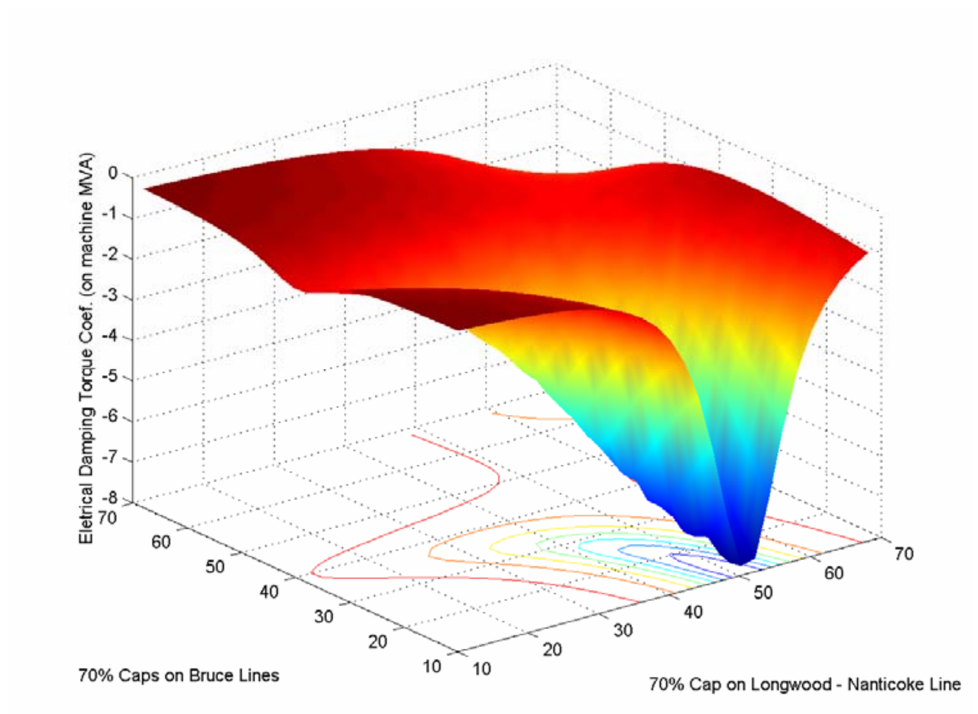


Figure J-9: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 35.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

56.2 Hz Mode:

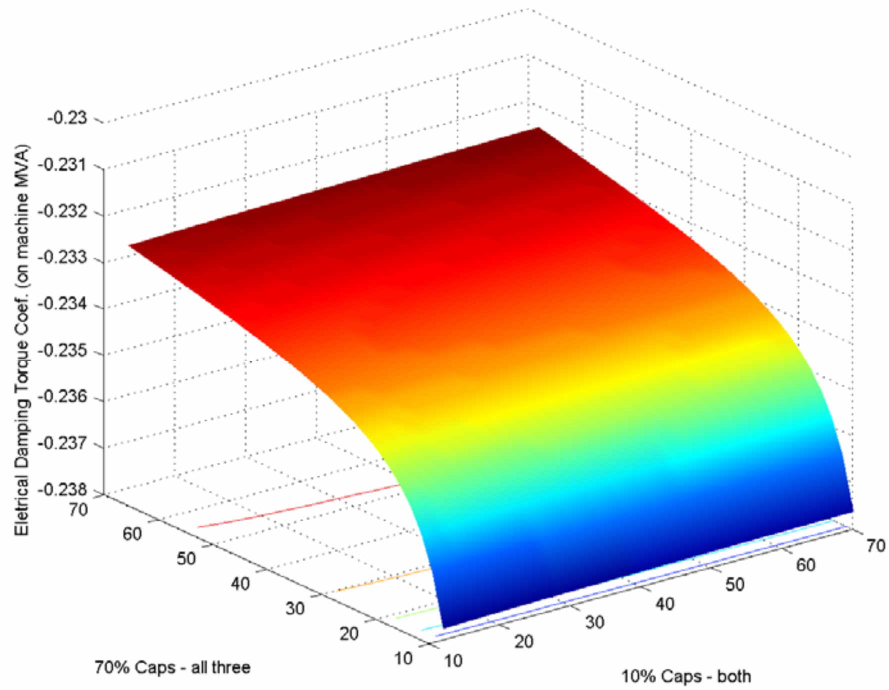


Figure J-10: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 56.2 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged.

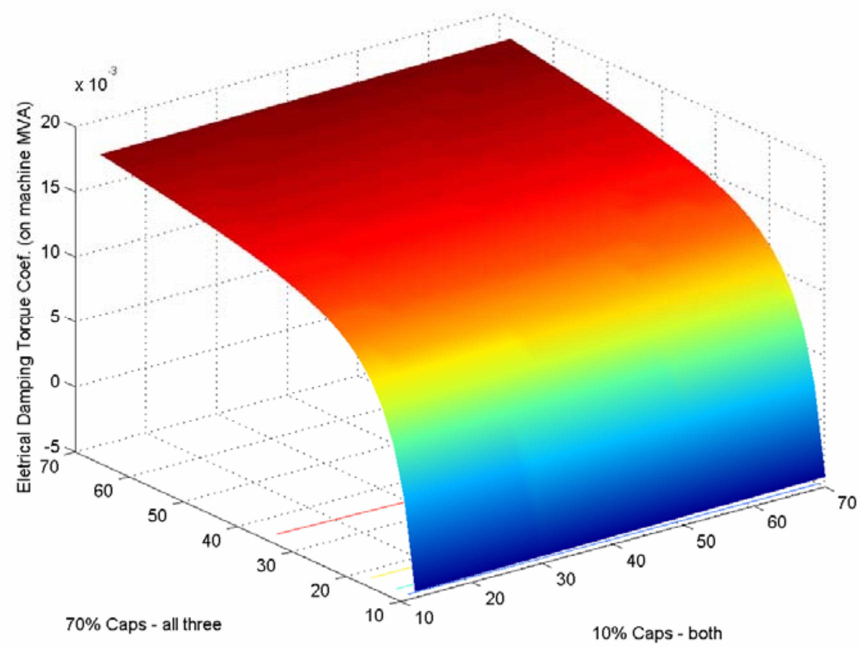


Figure J-11: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 56.2 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

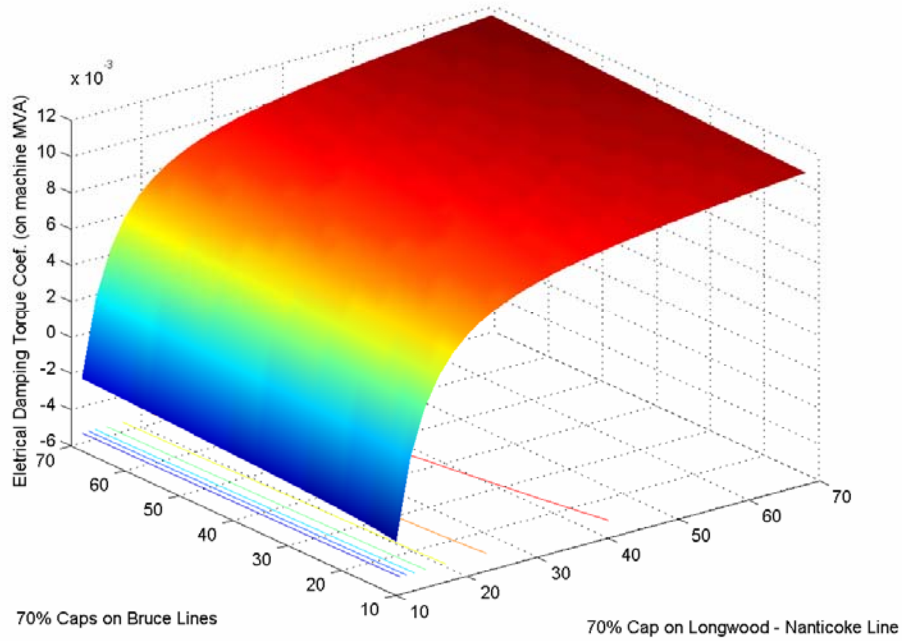


Figure J-12: Damping torque coefficient on machine MVA (G5 & 6 on-line). Plot at 56.2 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

14.3 Hz Mode:

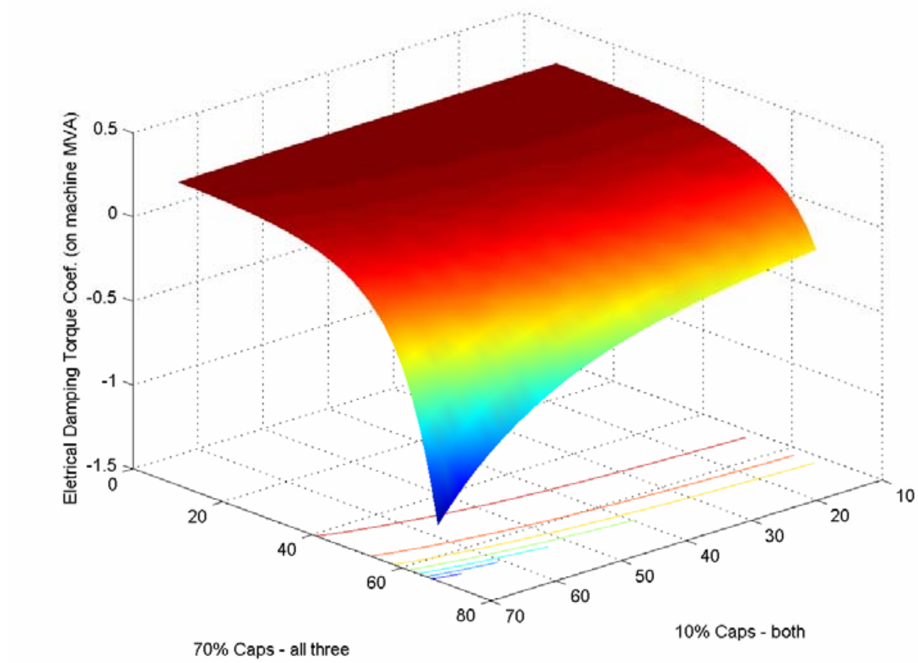


Figure J-13: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 14.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged.

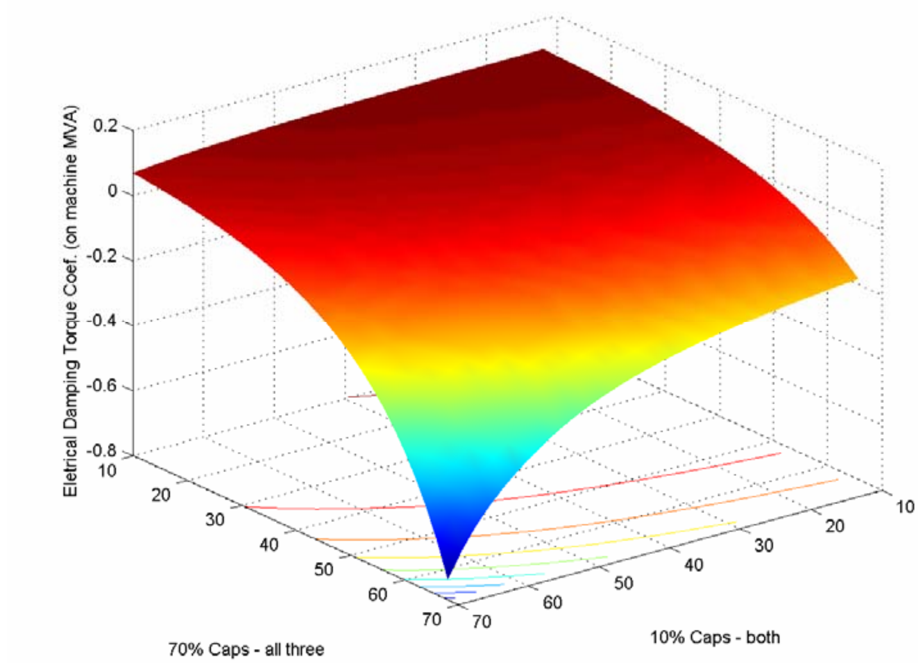


Figure J-14: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 14.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

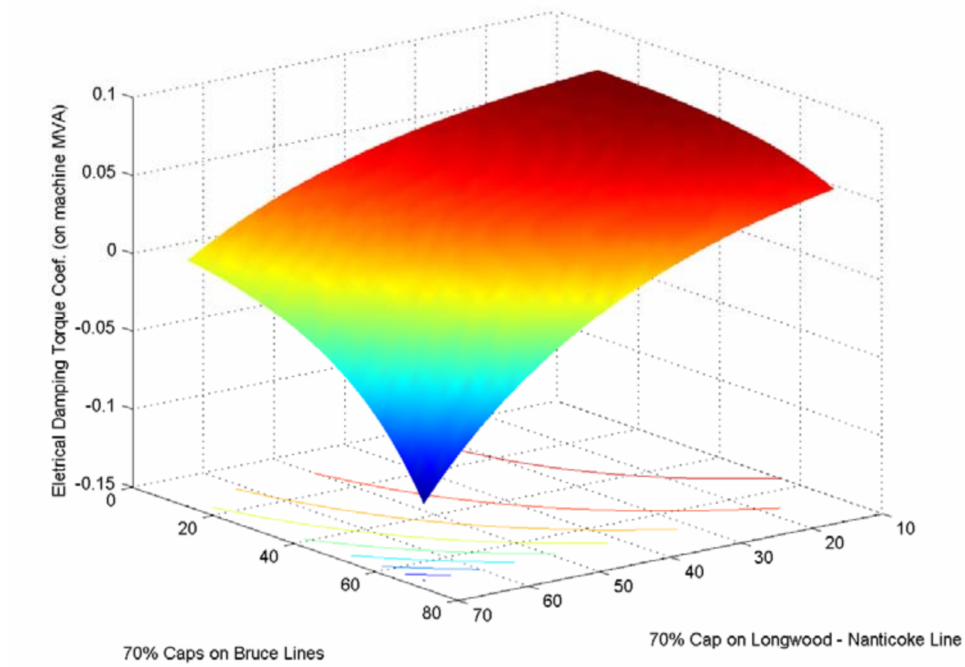


Figure J-15: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 14.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

25.9 Hz Mode:

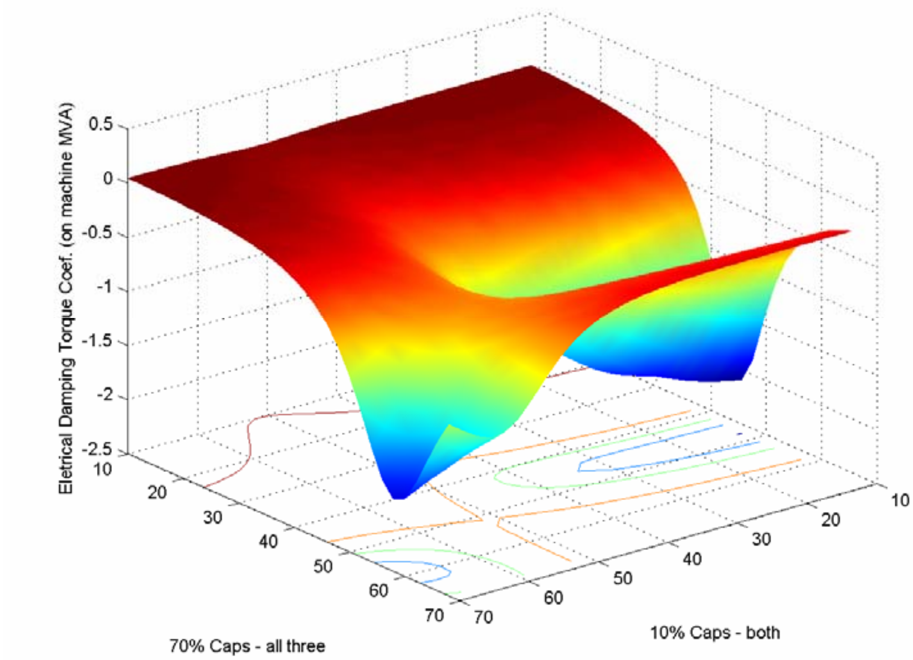


Figure J-16: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 25.9 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged.

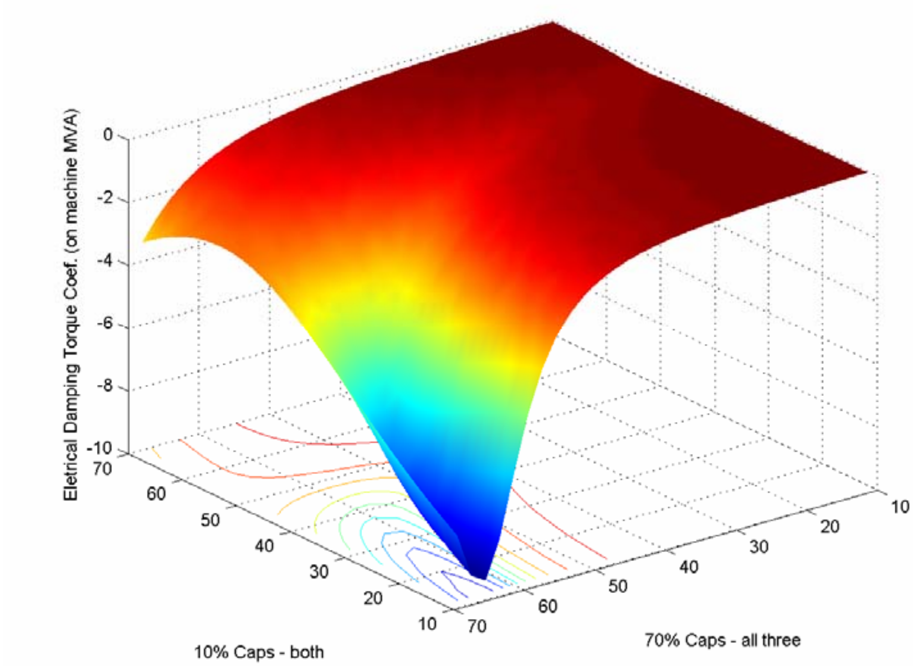


Figure J-17: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 25.9 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

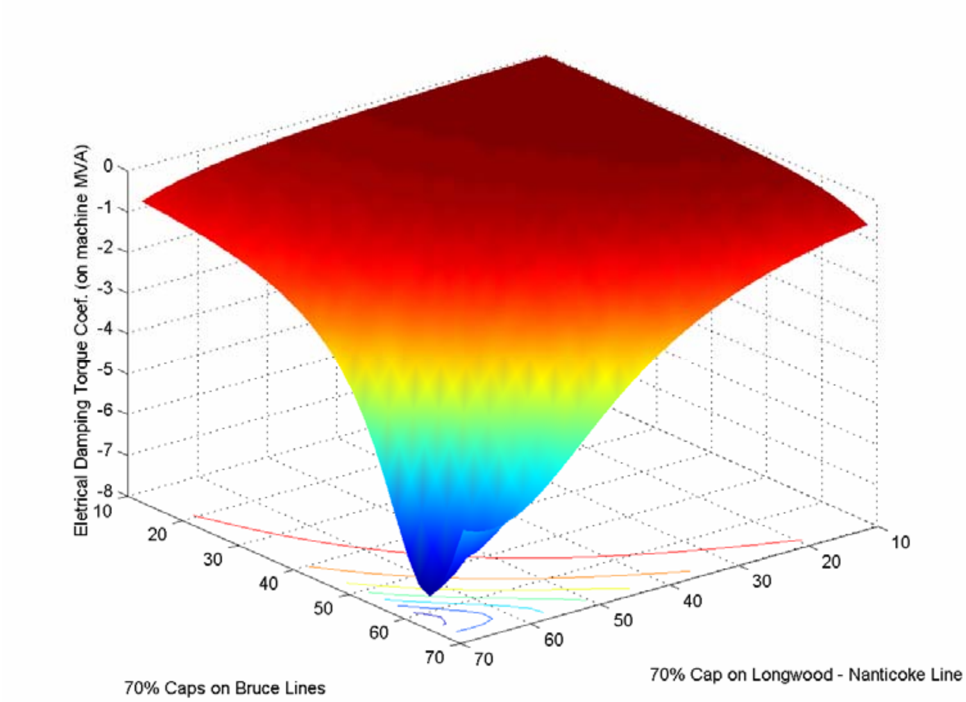


Figure J-18: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 25.9 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

<u>30.3 Hz Mode:</u>

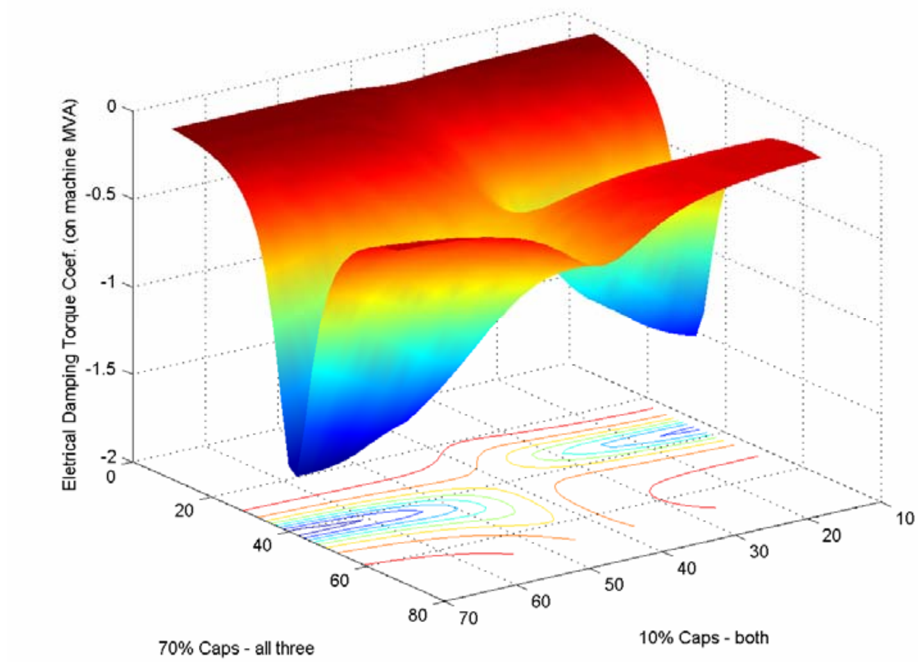


Figure J-19: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 30.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged.

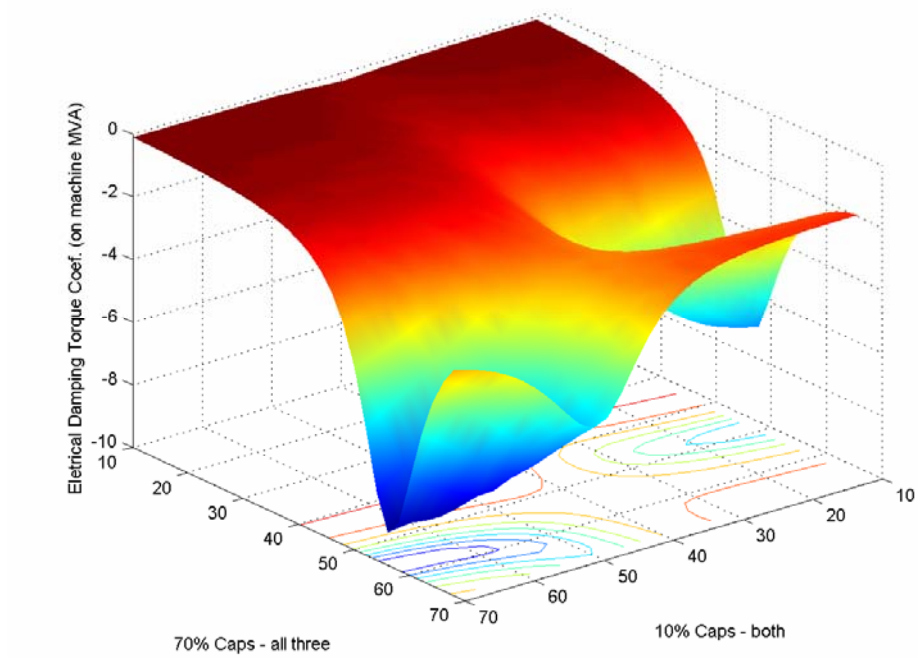


Figure J-20: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 30.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

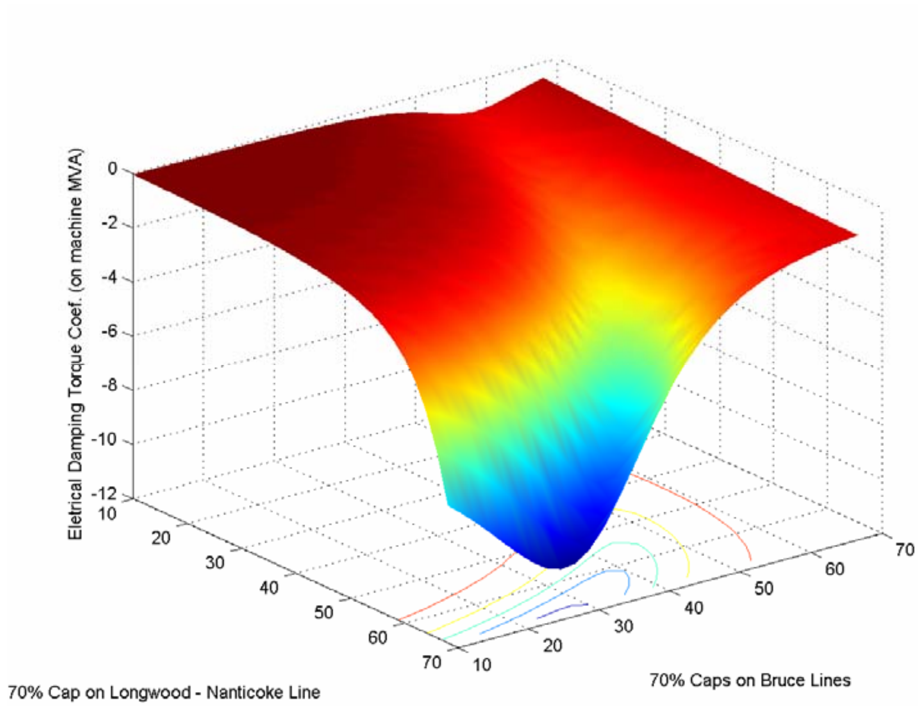


Figure J-21: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 30.3 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

53.7 Hz Mode:

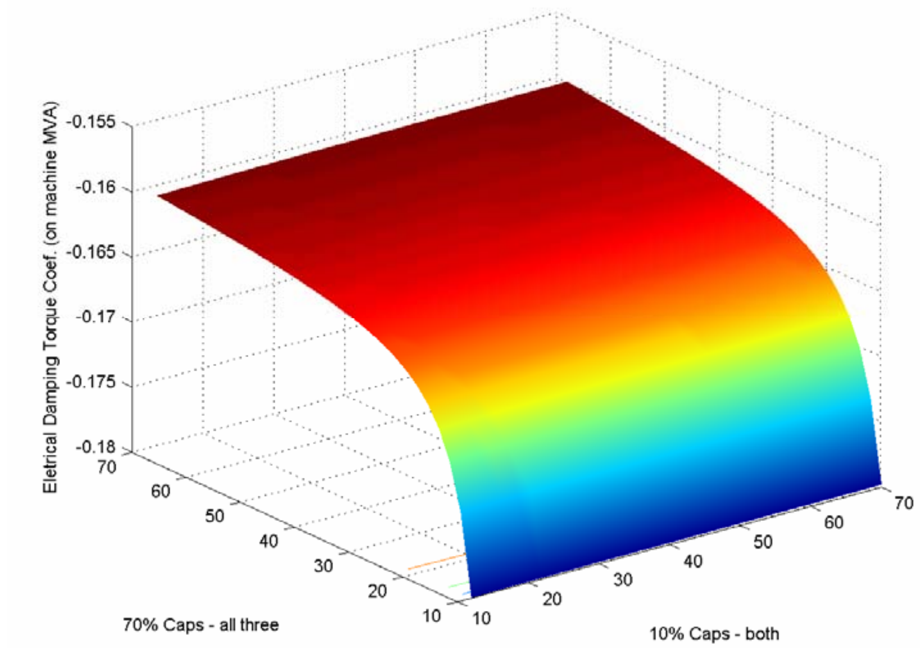


Figure J-22: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 53.7 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged.

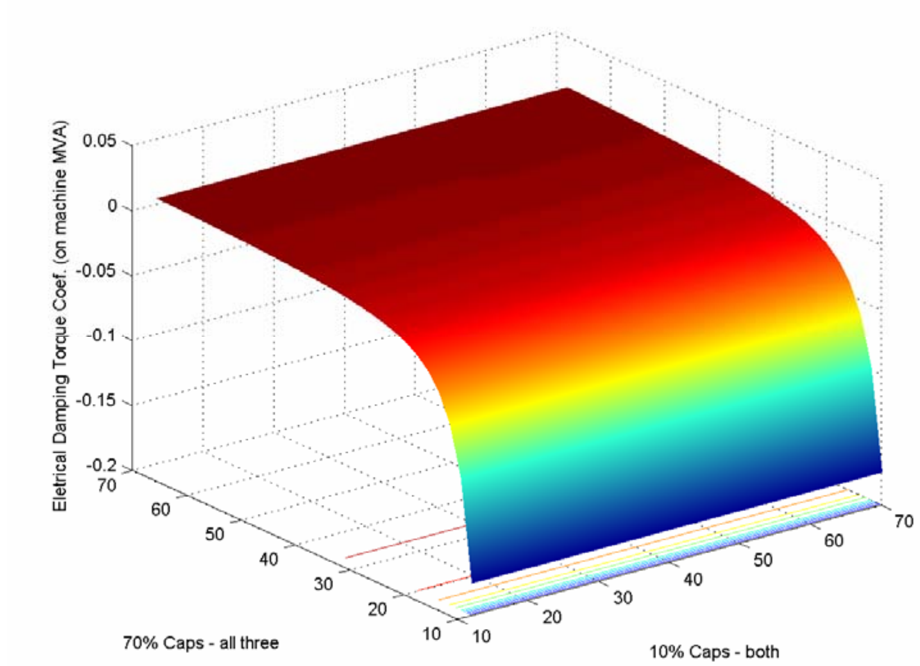


Figure J-23: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 53.7 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

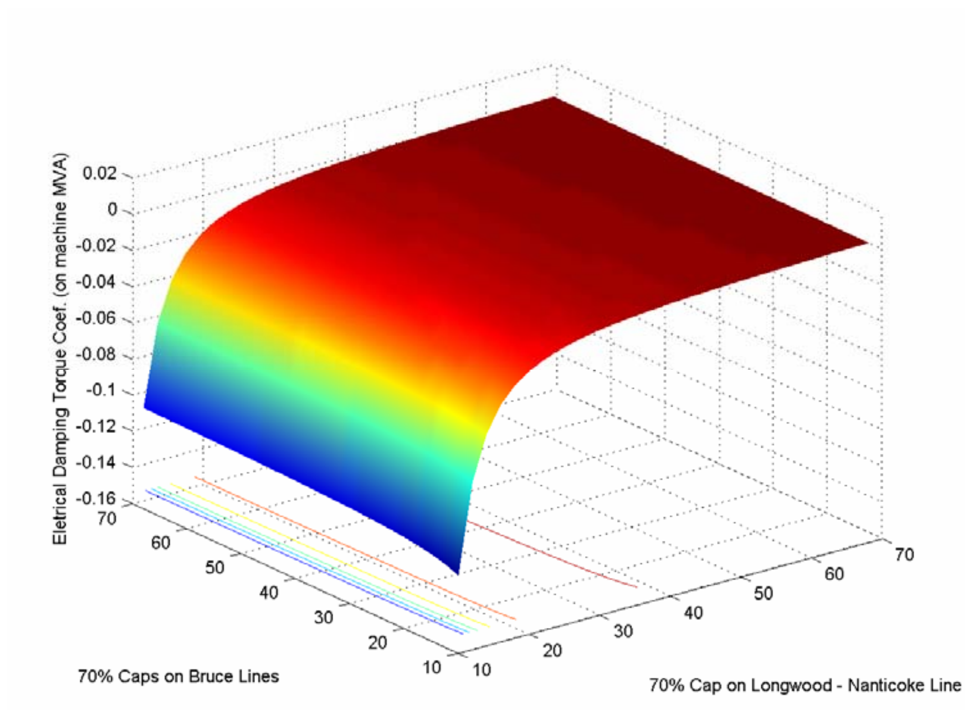


Figure J-24: Damping torque coefficient on machine MVA (G7 & 8 on-line). Plot at 53.7 Hz, with both Nanticoke to Milton and Nanticoke to Claireville 500 kV circuits outaged and both 500/230 kV Nanticoke transformers out of service.

APPENDIX K: 3-D Damping Plots for Bruce A Units

(Note: Z – axis on plots do not have the same scale)

K.1 Bruce A 230 kV units:

<u>8.66 Hz Mode:</u>

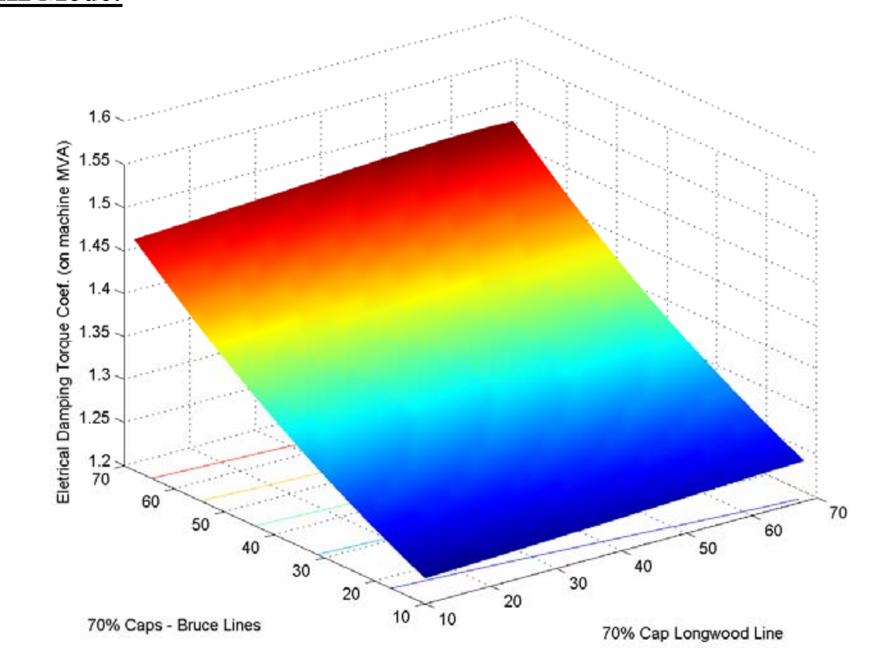


Figure K-1: Damping torque coefficient on machine MVA (two 230 kV units on-line; all 500 kV units off-line). Plot at 8.66 Hz, with Bruce A to Bruce B and Bruce A to Claireville 500 kV circuits outaged.

<u>16.06 Hz Mode:</u>

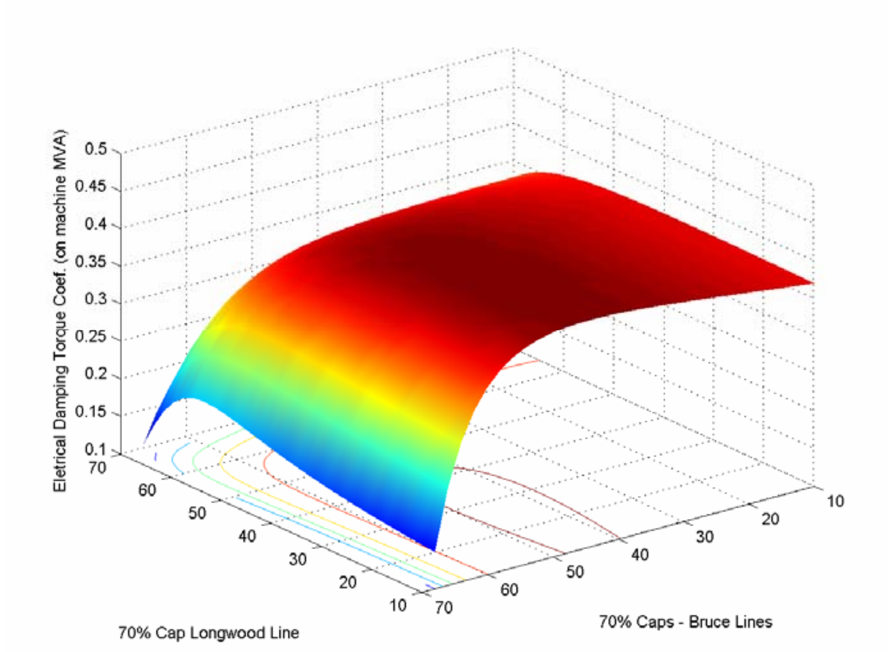


Figure K-2: Damping torque coefficient on machine MVA (two 230 kV units on-line; all 500 kV units off-line). Plot at 16.06 Hz, with Bruce A to Bruce B and Bruce A to Claireville 500 kV circuits outaged.

23.27 Hz Mode:

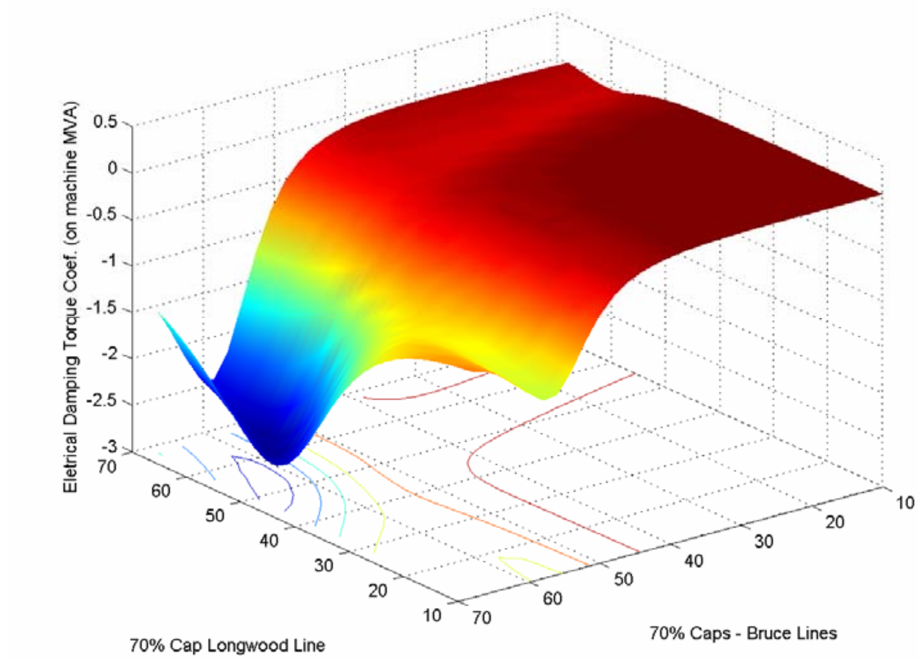


Figure K-3: Damping torque coefficient on machine MVA (two 230 kV units on-line; all 500 kV units off-line). Plot at 23.27Hz, with Bruce A to Bruce B and Bruce A to Claireville 500 kV circuits outaged.

23.89 Hz Mode:

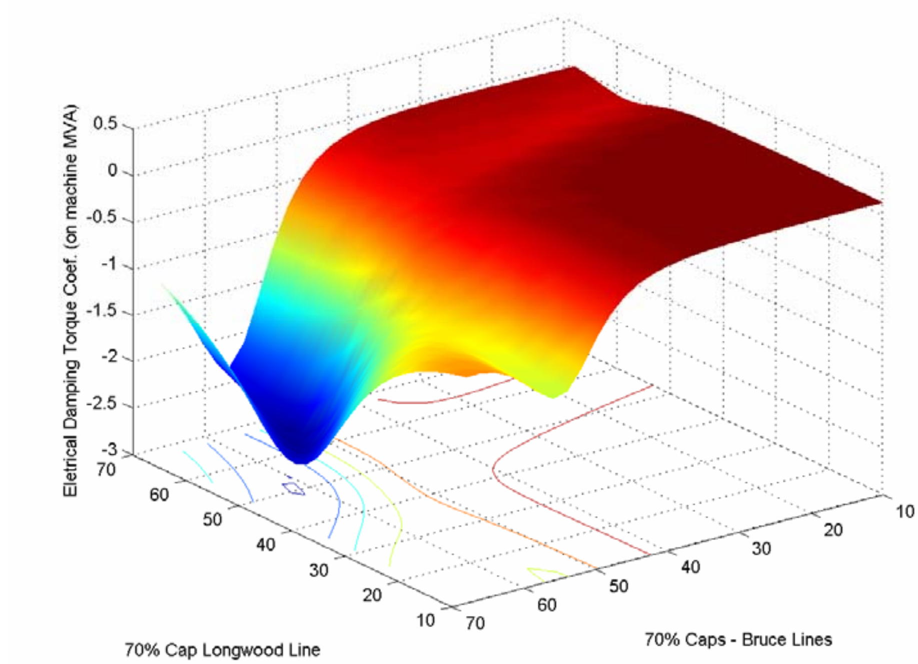


Figure K-4: Damping torque coefficient on machine MVA (two 230 kV units on-line; all 500 kV units off-line). Plot at 23.89 Hz, with Bruce A to Bruce B and Bruce A to Claireville 500 kV circuits outaged.

K.2 Bruce A 500 kV units:

<u>8.66 Hz Mode:</u>

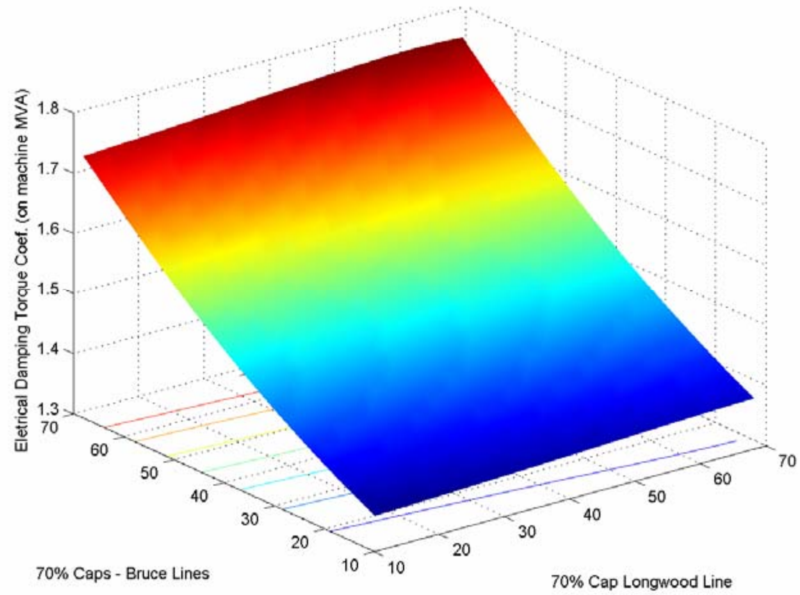


Figure K-5: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 8.66 Hz, with Bruce A to Bruce B and Bruce A to Claireville 500 kV circuits outaged.

<u>16.06 Hz Mode:</u>

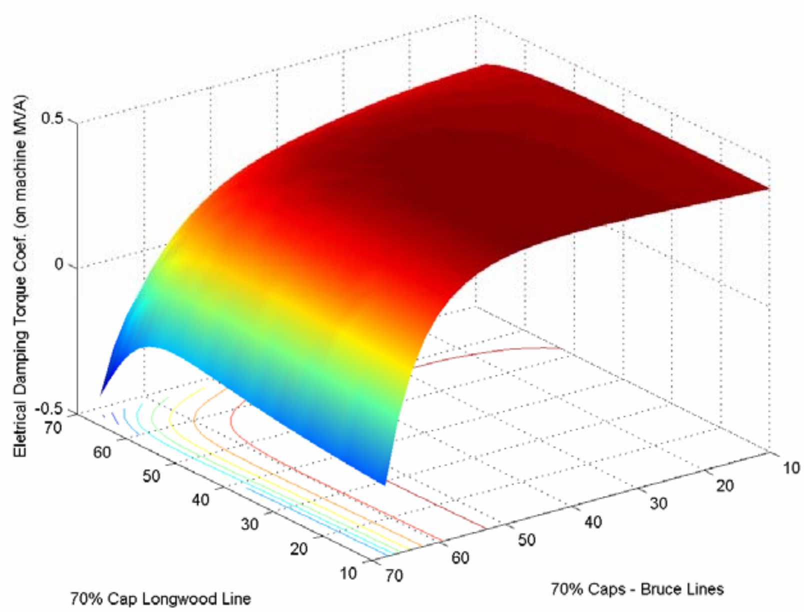


Figure K-6: Damping torque coefficient on machine MVA (two 500 kV units on-line; all230 kV units off-line). Plot at 16.06 Hz, with Bruce A to Bruce B and Bruce A to Claireville 500 kV circuits outaged.

23.27 Hz Mode:

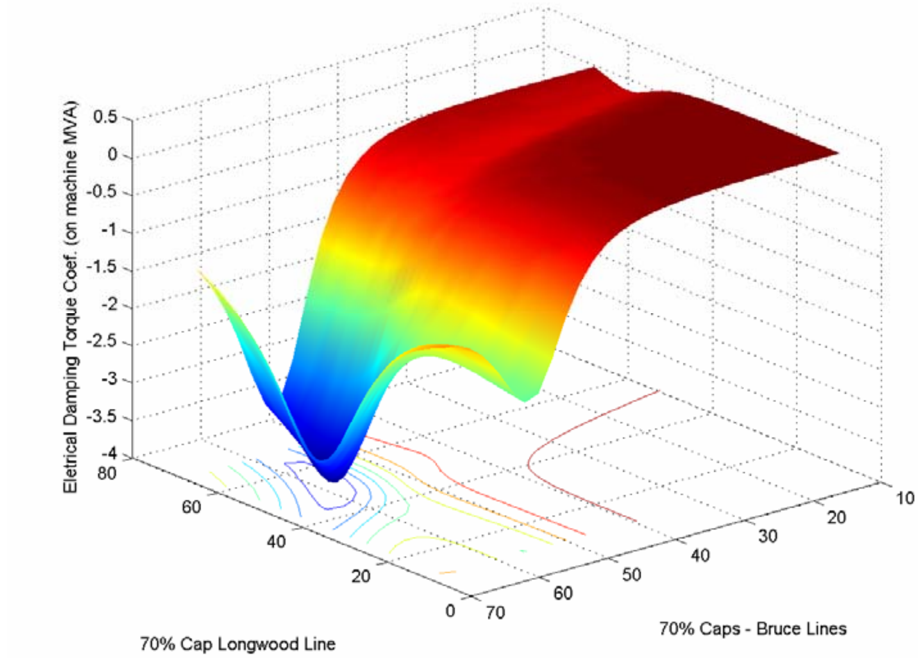


Figure K-7: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 23.27Hz, with Bruce A to Bruce B and Bruce A to Claireville 500 kV circuits outaged.

23.89 Hz Mode:

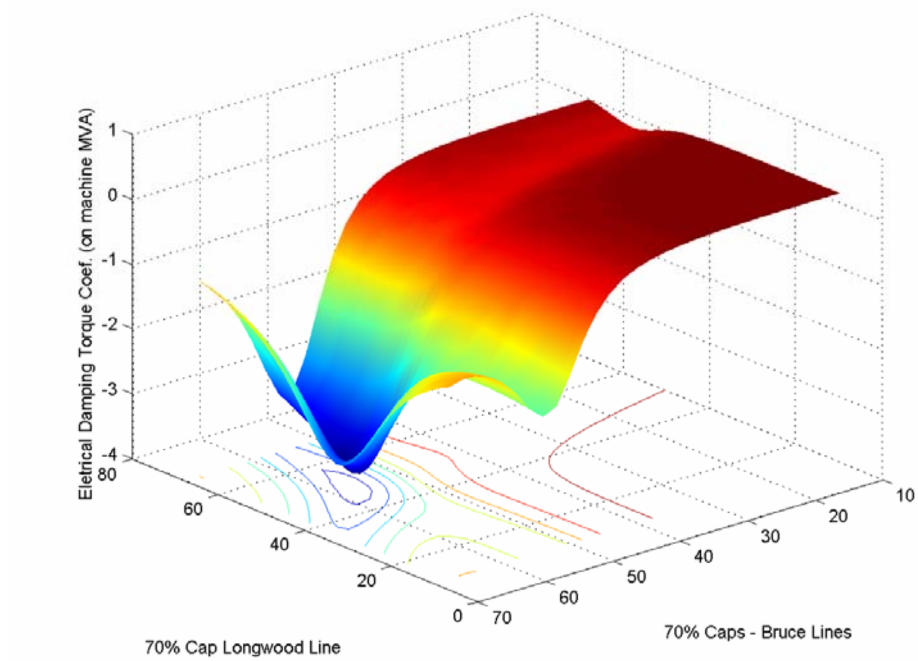


Figure K-8: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 23.89 Hz, with Bruce A to Bruce B and Bruce A to Claireville 500 kV circuits outaged.

8.66 Hz Mode:

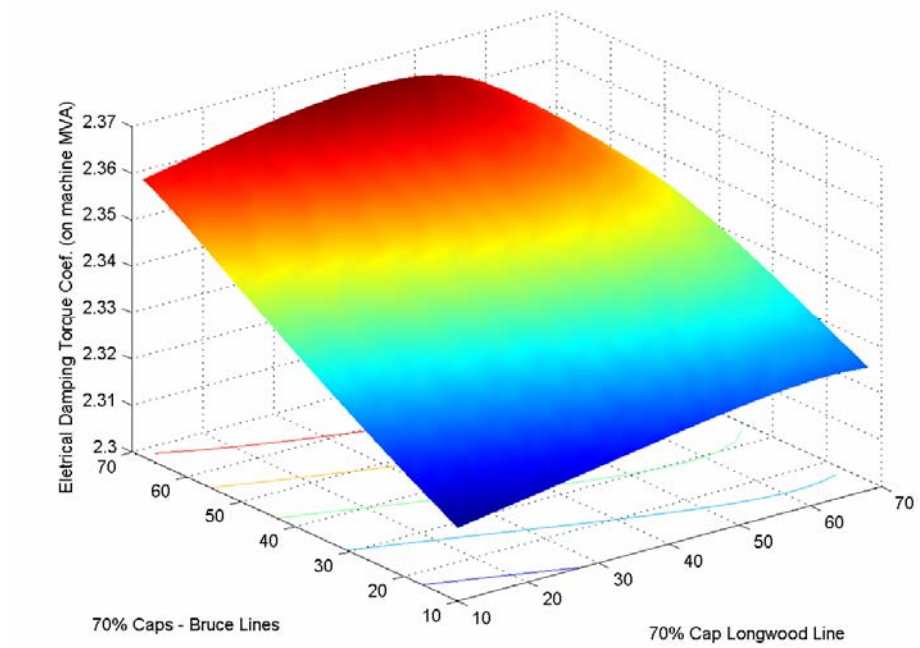


Figure K-9: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 8.66 Hz, with Bruce A to Claireville and Bruce B to Milton 500 kV circuits outaged.

16.06 Hz Mode:

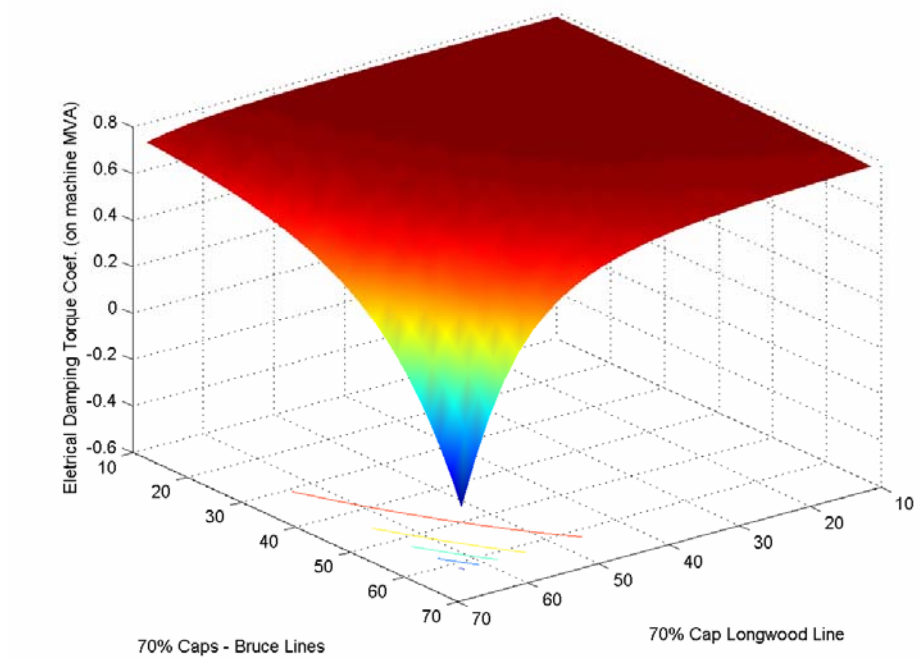


Figure K-10: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 16.06 Hz, with Bruce A to Claireville and Bruce B to Milton 500 kV circuits outaged.

23.27 Hz Mode:

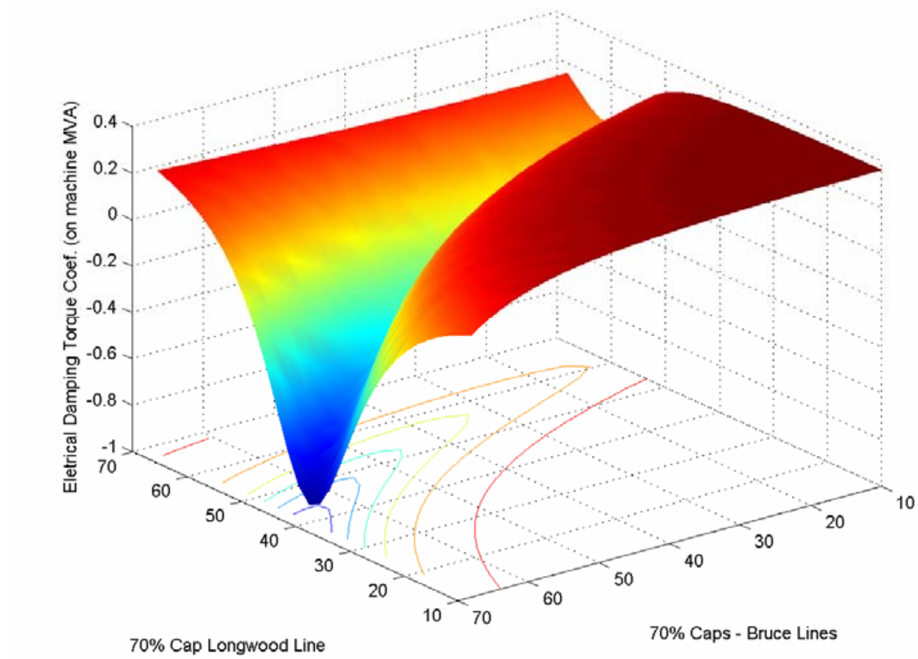


Figure K-11: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 23.27 Hz, with Bruce A to Claireville and Bruce B to Milton 500 kV circuits outaged.

23.89 Hz Mode:

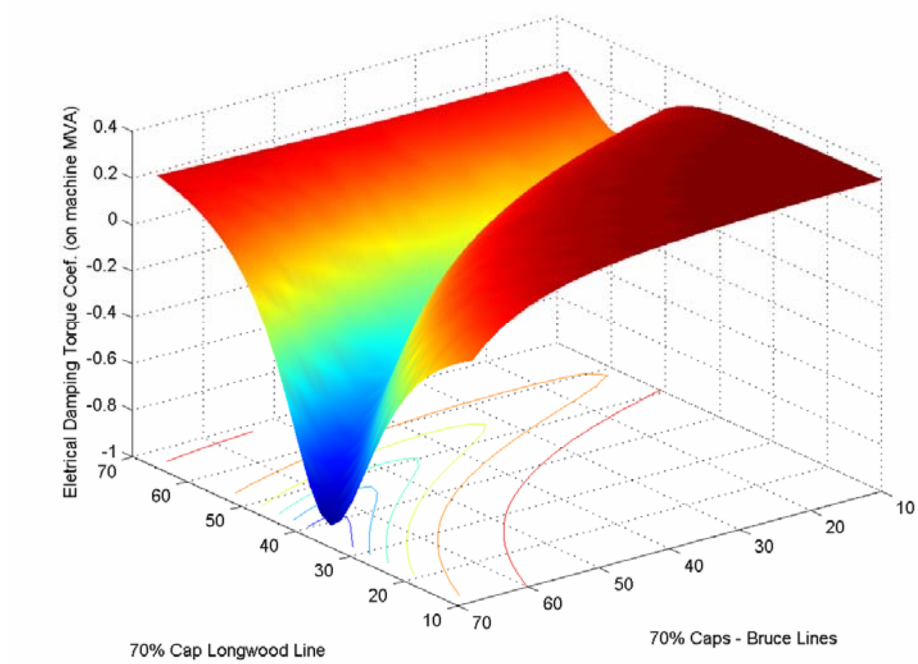


Figure K-12: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 23.89 Hz, with Bruce A to Claireville and Bruce B to Milton 500 kV circuits outaged.

8.66 Hz Mode:

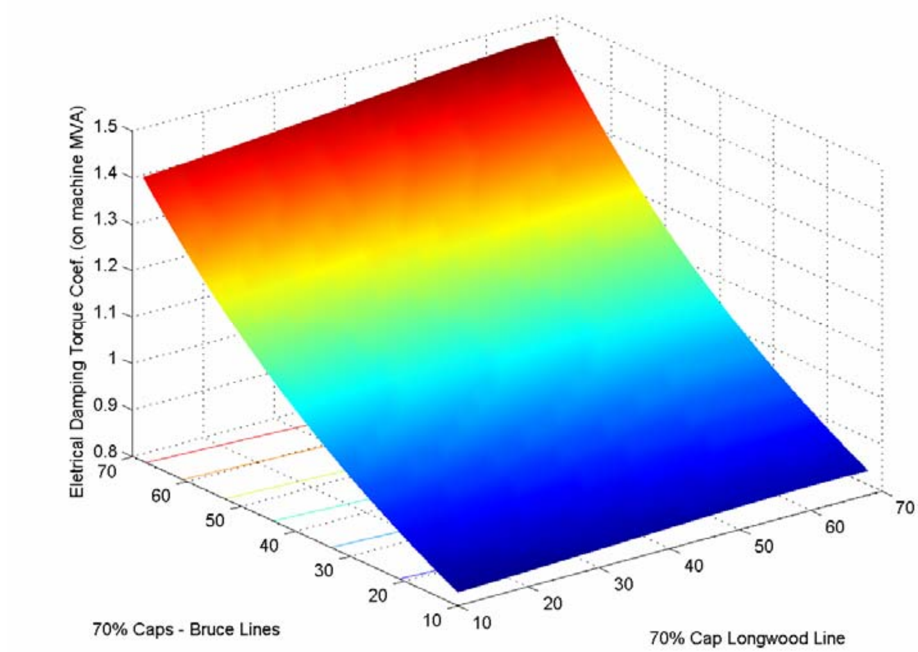


Figure K-13: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 8.66 Hz, with Bruce A to Claireville and Bruce A to Bruce B 500 kV lines and all three Bruce A 500/230 kV transformers out.

16.06 Hz Mode:

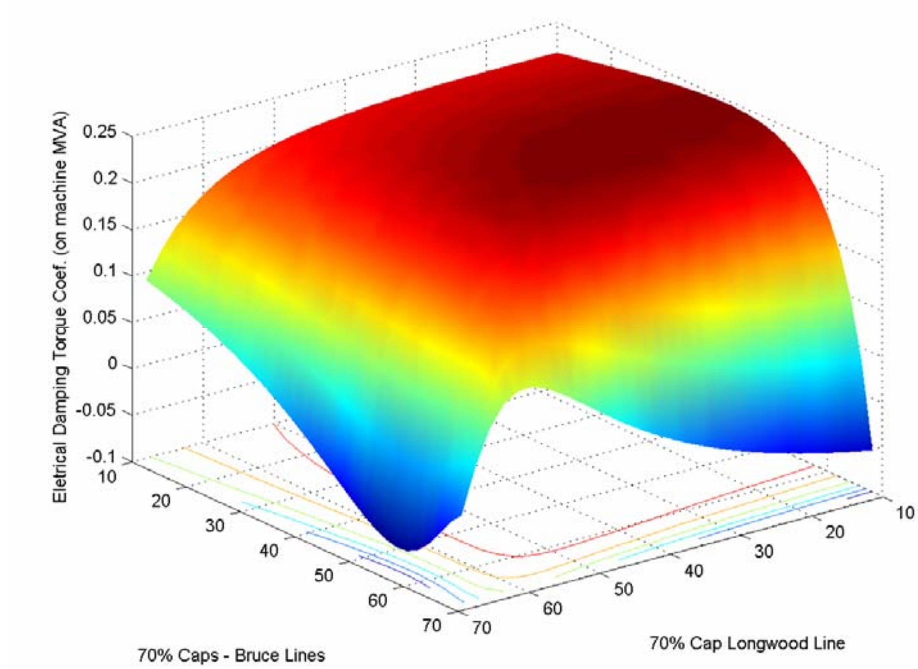


Figure K-14: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 16.06 Hz, with Bruce A to Claireville and Bruce A to Bruce B 500 kV lines and all three Bruce A 500/230 kV transformers out.

23.27 Hz Mode:

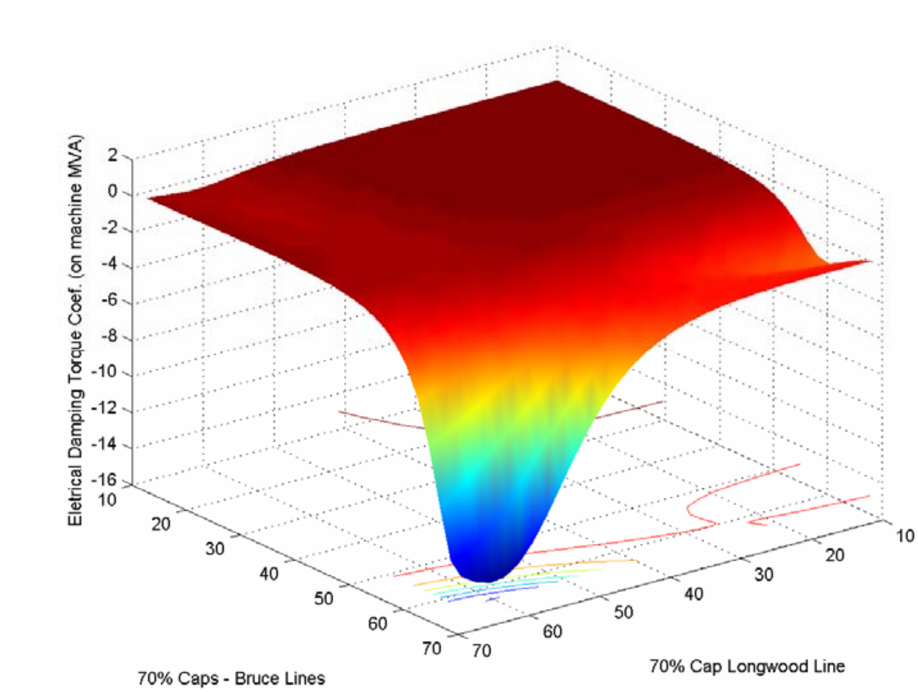


Figure K-15: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 23.27 Hz, with Bruce A to Claireville and Bruce A to Bruce B 500 kV lines and all three Bruce A 500/230 kV transformers out.

23.89 Hz Mode:

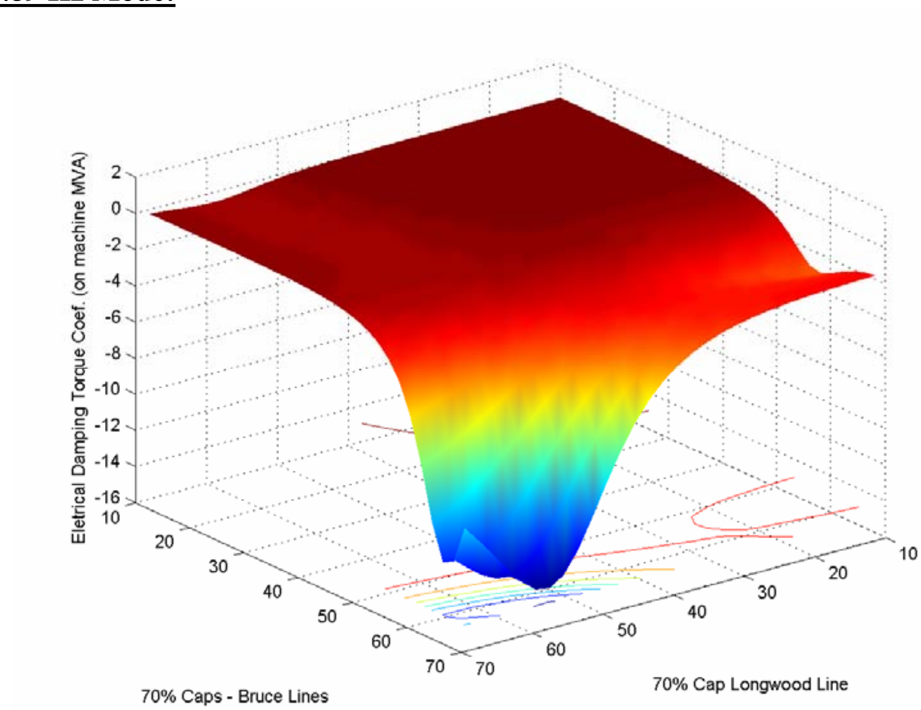


Figure K-16: Damping torque coefficient on machine MVA (two 500 kV units on-line; all 230 kV units off-line). Plot at 23.89 Hz, with Bruce A to Claireville and Bruce A to Bruce B 500 kV lines and all three Bruce A 500/230 kV transformers out.

APPENDIX L: 3-D Damping Plots for Bruce B units

(Note: Z – axis on plots do not have the same scale)

7.5 Hz Mode:

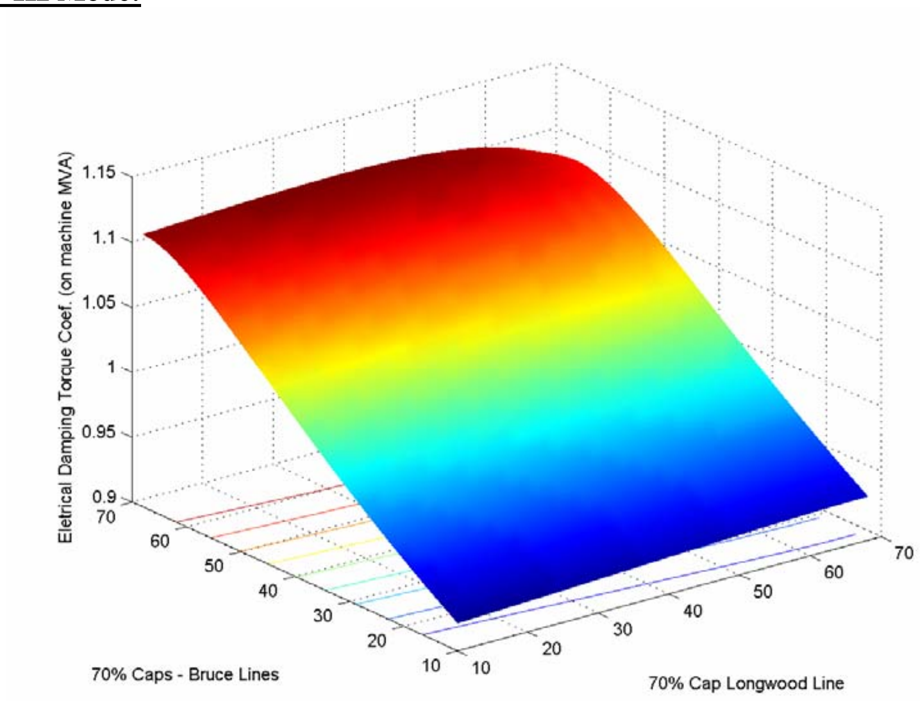


Figure L-1: Damping torque coefficient on machine MVA (four units on-line). Plot at 7.5 Hz, with Bruce A to Bruce B 500 kV circuit outaged.

14.19 Hz Mode:

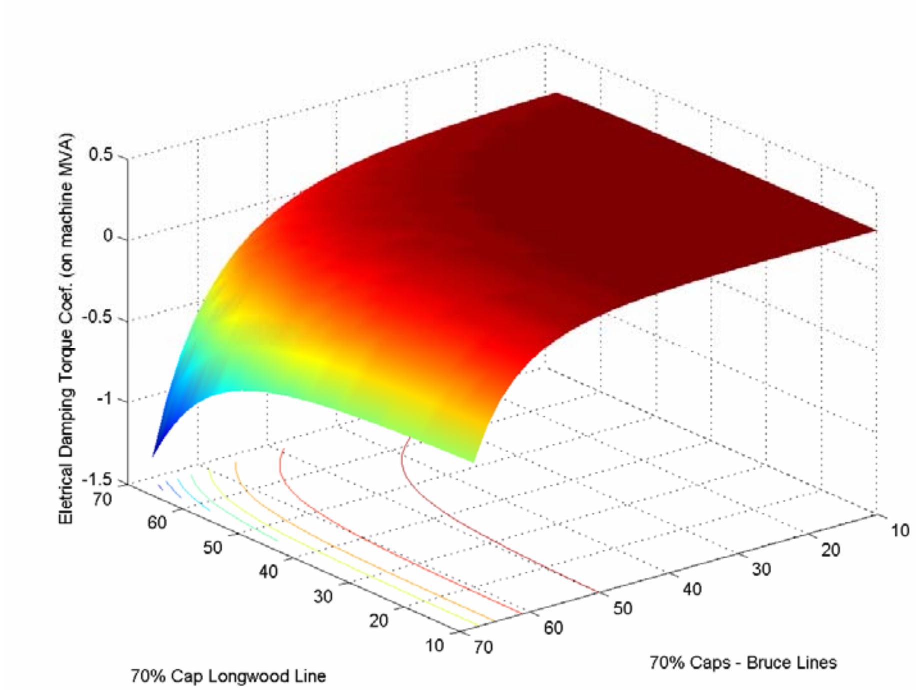


Figure L-2: Damping torque coefficient on machine MVA (four units on-line). Plot at 14.19 Hz, with Bruce A to Bruce B 500 kV circuit outaged.

19.31 Hz Mode:

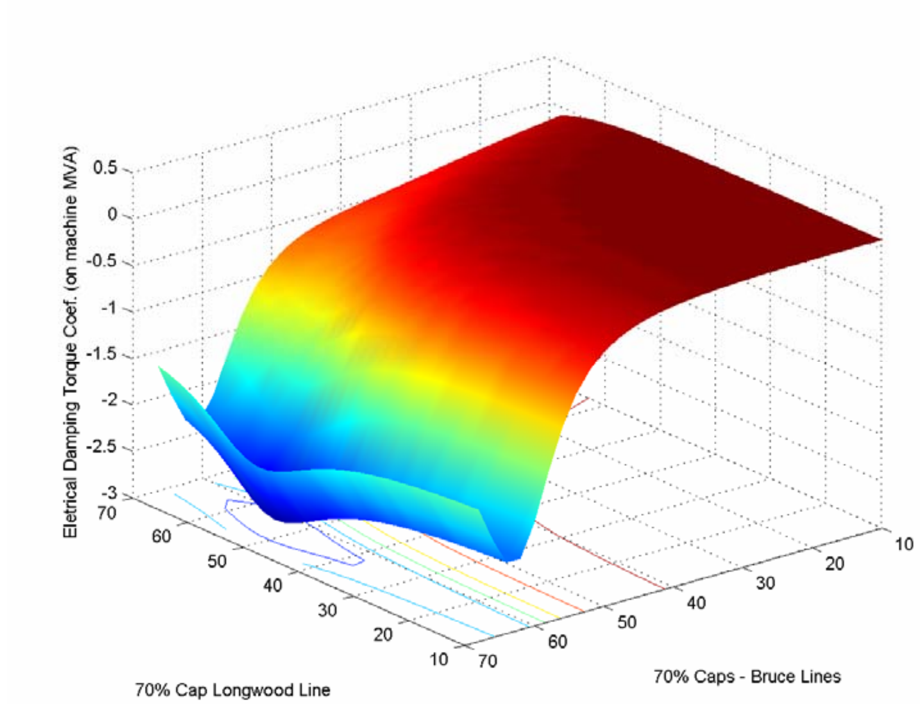


Figure L-3: Damping torque coefficient on machine MVA (four units on-line). Plot at 19.31 Hz, with Bruce A to Bruce B 500 kV circuit outaged.

22.25 Hz Mode:

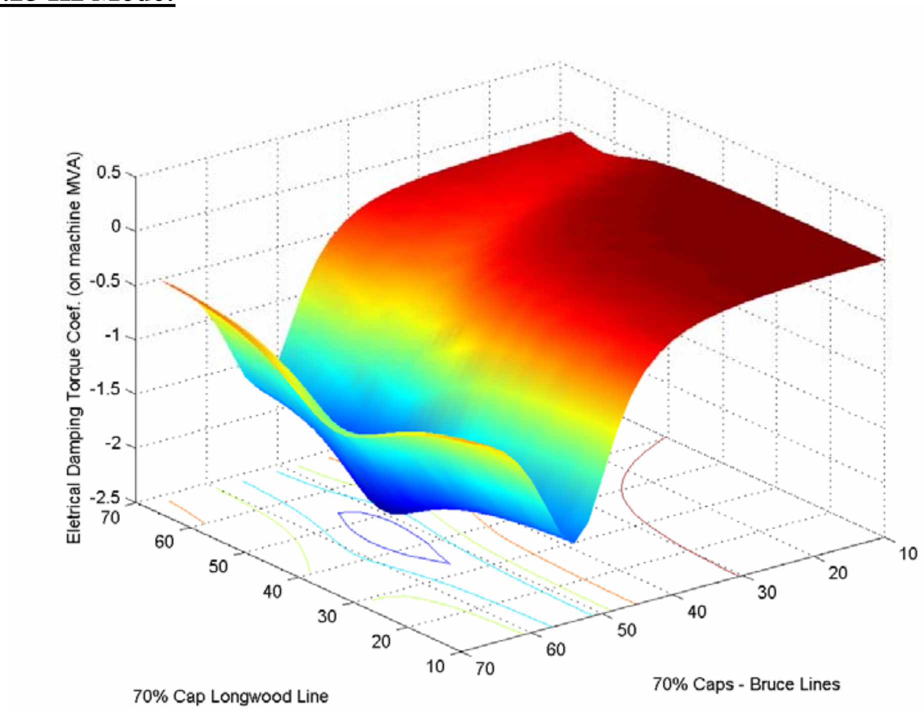


Figure L-4: Damping torque coefficient on machine MVA (four units on-line). Plot at 22.25 Hz, with Bruce A to Bruce B 500 kV circuit outaged.

7.5 Hz Mode:

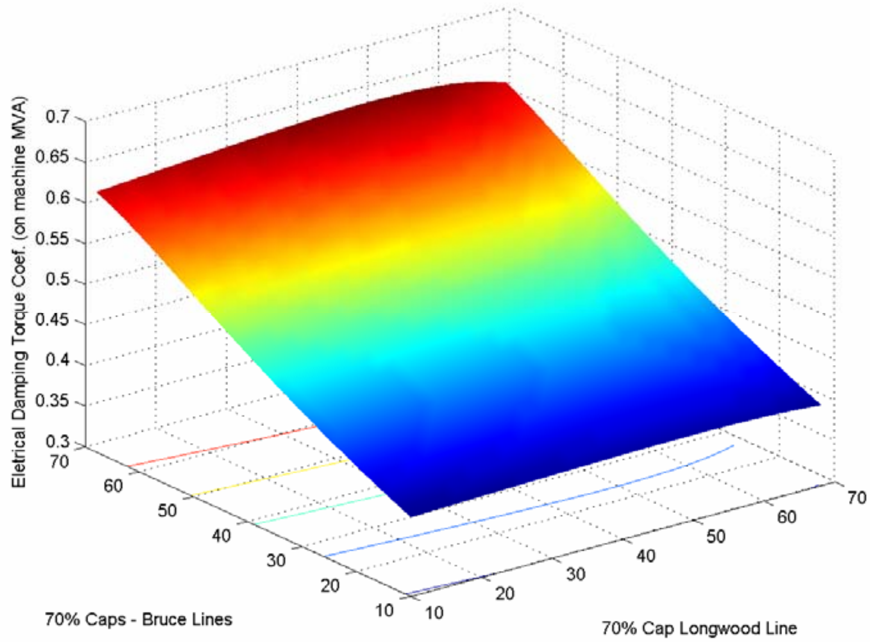


Figure L-5: Damping torque coefficient on machine MVA (four units on-line). Plot at 7.5 Hz, with Bruce A to Bruce B and Bruce B to Milton 500 kV circuits outaged.

14.19 Hz Mode:

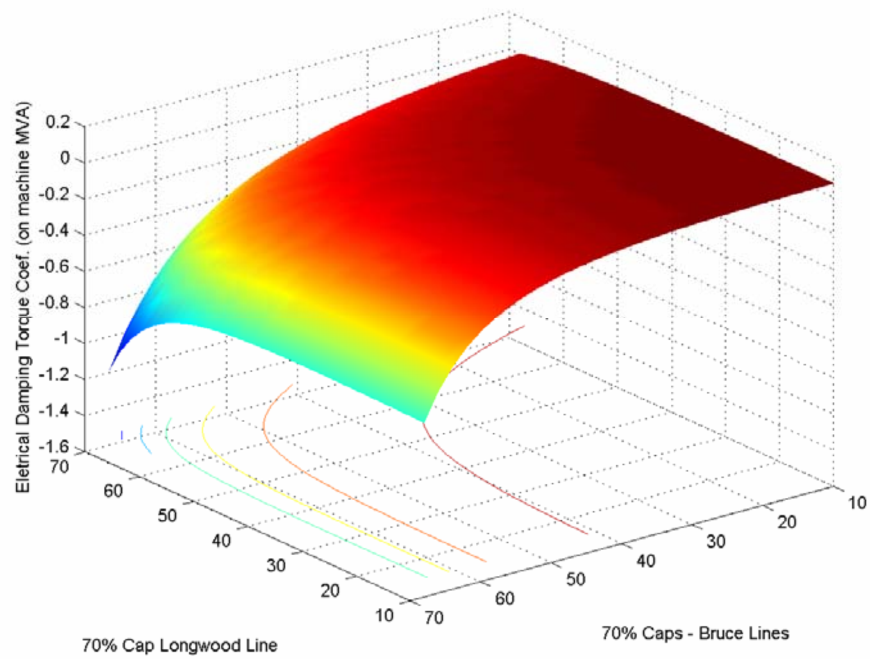


Figure L-6: Damping torque coefficient on machine MVA (four units on-line). Plot at 14.19 Hz, with Bruce A to Bruce B and Bruce B to Milton 500 kV circuits outaged.

19.31 Hz Mode:

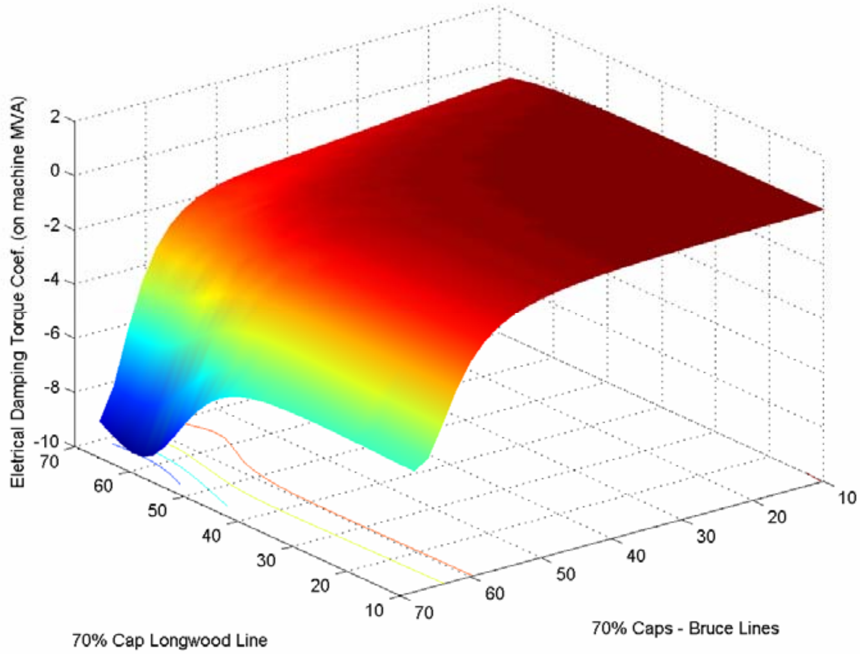


Figure L-7: Damping torque coefficient on machine MVA (four units on-line). Plot at 19.31 Hz, with Bruce A to Bruce B and Bruce B to Milton 500 kV circuits outaged.

22.25 Hz Mode:

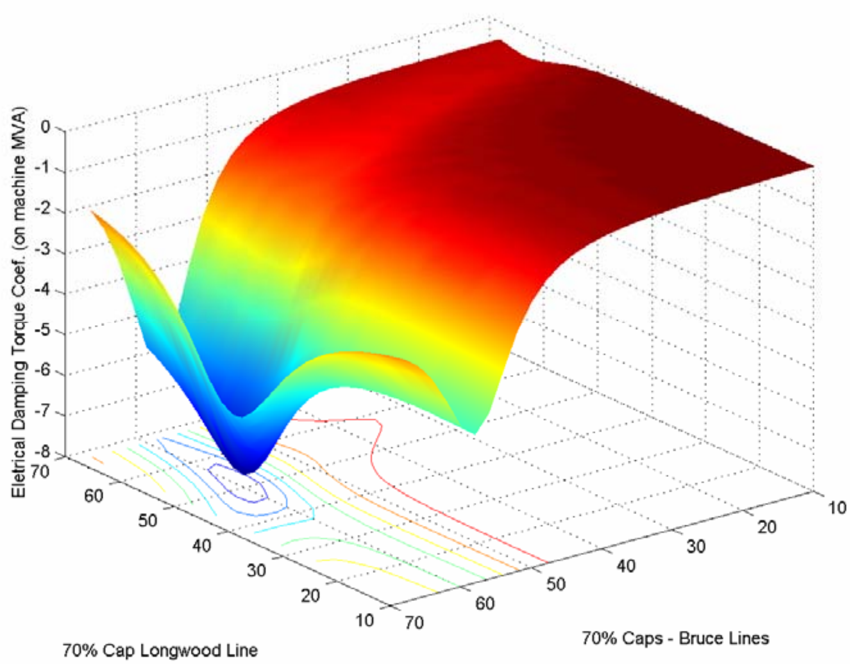


Figure L-8: Damping torque coefficient on machine MVA (four units on-line). Plot at 22.25Hz, with Bruce A to Bruce B and Bruce B to Milton 500 kV circuits outaged.

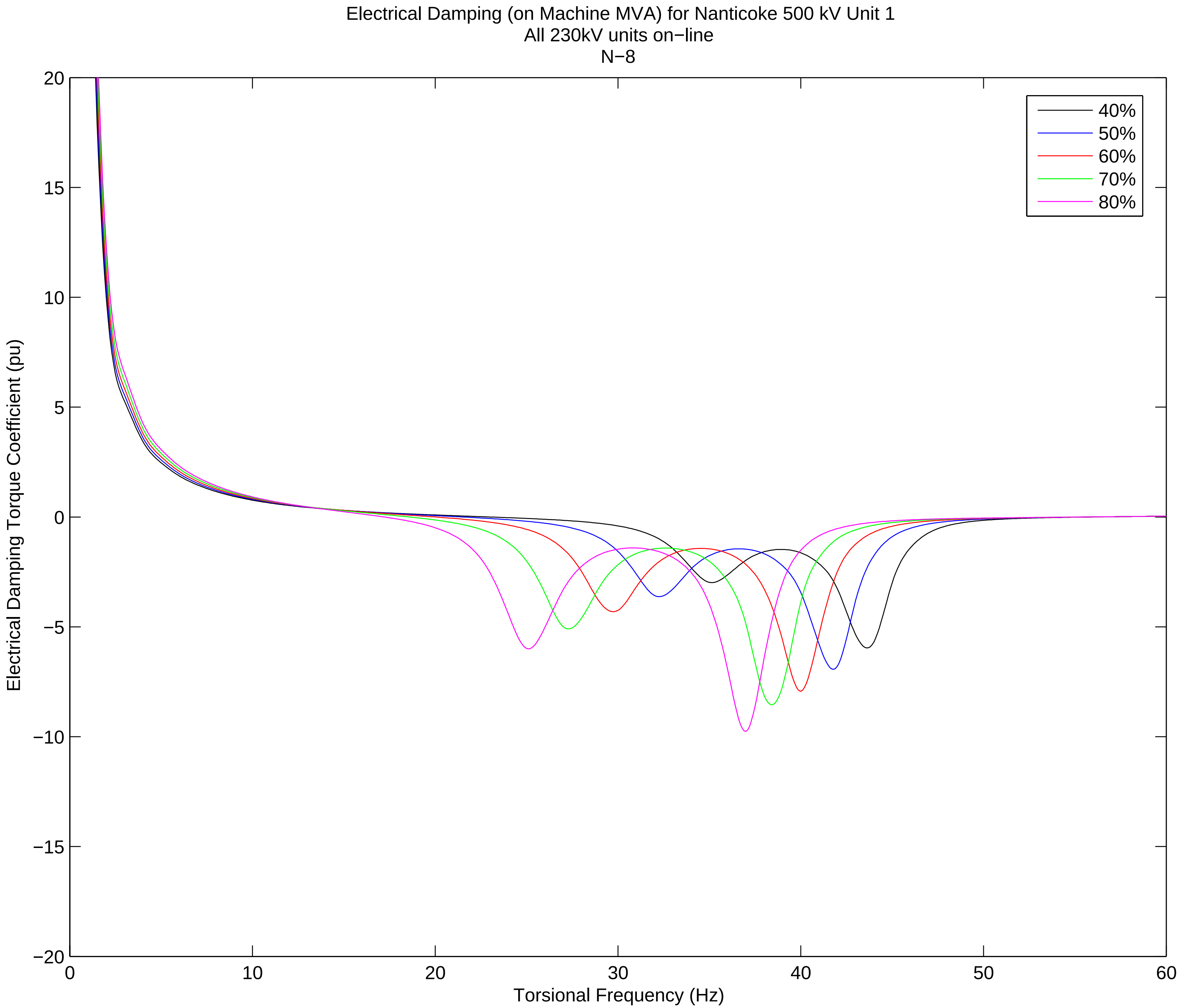
APPENDIX M: Damping Sensitivity Plots

Appendix M – Damping Sensitivity Plots

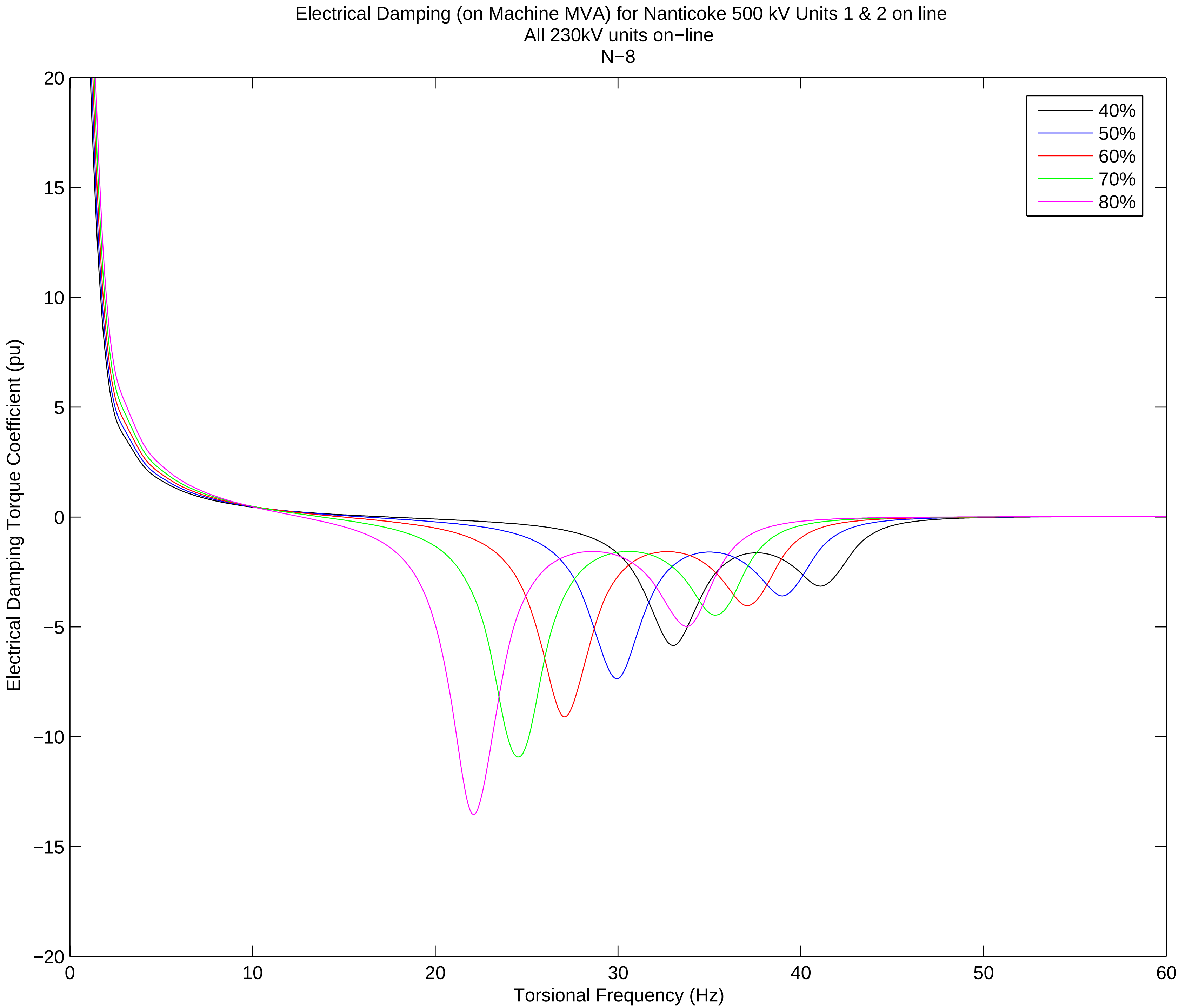
This appendix contains the electrical damping plots for several generator combinations, contingencies, and compensation levels. The plots are described in Table M-1 below. The generator bus being evaluated along with the Appendix in which the details of the generator Set ID and the contingency description are given. In addition, the lines for which the compensation was varied are identified along with the range of variation. The plots follow the order shown in the Table.

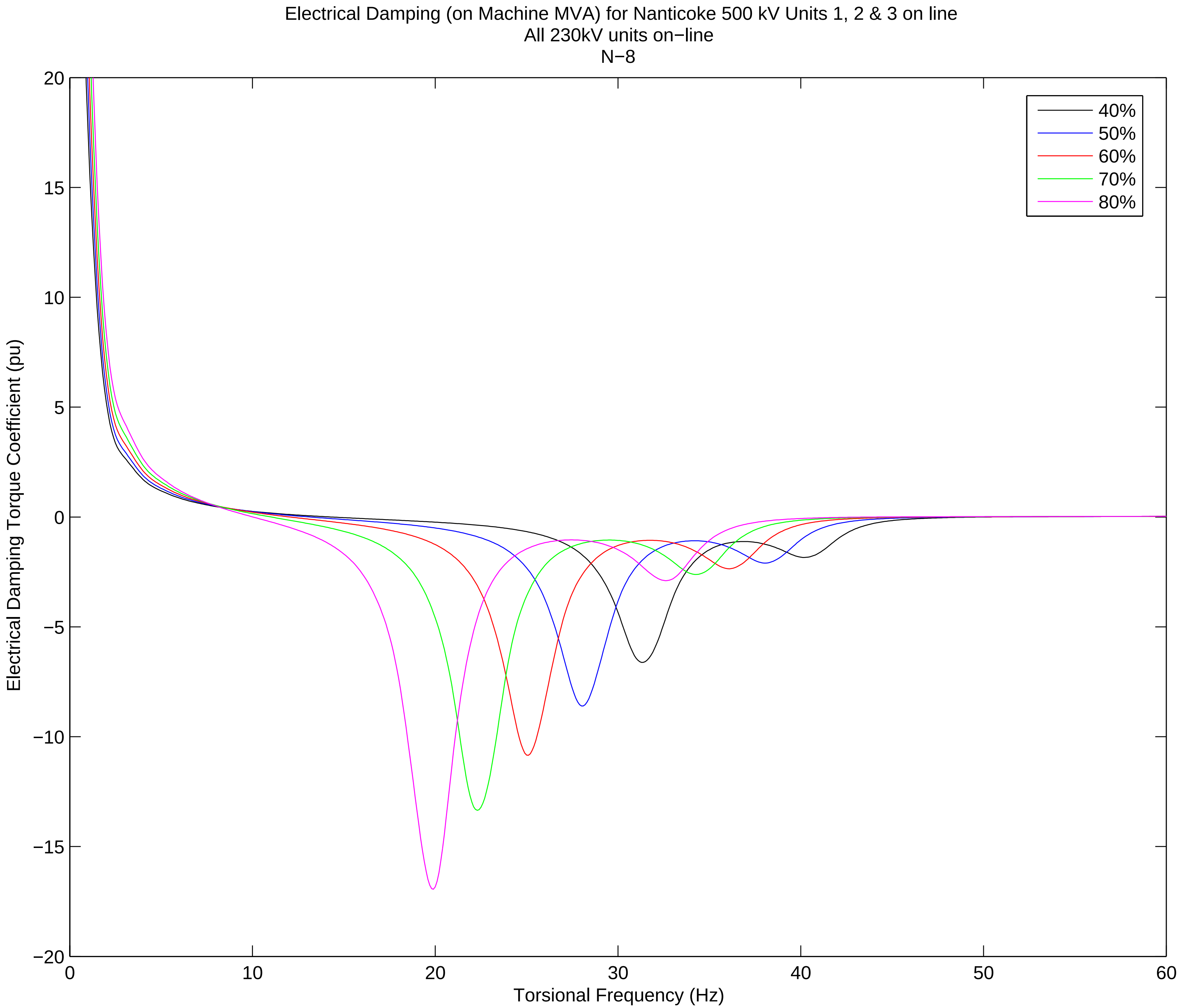
Table M-1: Compensation Variation Case Descriptions

Plot	Reference Appendix	Generator Set ID	Contingency	Lines for which compensation was varied	Compensation Level
1	C (Bruce A)	A1	N-5	Bruce – Longwood, Longwood – Nanticoke	40%-80%
2			N-5b	Bruce – Milton	10%-70%
3			N-6	Bruce – Longwood, Longwood – Nanticoke	40%-80%
4		A2	N-5	Bruce – Longwood, Longwood – Nanticoke	40%-80%
5			N-5b	Bruce – Milton	10%-70%
6			N-6	Bruce – Longwood, Longwood – Nanticoke	40%-80%
7		A1a	N-5	Bruce – Longwood, Longwood – Nanticoke	40%-80%
8			N-5b	Bruce – Milton	10%-70%
9			N-6	Bruce – Longwood, Longwood – Nanticoke	40%-80%
10		A2a	N-5	Bruce – Longwood, Longwood – Nanticoke	40%-80%
11			N-5b	Bruce – Milton	10%-70%
12			N-6	Bruce – Longwood, Longwood – Nanticoke	40%-80%
13	D (Bruce B)	A1	N-1	Bruce – Longwood, Longwood – Nanticoke	40%-80%
14			N-2	Bruce – Longwood, Longwood – Nanticoke	40%-80%
15			N-2b	Bruce – Milton	10%-70%
16		A2	N-1	Bruce – Longwood, Longwood – Nanticoke	40%-80%
17			N-2	Bruce – Longwood, Longwood – Nanticoke	40%-80%
18			N-2b	Bruce – Milton	10%-70%
19		A3	N-1	Bruce – Longwood, Longwood – Nanticoke	40%-80%
20			N-2	Bruce – Longwood, Longwood – Nanticoke	40%-80%
21			N-2b	Bruce – Milton	10%-70%
22		A4	N-1	Bruce – Longwood, Longwood – Nanticoke	40%-80%
23			N-2	Bruce – Longwood, Longwood – Nanticoke	40%-80%
24			N-2b	Bruce – Milton	10%-70%
25	E (Nanticoke)	A1	N-8	Bruce – Longwood, Longwood – Nanticoke	40%-80%
26		A2	N-8	Bruce – Longwood, Longwood – Nanticoke	40%-80%
27		A3	N-8	Bruce – Longwood, Longwood – Nanticoke	40%-80%
28		B1	N-8	Bruce – Longwood, Longwood – Nanticoke	40%-80%
29		C1	N-6	Bruce – Longwood, Longwood – Nanticoke	40%-80%
30		C2	N-6	Bruce – Longwood, Longwood – Nanticoke	40%-80%
31		C3	N-6	Bruce – Longwood, Longwood – Nanticoke	40%-80%
32		C4	N-6	Bruce – Longwood, Longwood – Nanticoke	40%-80%

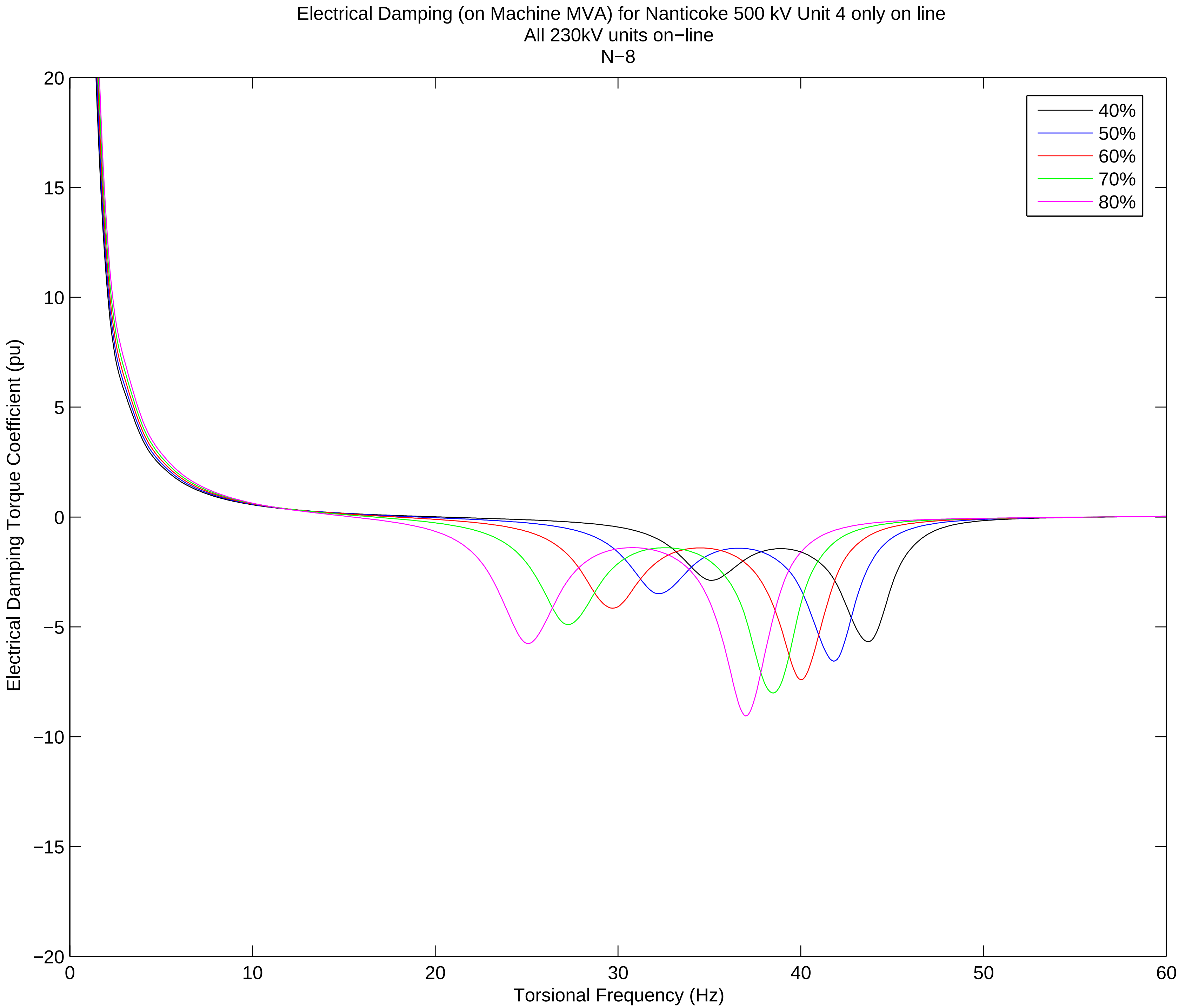


Electrical Damping (on Machine MVA) for Nanticoke 500 kV Unit 1
All 230kV units on−line
N−8
40%
50%
60%
70%
80%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)

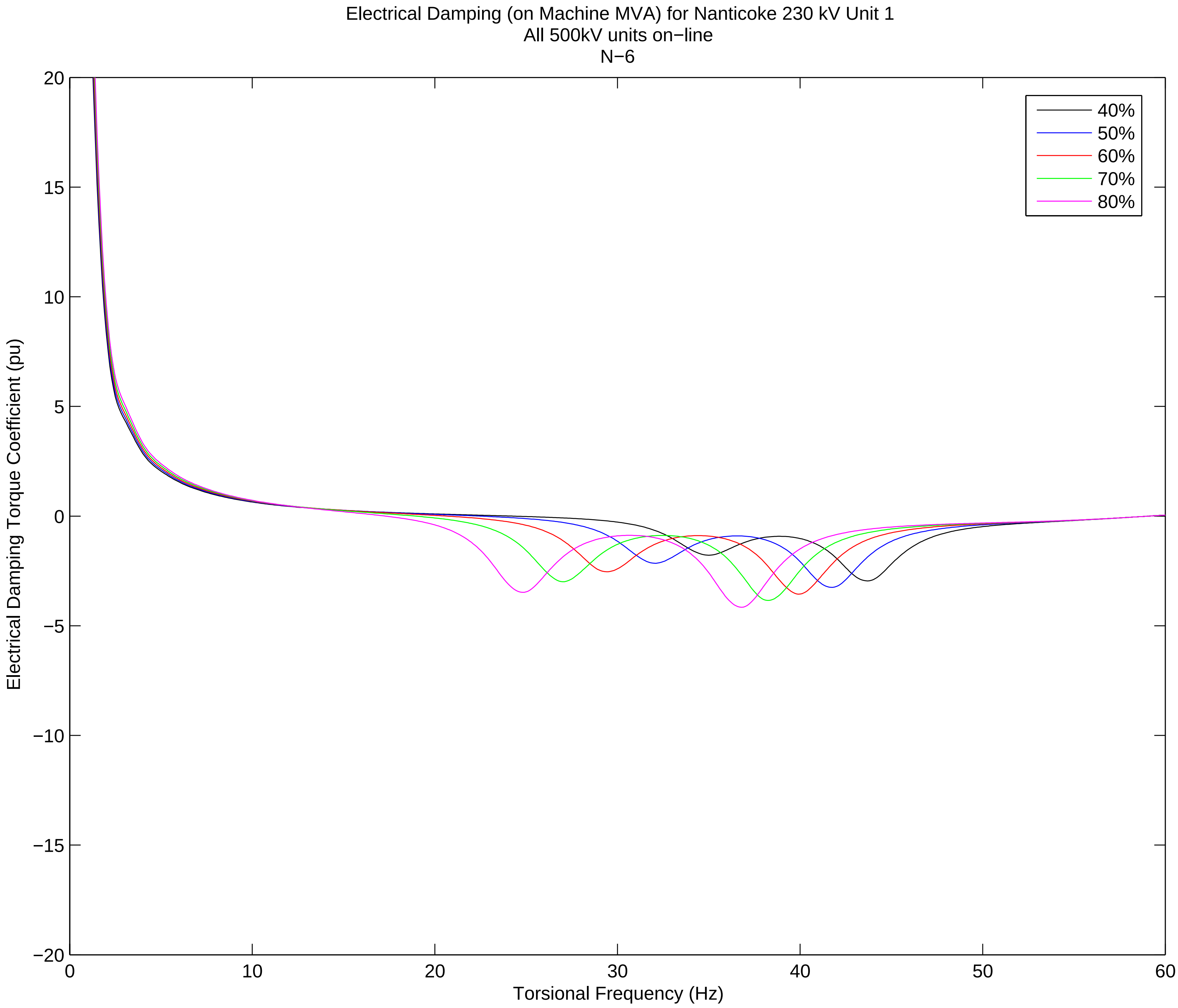

Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units 1 & 2 on line
All 230kV units on−line
N−8
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
40%
50%
60%
70%
80%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

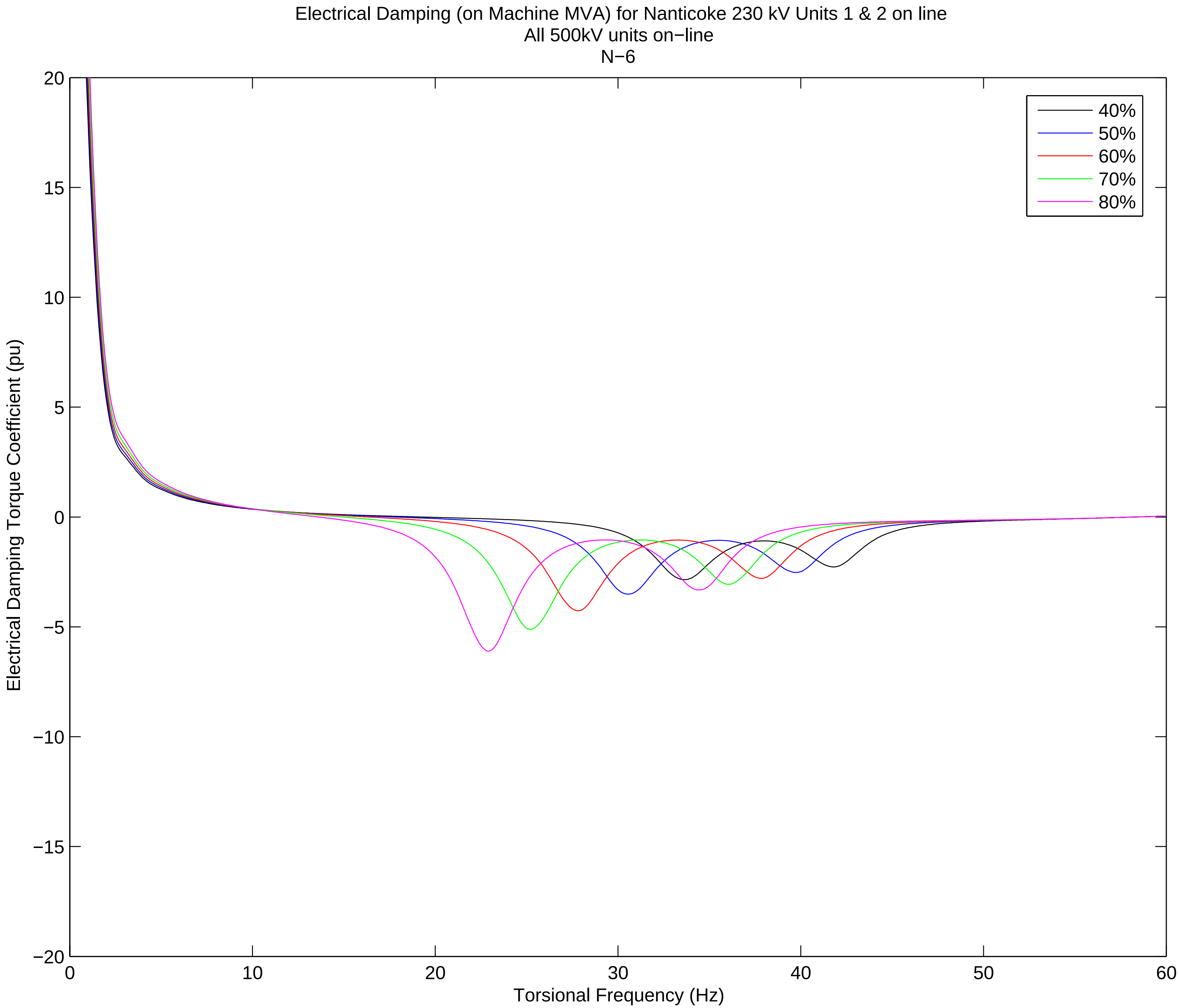


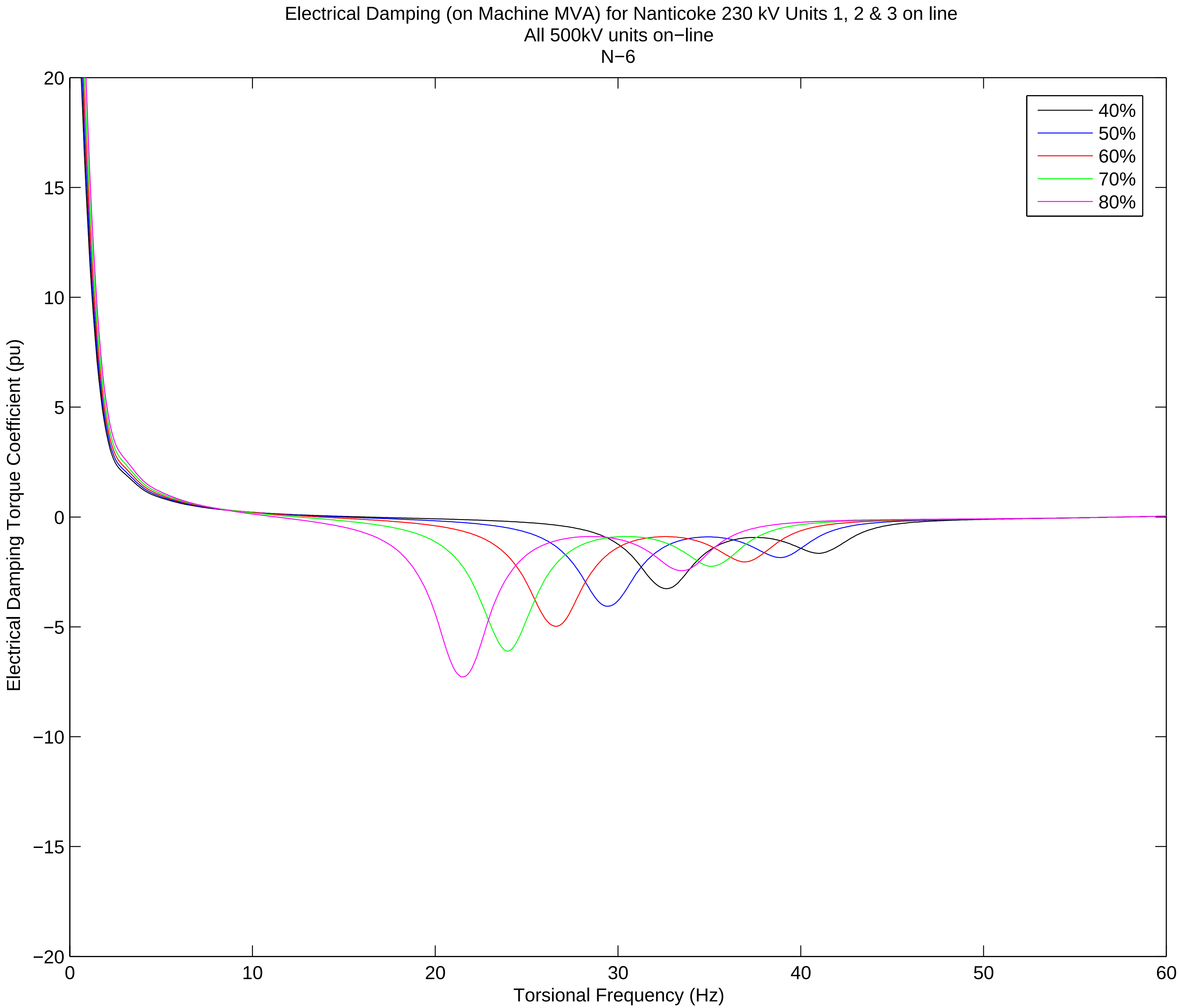
Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units 1, 2 & 3 on line
All 230kV units on−line
N−8
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
40%
50%
60%
70%
80%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



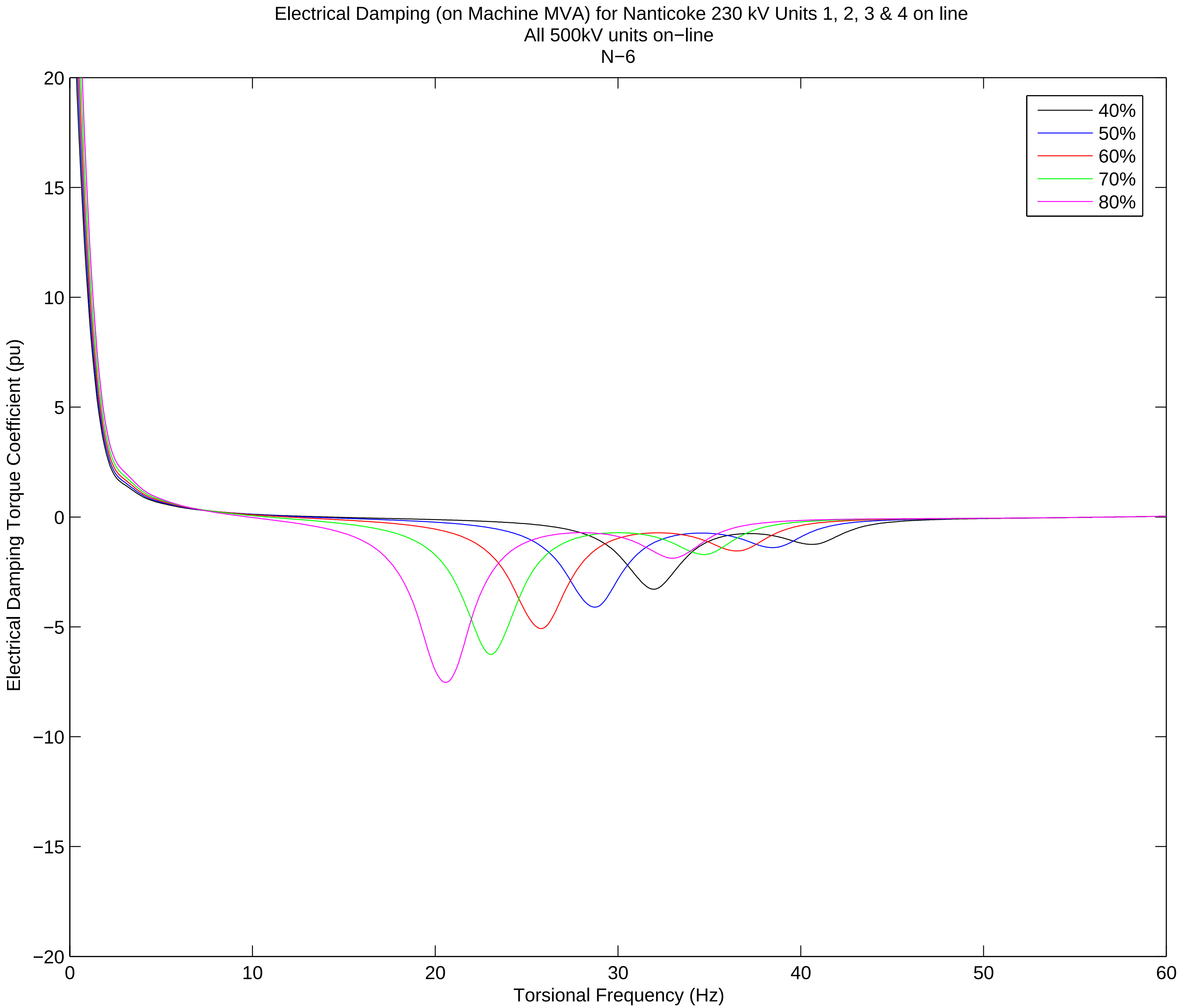
Electrical Damping (on Machine MVA) for Nanticoke 500 kV Unit 4 only on line
All 230kV units on−line
N−8
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
40%
50%
60%
70%
80%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Nanticoke 230 kV Unit 1
All 500kV units on−line
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
40%
50%
60%
70%
80%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units 1 & 2 on line
All 500kV units on−line
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
40%
50%
60%
70%
80%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units 1, 2 & 3 on line
All 500kV units on−line
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
40%
50%
60%
70%
80%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units 1, 2, 3 & 4 on line
All 500kV units on−line
N−6
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
40%
50%
60%
70%
80%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

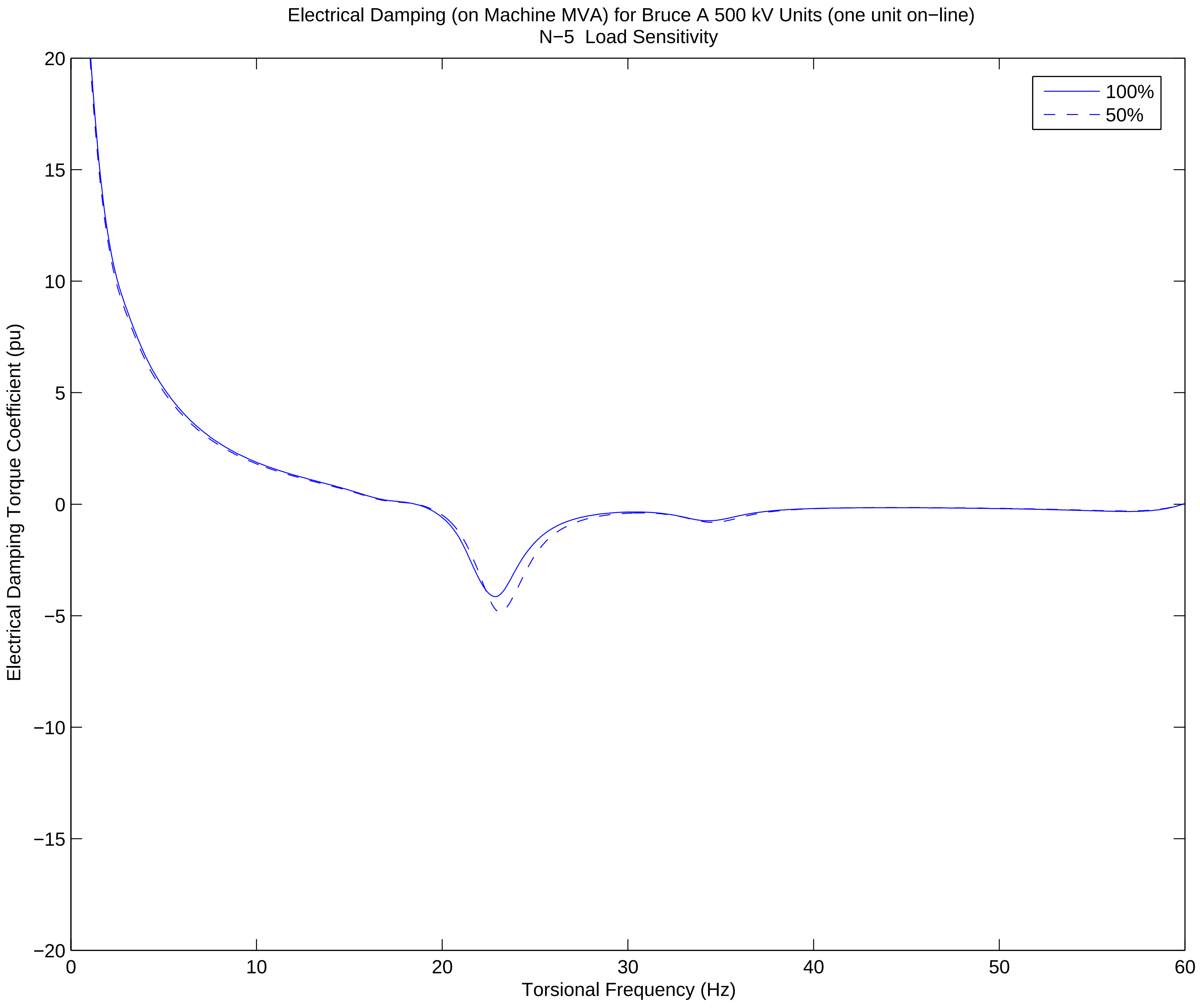
APPENDIX N: Load Sensitivity Plots

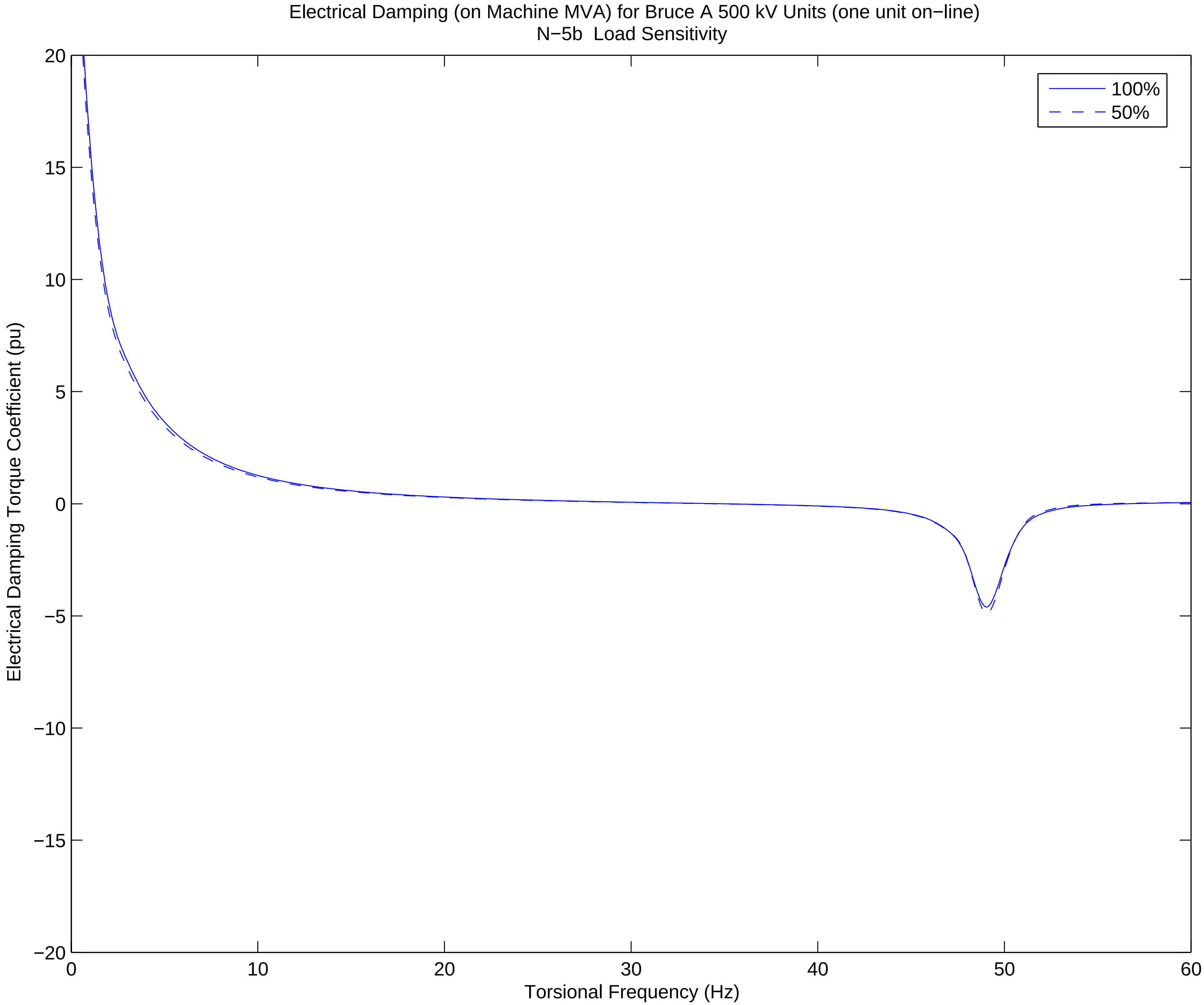
Appendix N – Load Sensitivity Plots

This appendix contains the electrical damping comparison plots for several generator combinations, contingencies, and two load levels. The plots are described in Table N-1 below. The generator bus being evaluated along with the Appendix in which the details of the generator Set ID and the contingency description are given. Each plot compares the electrical damping for the system load at 100% and 50% of that provided in the system data. The plots follow the order shown in the Table.

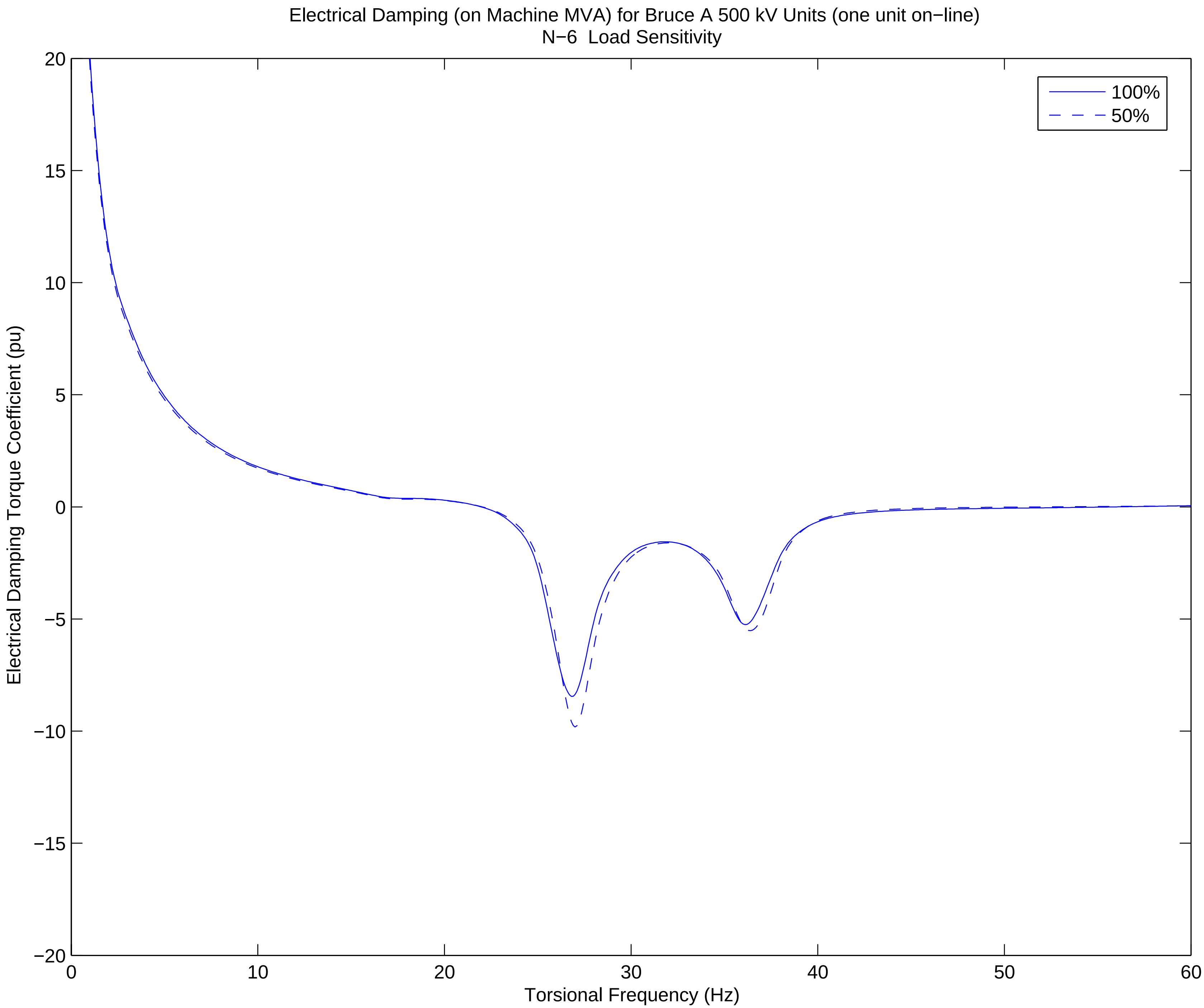
Table N-1: Compensation Variation Case Descriptions

Plot	Reference Appendix	Generator Set ID	Contingency
1	C (Bruce A)	A1	N-5
2			N-5b
3			N-6
4		A2	N-5
5			N-5b
6			N-6
7		A1a	N-5
8			N-5b
9			N-6
10		A2a	N-5
11			N-5b
12			N-6
13	D (Bruce B)	A1	N-1
14			N-2
15		A2	N-1
16			N-2
17		A3	N-2
18		A4	N-2
19	E (Nanticoke)	A1	N-8
20		A2	N-8
21		A3	N-8
22		B1	N-8
23		C1	N-6
24		C2	N-6
25		C3	N-6
26		C4	N-6

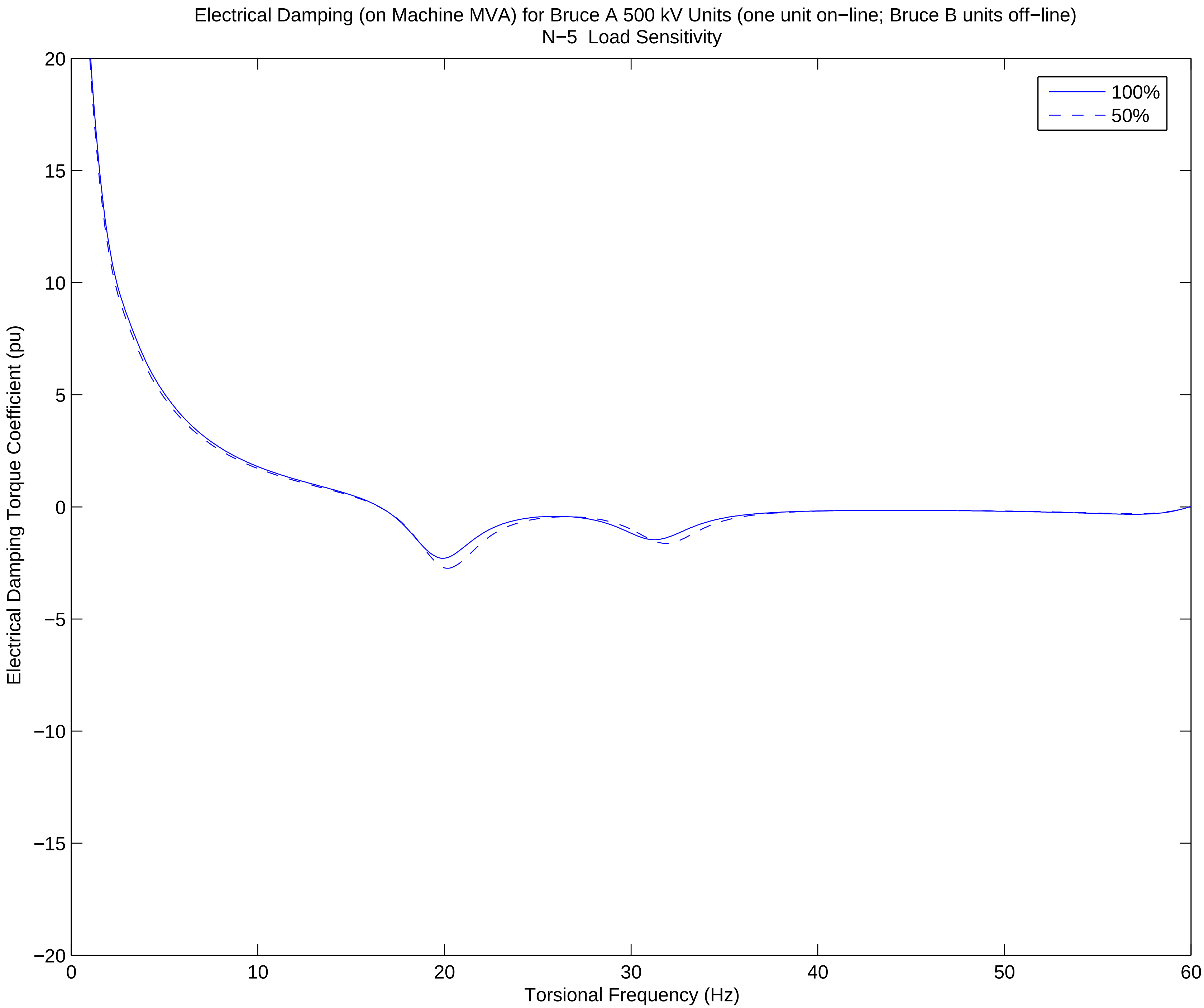

Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line)
N−5 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

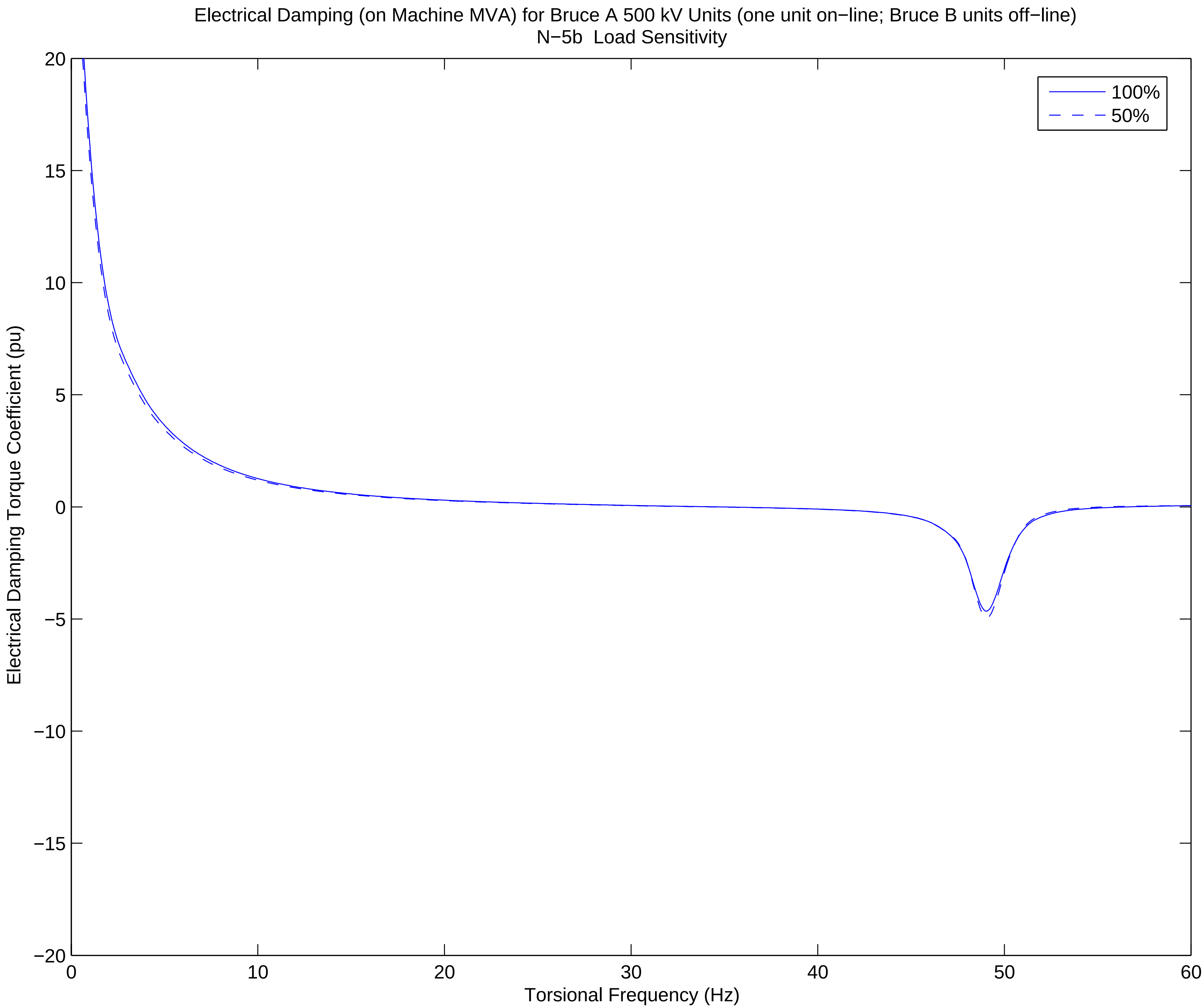


Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line)
N−5b Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)

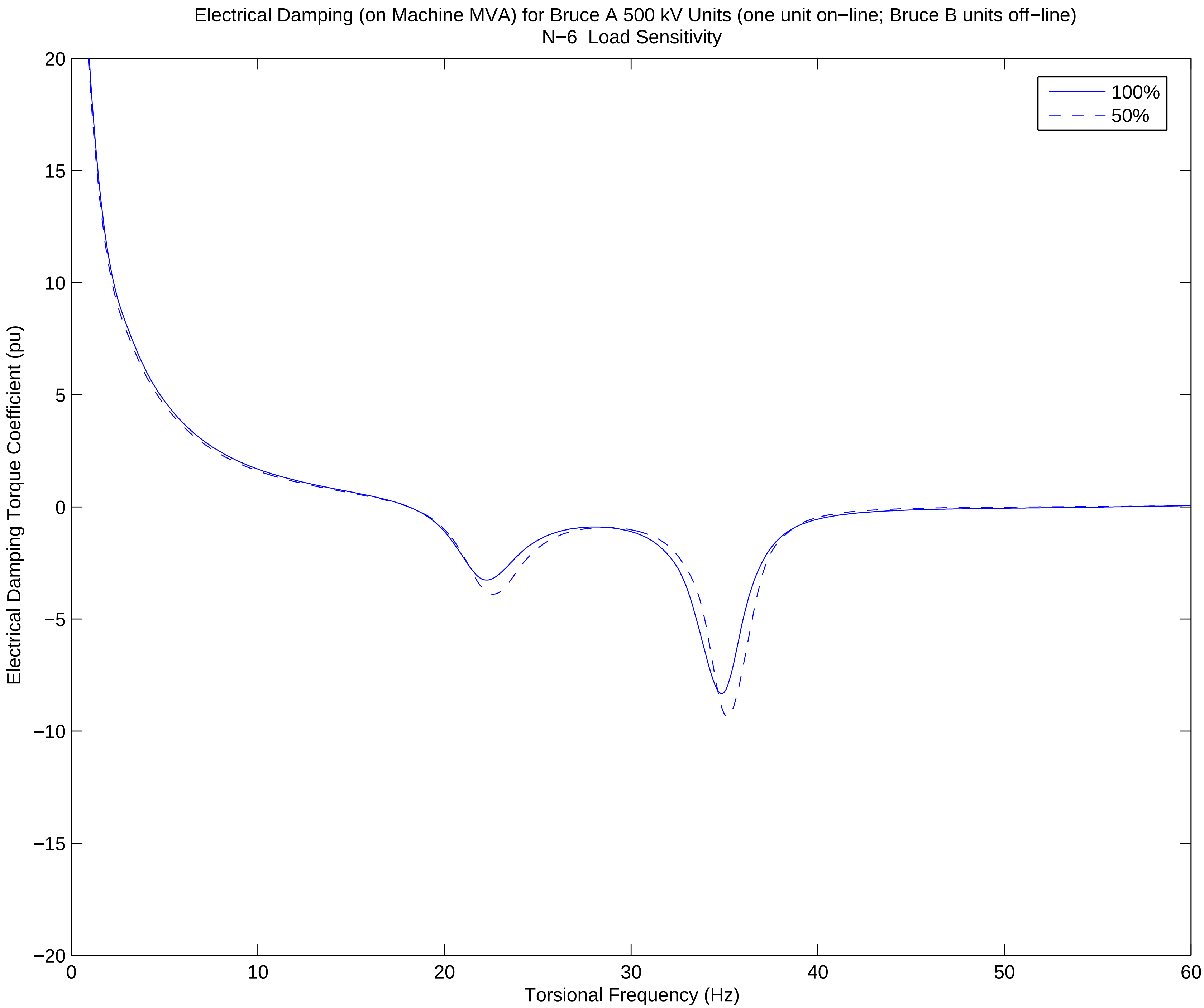


Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line)
N−6 Load Sensitivity
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
100%
50%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

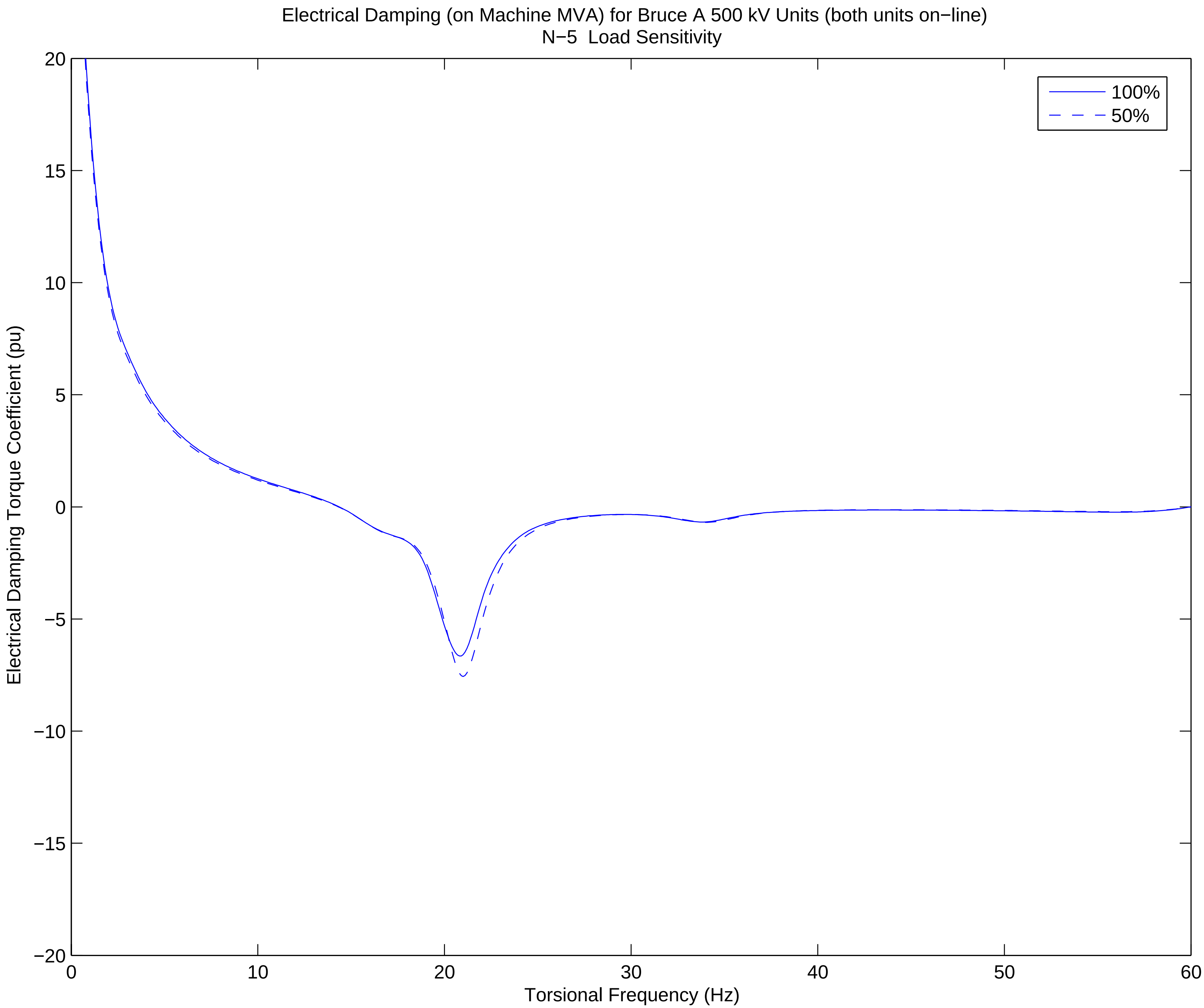

Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line; Bruce B units off−line)
N−5 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



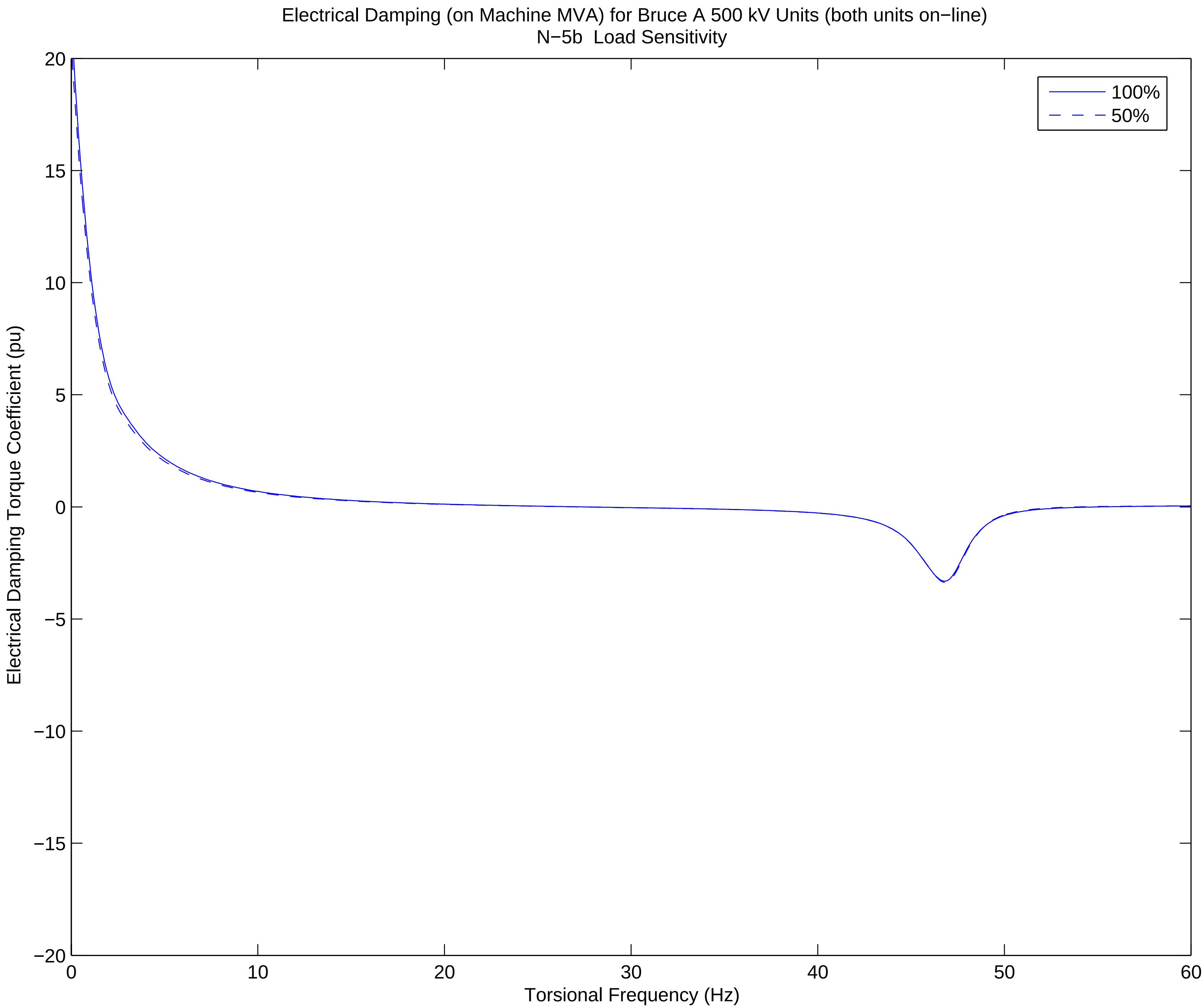
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line; Bruce B units off−line)
N−5b Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



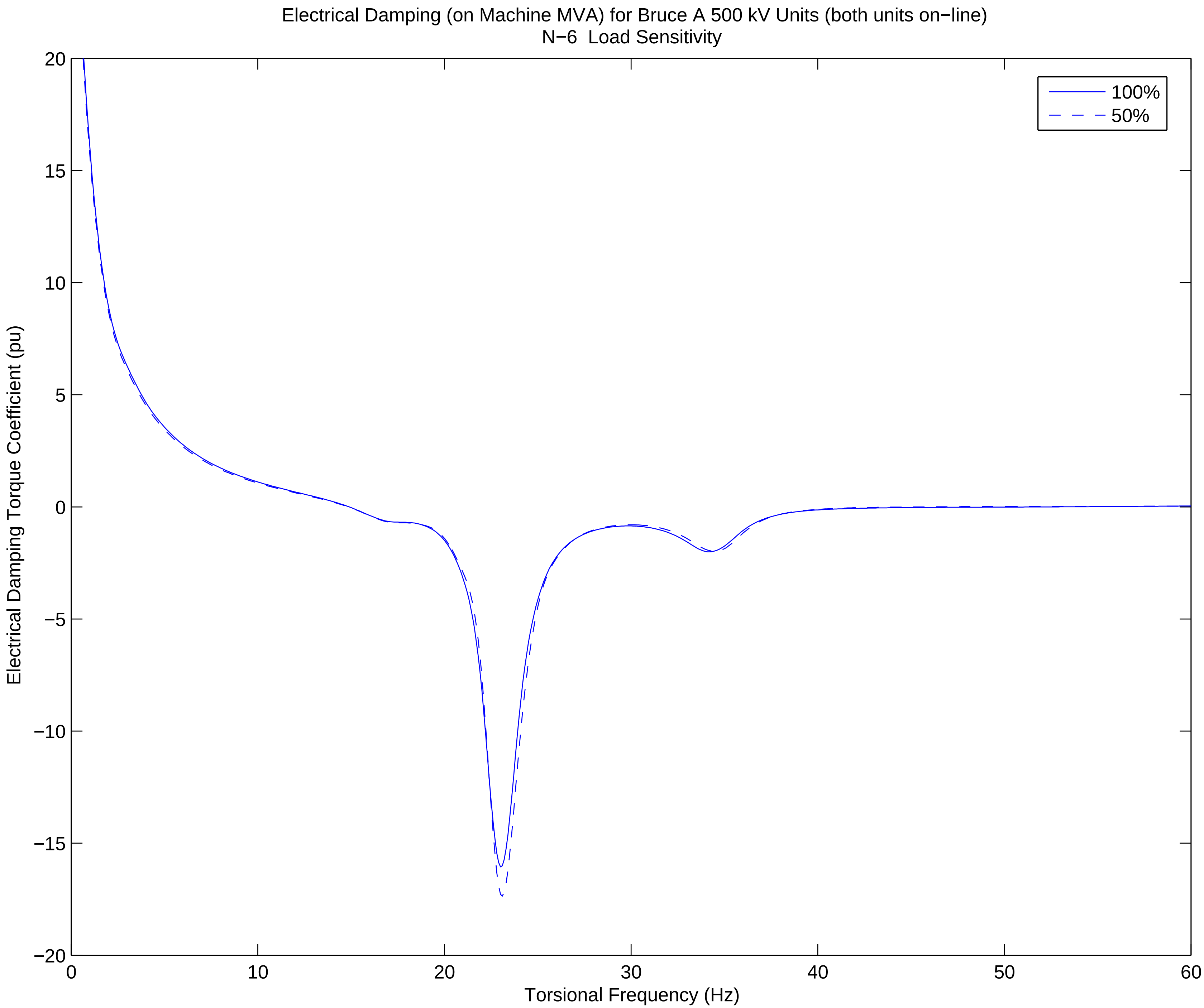
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (one unit on−line; Bruce B units off−line)
N−6 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



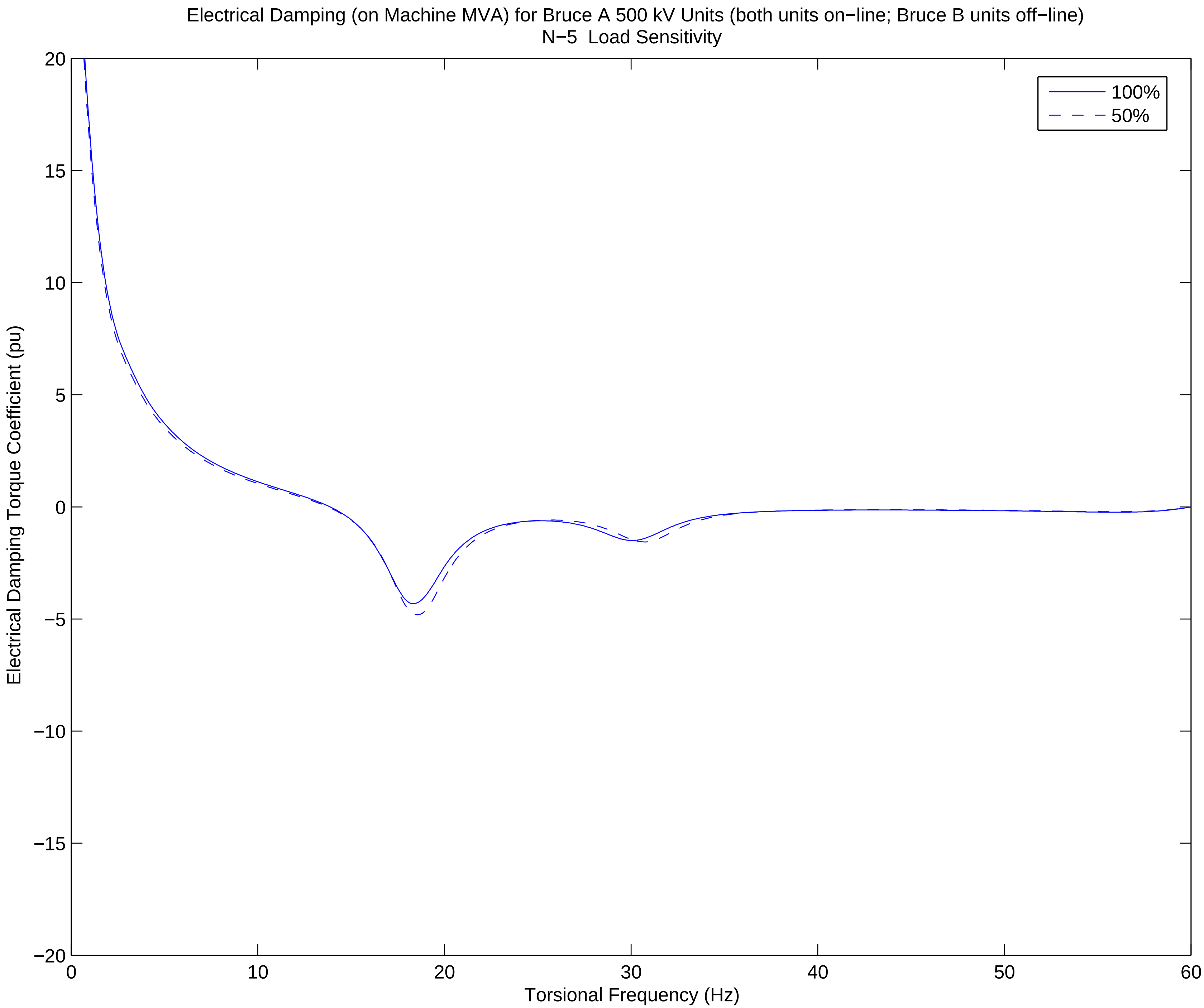
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
N−5 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

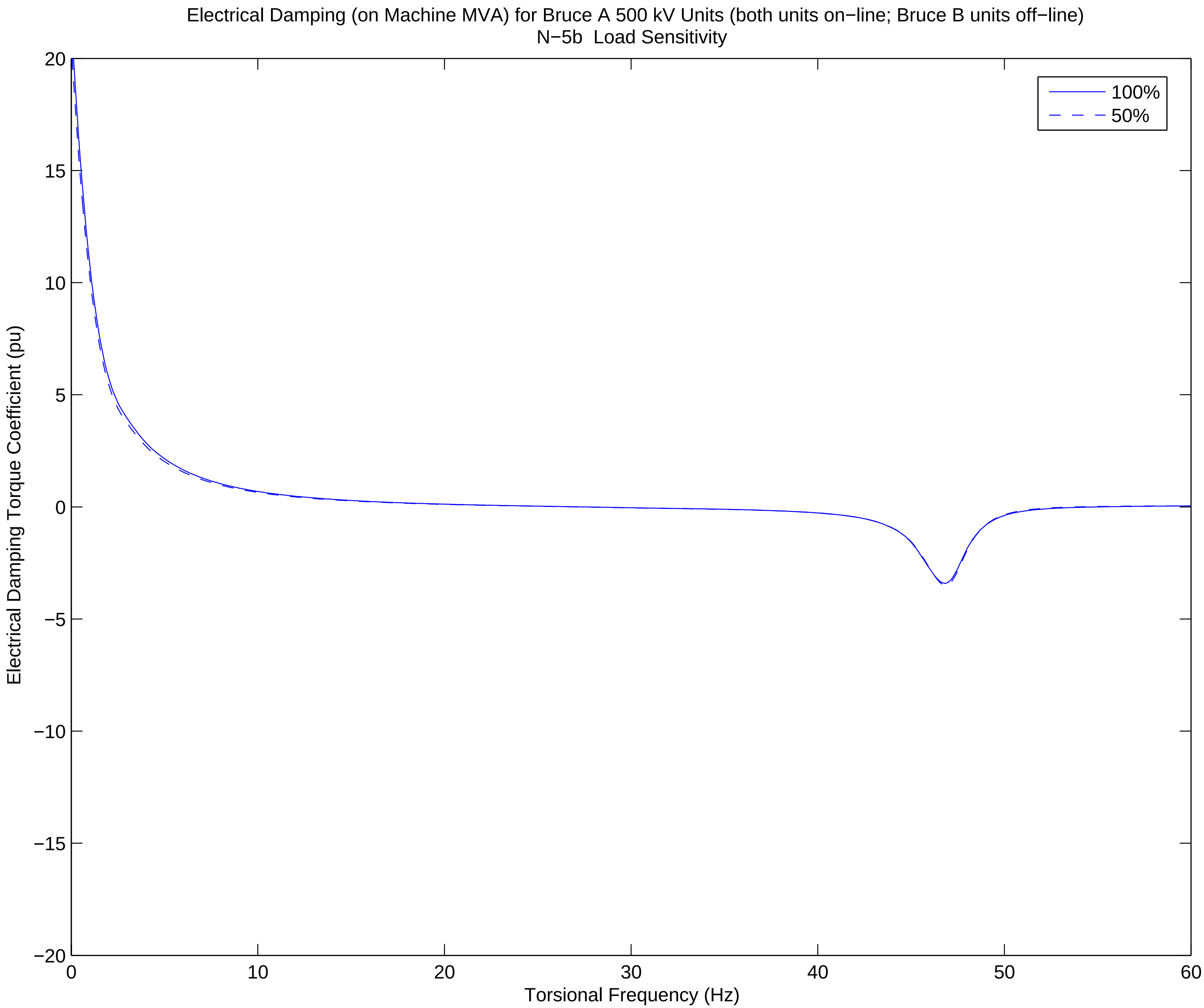


Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
N−5b Load Sensitivity
100%
50%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)

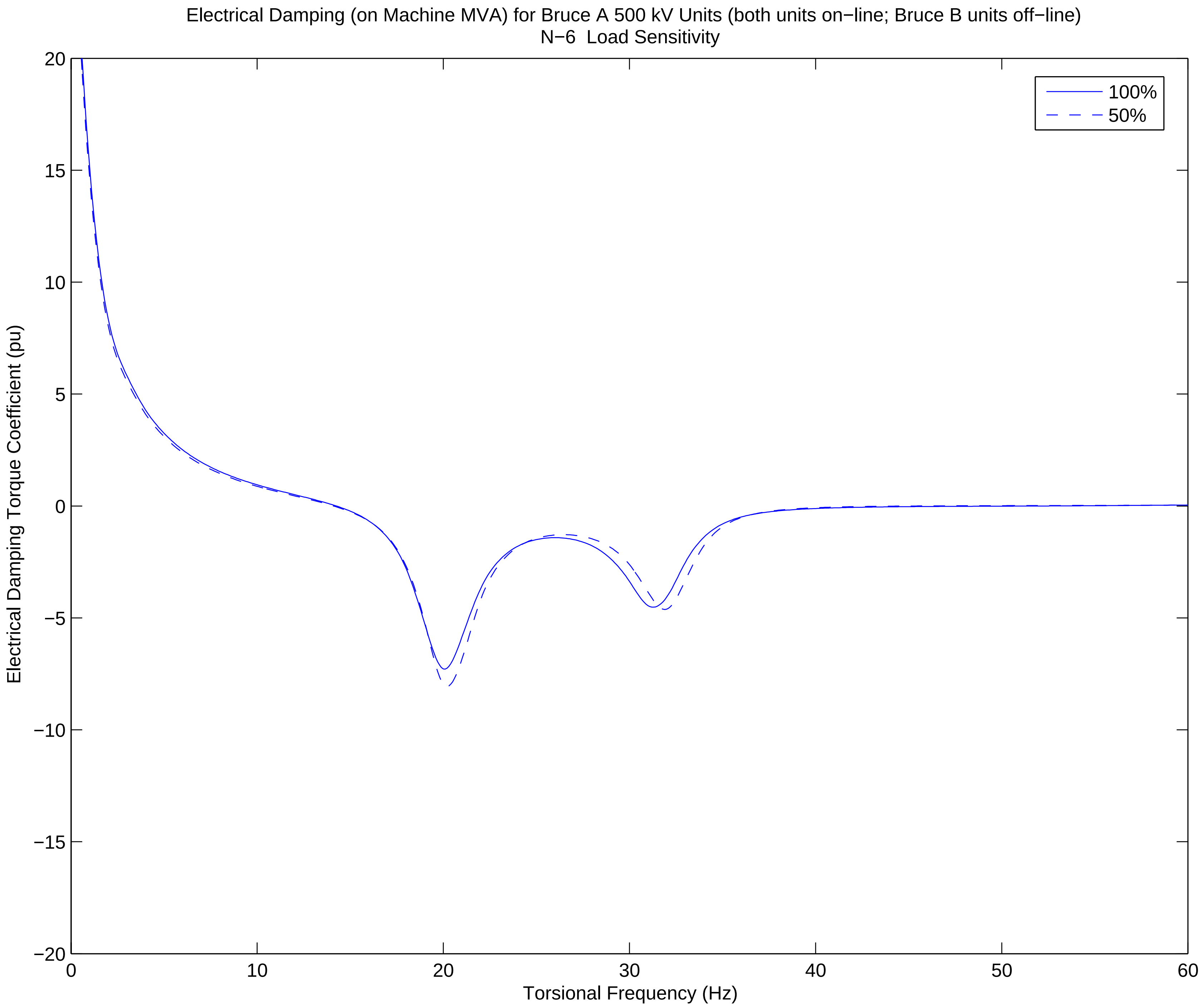


Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
N−6 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

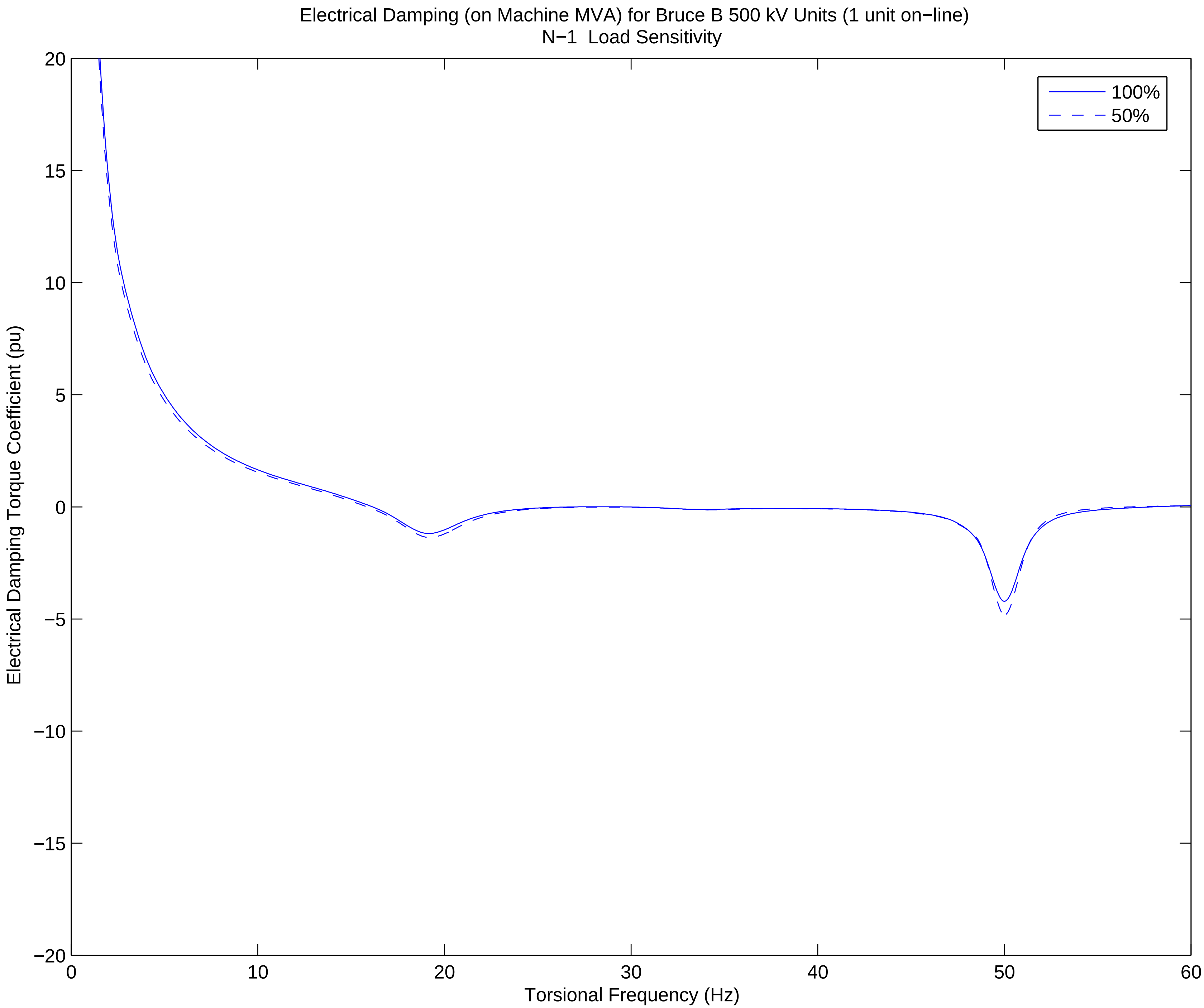

Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line; Bruce B units off−line)
N−5 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)



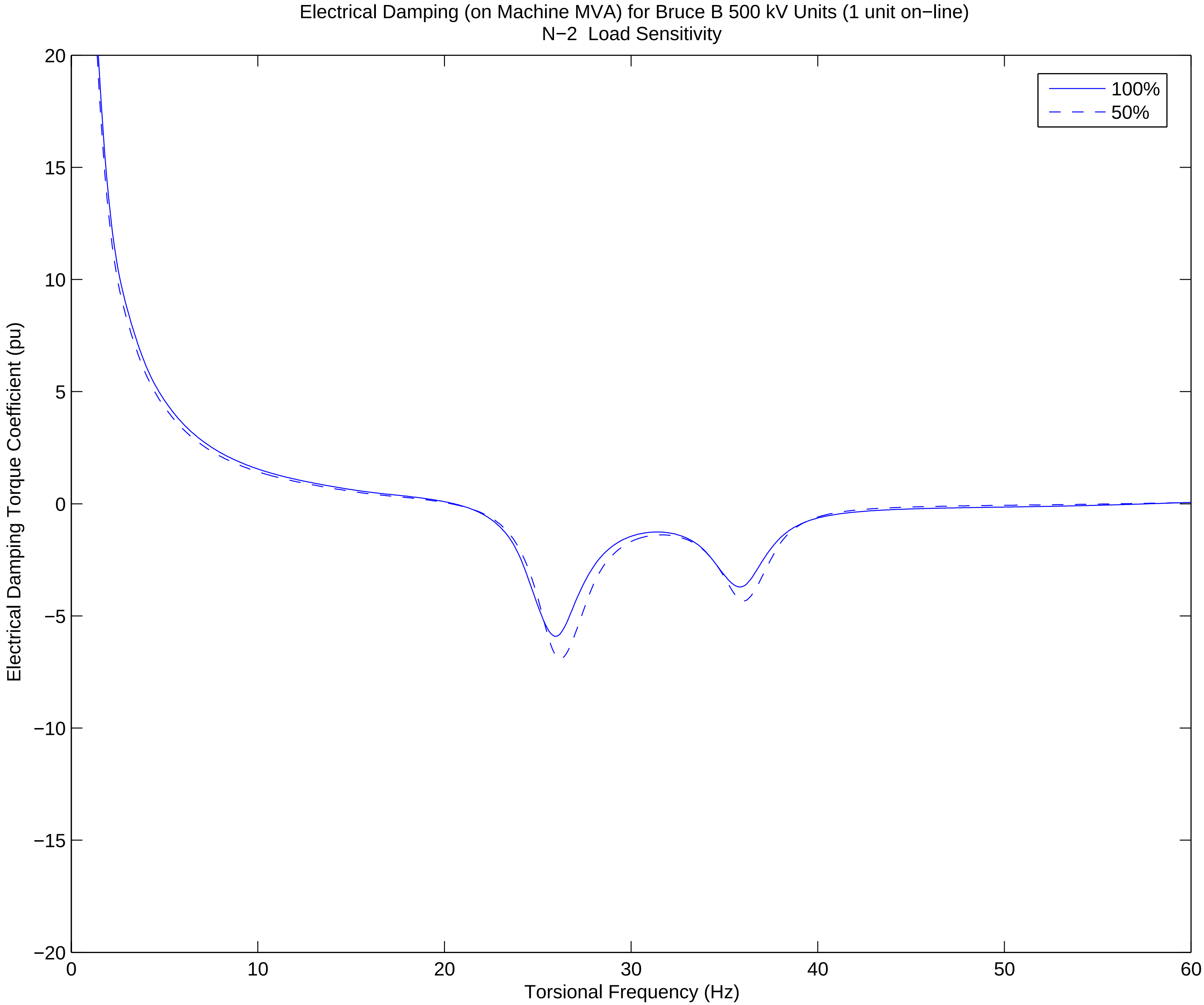
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line; Bruce B units off−line)
N−5b Load Sensitivity
100%
50%
20
15
10
5
0
−5
−10
−15
−20
Electrical Damping Torque Coefficient (pu)
0
10
20
30
40
50
60
Torsional Frequency (Hz)



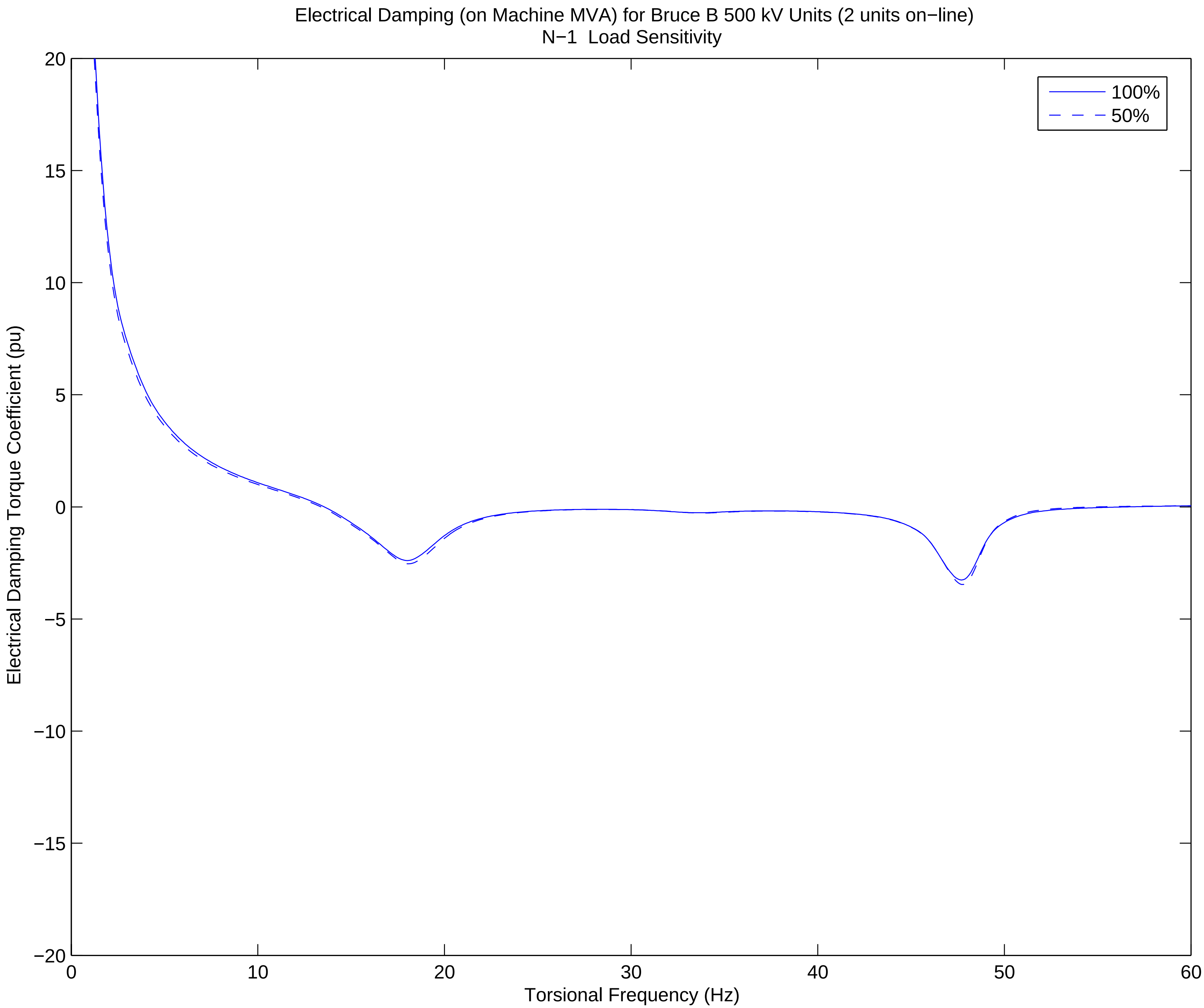
Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line; Bruce B units off−line)
N−6 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

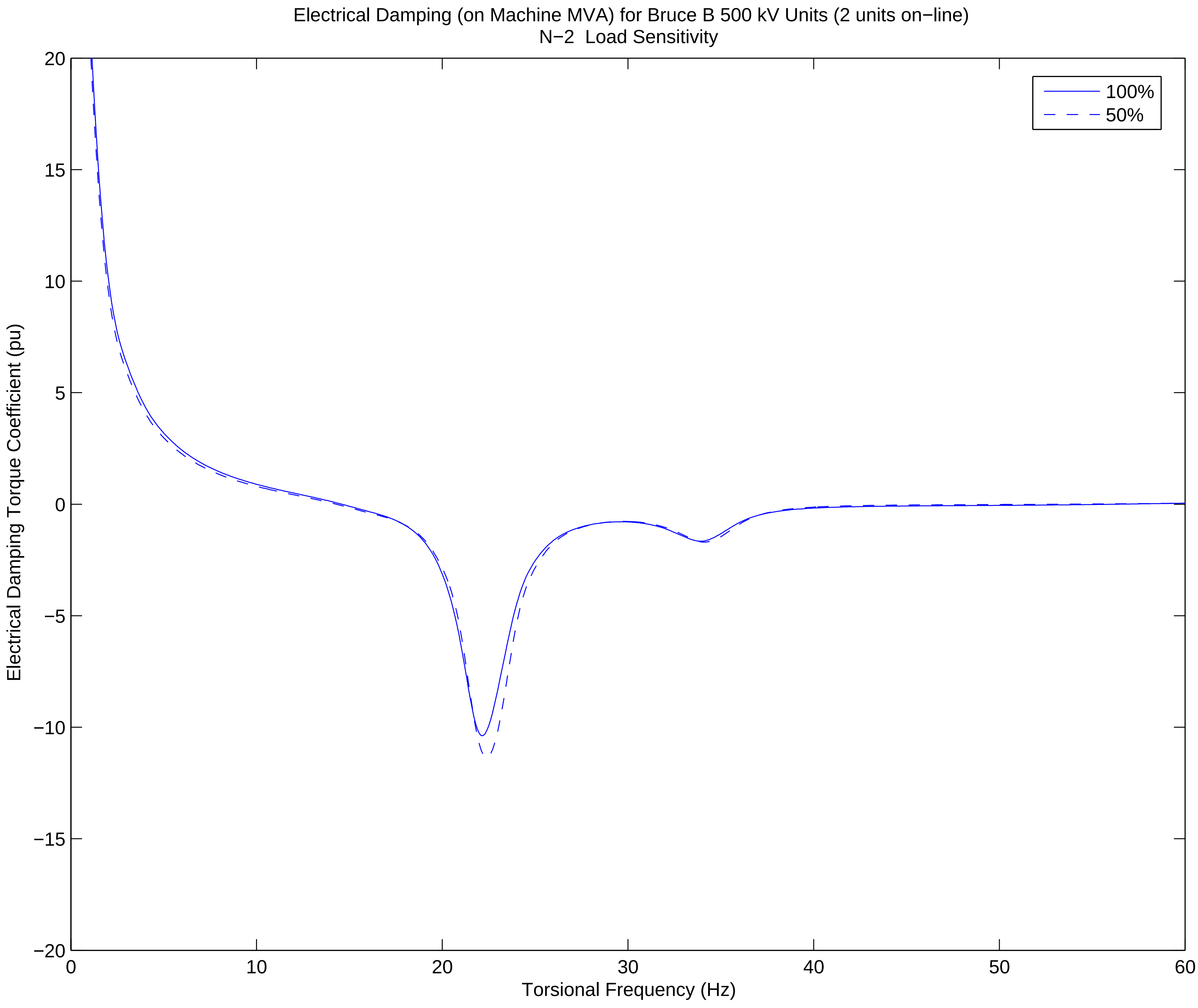


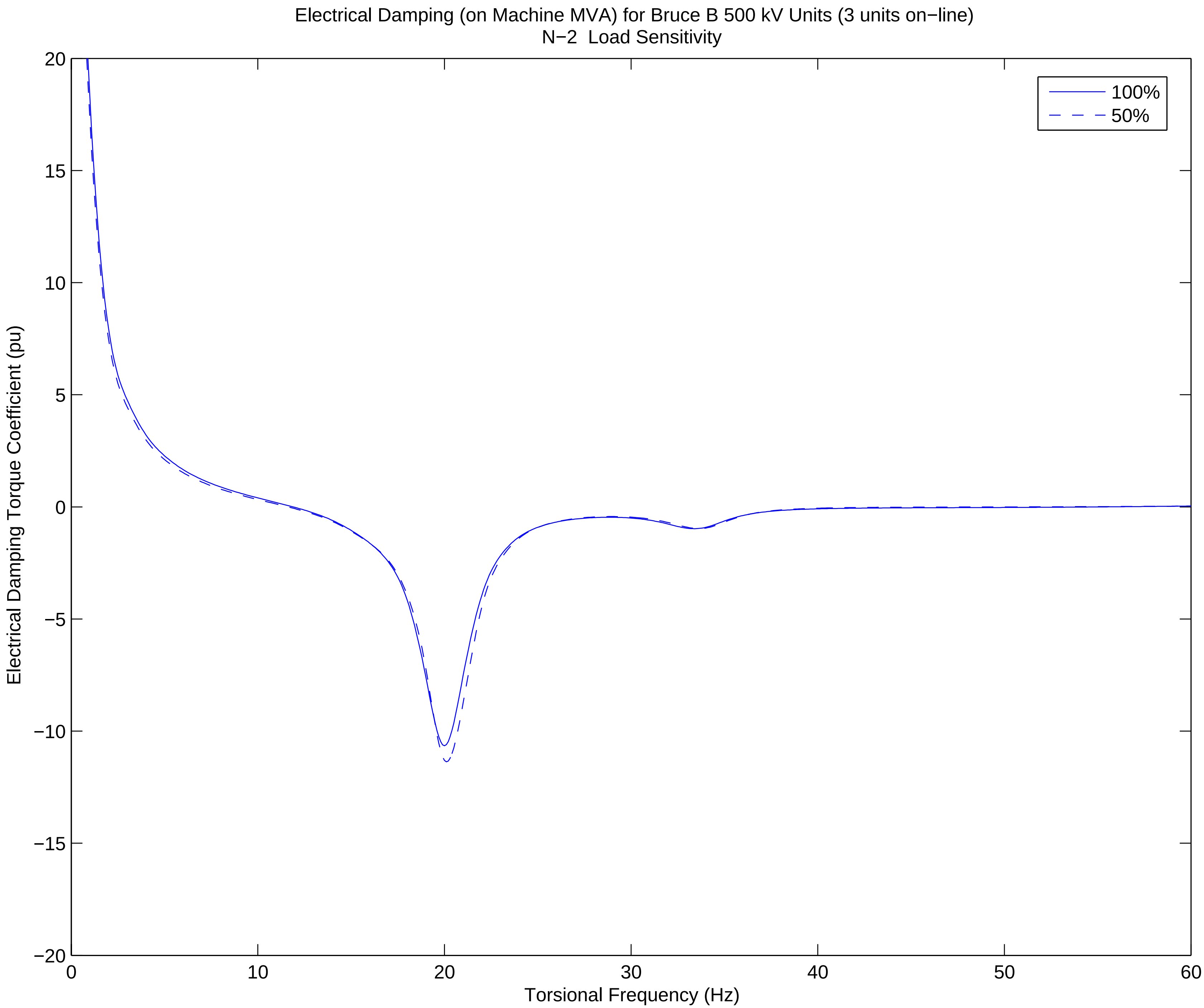
Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (1 unit on−line)
N−1 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



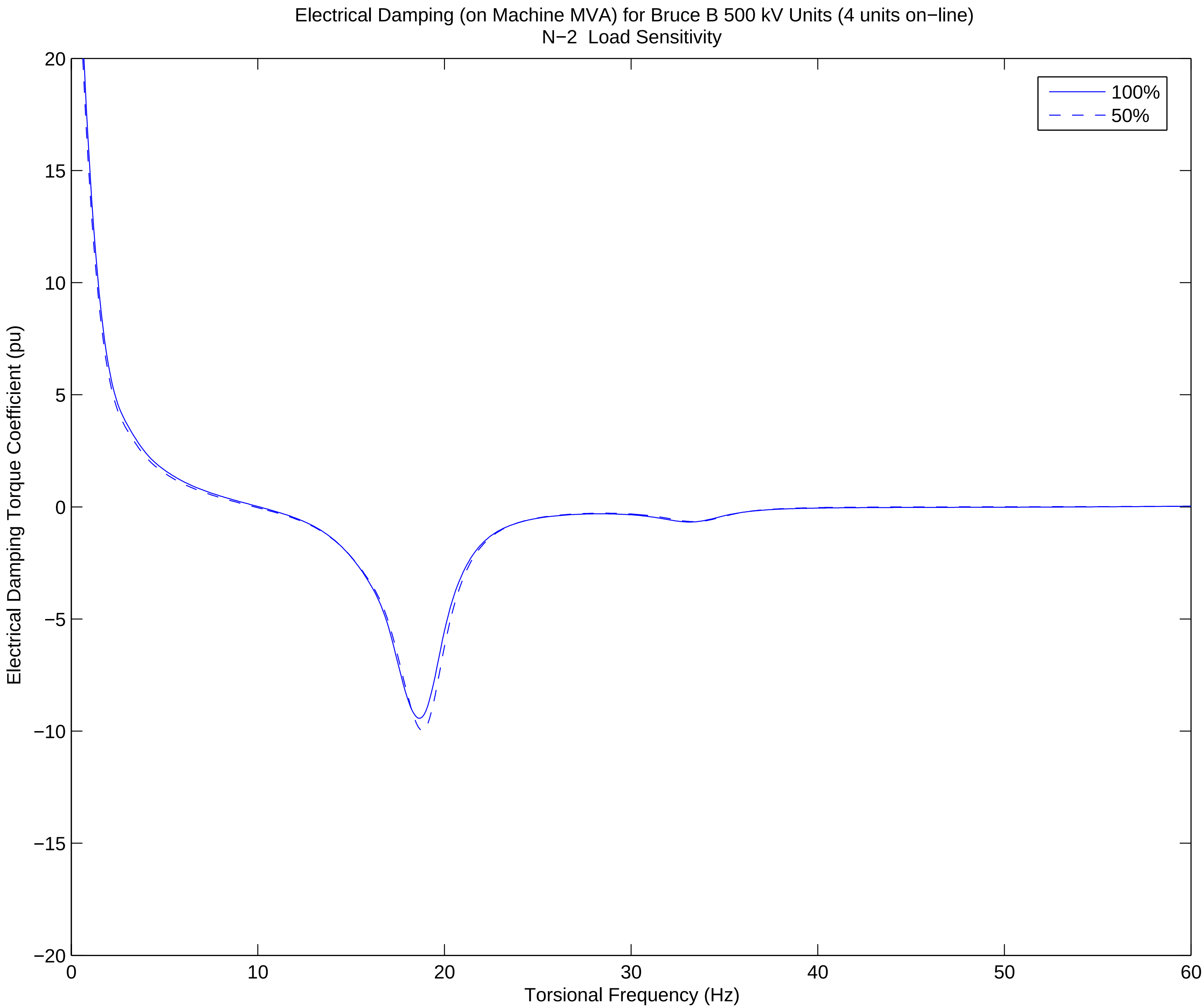
Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (1 unit on−line)
N−2 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

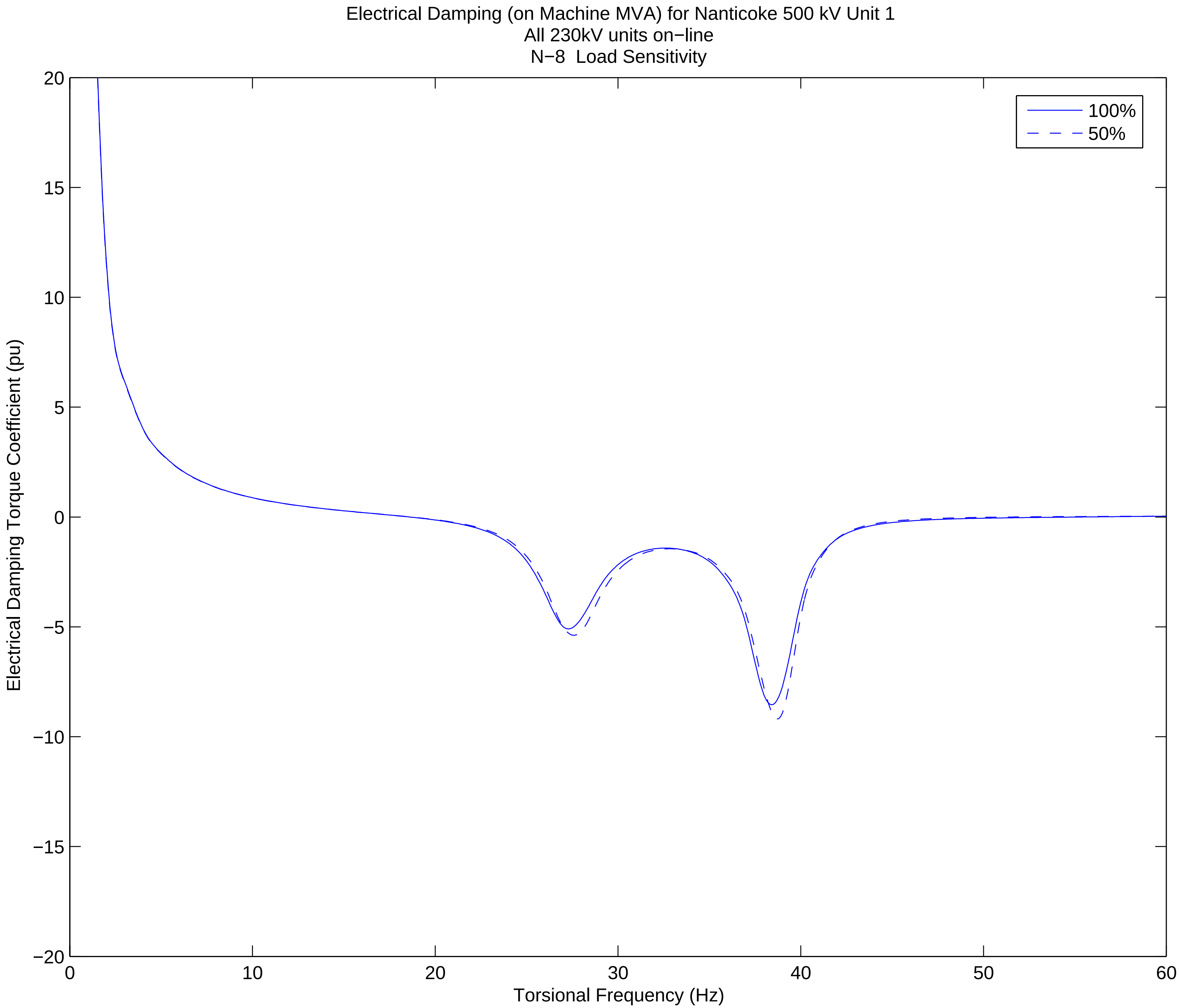

Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (2 units on−line)
N−1 Load Sensitivity
100%
50%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)
Electrical Damping Torque Coefficient (pu)

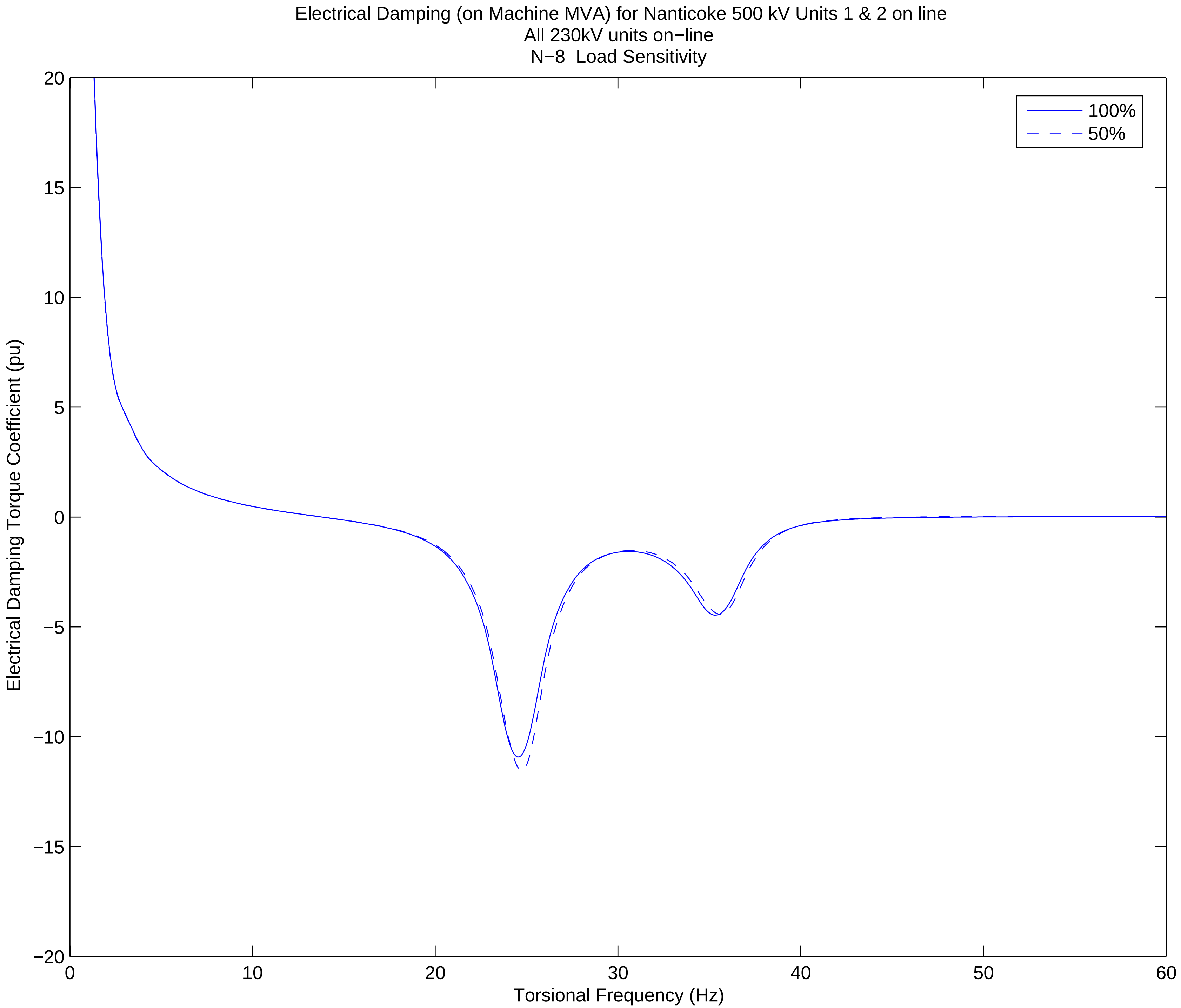

Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (2 units on−line)
N−2 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



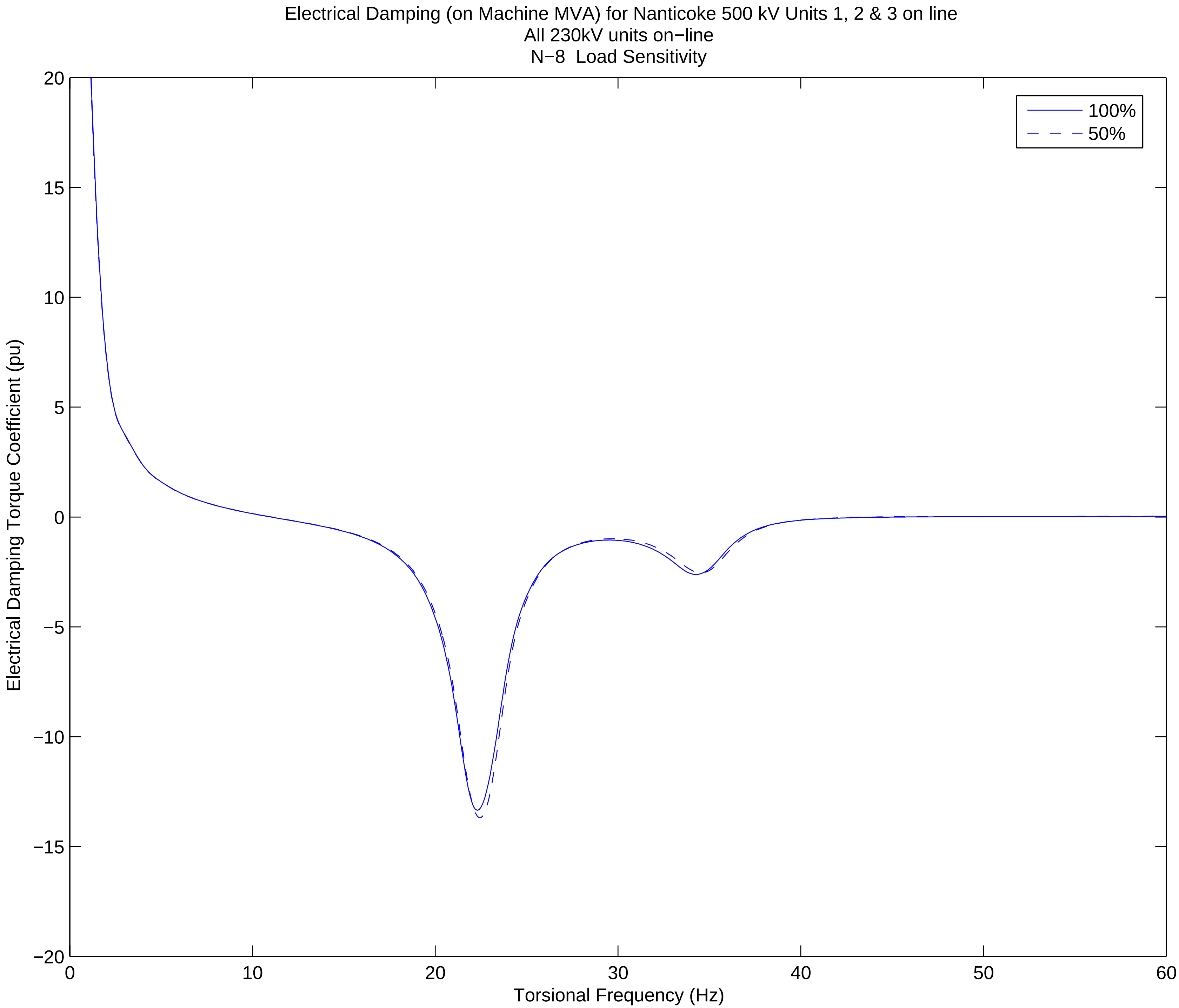
Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (3 units on−line)
N−2 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

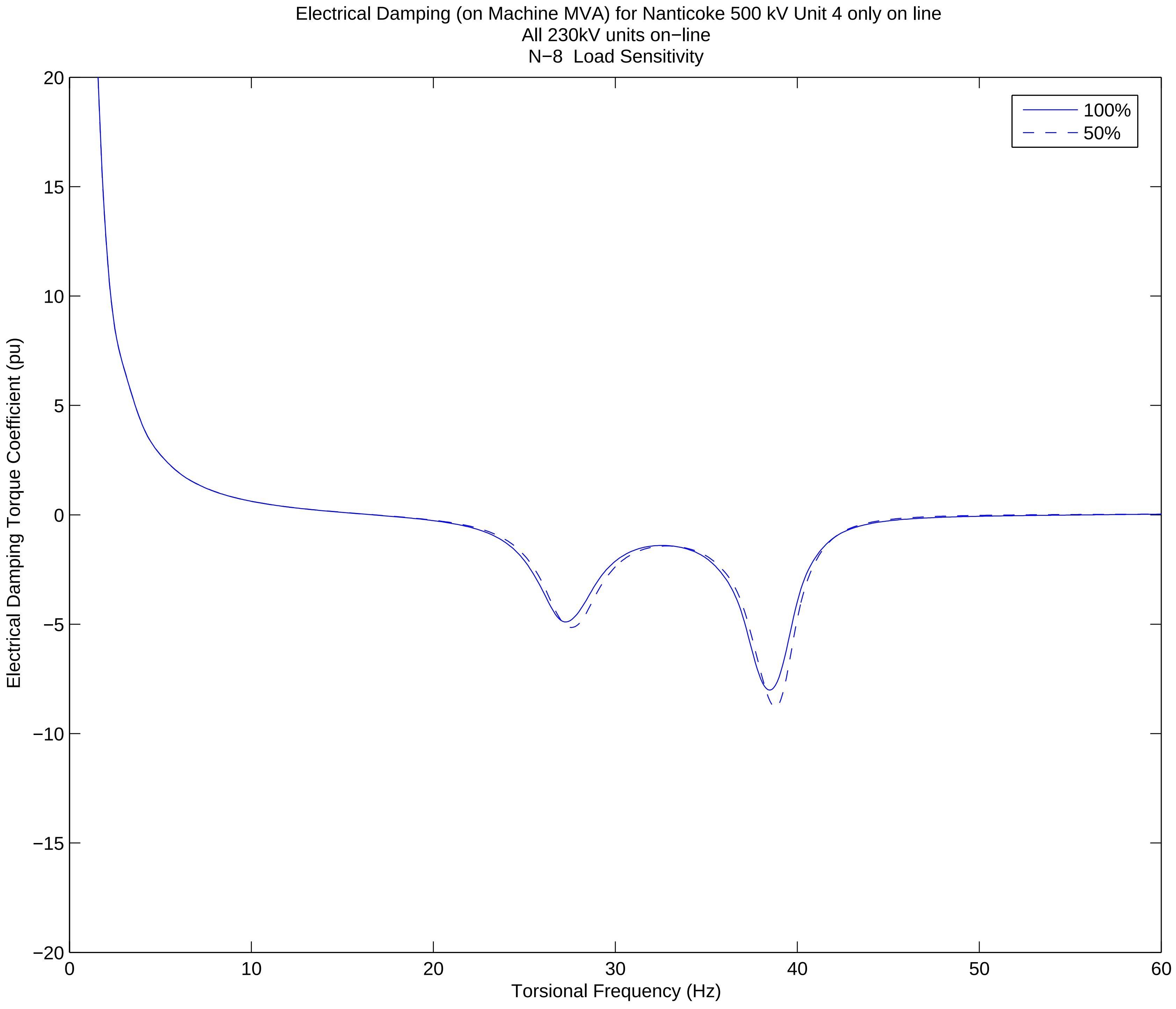

Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (4 units on−line)
N−2 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Nanticoke 500 kV Unit 1
All 230kV units on−line
N−8 Load Sensitivity
100%
50%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Torsional Frequency (Hz)
Electrical Damping Torque Coefficient (pu)

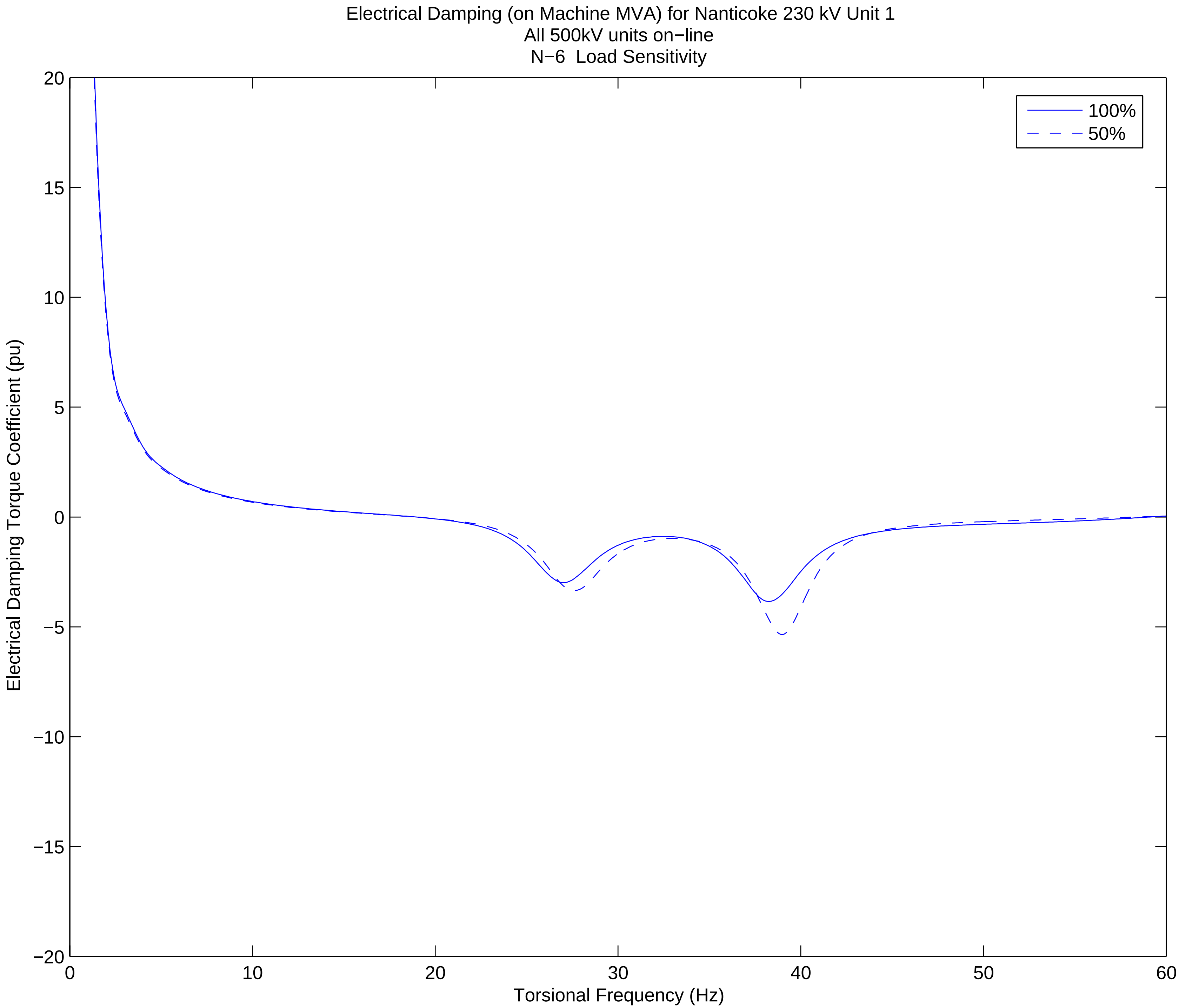


Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units 1 & 2 on line
All 230kV units on−line
N−8 Load Sensitivity
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
100%
50%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

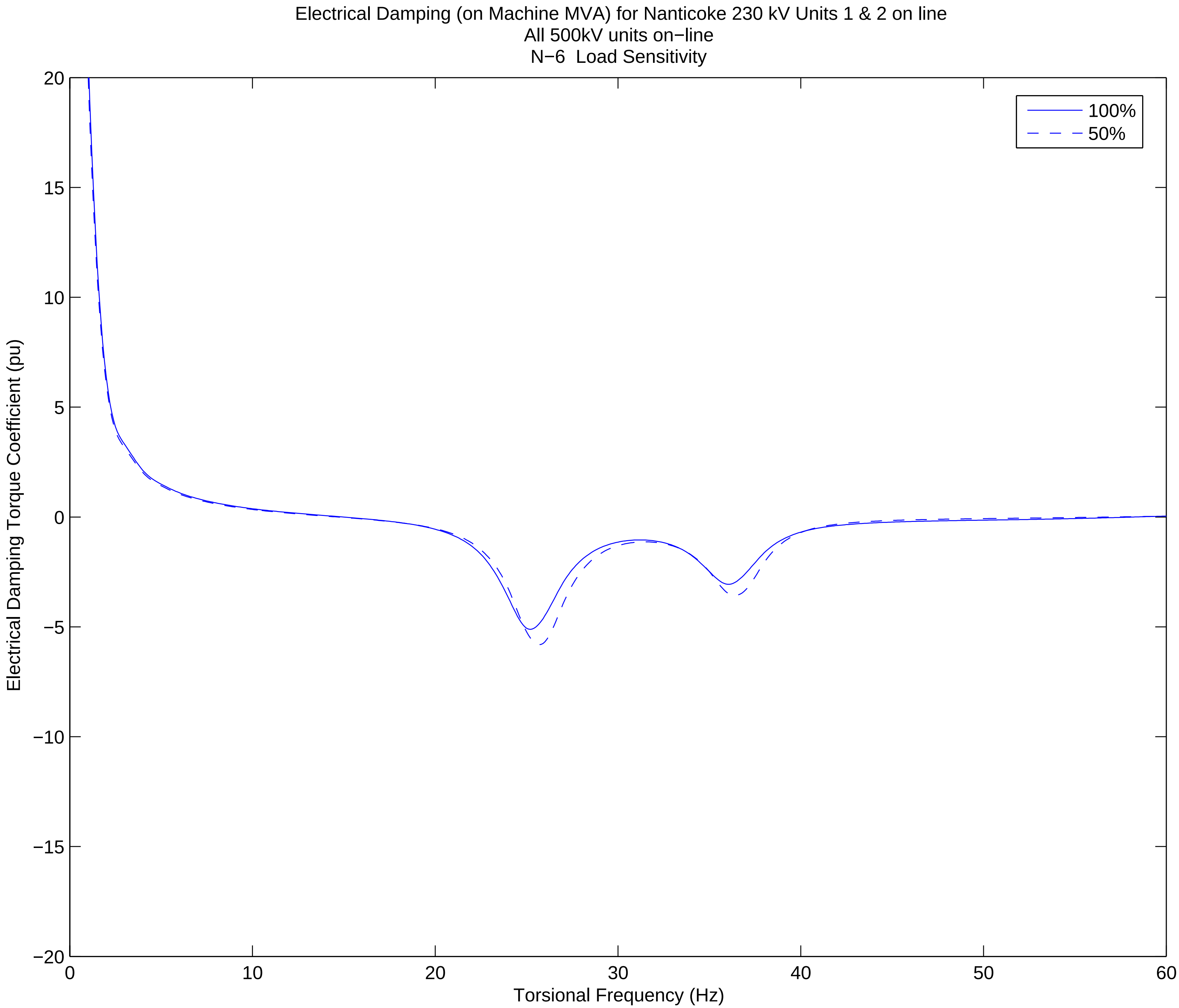

Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units 1, 2 & 3 on line
All 230kV units on−line
N−8 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

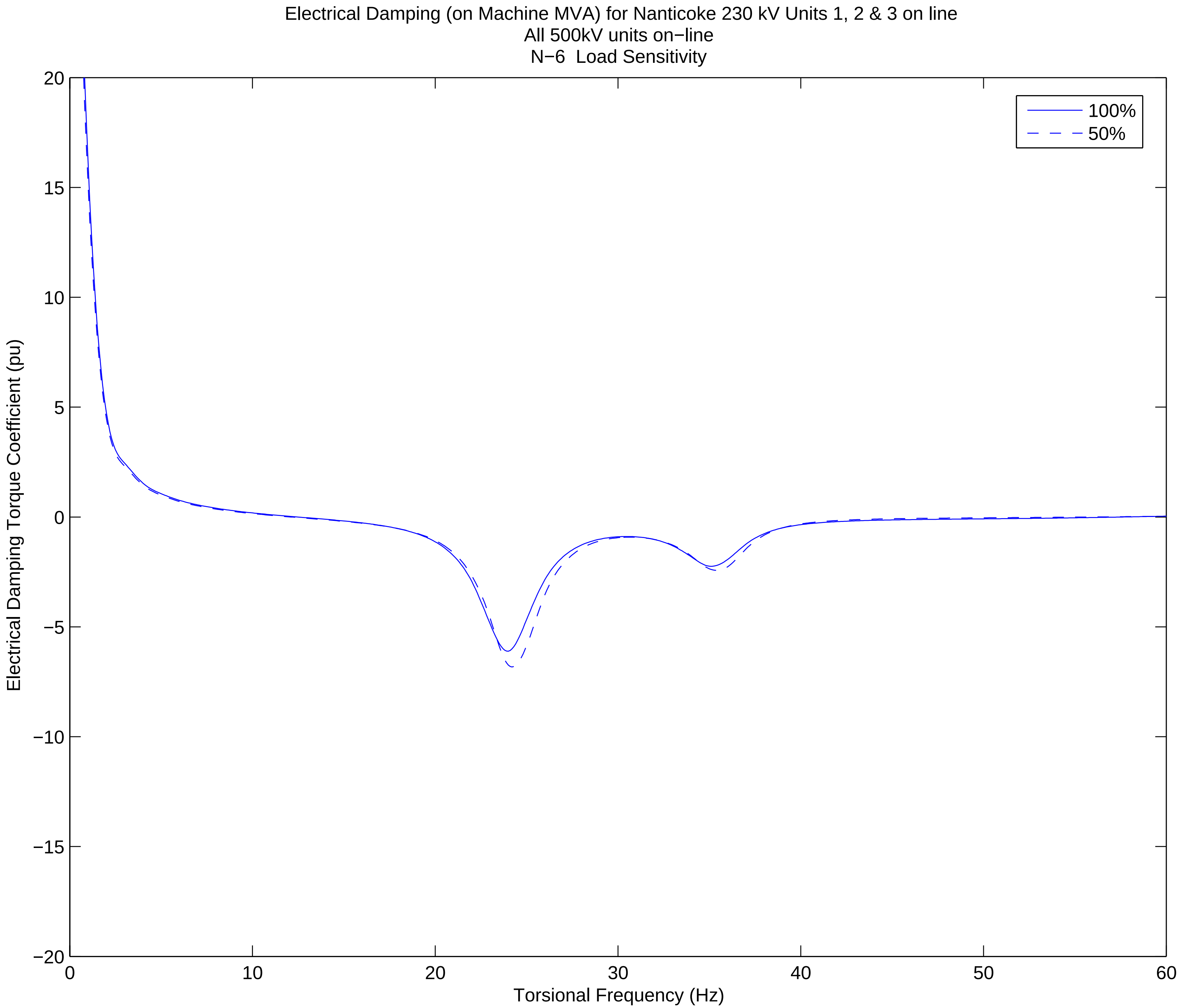


Electrical Damping (on Machine MVA) for Nanticoke 500 kV Unit 4 only on line
All 230kV units on−line
N−8 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

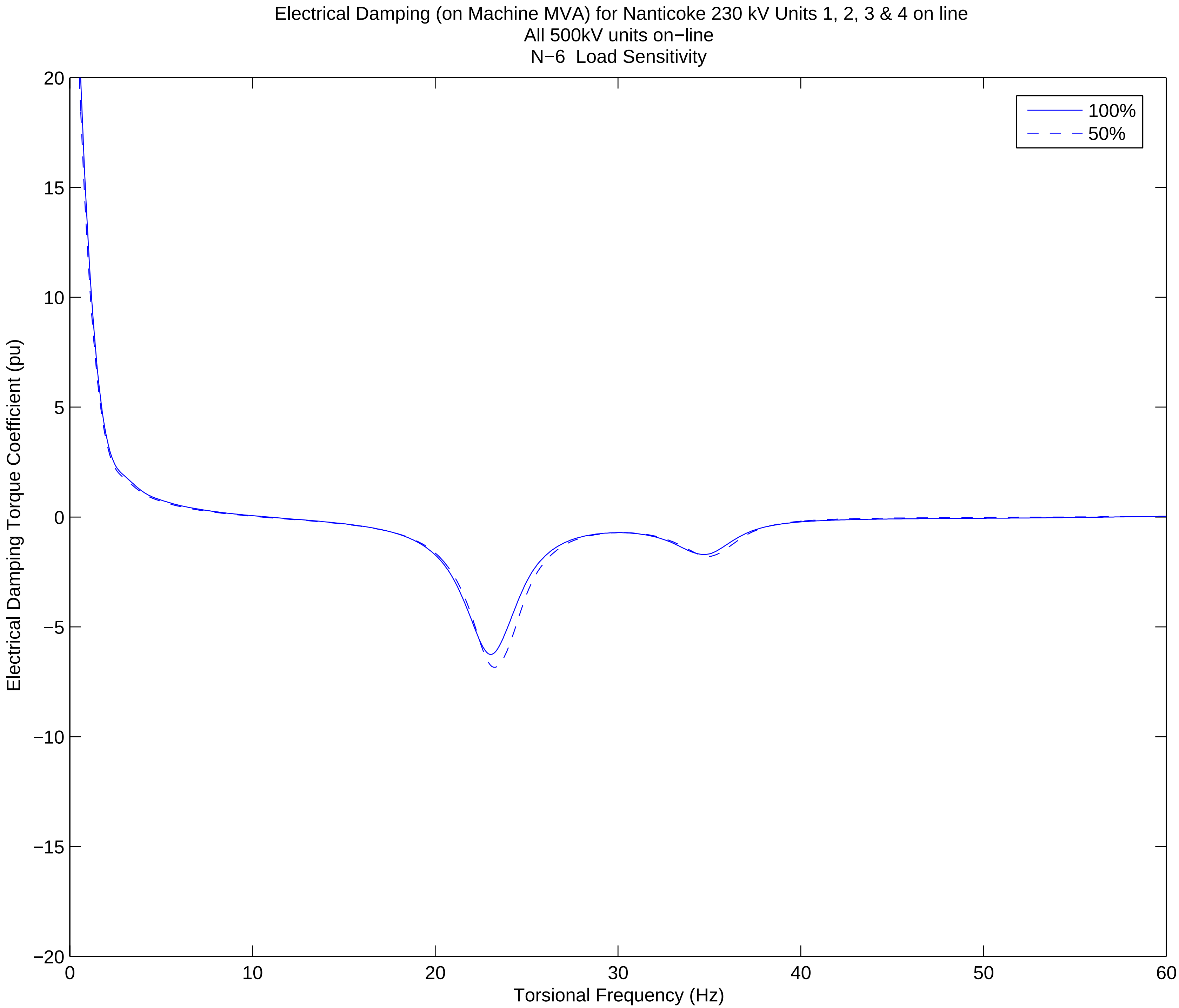


Electrical Damping (on Machine MVA) for Nanticoke 230 kV Unit 1
All 500kV units on−line
N−6 Load Sensitivity
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
100%
50%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units 1 & 2 on line
All 500kV units on−line
N−6 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units 1, 2 & 3 on line
All 500kV units on−line
N−6 Load Sensitivity
100%
50%
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)



Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units 1, 2, 3 & 4 on line
All 500kV units on−line
N−6 Load Sensitivity
100%
50%
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

APPENDIX O: Comparison Plots Among Simple, Full and Transfer Function Calculations

Appendix O – Comparison Plots Among Simple, Full and Transfer Function Calculations

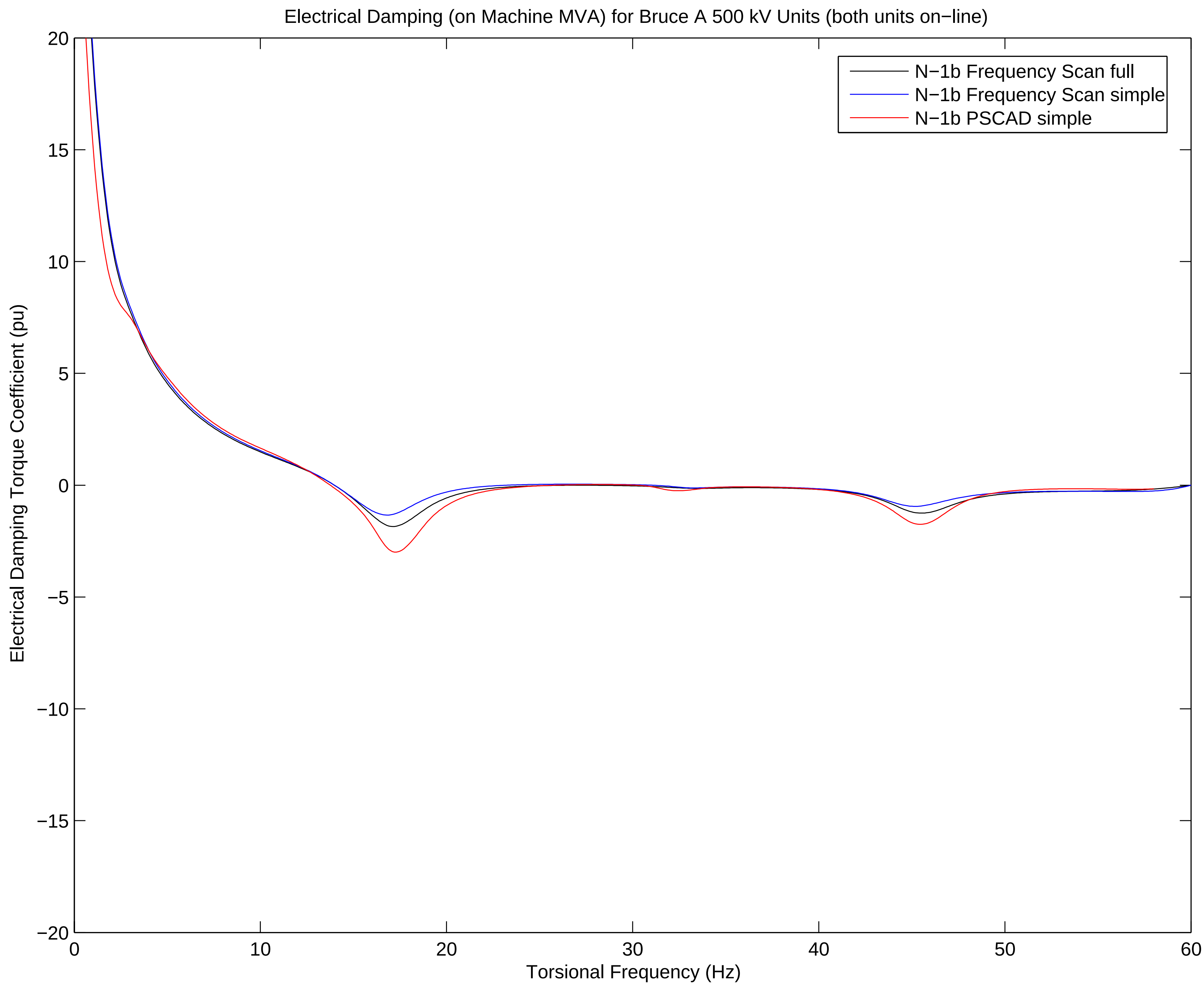
This appendix contains plots comparing the damping coefficients for the various models. The calculation results are compared for several generators and contingencies. The descriptions of the contingencies are listed in Table O-1.

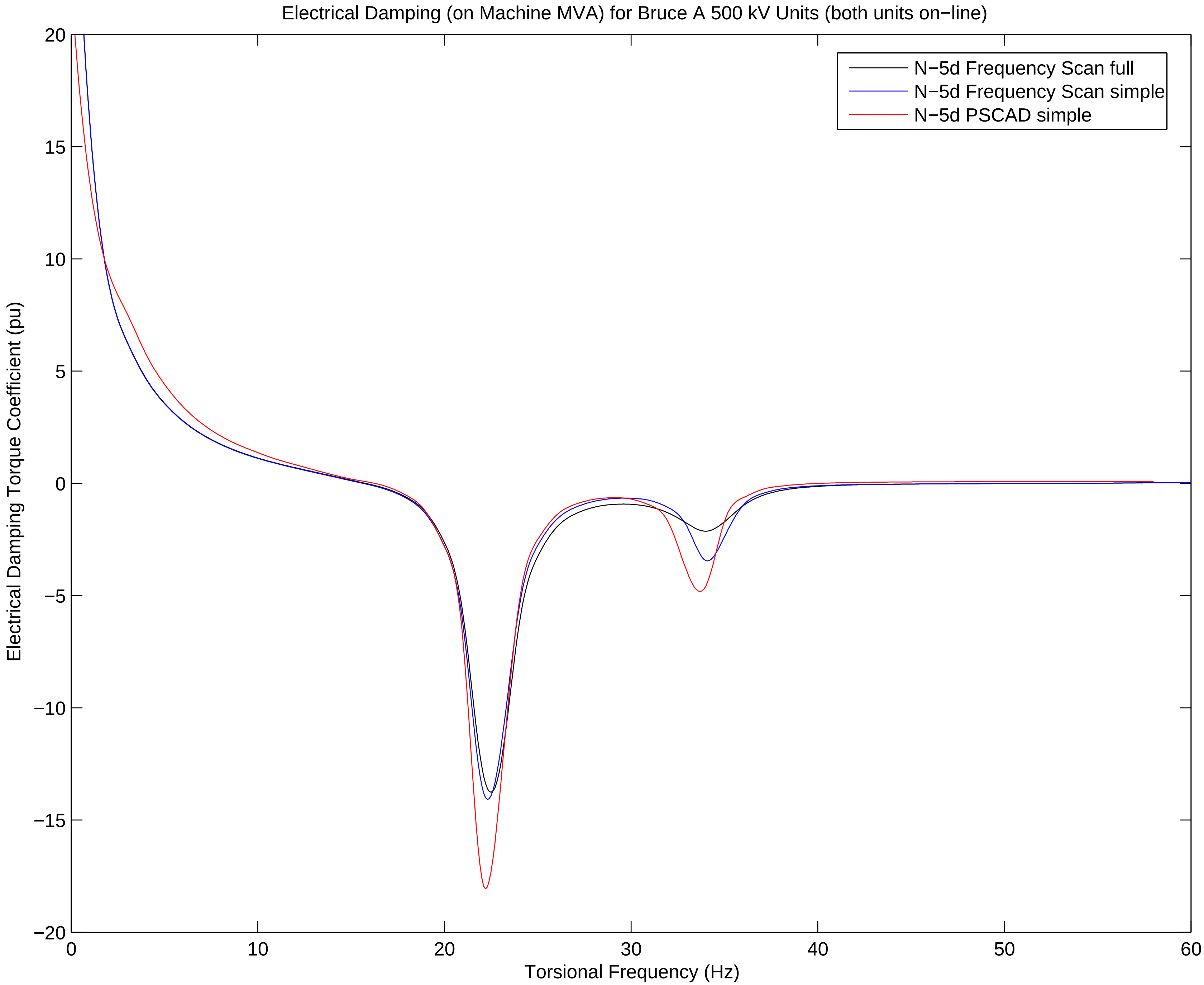
Table O-1: Contingency Descriptions

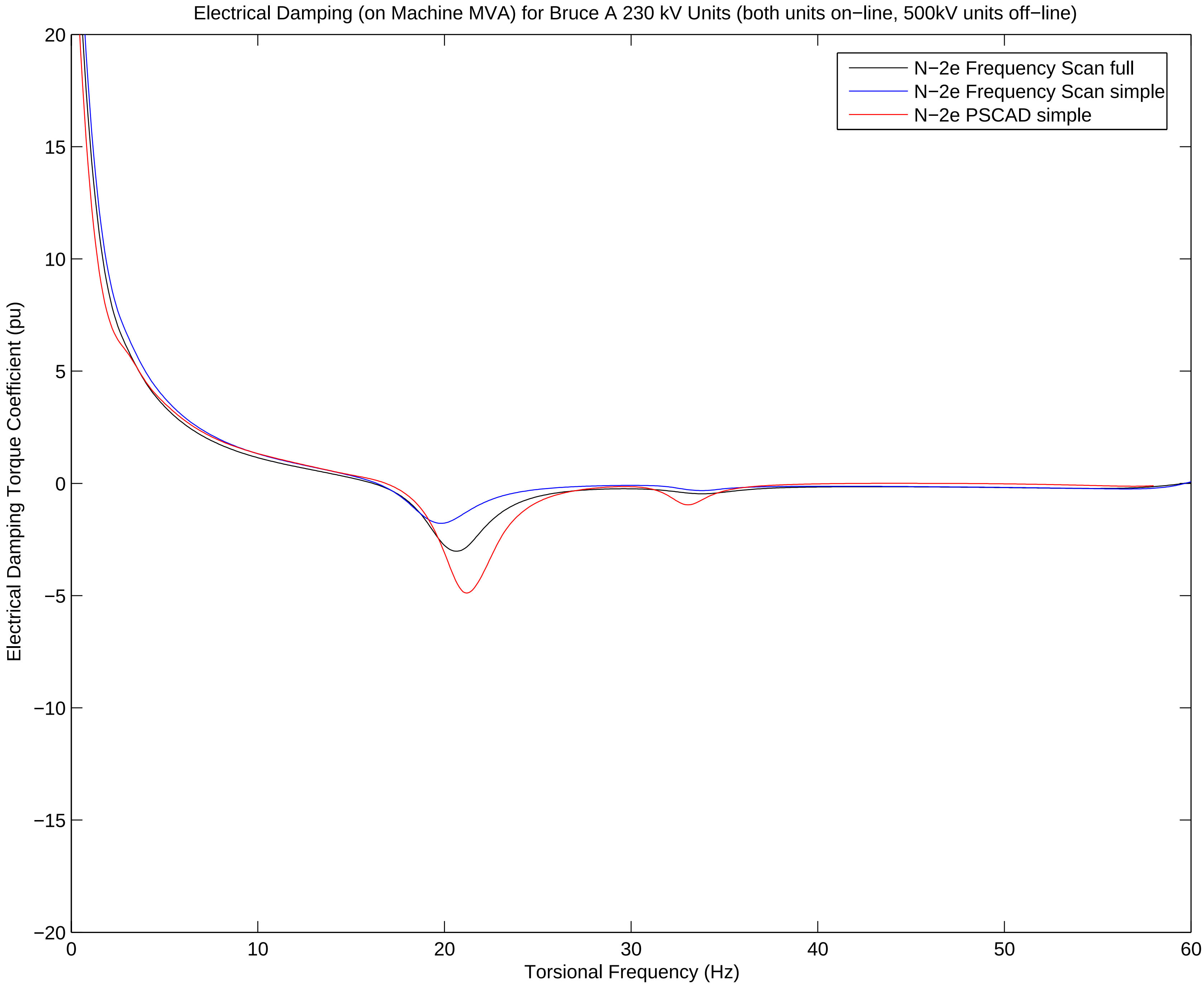
Contingency ID	Bruce A – Clairville 500kV Line 1	Bruce B – Milton 500kV Line 1	Bruce A – Bruce B 500kV Tie	Bruce A 500/230/27.6kV Transformer 25	Bruce A 500/230/27.6kV Transformer 27	Bruce A 500/230/27.6kV Transformer 28	Bruce A – Longwood 500kV Line 1	Bruce A – Bruce B 500kV Tie 1	Bruce B – Milton 500kV Line 1	Bruce B – Longwood 500kV Line 1
Bruce A 500kV Unit G3										
N-1b			X							
N-2	X	X								
N-5d	X		X	X	X	X				
Bruce A 230kV Unit G1										
N-2e	X		X							
Bruce B 500kV Unit G5										
N-1								X		
N-2								X	X	

Contingency ID	Midd8086 – Nanticoke 500kV Line 1	Midd8185 – Nanticoke 500kV Line 1	Nanticoke – Imp NanJ 230kV Line 1	Nanticoke – CaledJn1 230kV Line 1	Nanticoke – CaledJn5 230kV Line 1	Nanticoke – CaledJn6 230kV Line 1	Nanticoke 500kV/230kV Transformer 11	Nanticoke 500kV/230kV Transformer 12	Longwood 500kV/230kV/27.6kV Five (5) Transformers #3-#7	
Nanticoke 500kV Units										
N-4a	X	X					X	X		
Nanticoke 230kV Units										
N-6	X	X	X	X	X	X				

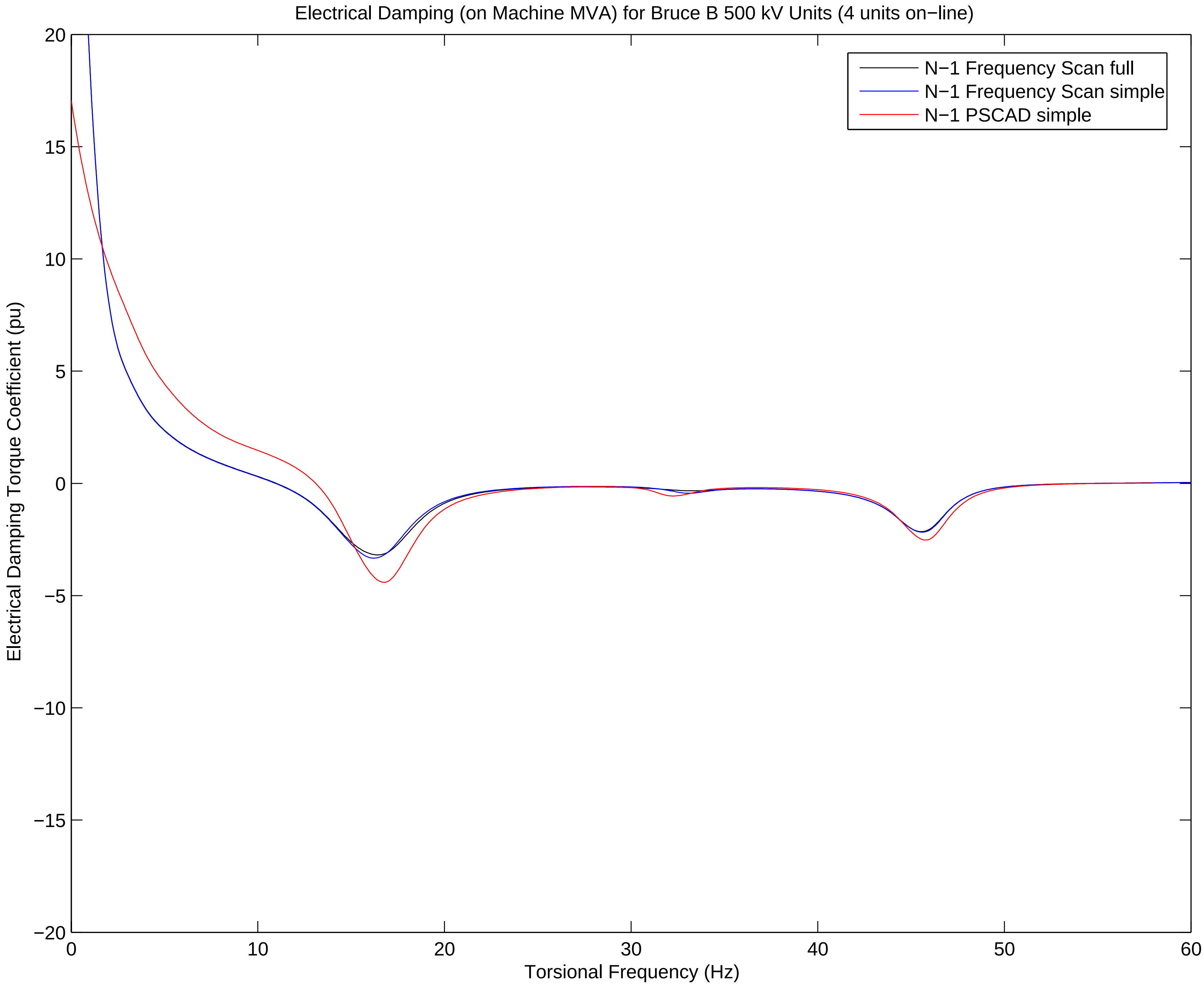
X – indicates the branch is out-of-service

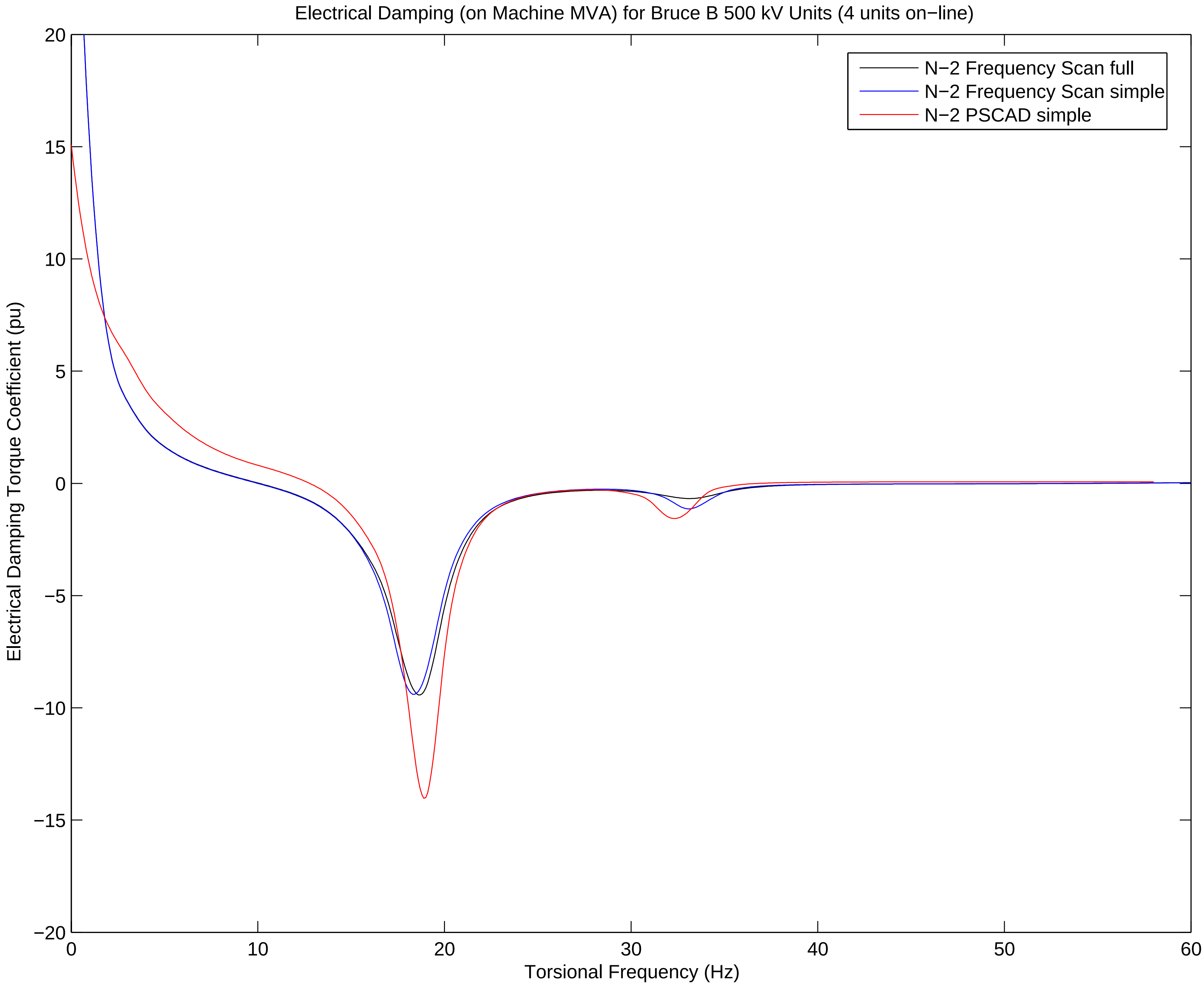

Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
N−1b Frequency Scan full
N−1b Frequency Scan simple
N−1b PSCAD simple
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
N−5d Frequency Scan full
N−5d Frequency Scan simple
N−5d PSCAD simple
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

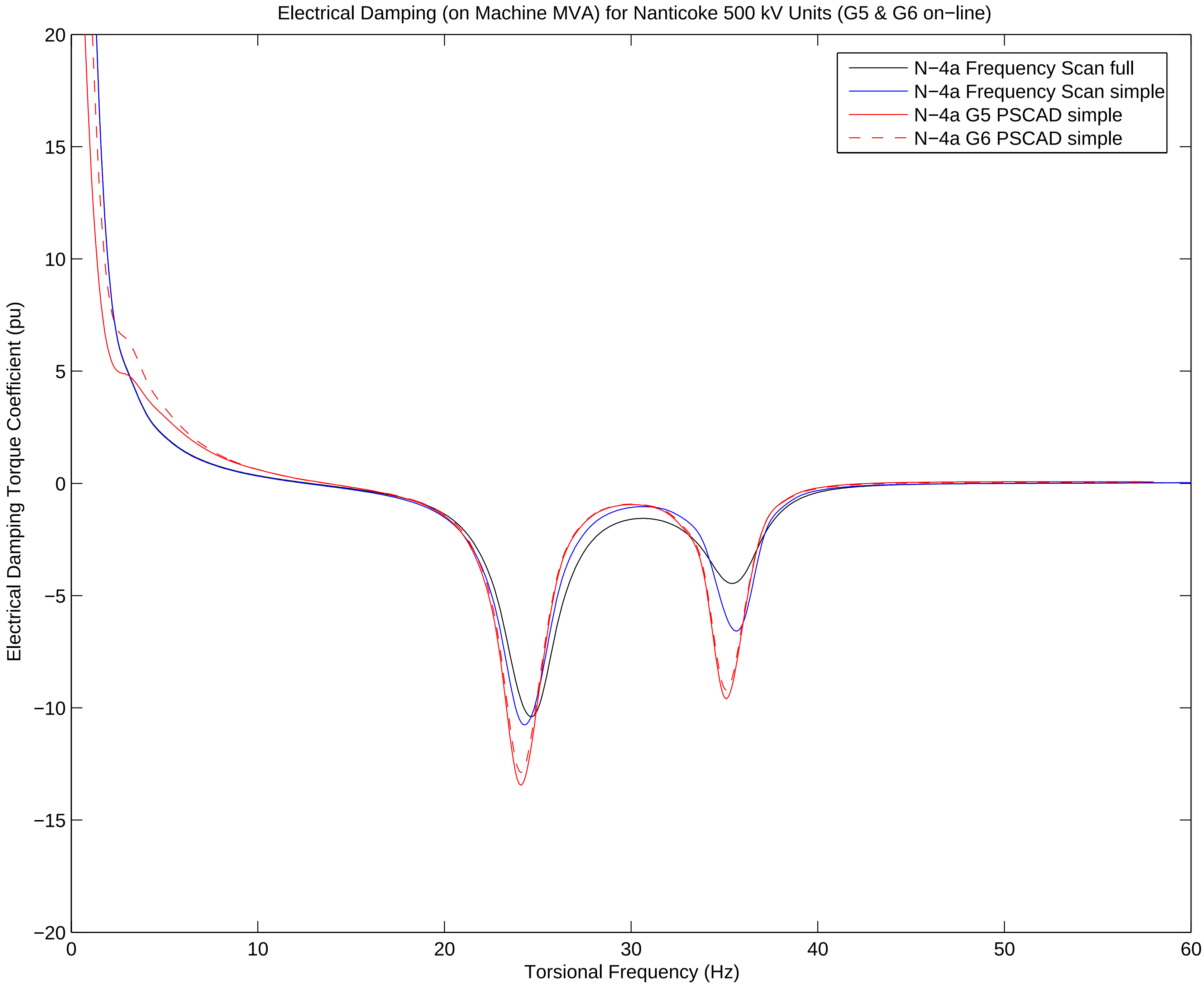


Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line, 500kV units off−line)
N−2e Frequency Scan full
N−2e Frequency Scan simple
N−2e PSCAD simple
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

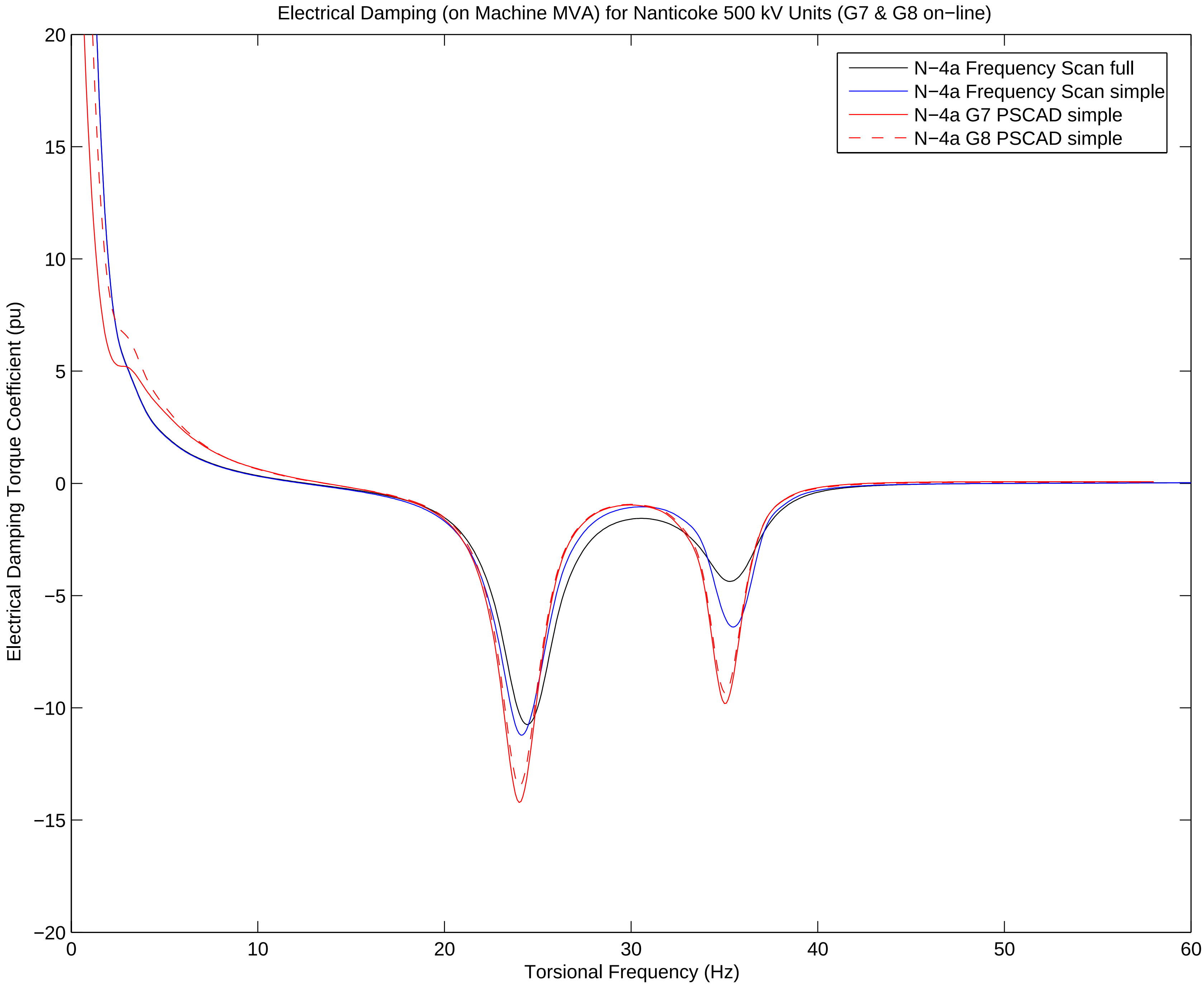

Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (4 units on−line)
N−1 Frequency Scan full
N−1 Frequency Scan simple
N−1 PSCAD simple
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

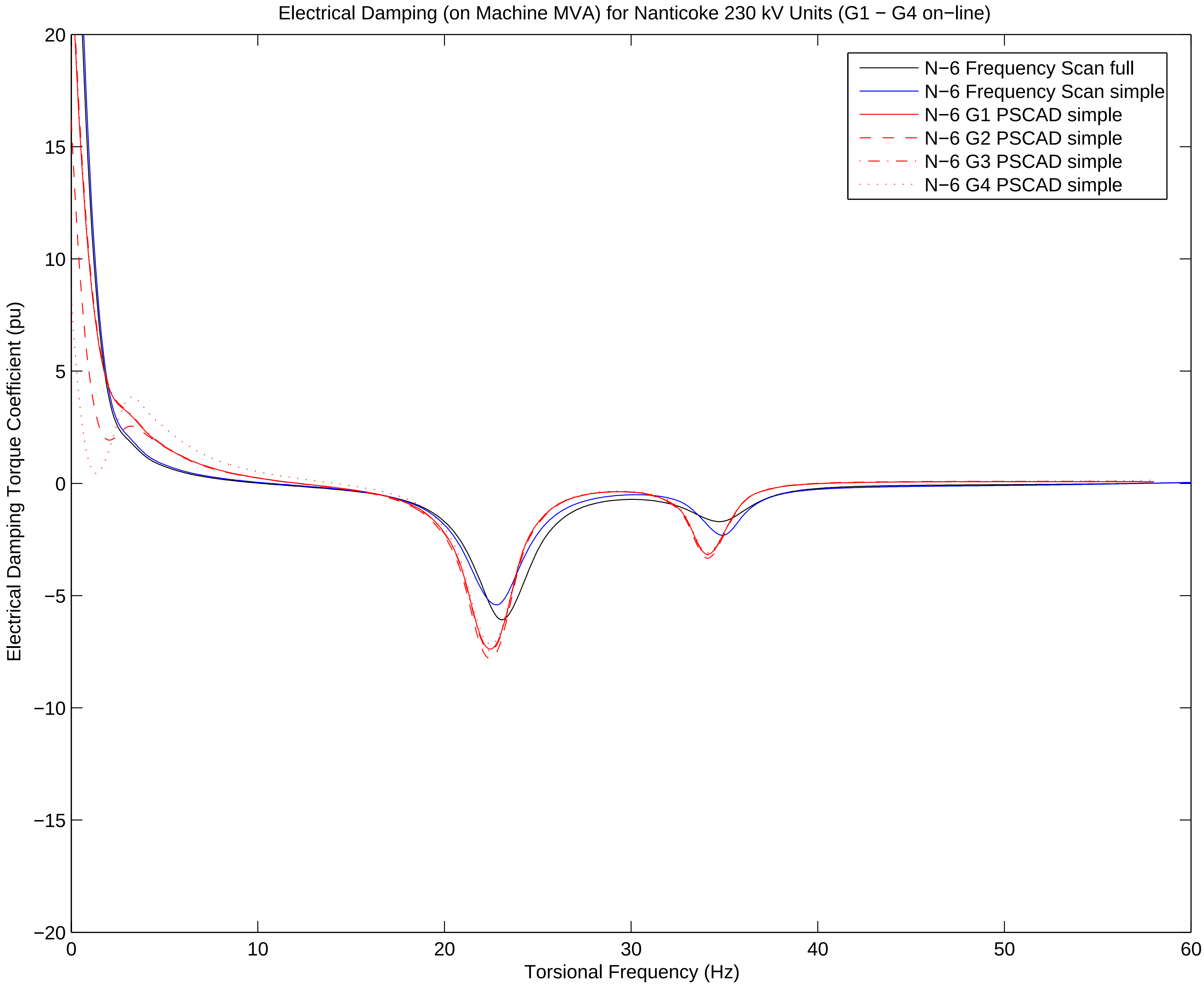


Electrical Damping (on Machine MVA) for Bruce B 500 kV Units (4 units on−line)
N−2 Frequency Scan full
N−2 Frequency Scan simple
N−2 PSCAD simple
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units (G5 & G6 on−line)
N−4a Frequency Scan full
N−4a Frequency Scan simple
N−4a G5 PSCAD simple
N−4a G6 PSCAD simple
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Nanticoke 500 kV Units (G7 & G8 on−line)
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
N−4a Frequency Scan full
N−4a Frequency Scan simple
N−4a G7 PSCAD simple
N−4a G8 PSCAD simple
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60


Electrical Damping (on Machine MVA) for Nanticoke 230 kV Units (G1 − G4 on−line)
N−6 Frequency Scan full
N−6 Frequency Scan simple
N−6 G1 PSCAD simple
N−6 G2 PSCAD simple
N−6 G3 PSCAD simple
N−6 G4 PSCAD simple
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

APPENDIX P: Comparison Plots of Damping Torque Calculations Between Original and New Bruce A Machine Parameters

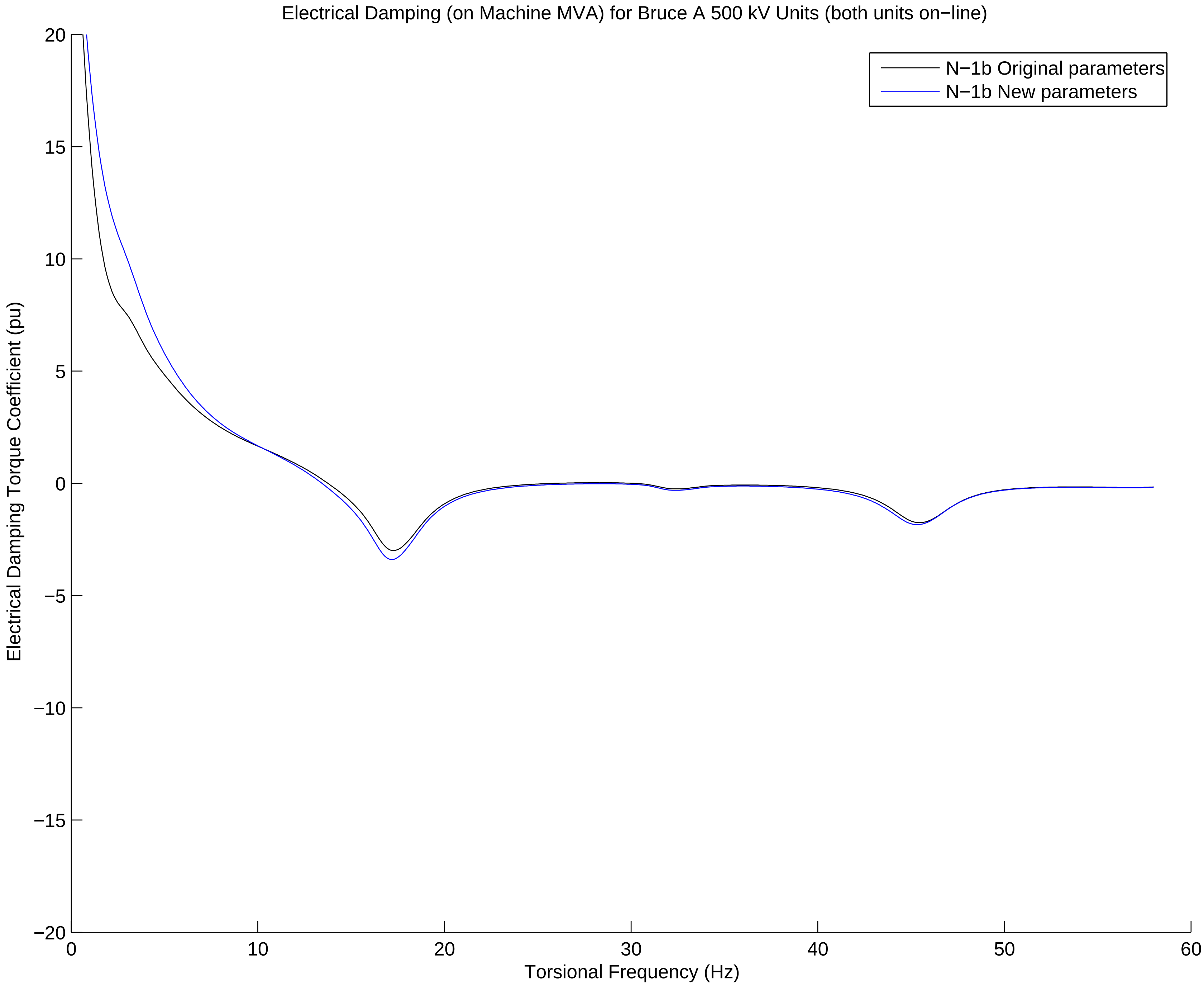
Appendix P – Comparison Plots of Damping Torque Calculations Between Original and New Bruce A Machine Parameters

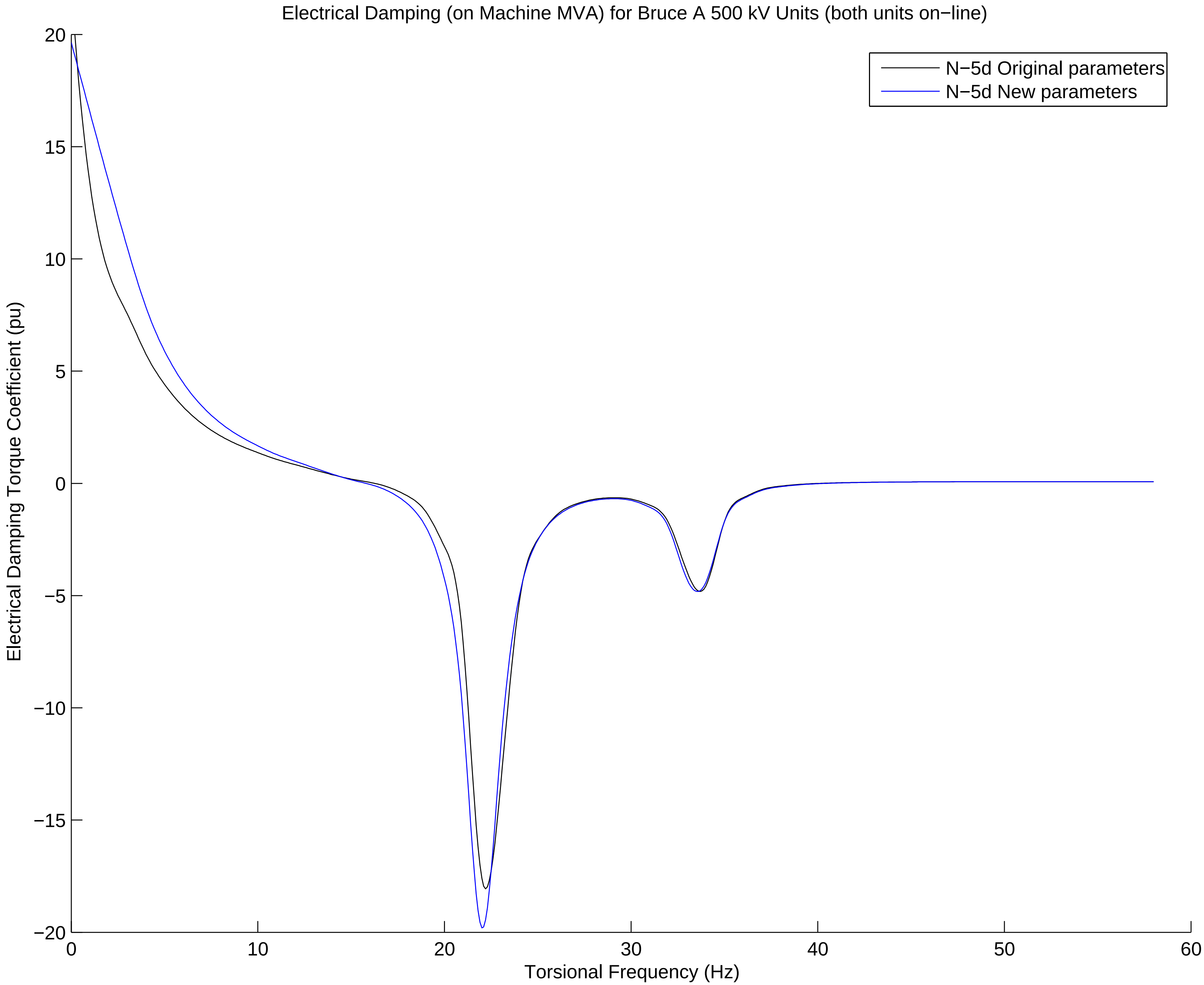
This appendix contains plots comparing the damping coefficients results for the original and updated Bruce A generator parameters. The comparisons are made for the contingencies listed in Table P-1.

Table P-1: Contingency Descriptions

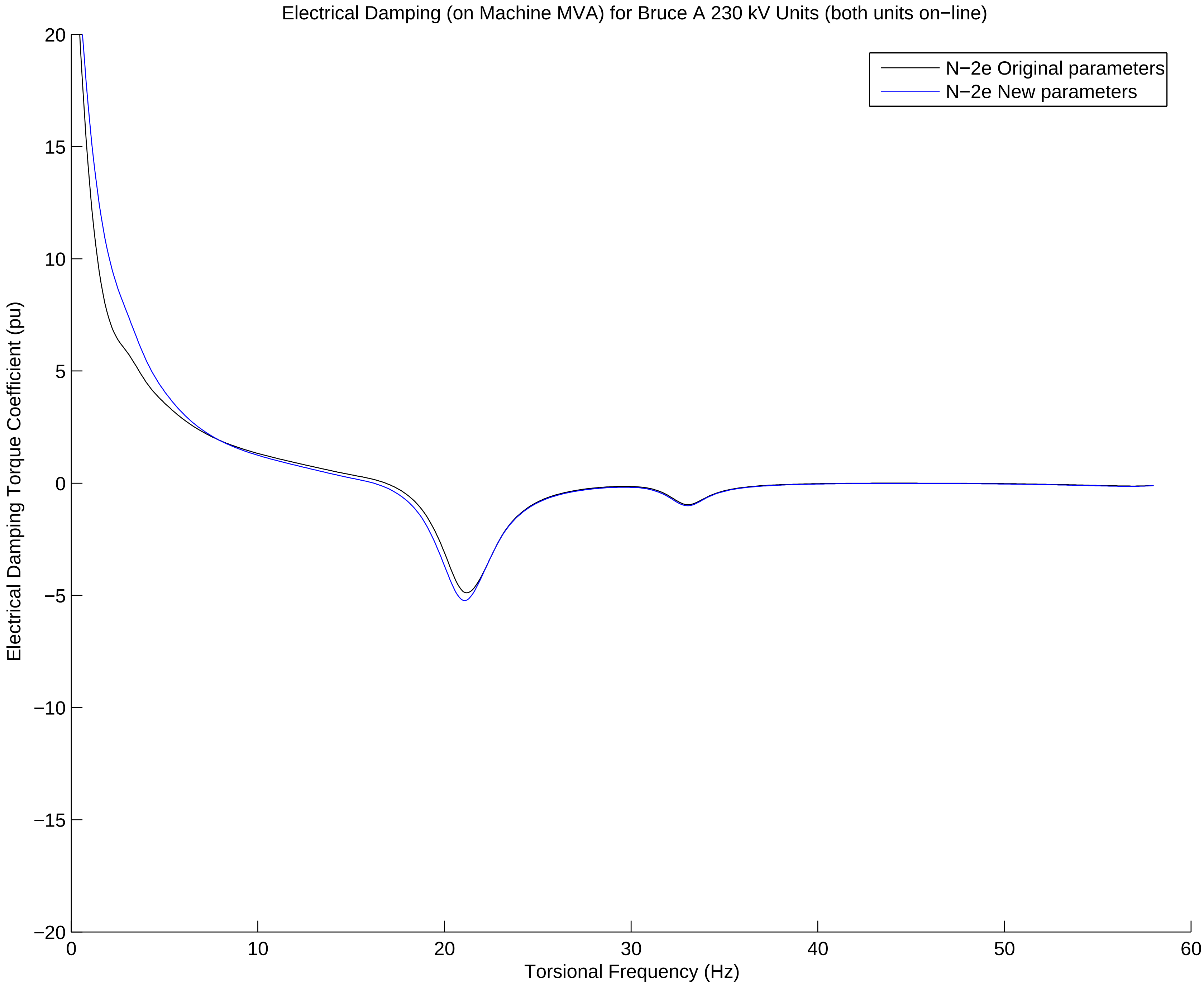
Contingency ID	Bruce A – Clairville 500kV Line 1	Bruce B – Milton 500kV Line 1	Bruce A – Bruce B 500kV Tie	Bruce A 500/230/27.6kV Transformer 25	Bruce A 500/230/27.6kV Transformer 27	Bruce A 500/230/27.6kV Transformer 28	Bruce A – Longwood 500kV Line 1	Bruce A – Bruce B 500kV Tie 1	Bruce B – Milton 500kV Line 1	Bruce B – Longwood 500kV Line 1
Bruce A 500kV Unit G3										
N-1b			X							
N-5d	X		X	X	X	X				
Bruce A 230kV Unit G1										
N-2e	X		X							

X – indicates the branch is out-of-service


Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
N−1b Original parameters
N−1b New parameters
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Bruce A 500 kV Units (both units on−line)
N−5d Original parameters
N−5d New parameters
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60



Electrical Damping (on Machine MVA) for Bruce A 230 kV Units (both units on−line)
N−2e Original parameters
N−2e New parameters
Electrical Damping Torque Coefficient (pu)
Torsional Frequency (Hz)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

APPENDIX Q: Transient Torque Plots for Various Fault Clearing Times – Bruce A

Appendix Q – Transient Torque Plots for Various Fault Clearing Times – Bruce A

This appendix contains compares the transient torque on Bruce A G3 (500kV Unit) during the first second following fault inception for various clearing times. Contingency N-5d, which represents the outage shown in Table Q-1, was simulated. The resulting maximum observed transient torques are summarized in Table Q-2.

Table R-1: Contingency Description

Contingency ID	Bruce A – Clairville 500kV Line 1	Bruce B – Milton 500kV Line 1	Bruce A – Bruce B 500kV Tie	Bruce A 500/230/27.6kV Transformer 25	Bruce A 500/230/27.6kV Transformer 27	Bruce A 500/230/27.6kV Transformer 28	Bruce A – Longwood 500kV Line 1
N-5d	X		X	X	X	X	

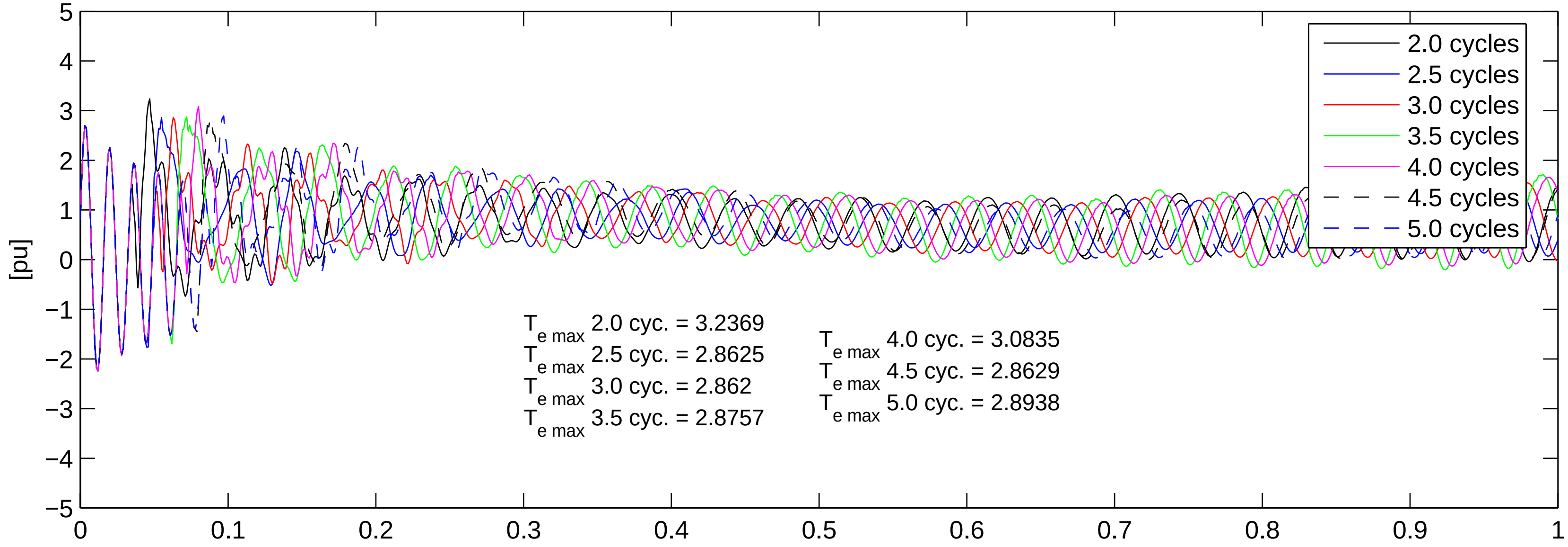
X – indicates the branch is out-of-service

Table R-2: Maximum Observed Transient Electrical Torques

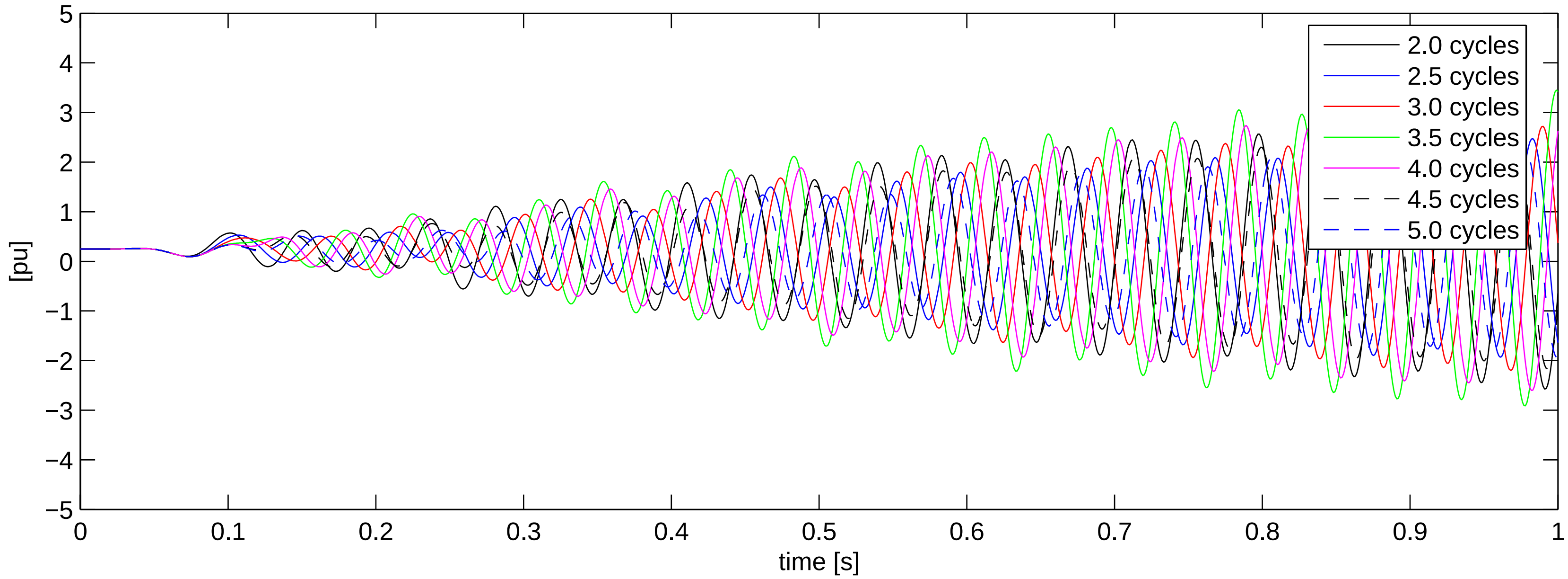
Fault Duration (cycles)	Max. Transient Electrical Torque (pu)
2.0	3.2369
2.5	2.8625
3.0	2.8620
3.5	2.8757
4.0	3.0835
4.5	2.8629
5.0	2.8938

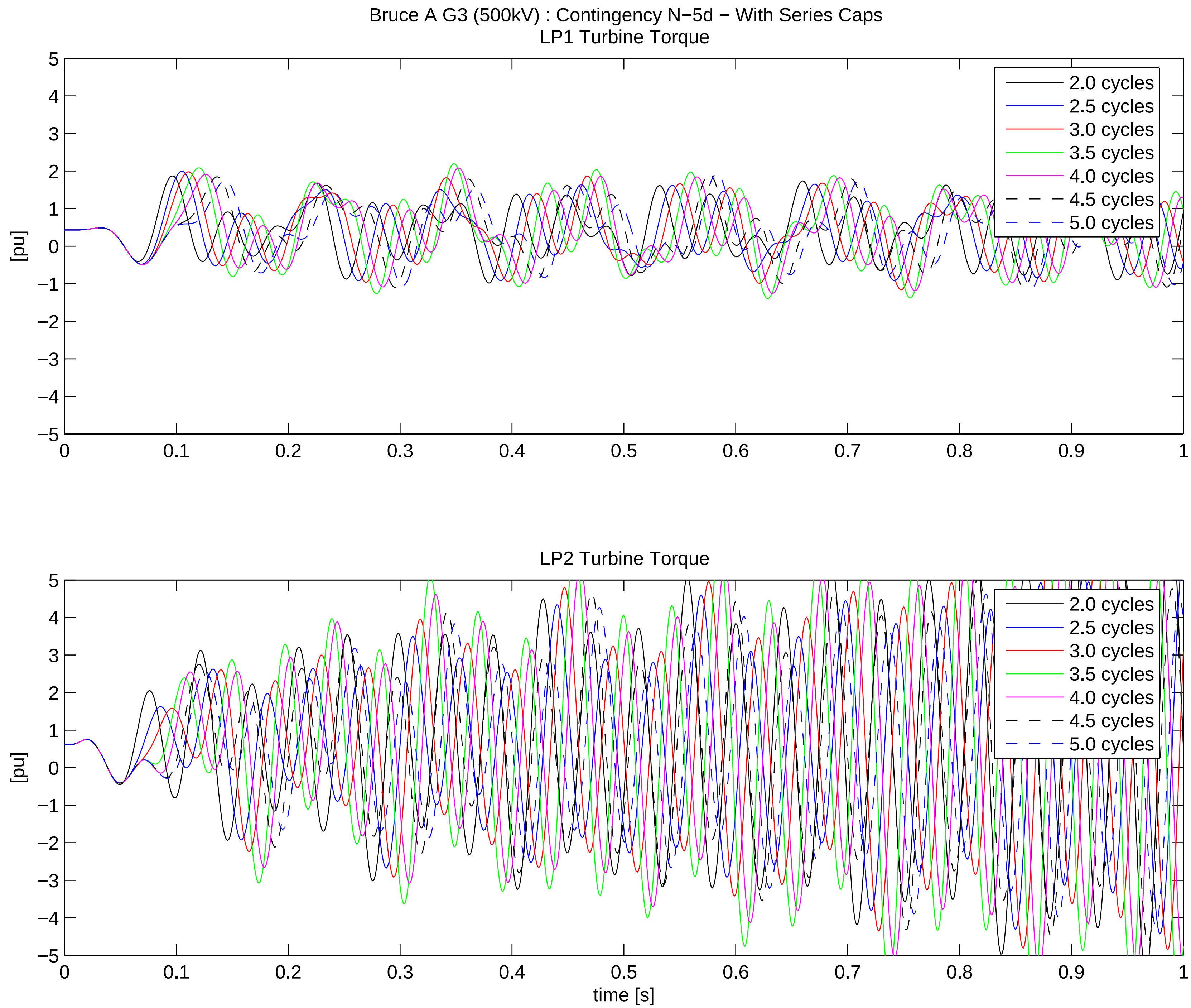
Bruce A G3 (500kV) : Contingency N−5d − With Series Caps

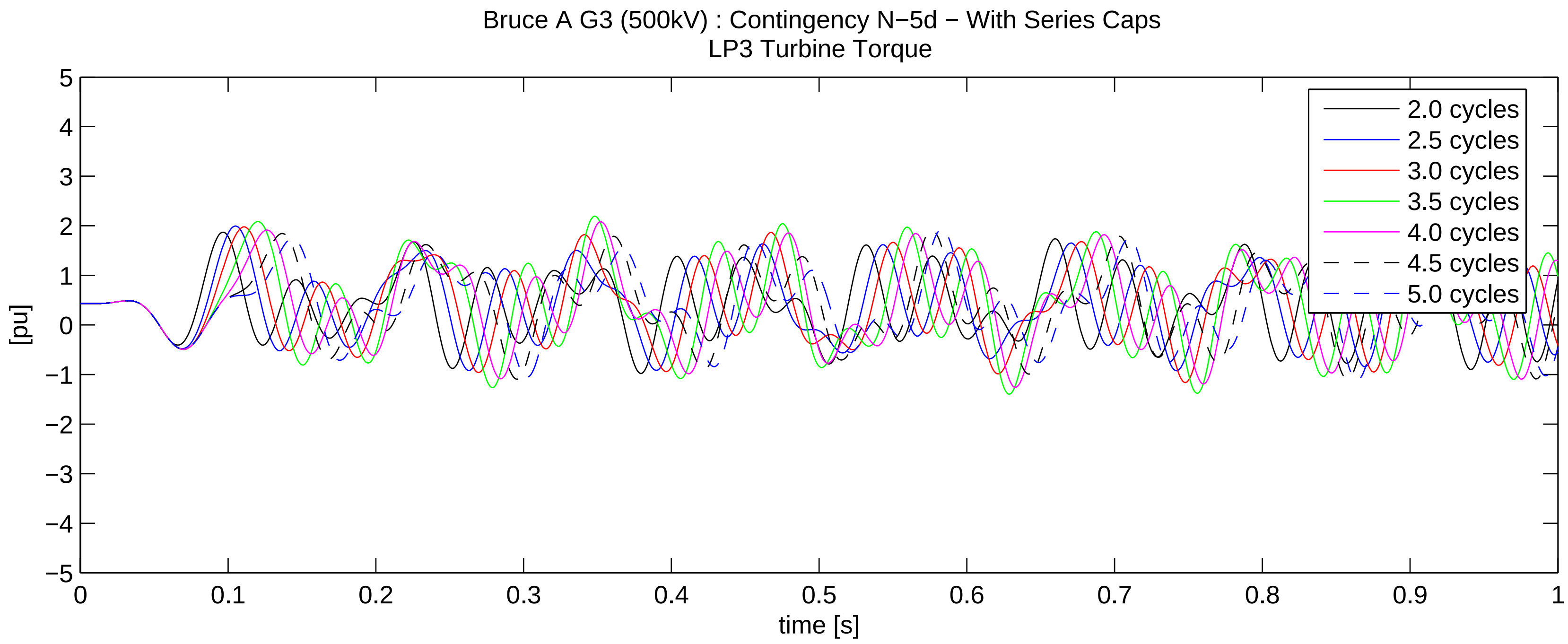
Electrical Torque



HP Turbine Torque




Bruce A G3 (500kV) : Contingency N−5d − With Series Caps
LP1 Turbine Torque
[pu]
2.0 cycles
2.5 cycles
3.0 cycles
3.5 cycles
4.0 cycles
4.5 cycles
5.0 cycles
LP2 Turbine Torque
[pu]
2.0 cycles
2.5 cycles
3.0 cycles
3.5 cycles
4.0 cycles
4.5 cycles
5.0 cycles
time [s]



Bruce A G3 (500kV) : Contingency N−5d − With Series Caps
LP3 Turbine Torque
[pu]
time [s]
2.0 cycles
2.5 cycles
3.0 cycles
3.5 cycles
4.0 cycles
4.5 cycles
5.0 cycles

APPENDIX R: Transient Torque Plots for Various Fault Clearing Times – Bruce B

Appendix R – Transient Torque Plots for Various Fault Clearing Times – Bruce B

This appendix contains compares the transient torque on Bruce B G5 (500kV Unit) during the first second following fault inception for various clearing times. Contingency N-2, which represents the outages shown in Table R-1, was simulated. The resulting maximum transient torques were the same for all fault times simulated as shown in Table R-2.

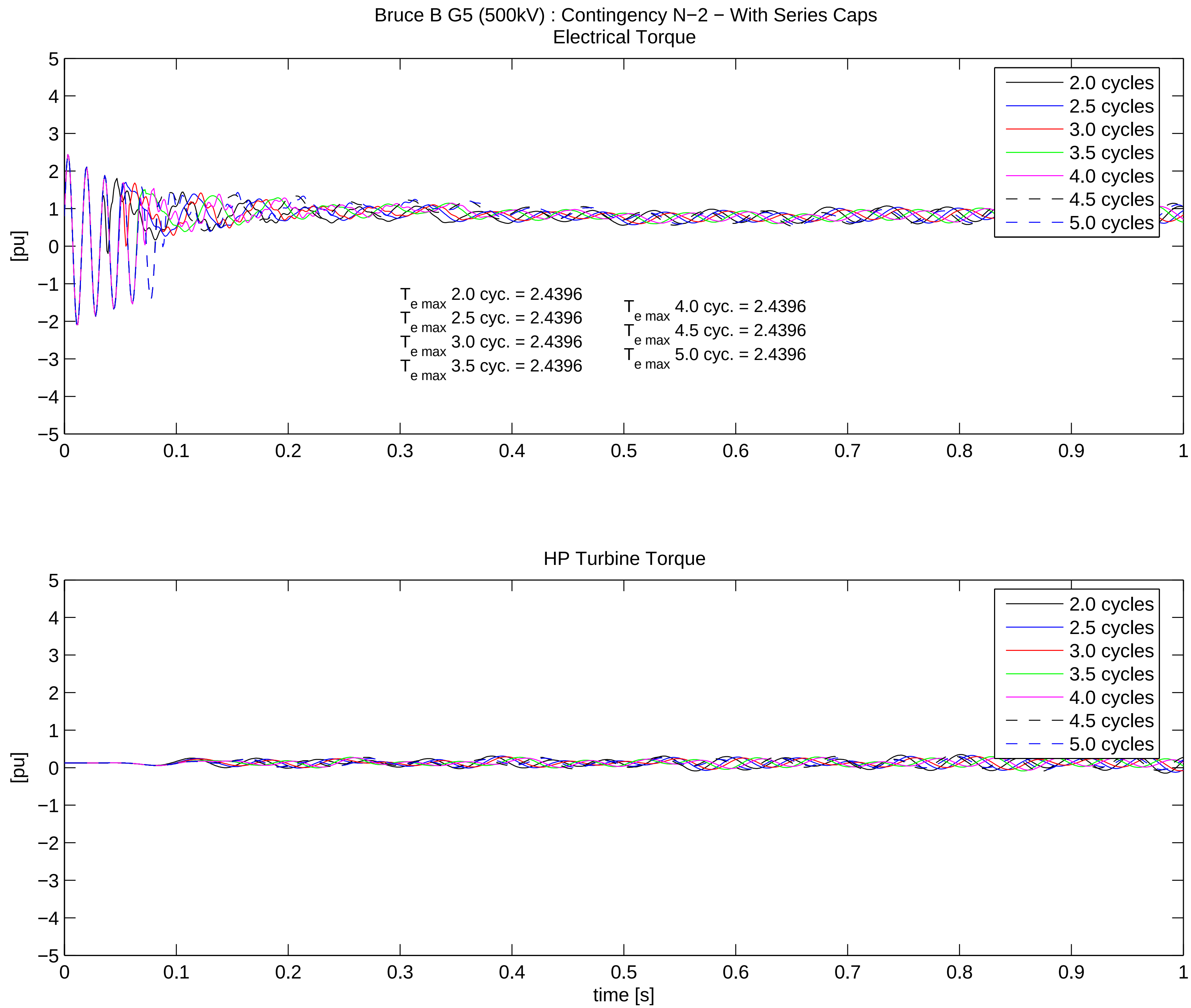
Table R-1: Contingency Description

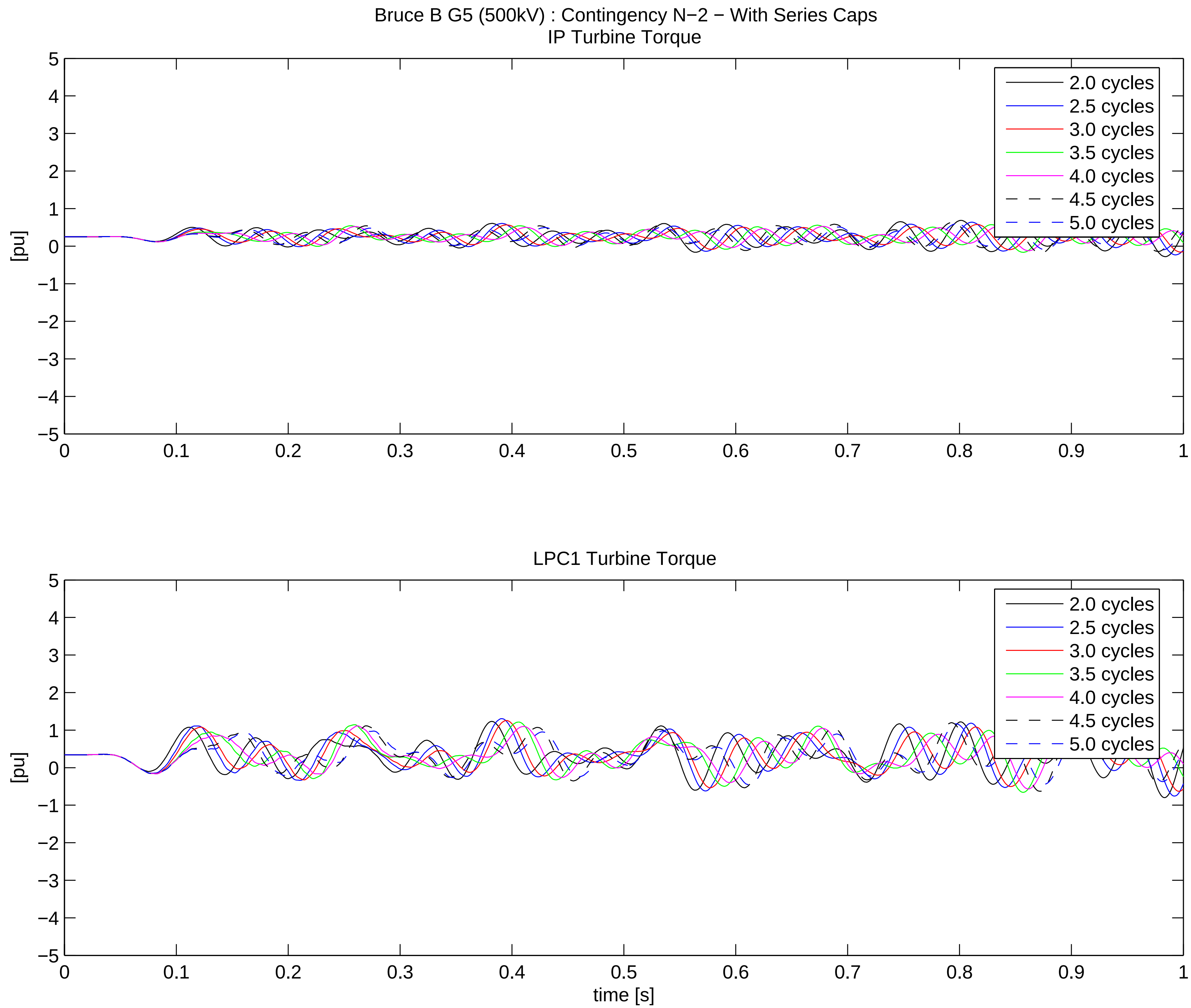
Contingency ID	Bruce A – Bruce B 500kV Tie 1	Bruce B – Milton 500kV Line 1	Bruce B – Longwood 500kV Line 1
N-2	X	X	

X – indicates the branch is out-of-service

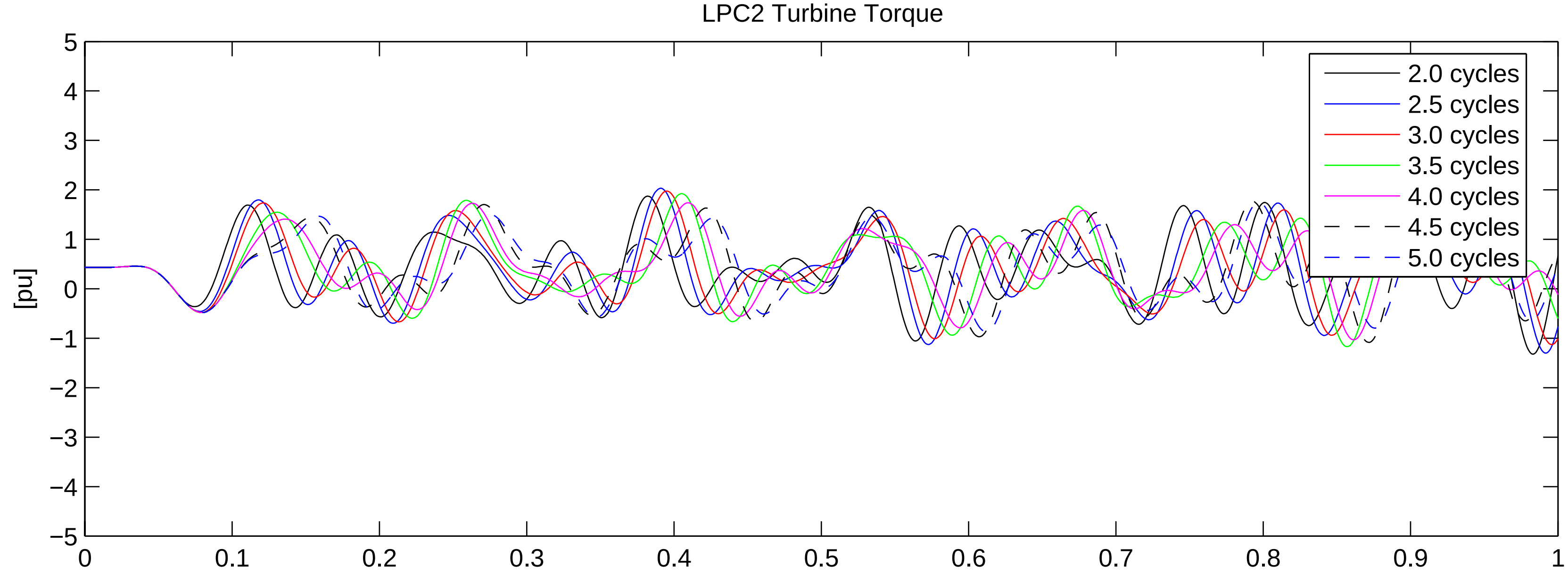
Table R-2: Maximum Observed Transient Electrical Torques

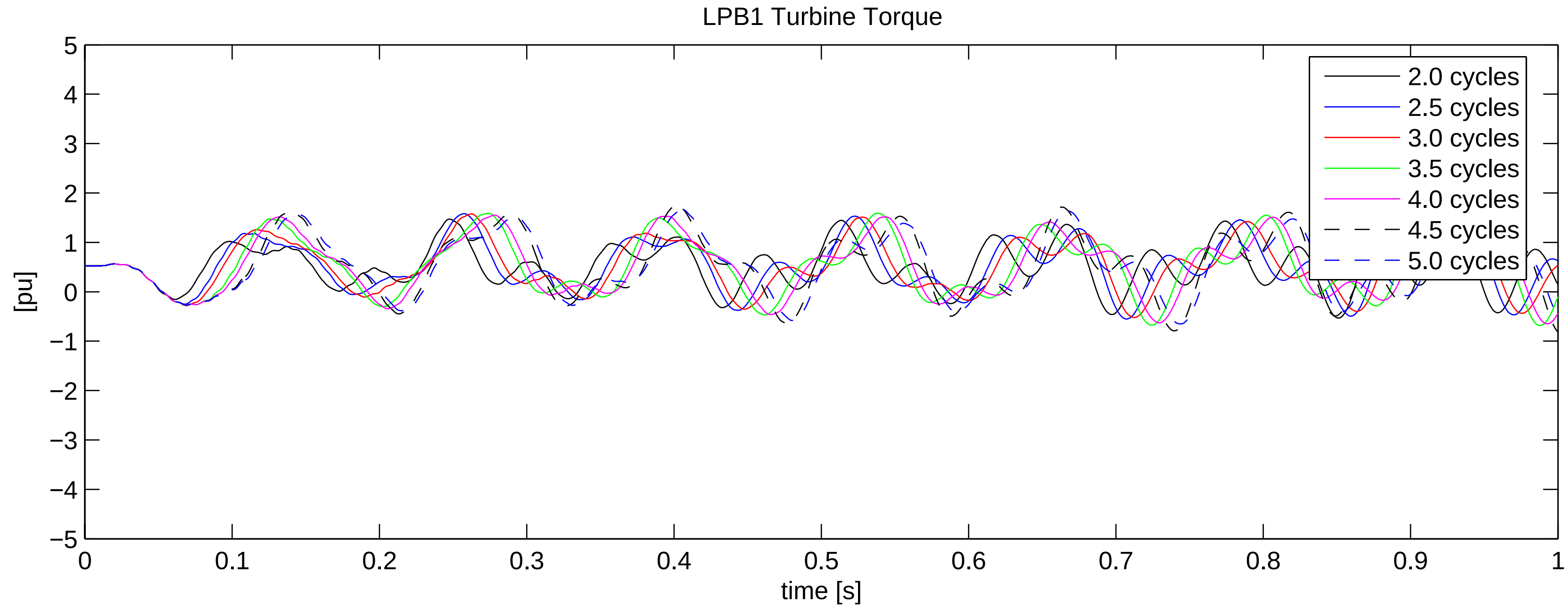
Fault Duration (cycles)	Max. Transient Electrical Torque (pu)
2.0	2.4396
2.5	2.4396
3.0	2.4396
3.5	2.4396
4.0	2.4396
4.5	2.4396
5.0	2.4396

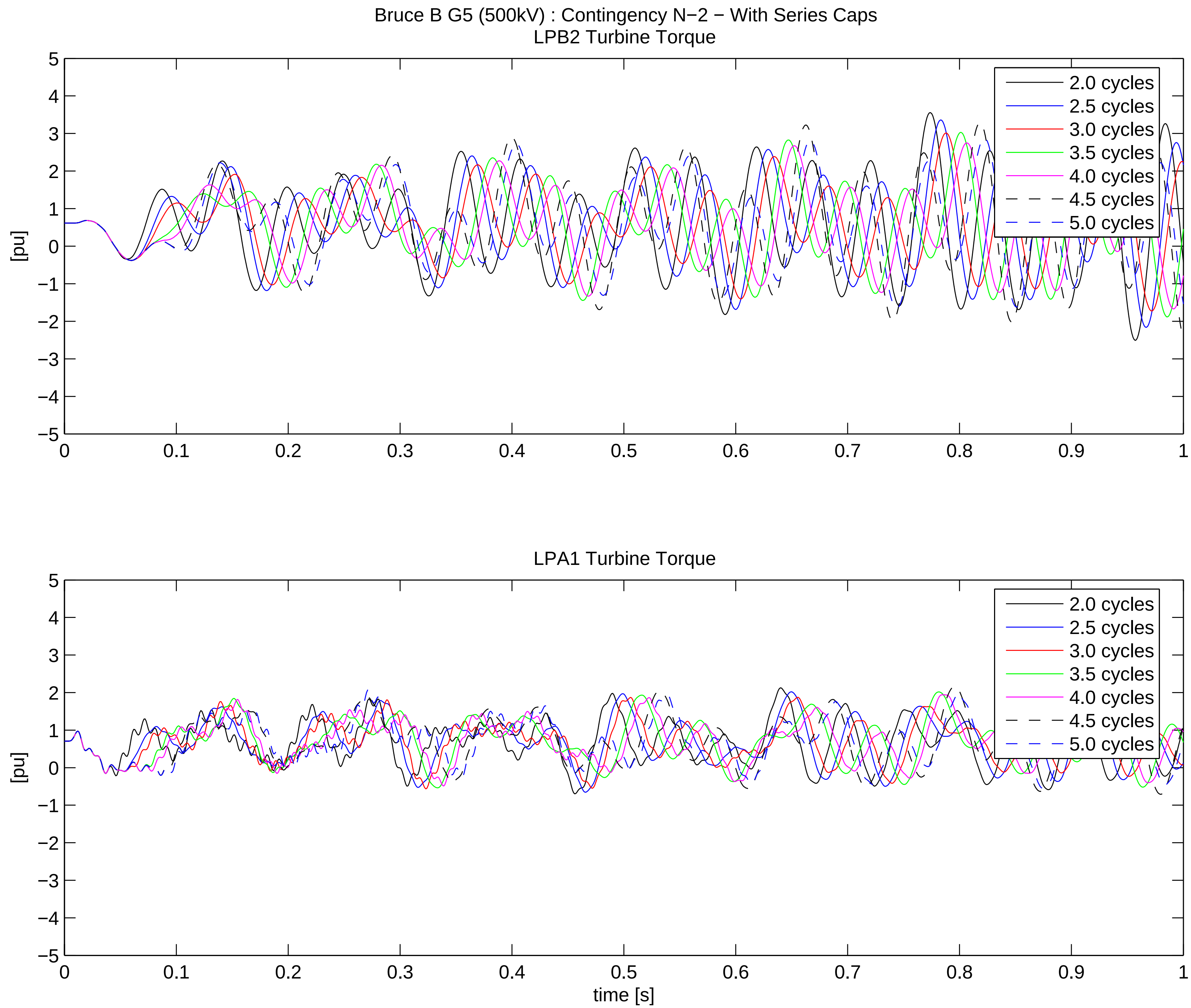

Bruce B G5 (500kV) : Contingency N−2 − With Series Caps
Electrical Torque
[pu]
time [s]
2.0 cycles
2.5 cycles
3.0 cycles
3.5 cycles
4.0 cycles
4.5 cycles
5.0 cycles
$T_{e\ max}$ 2.0 cyc. = 2.4396
$T_{e\ max}$ 2.5 cyc. = 2.4396
$T_{e\ max}$ 3.0 cyc. = 2.4396
$T_{e\ max}$ 3.5 cyc. = 2.4396
$T_{e\ max}$ 4.0 cyc. = 2.4396
$T_{e\ max}$ 4.5 cyc. = 2.4396
$T_{e\ max}$ 5.0 cyc. = 2.4396
HP Turbine Torque

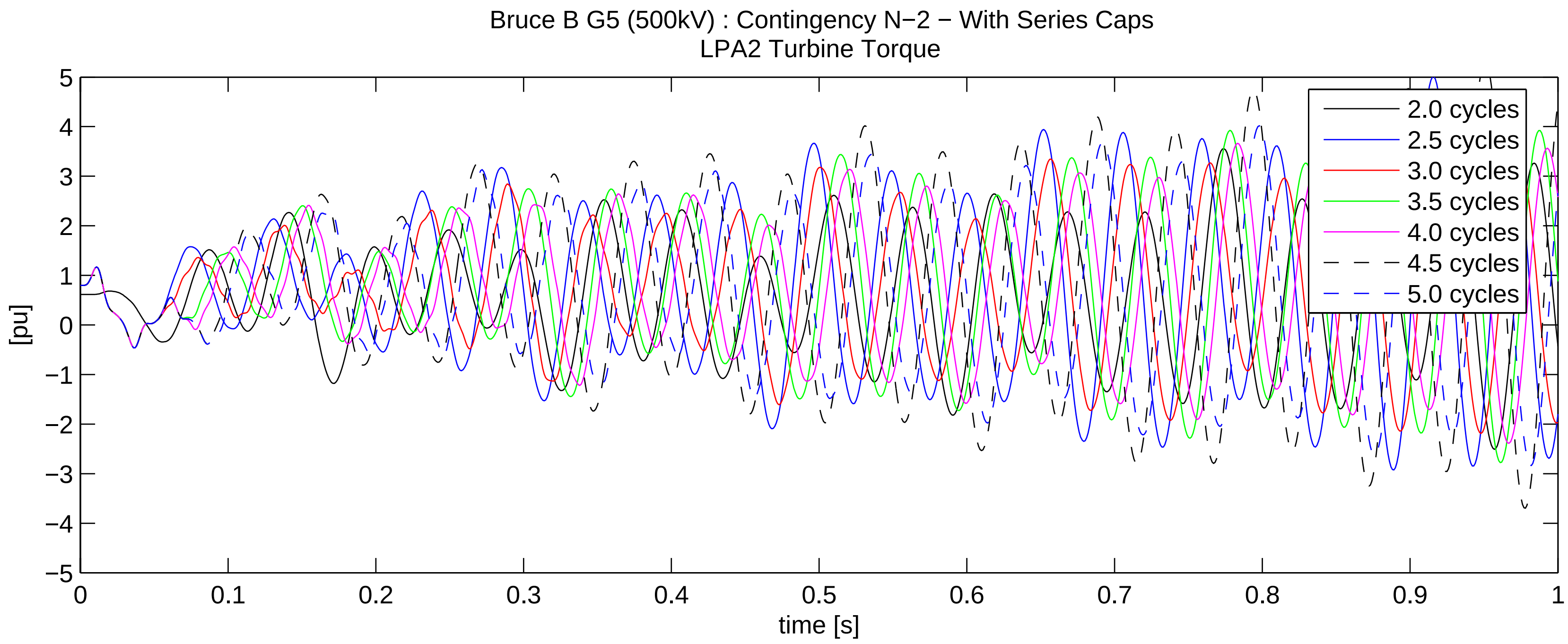

Bruce B G5 (500kV) : Contingency N−2 − With Series Caps
IP Turbine Torque
[pu]
5
4
3
2
1
0
−1
−2
−3
−4
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2.0 cycles
2.5 cycles
3.0 cycles
3.5 cycles
4.0 cycles
4.5 cycles
5.0 cycles
LPC1 Turbine Torque
[pu]
5
4
3
2
1
0
−1
−2
−3
−4
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]
2.0 cycles
2.5 cycles
3.0 cycles
3.5 cycles
4.0 cycles
4.5 cycles
5.0 cycles

Bruce B G5 (500kV) : Contingency N−2 − With Series Caps






Bruce B G5 (500kV) : Contingency N−2 − With Series Caps
LPB2 Turbine Torque
[pu]
2.0 cycles
2.5 cycles
3.0 cycles
3.5 cycles
4.0 cycles
4.5 cycles
5.0 cycles
LPA1 Turbine Torque
[pu]
time [s]


Bruce B G5 (500kV) : Contingency N−2 − With Series Caps
LPA2 Turbine Torque
[pu]
time [s]
5
4
3
2
1
0
−1
−2
−3
−4
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2.0 cycles
2.5 cycles
3.0 cycles
3.5 cycles
4.0 cycles
4.5 cycles
5.0 cycles

APPENDIX S: Comparison Plots of Transient Torques Between Original and New Bruce A Machine Parameters

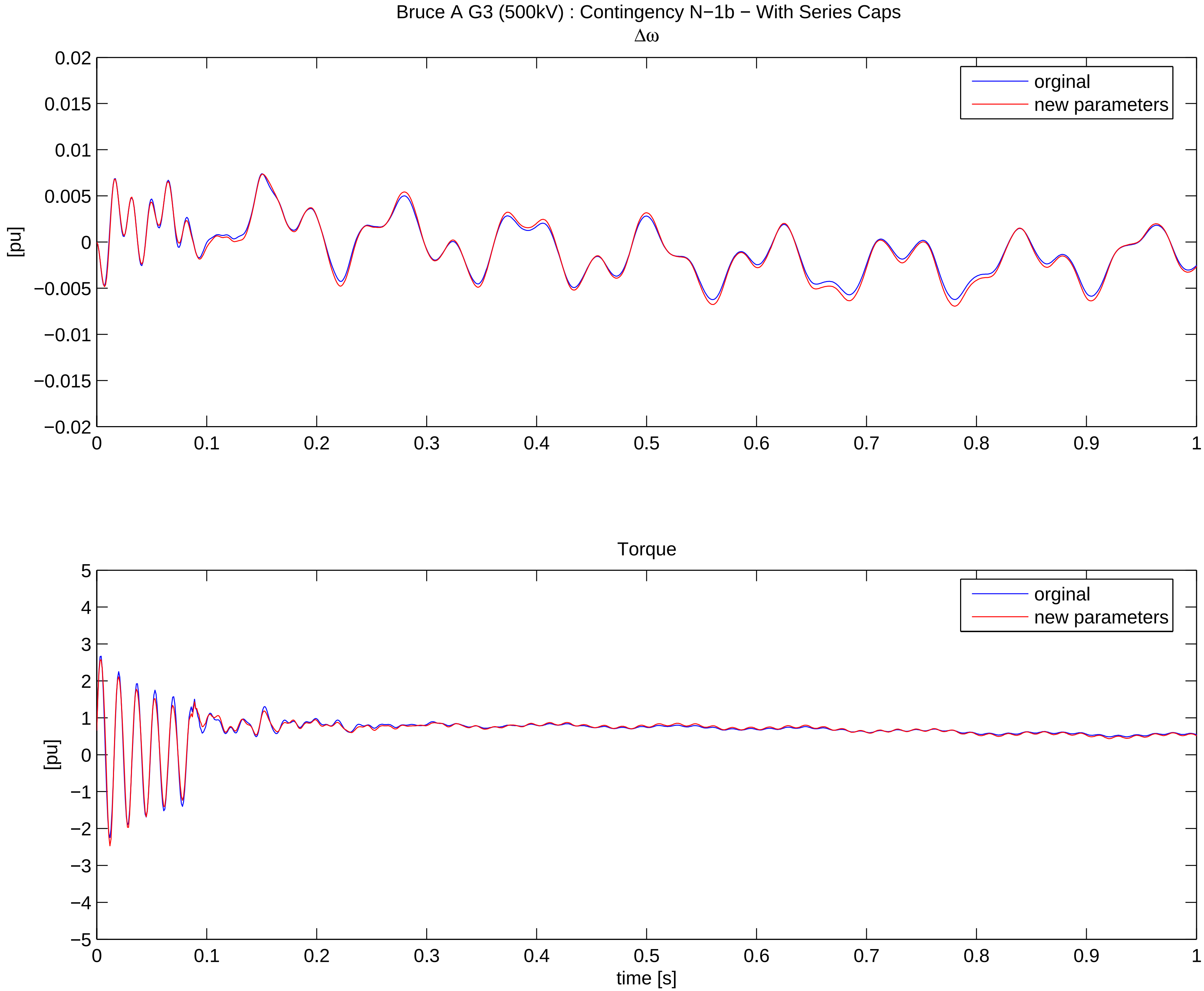
Appendix S – Comparison Plots of Transient Torques Between Original and New Bruce A Machine Parameters

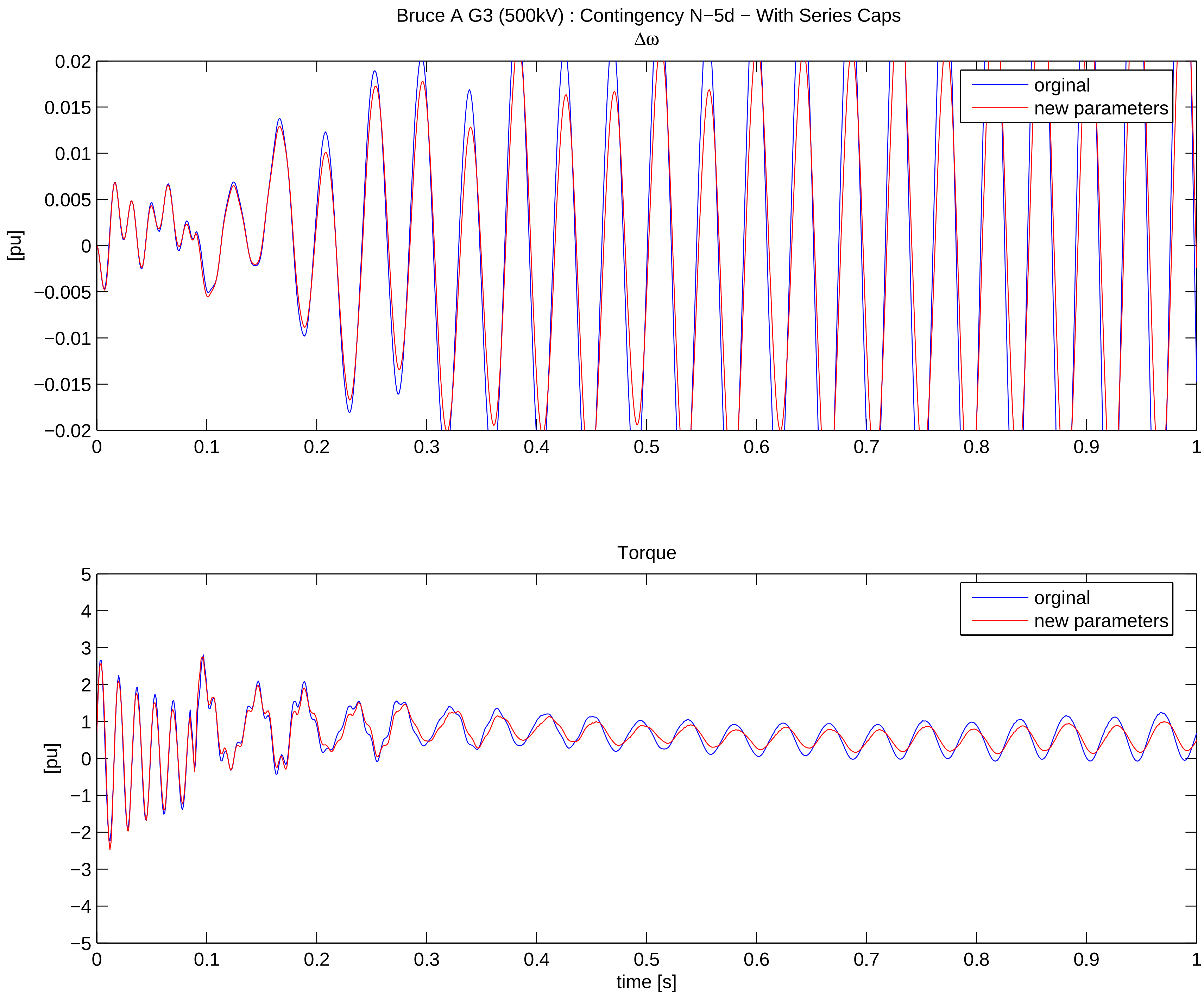
This appendix contains compares the transient torque response for two machine parameter sets provided for the Bruce A units. The response using the original parameters and those provided in January 2006 are compared for the units and contingencies listed in Table S-1. The parameters are not provided in this report for proprietary reasons.

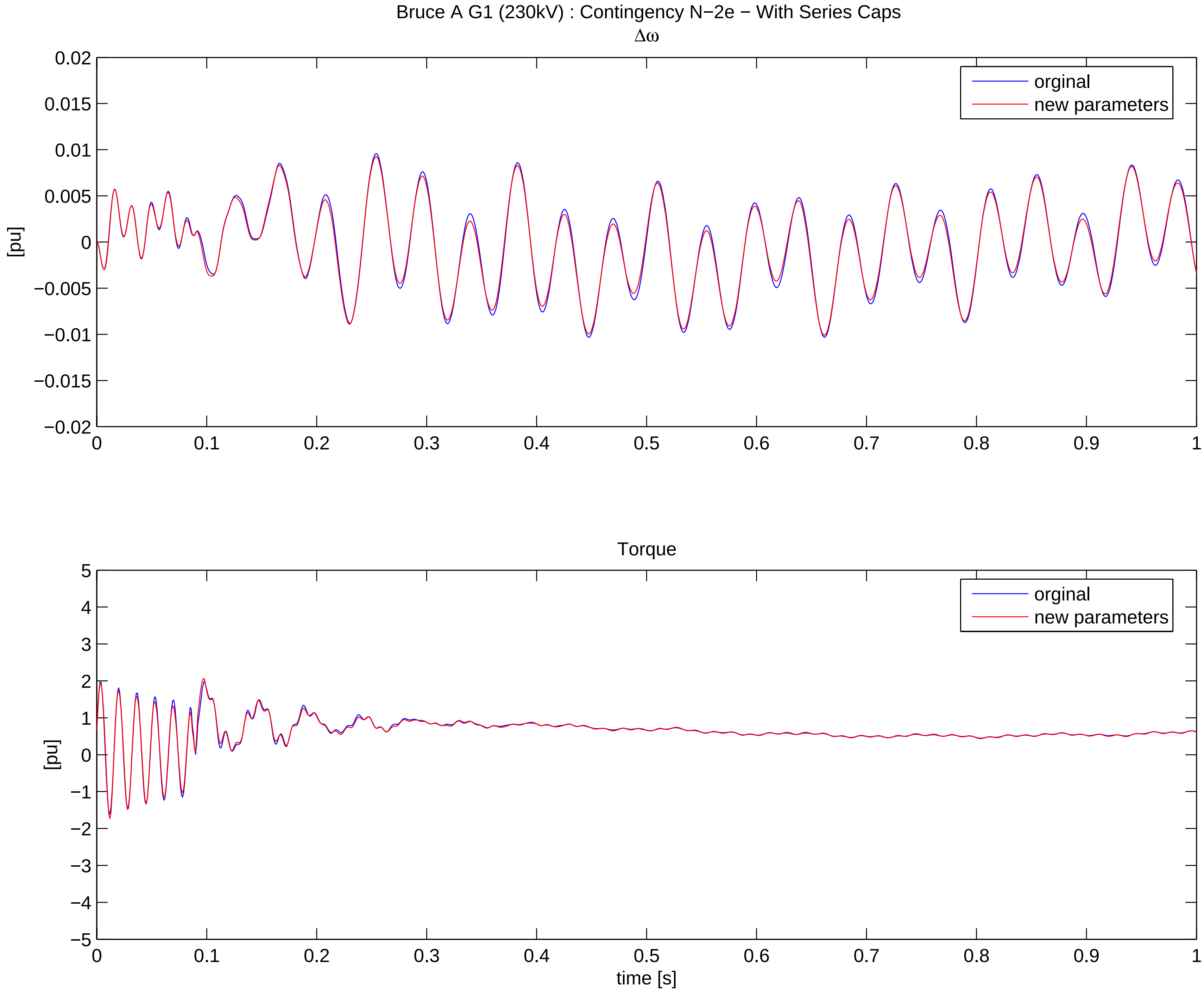
Table S-1: Contingency Description

Contingency ID	Bruce A – Clairville 500kV Line 1	Bruce B – Milton 500kV Line 1	Bruce A – Bruce B 500kV Tie	Bruce A 500/230/27.6kV Transformer 25	Bruce A 500/230/27.6kV Transformer 27	Bruce A 500/230/27.6kV Transformer 28	Bruce A – Longwood 500kV Line 1
Bruce A 500kV Unit G3							
N-1b			X				
N-5d	X		X	X	X	X	
Bruce A 230kV Unit G1							
N-2e	X		X				

X – indicates the branch is out-of-service


Bruce A G3 (500kV) : Contingency N−1b − With Series Caps
Δω
orginal
new parameters
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Torque
orginal
new parameters
[pu]
5
4
3
2
1
0
−1
−2
−3
−4
−5
time [s]


Bruce A G3 (500kV) : Contingency N−5d − With Series Caps
Δω
[pu]
orginal
new parameters
Torque
[pu]
orginal
new parameters
time [s]



Bruce A G1 (230kV) : Contingency N−2e − With Series Caps
Δω
orginal
new parameters
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Torque
orginal
new parameters
[pu]
5
4
3
2
1
0
−1
−2
−3
−4
−5
time [s]

APPENDIX T-1: Complete Transient Torque Plots – No Series Cap

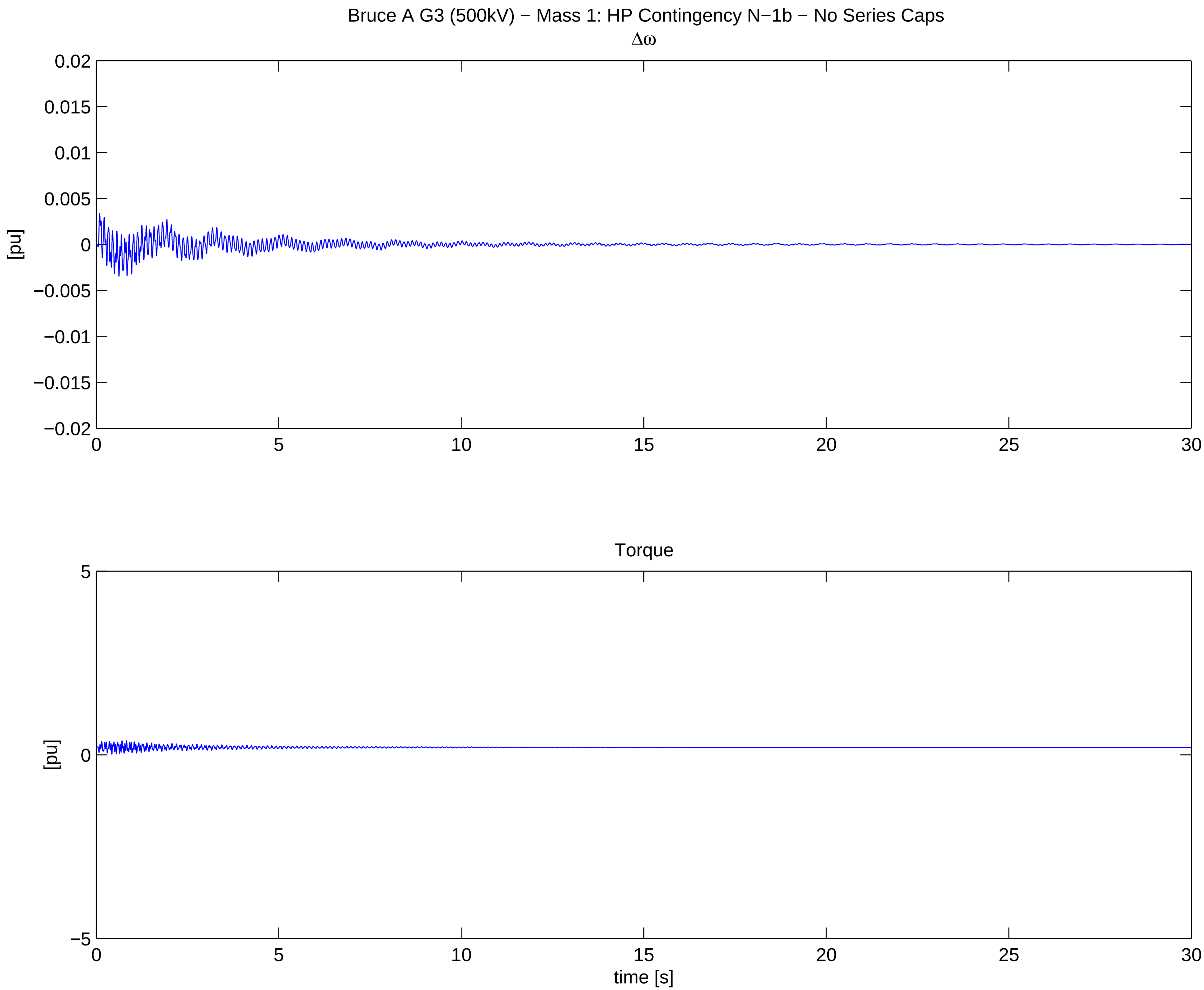
Appendix T1 – Complete Transient Torque Plots – No Series Cap

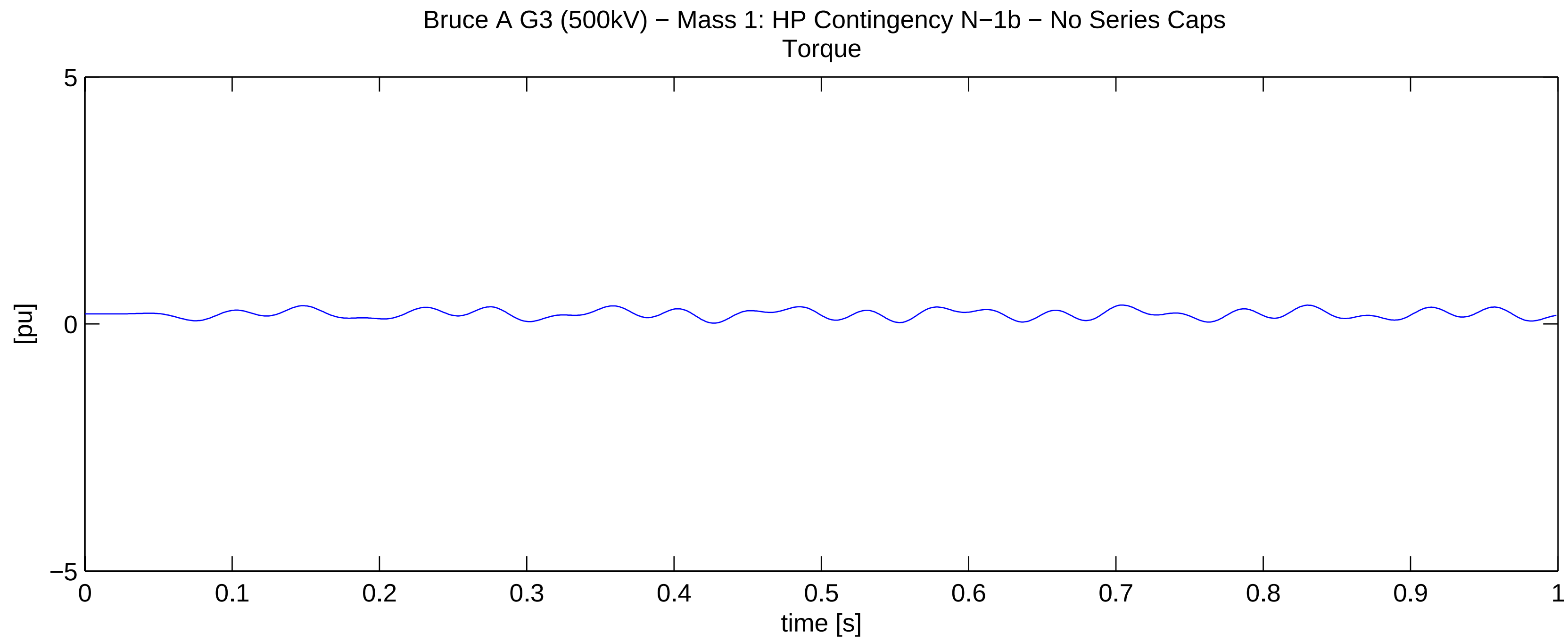
This appendix contains plots of the torques experienced at the various shaft locations for the most critical contingencies at Bruce A and Bruce B units. The descriptions of the contingencies simulated are provided in Table T1-1.

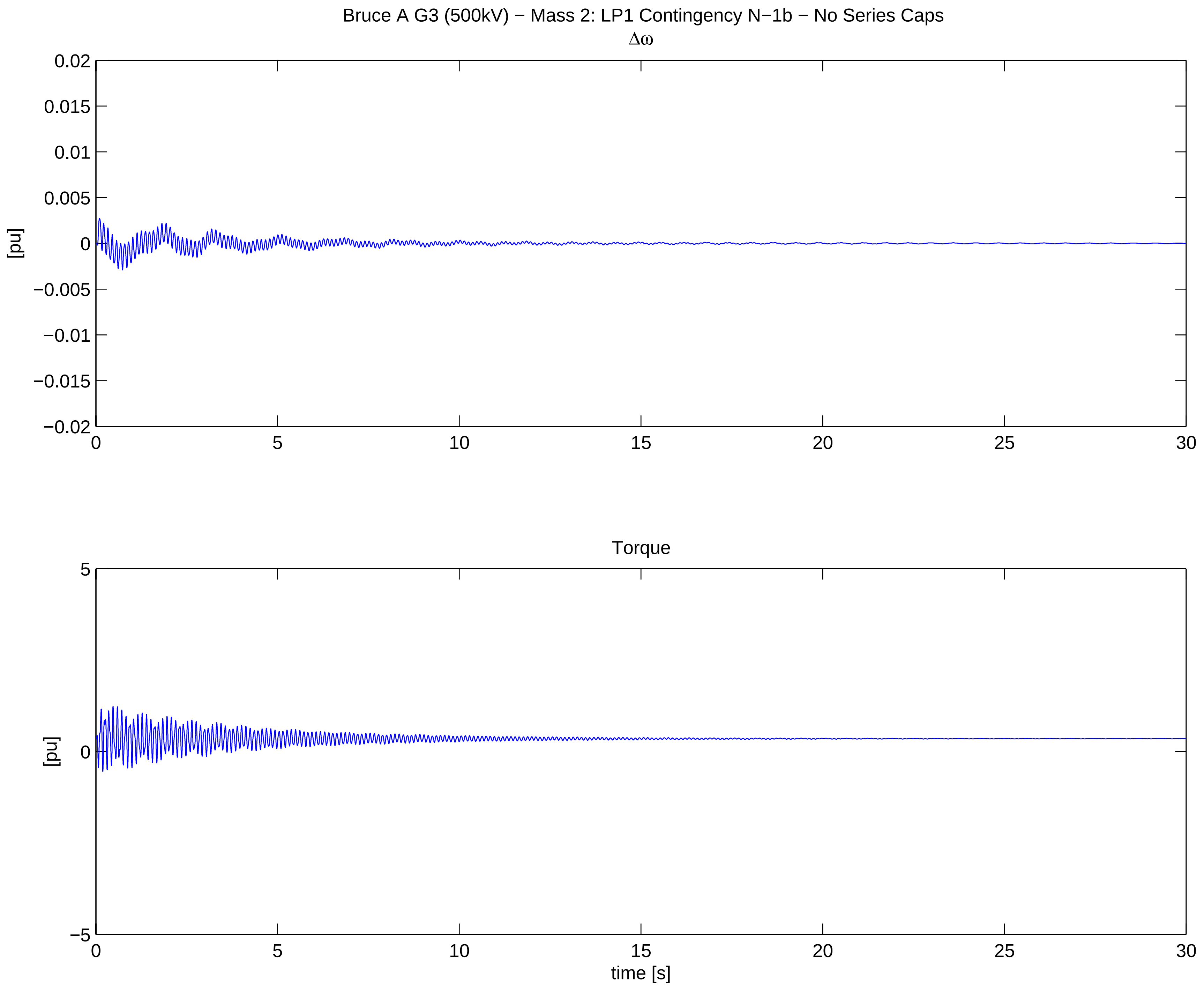
Table T1-1: Contingency Descriptions

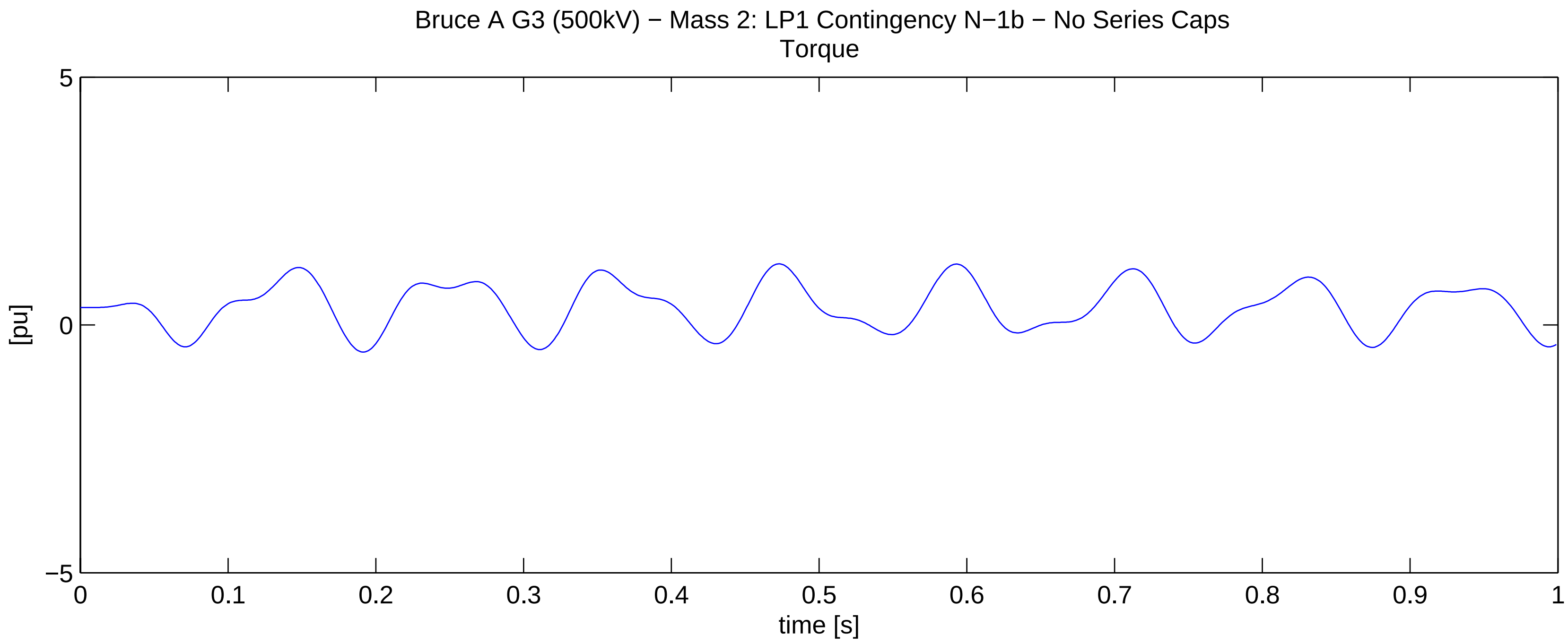
Contingency ID	Bruce A – Clairville 500kV Line 1	Bruce B – Milton 500kV Line 1	Bruce A – Bruce B 500kV Tie	Bruce A 500/230/27.6kV Transformer 25	Bruce A 500/230/27.6kV Transformer 27	Bruce A 500/230/27.6kV Transformer 28	Bruce A – Longwood 500kV Line 1	Bruce A – Bruce B 500kV Tie 1	Bruce B – Milton 500kV Line 1	Bruce B – Longwood 500kV Line 1	
Bruce A 500kV Unit G3											
N-1b			X								
N-2	X	X									
N-5d	X		X	X	X	X					
N-5d alternate fault	X		X	X	X	X					Fault duration changed from 5 cycles to 3.768 cycles
Bruce A 230kV Unit G1											
N-2e	X		X								
Bruce B 500kV Unit G5											
N-1								X			
N-2								X	X		
N-2 alternate fault								X	X		Fault duration changed from 5 cycles to 6.372 cycles

X – indicates the branch is out-of-service

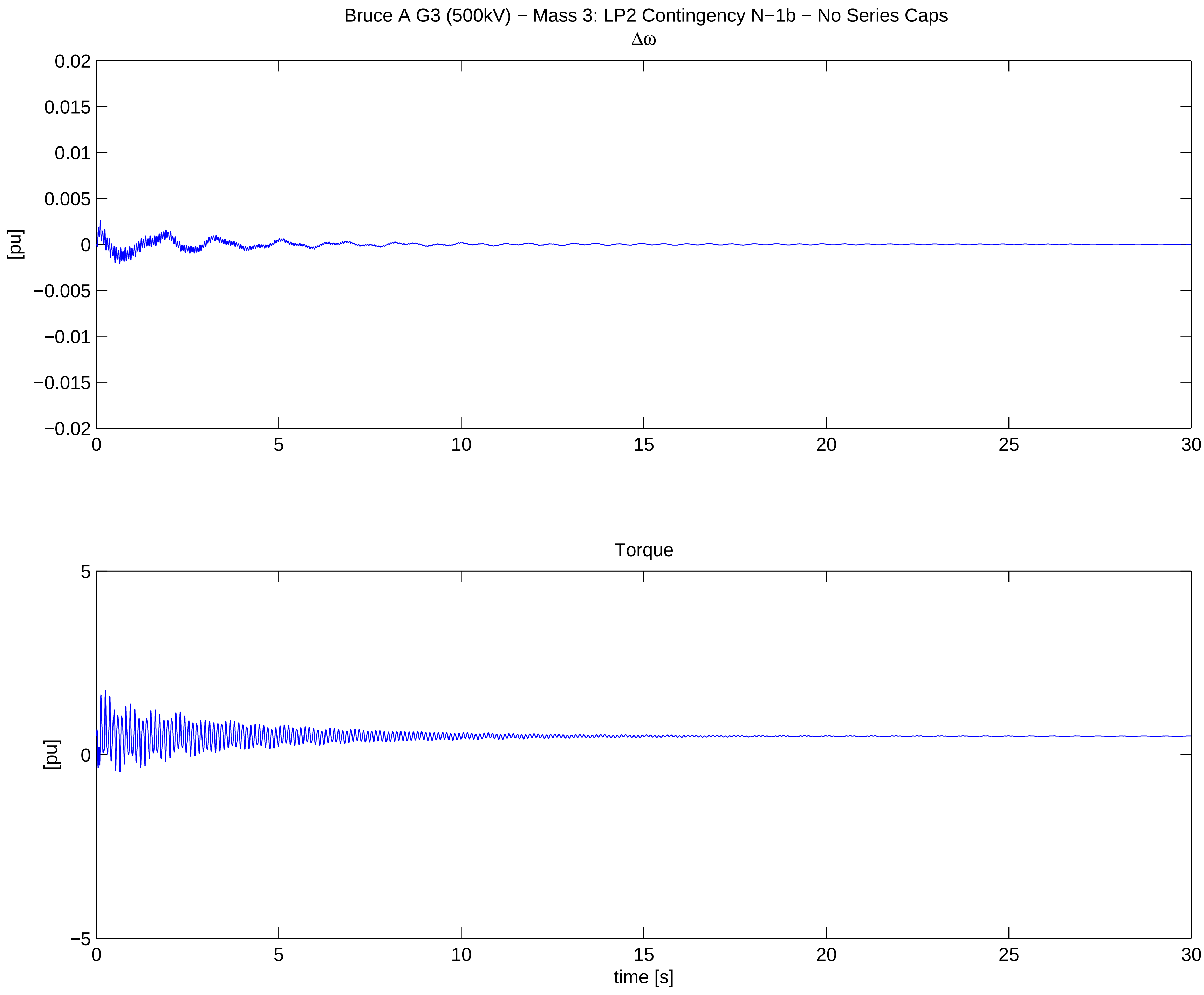

Bruce A G3 (500kV) − Mass 1: HP Contingency N−1b − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce A G3 (500kV) − Mass 1: HP Contingency N−1b − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

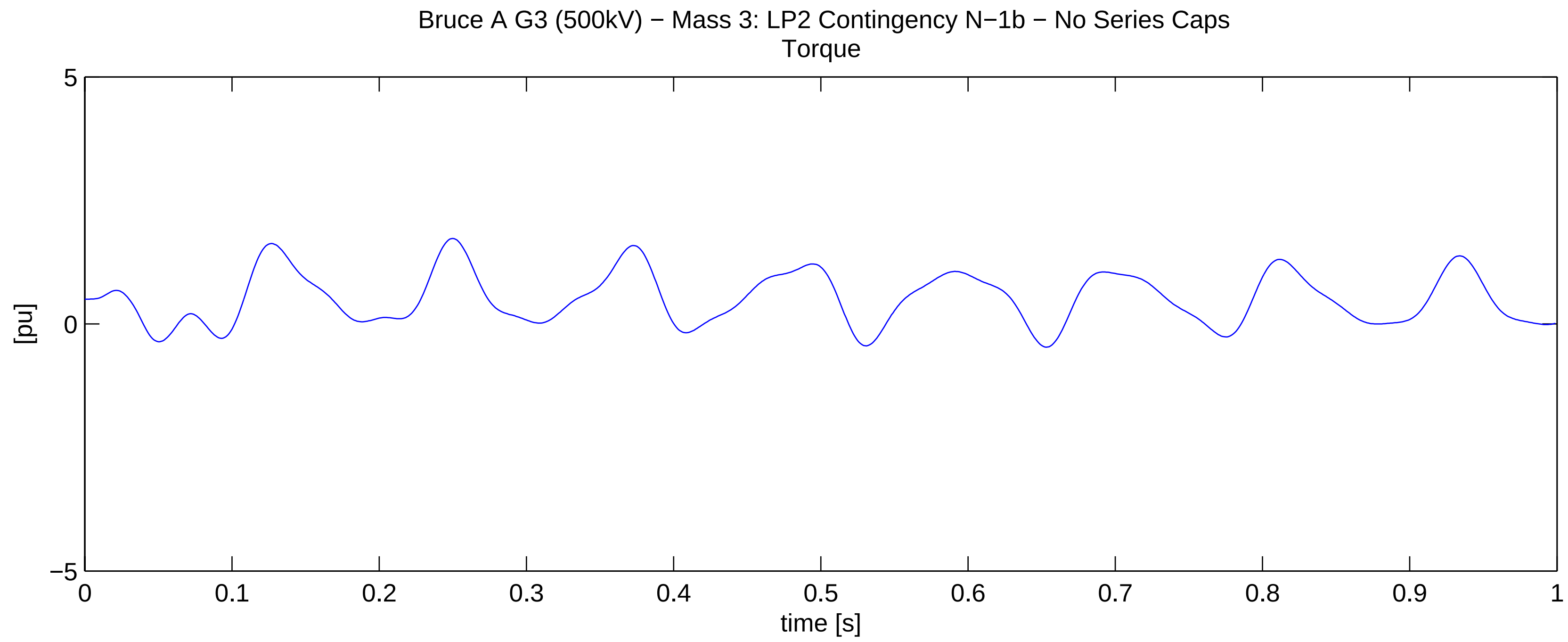

Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−1b − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



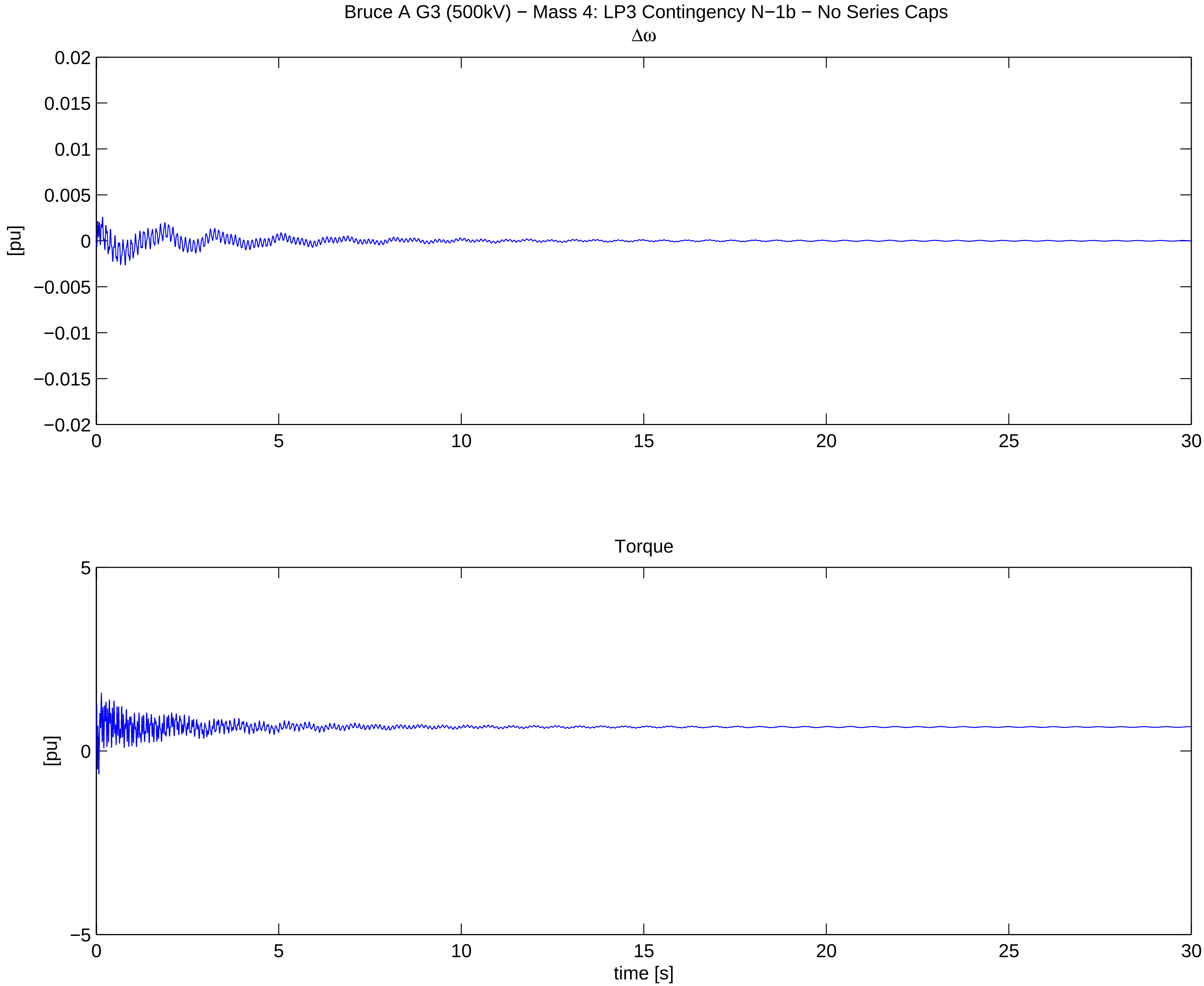
Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−1b − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

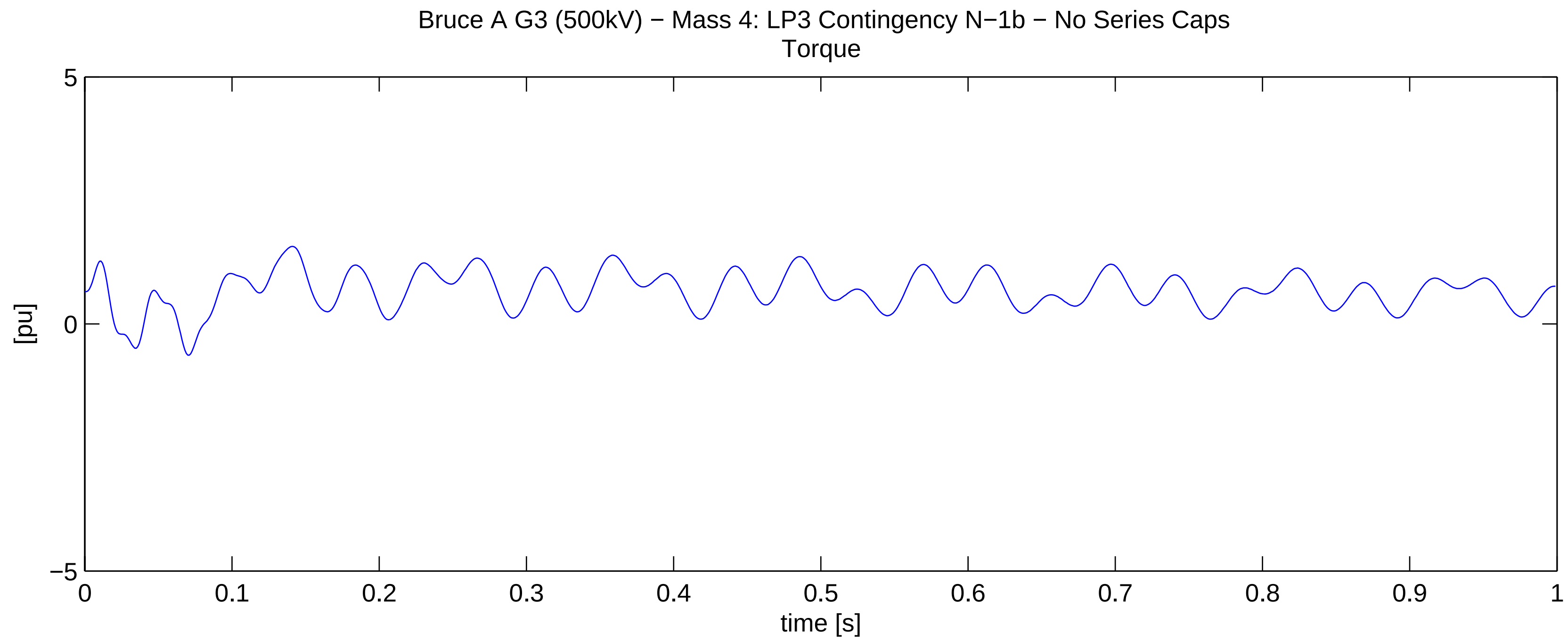


Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−1b − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

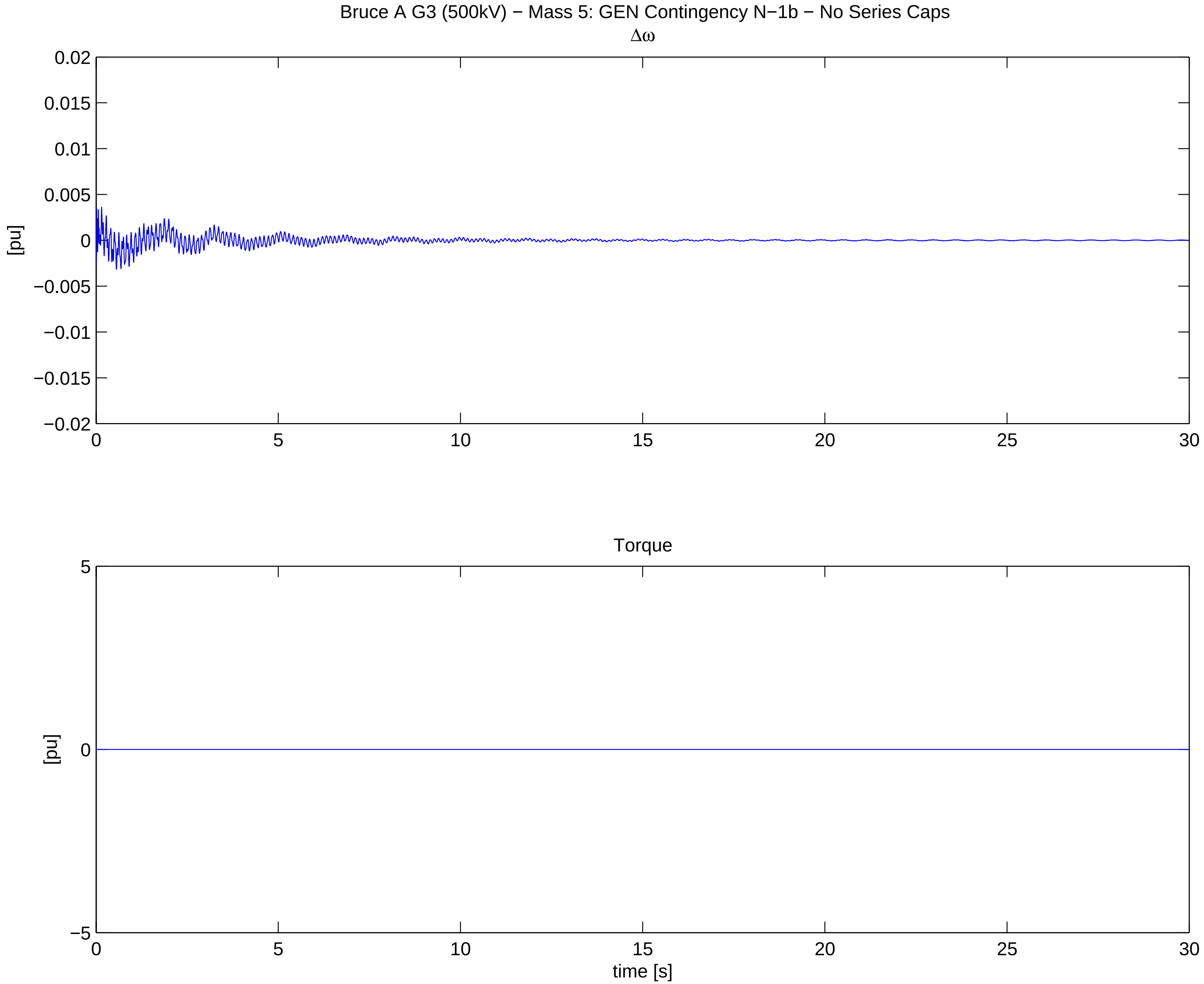


Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−1b − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

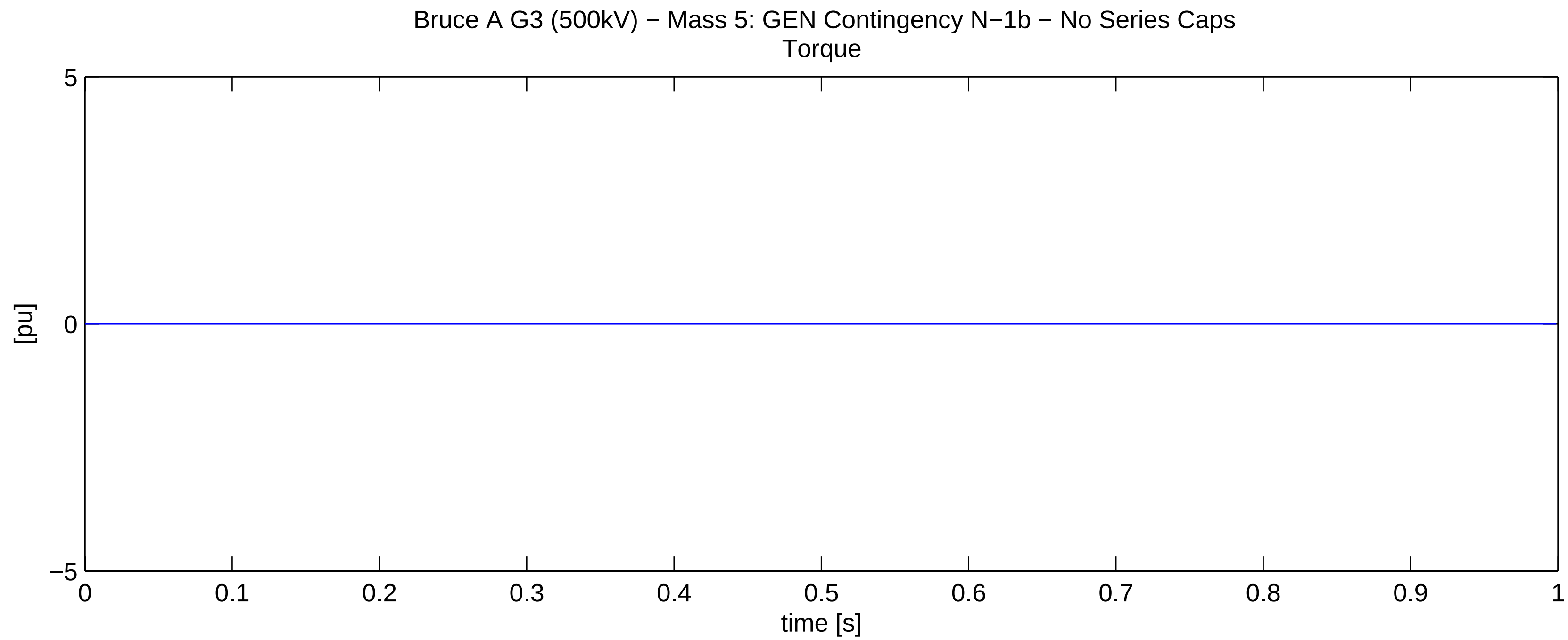

Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−1b − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



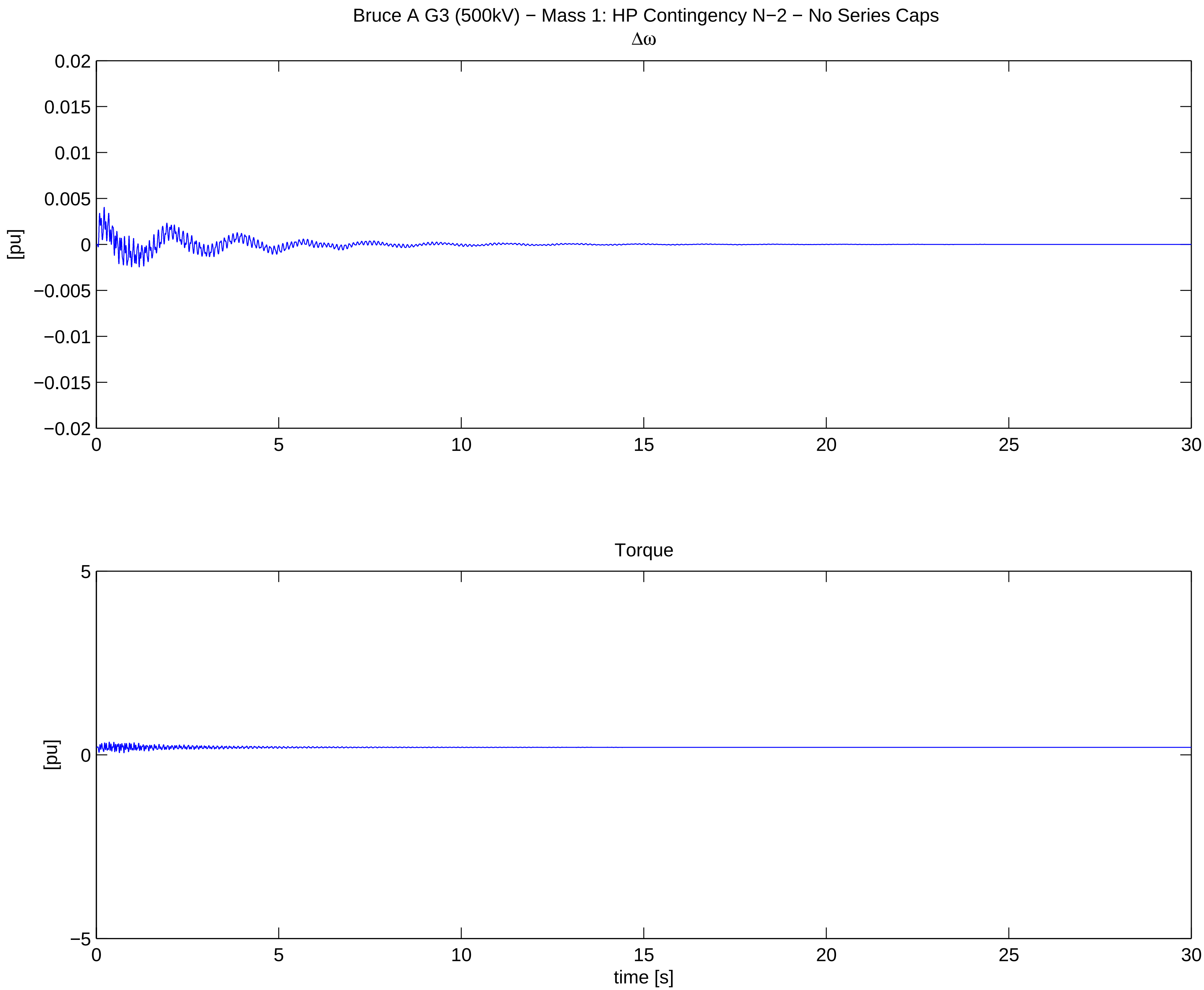
Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−1b − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

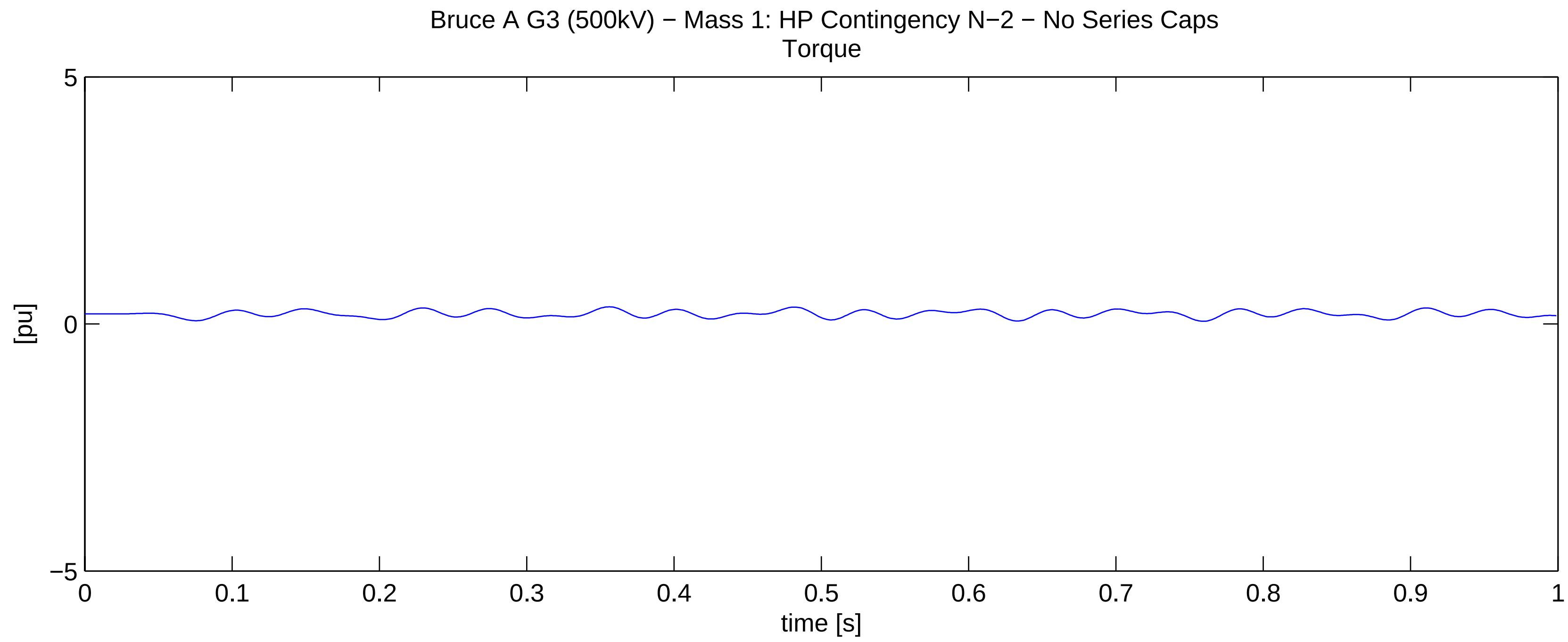


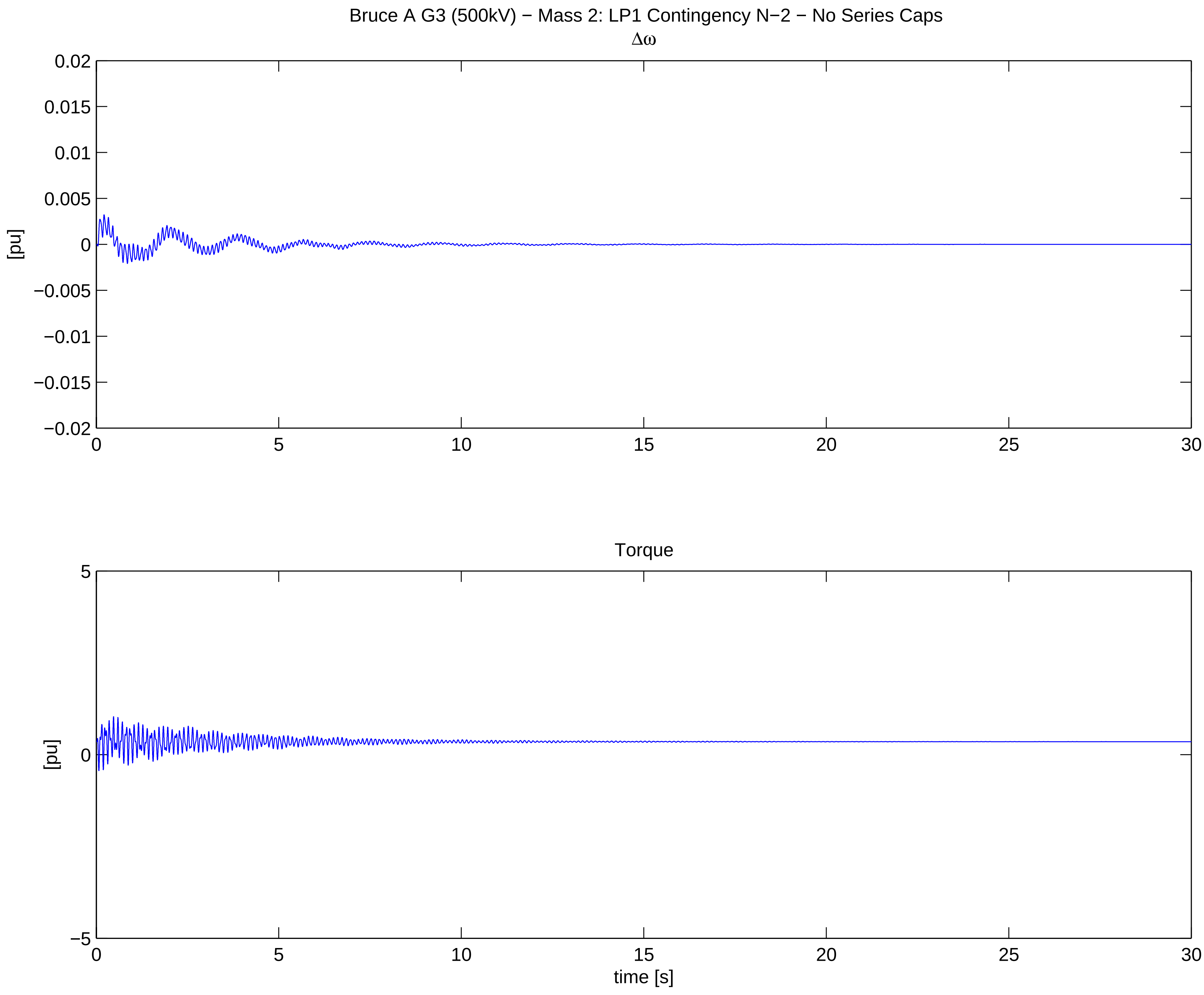
Bruce A G3 (500kV) − Mass 5: GEN Contingency N−1b − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

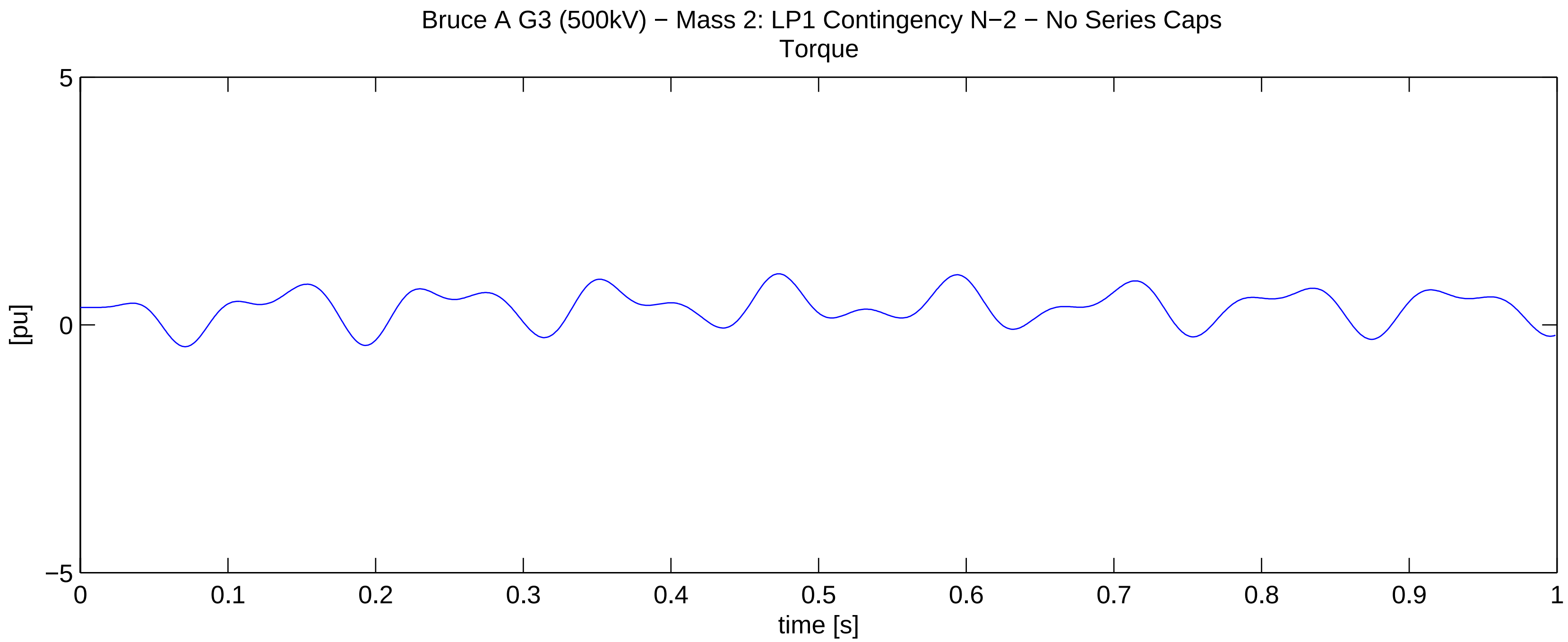


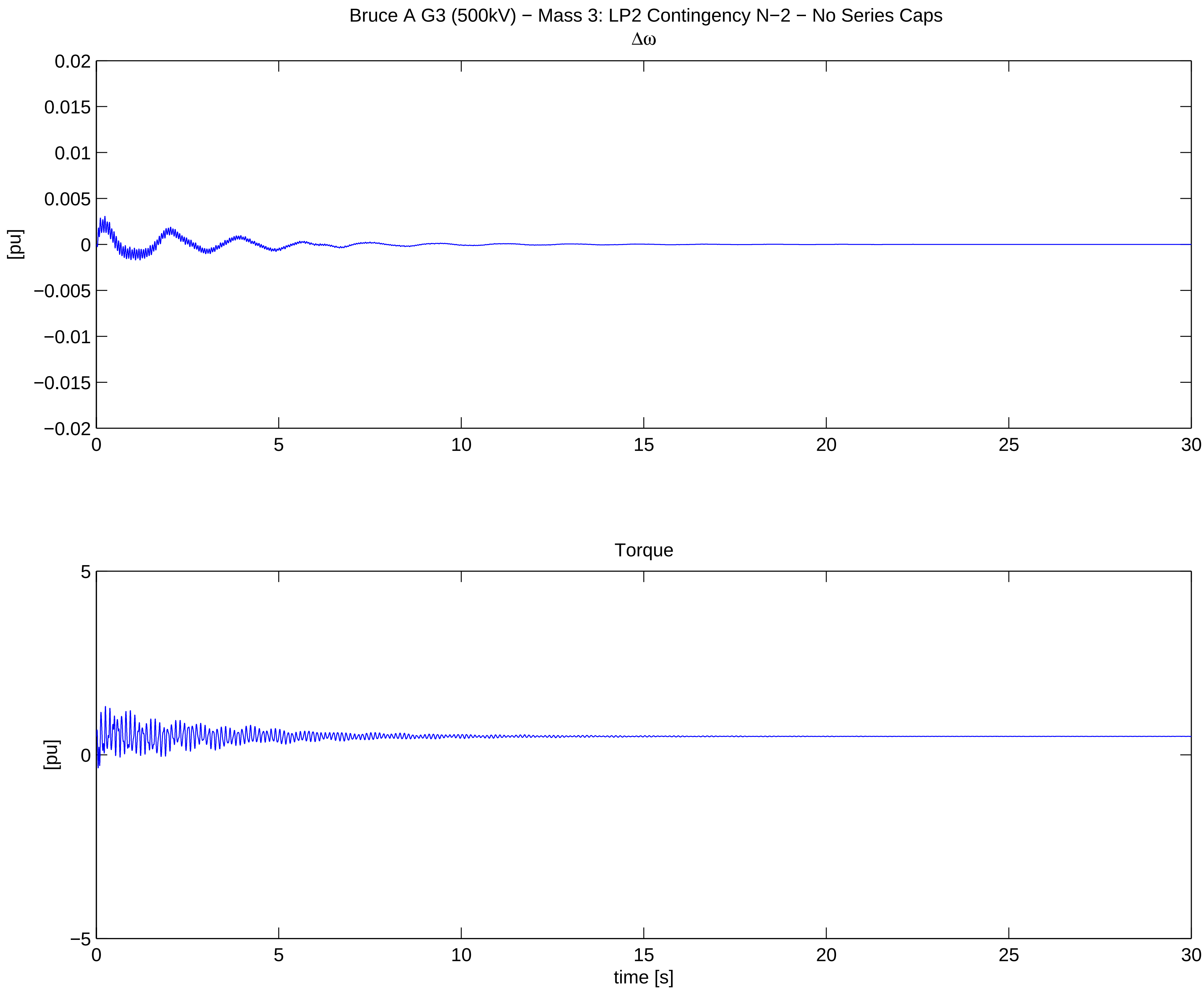
Bruce A G3 (500kV) − Mass 5: GEN Contingency N−1b − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce A G3 (500kV) − Mass 1: HP Contingency N−2 − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

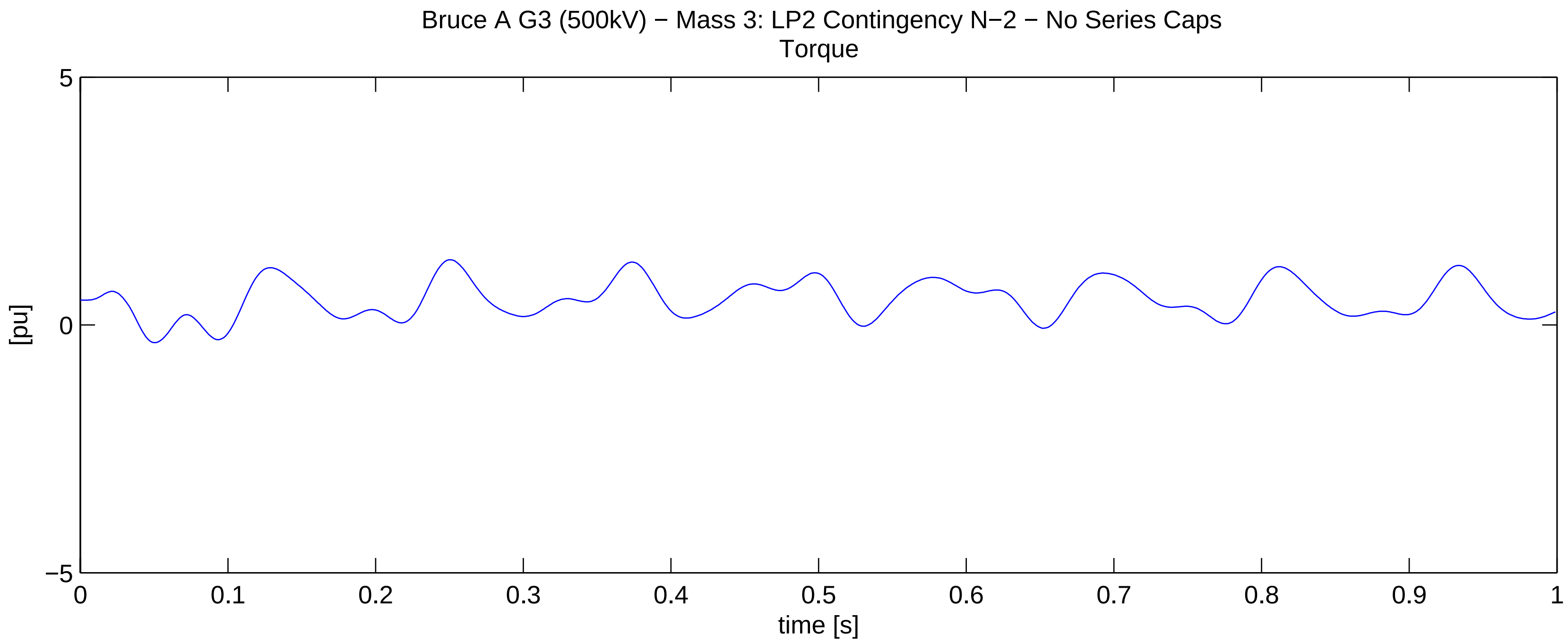

Bruce A G3 (500kV) − Mass 1: HP Contingency N−2 − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

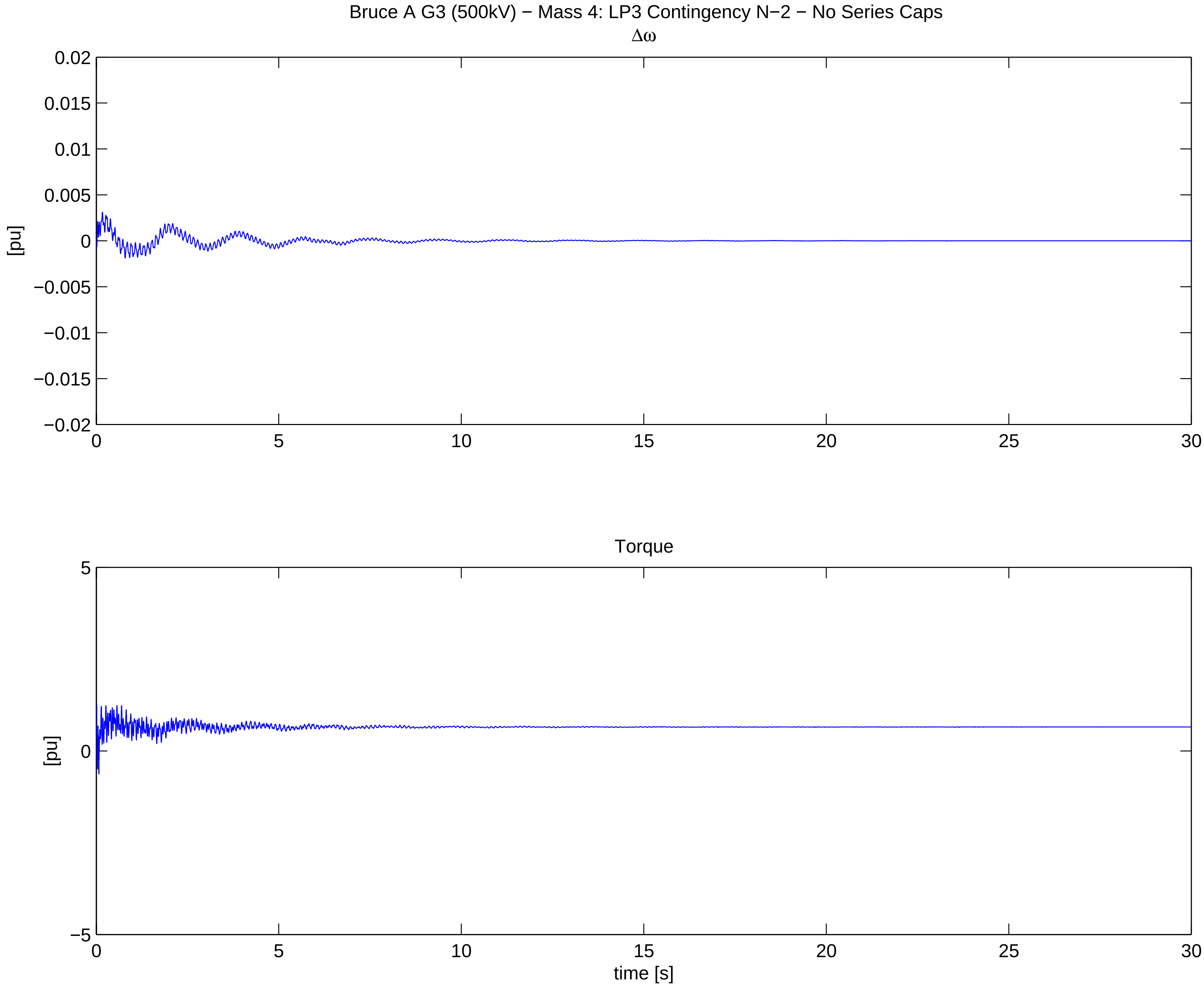

Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−2 − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−2 − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

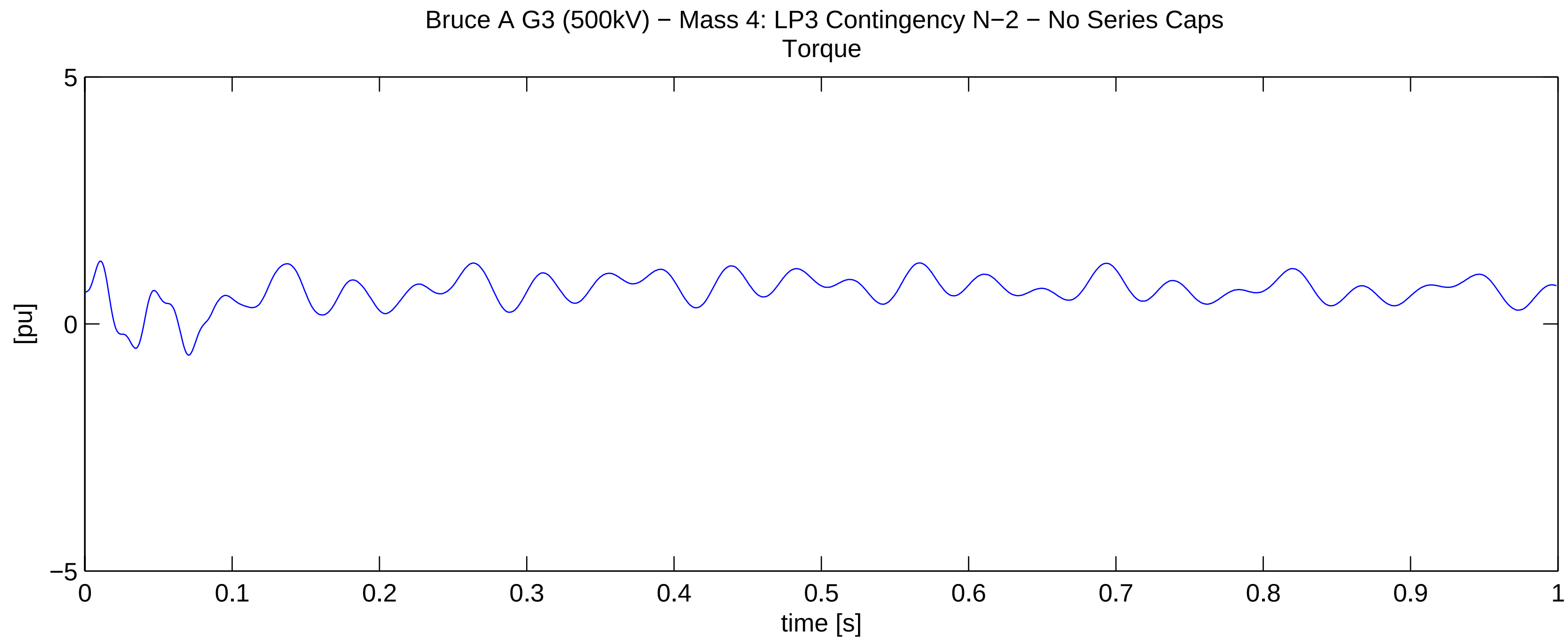


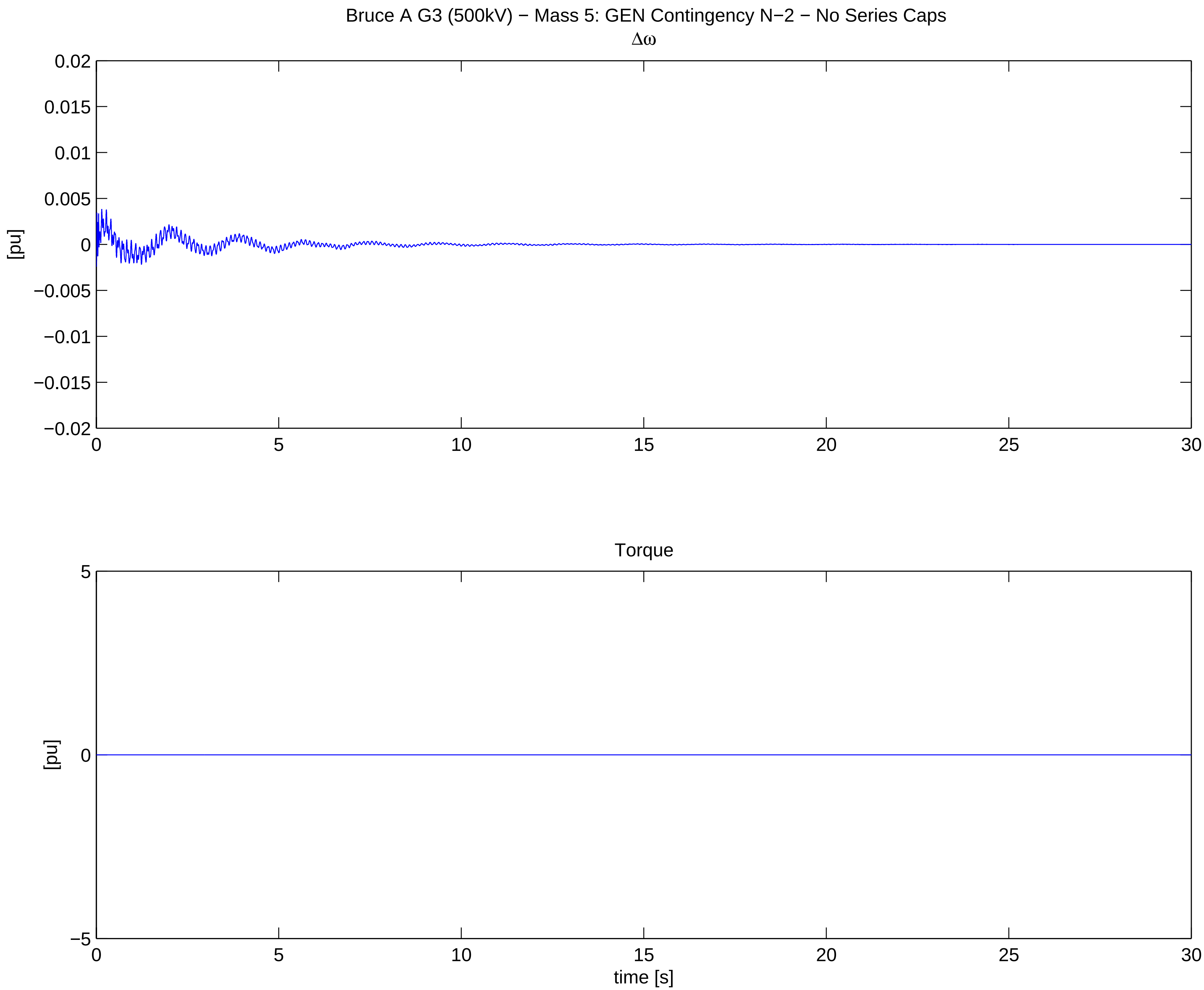
Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−2 − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−2 − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

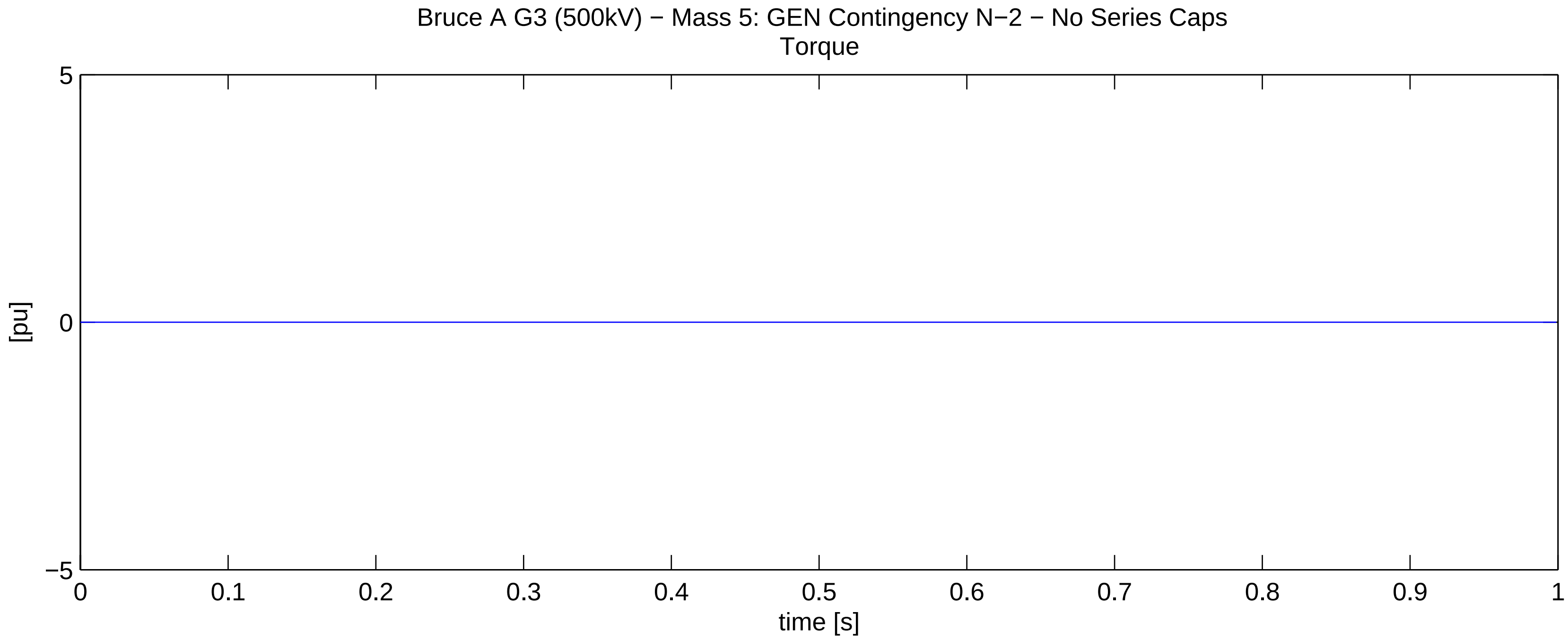


Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−2 − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

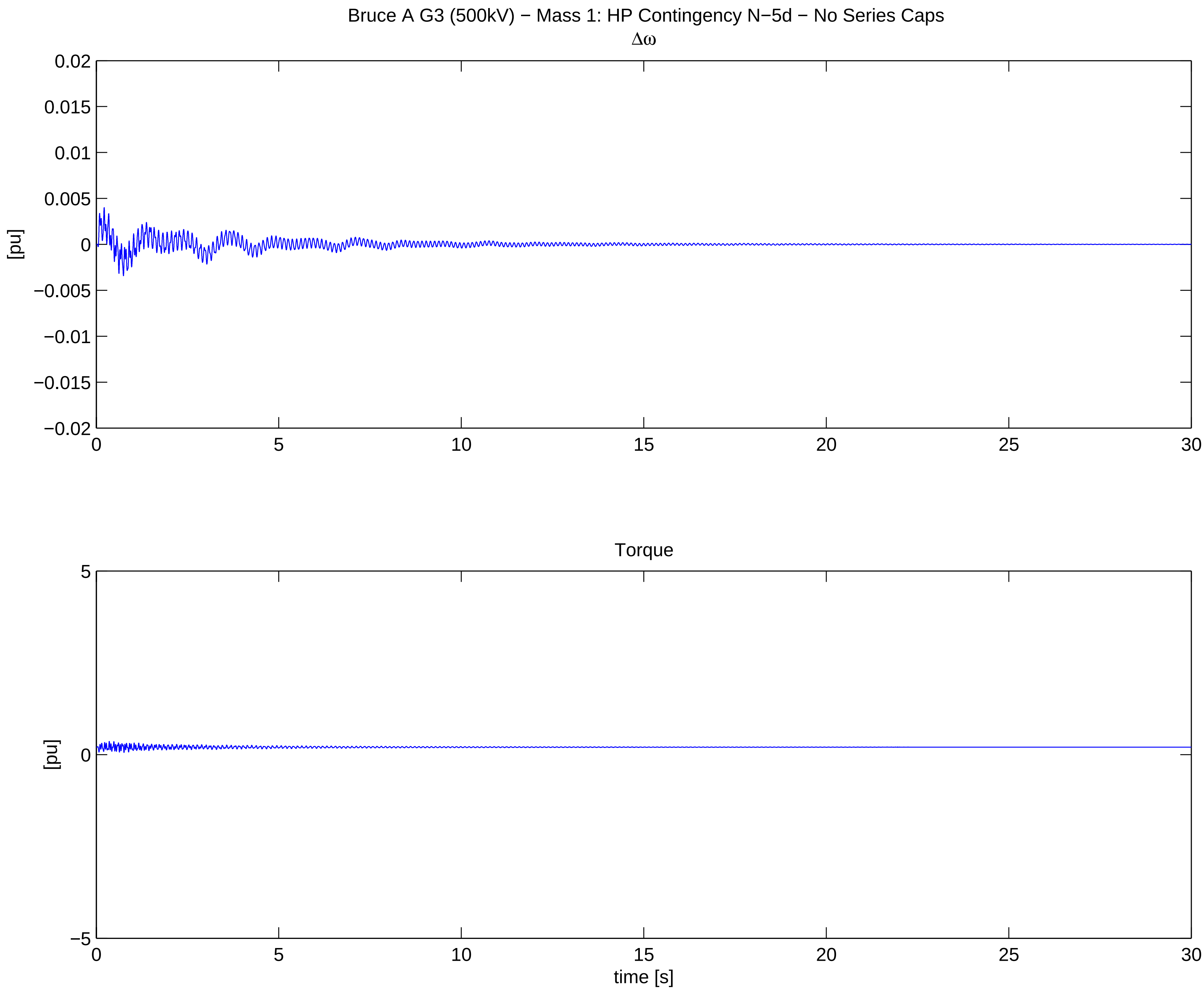

Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−2 − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



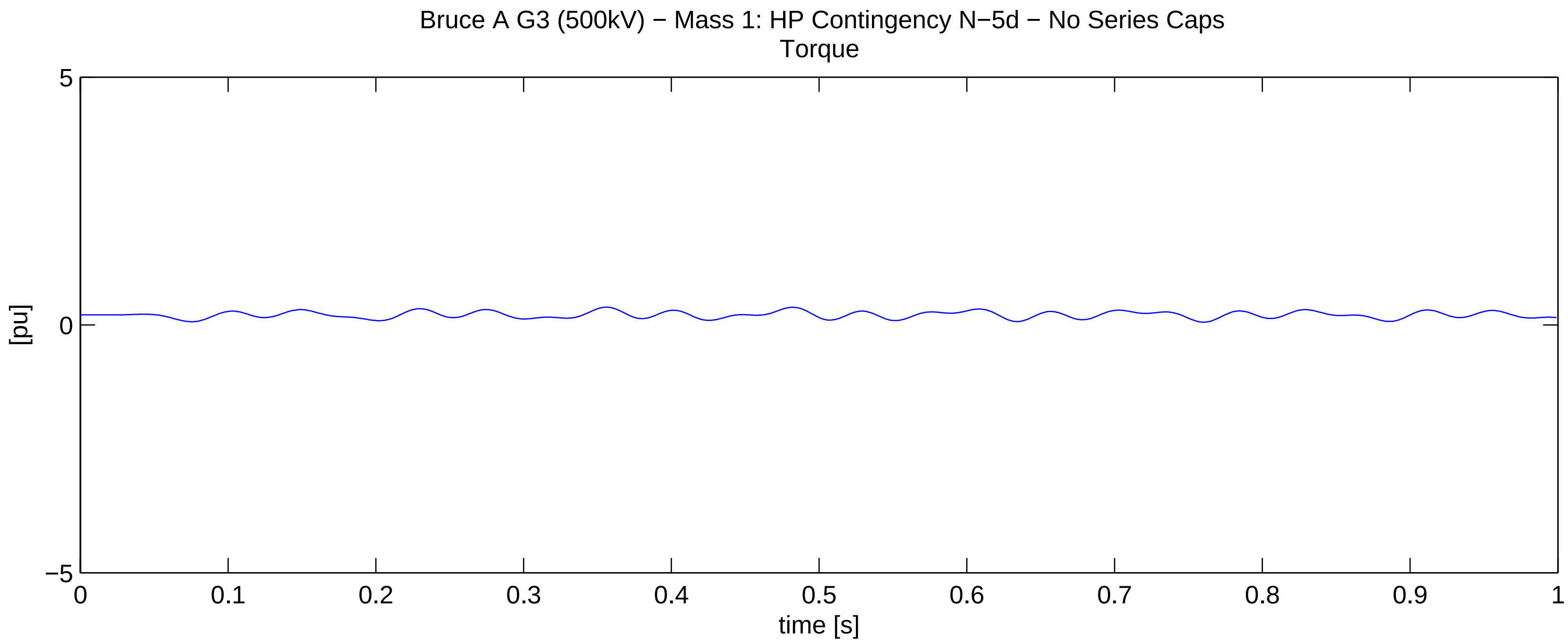
Bruce A G3 (500kV) − Mass 5: GEN Contingency N−2 − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

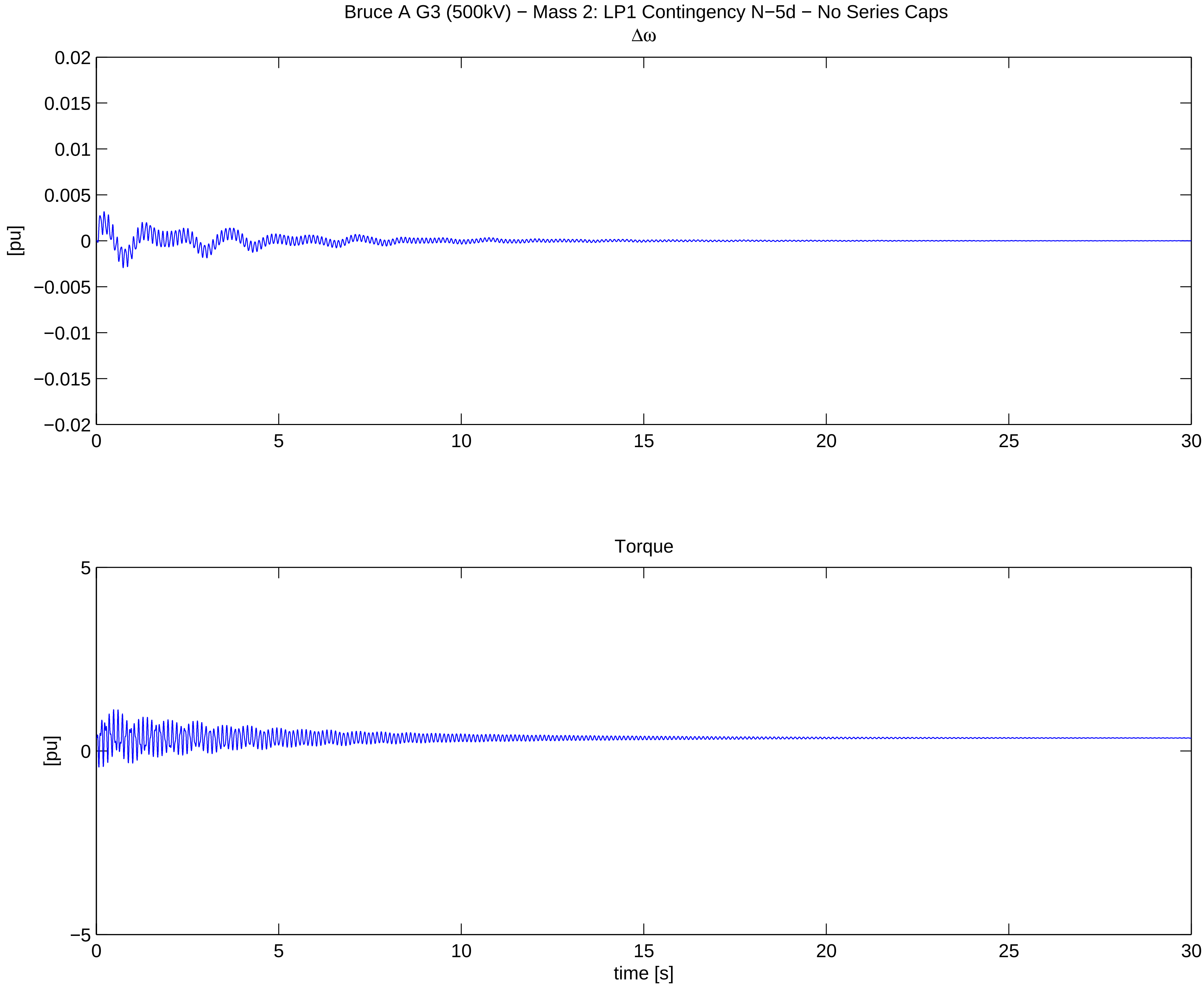


Bruce A G3 (500kV) − Mass 5: GEN Contingency N−2 − No Series Caps
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

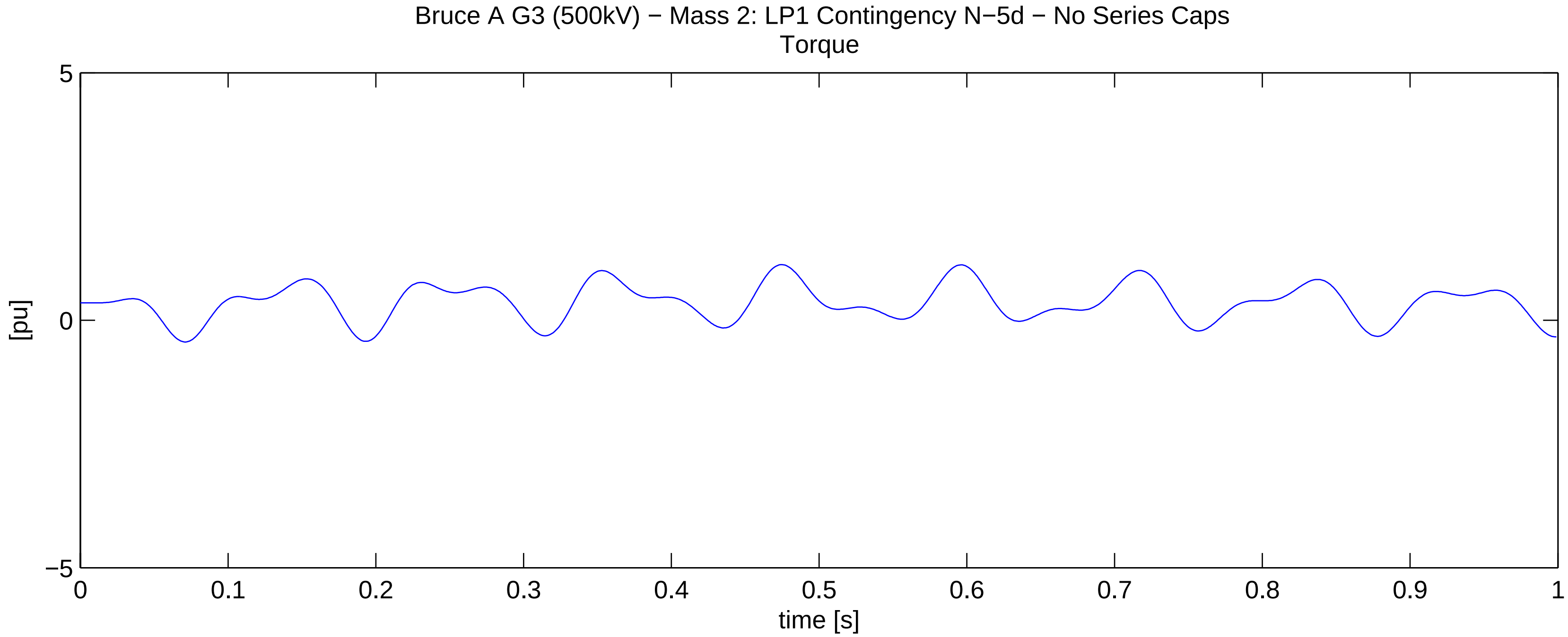


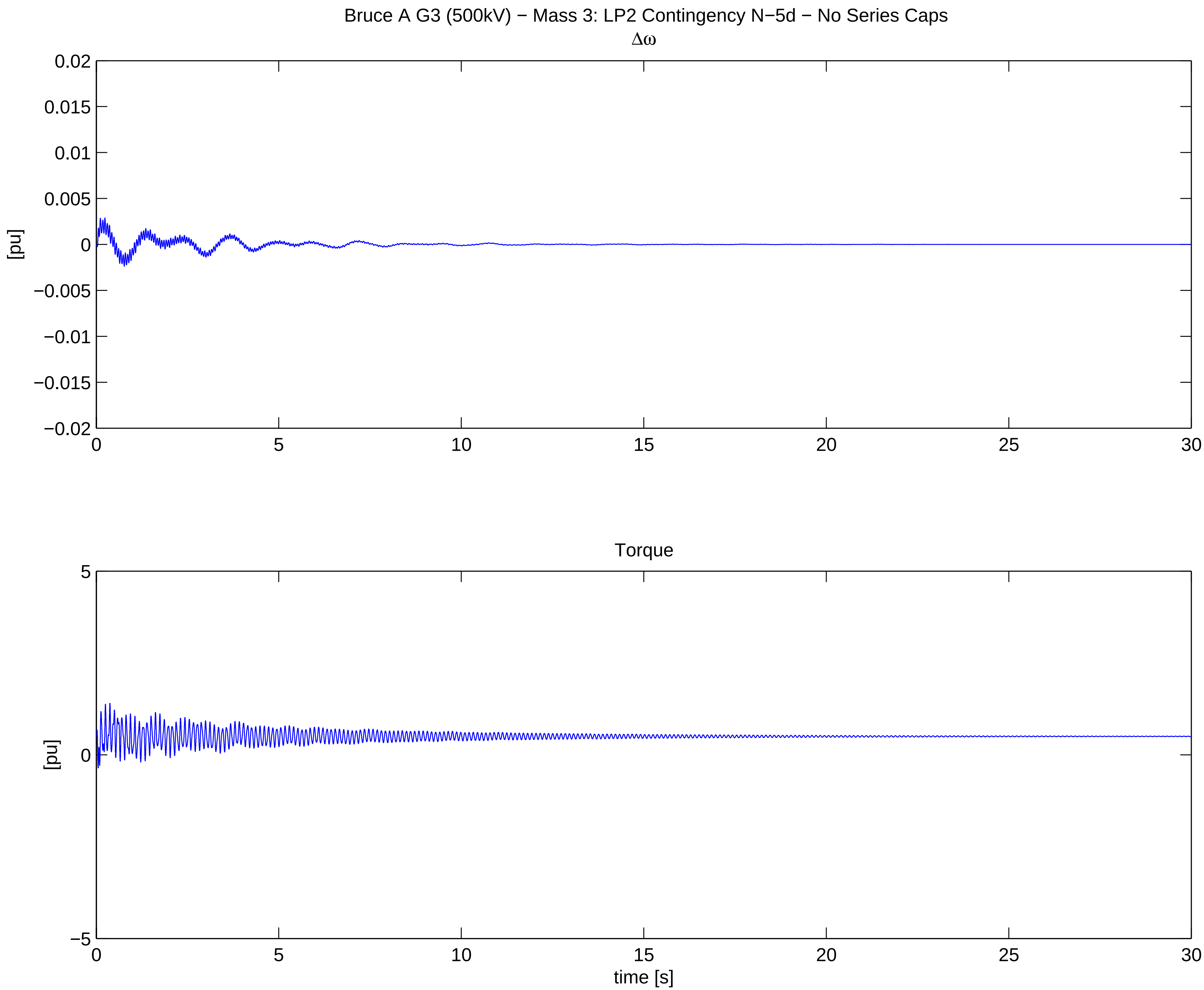
Bruce A G3 (500kV) − Mass 1: HP Contingency N−5d − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

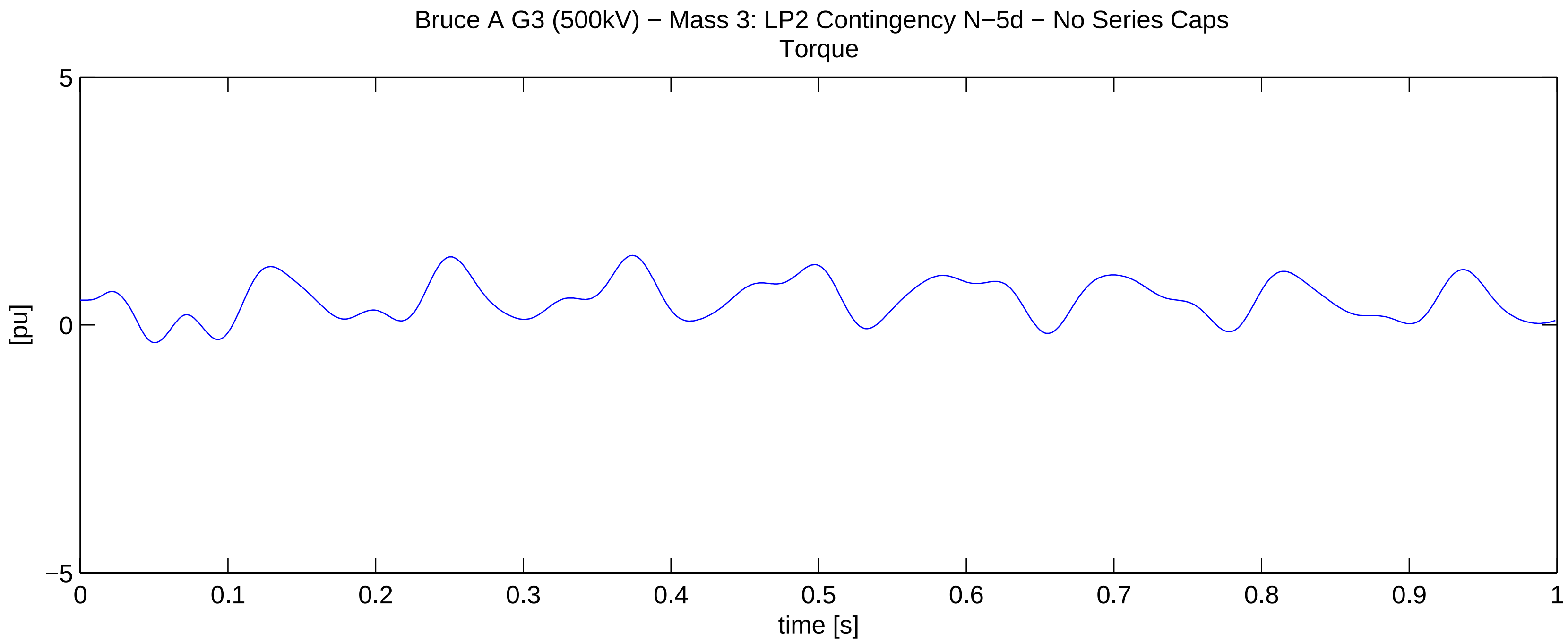

Bruce A G3 (500kV) − Mass 1: HP Contingency N−5d − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−5d − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

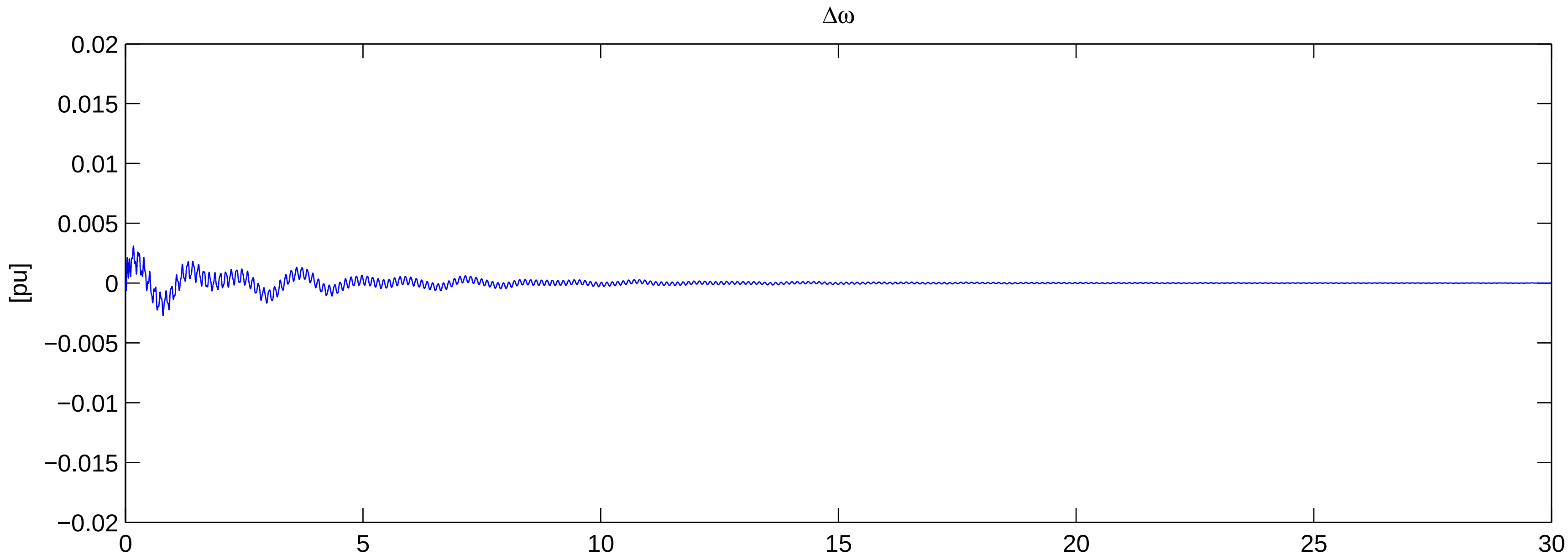

Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−5d − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

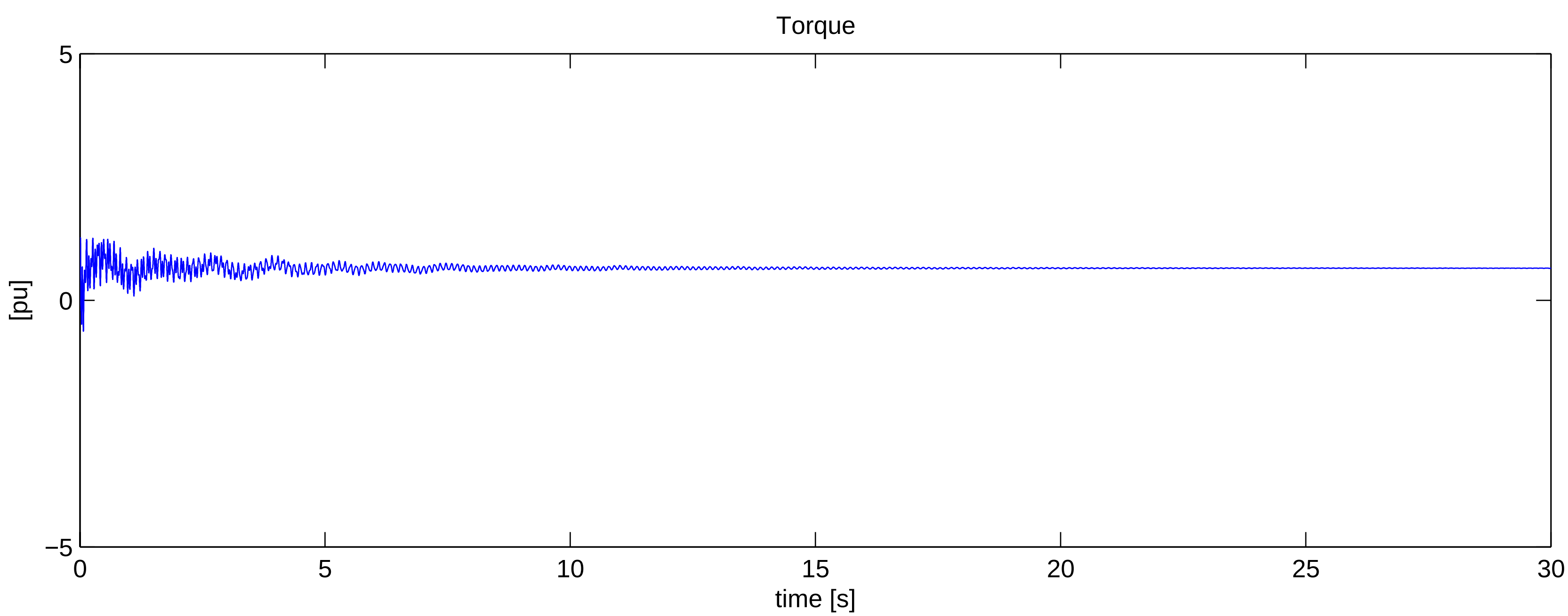

Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−5d − No Series Caps
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
time [s]

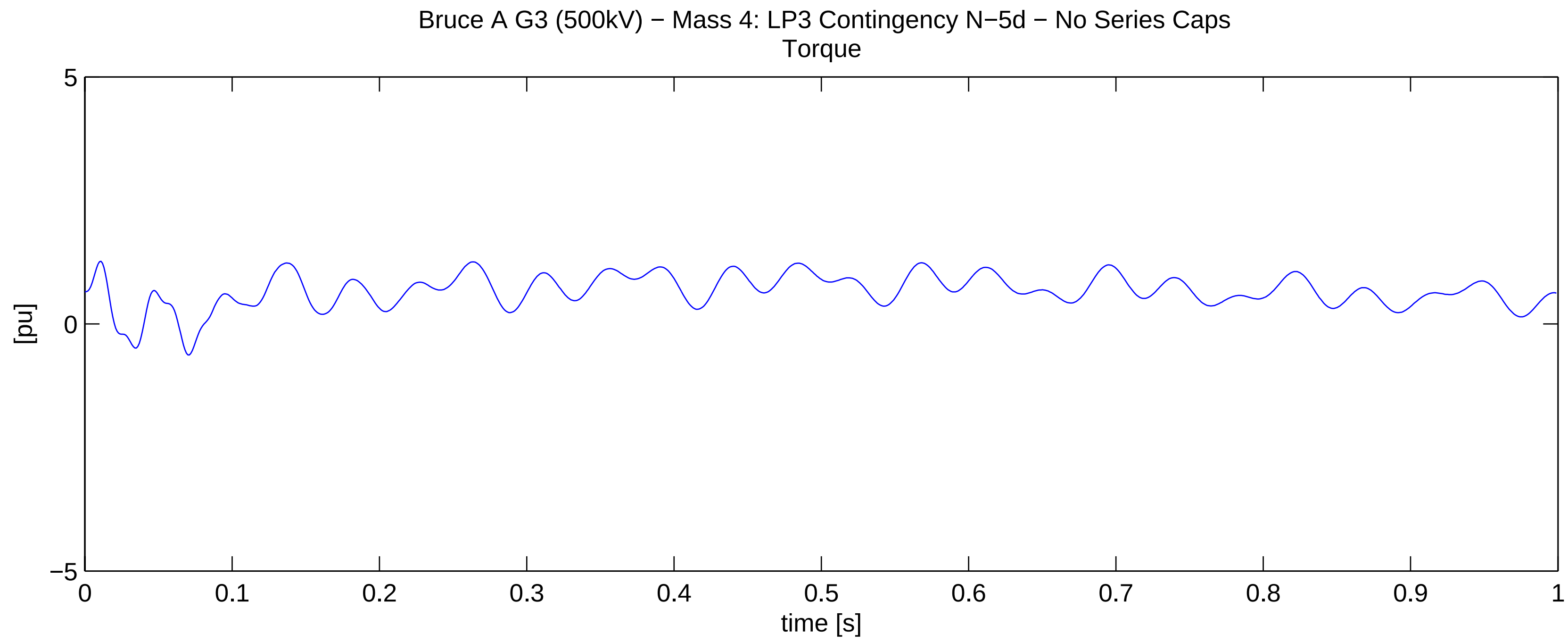


Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−5d − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

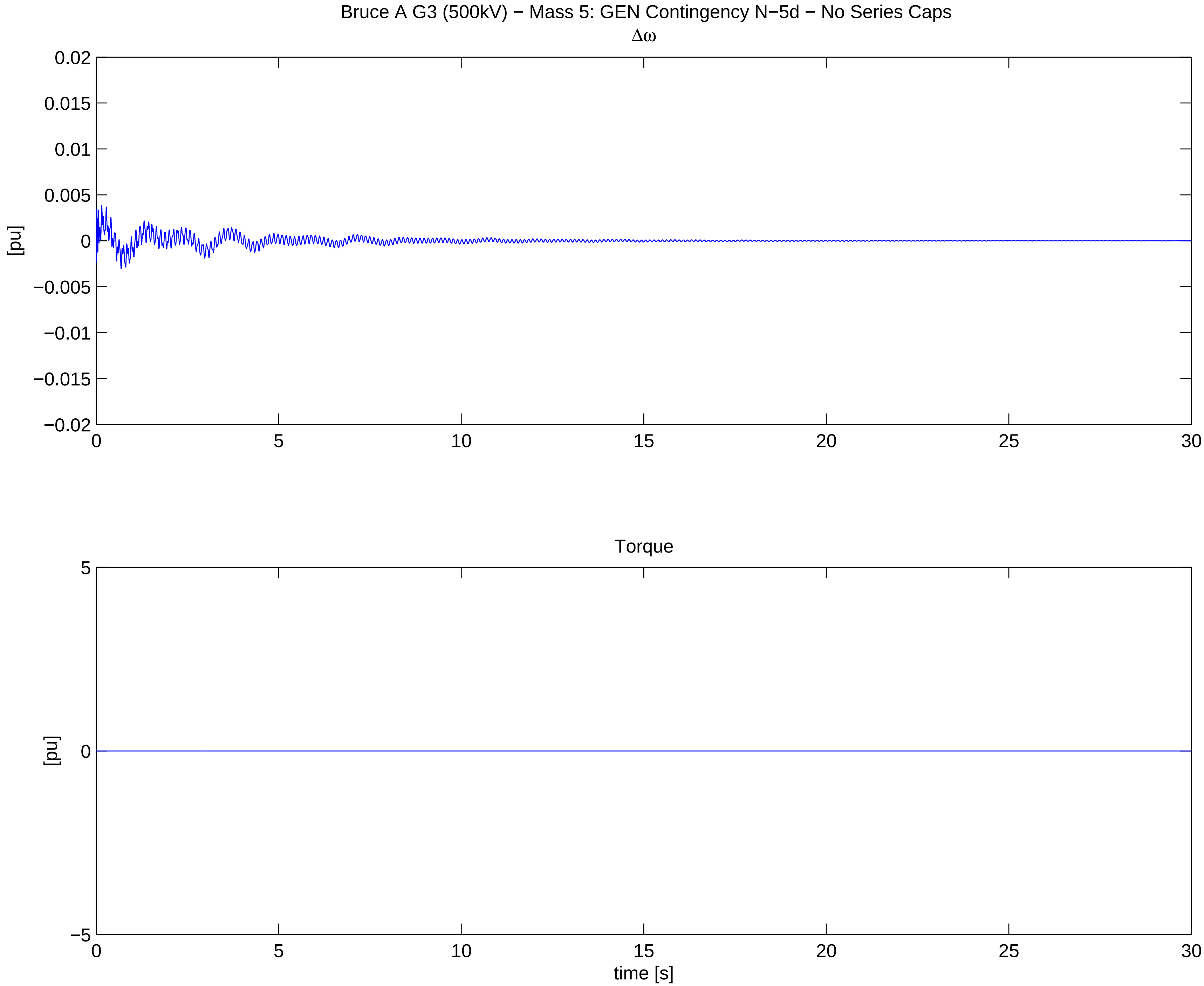
Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−5d − No Series Caps

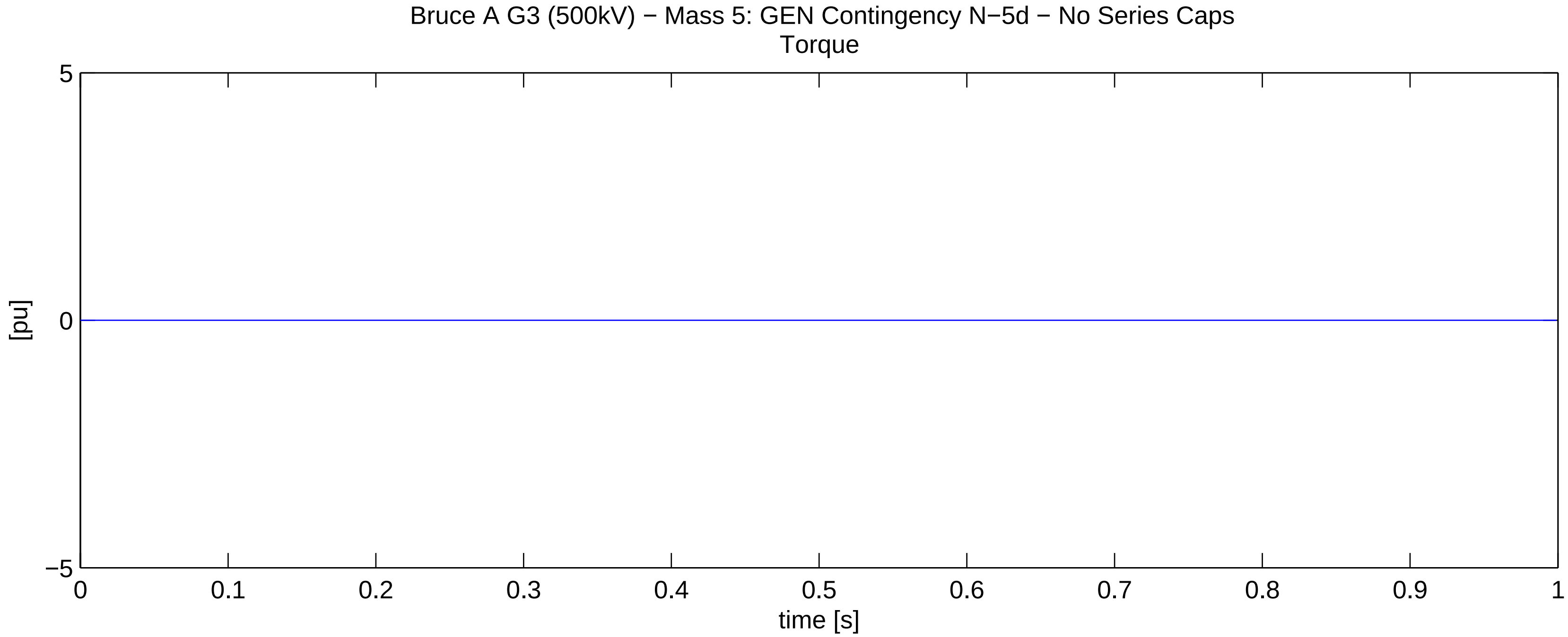


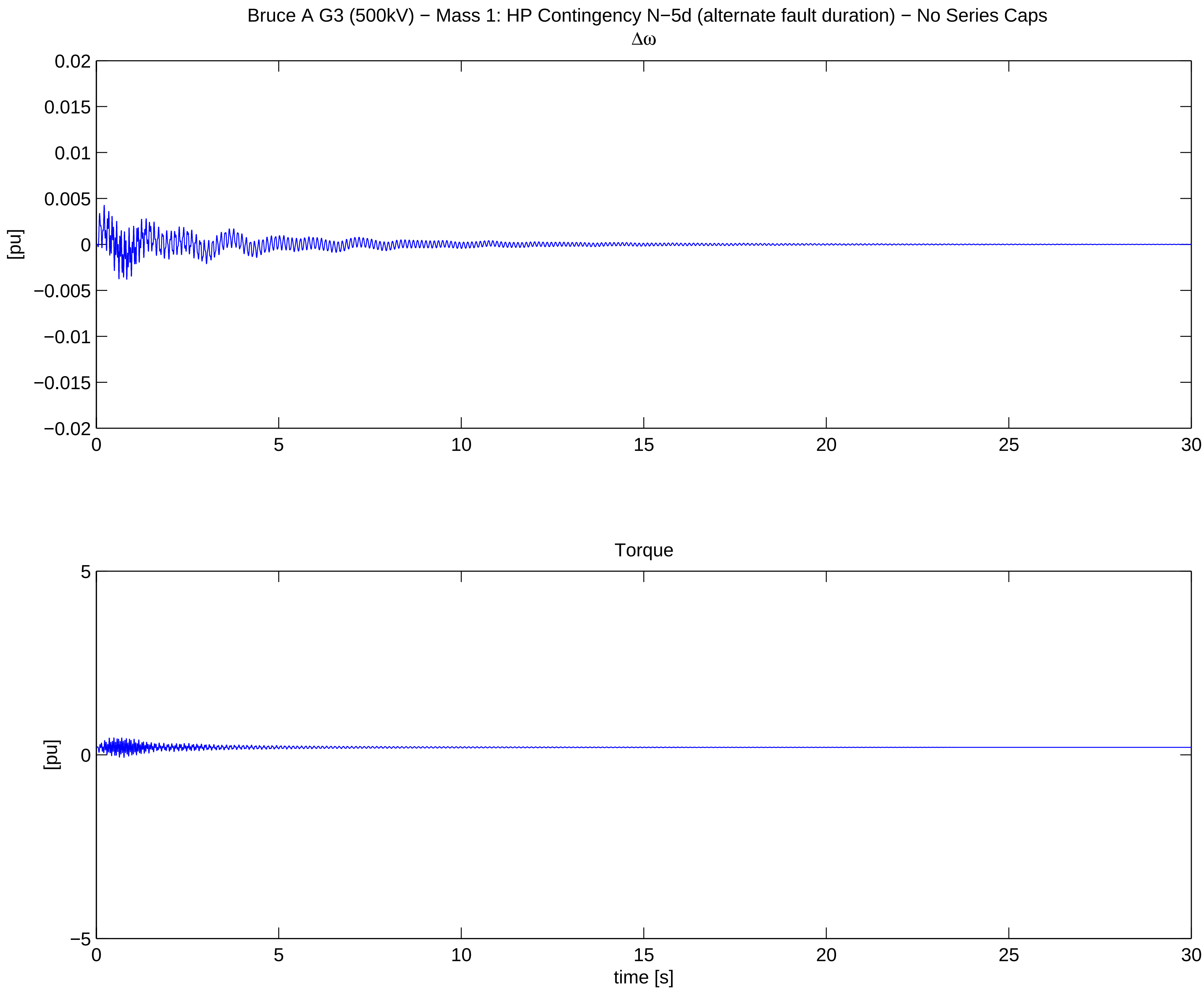




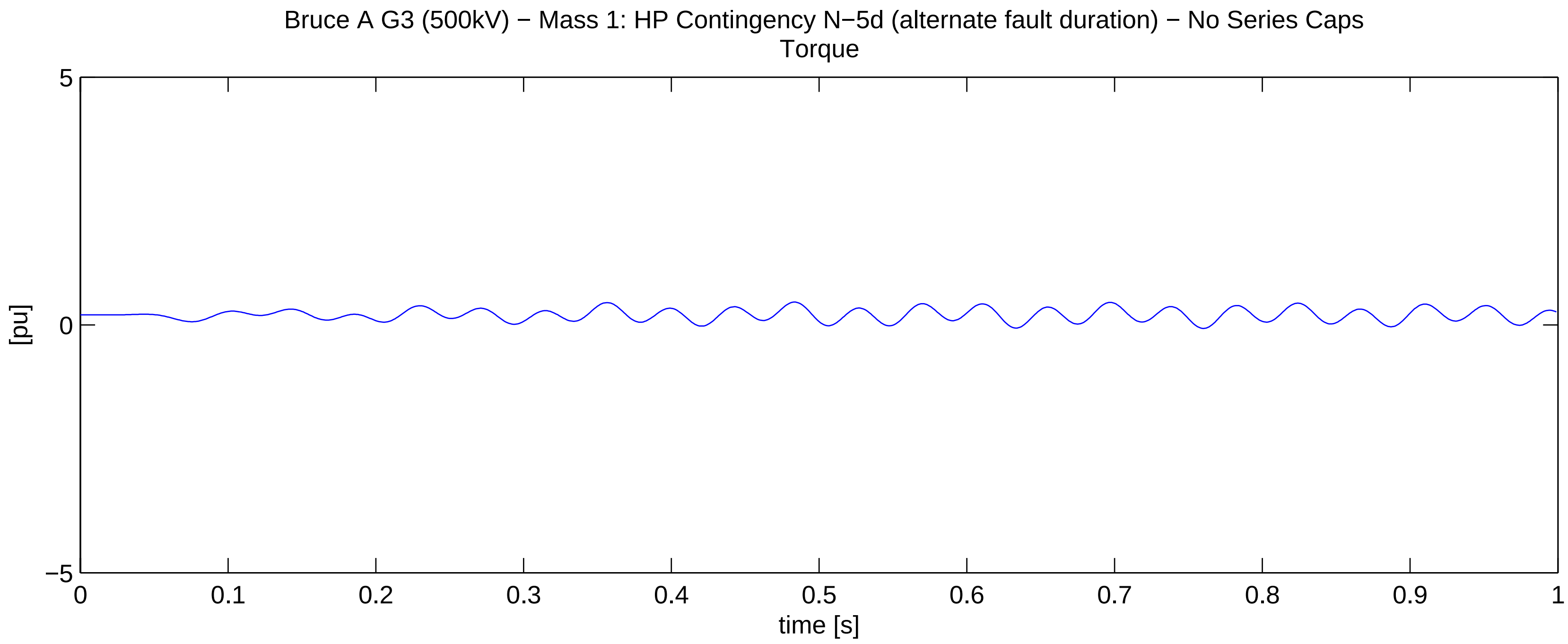
Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−5d − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce A G3 (500kV) − Mass 5: GEN Contingency N−5d − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

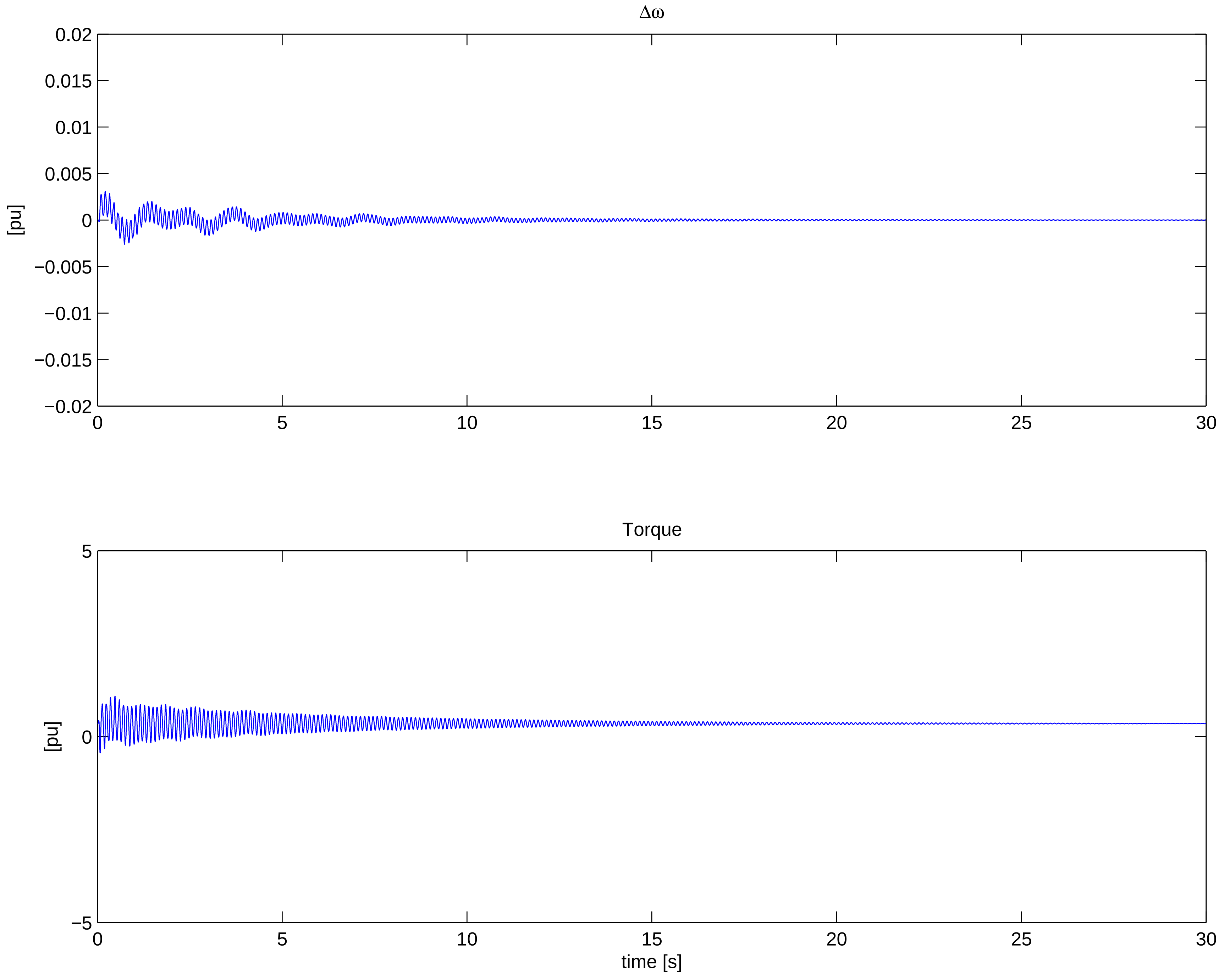

Bruce A G3 (500kV) − Mass 5: GEN Contingency N−5d − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

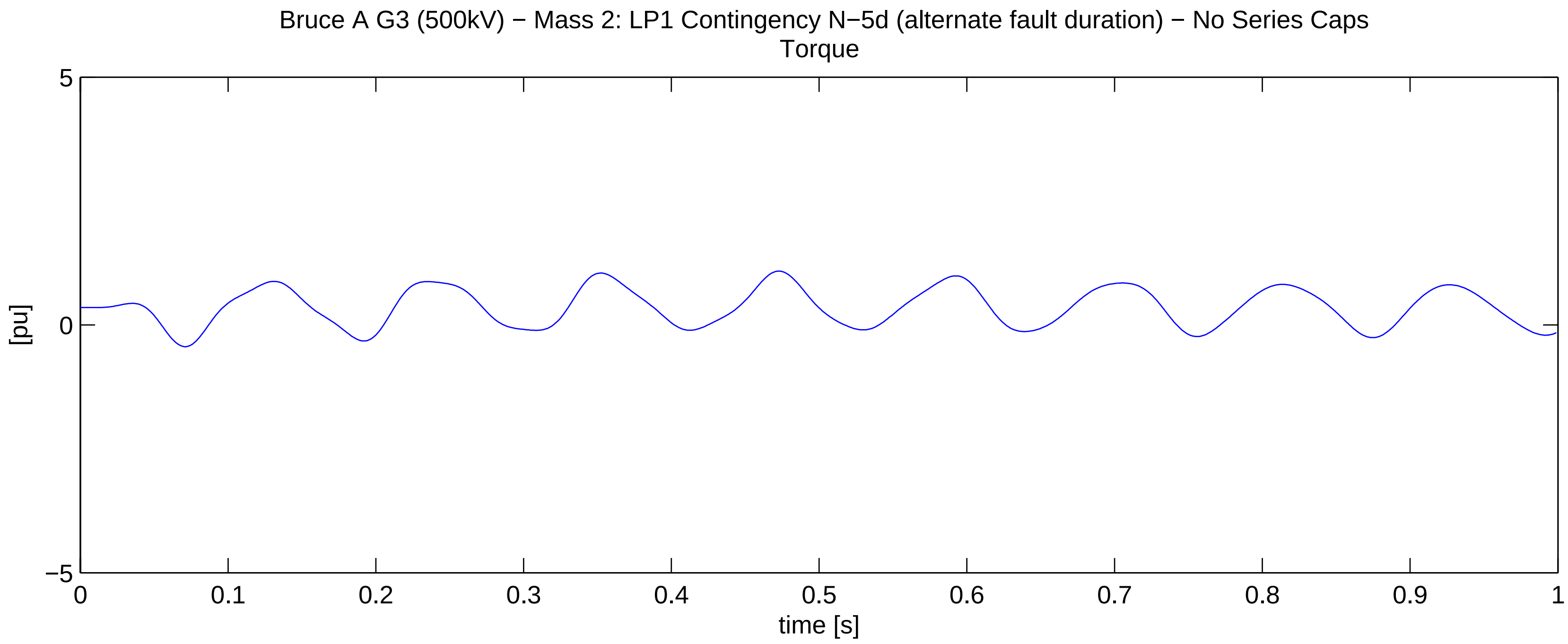


Bruce A G3 (500kV) − Mass 1: HP Contingency N−5d (alternate fault duration) − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

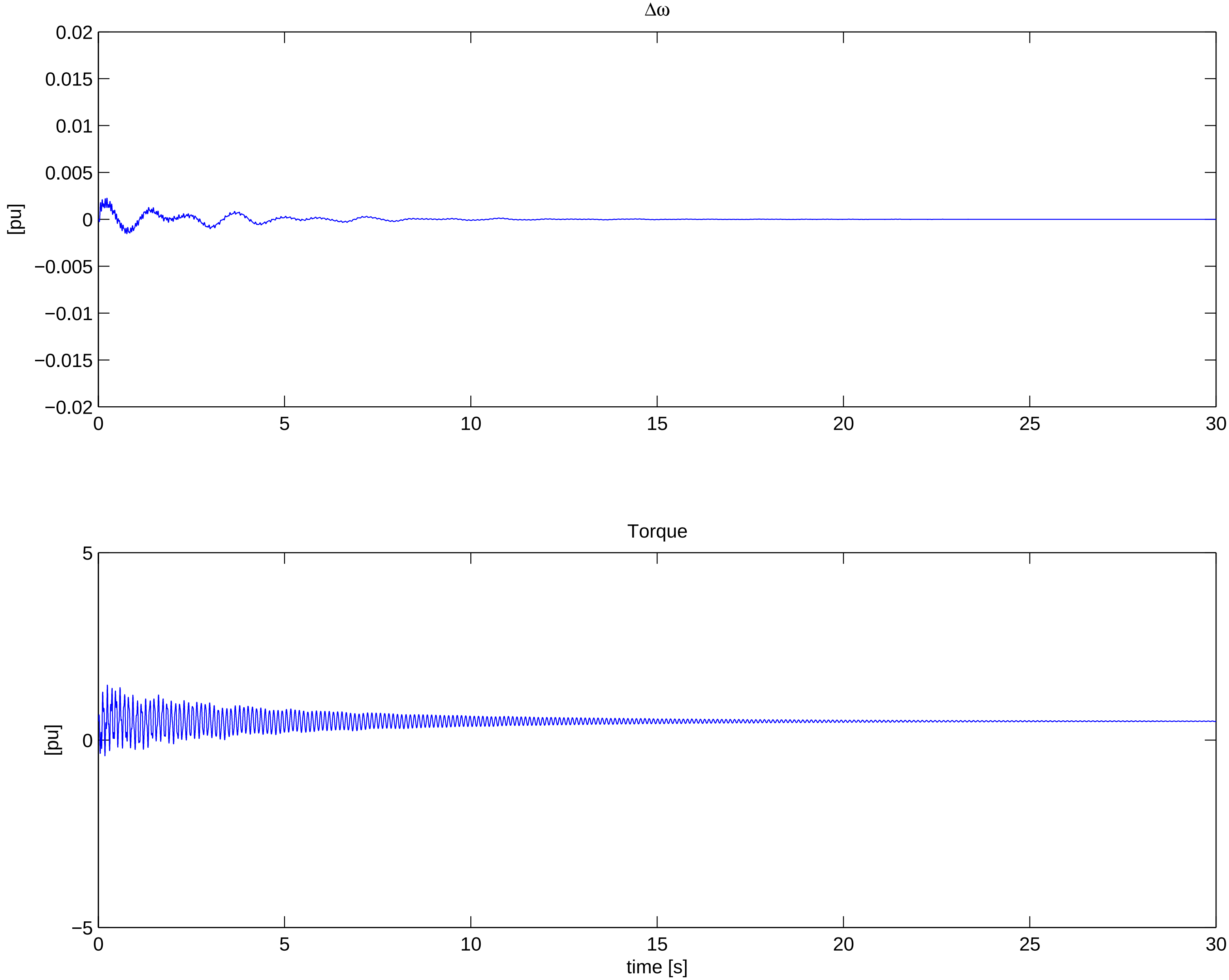

Bruce A G3 (500kV) − Mass 1: HP Contingency N−5d (alternate fault duration) − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

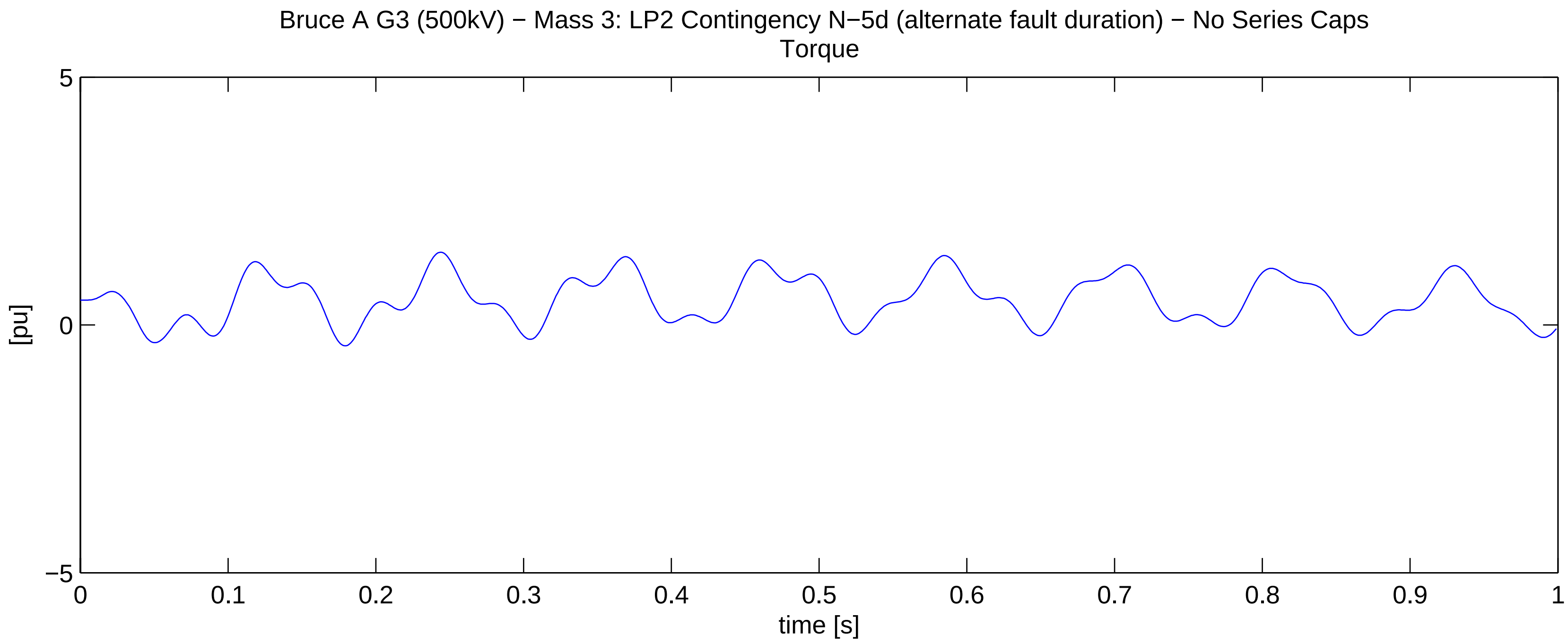
Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−5d (alternate fault duration) − No Series Caps

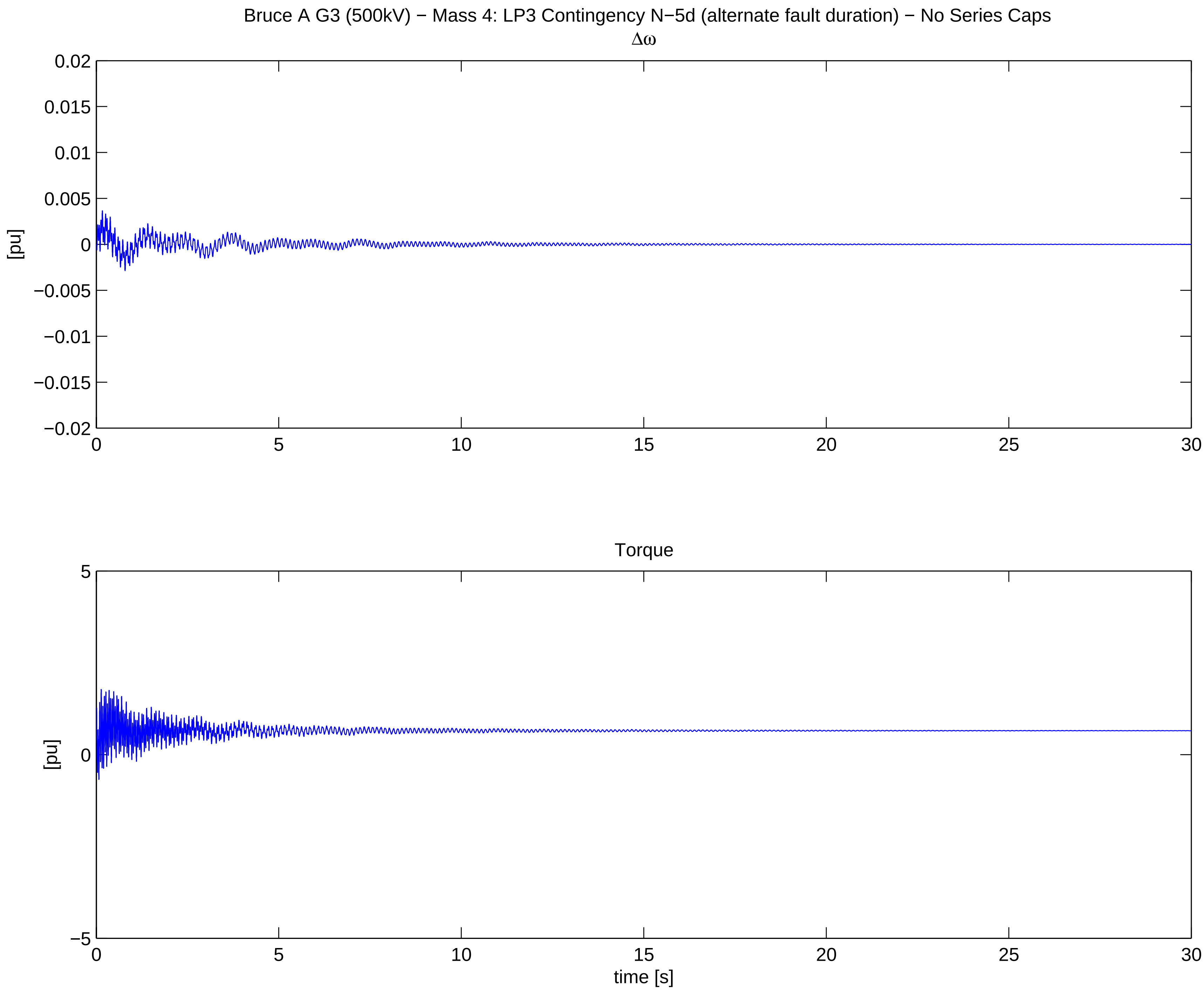


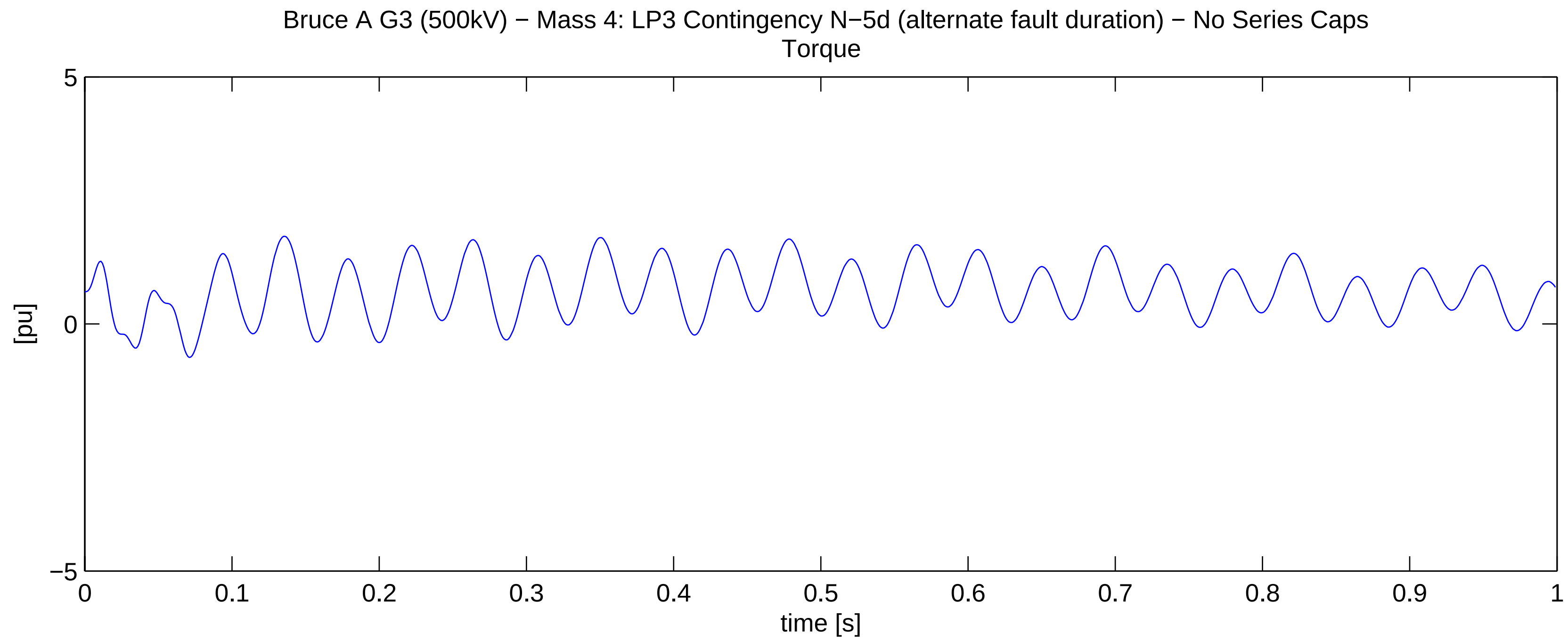

Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−5d (alternate fault duration) − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

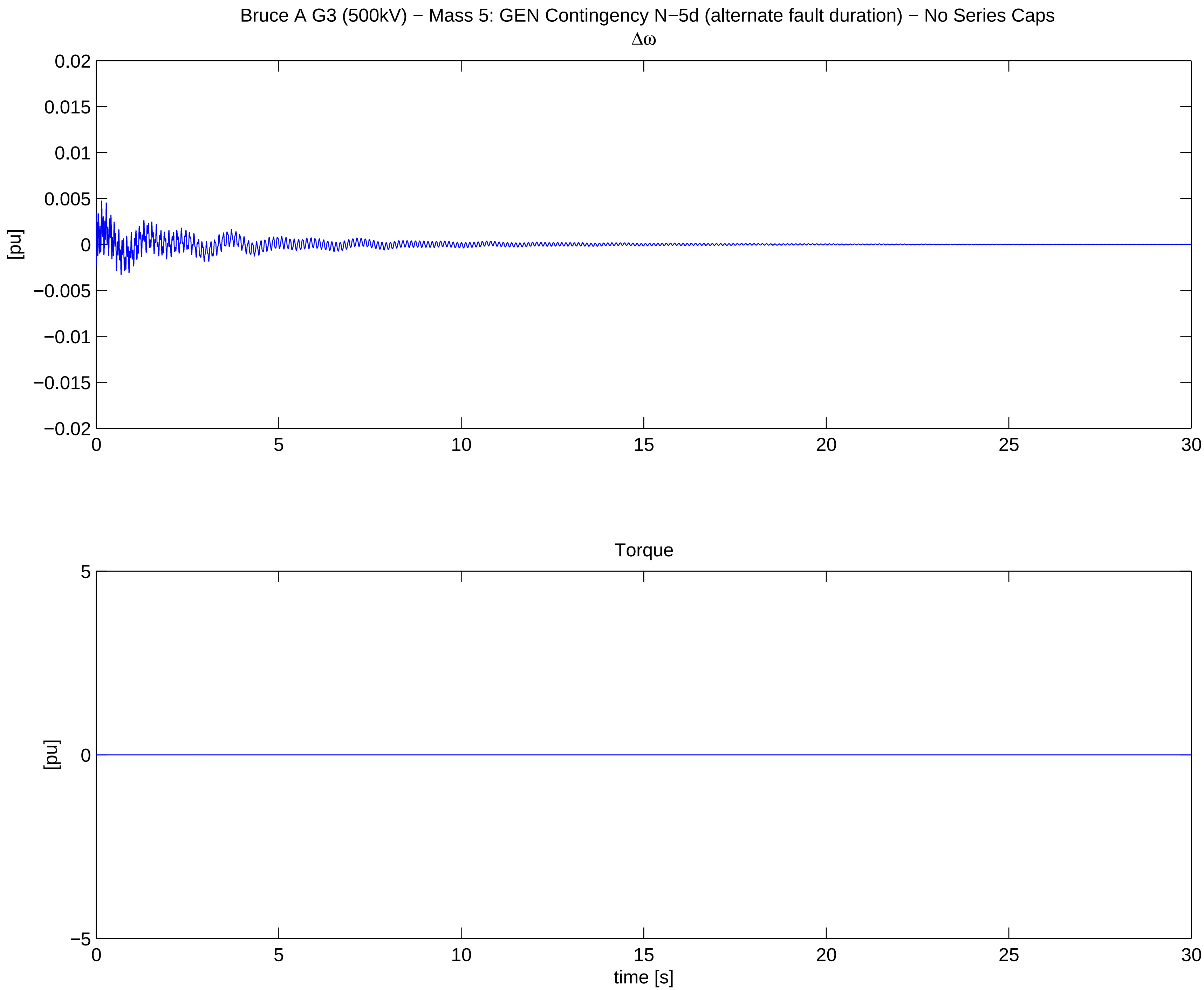
Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−5d (alternate fault duration) − No Series Caps

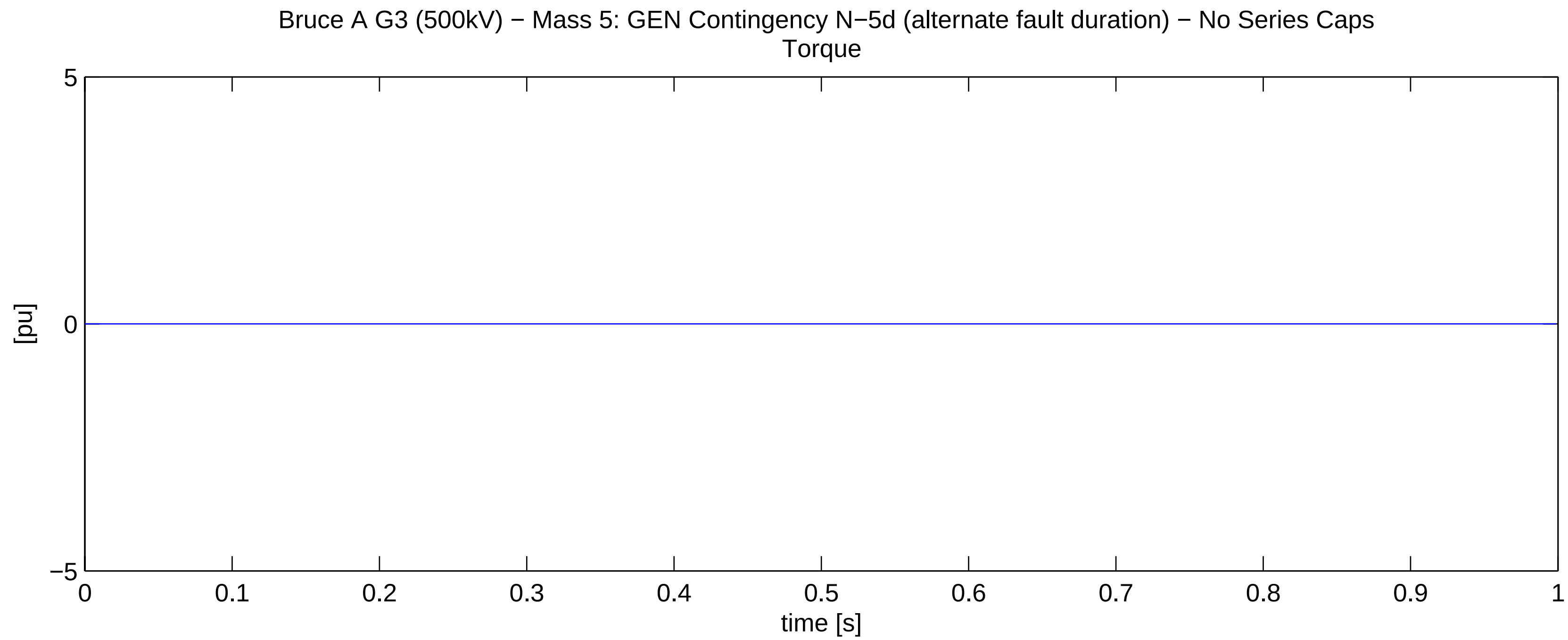



Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−5d (alternate fault duration) − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

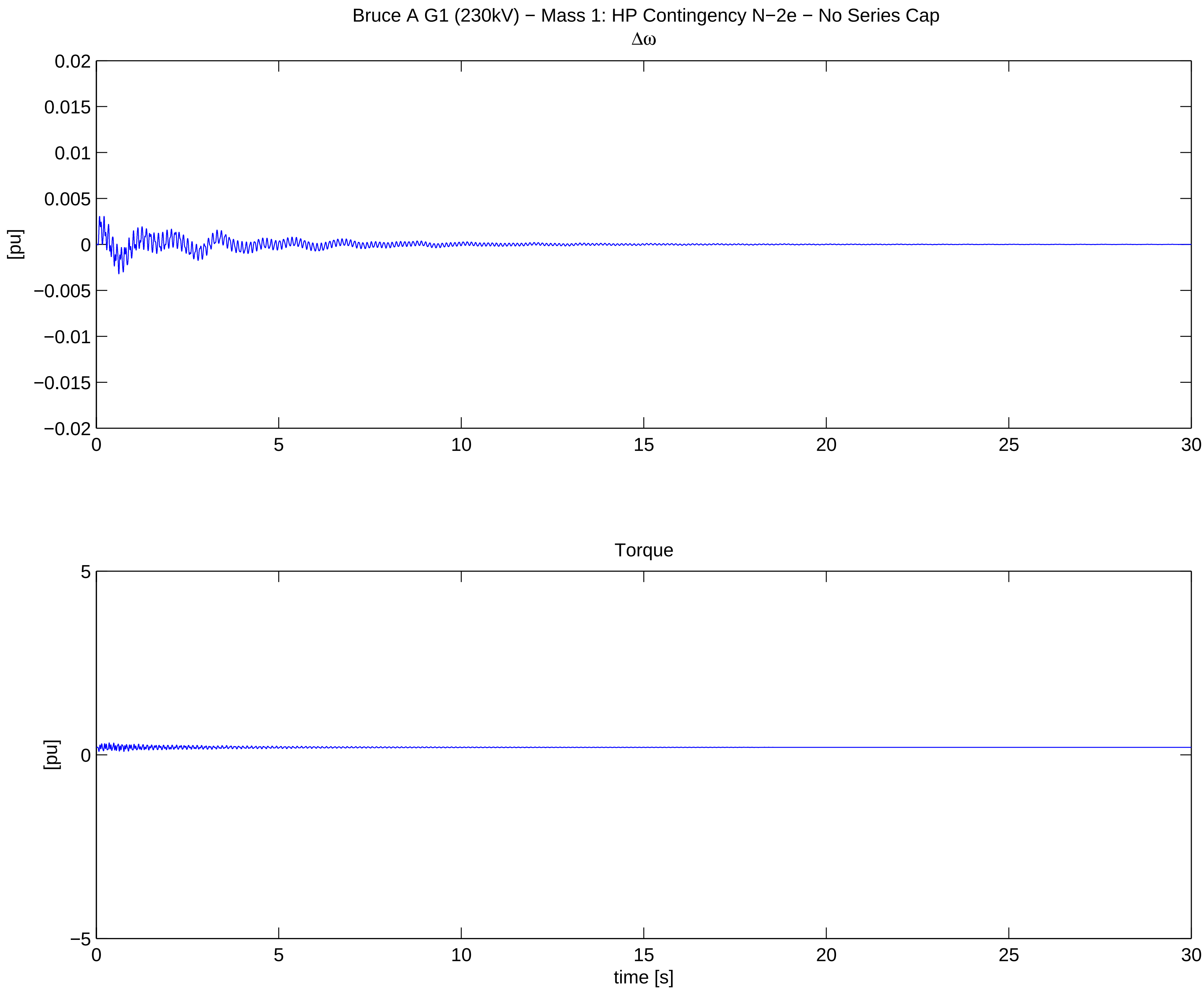

Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−5d (alternate fault duration) − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

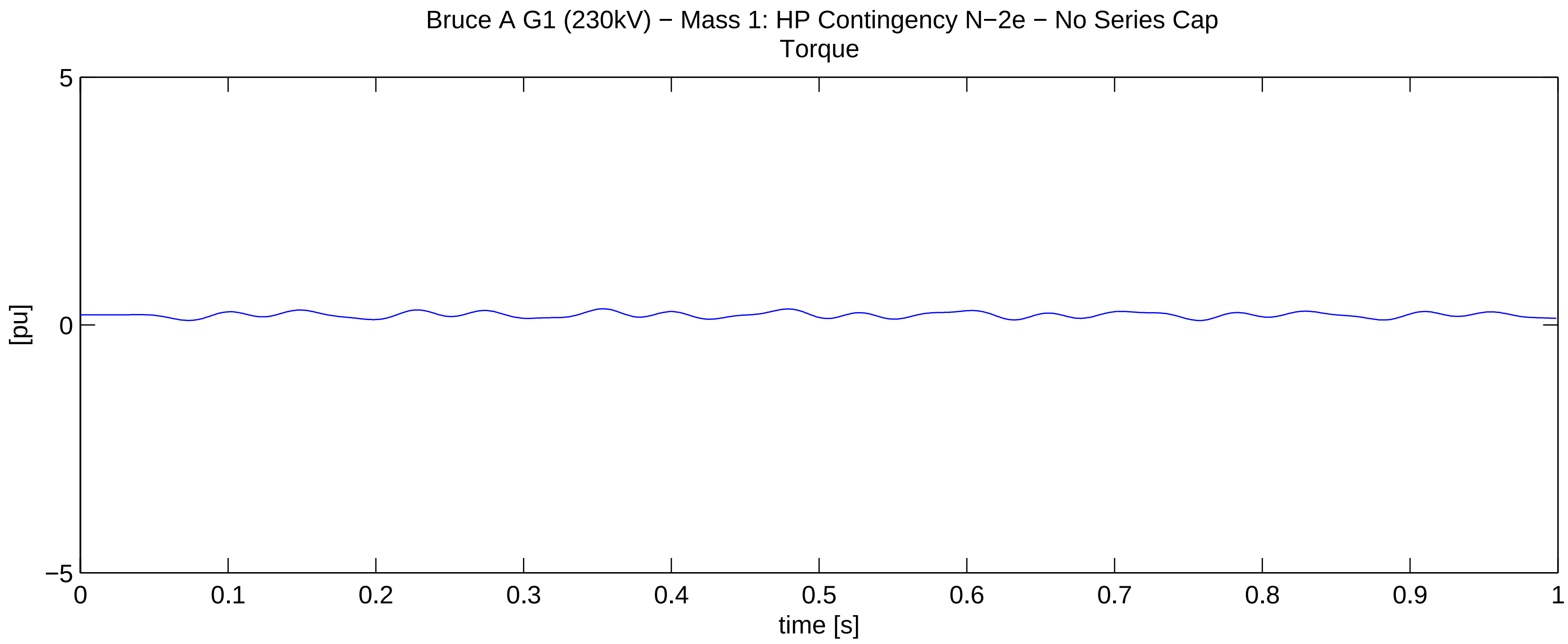

Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−5d (alternate fault duration) − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

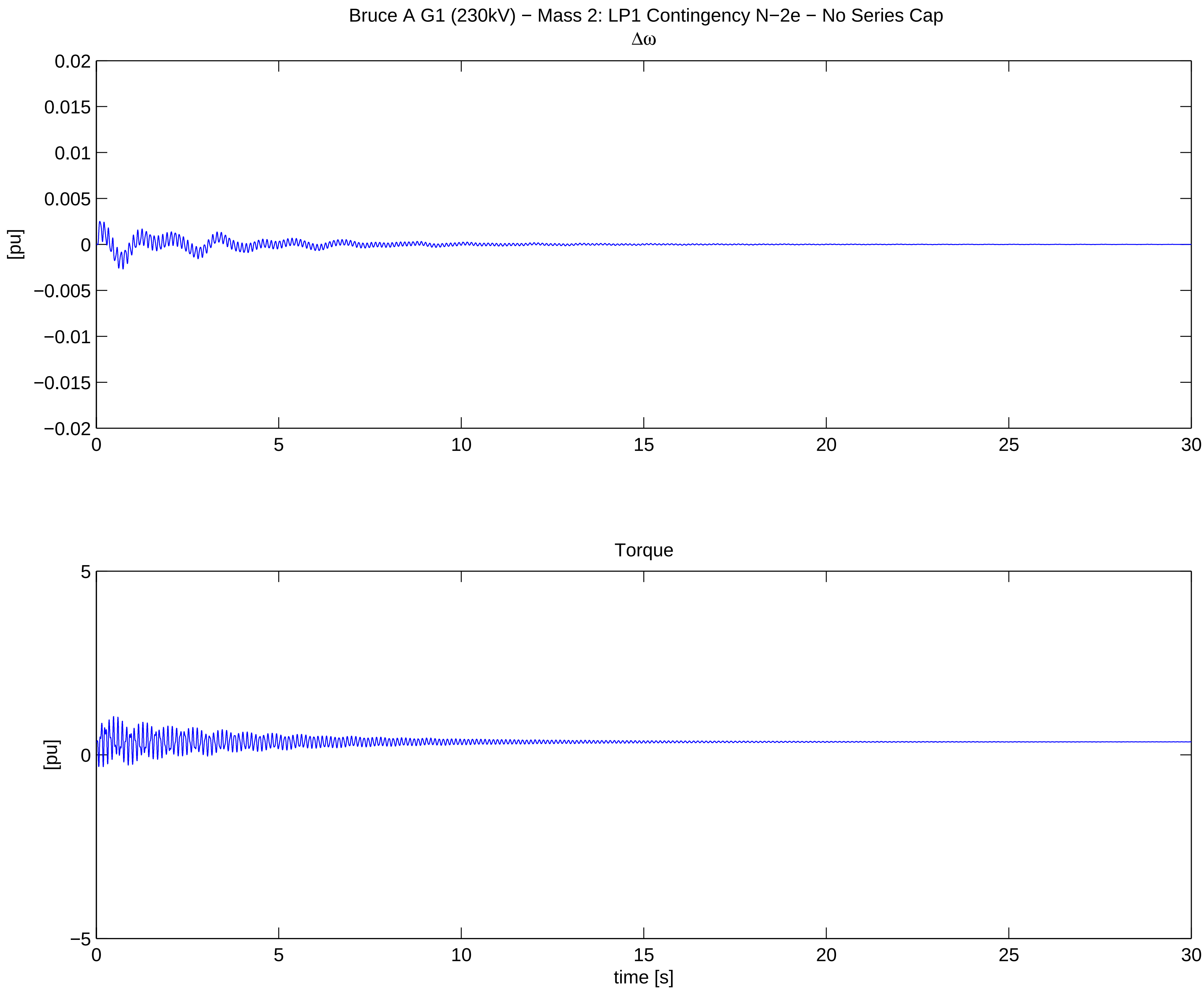

Bruce A G3 (500kV) − Mass 5: GEN Contingency N−5d (alternate fault duration) − No Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



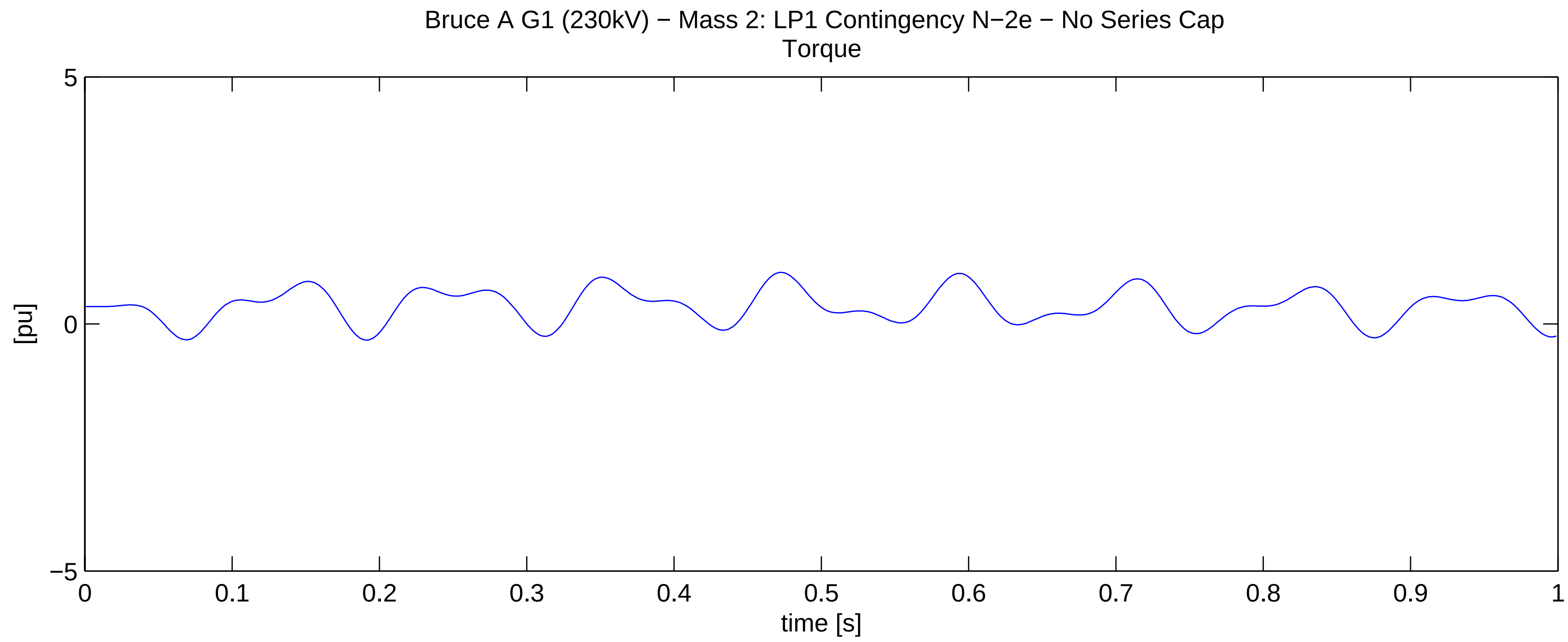
Bruce A G3 (500kV) − Mass 5: GEN Contingency N−5d (alternate fault duration) − No Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

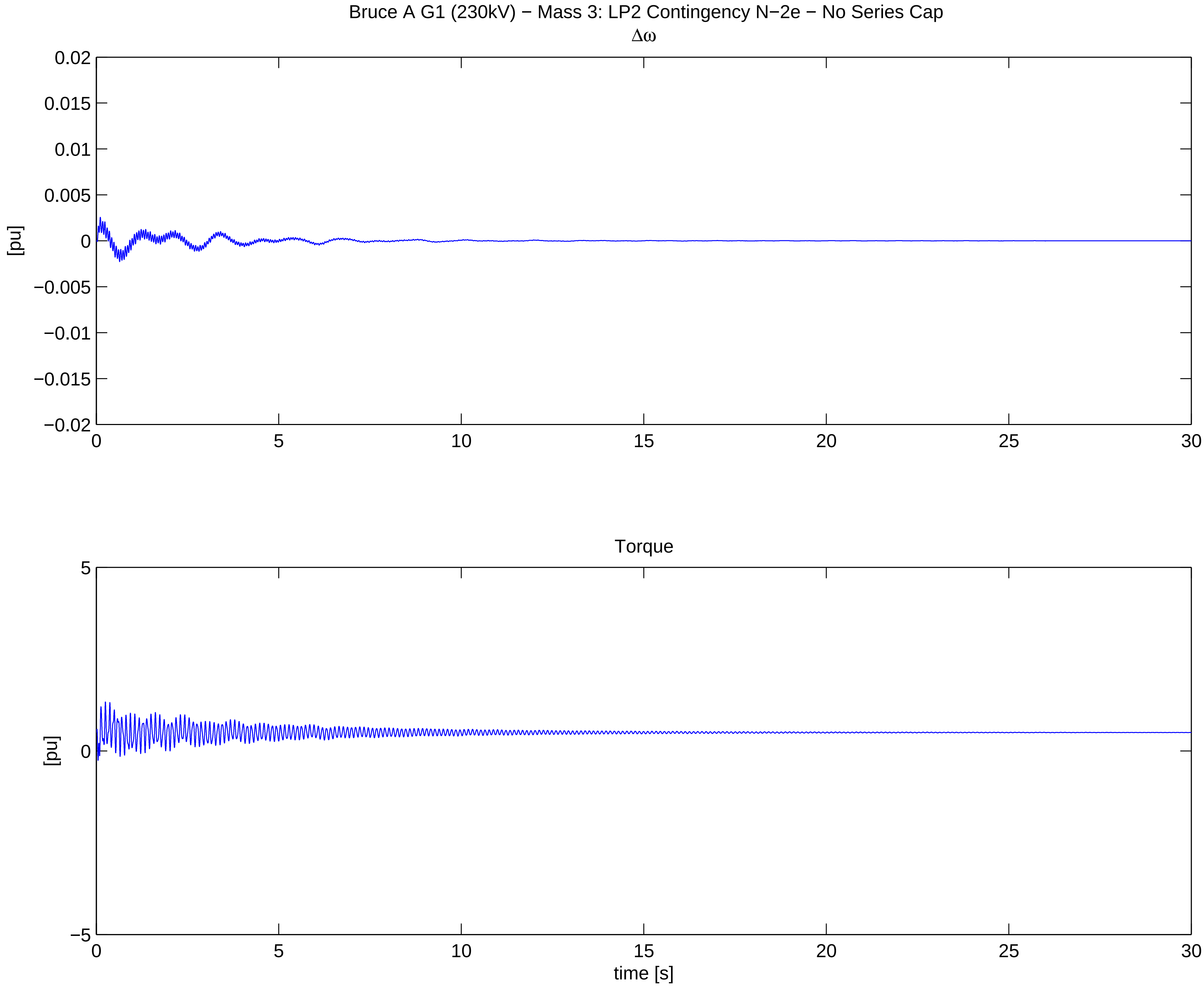

Bruce A G1 (230kV) − Mass 1: HP Contingency N−2e − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

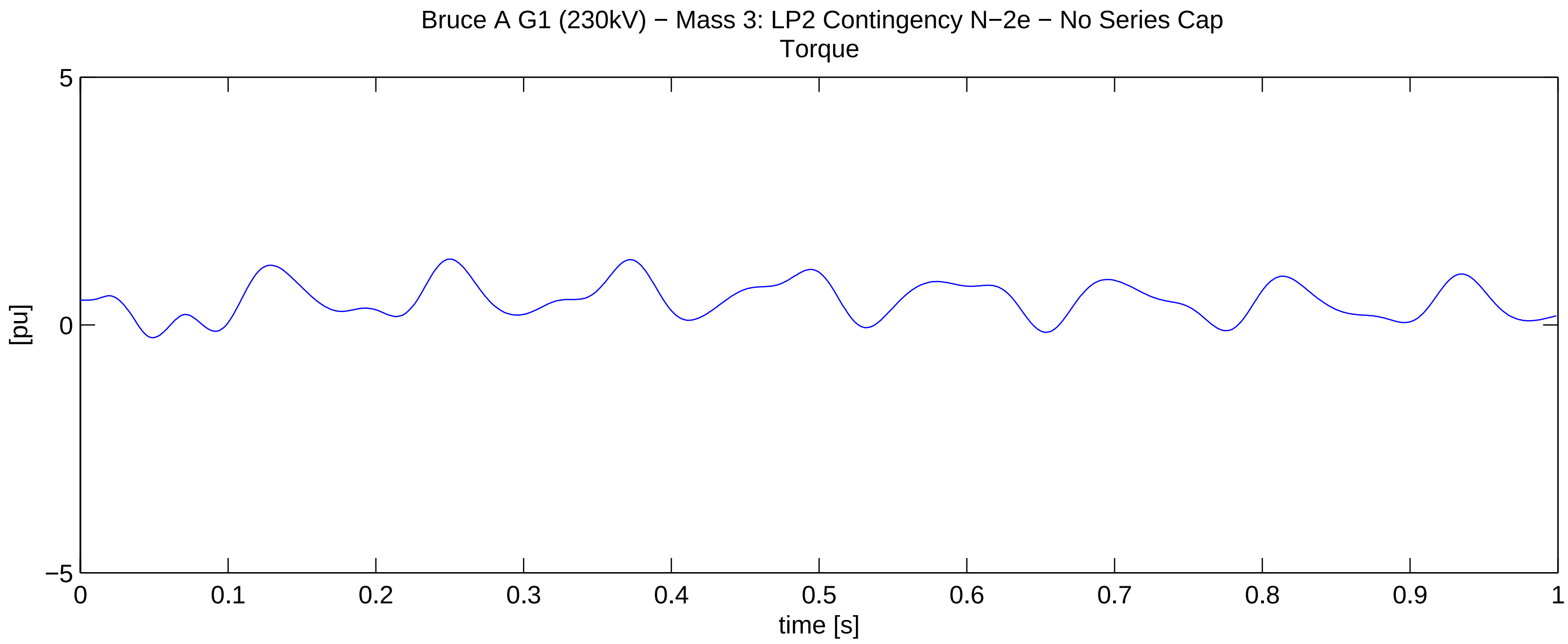

Bruce A G1 (230kV) − Mass 1: HP Contingency N−2e − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

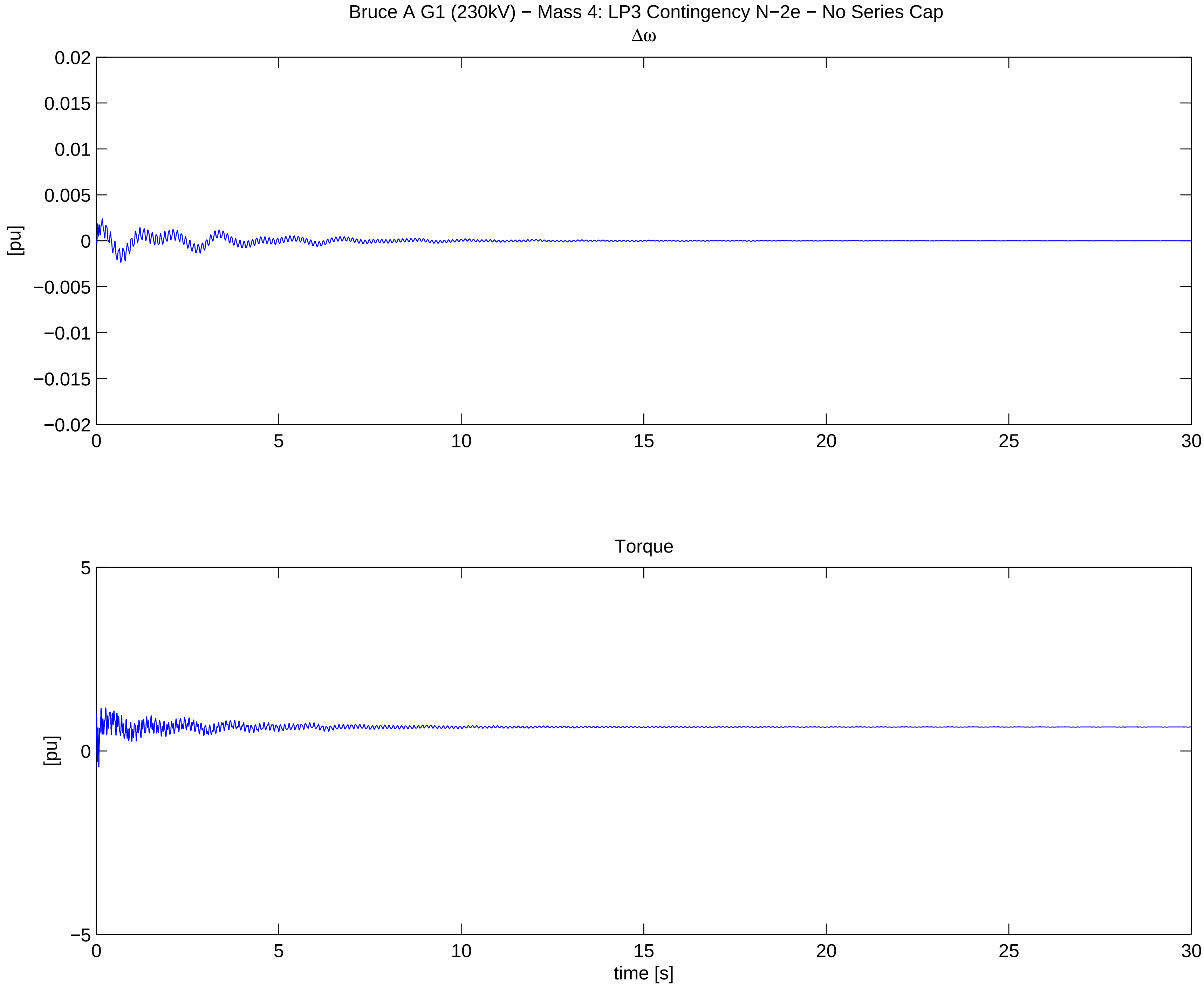


Bruce A G1 (230kV) − Mass 2: LP1 Contingency N−2e − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

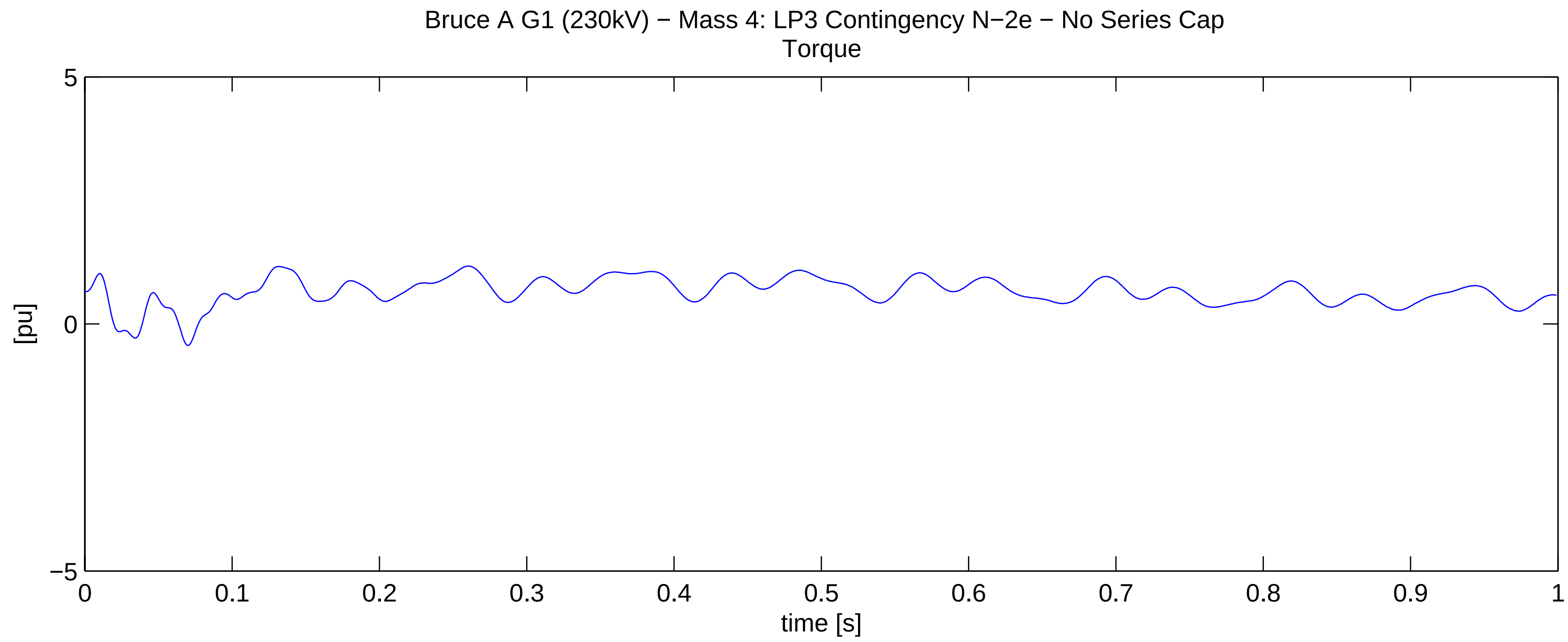

Bruce A G1 (230kV) − Mass 2: LP1 Contingency N−2e − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

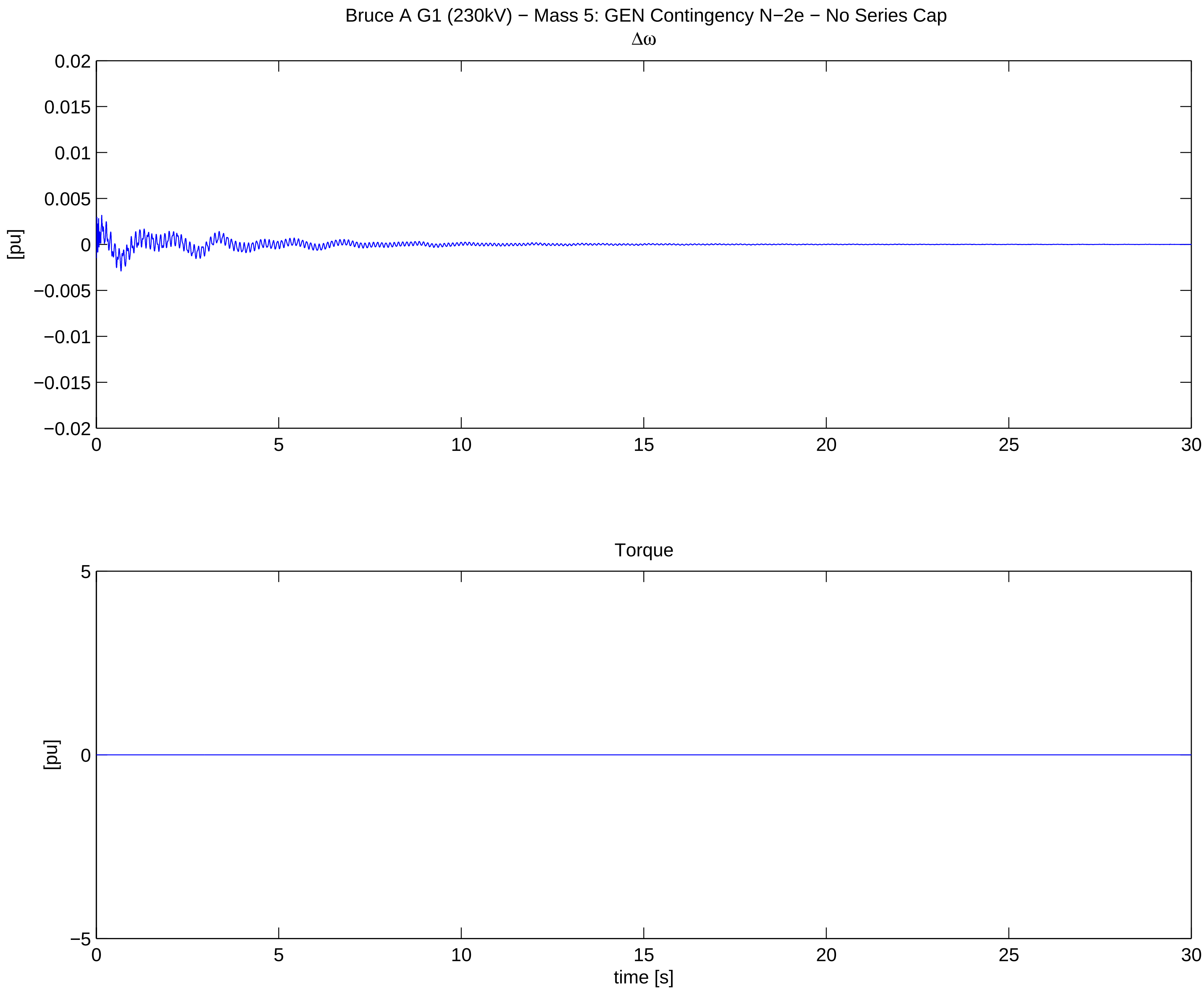

Bruce A G1 (230kV) − Mass 3: LP2 Contingency N−2e − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce A G1 (230kV) − Mass 3: LP2 Contingency N−2e − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

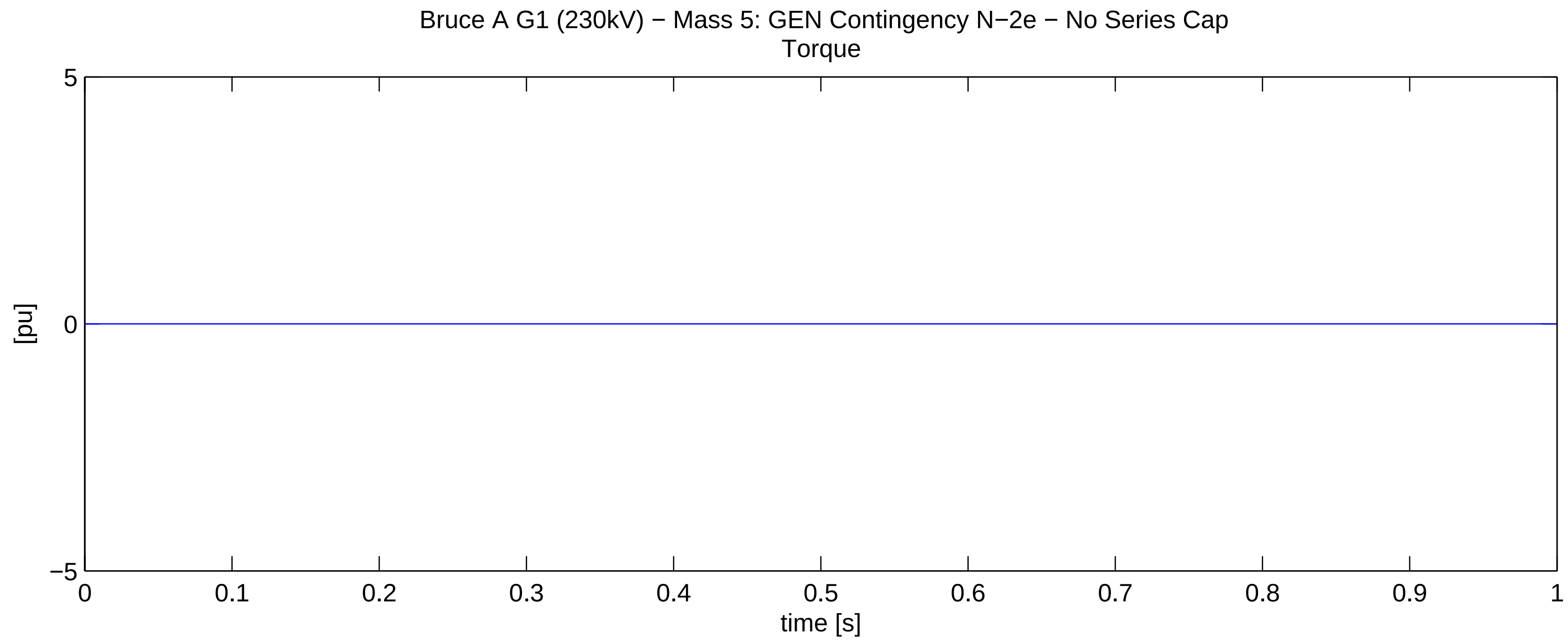


Bruce A G1 (230kV) − Mass 4: LP3 Contingency N−2e − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

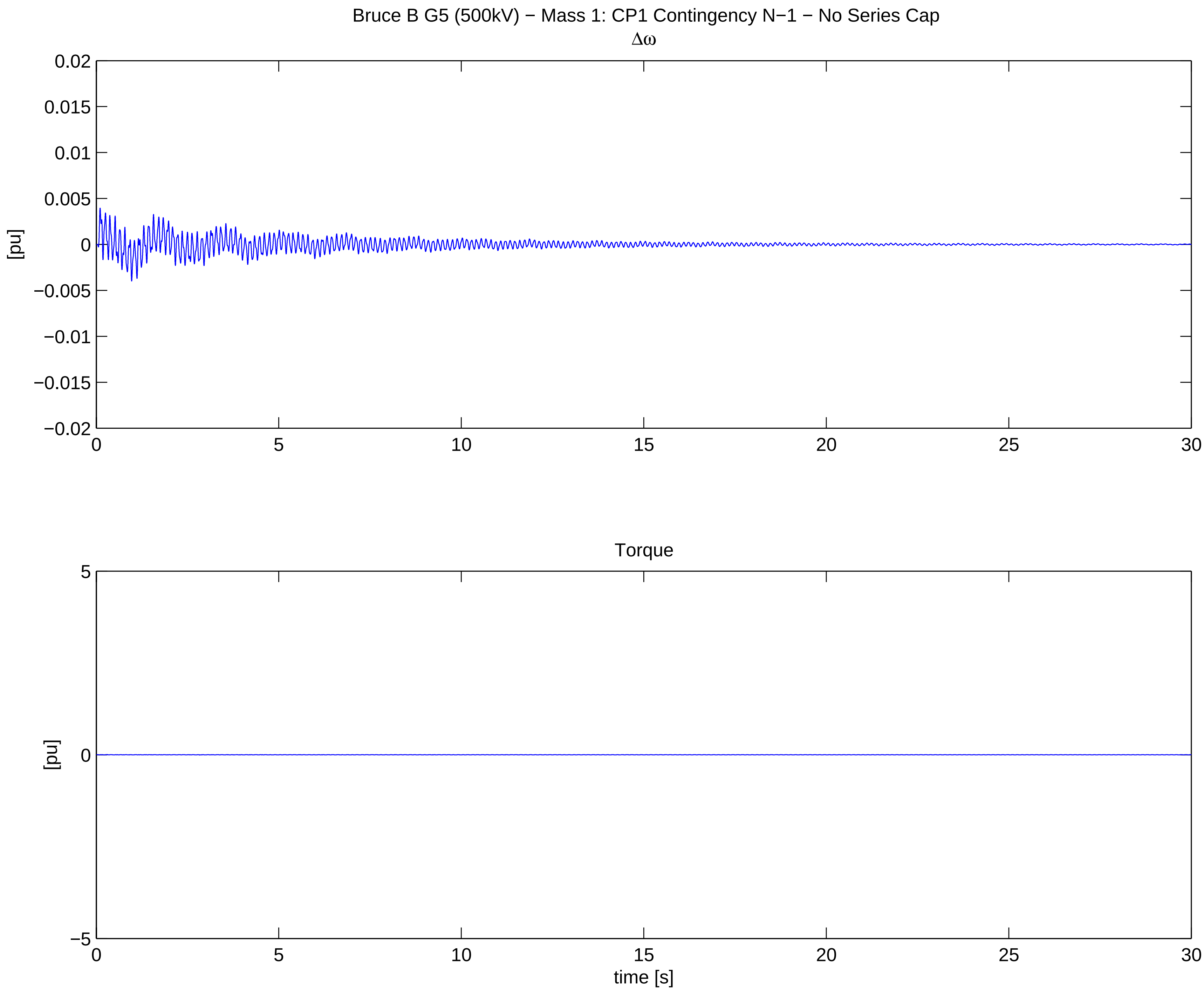

Bruce A G1 (230kV) − Mass 4: LP3 Contingency N−2e − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



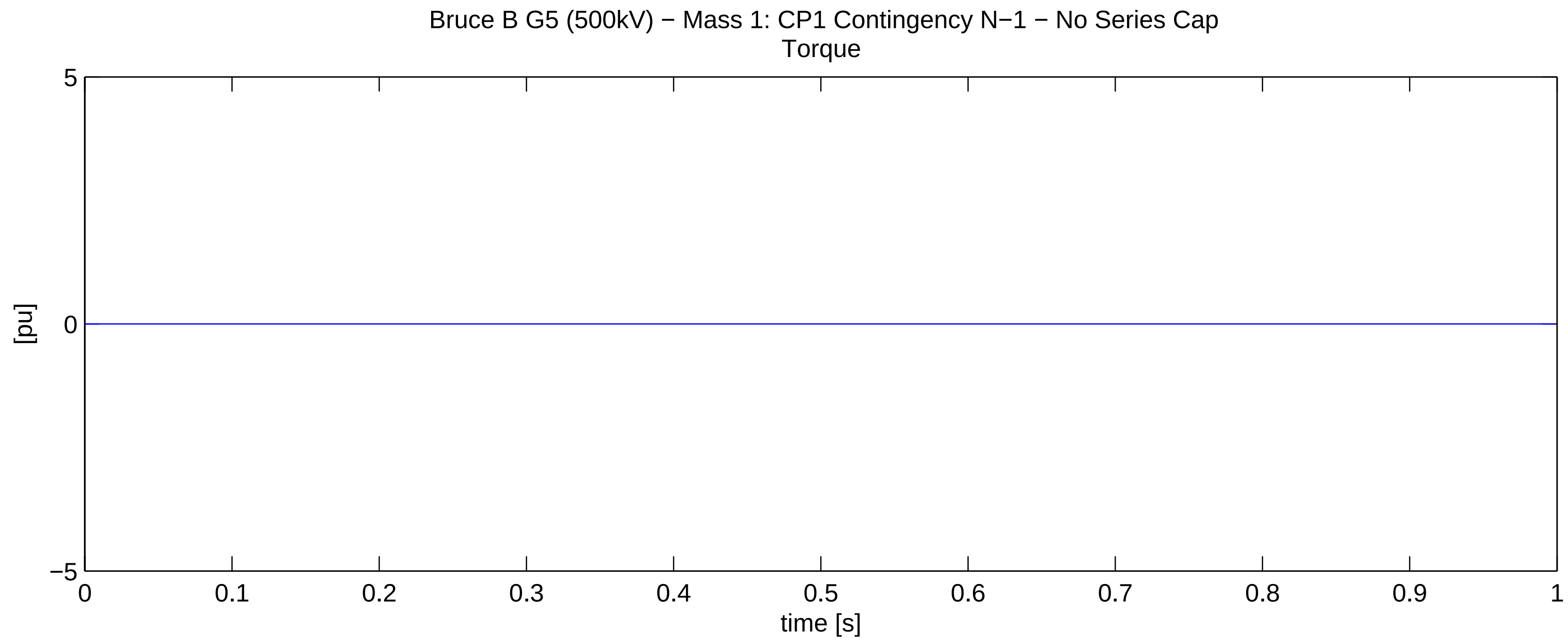
Bruce A G1 (230kV) − Mass 5: GEN Contingency N−2e − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



Bruce A G1 (230kV) − Mass 5: GEN Contingency N−2e − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

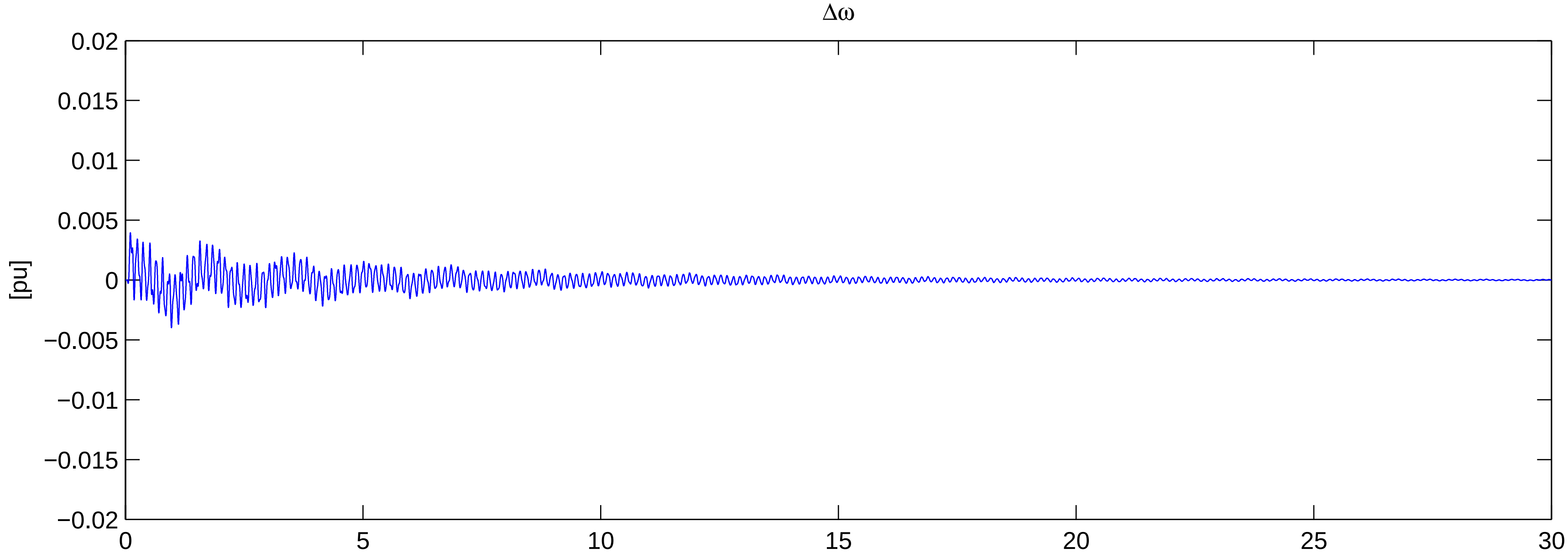


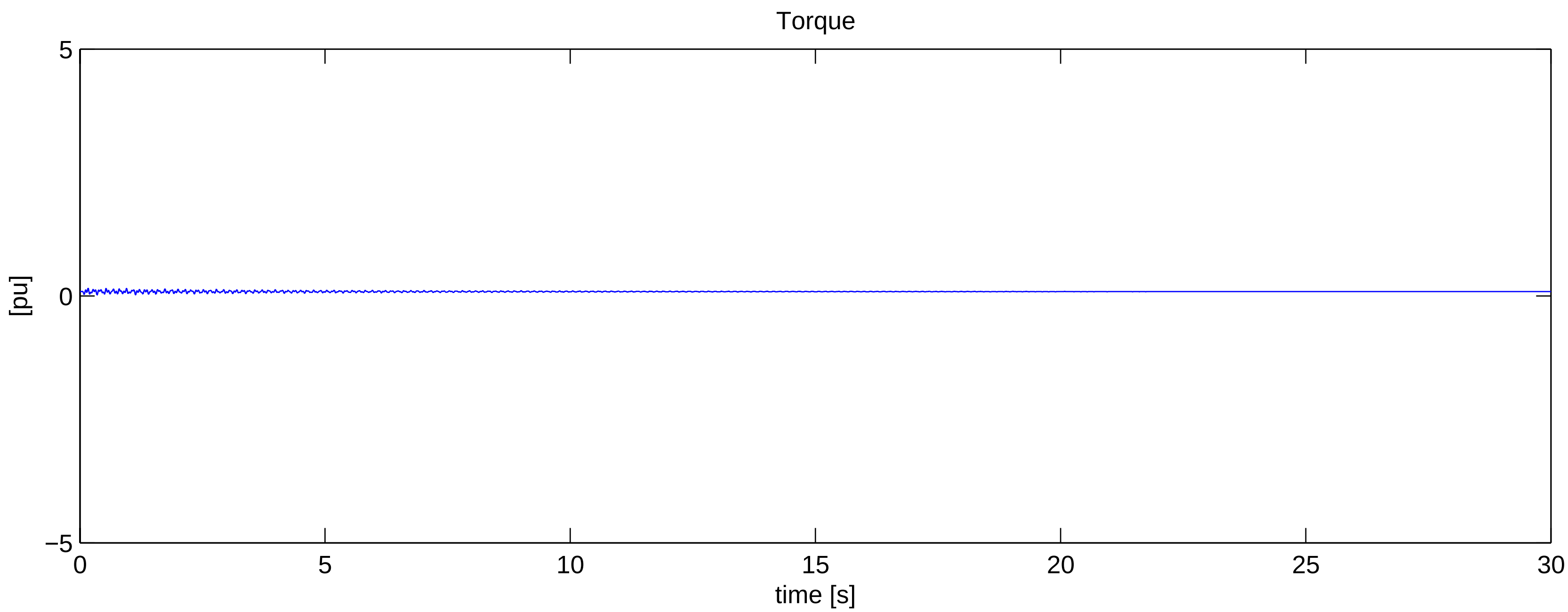
Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



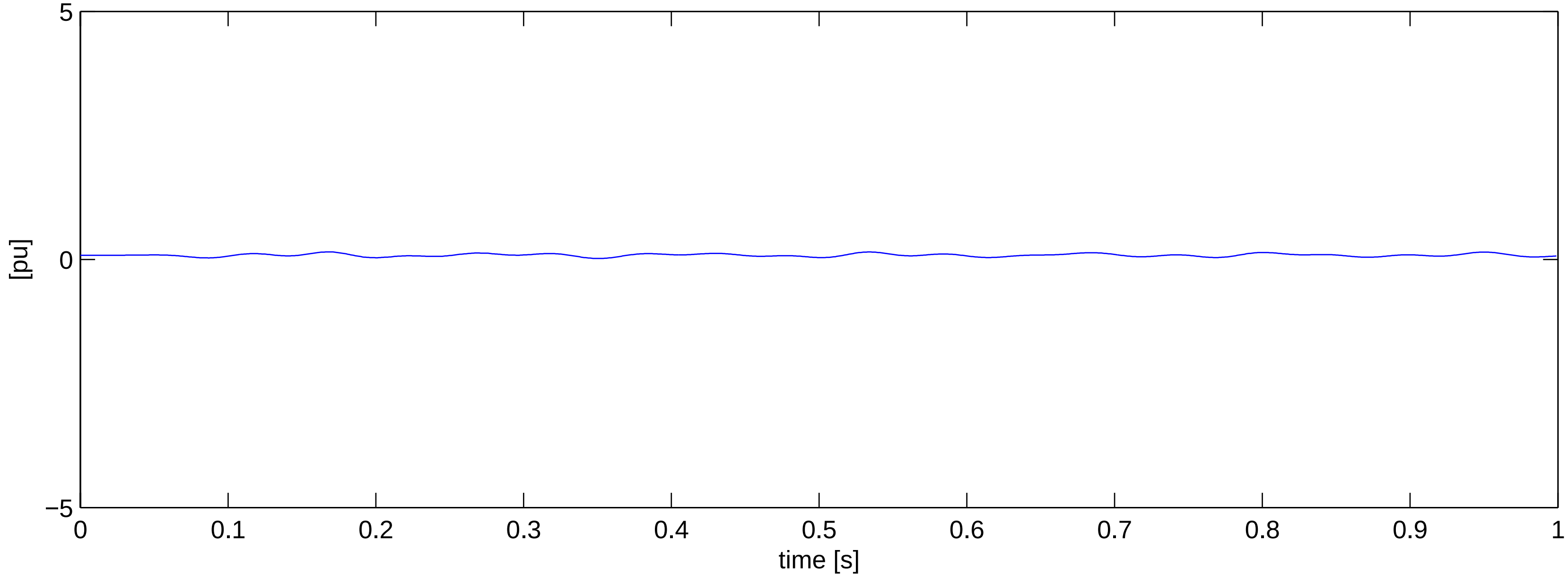
Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−1 − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

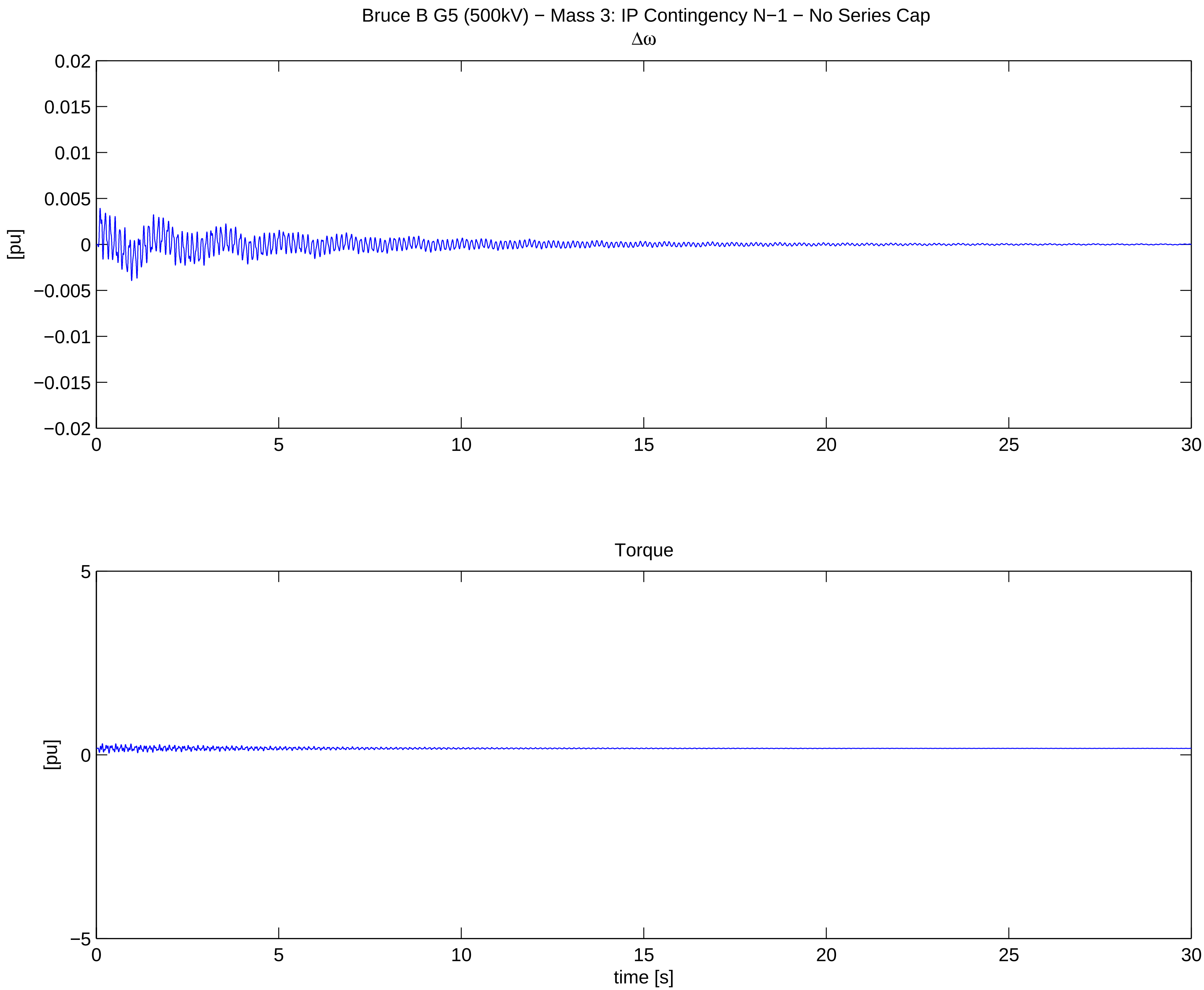
Bruce B G5 (500kV) − Mass 2: HP Contingency N−1 − No Series Cap



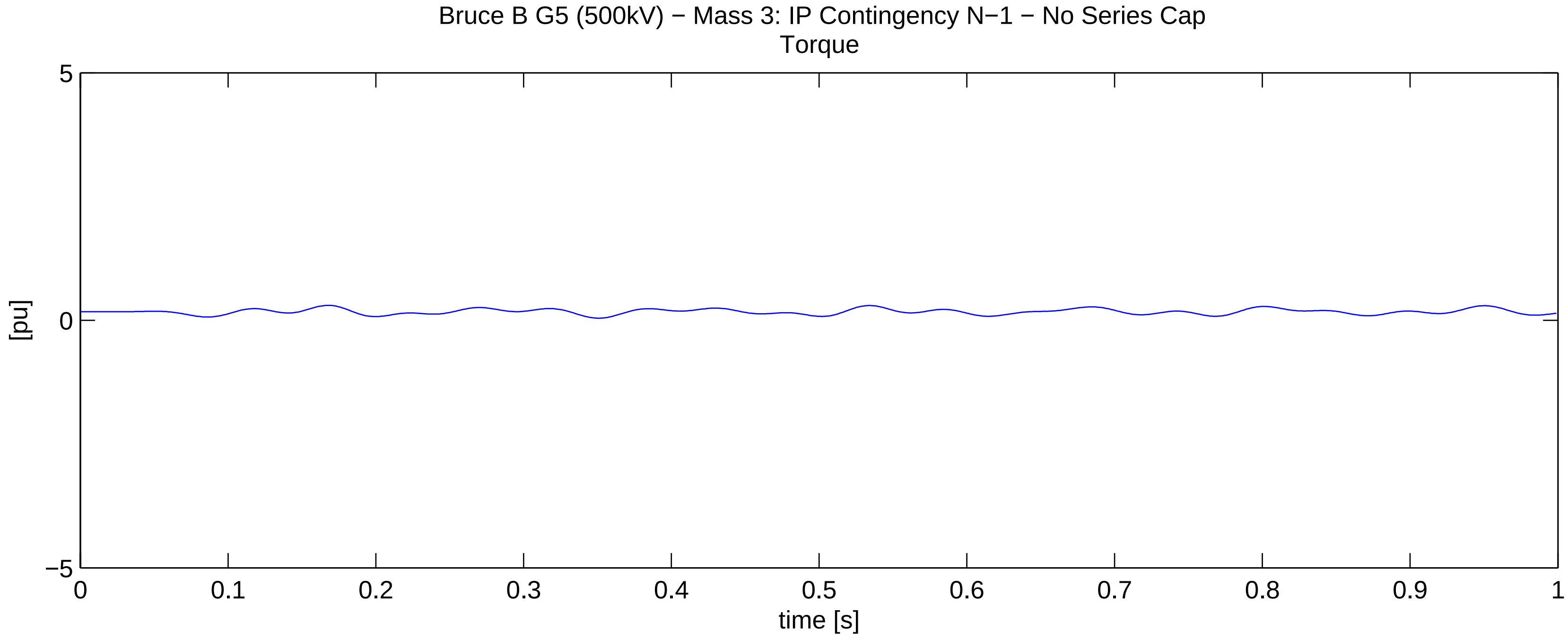


Bruce B G5 (500kV) − Mass 2: HP Contingency N−1 − No Series Cap
Torque

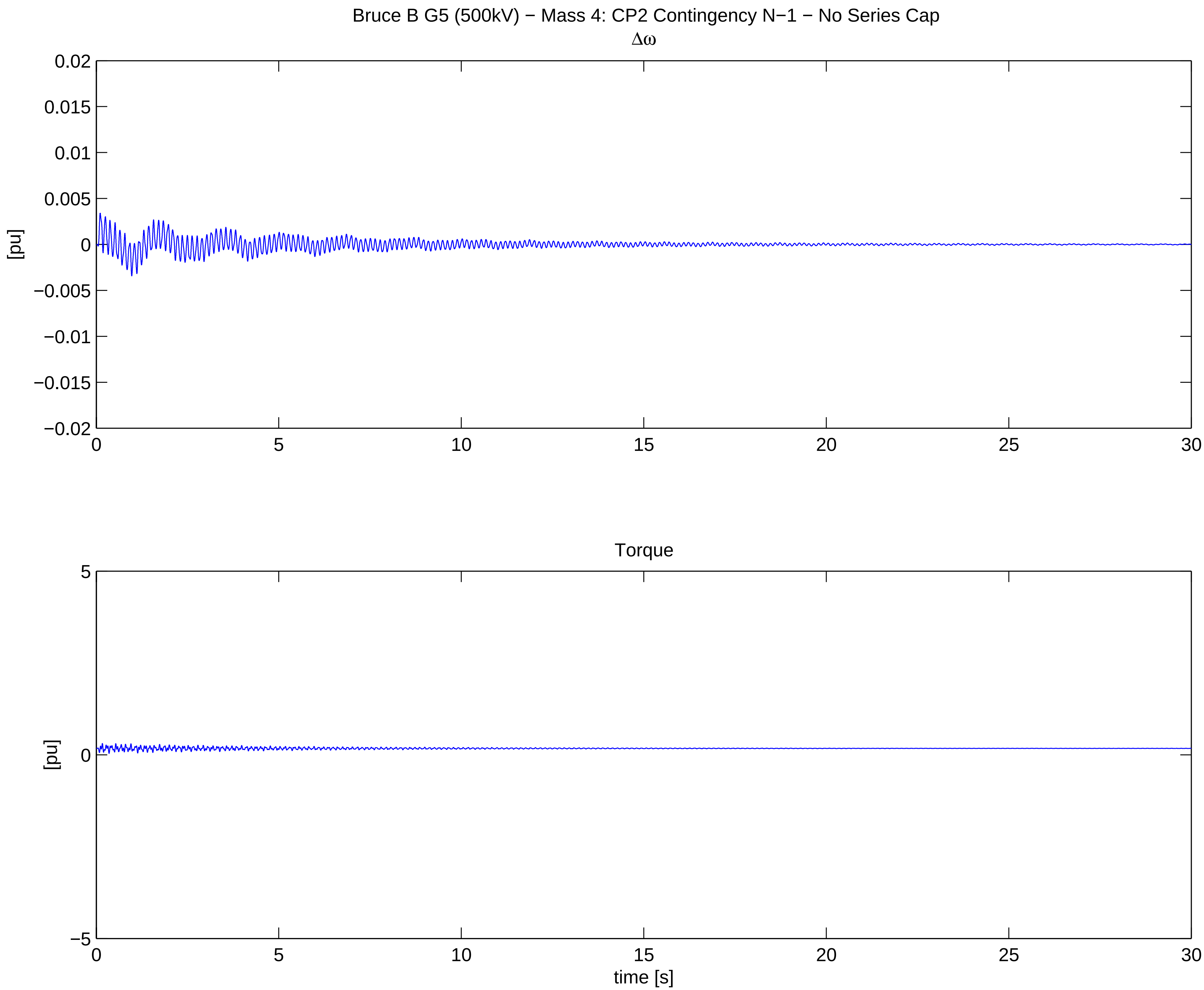




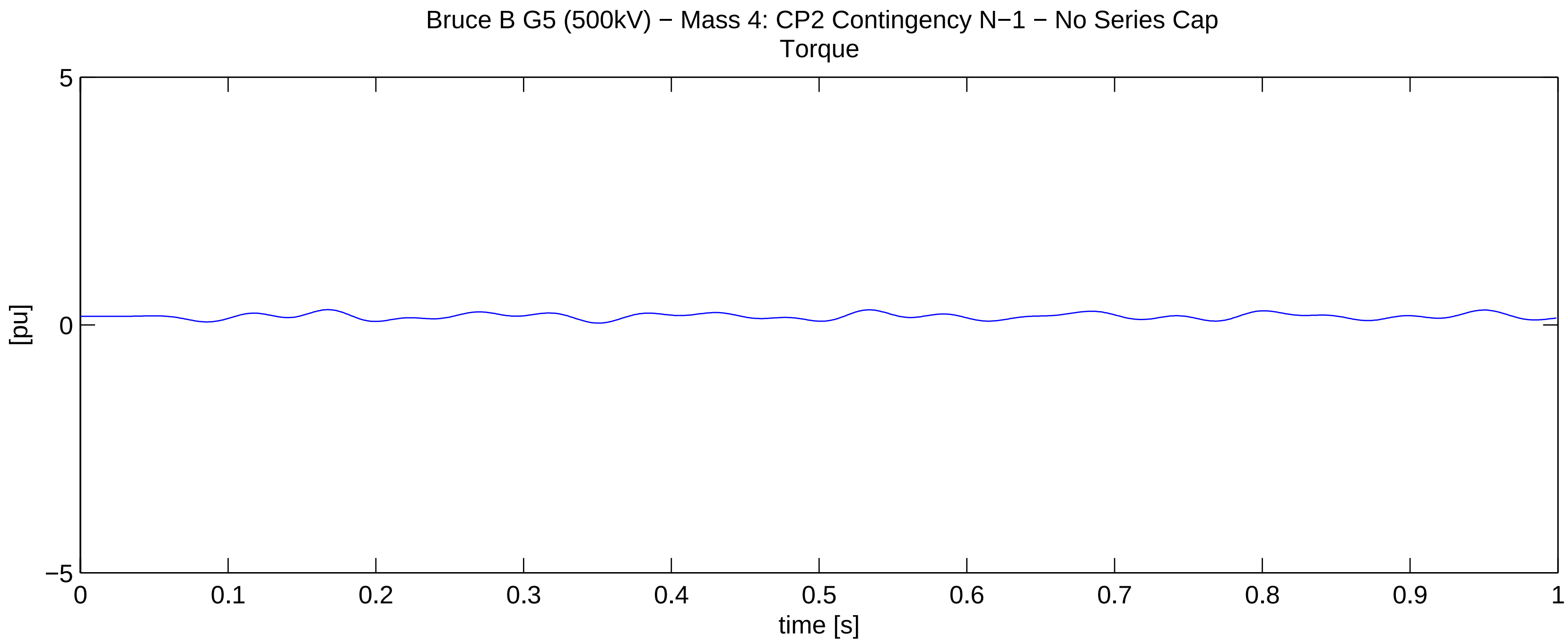
Bruce B G5 (500kV) − Mass 3: IP Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



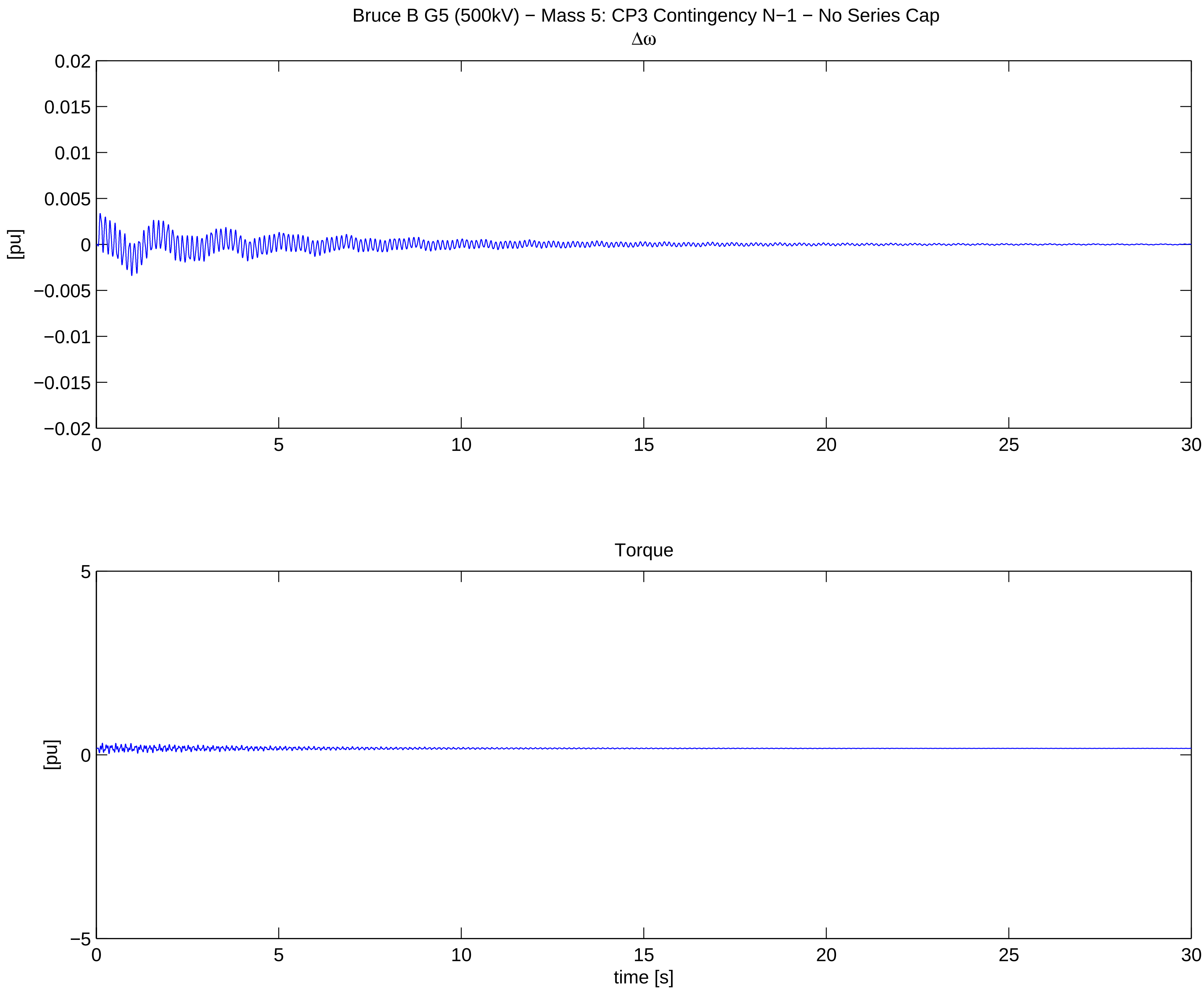
Bruce B G5 (500kV) − Mass 3: IP Contingency N−1 − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



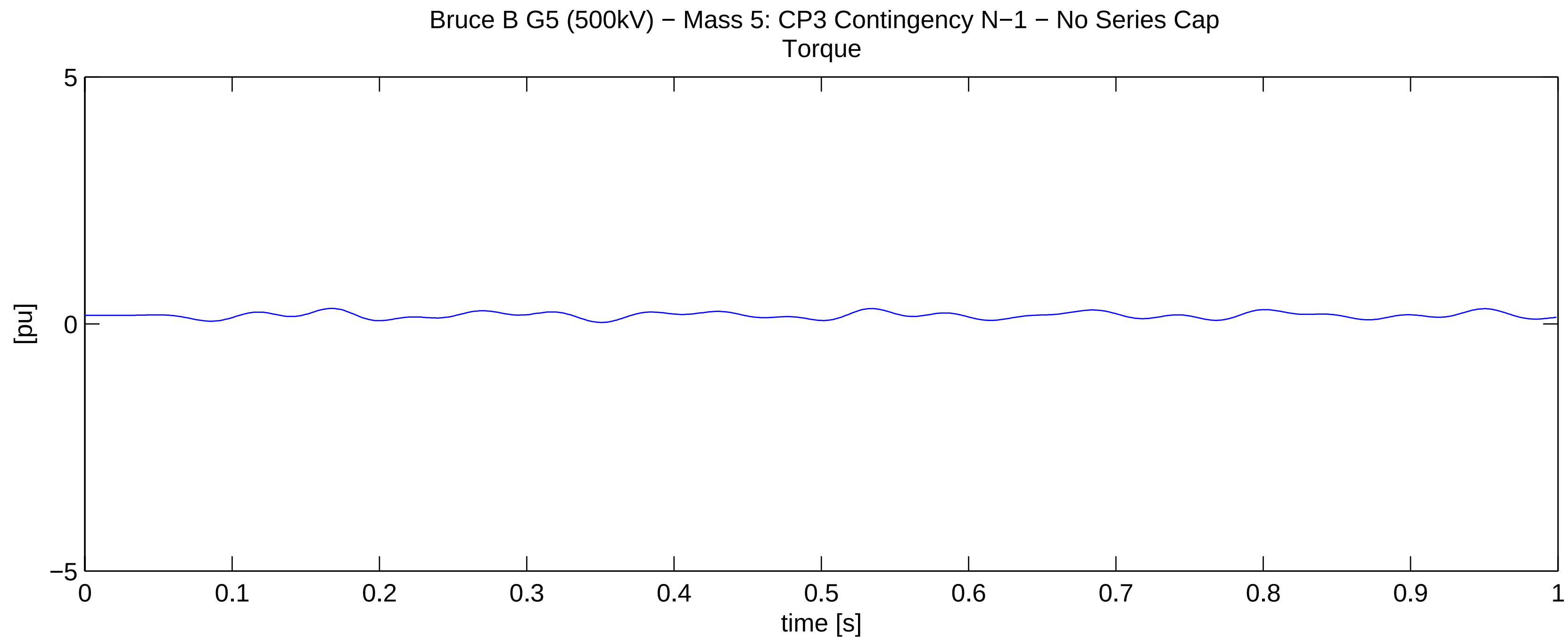
Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

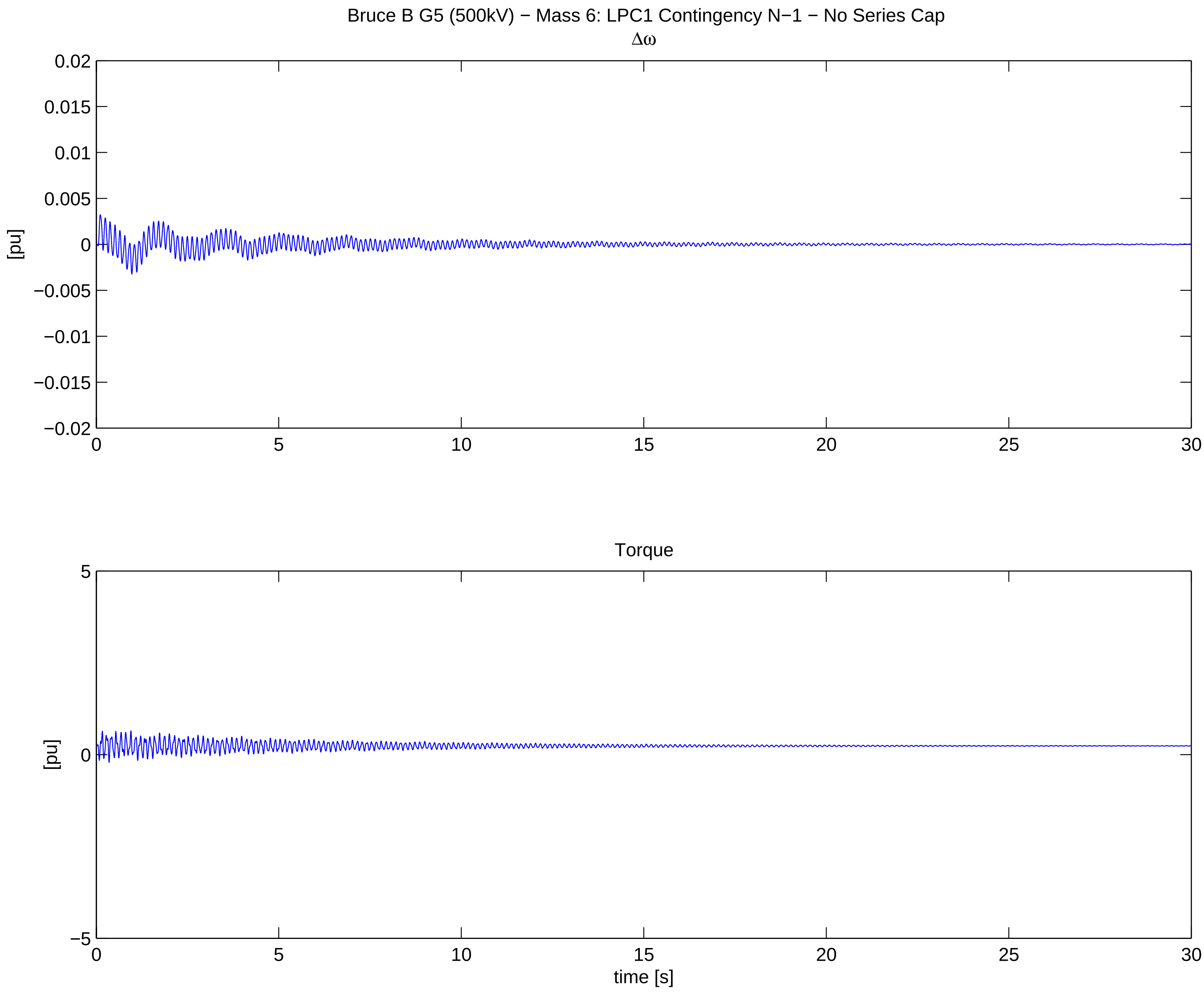


Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

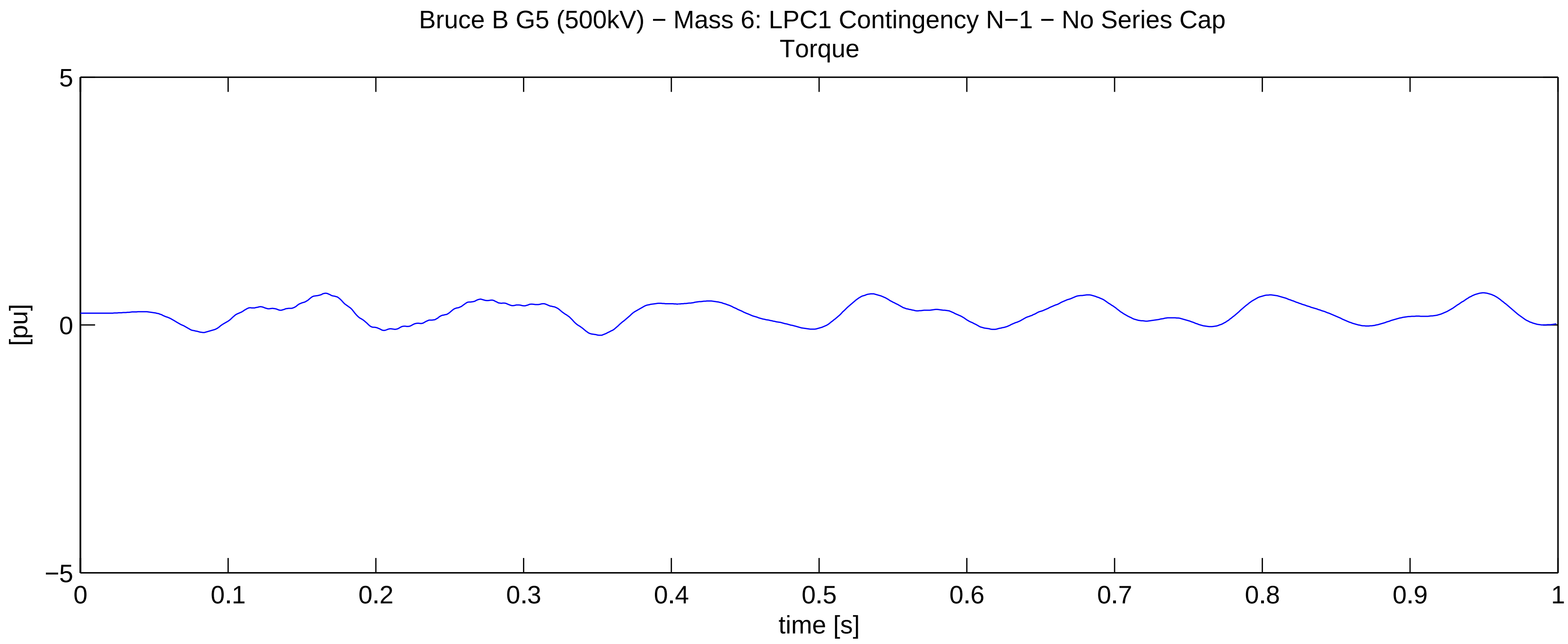


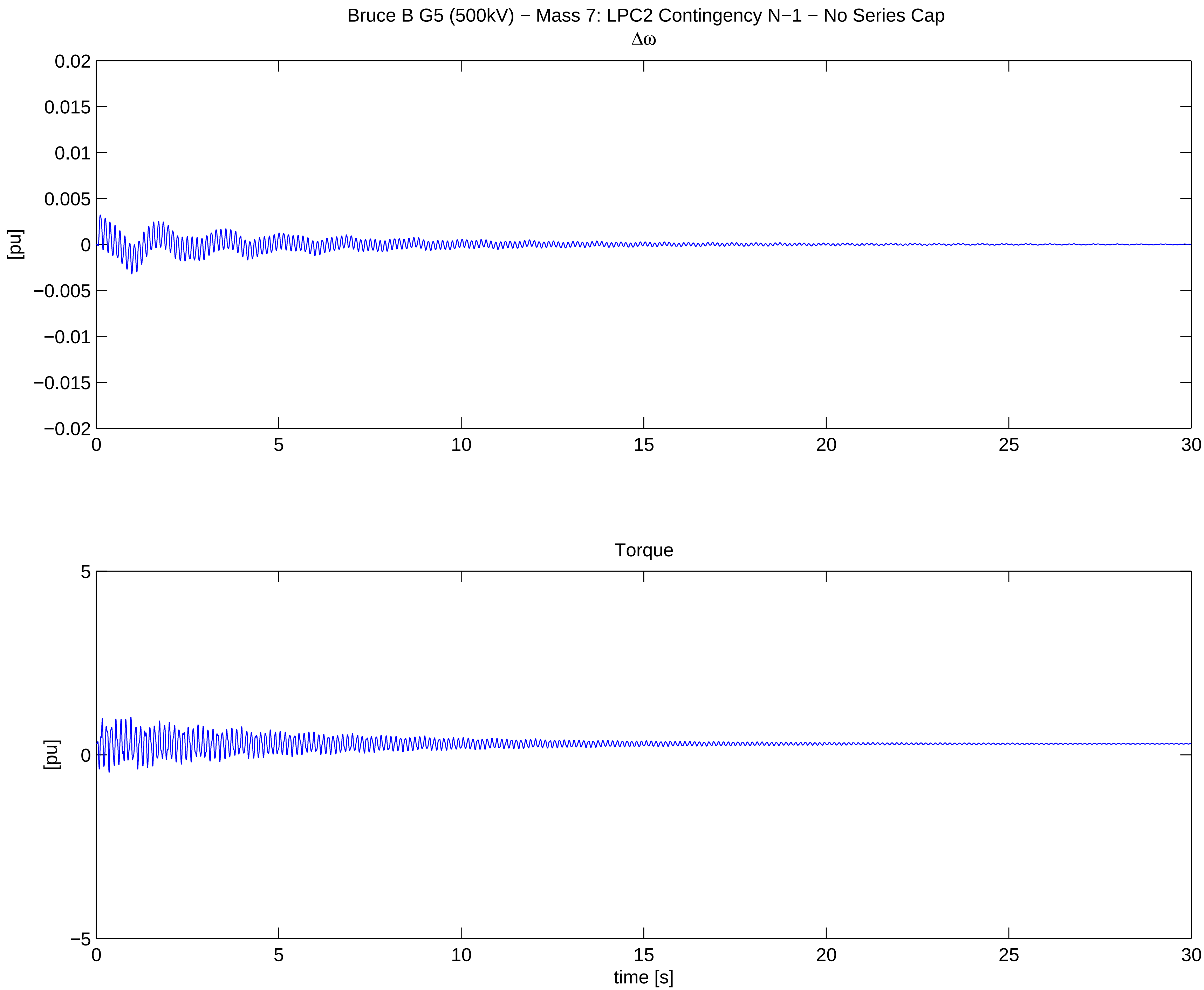
Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

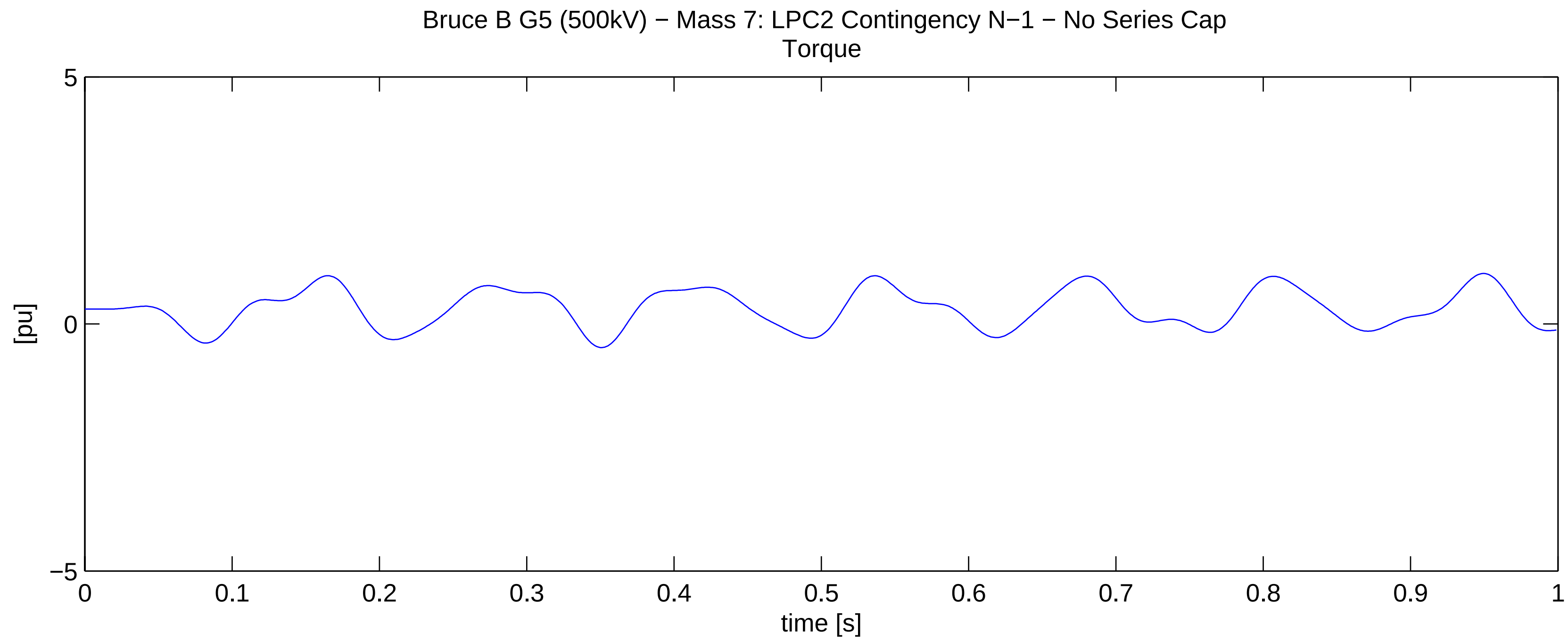


Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

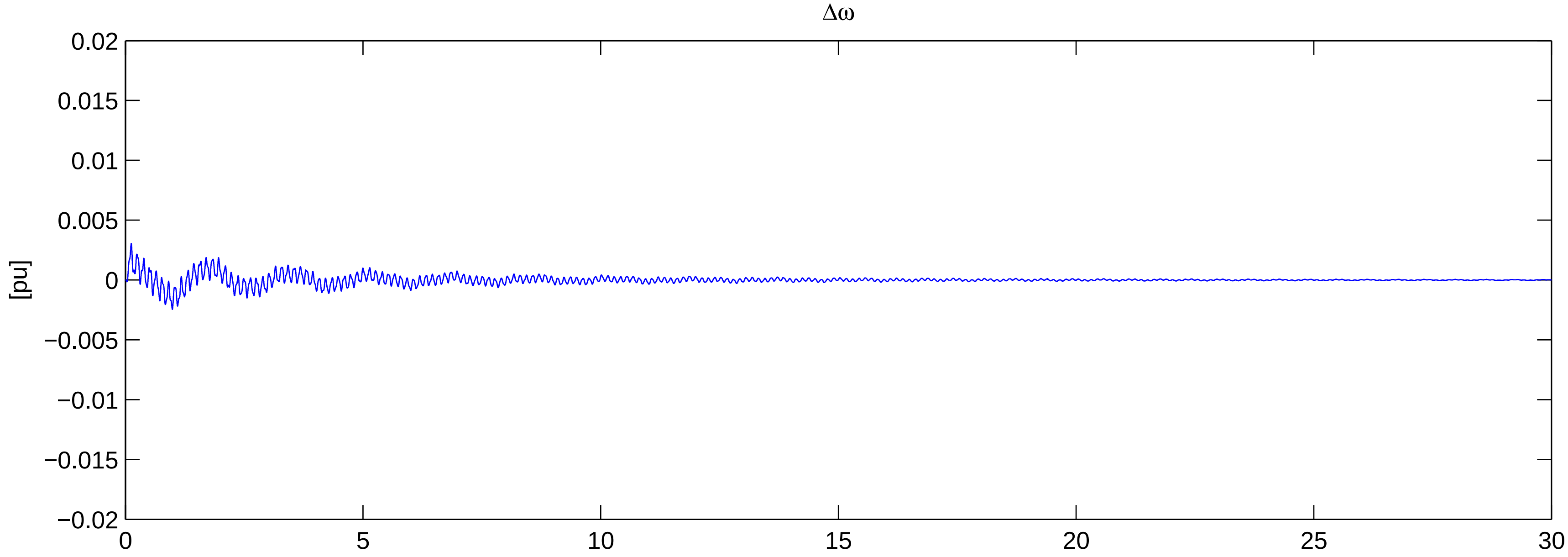

Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

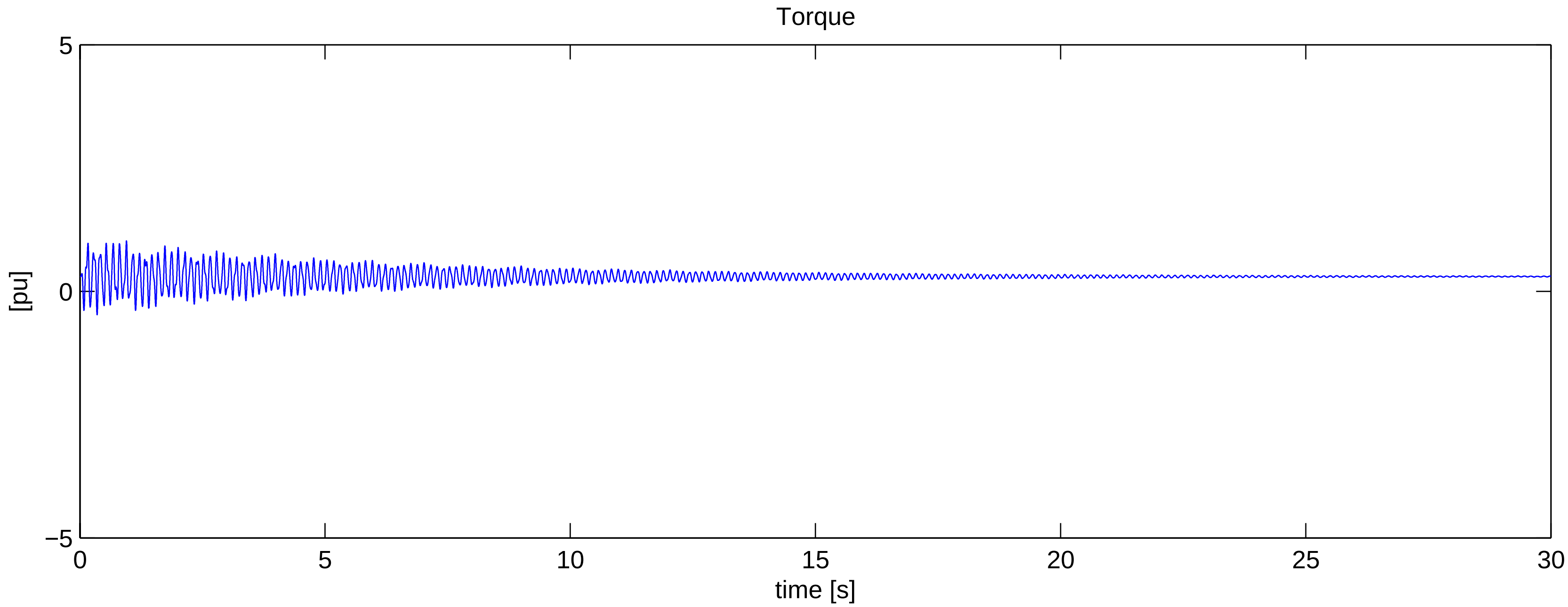


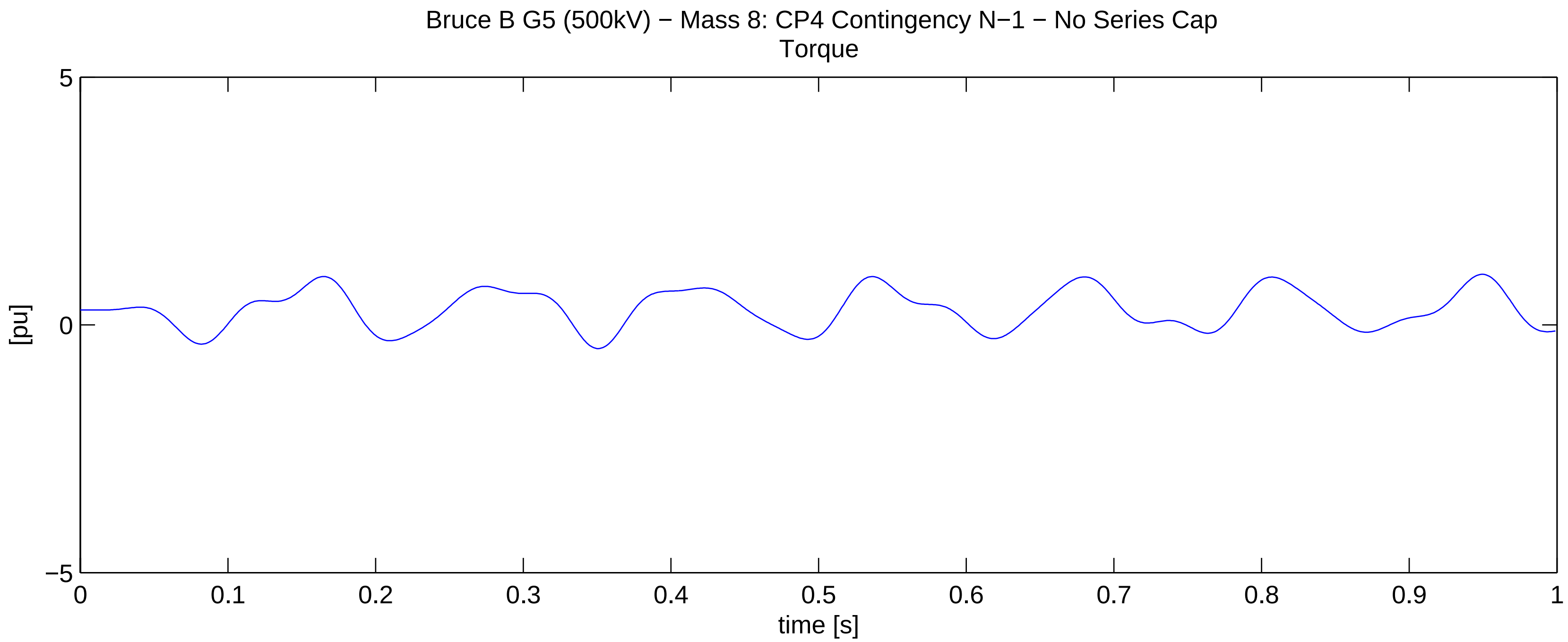
Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

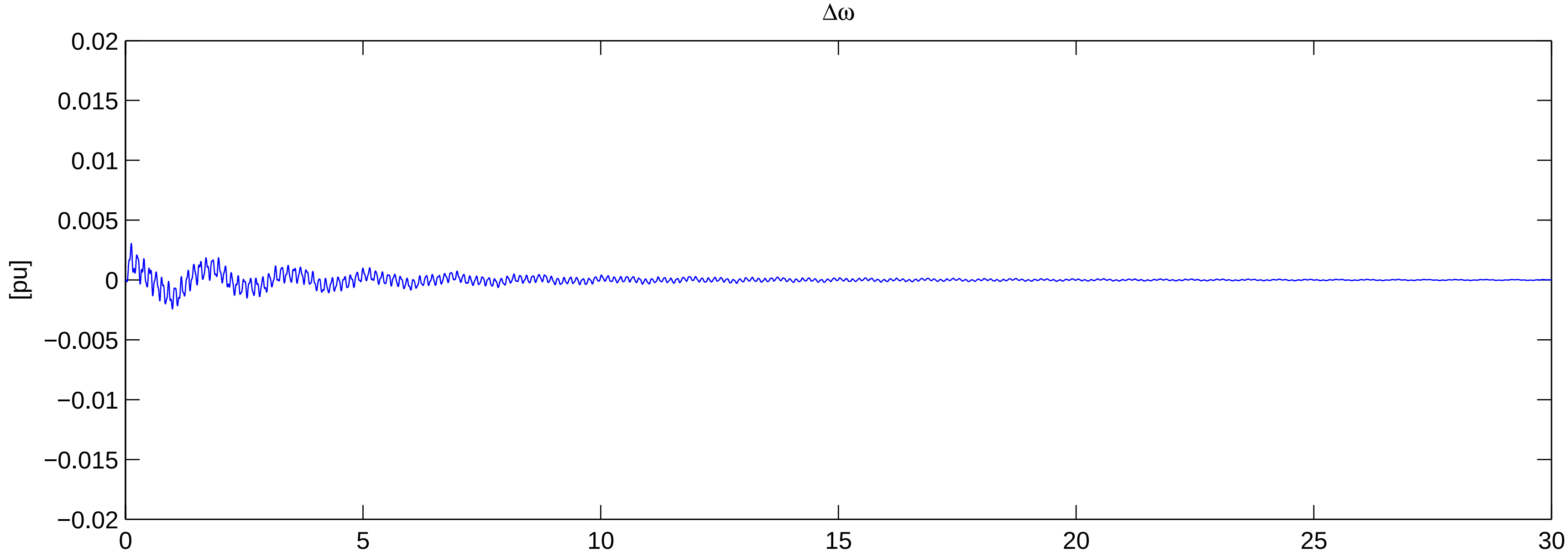
Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−1 − No Series Cap

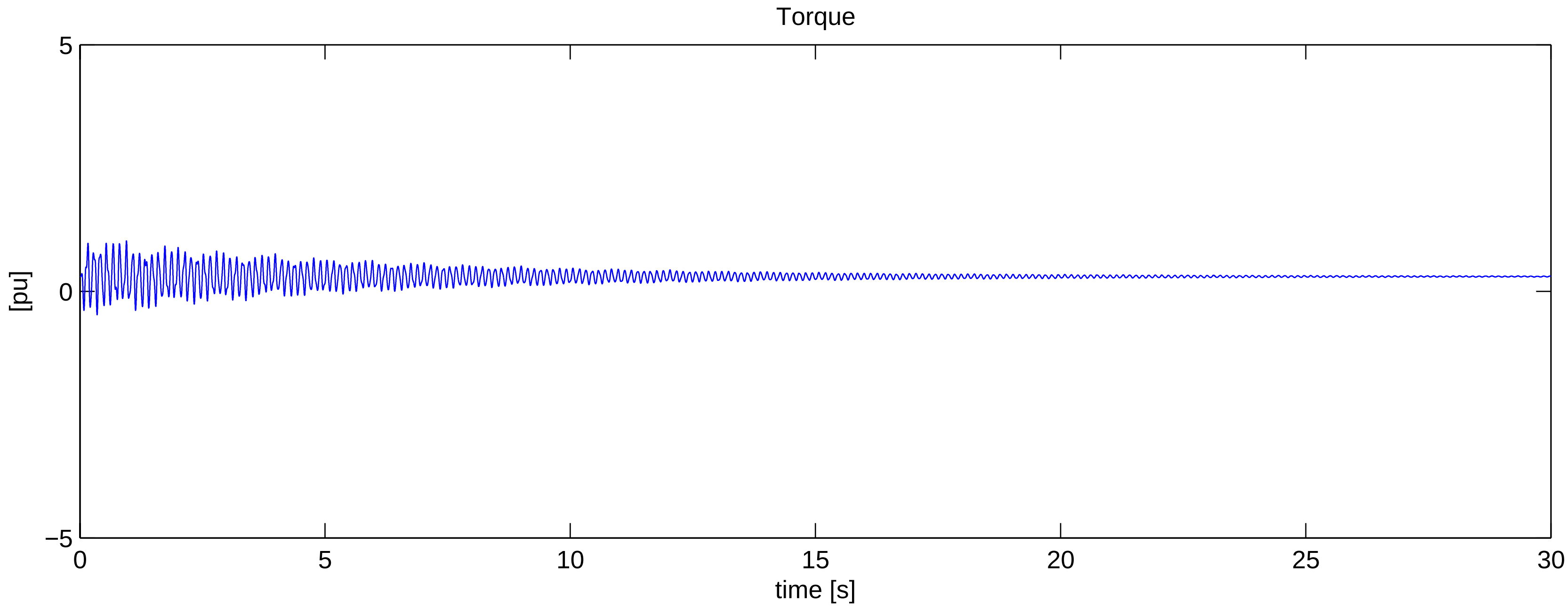


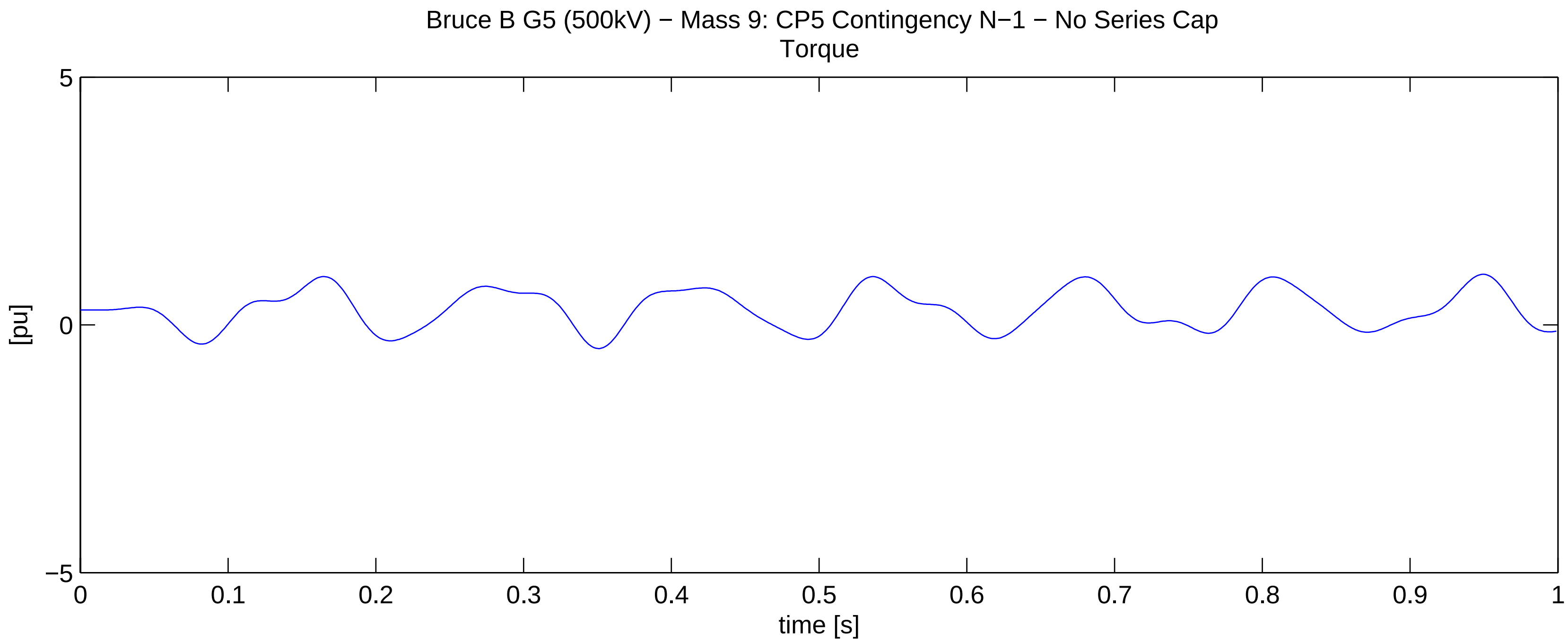


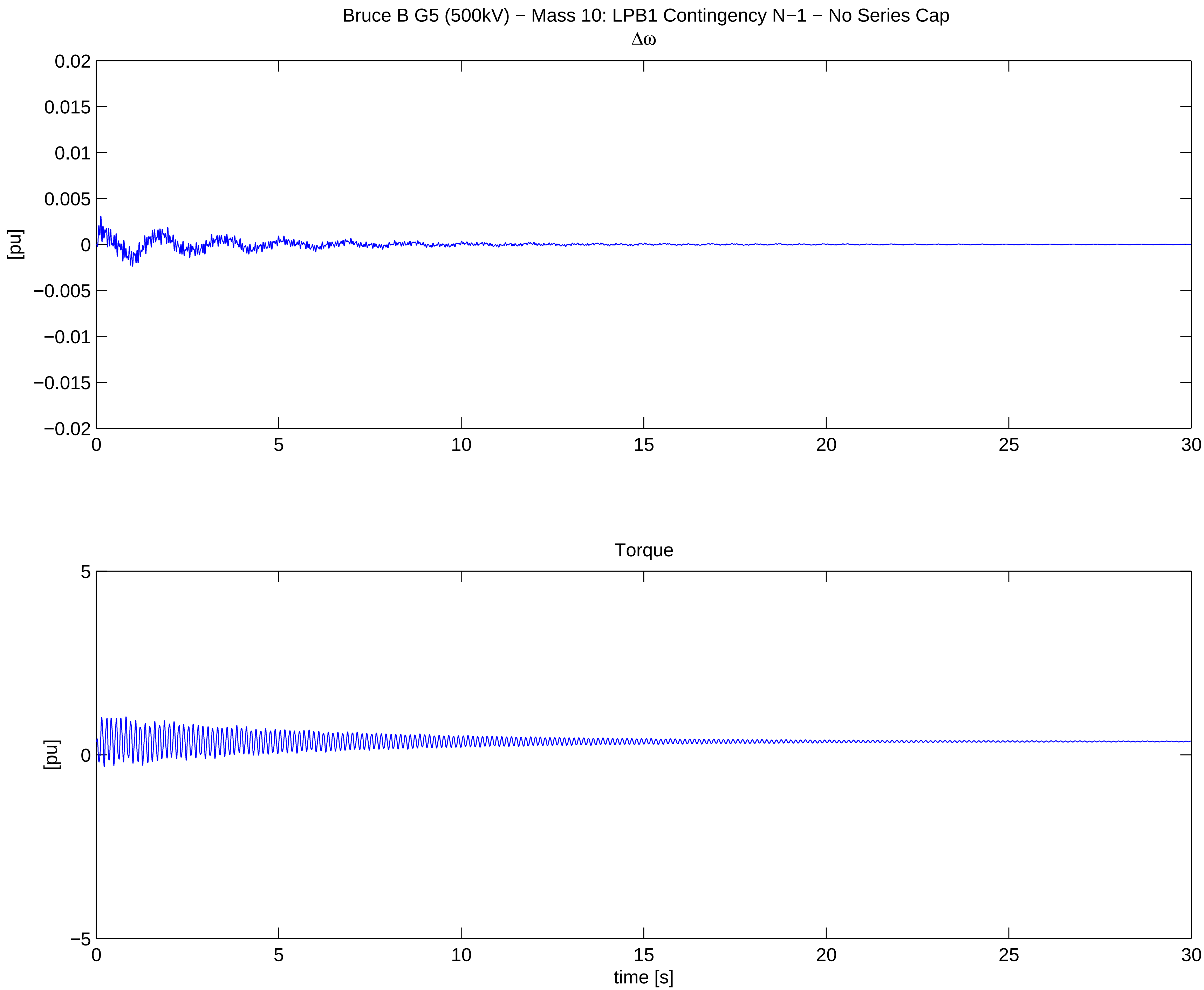

Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

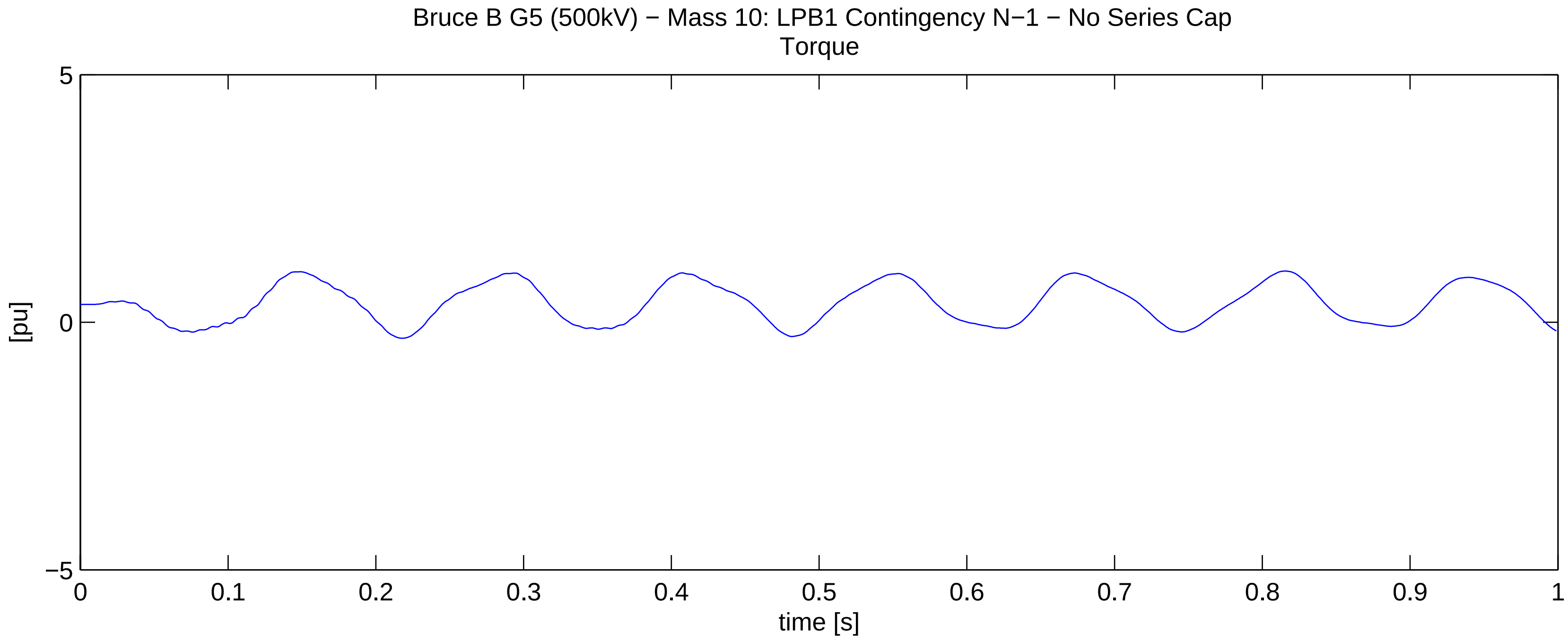
Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−1 − No Series Cap



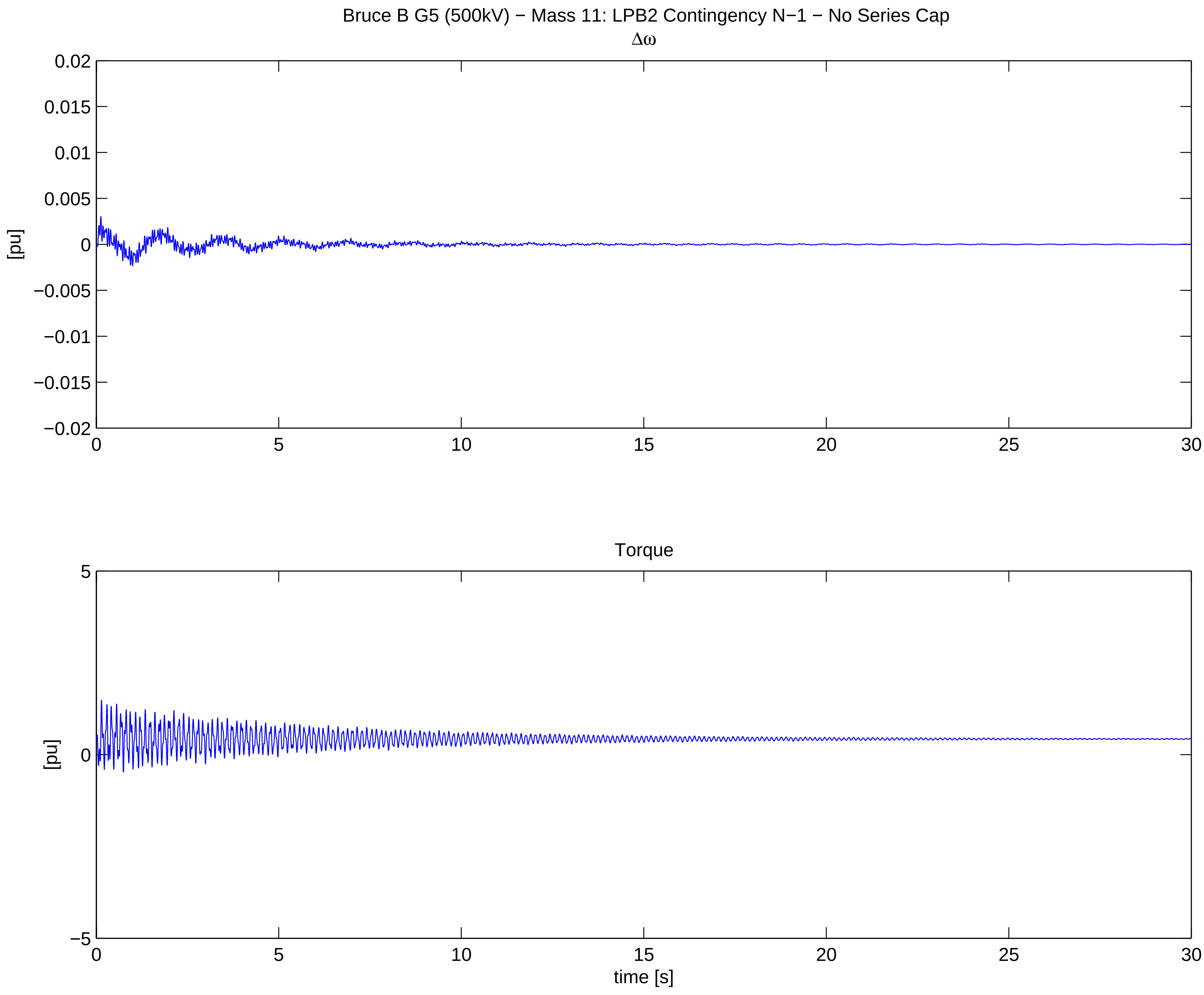



Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

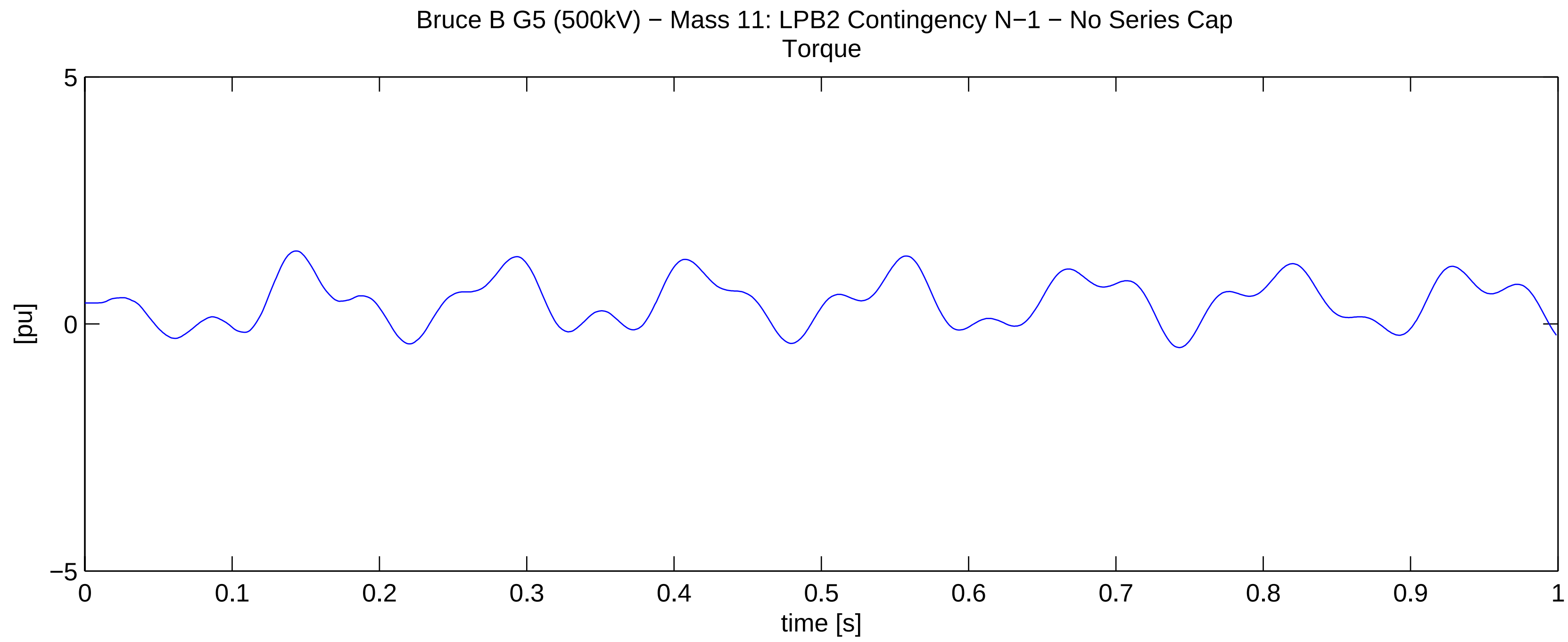

Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



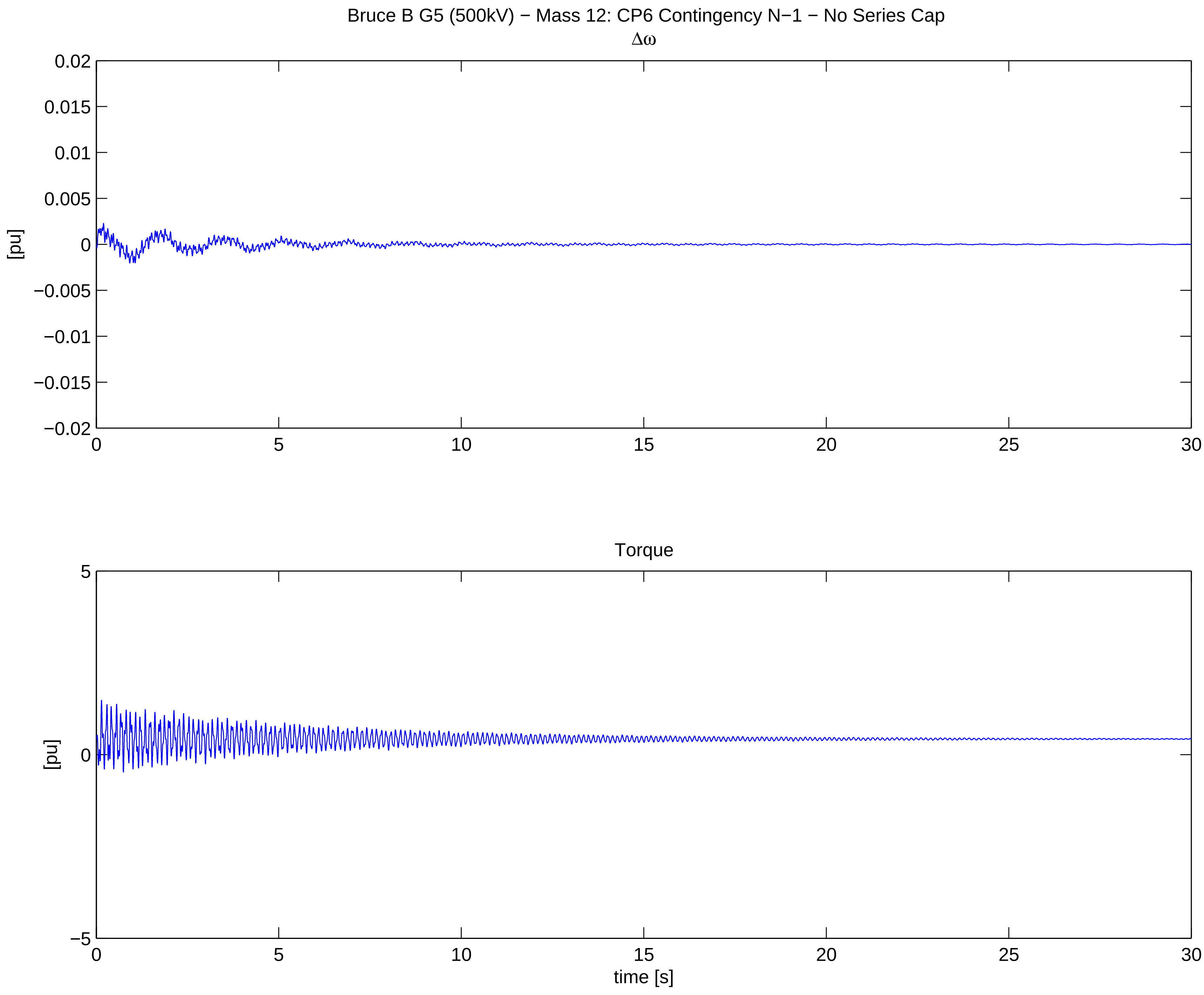
Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

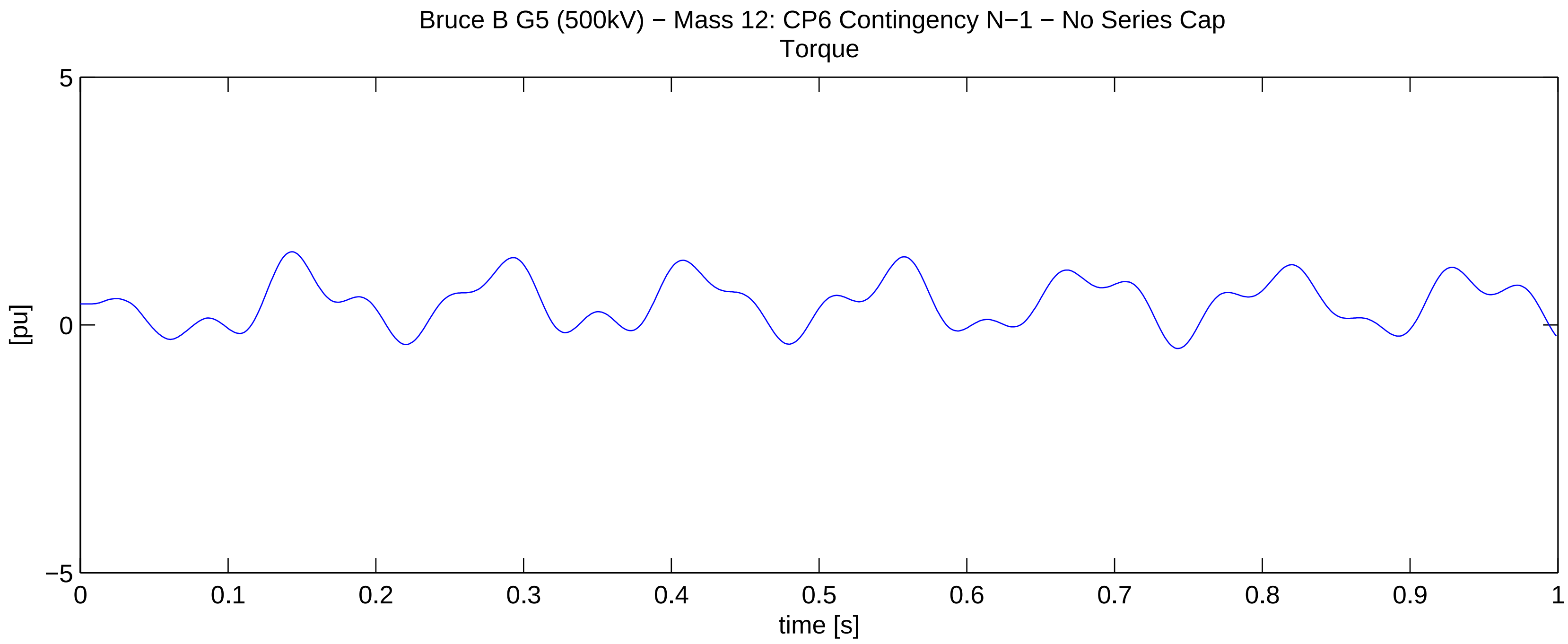


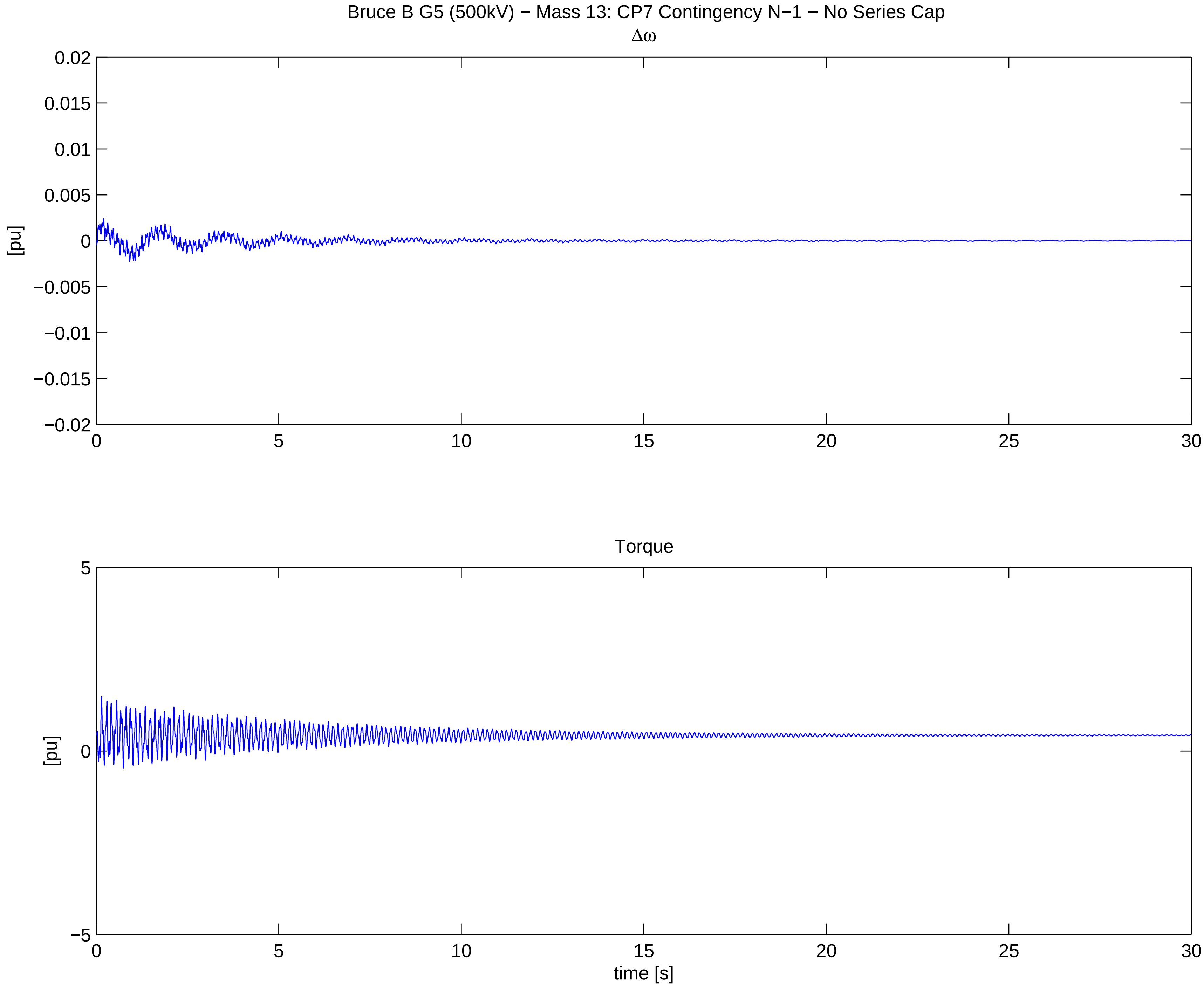
Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



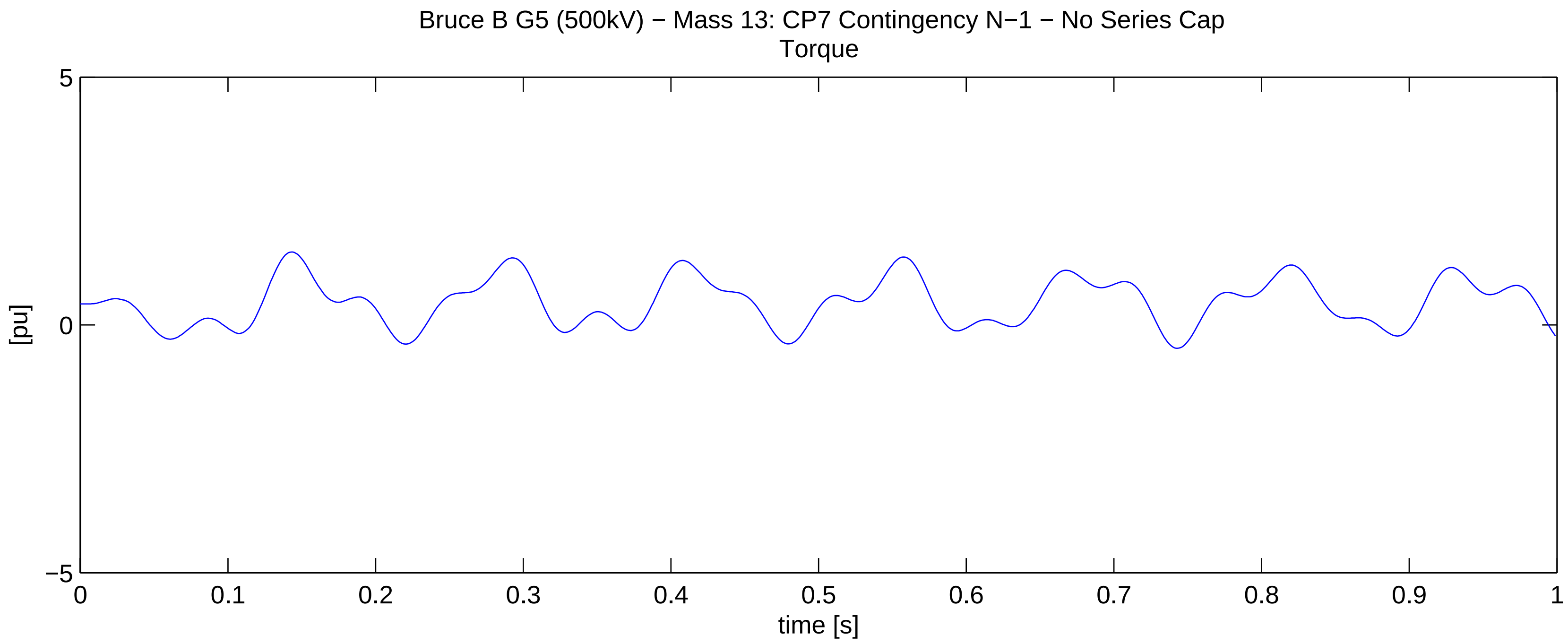
Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

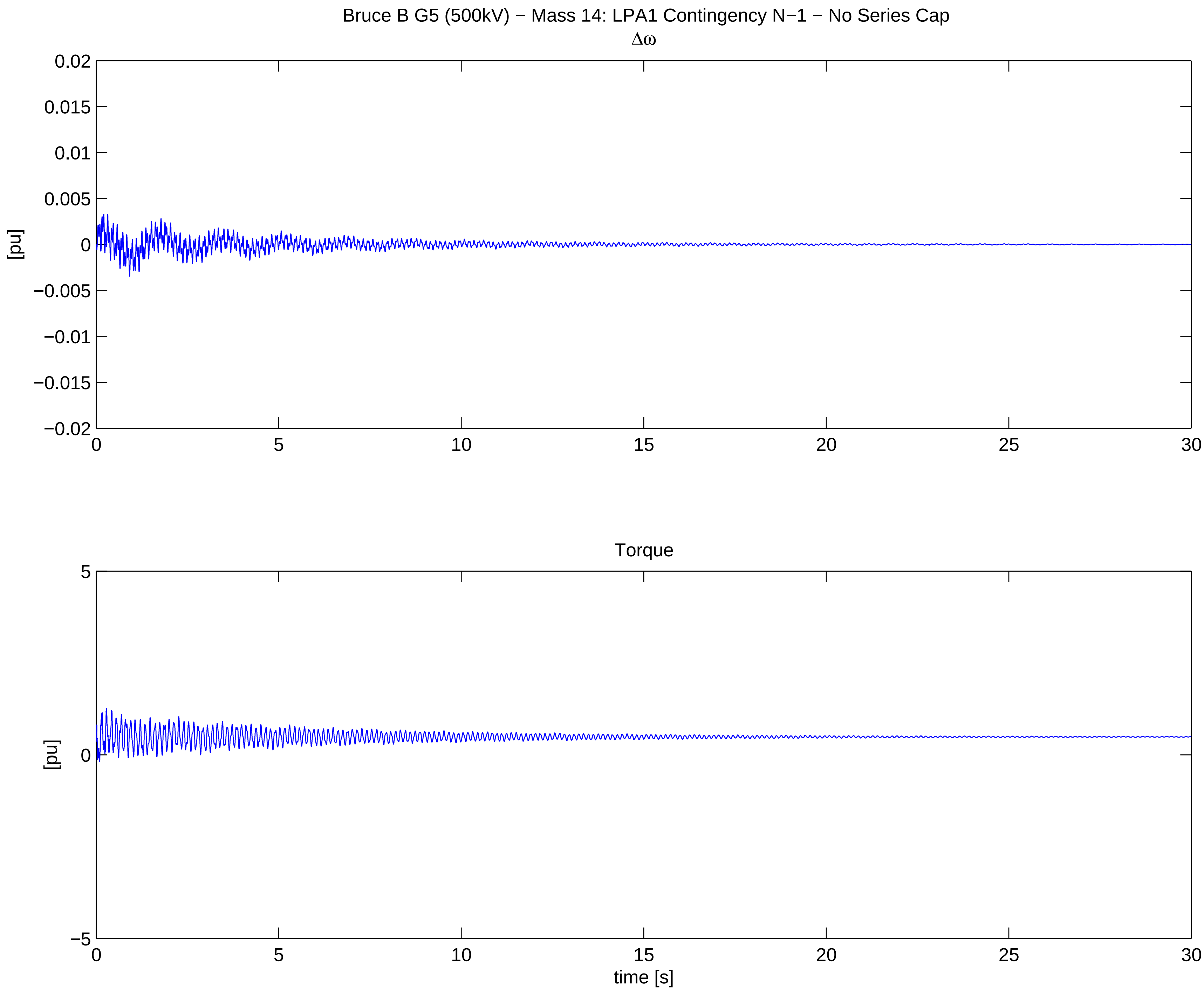

Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

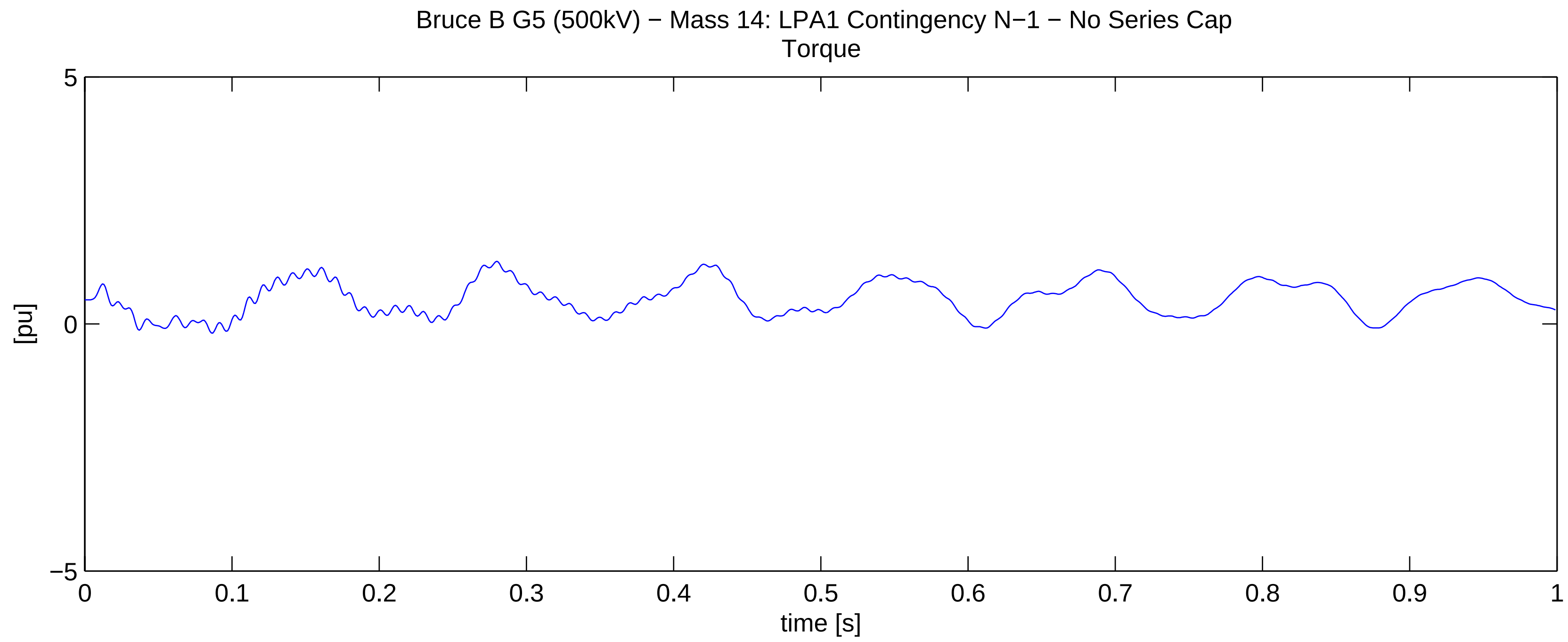


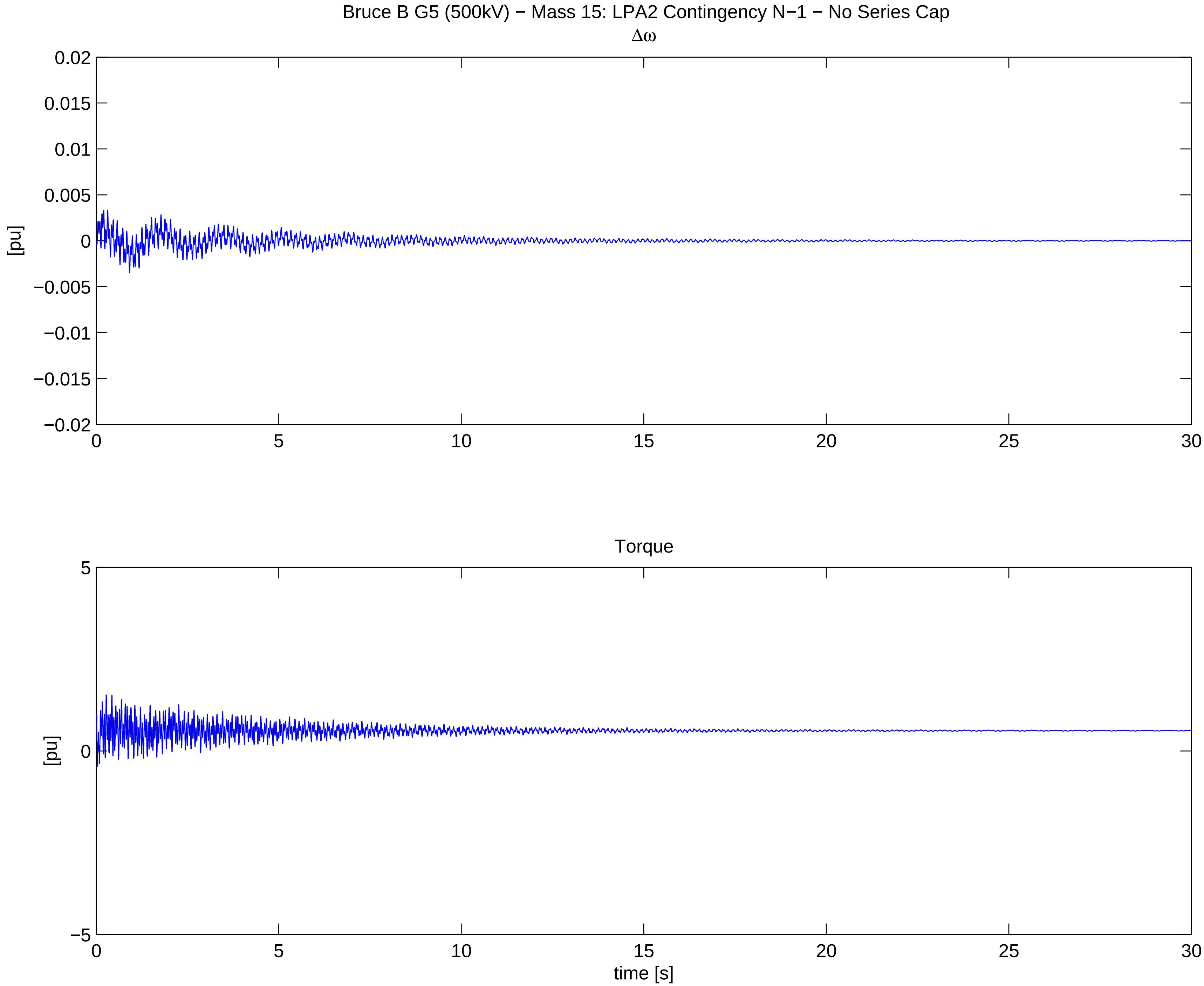
Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

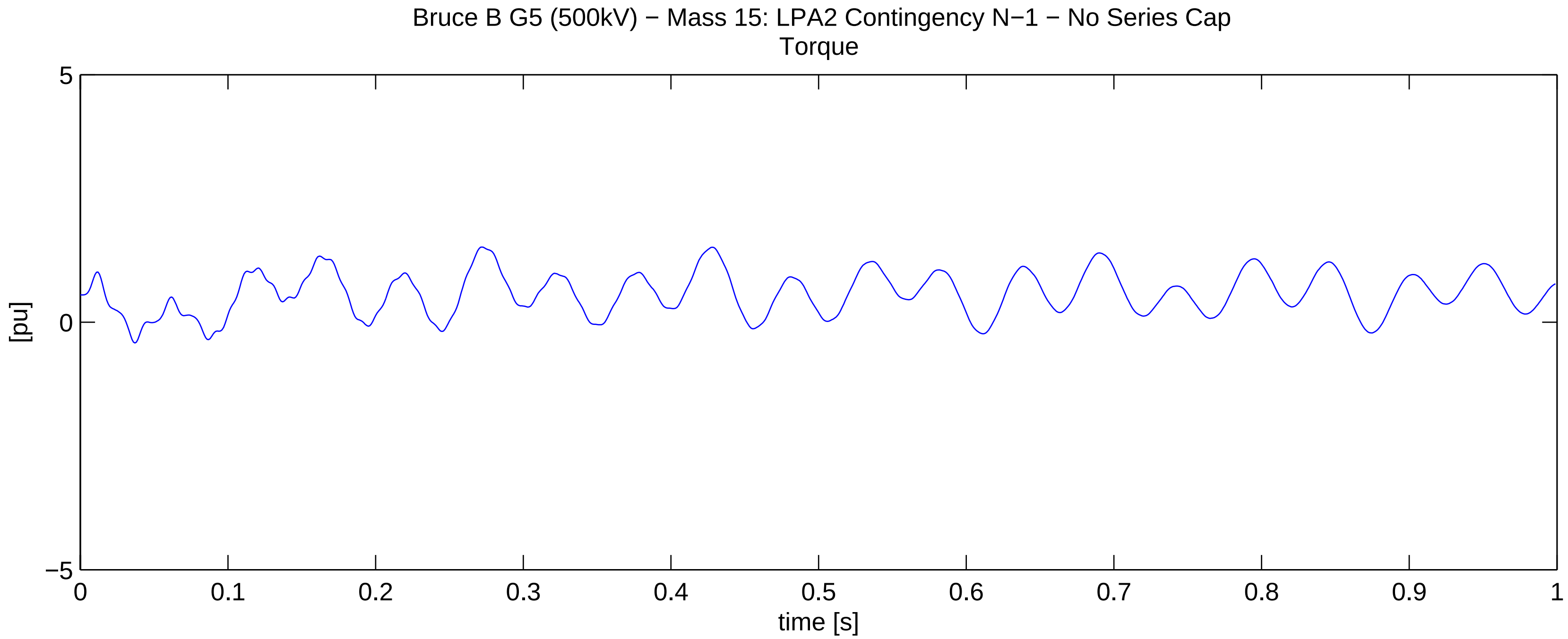

Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



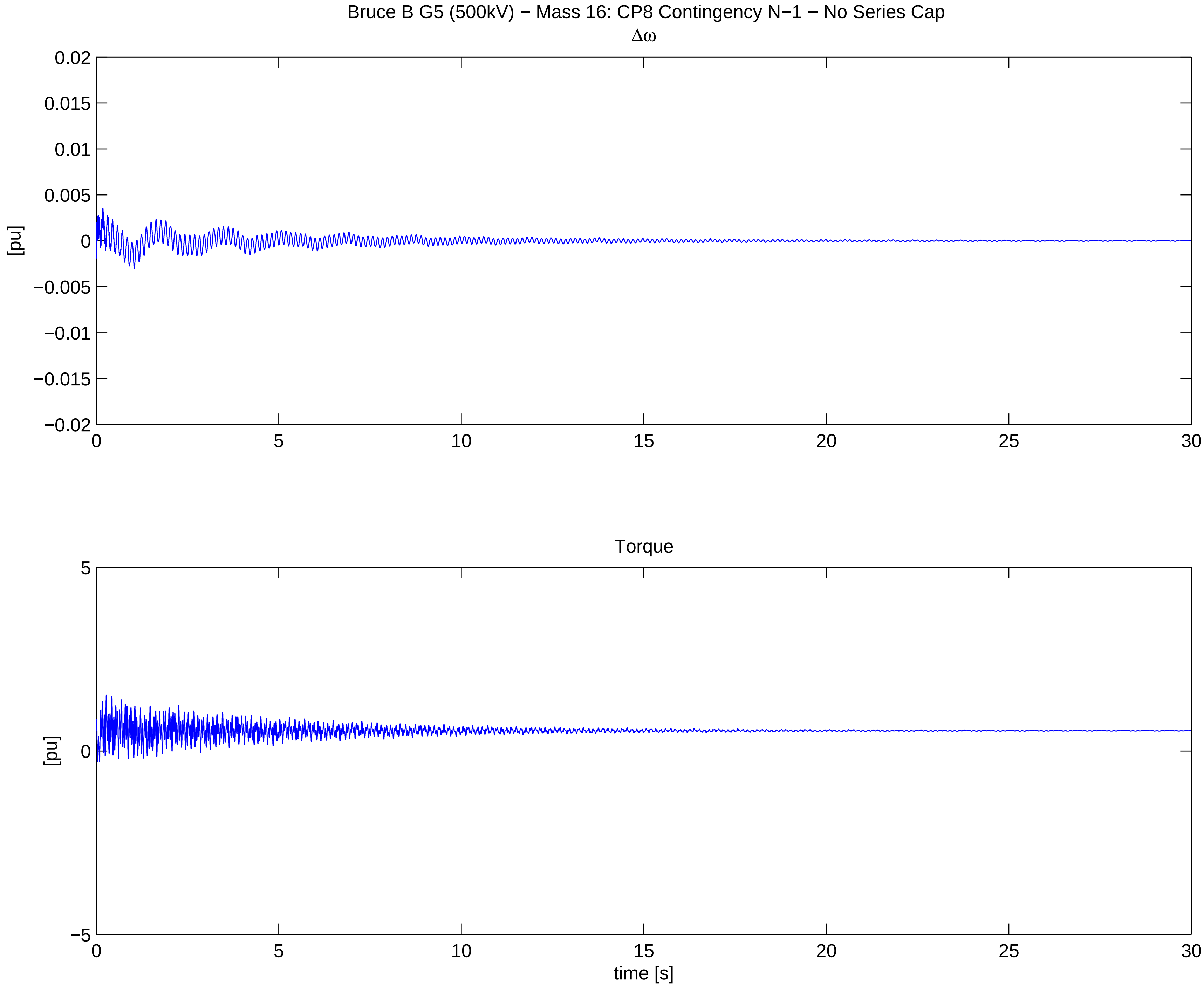
Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

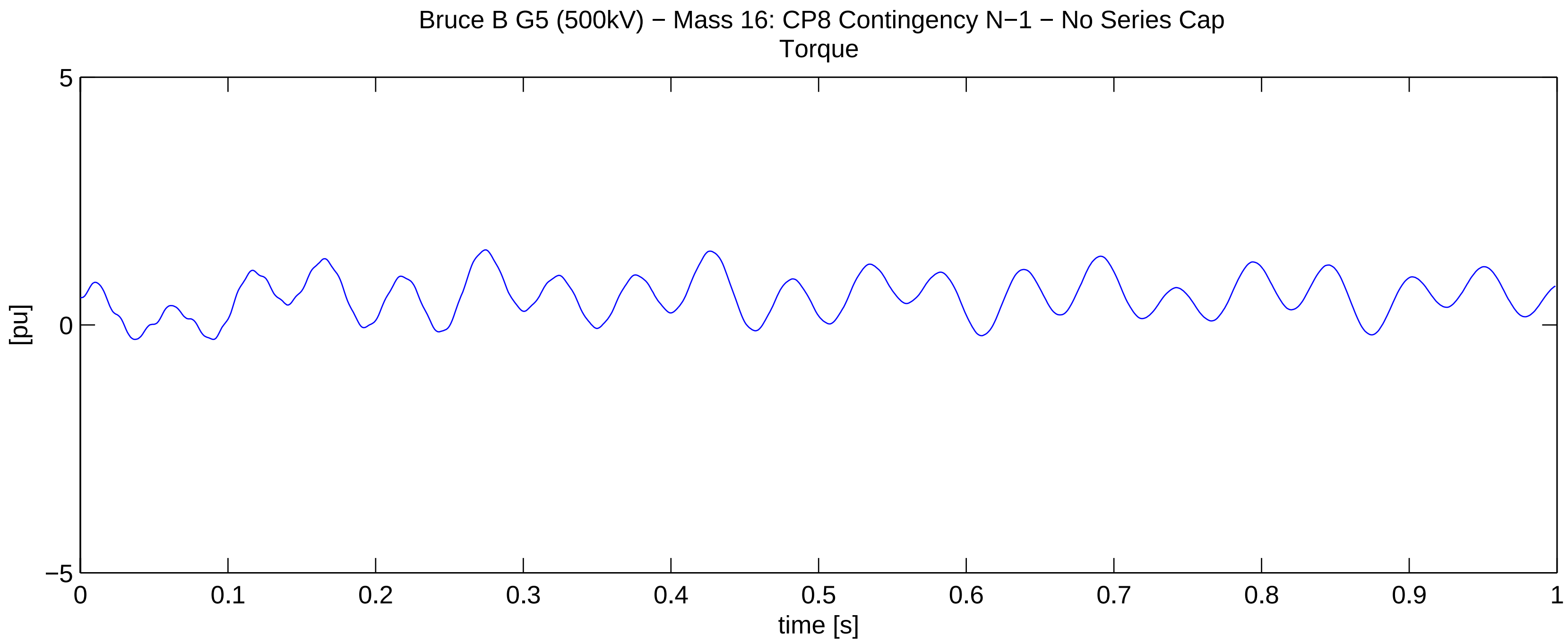

Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

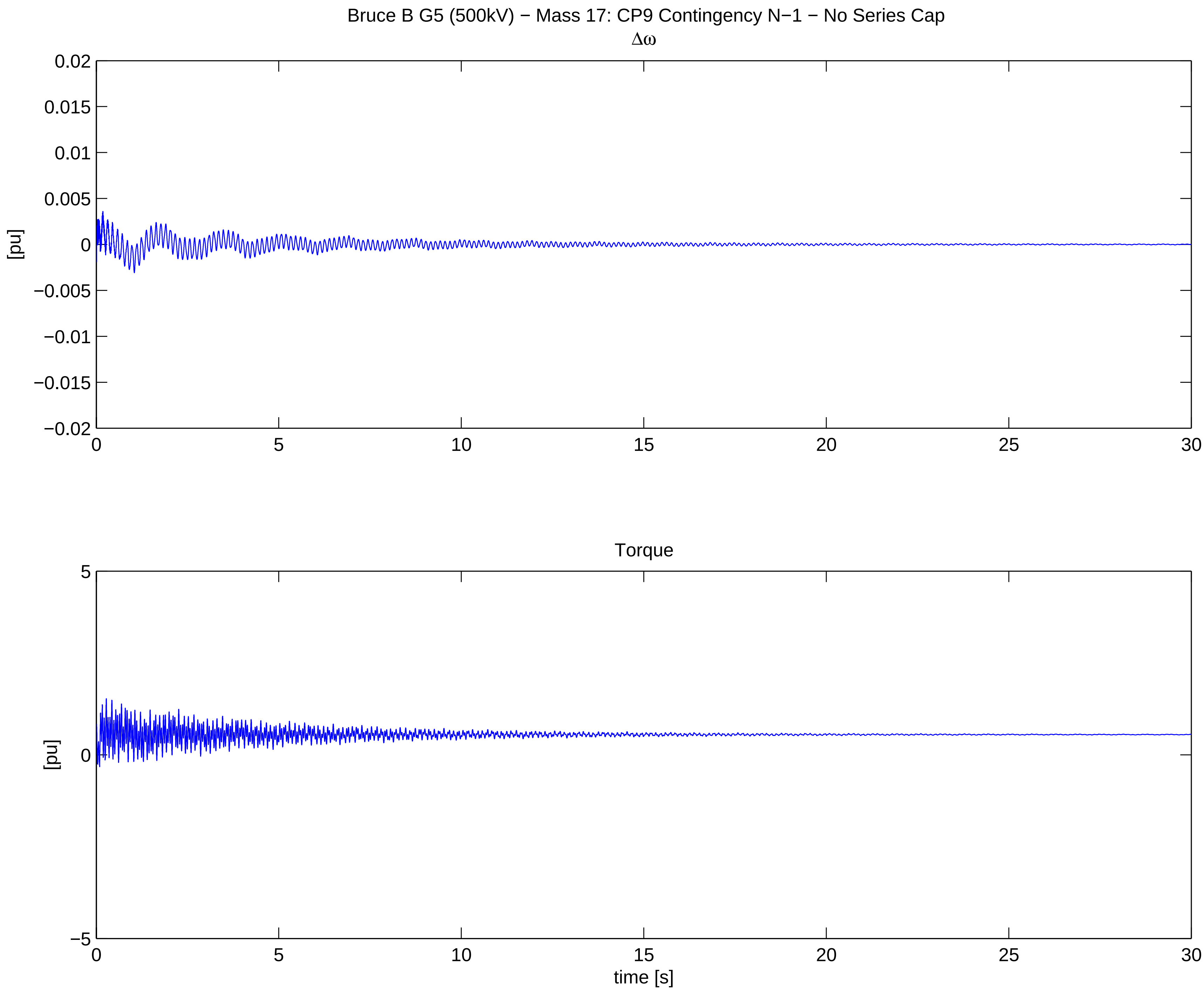


Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

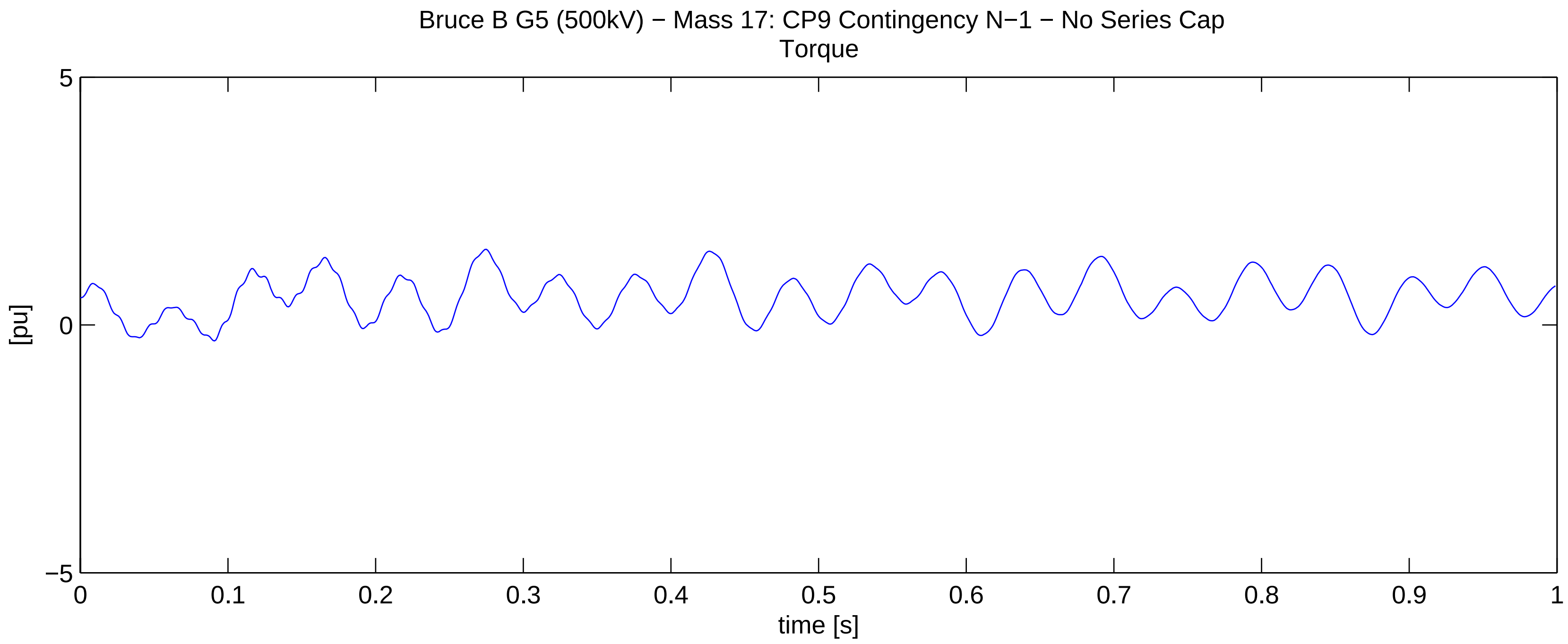


Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

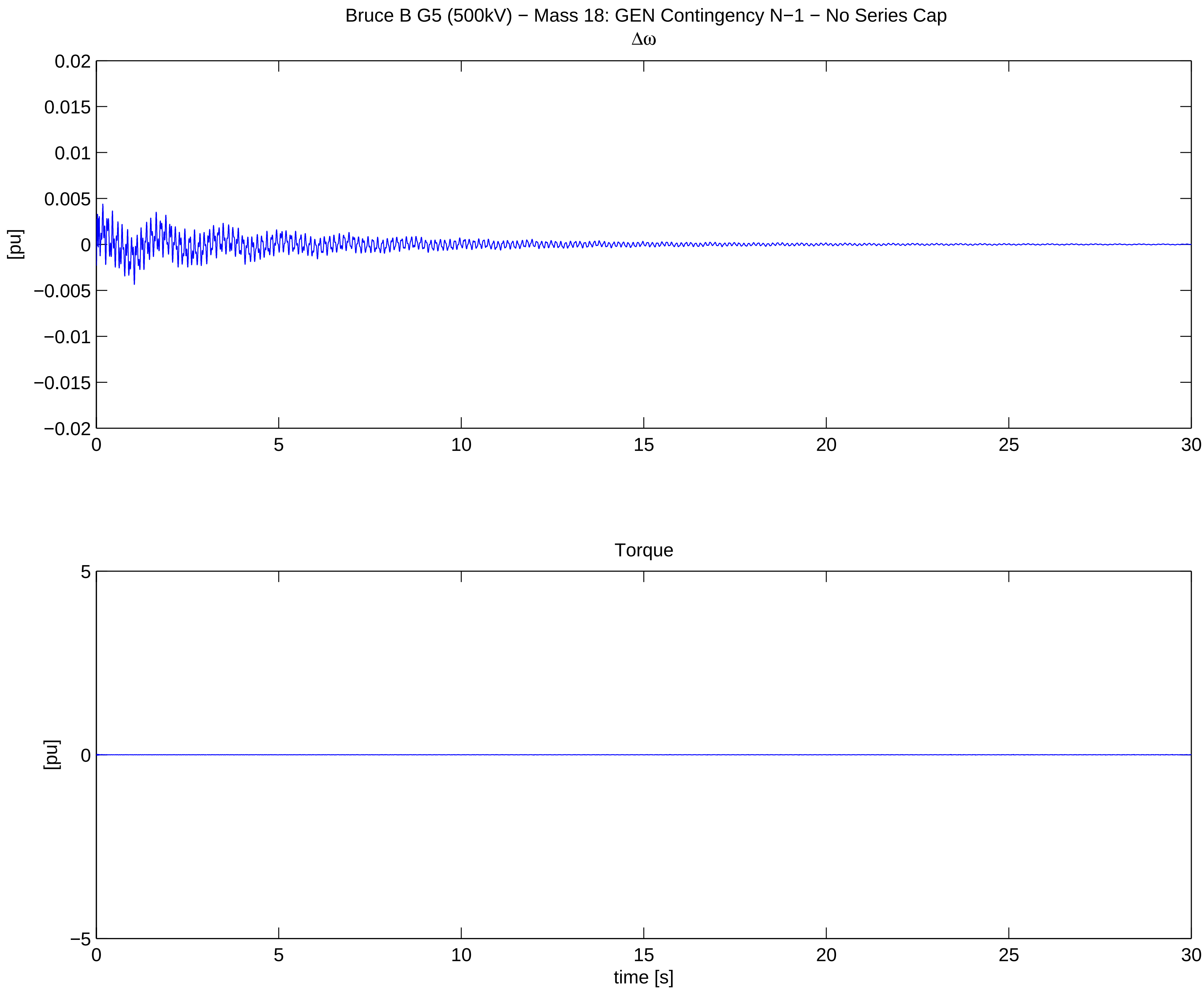

Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

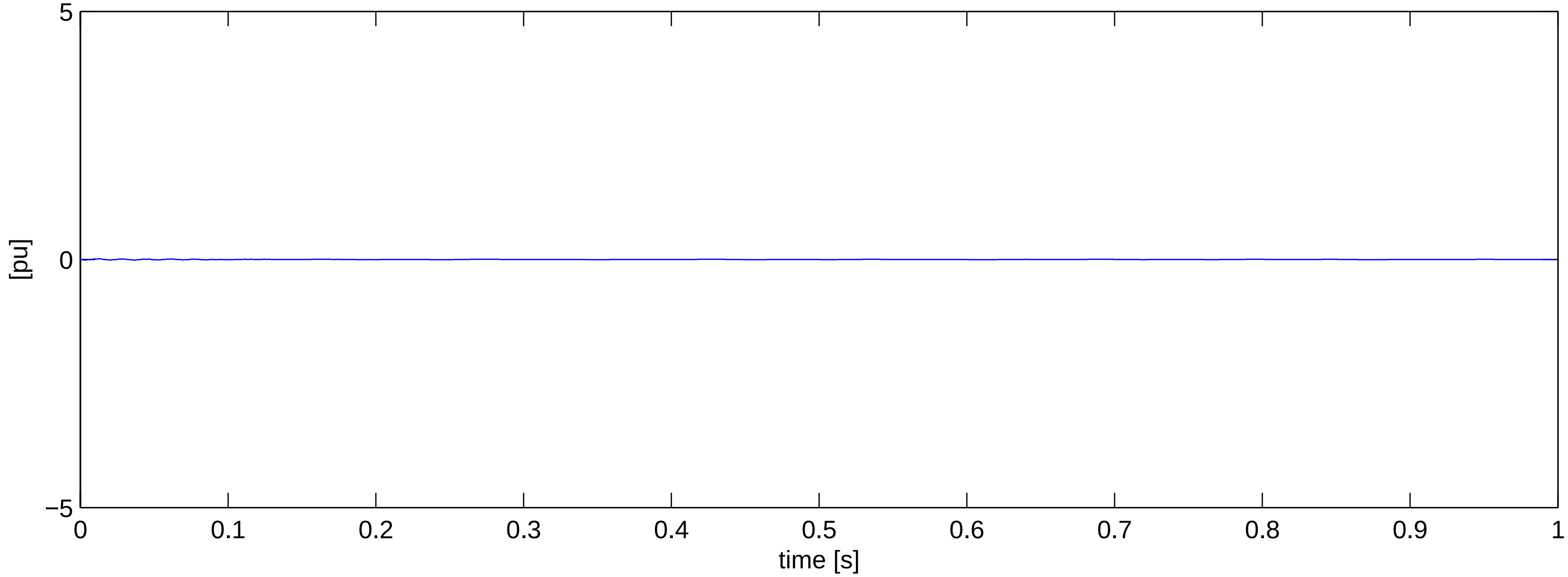


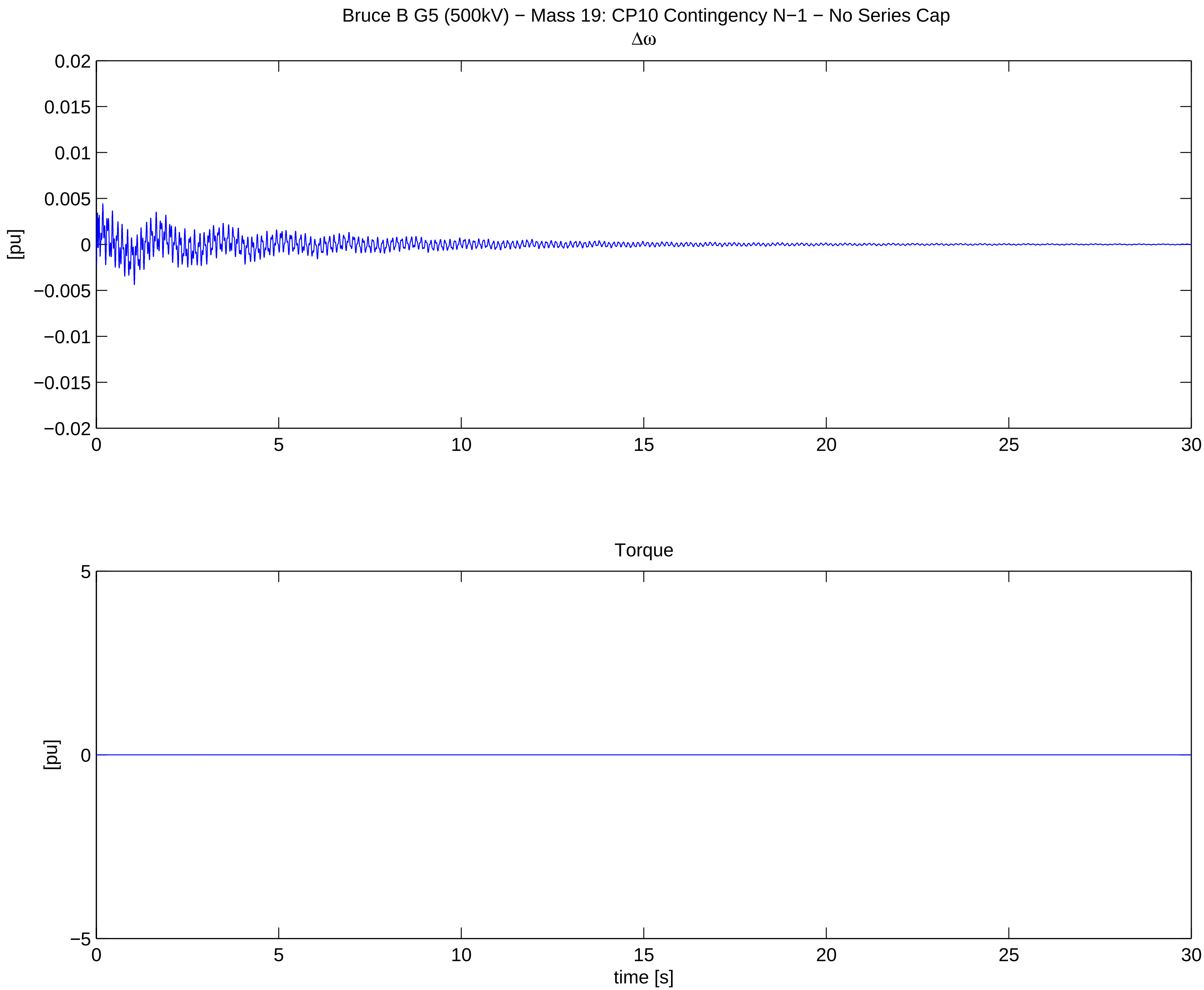
Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−1 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

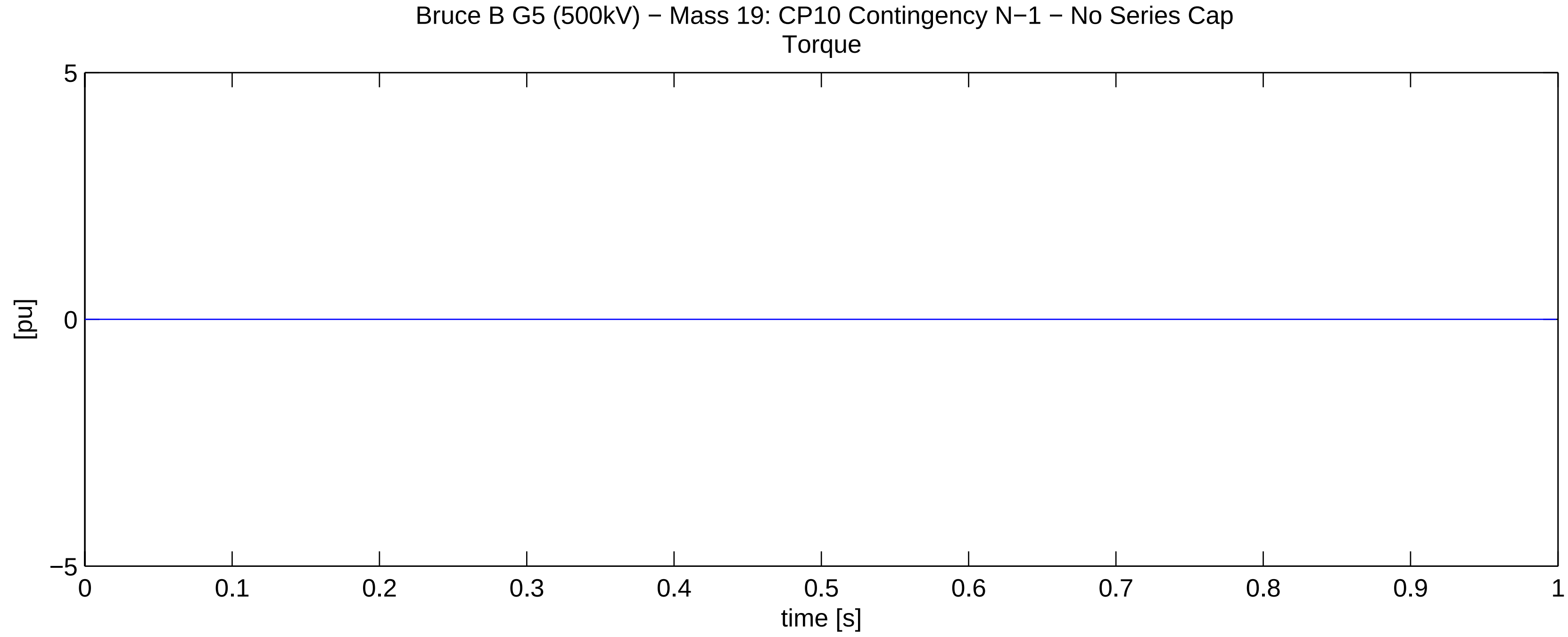


Bruce B G5 (500kV) − Mass 18: GEN Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

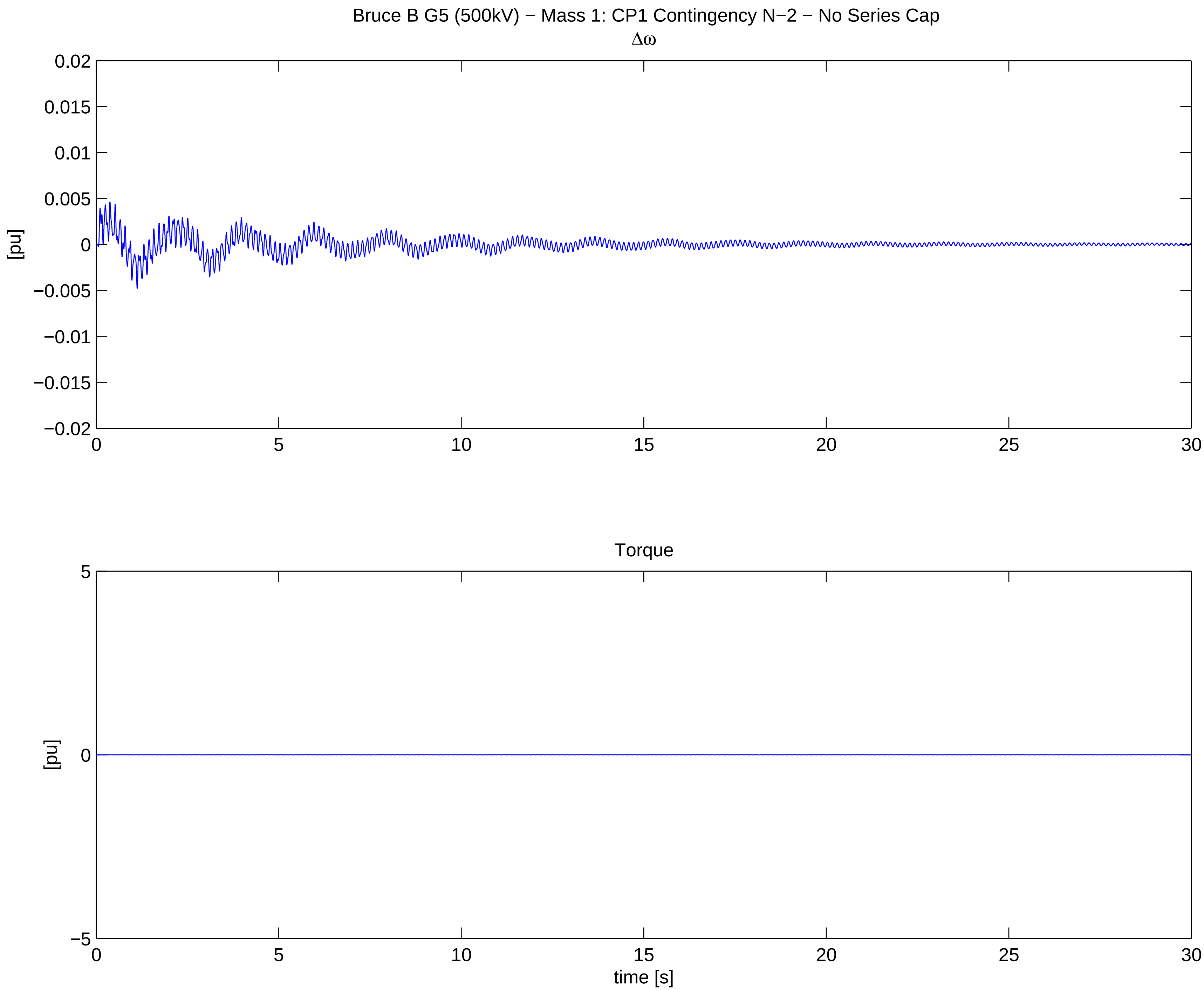
Bruce B G5 (500kV) − Mass 18: GEN Contingency N−1 − No Series Cap
Torque

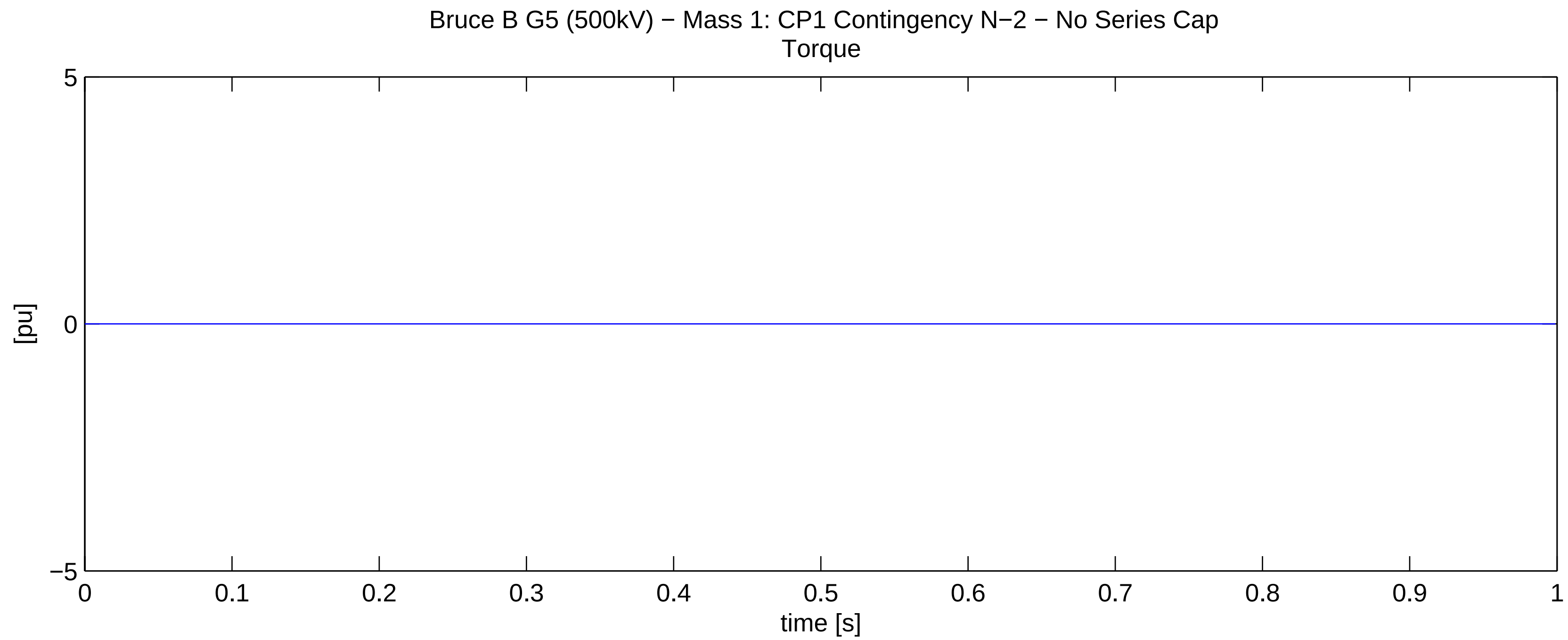



Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−1 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

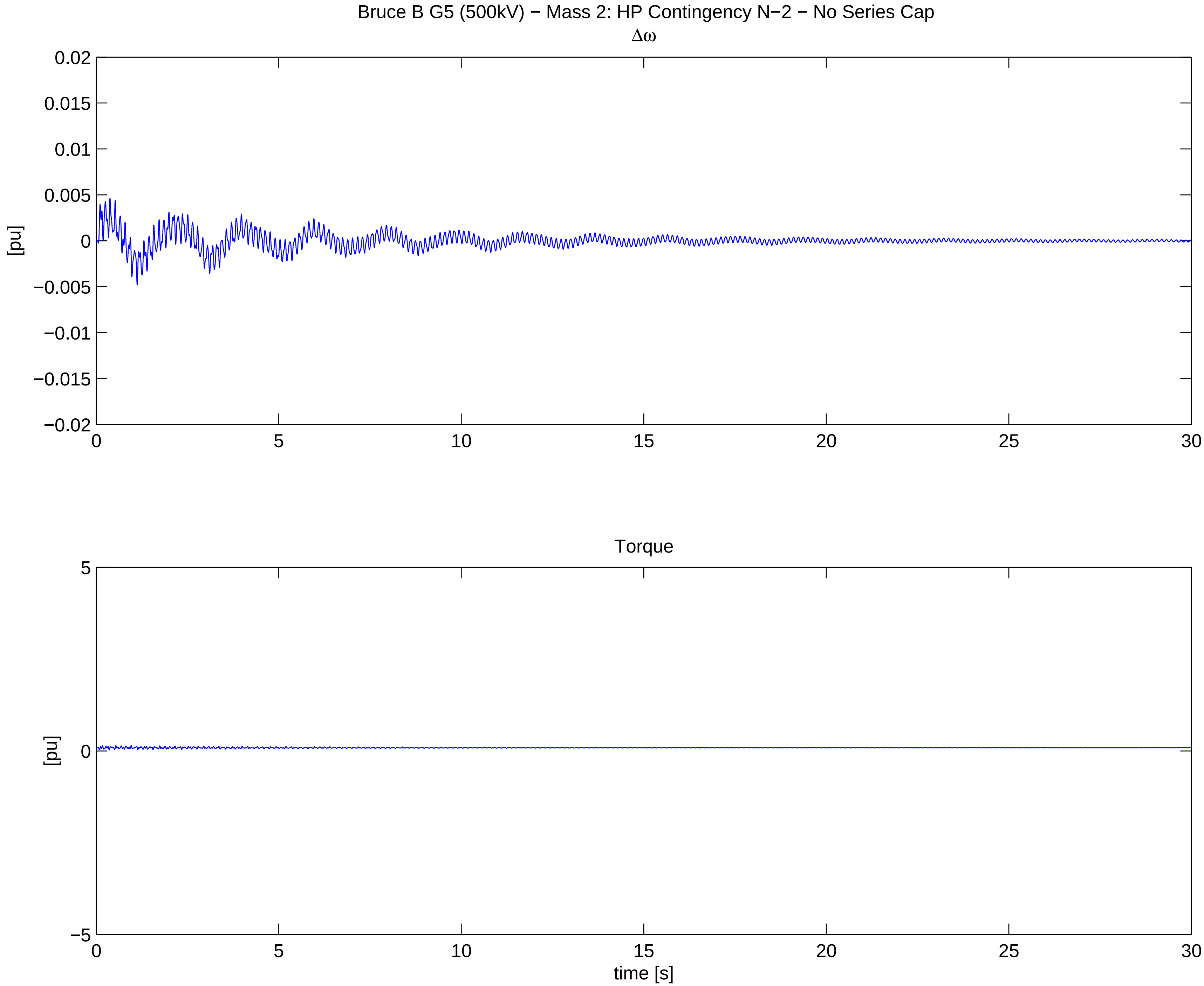


Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−1 − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

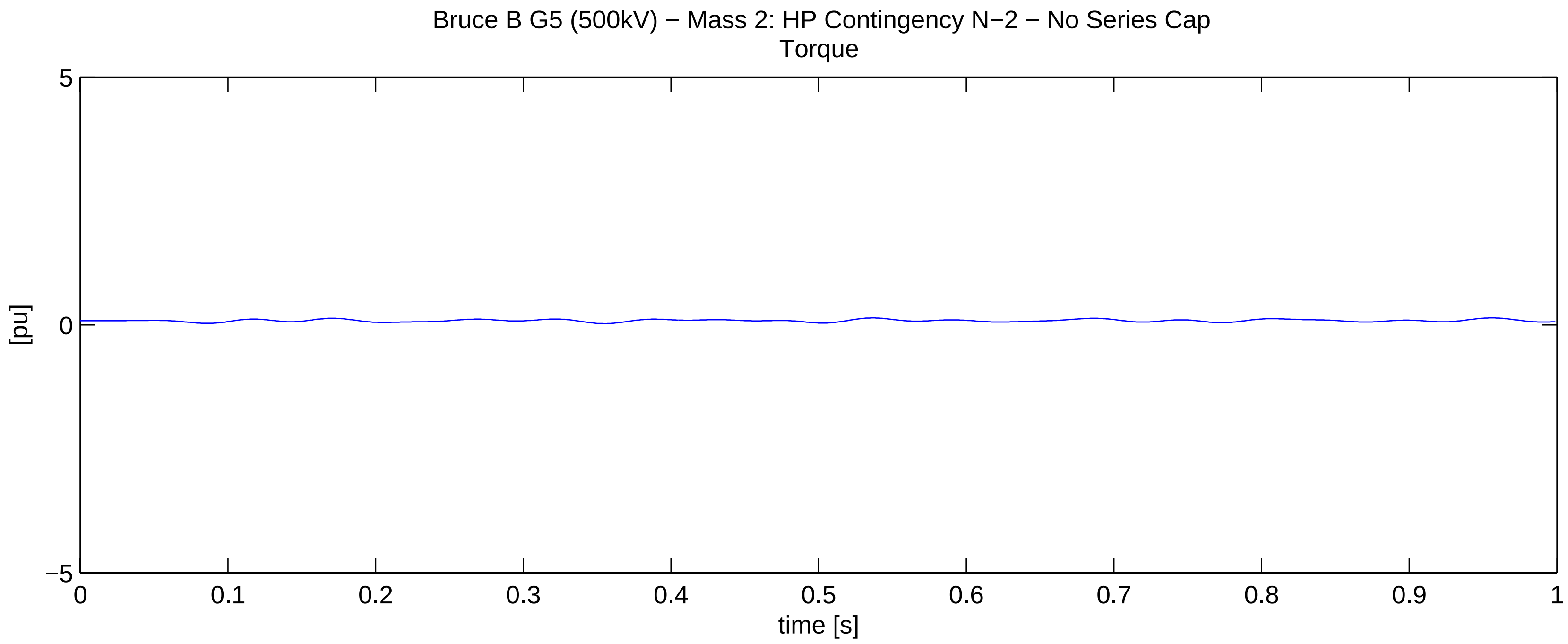

Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



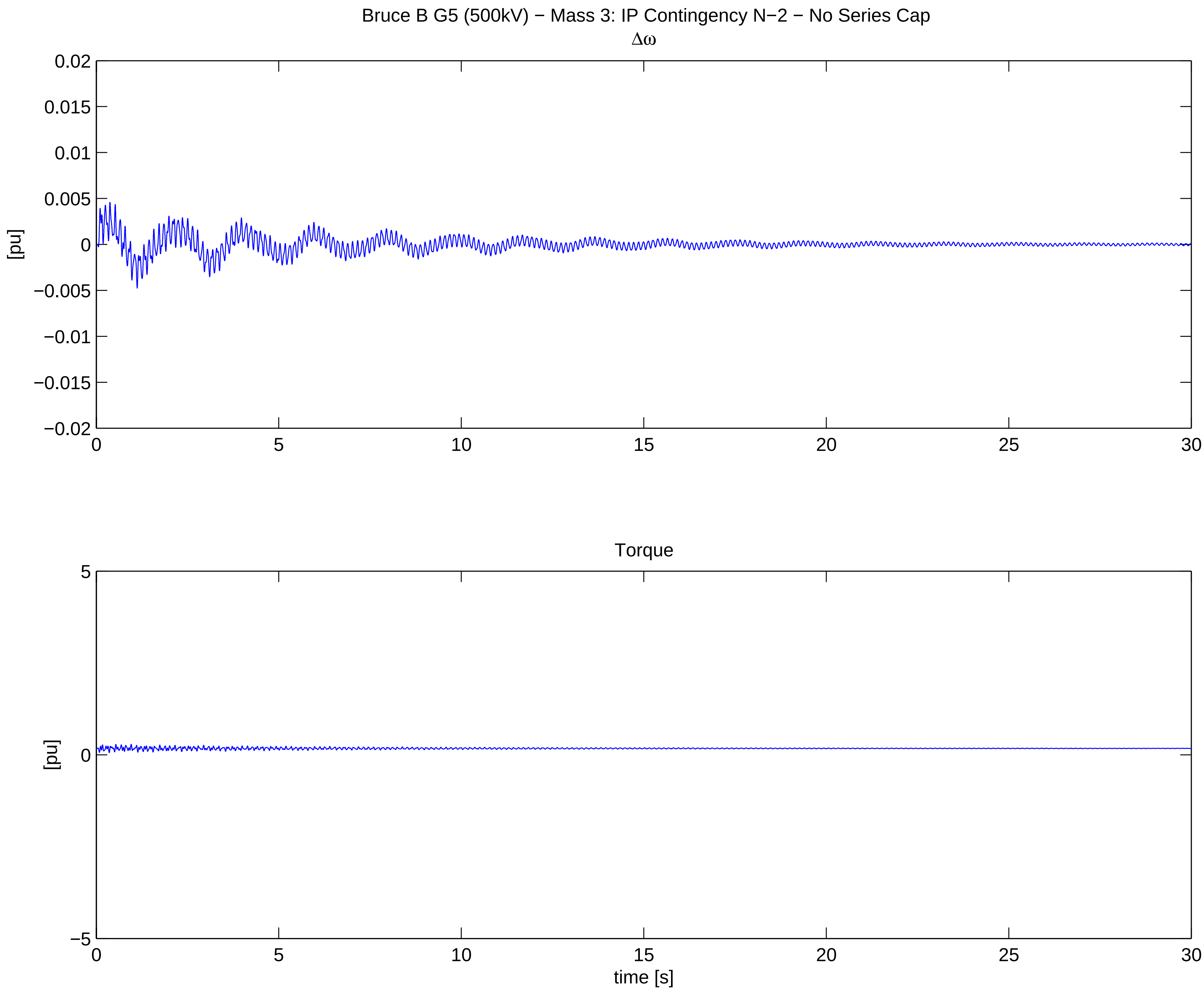
Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−2 − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



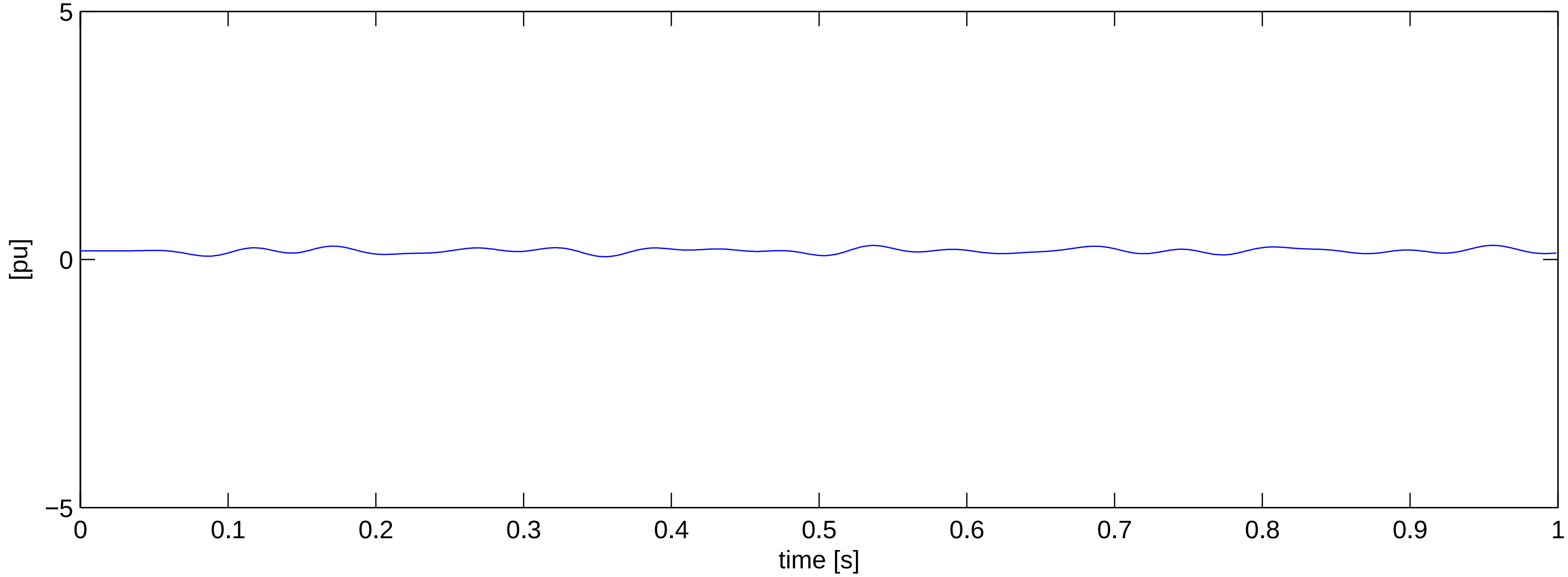
Bruce B G5 (500kV) − Mass 2: HP Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

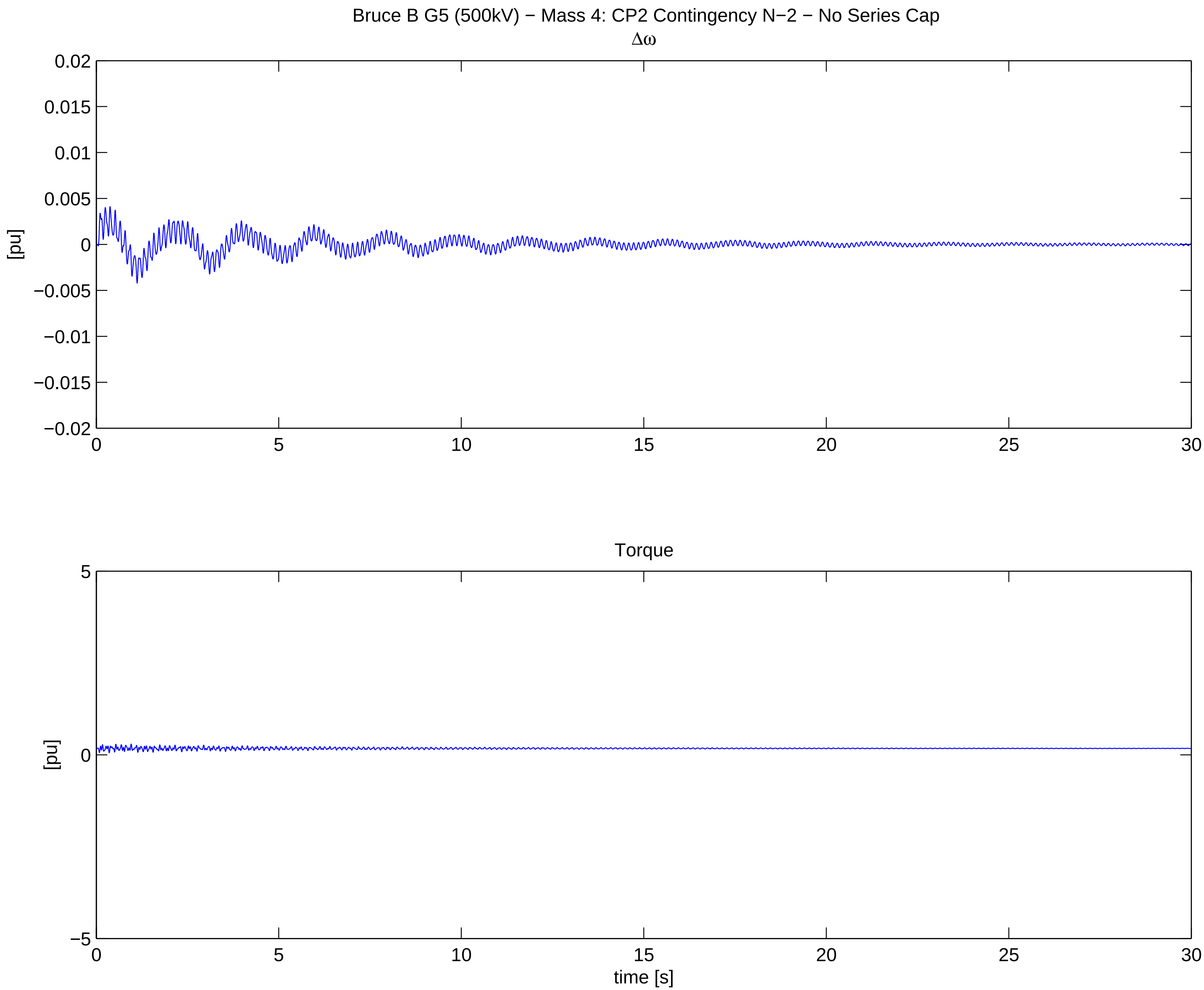


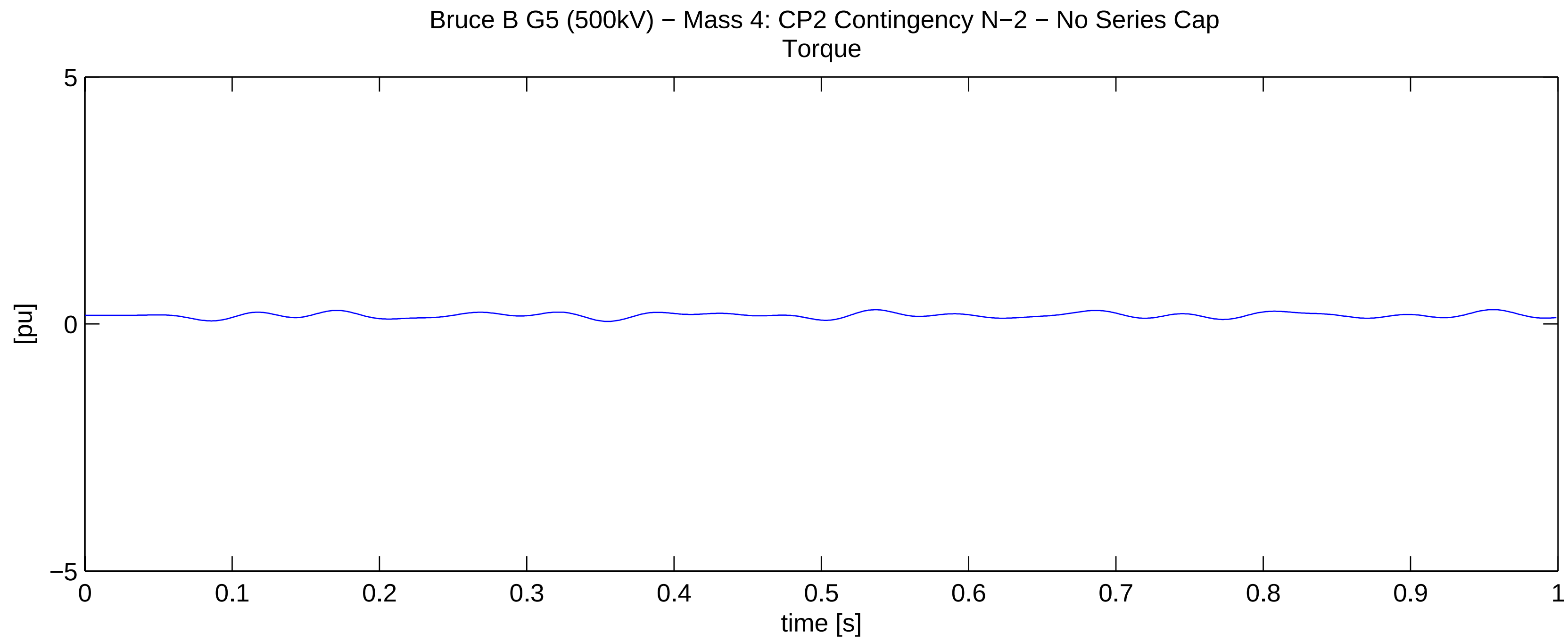
Bruce B G5 (500kV) − Mass 2: HP Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

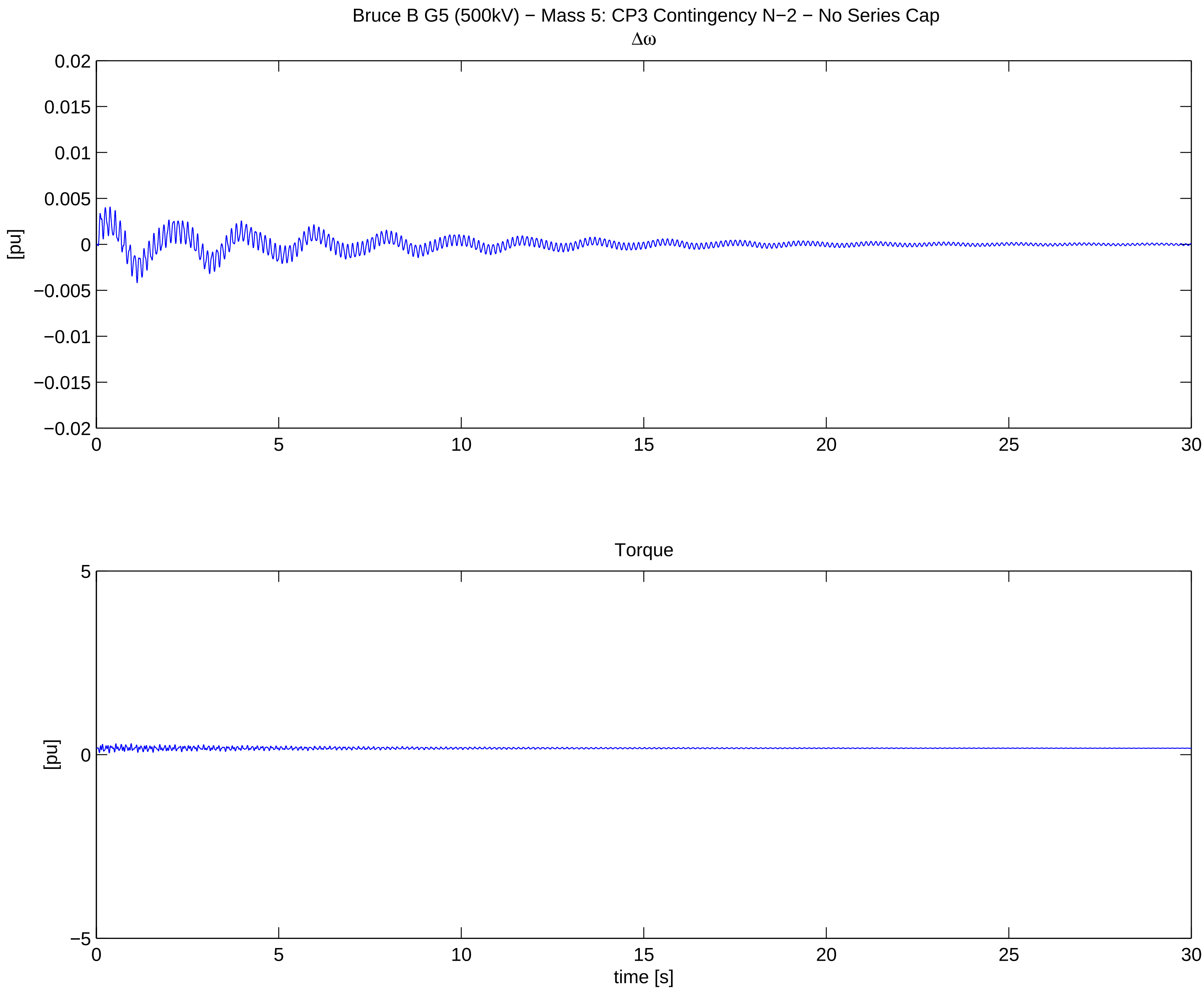

Bruce B G5 (500kV) − Mass 3: IP Contingency N−2 − No Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

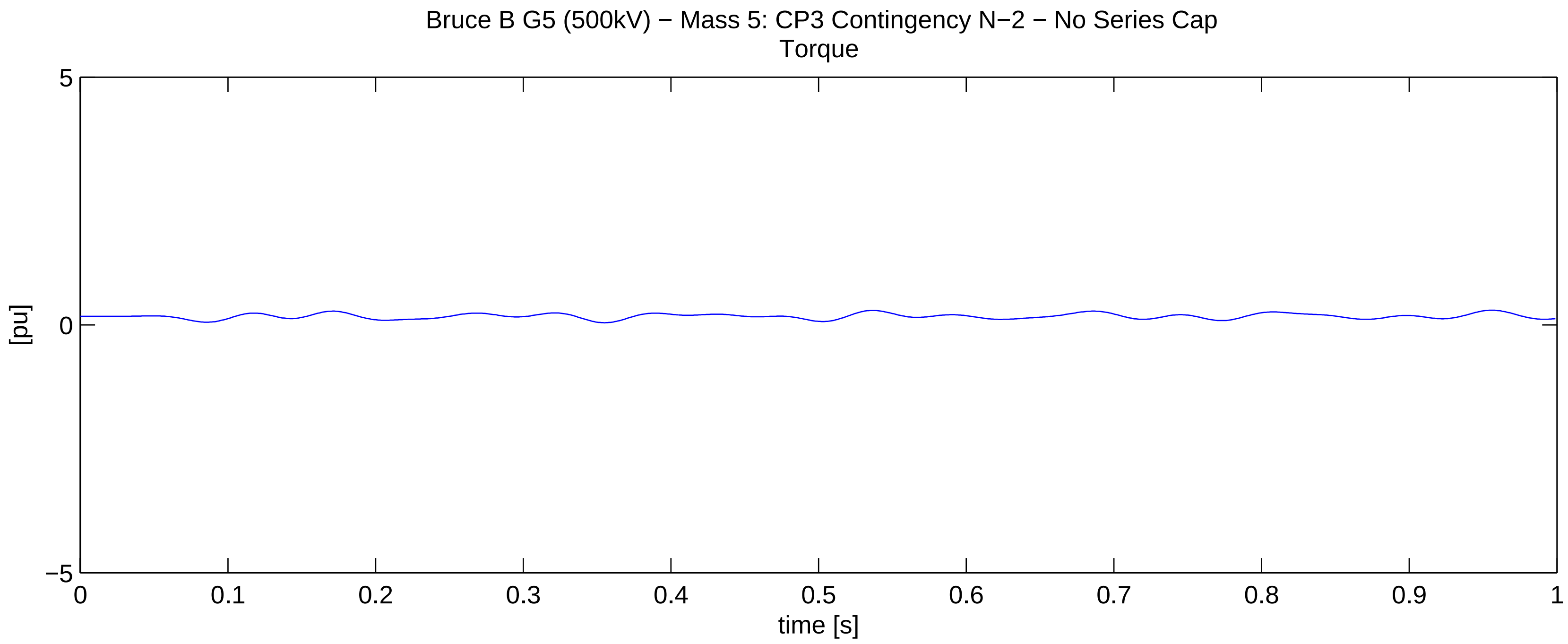
Bruce B G5 (500kV) − Mass 3: IP Contingency N−2 − No Series Cap
Torque

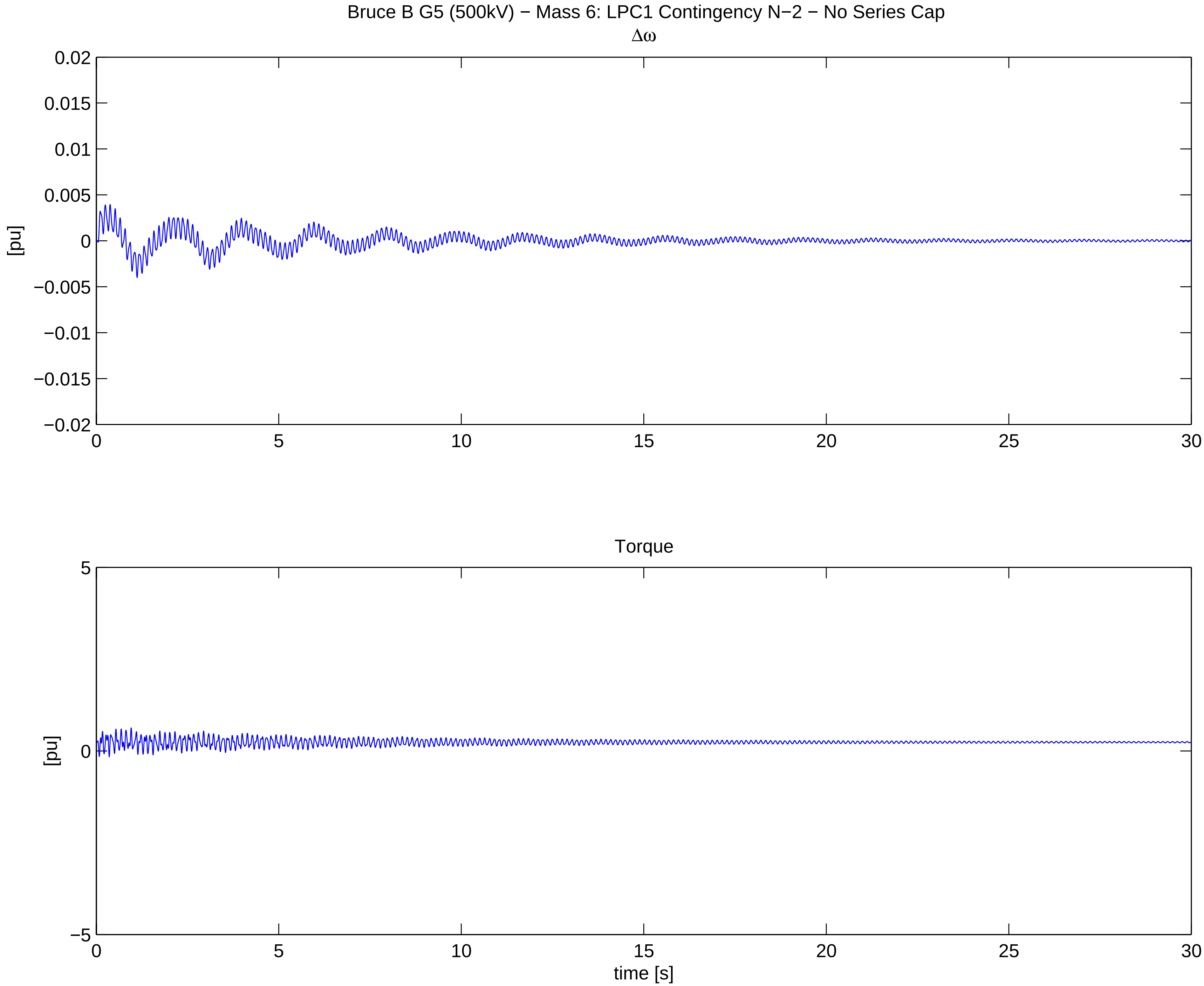



Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

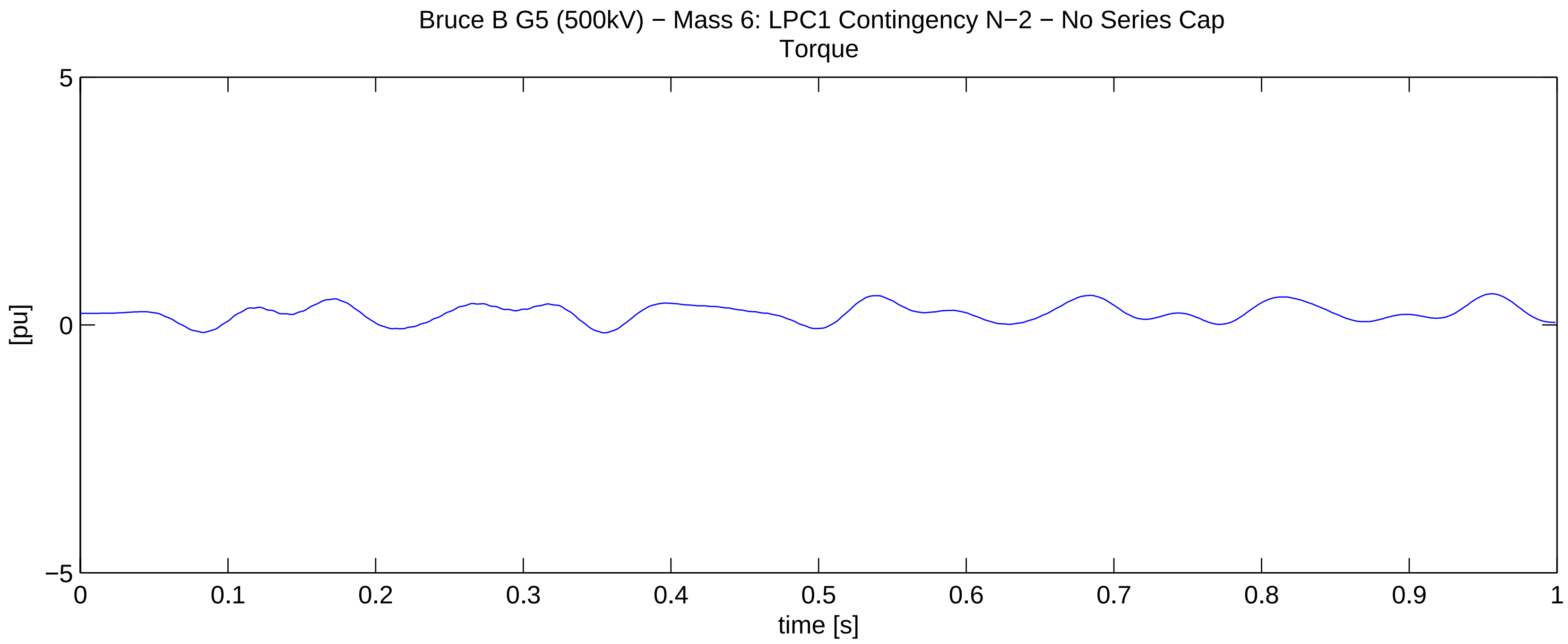

Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−2 − No Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

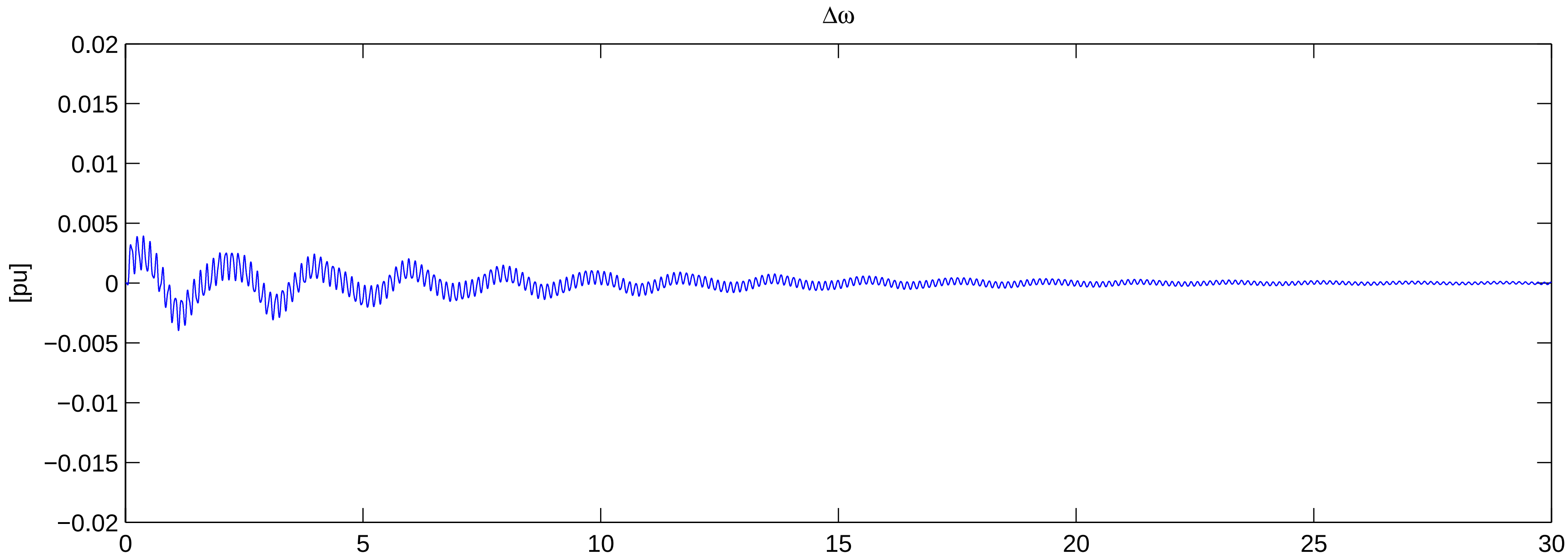


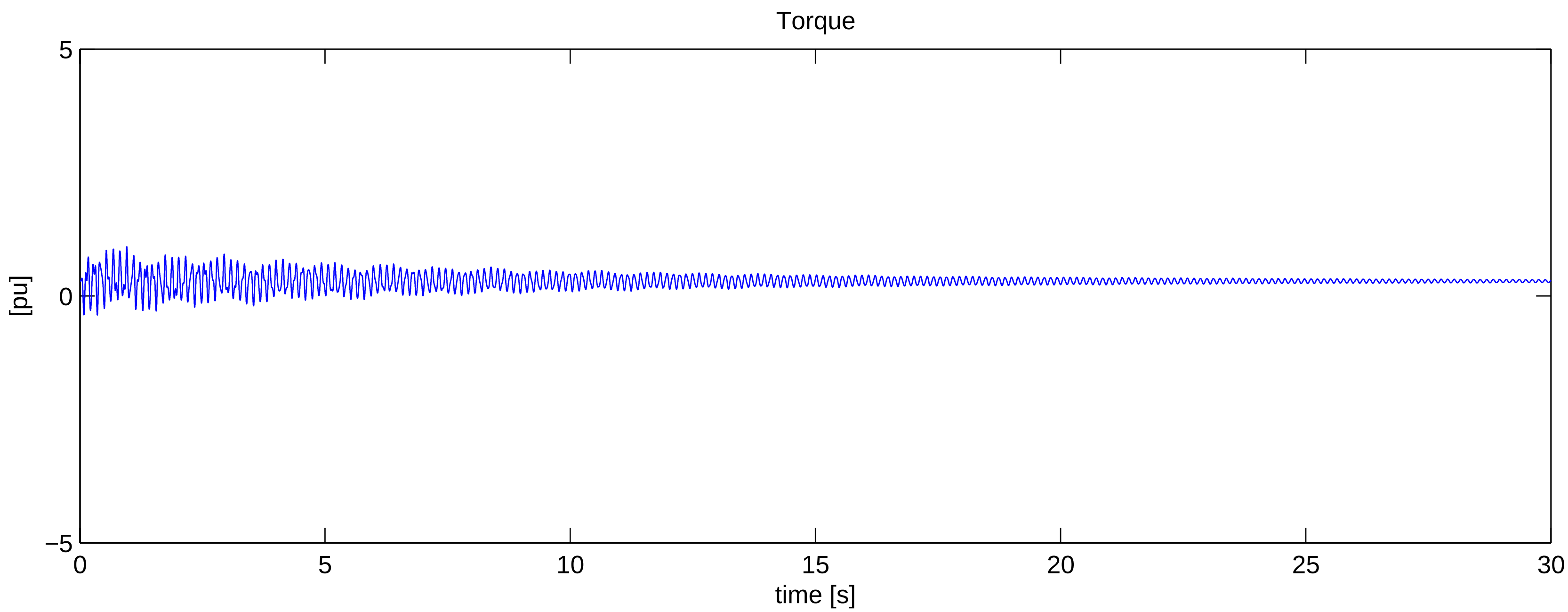
Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

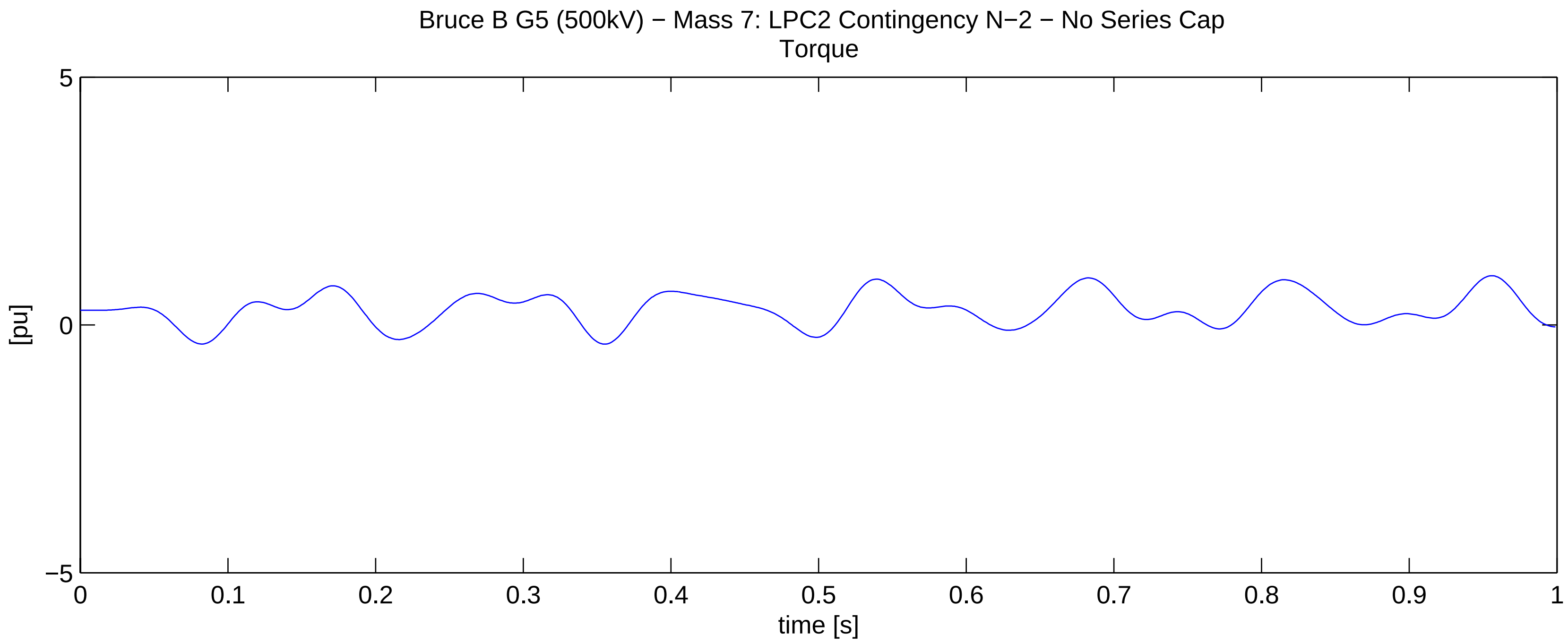


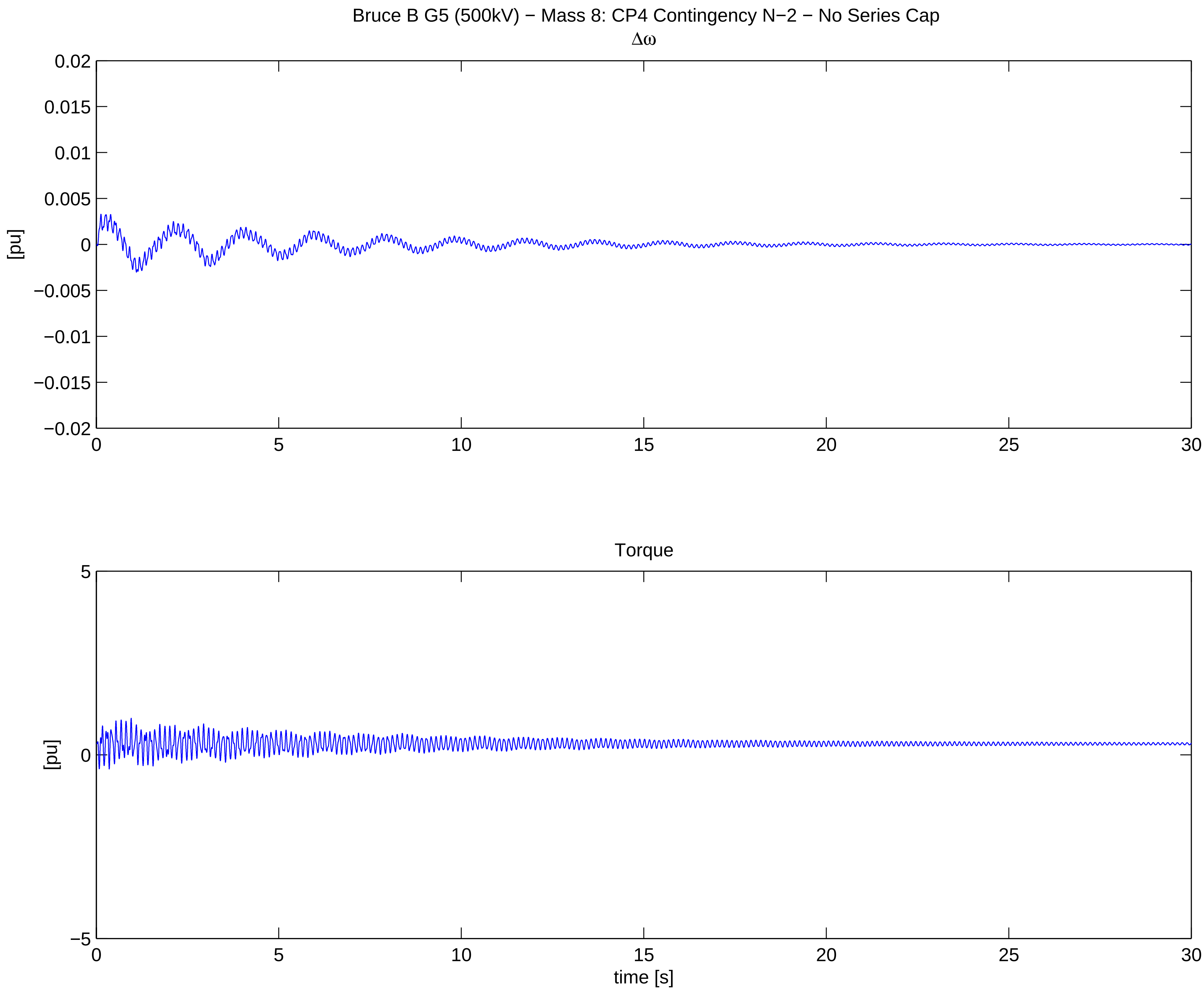
Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

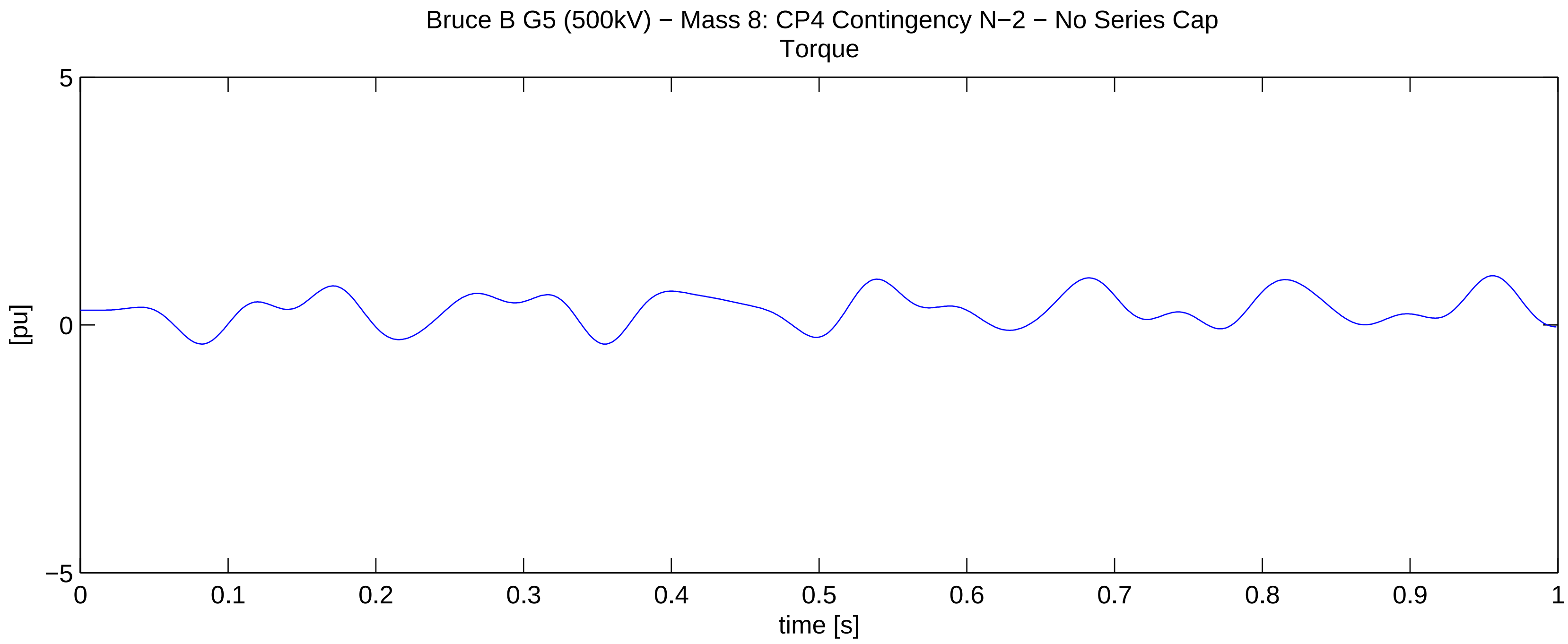
Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−2 − No Series Cap

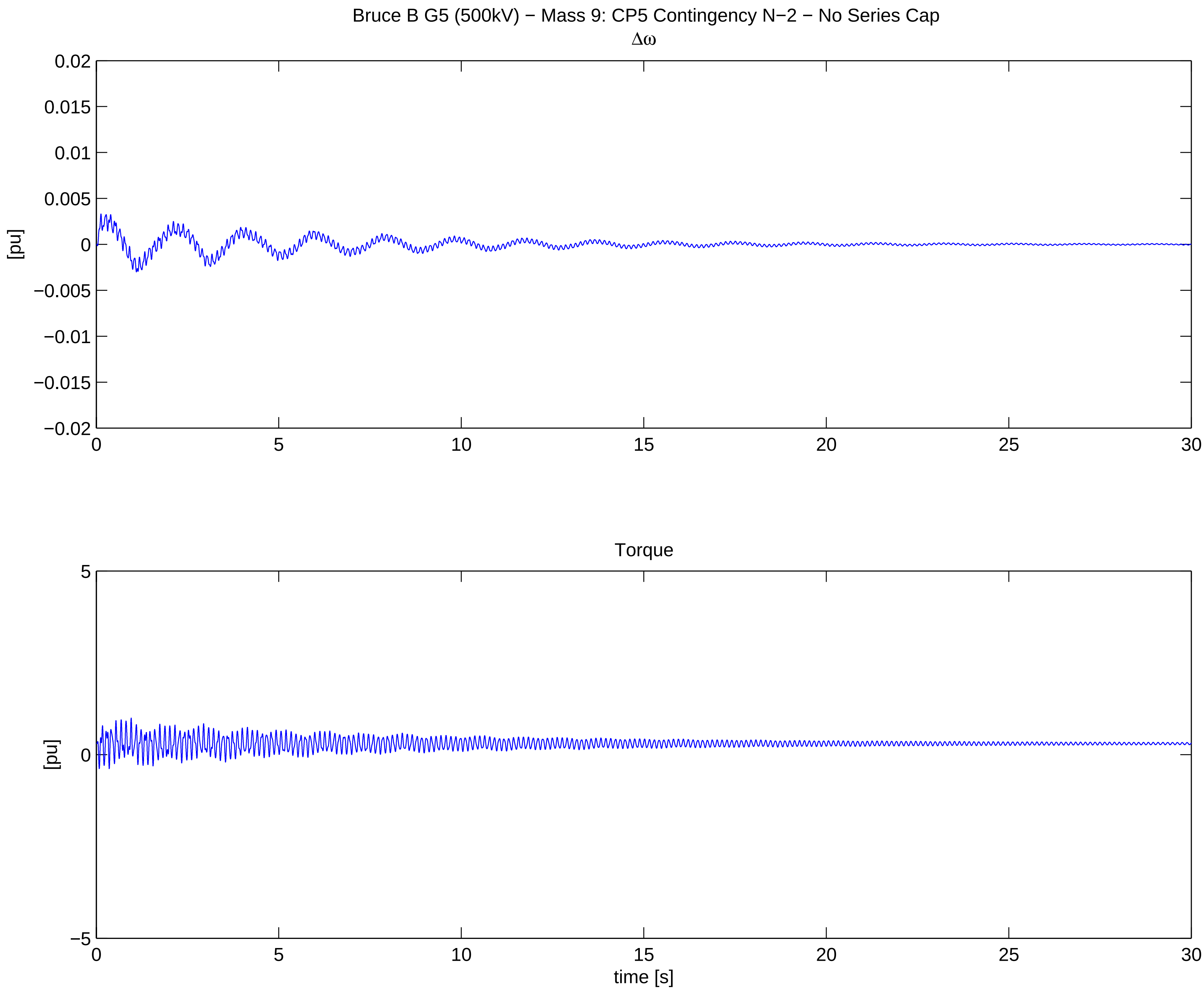




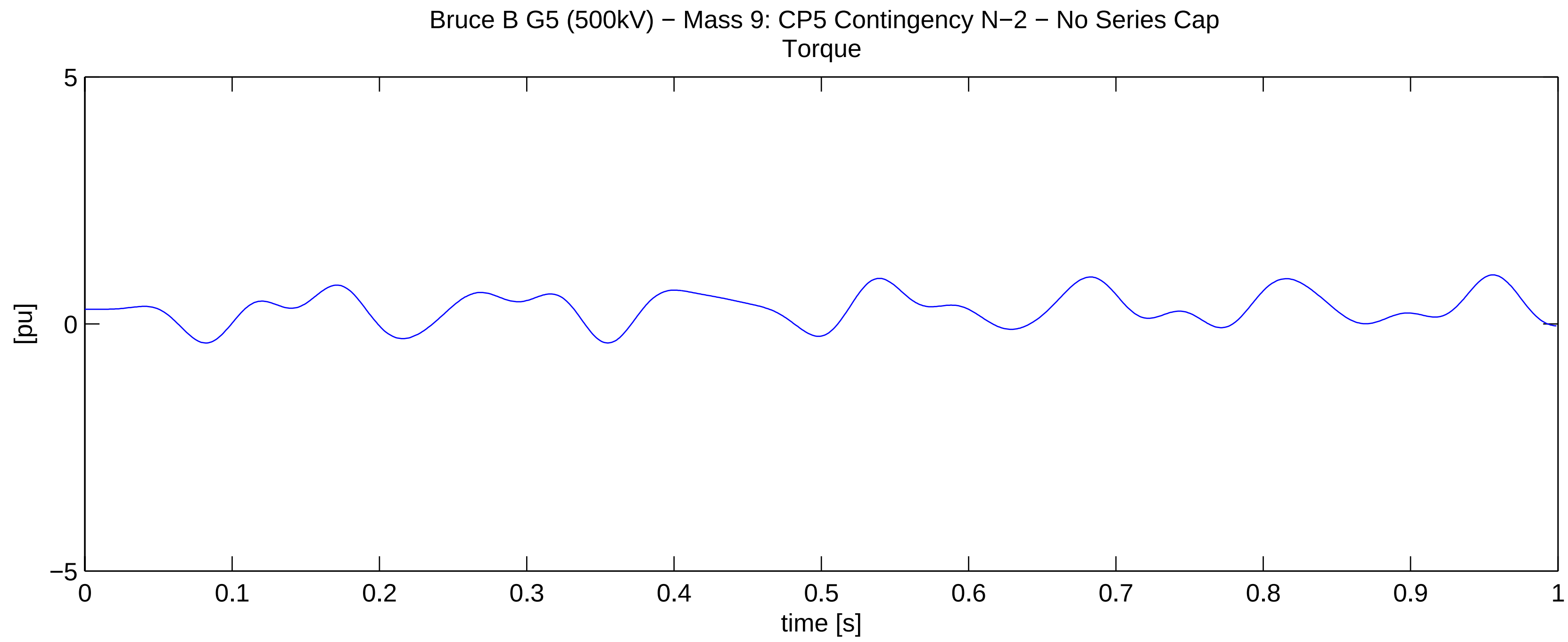

Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

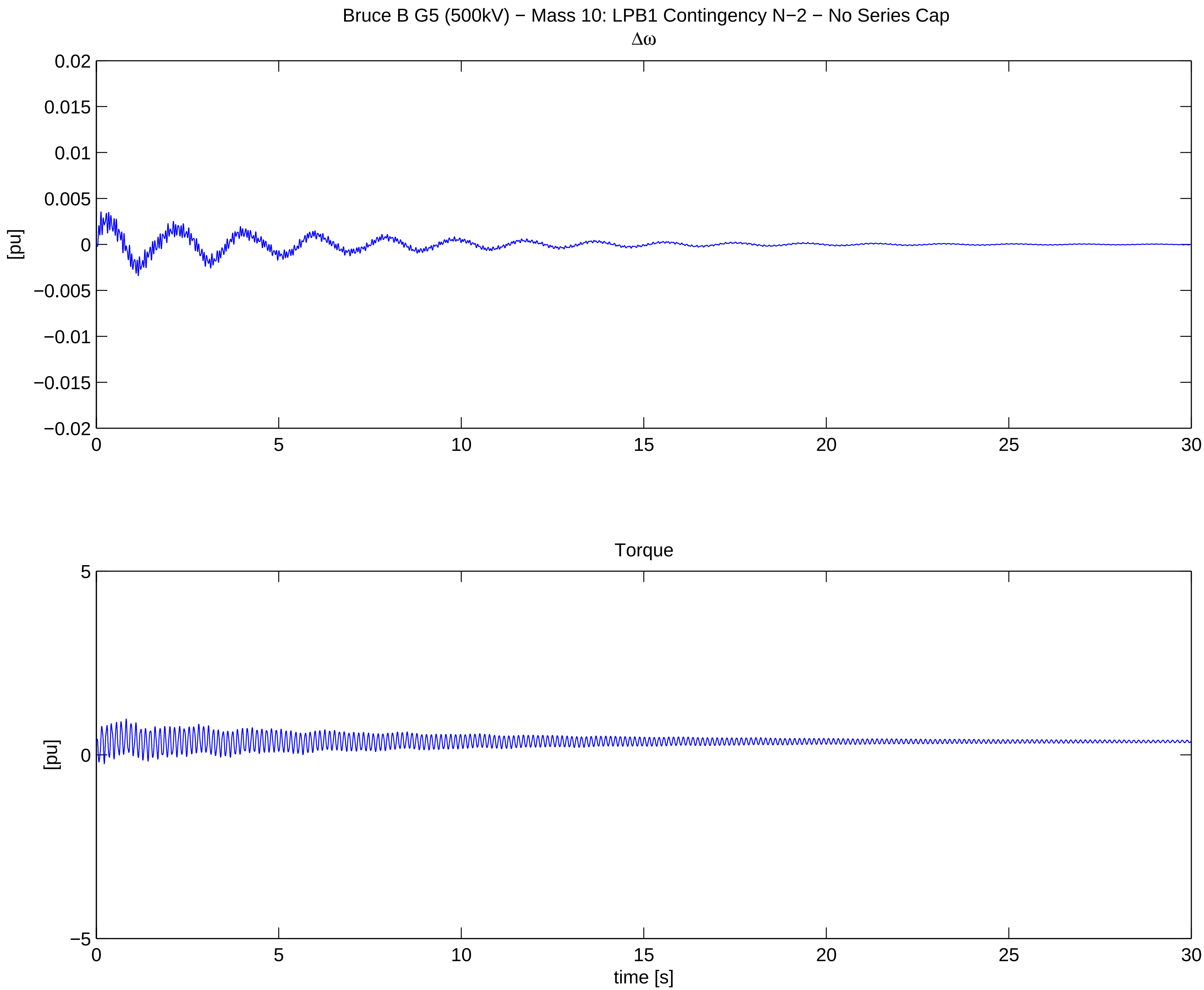

Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

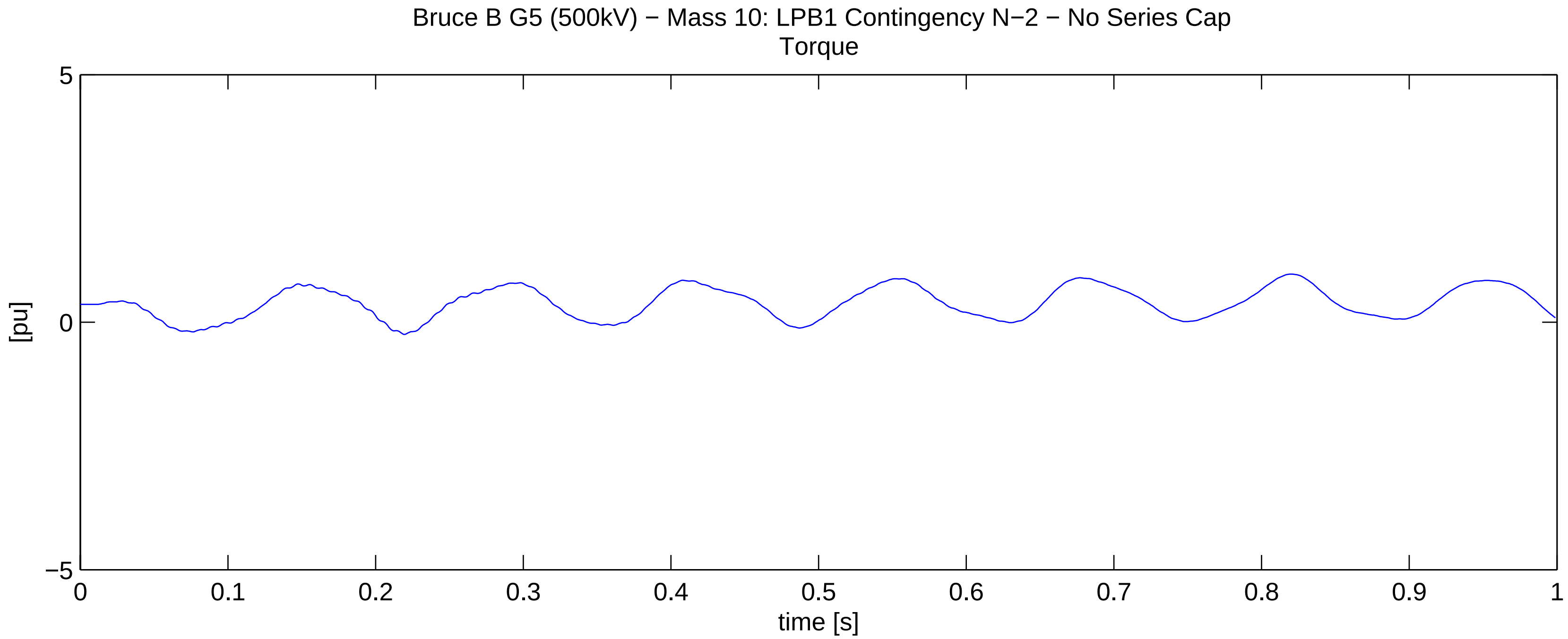


Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

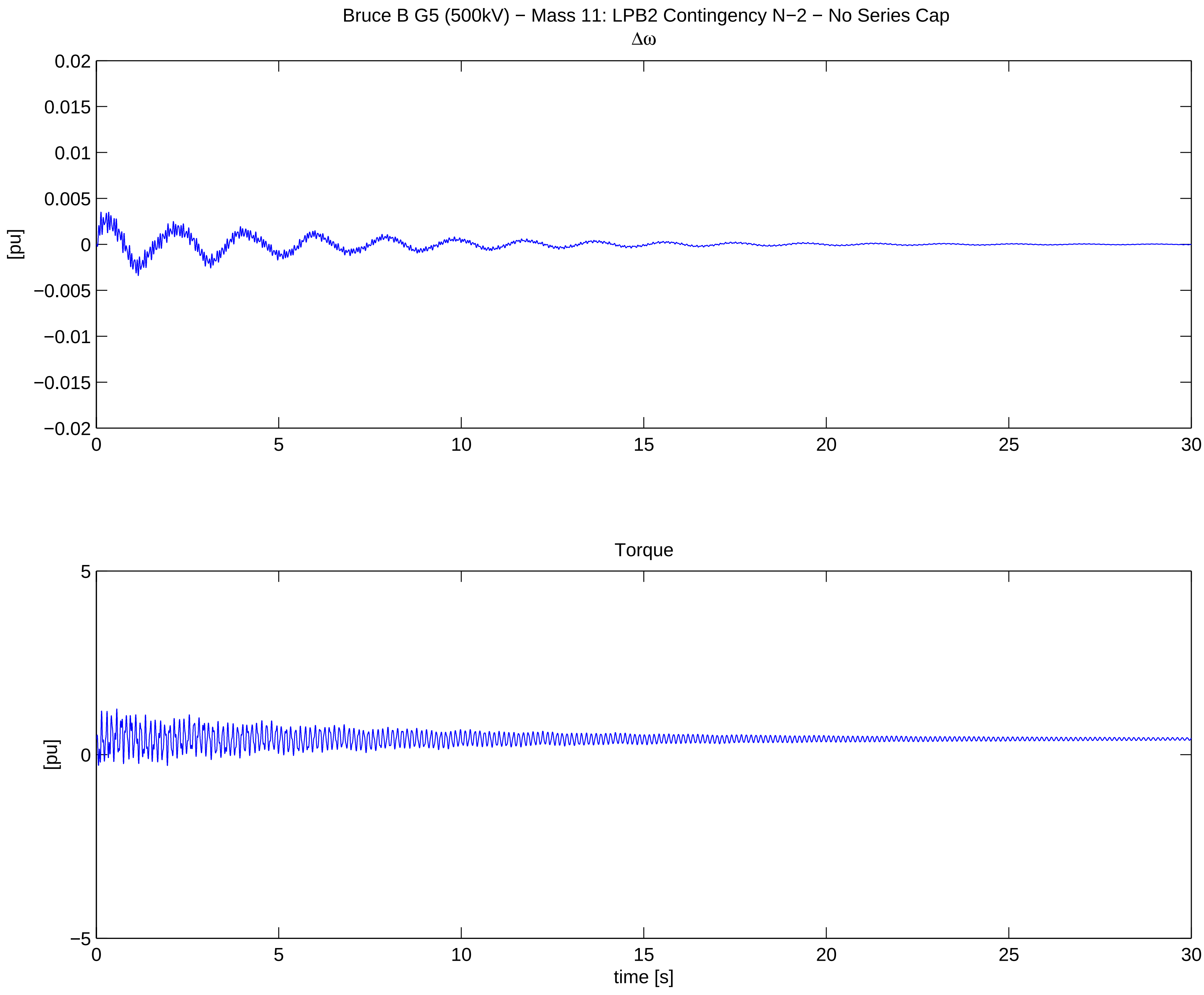

Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



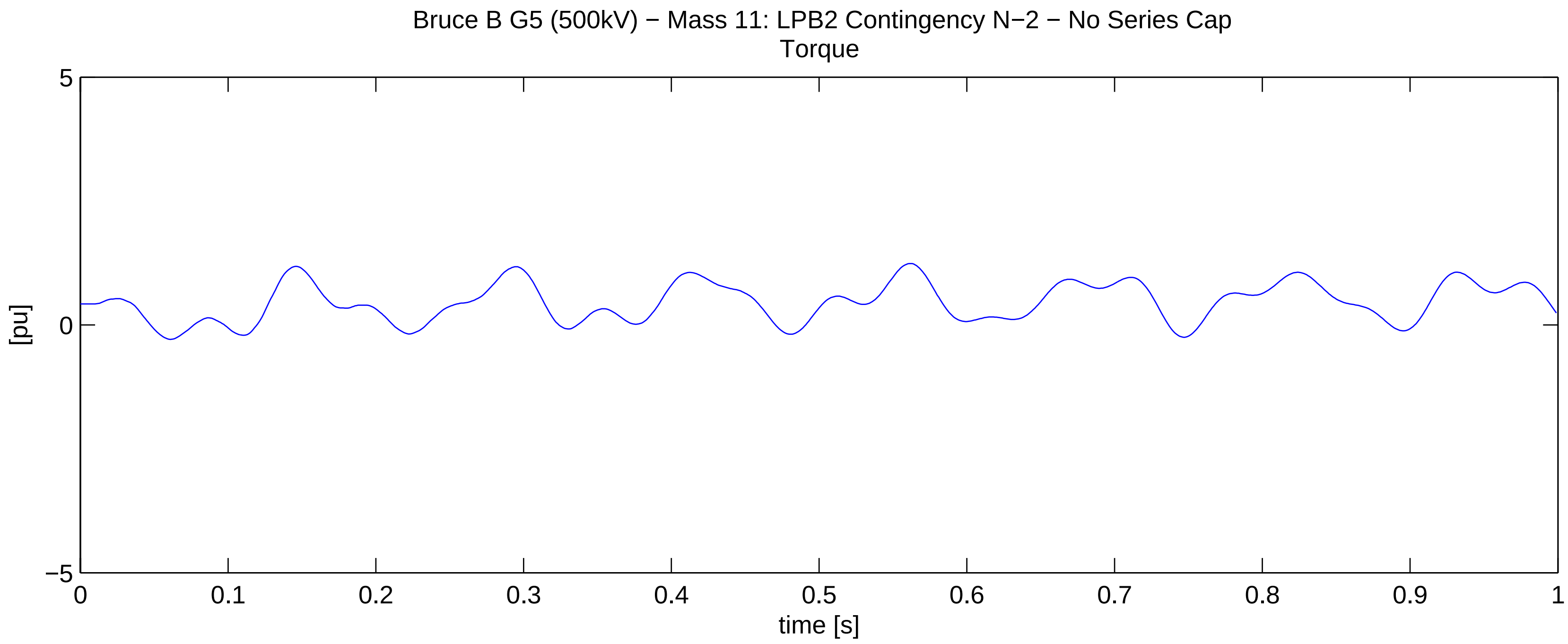
Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−2 − No Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

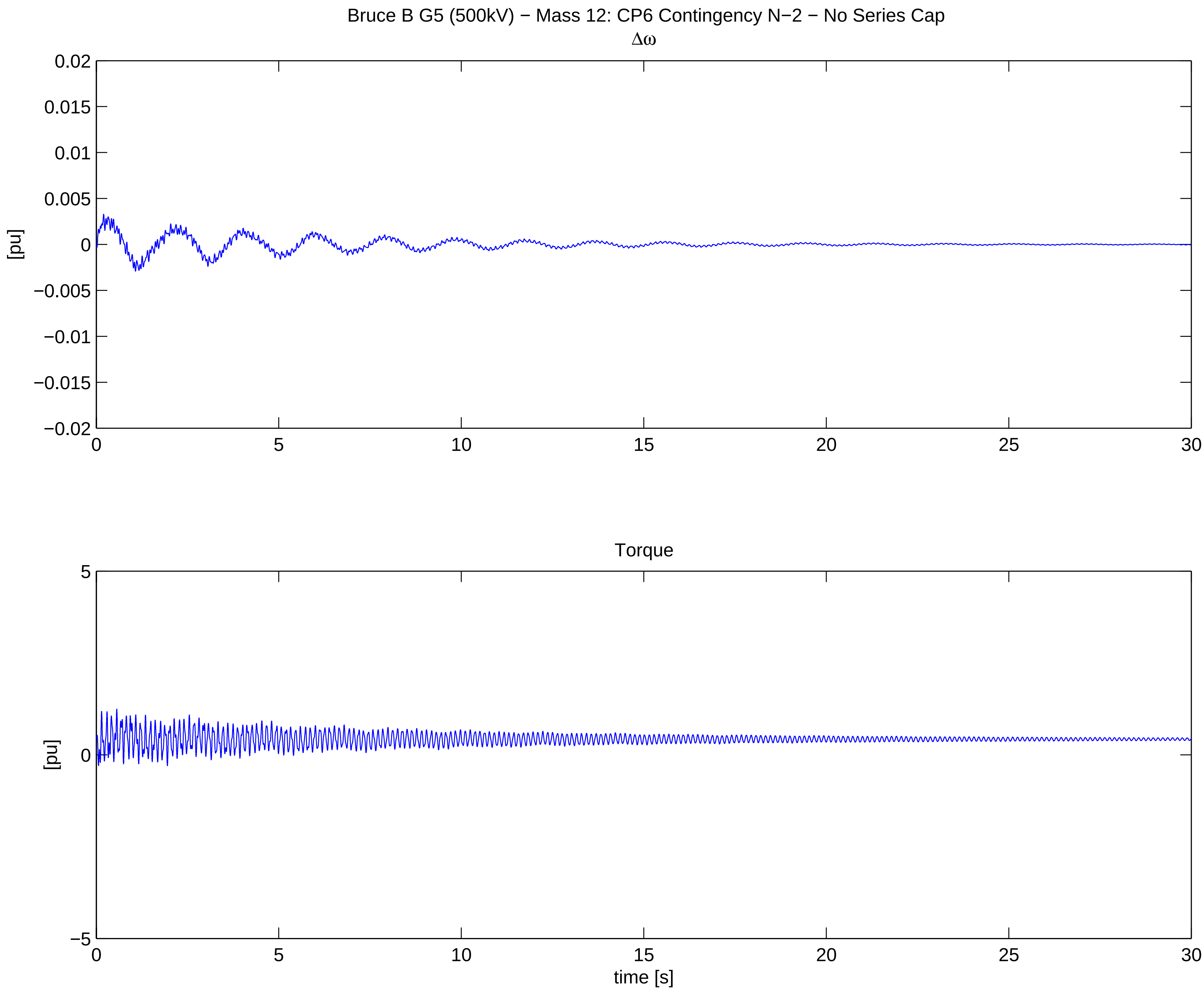


Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

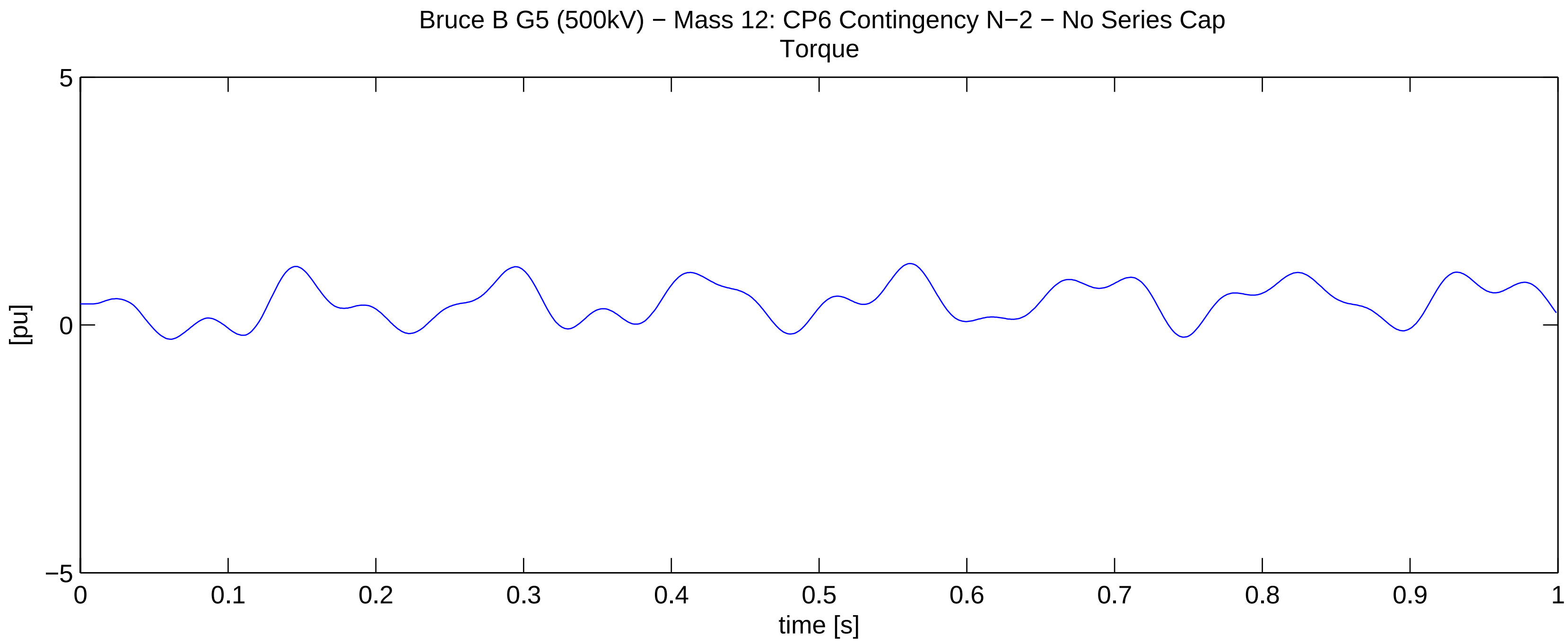


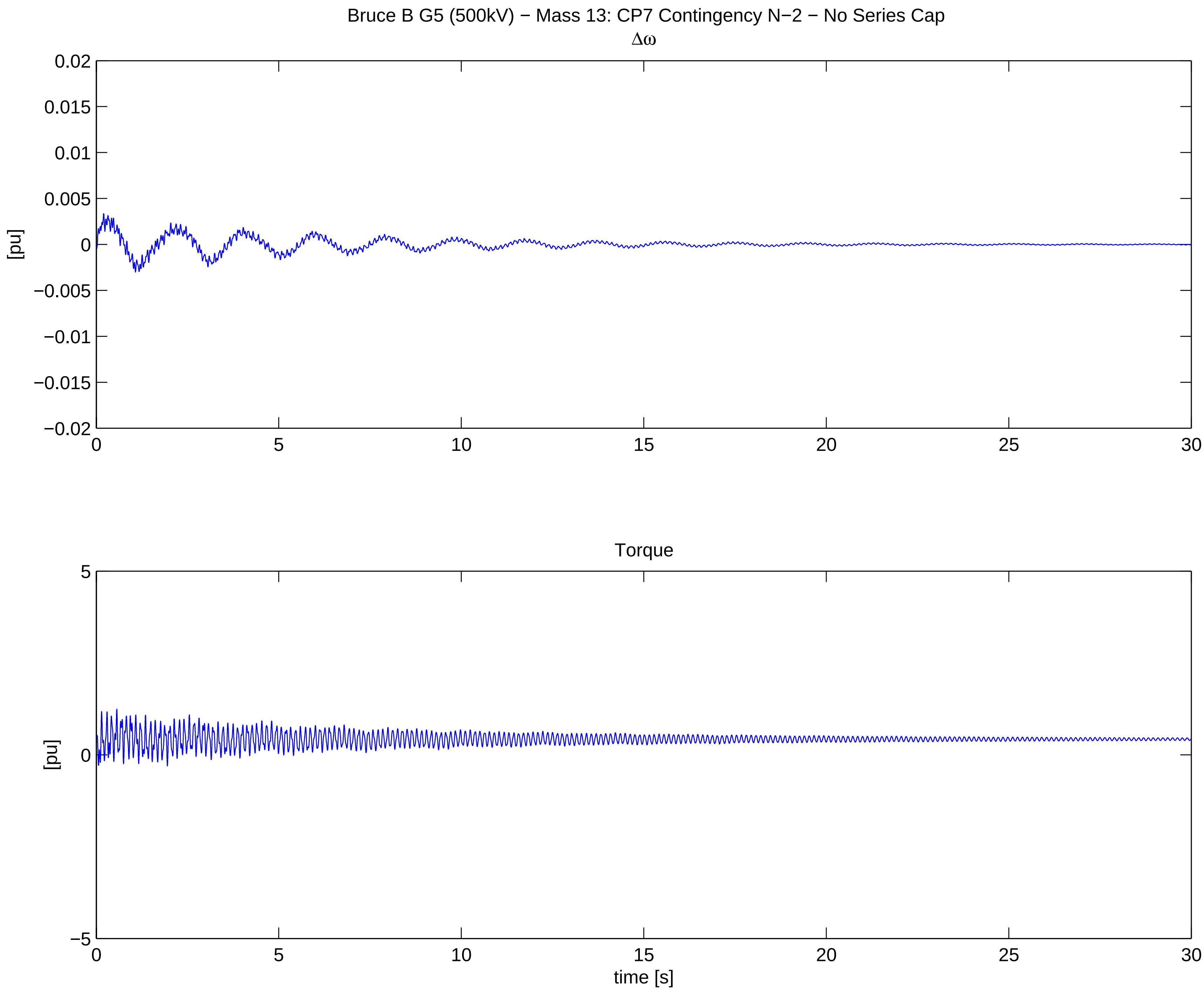
Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−2 − No Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
time [s]

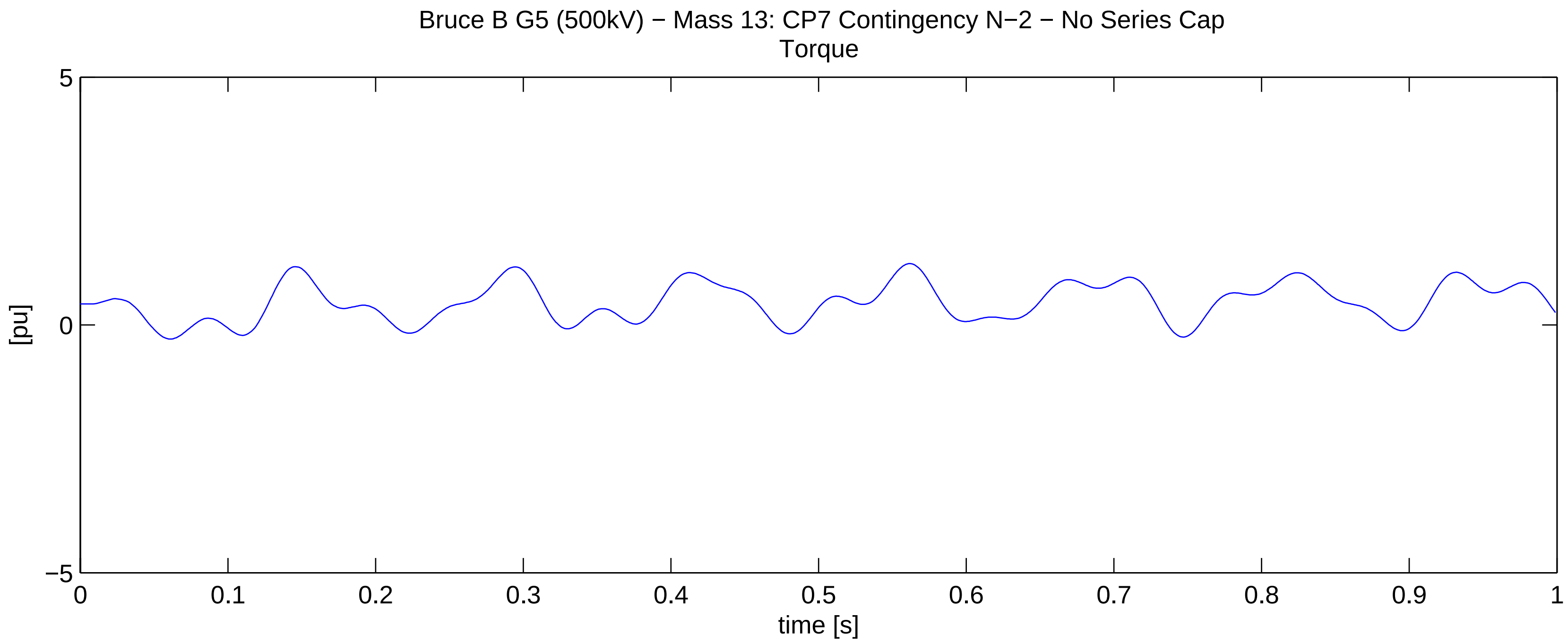

Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−2 − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

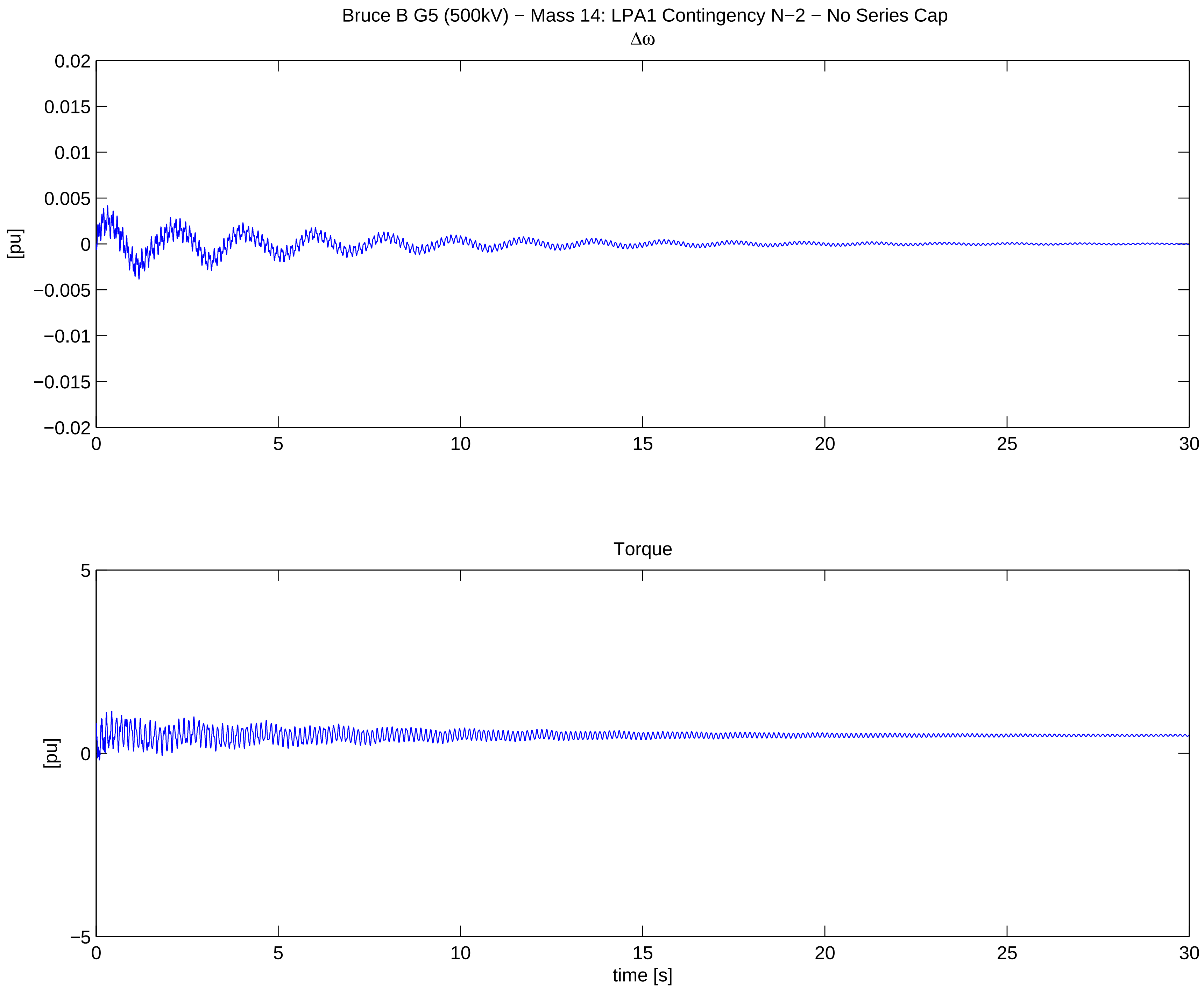


Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

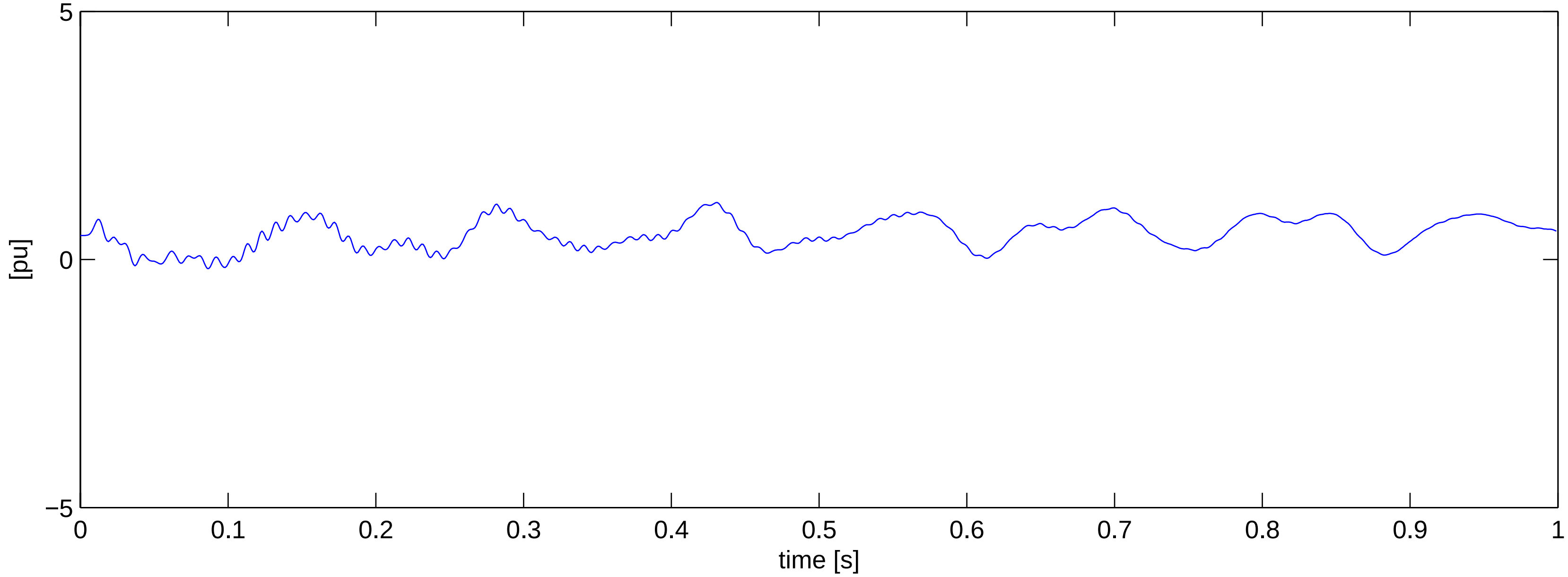

Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

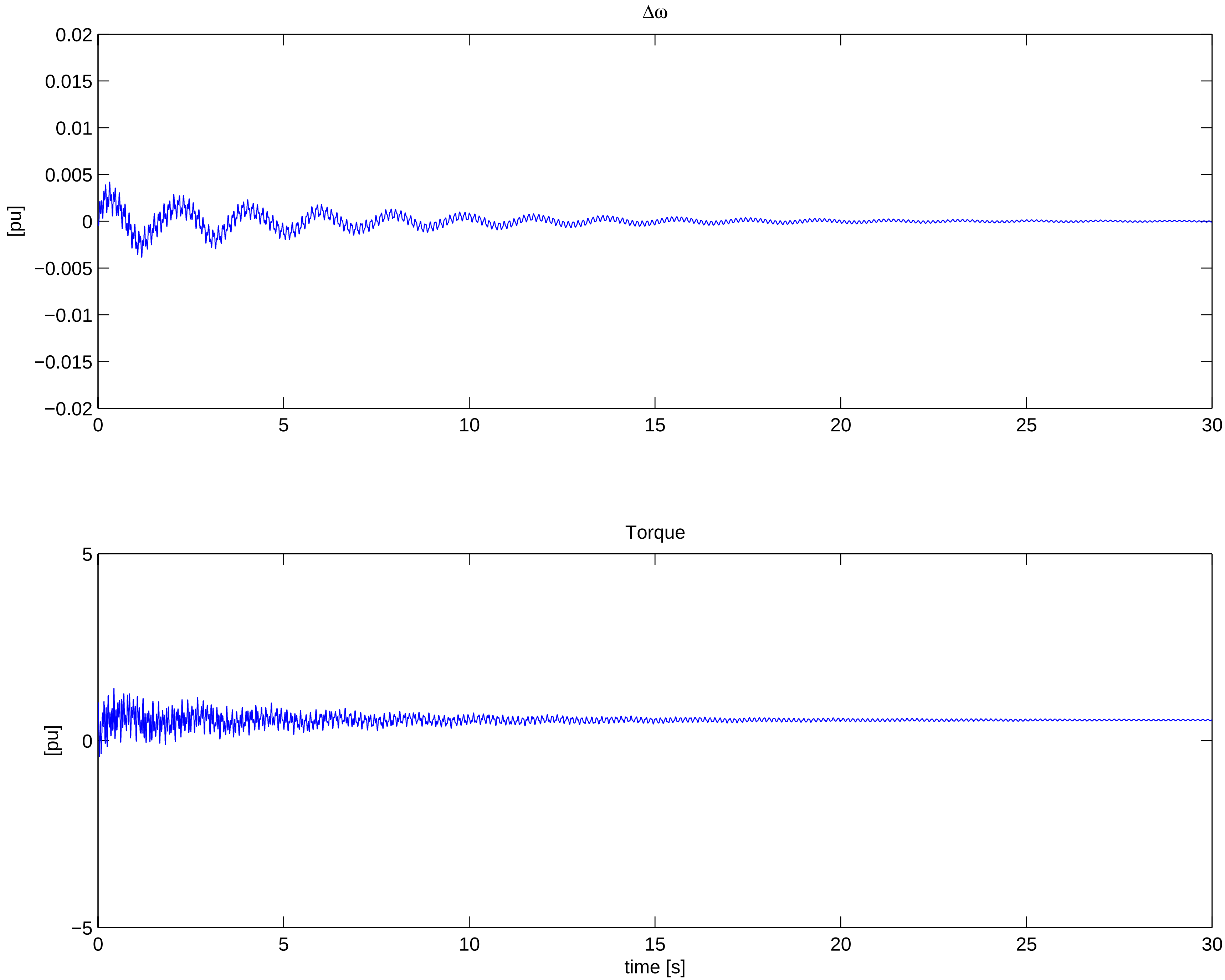

Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

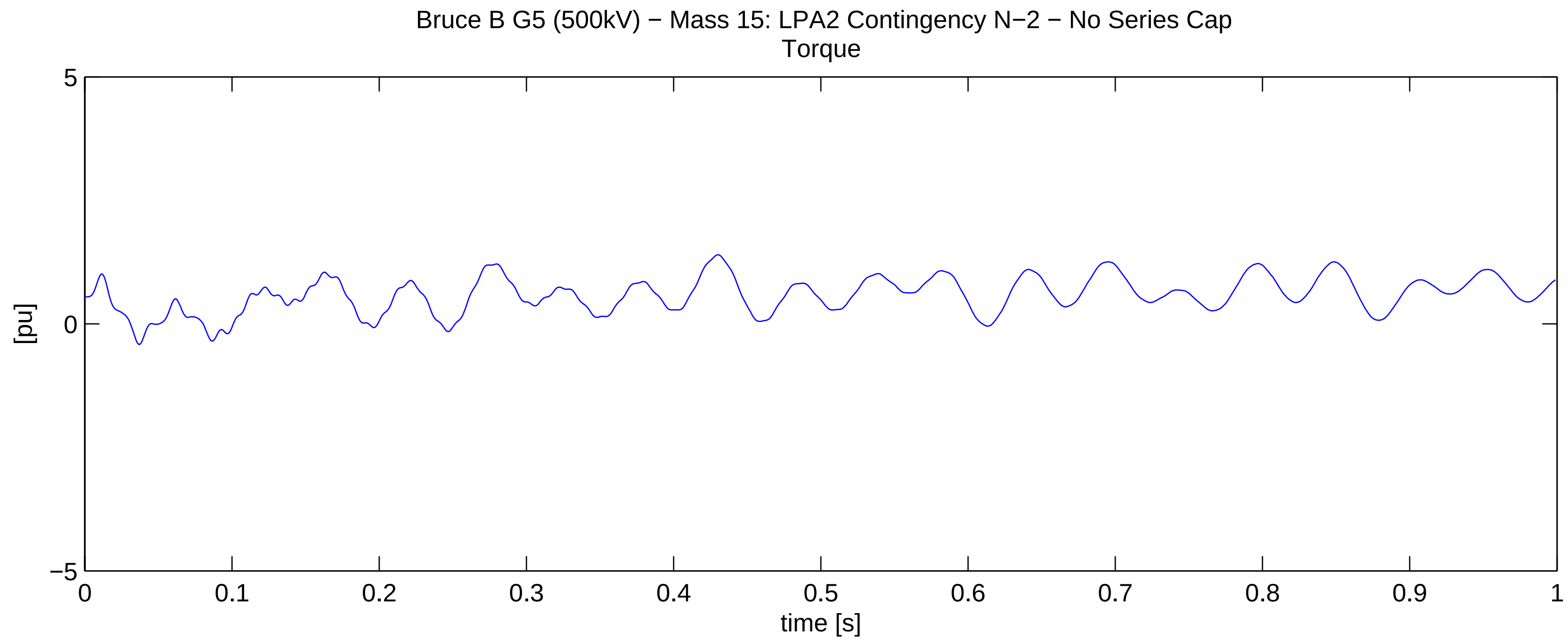

Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−2 − No Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−2 − No Series Cap
Torque



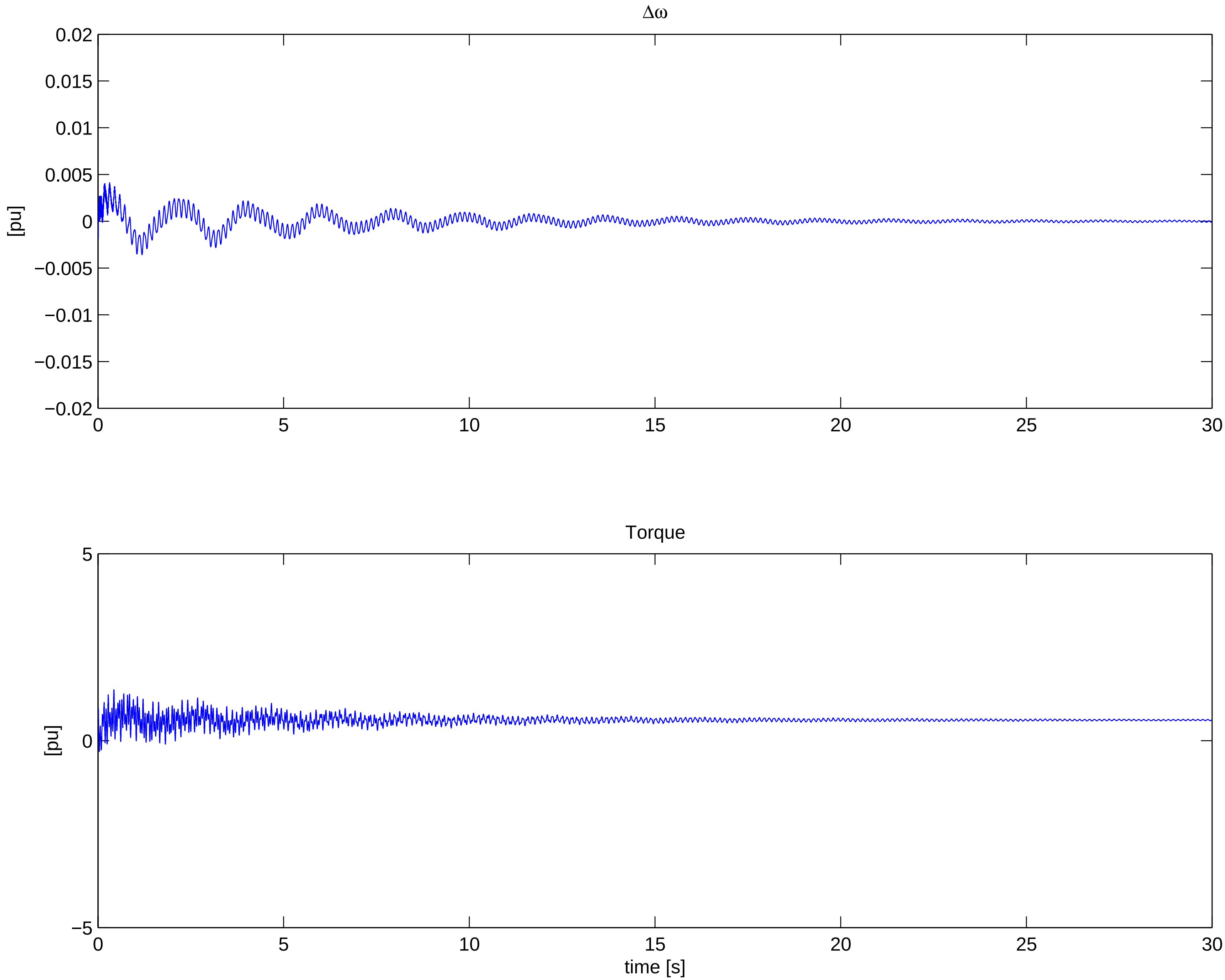
Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−2 − No Series Cap

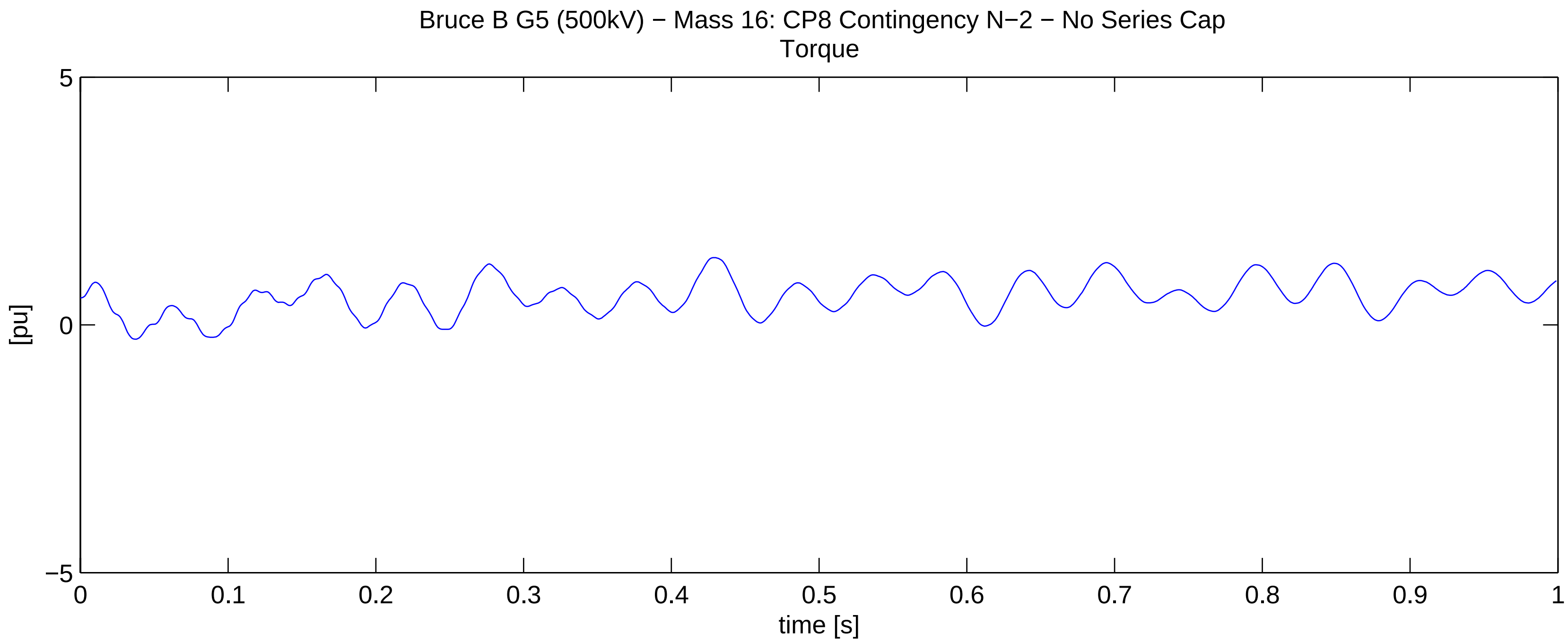




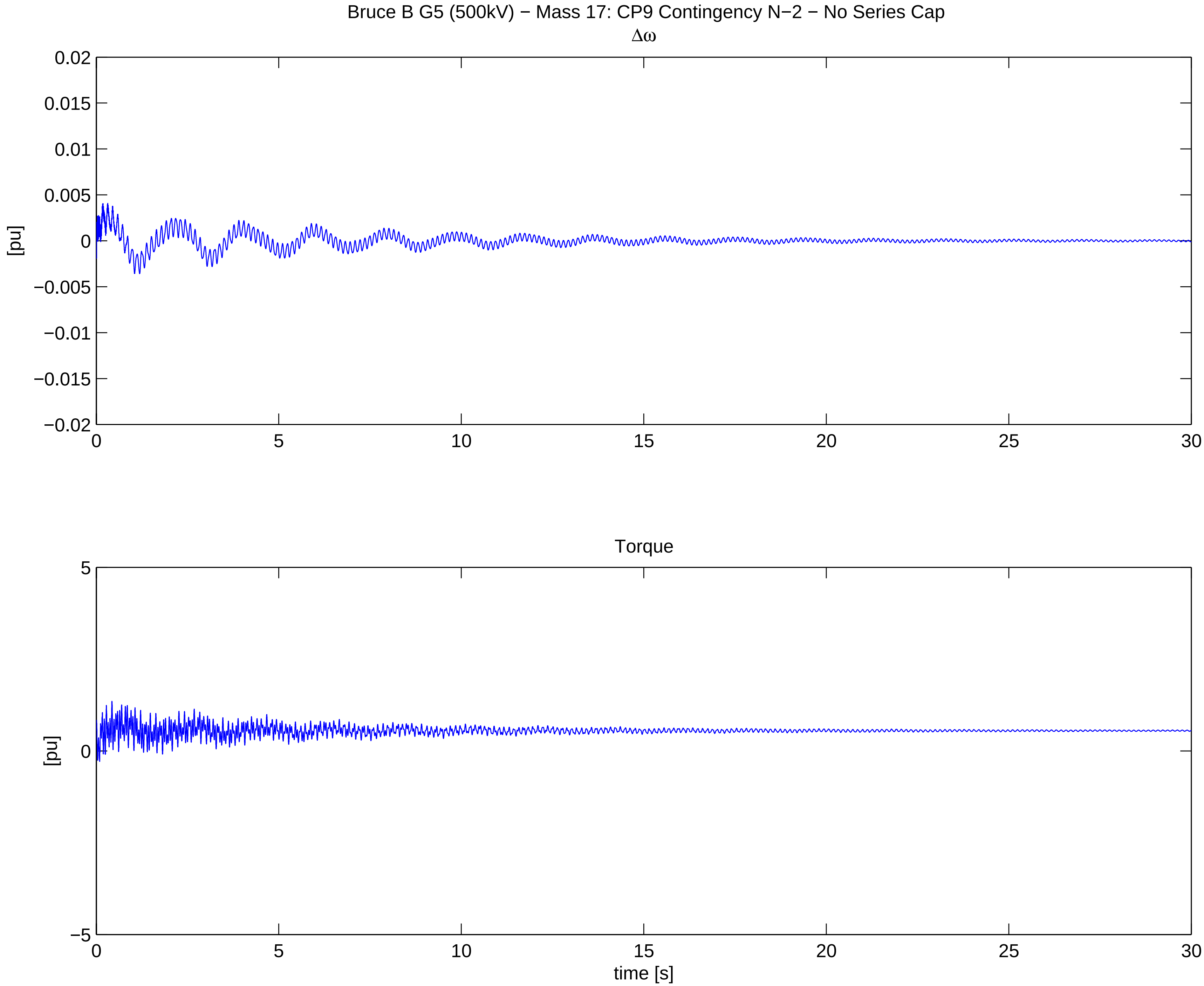
Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

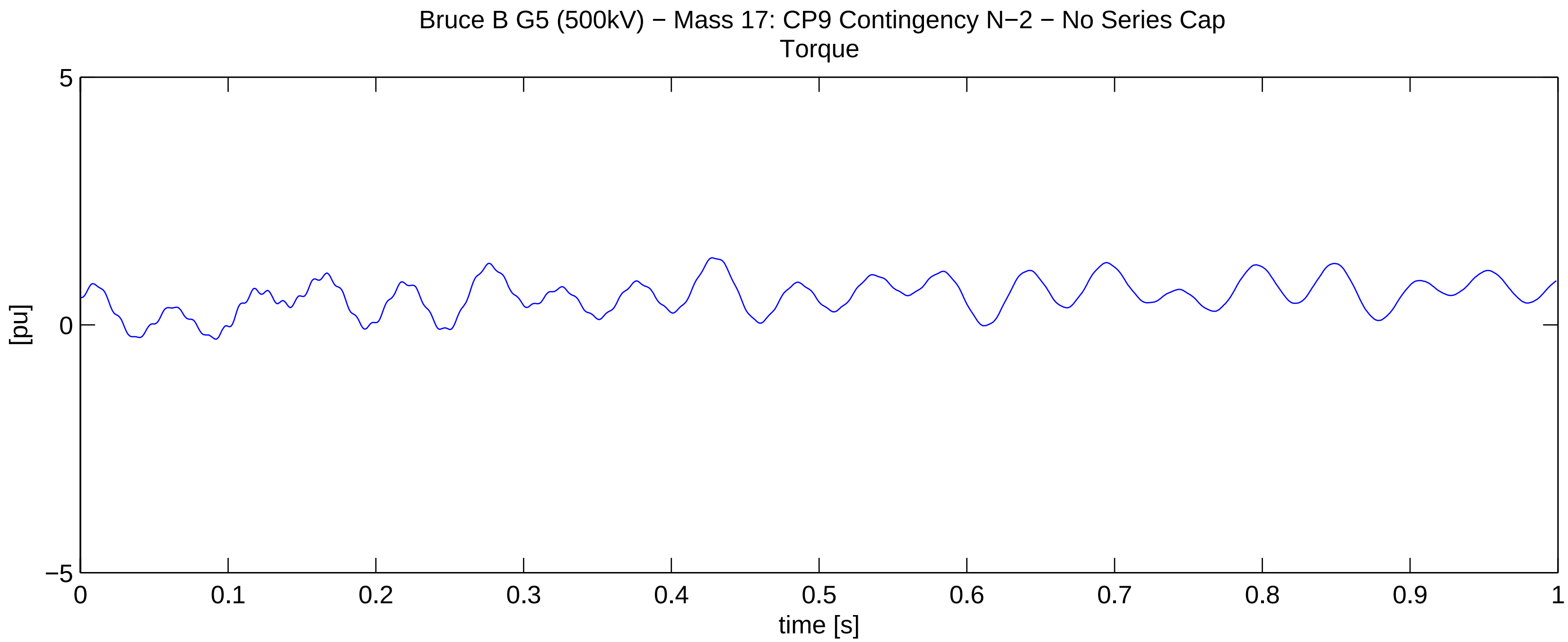
Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−2 − No Series Cap

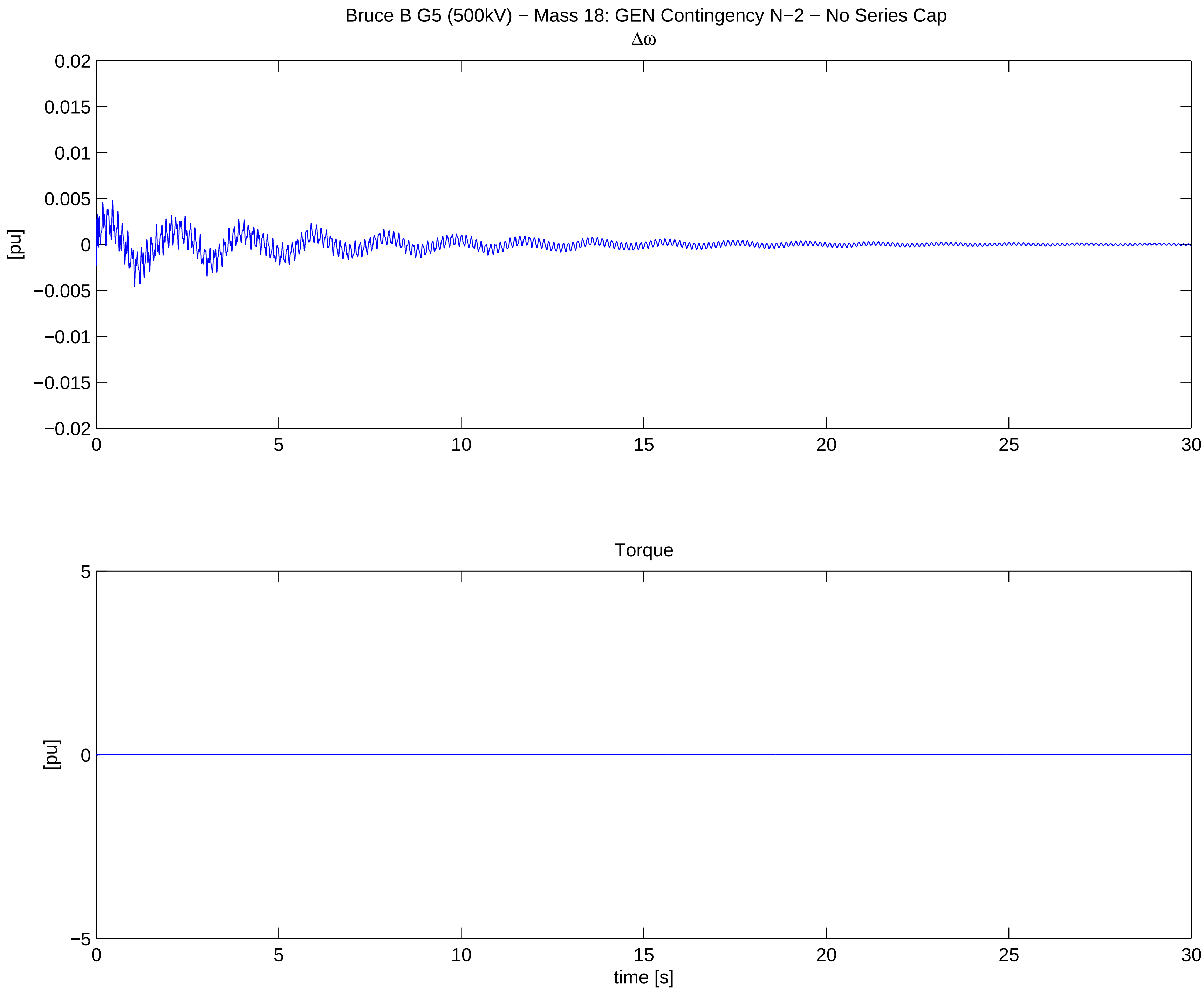


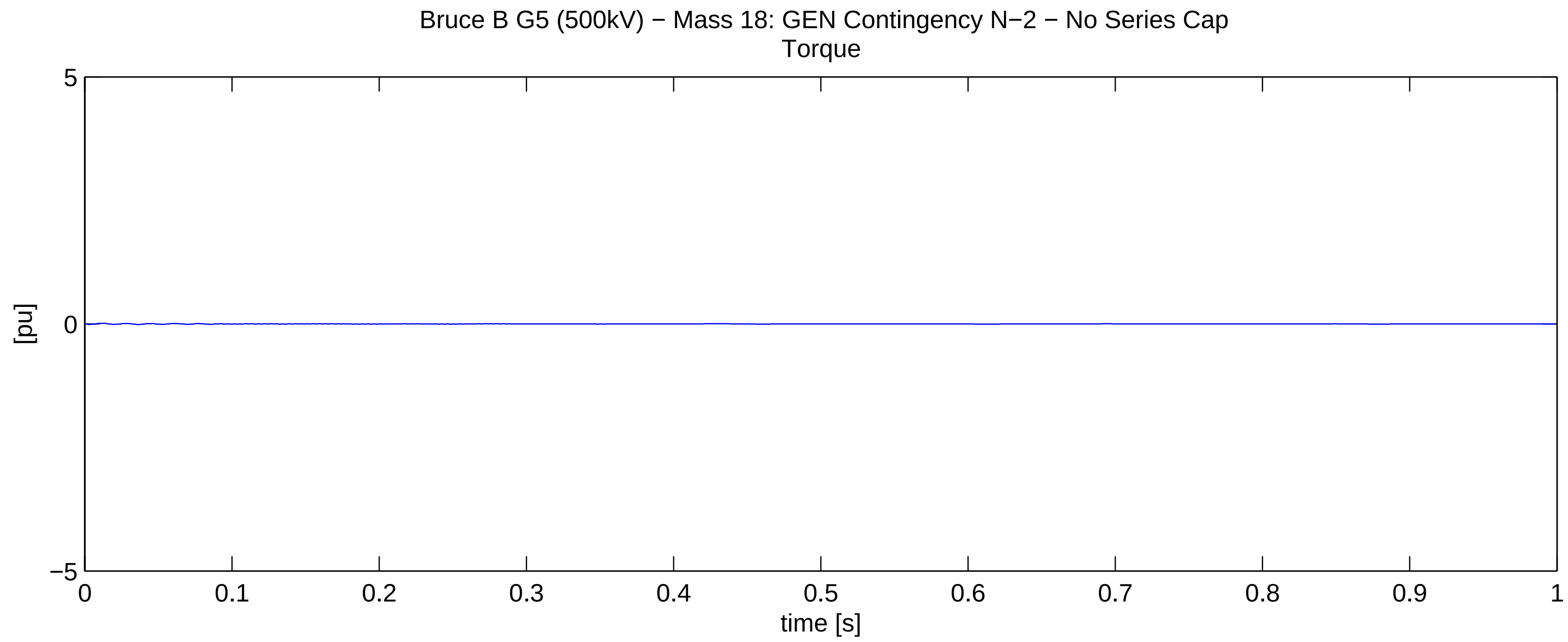


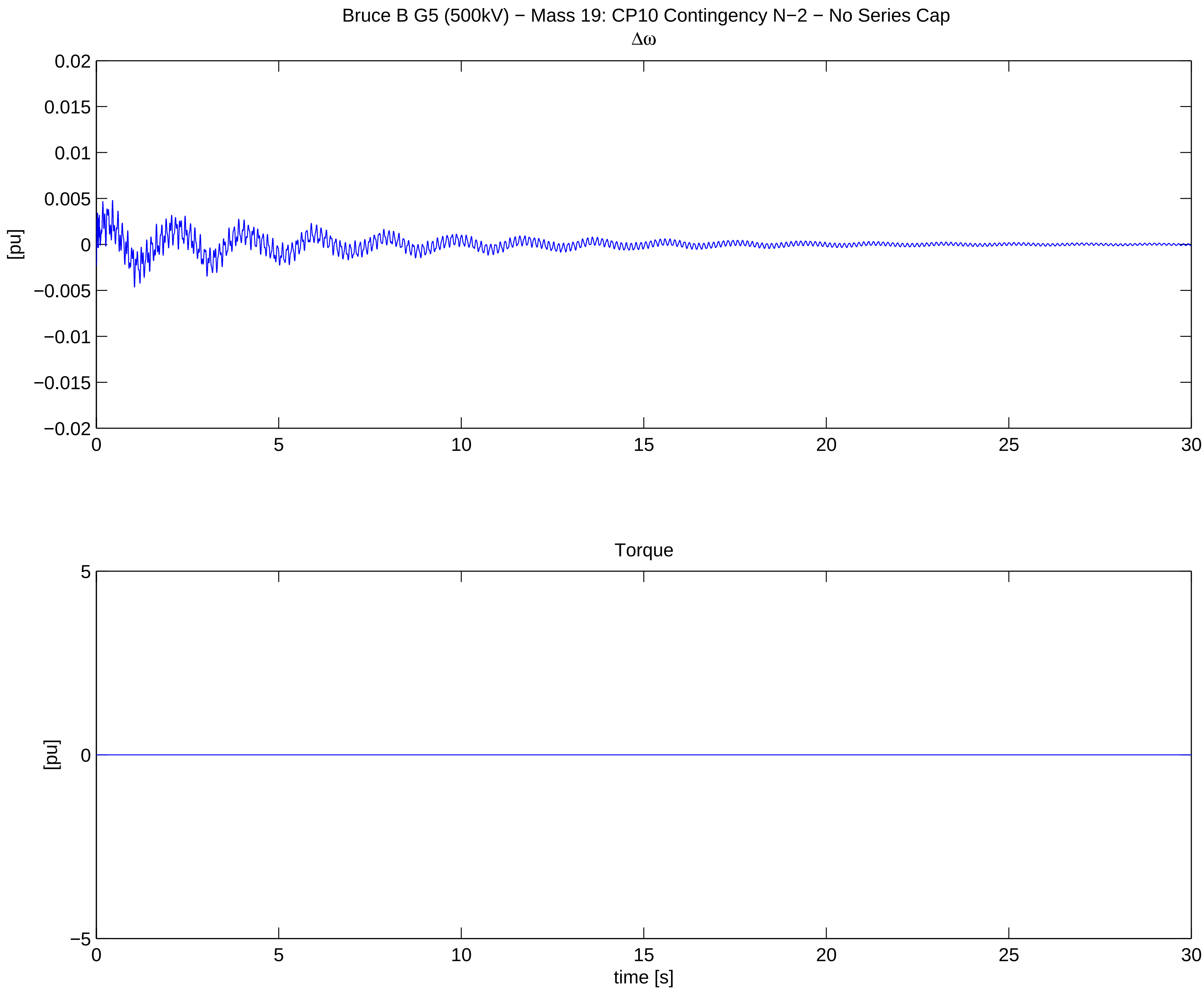
Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

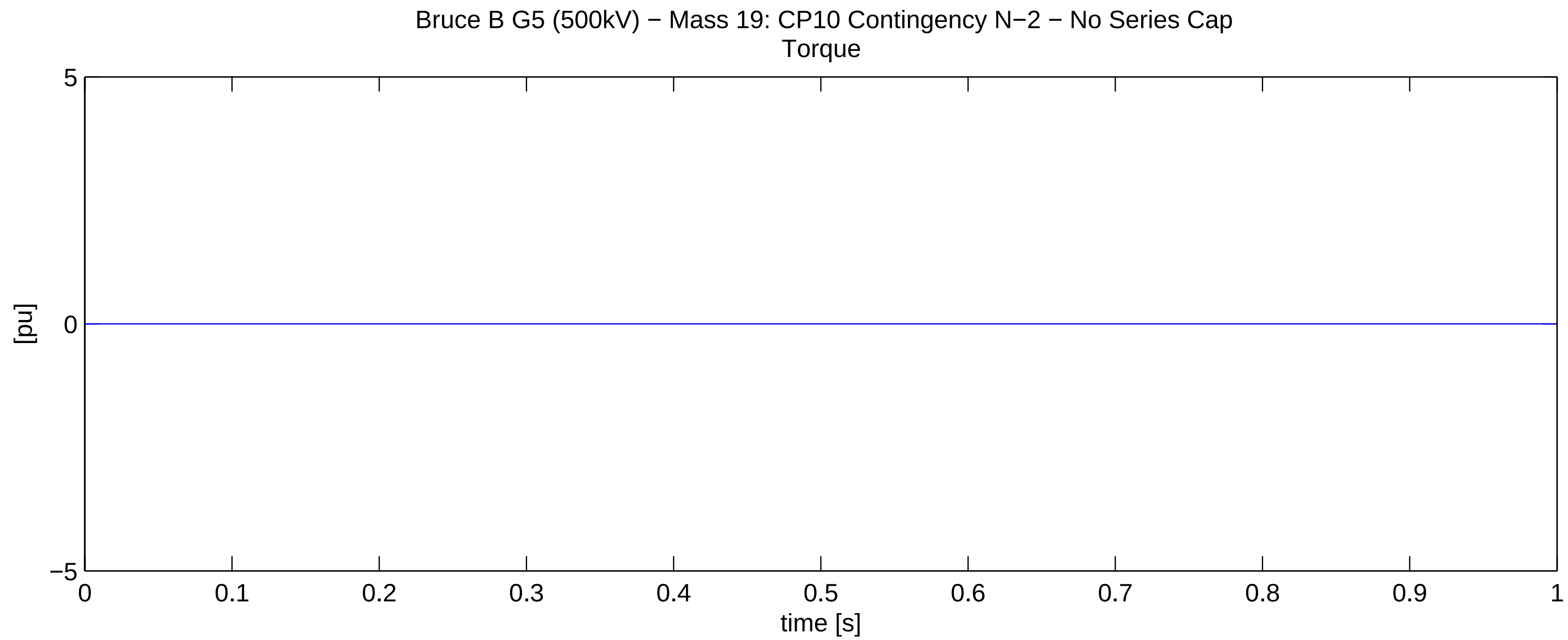

Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 18: GEN Contingency N−2 − No Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

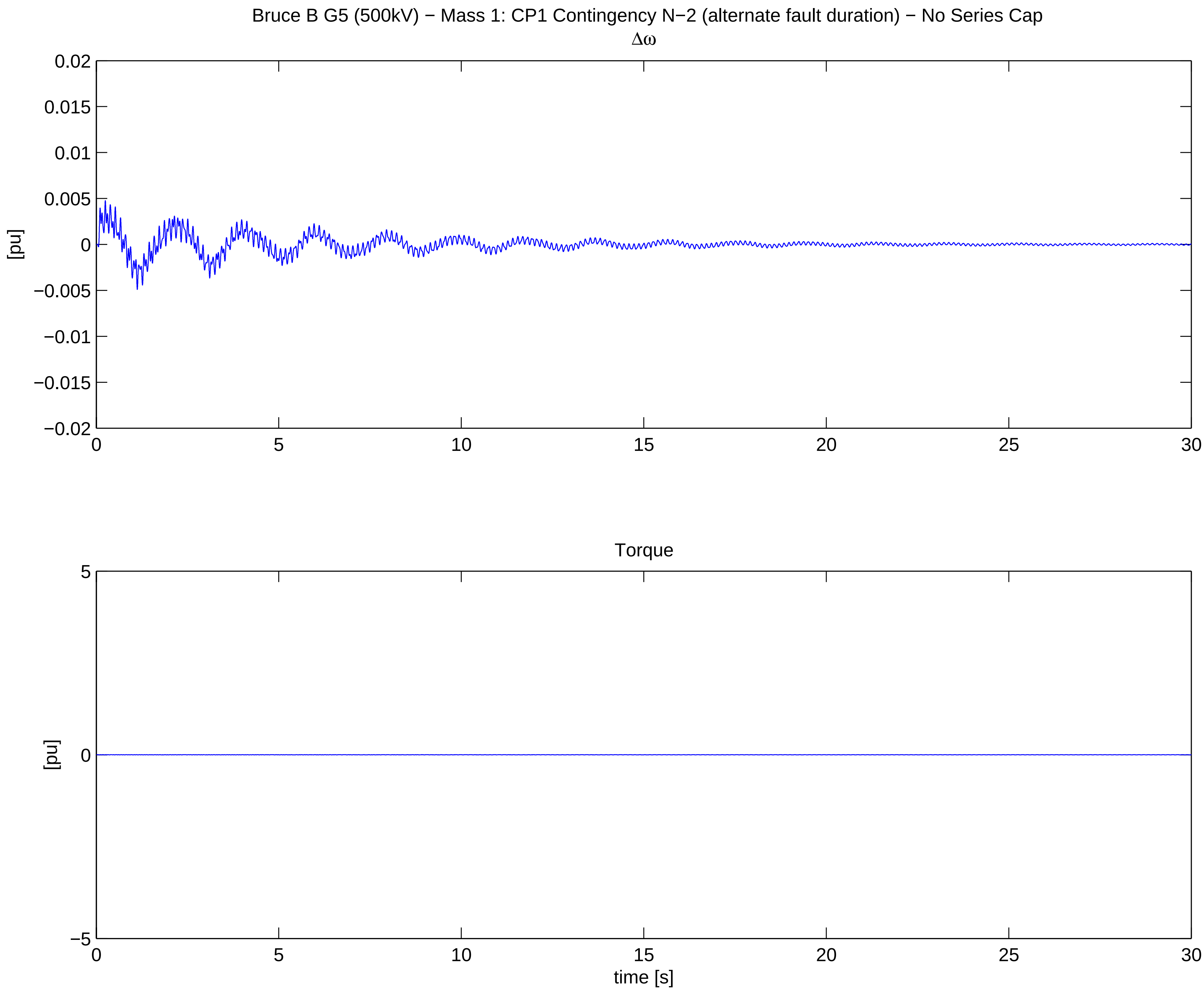

Bruce B G5 (500kV) − Mass 18: GEN Contingency N−2 − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

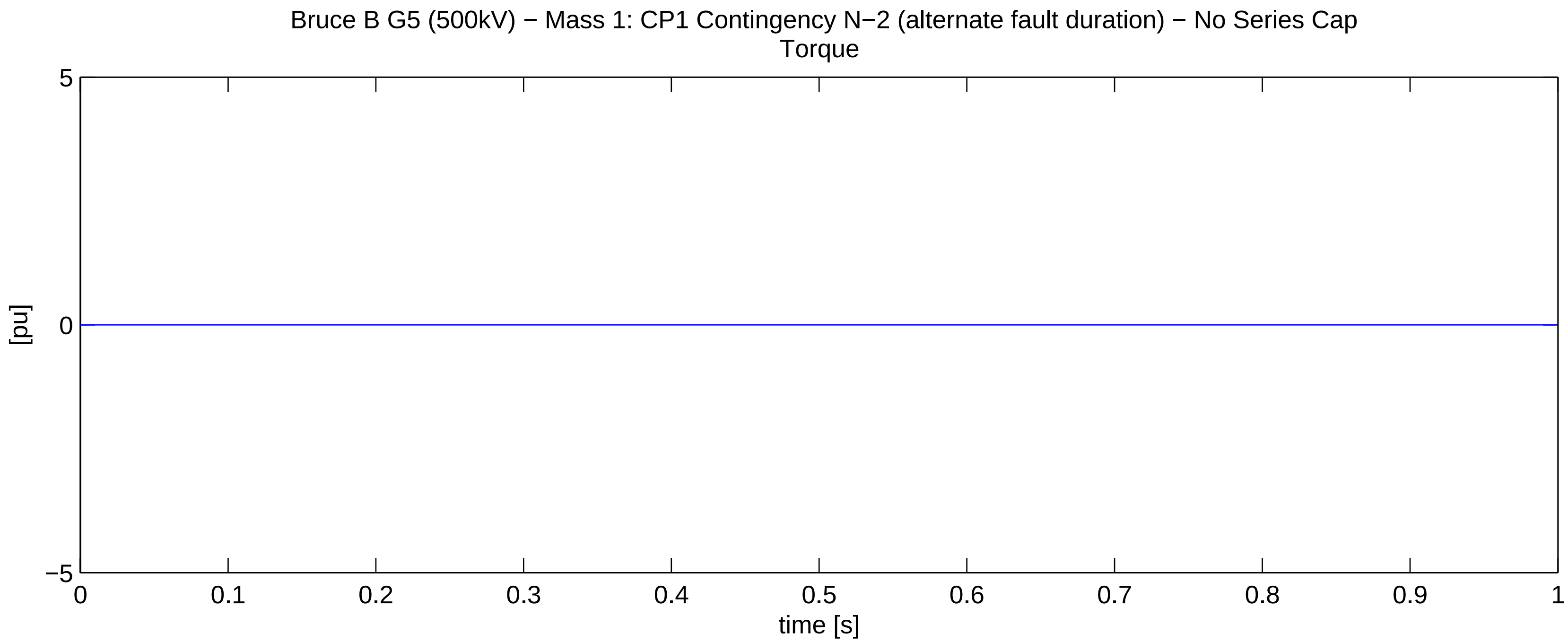


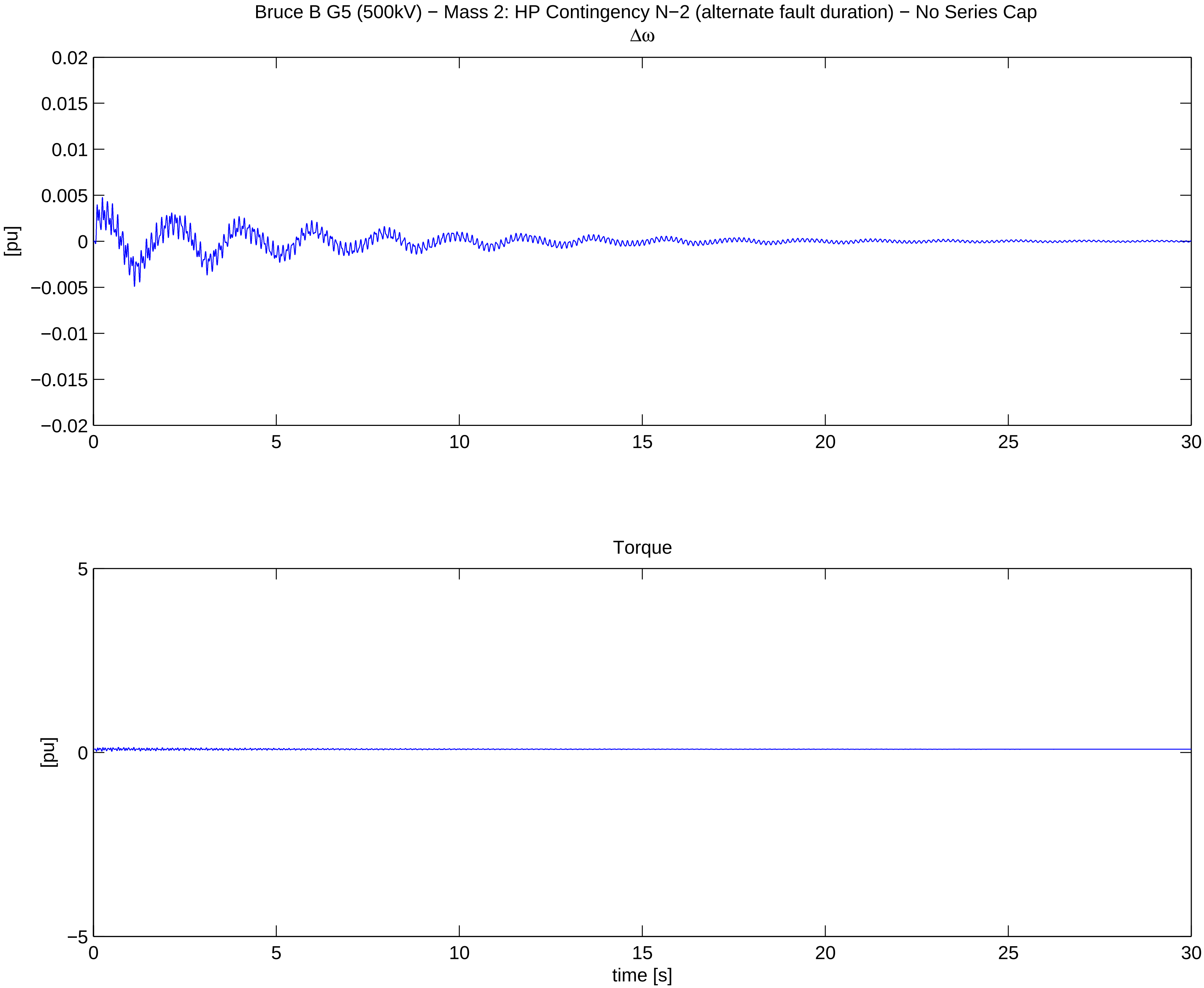
Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−2 − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



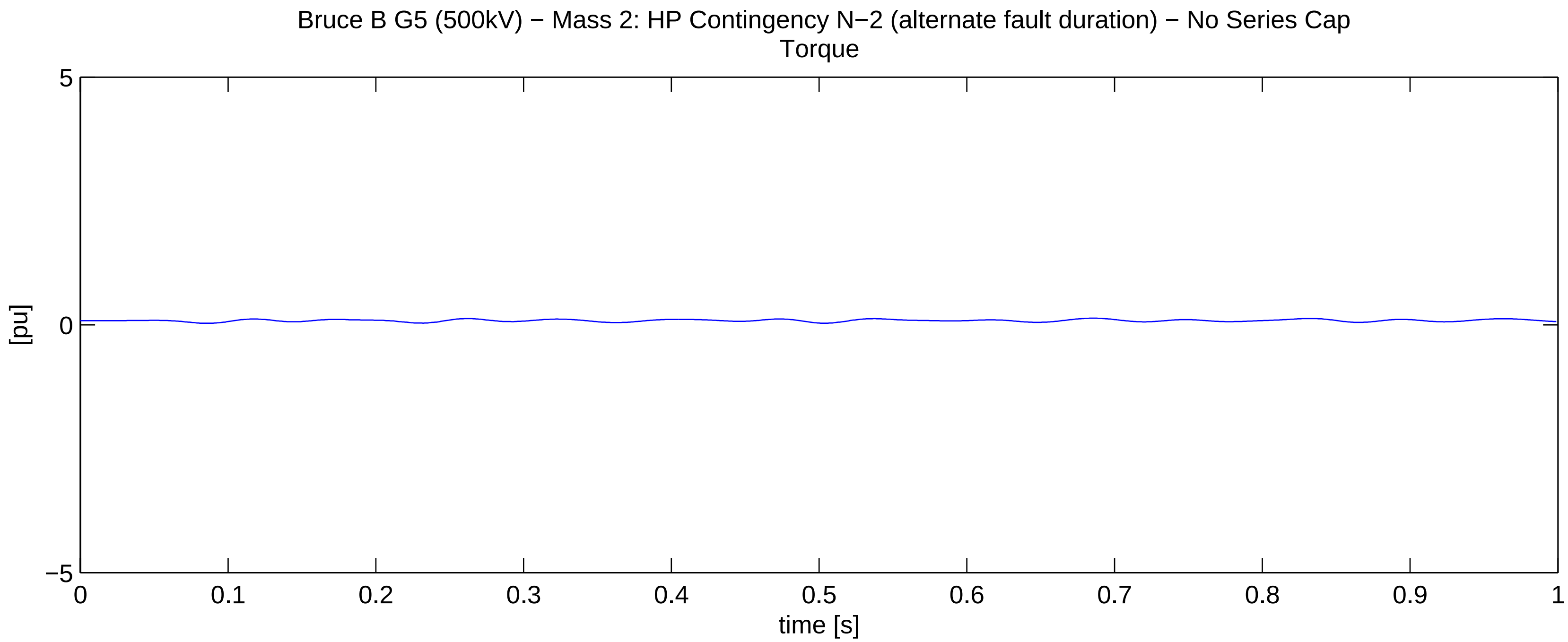
Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−2 − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

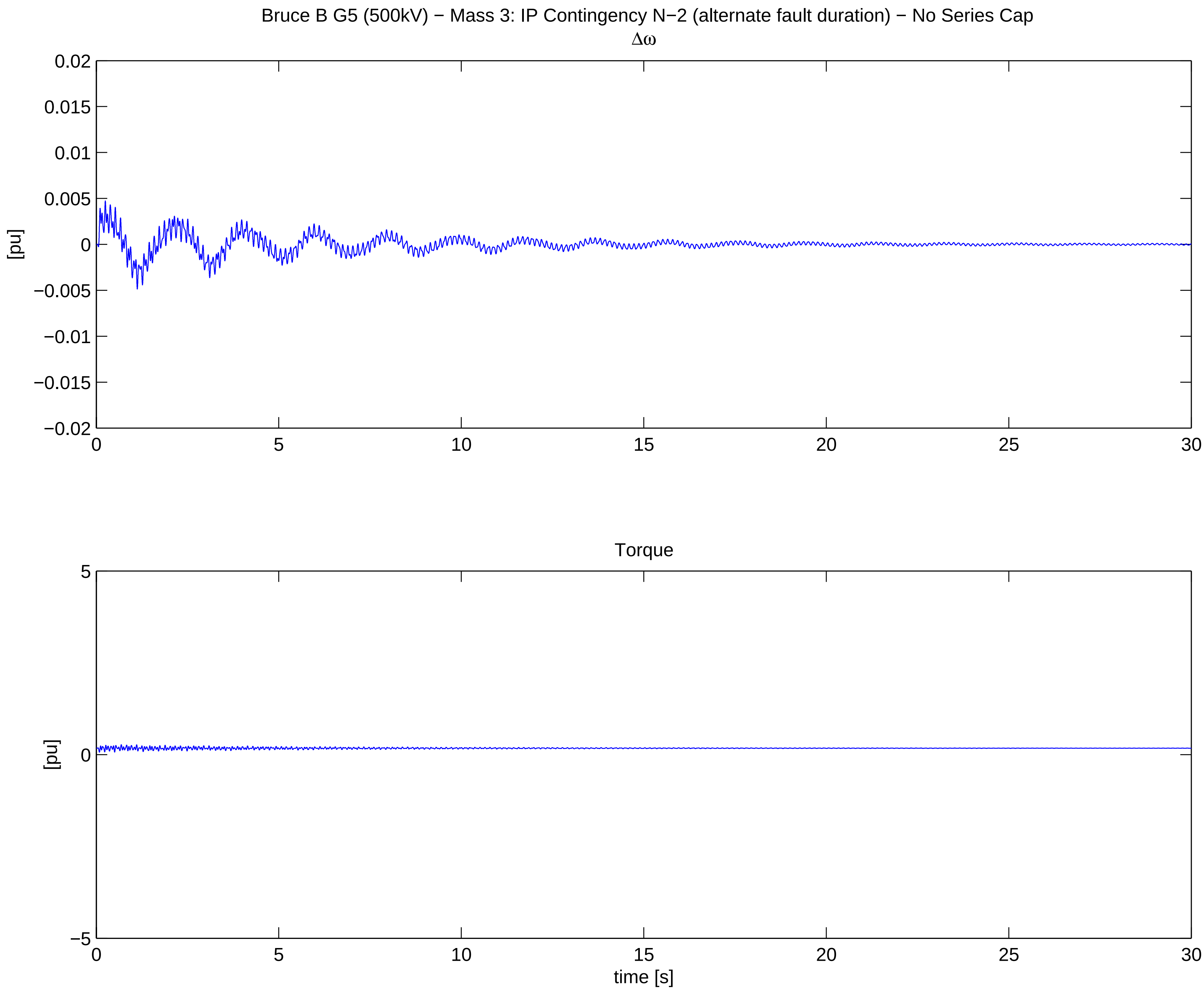

Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

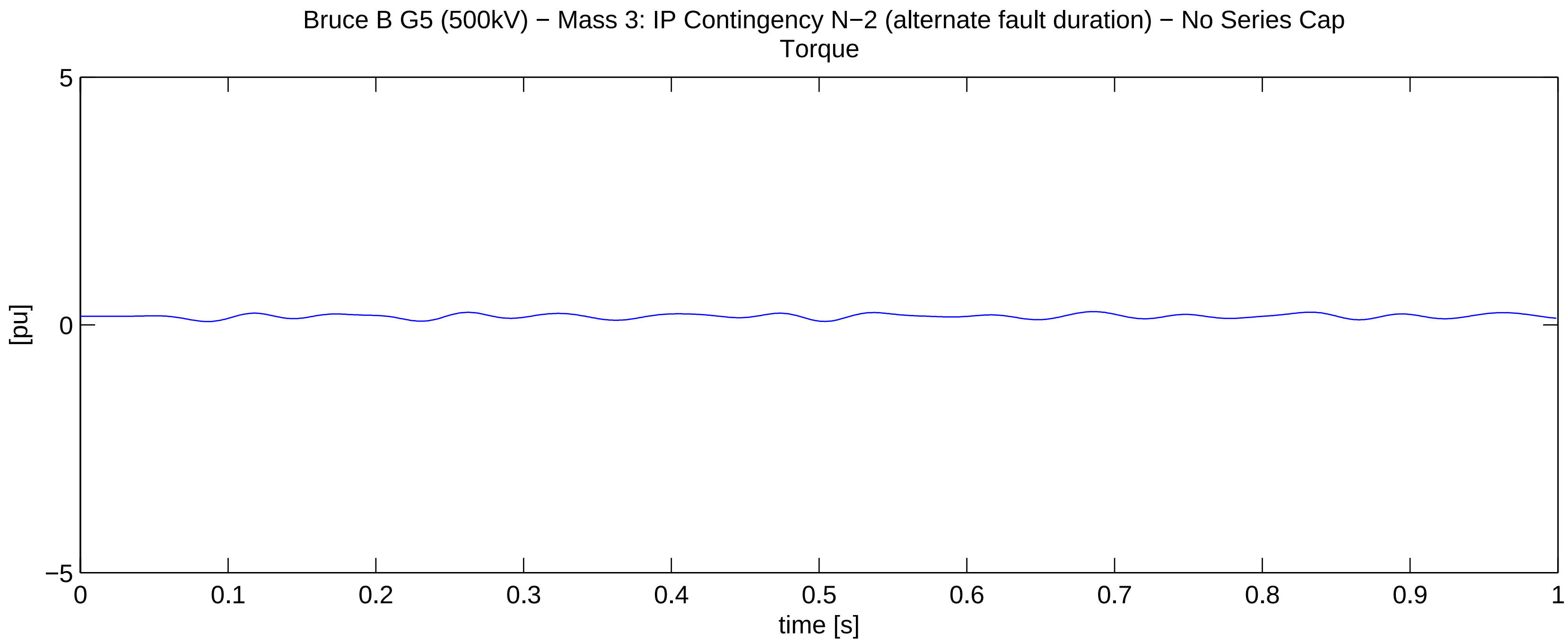


Bruce B G5 (500kV) − Mass 2: HP Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

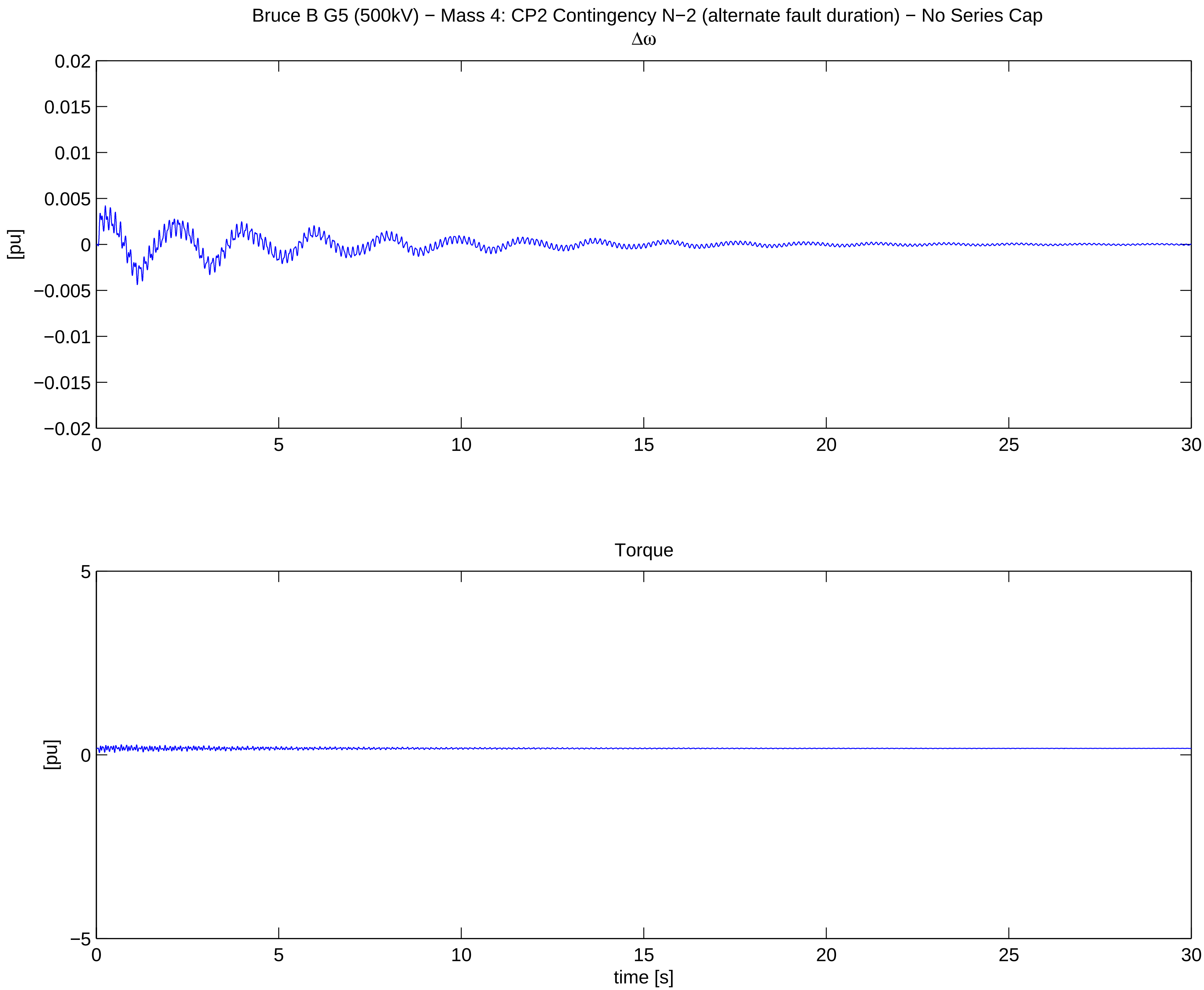

Bruce B G5 (500kV) − Mass 2: HP Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

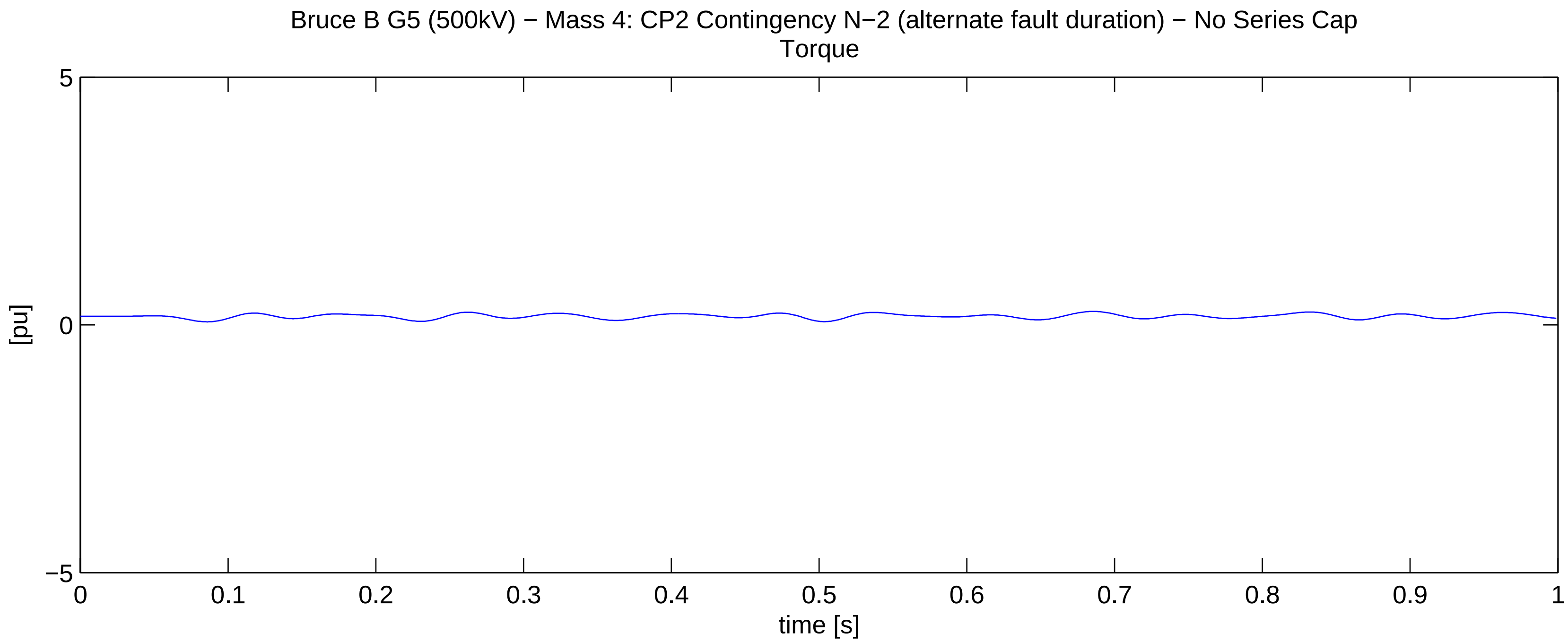


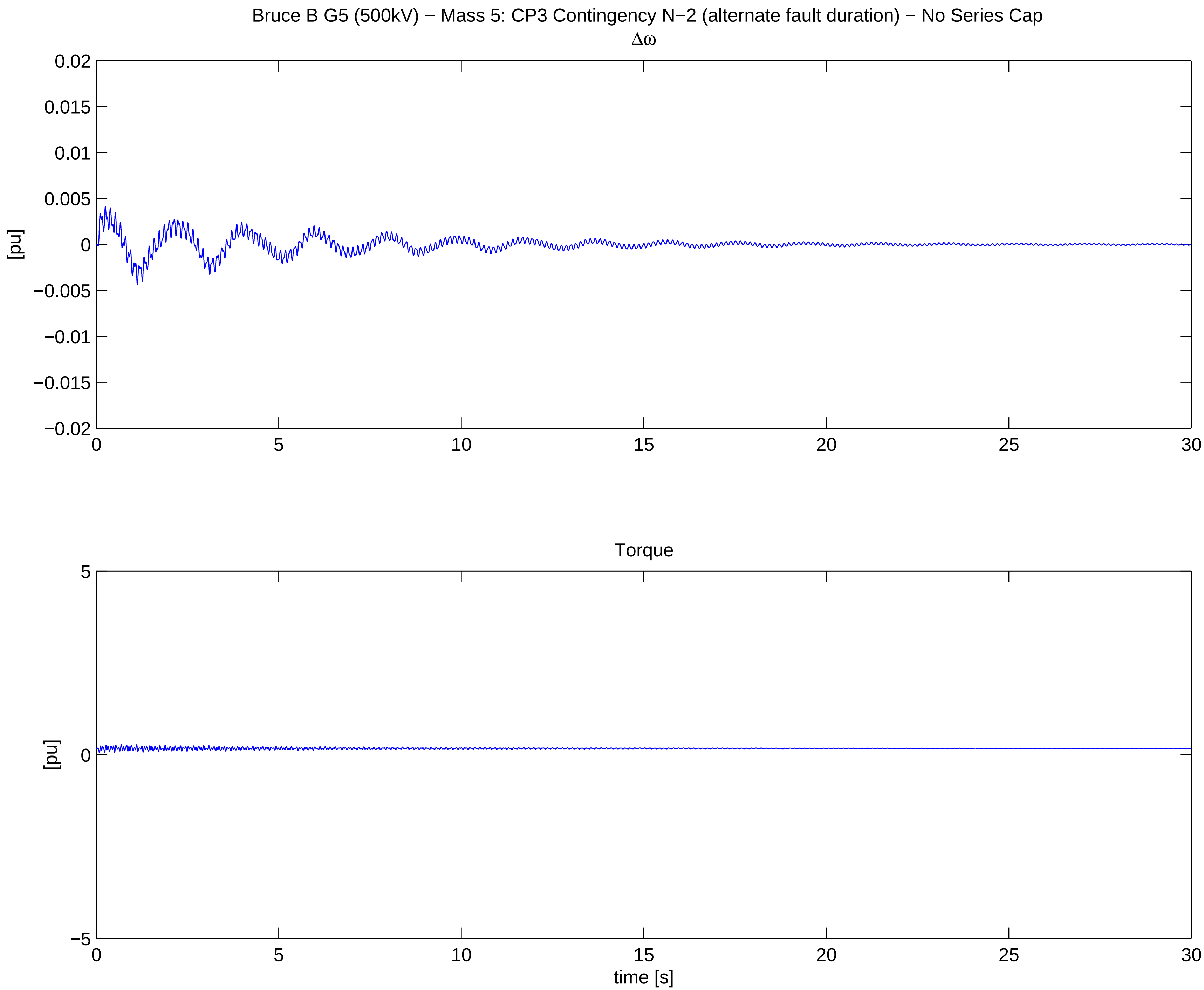
Bruce B G5 (500kV) − Mass 3: IP Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



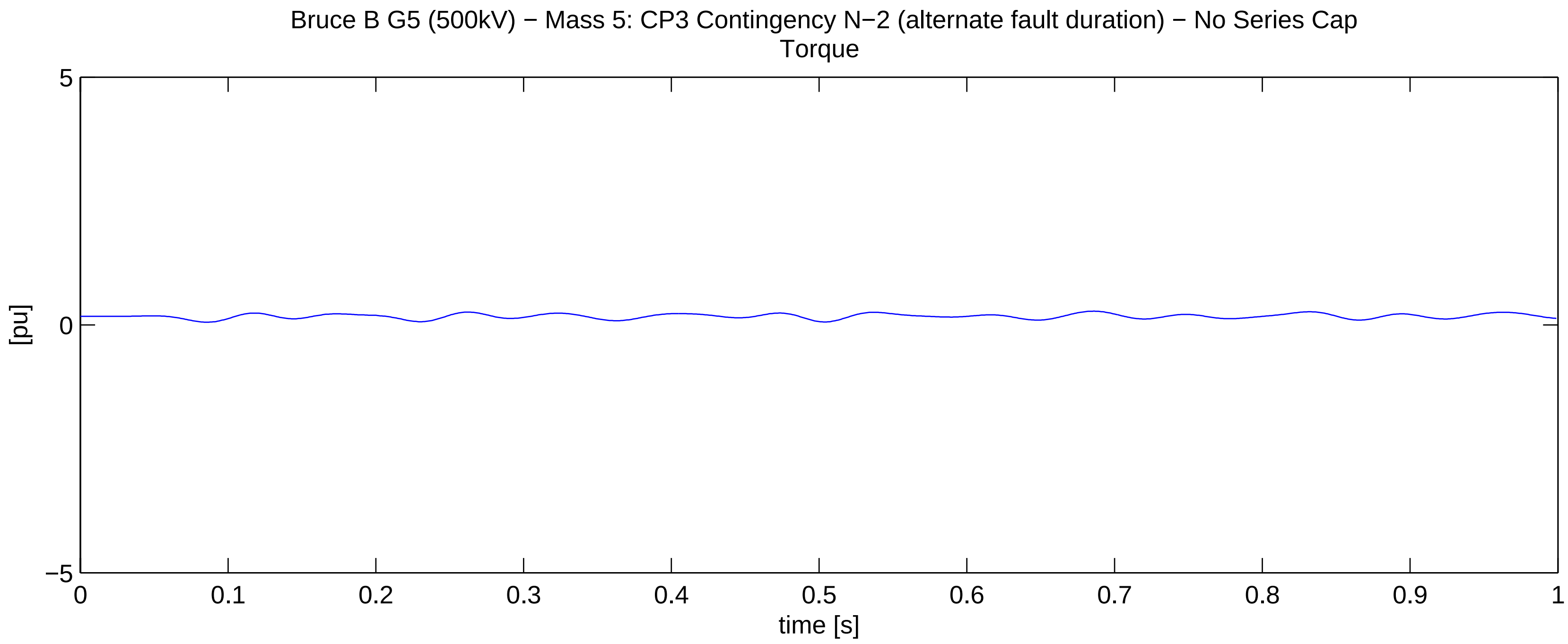
Bruce B G5 (500kV) − Mass 3: IP Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

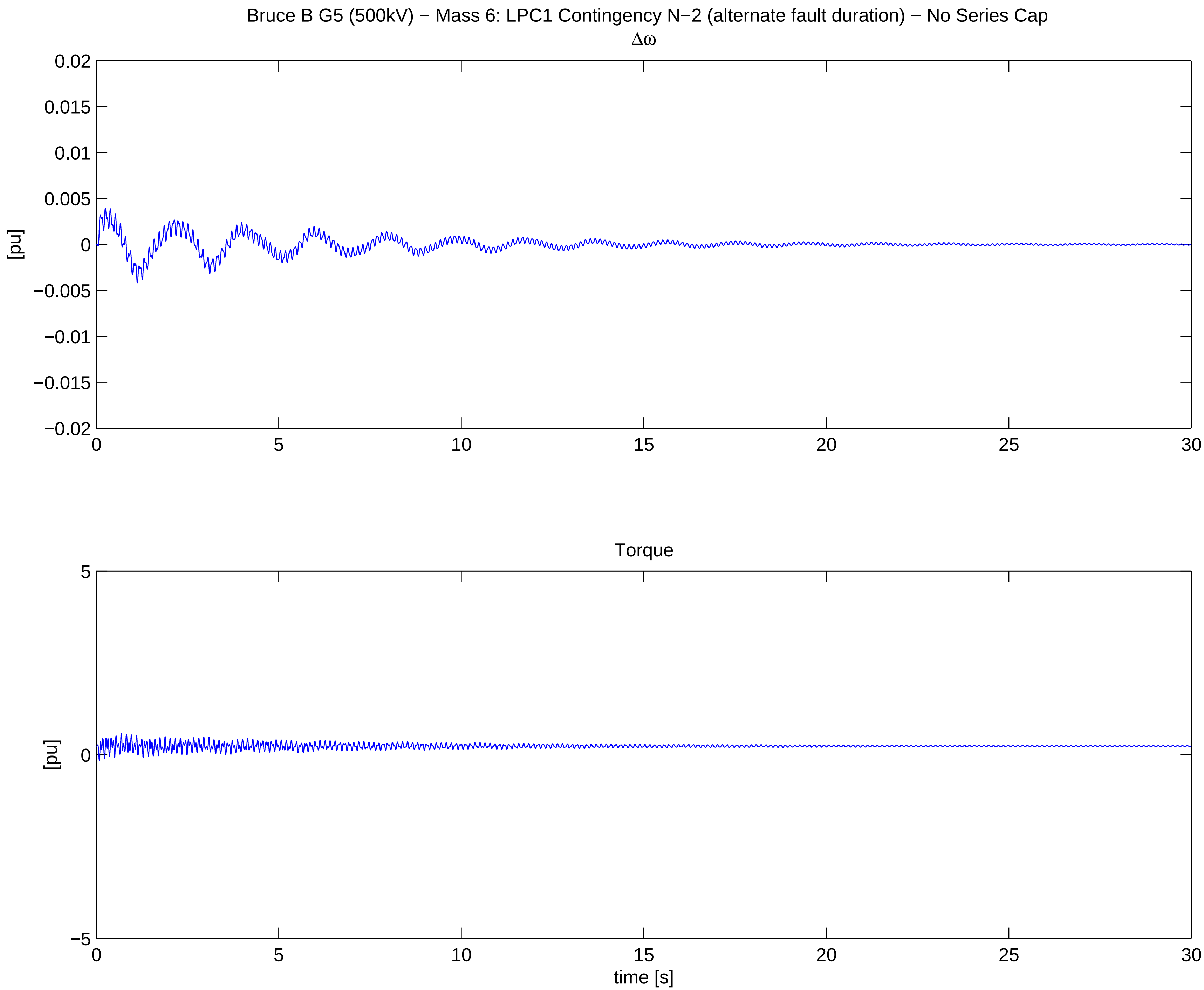

Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



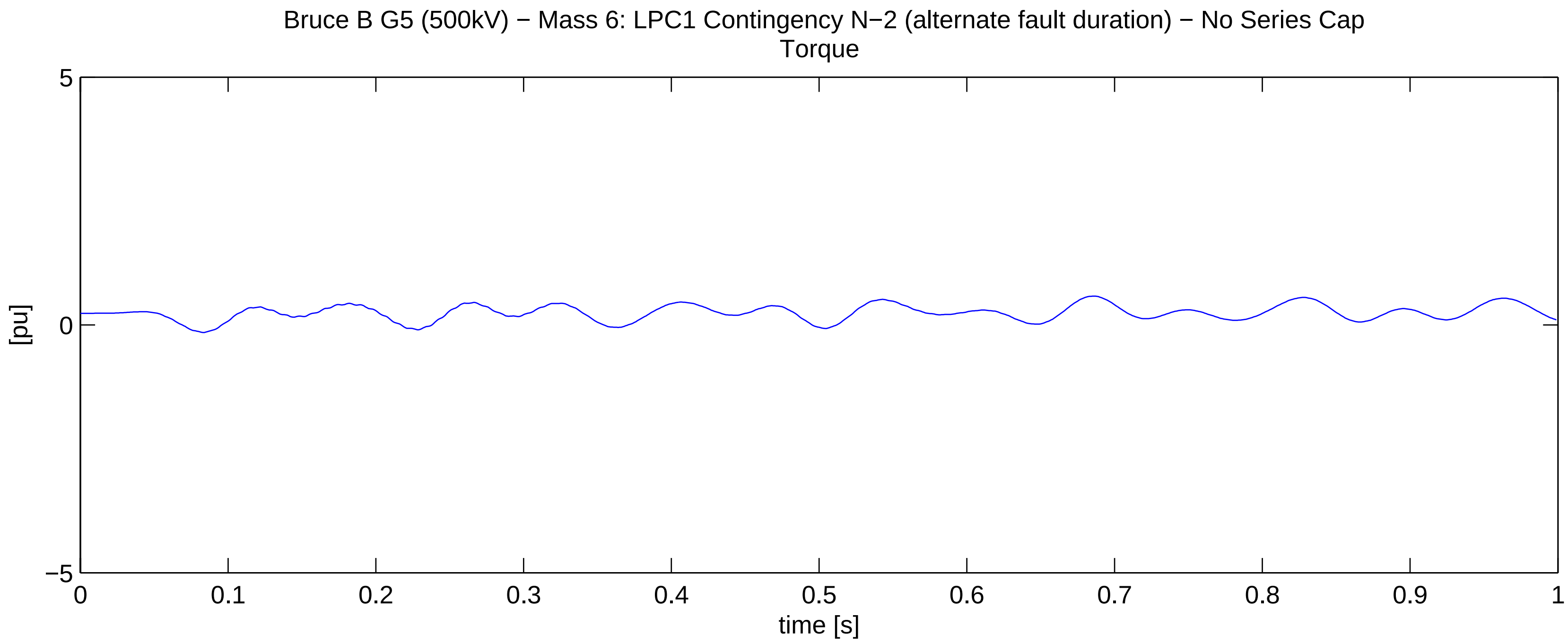
Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
time [s]



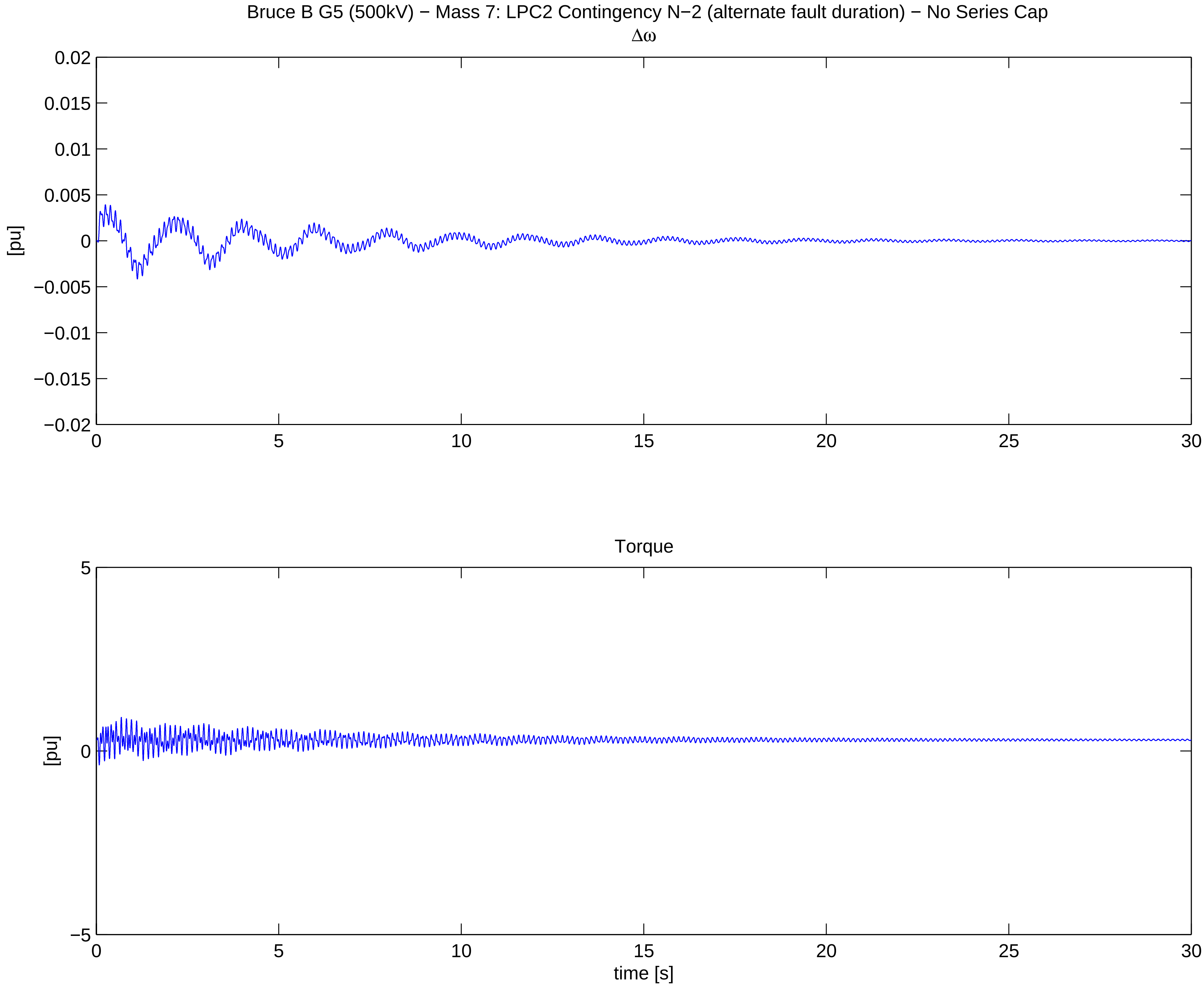
Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



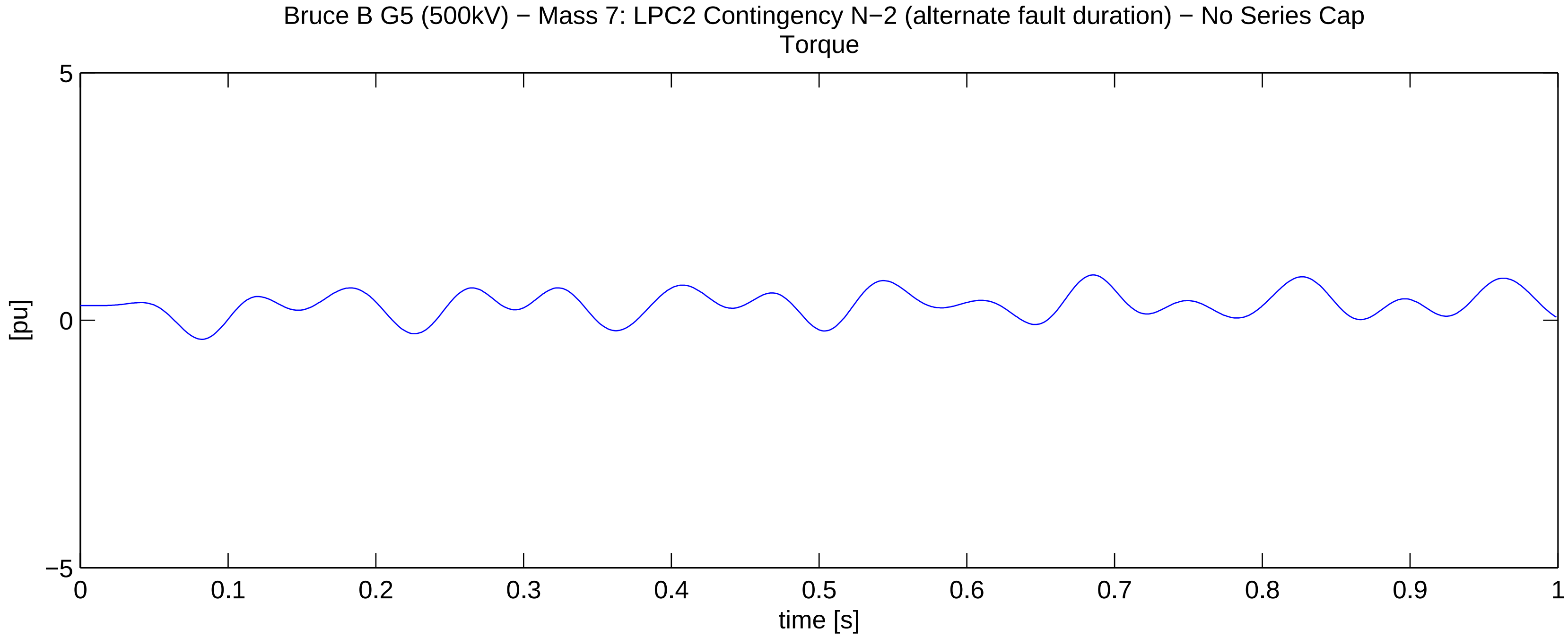
Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
time [s]



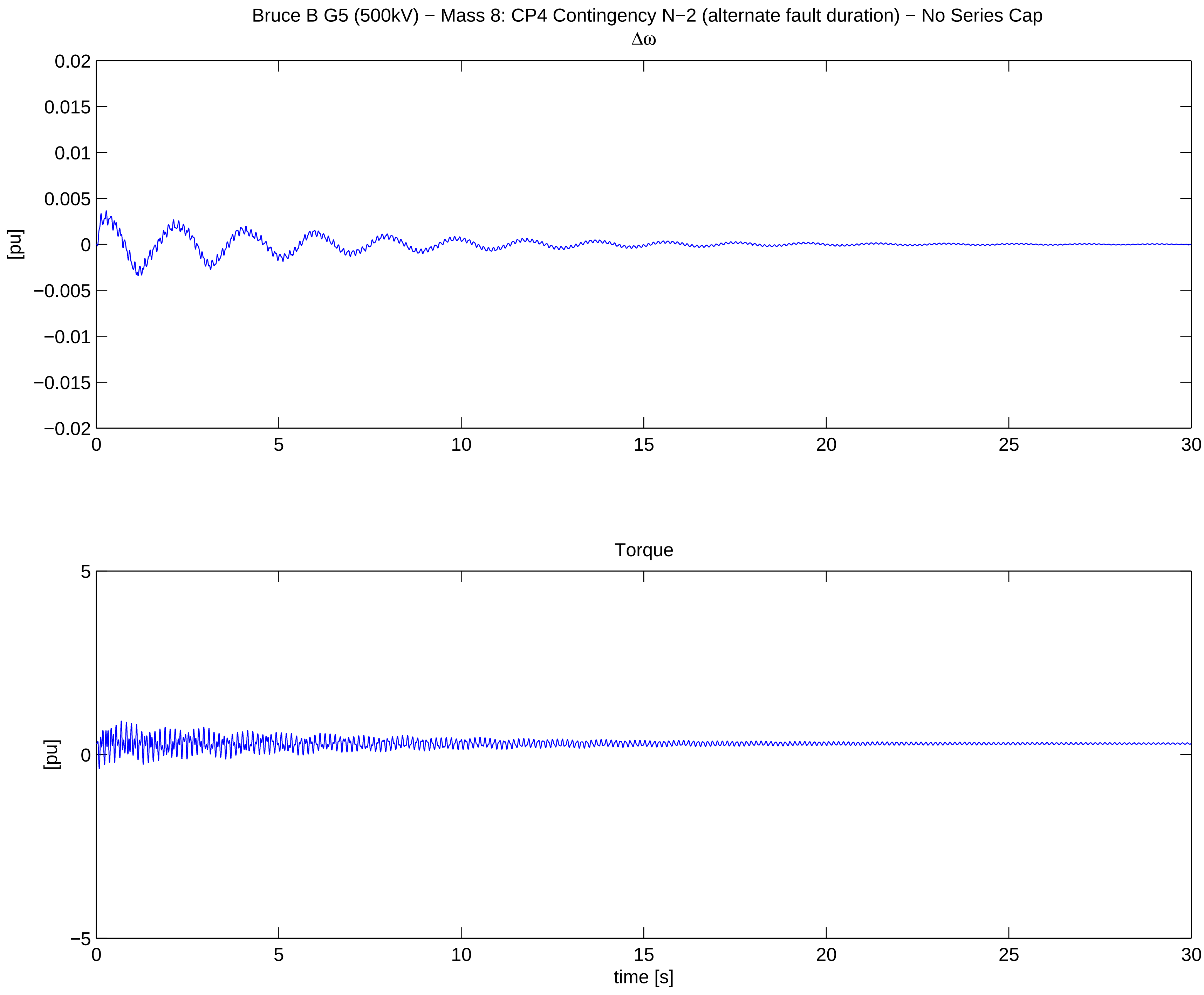
Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



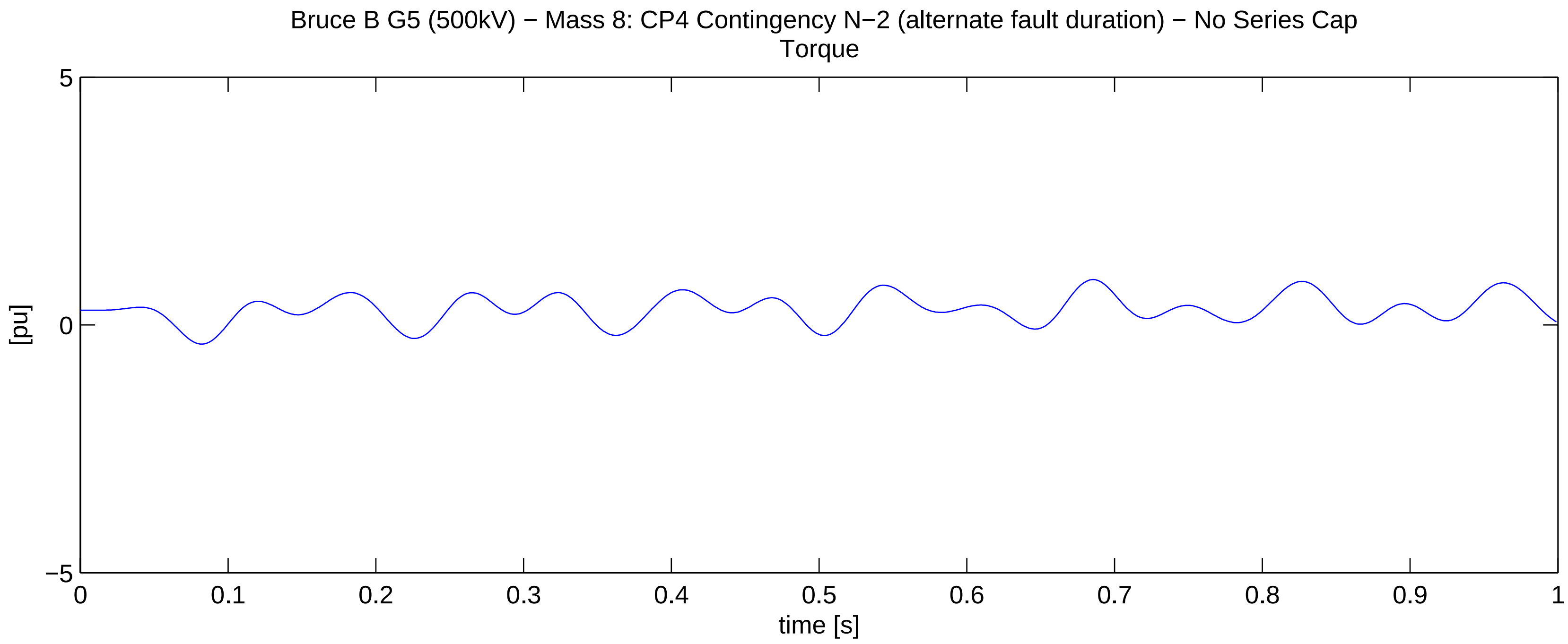
Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



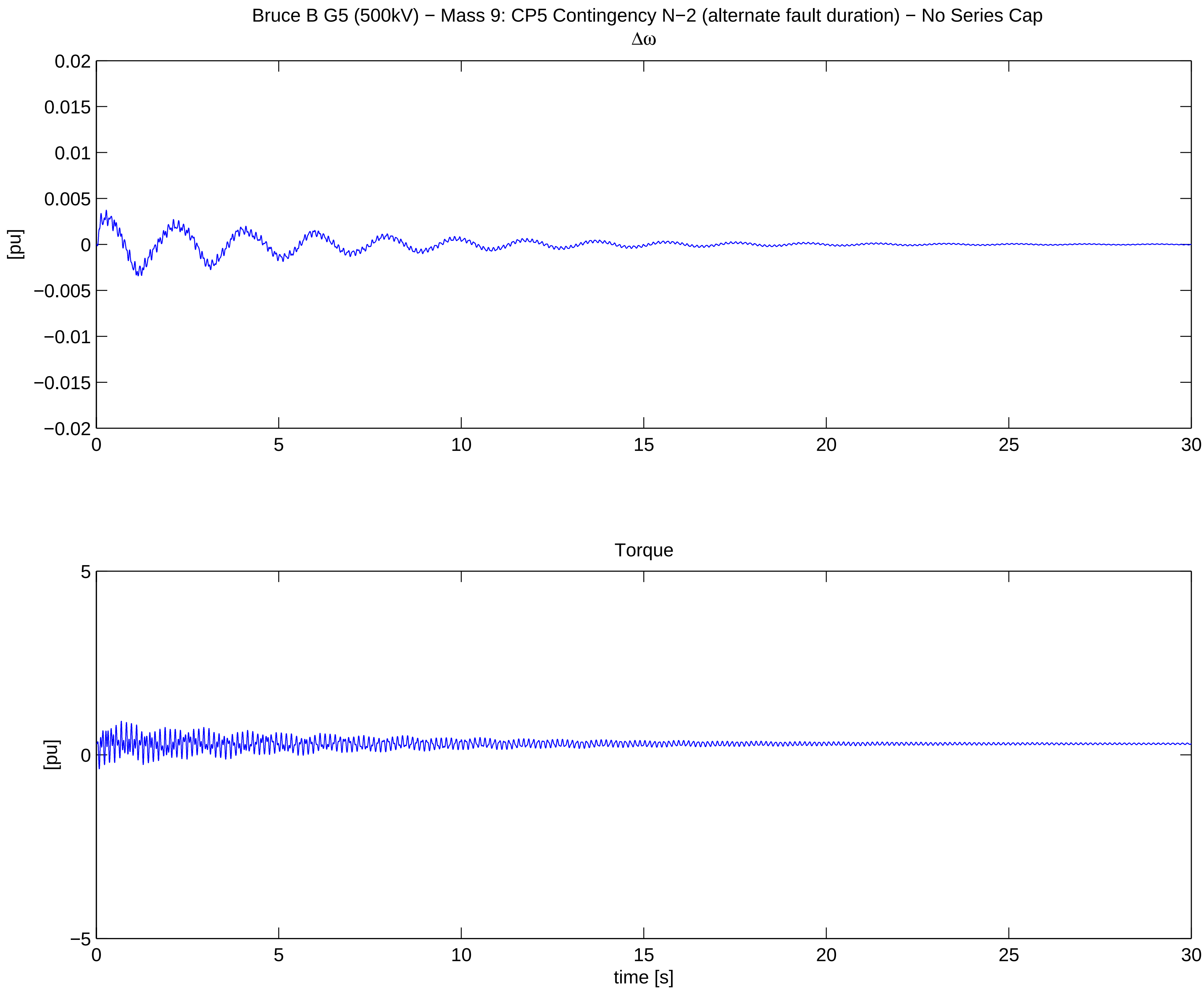
Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



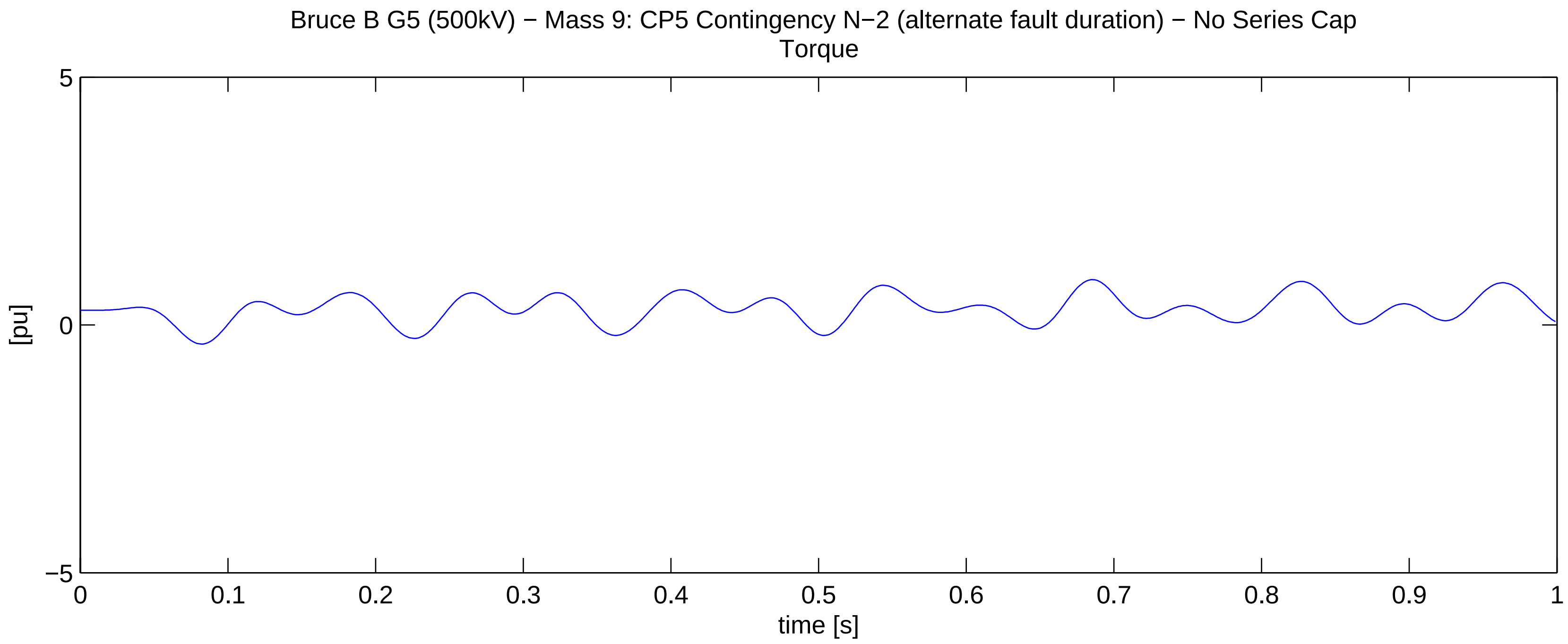
Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

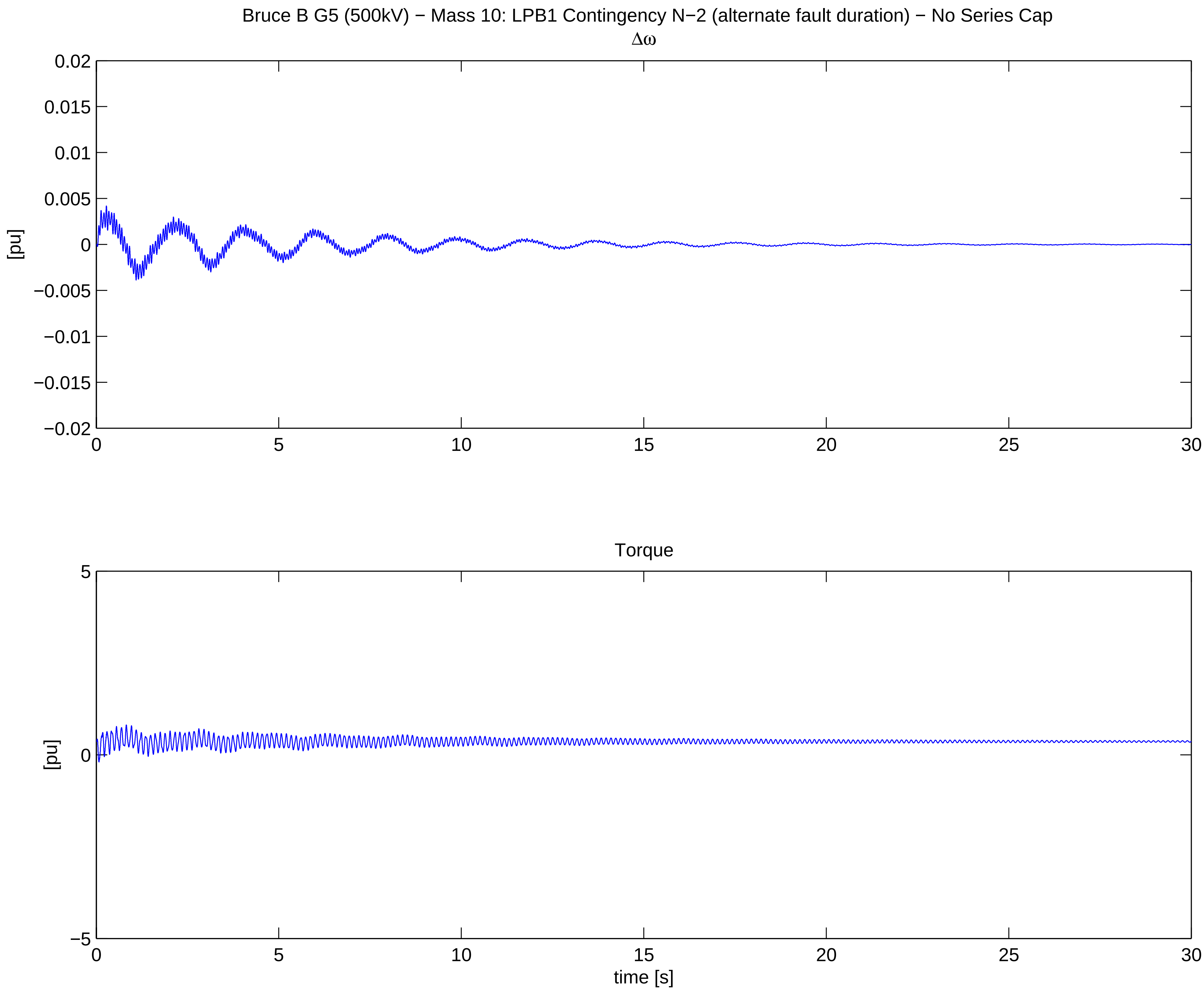


Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

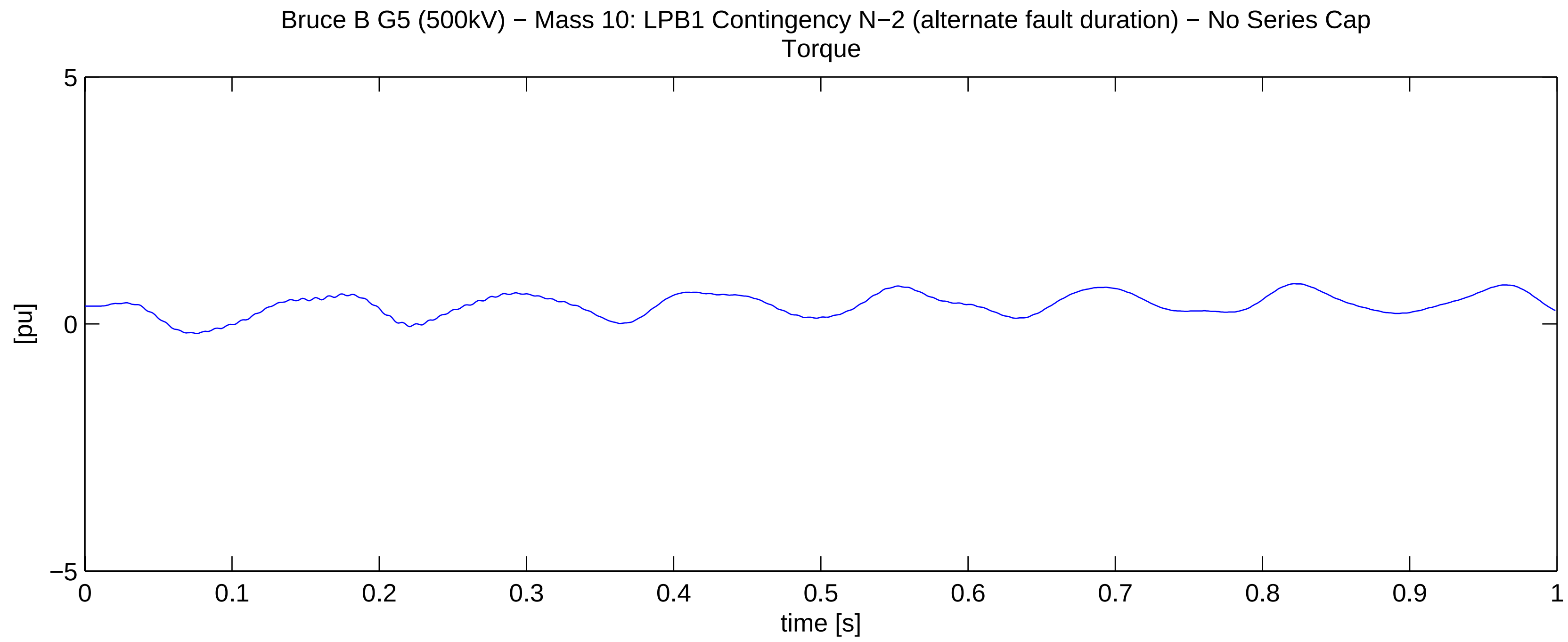


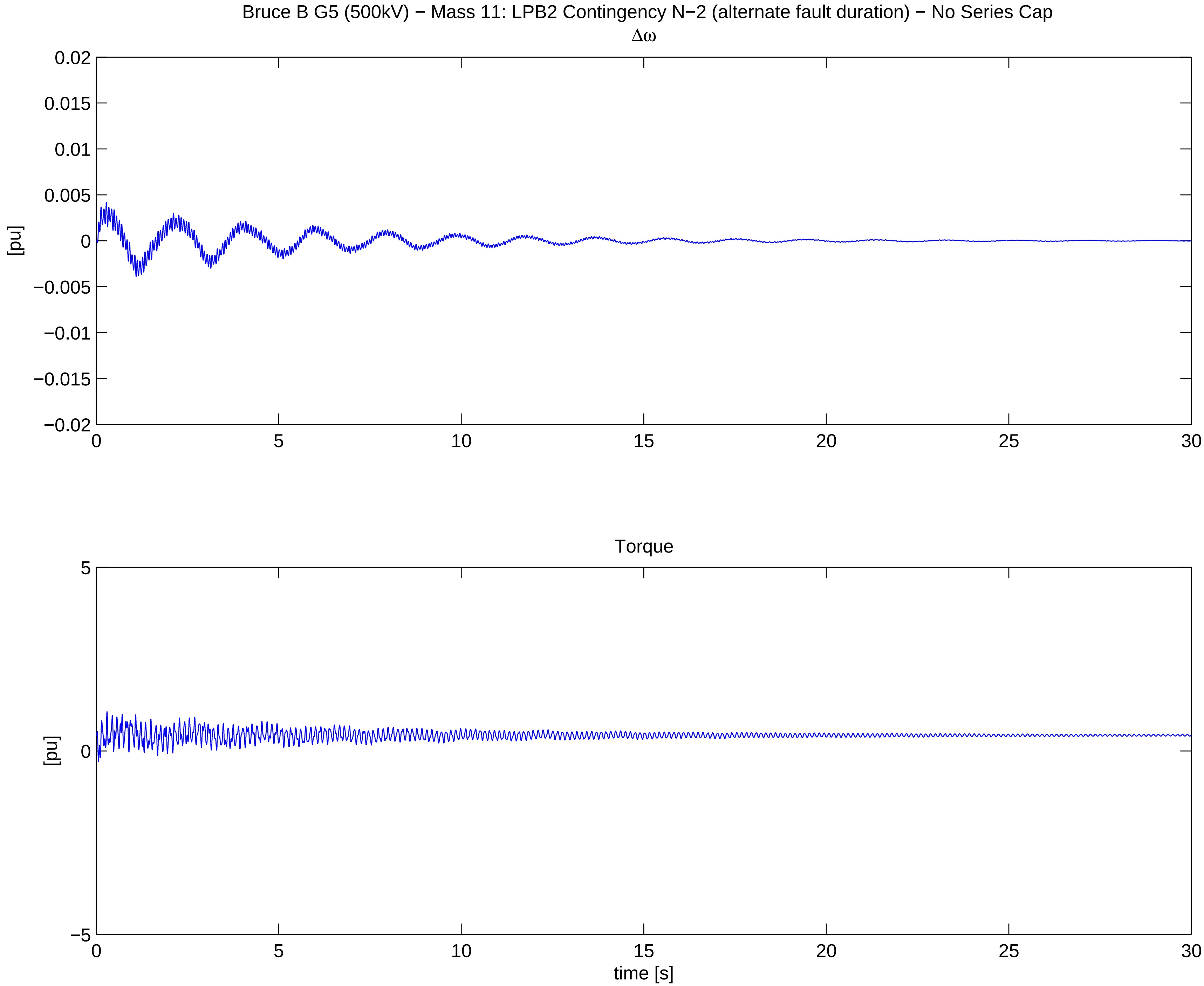
Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

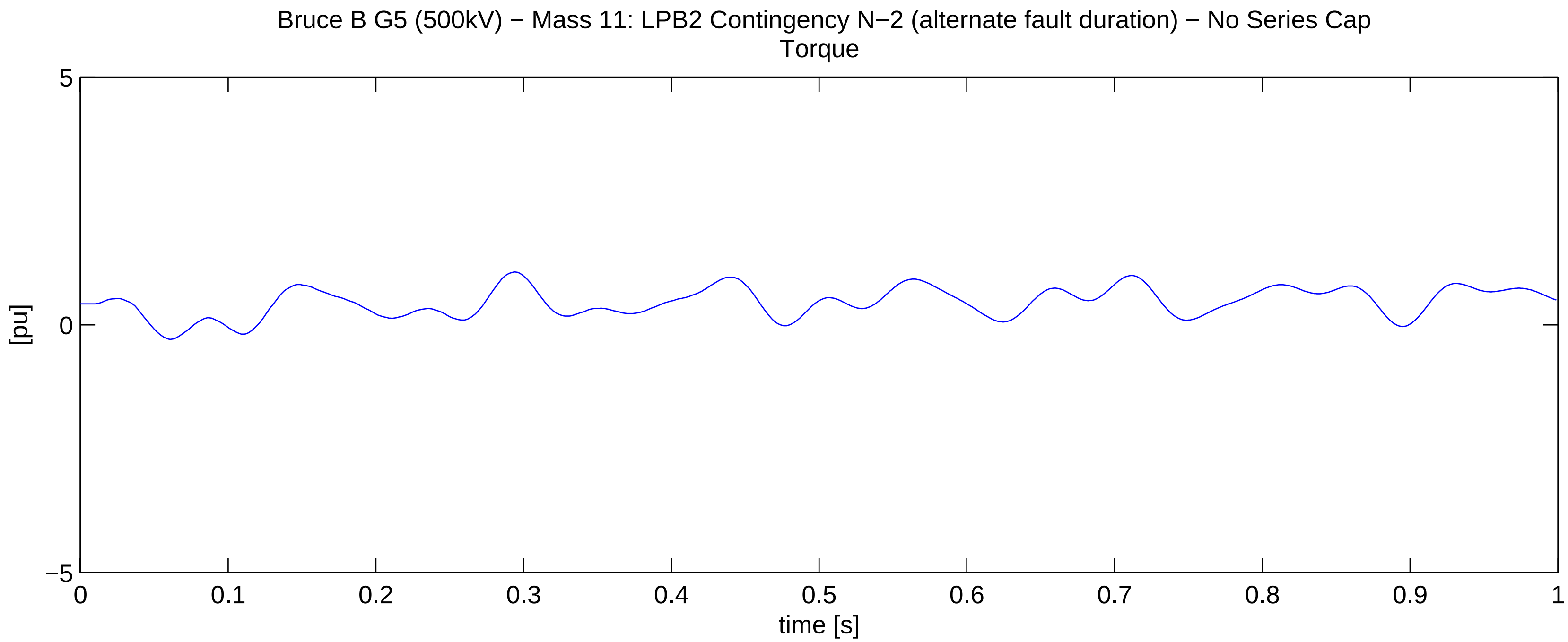

Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



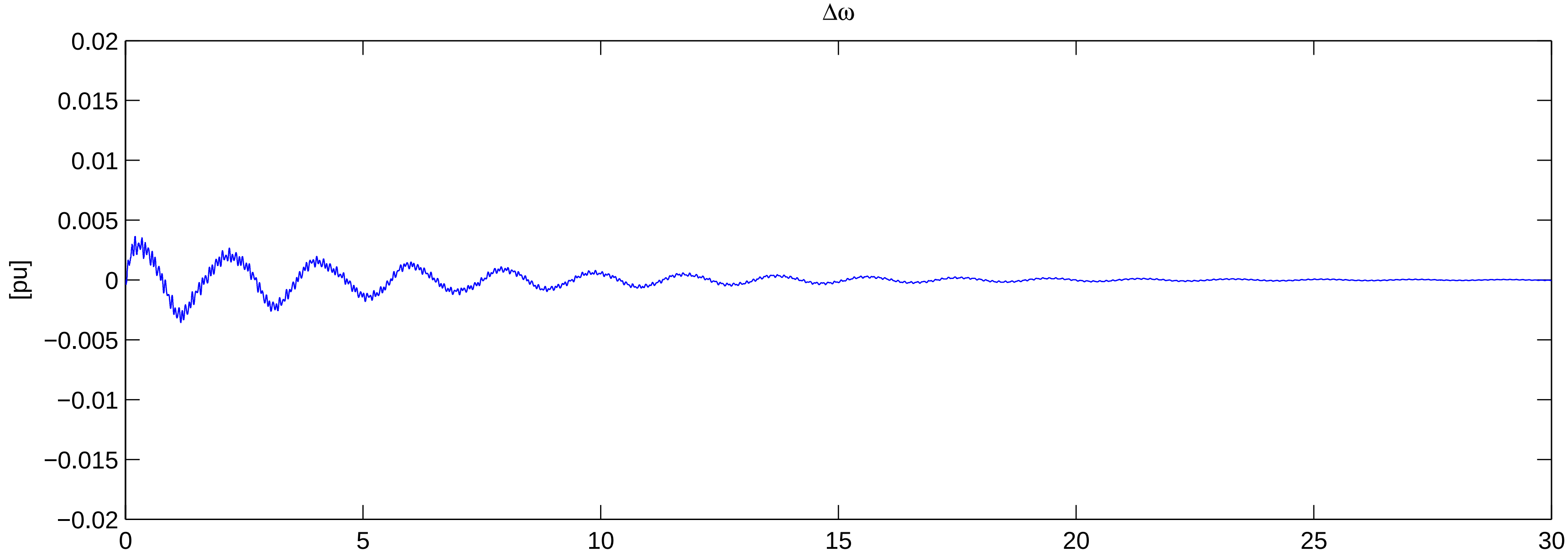
Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

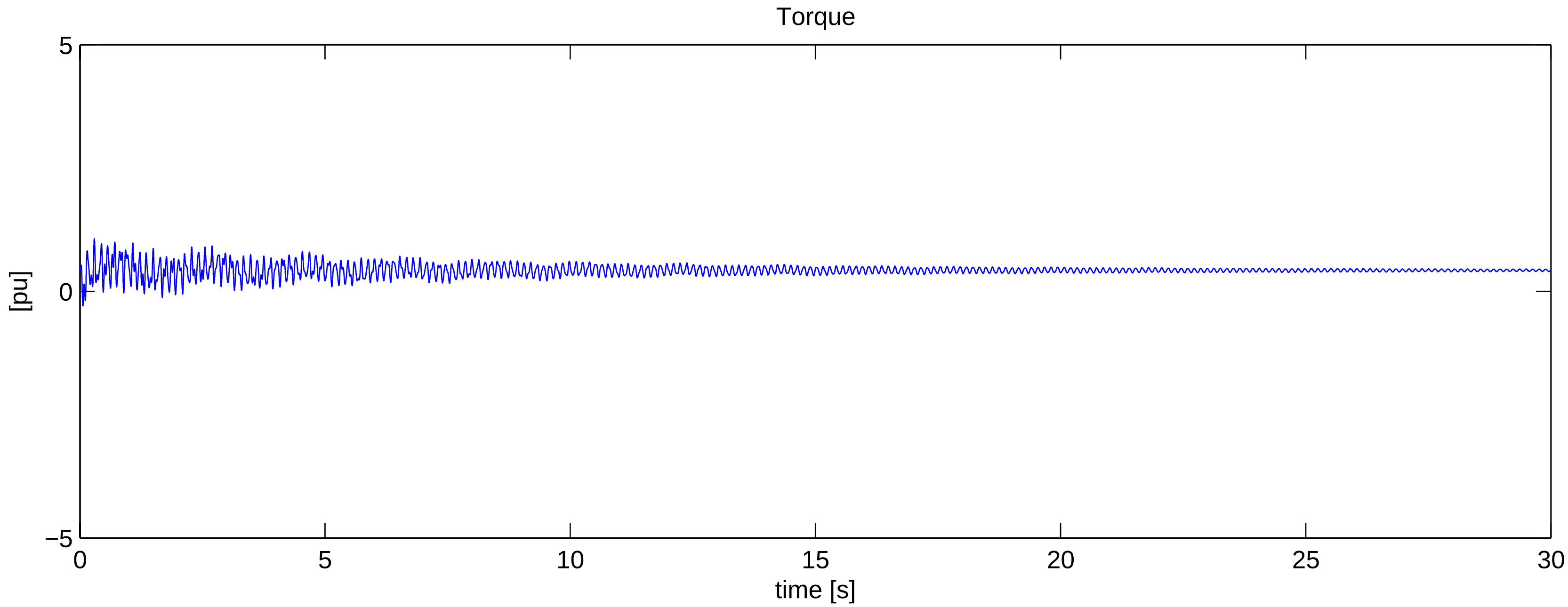

Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

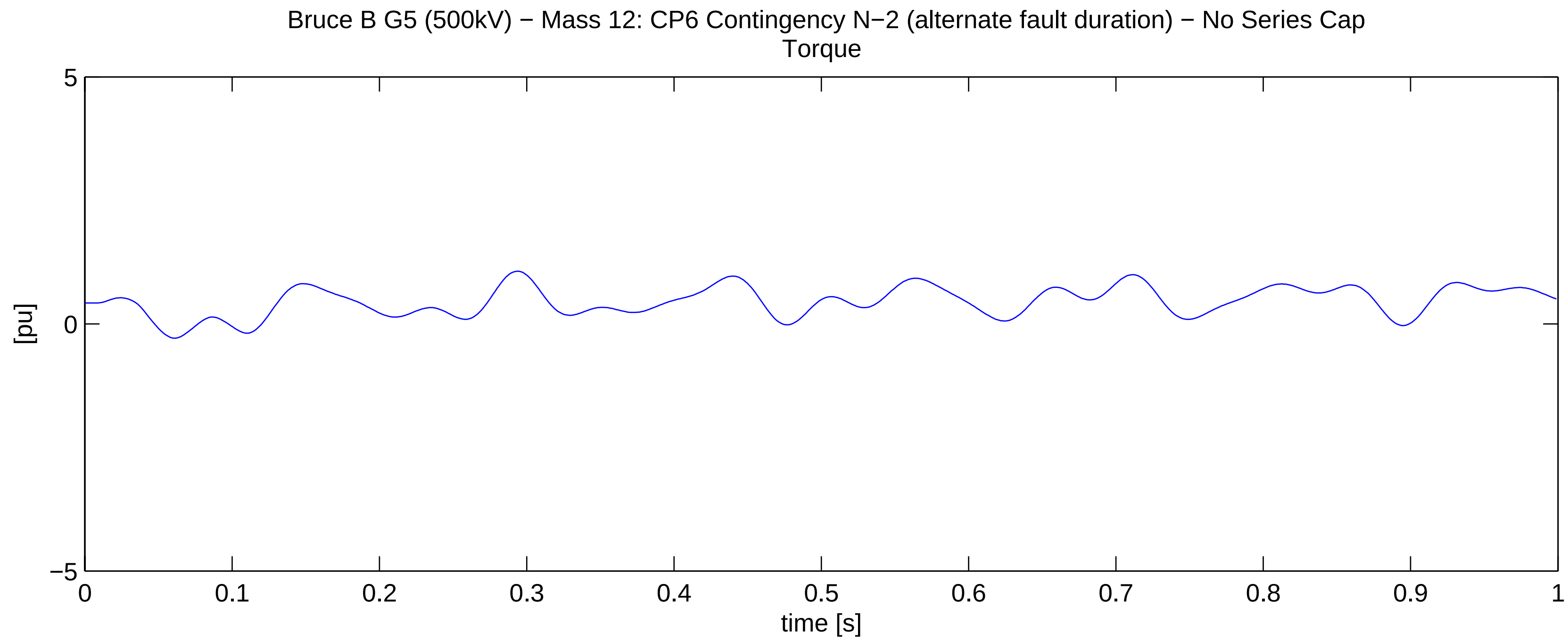

Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

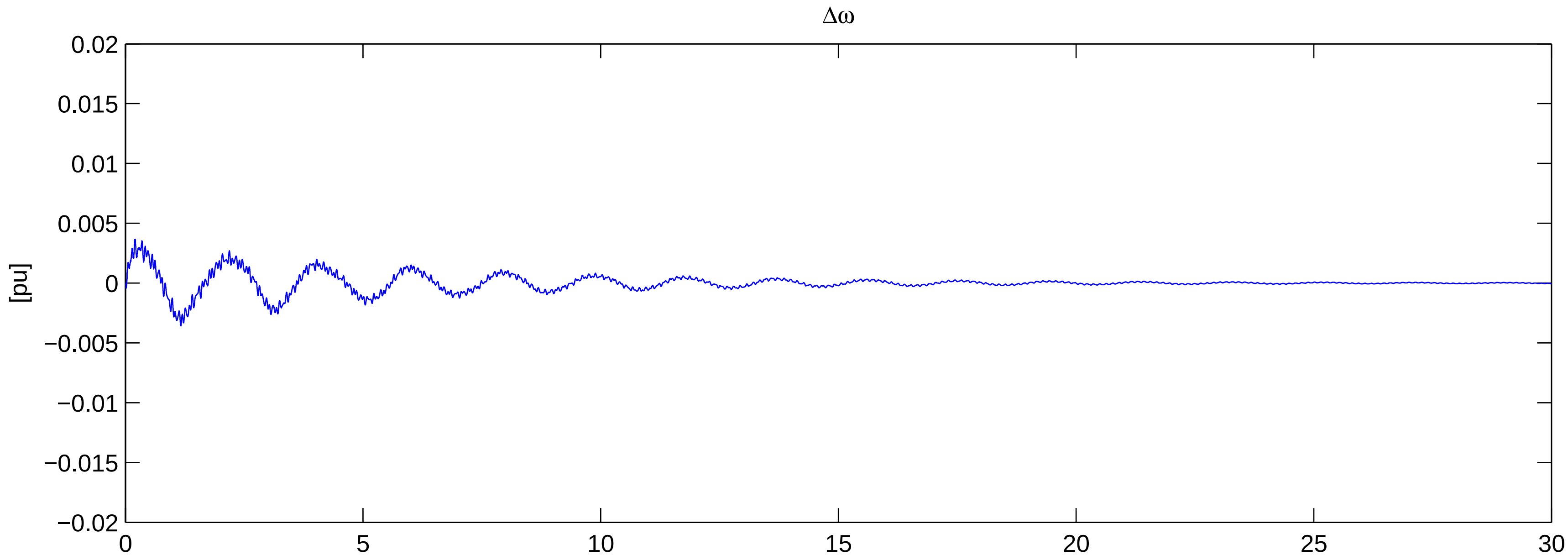
Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−2 (alternate fault duration) − No Series Cap

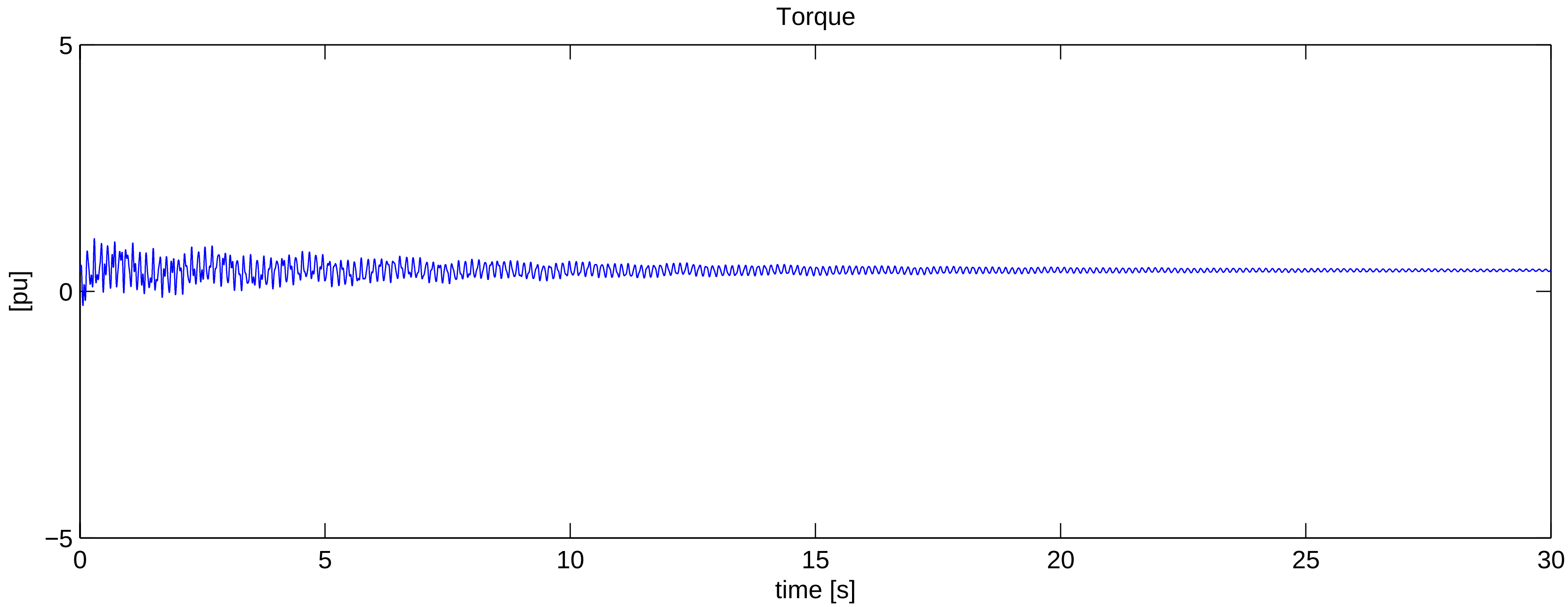




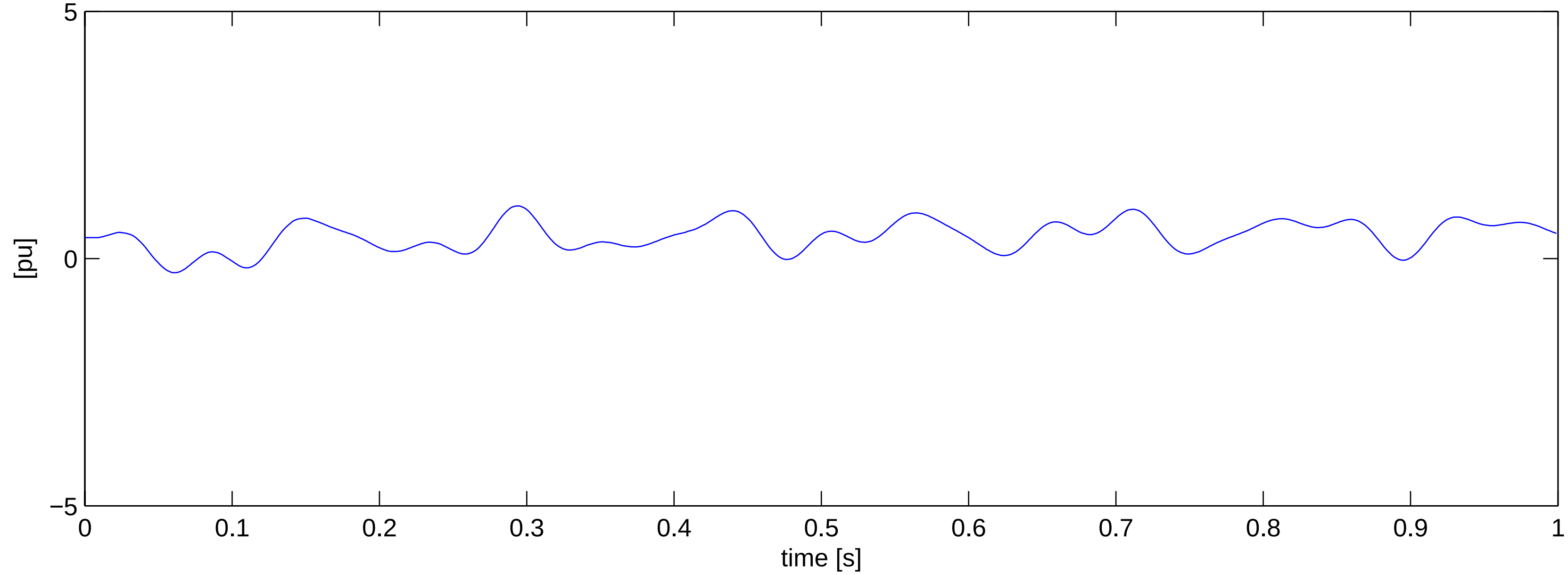

Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

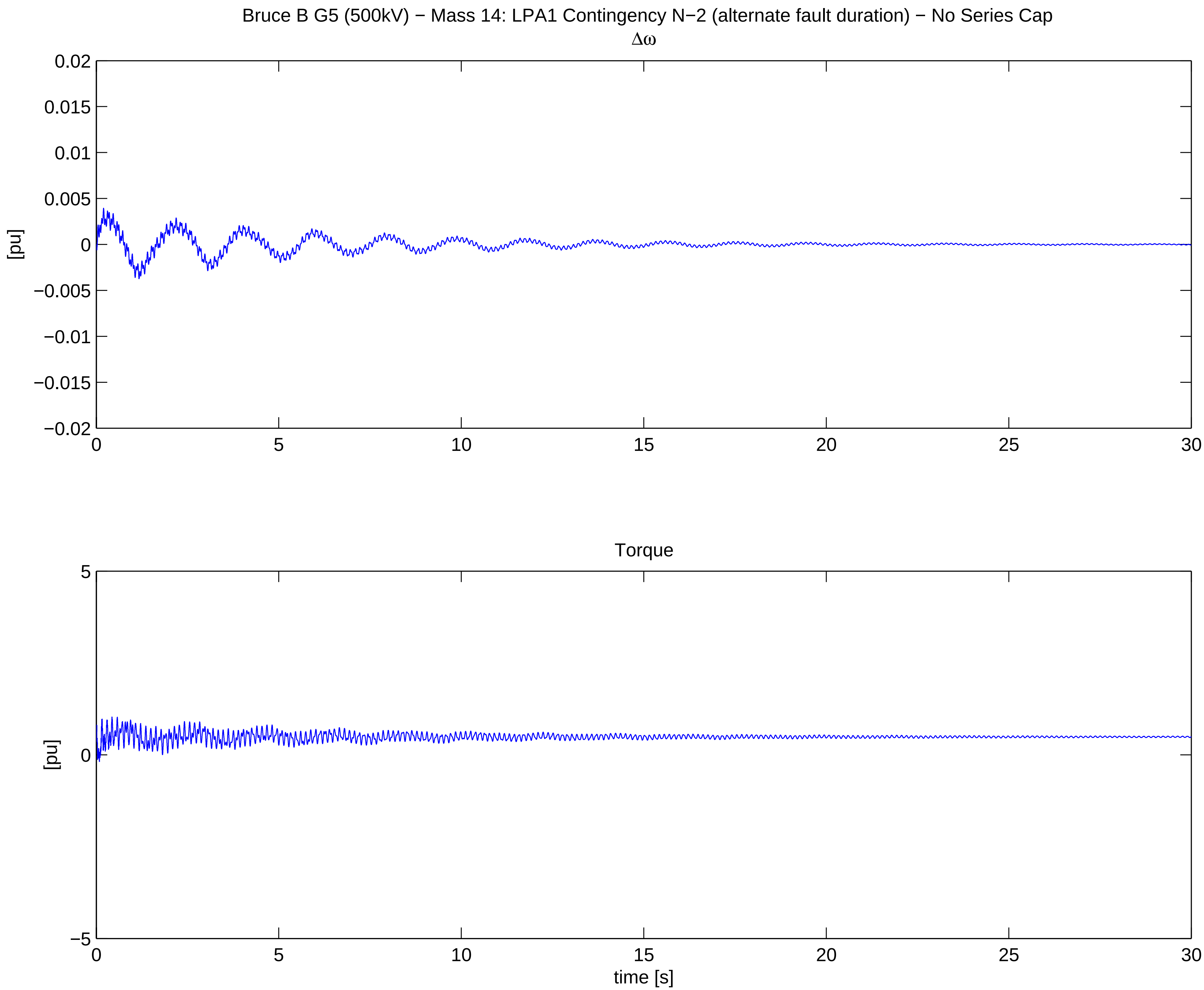
Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−2 (alternate fault duration) − No Series Cap

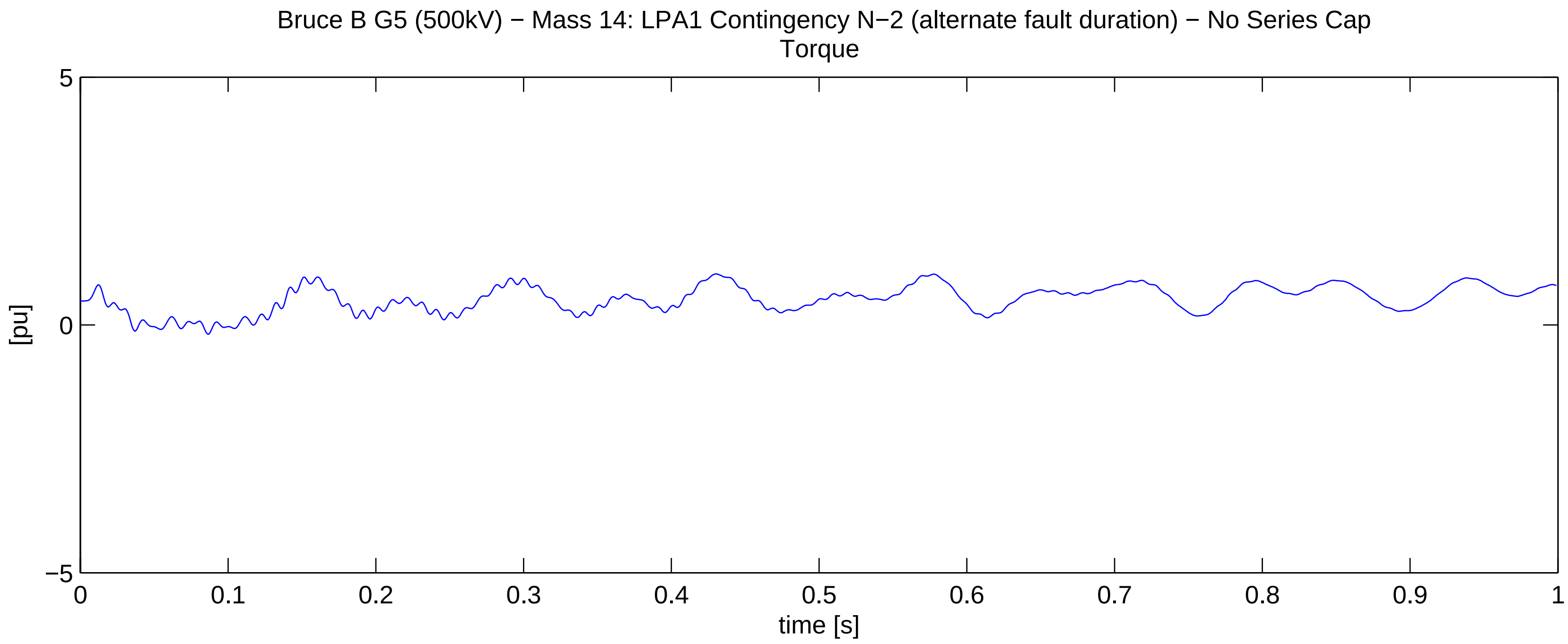


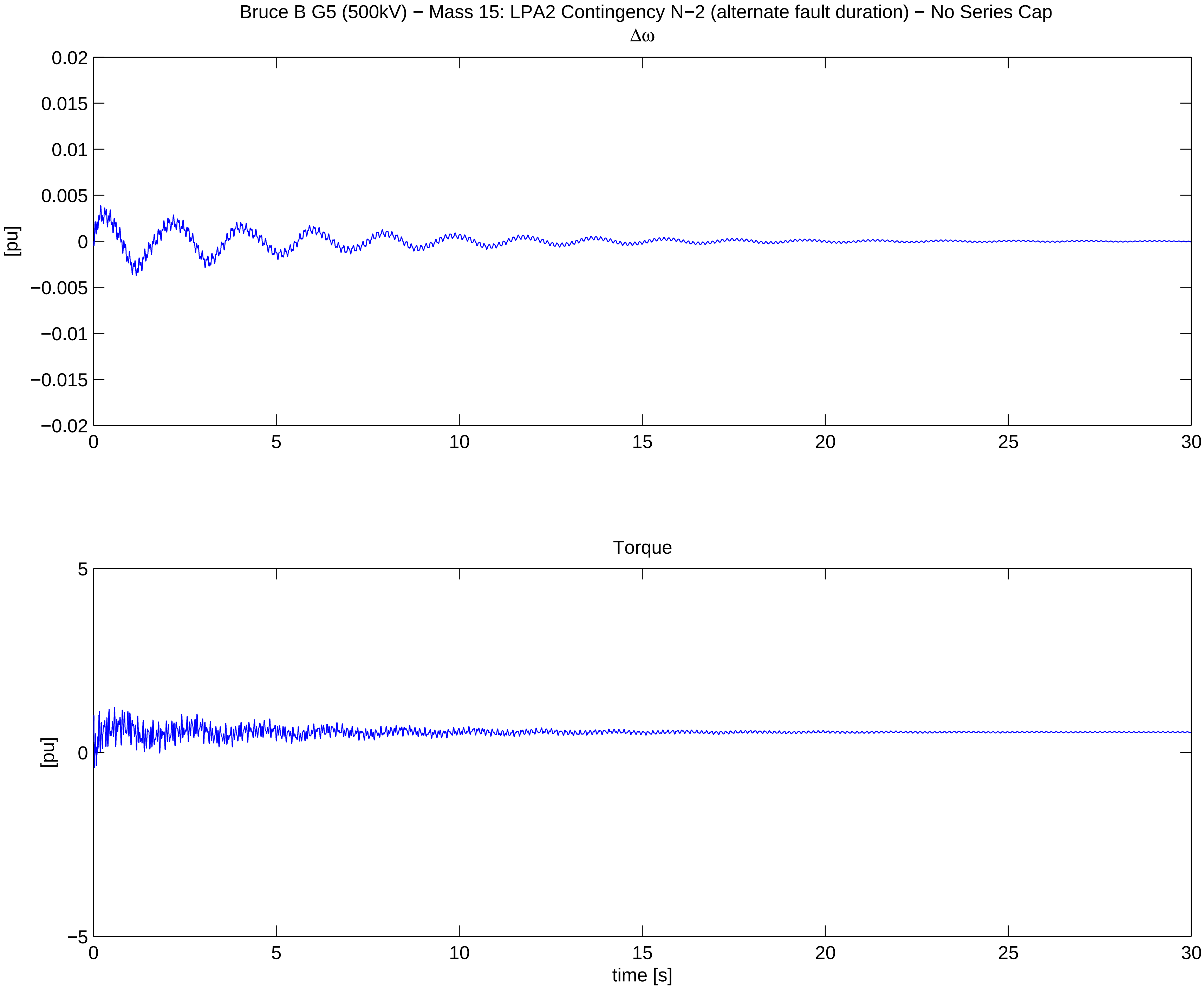


Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−2 (alternate fault duration) − No Series Cap
Torque

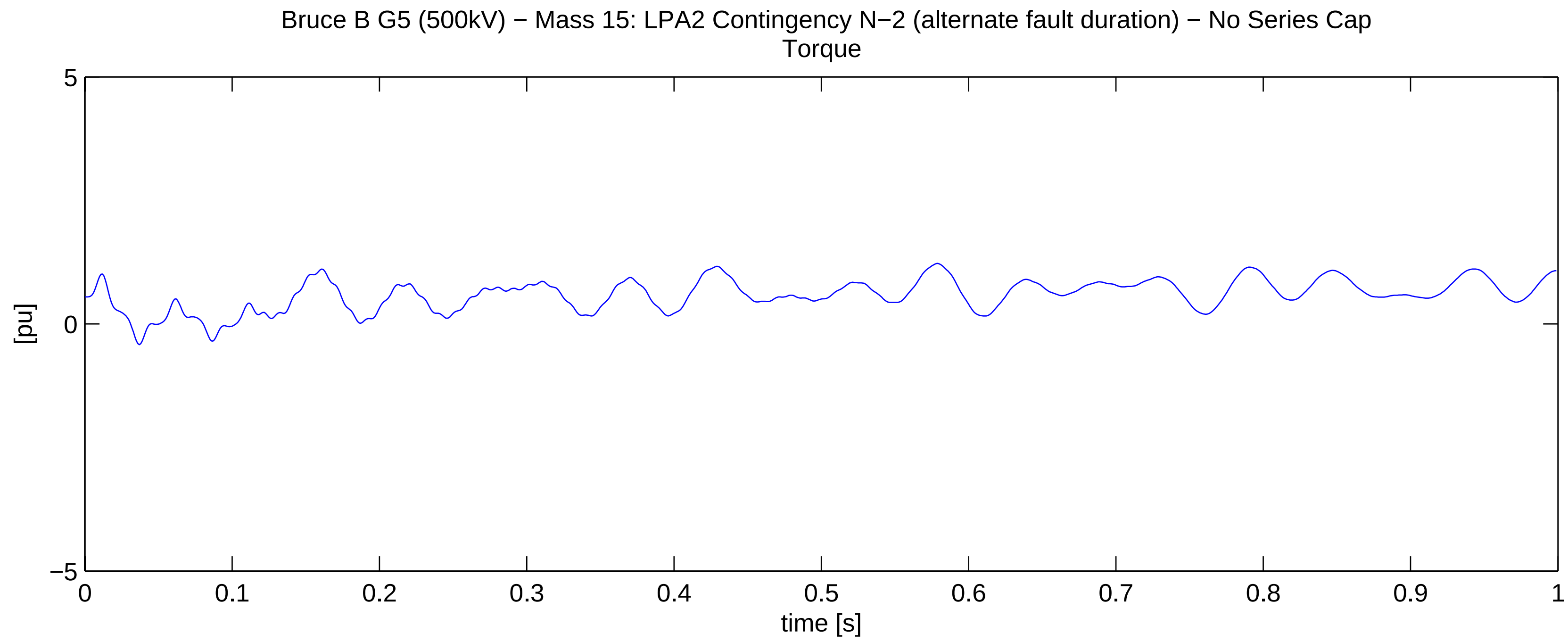


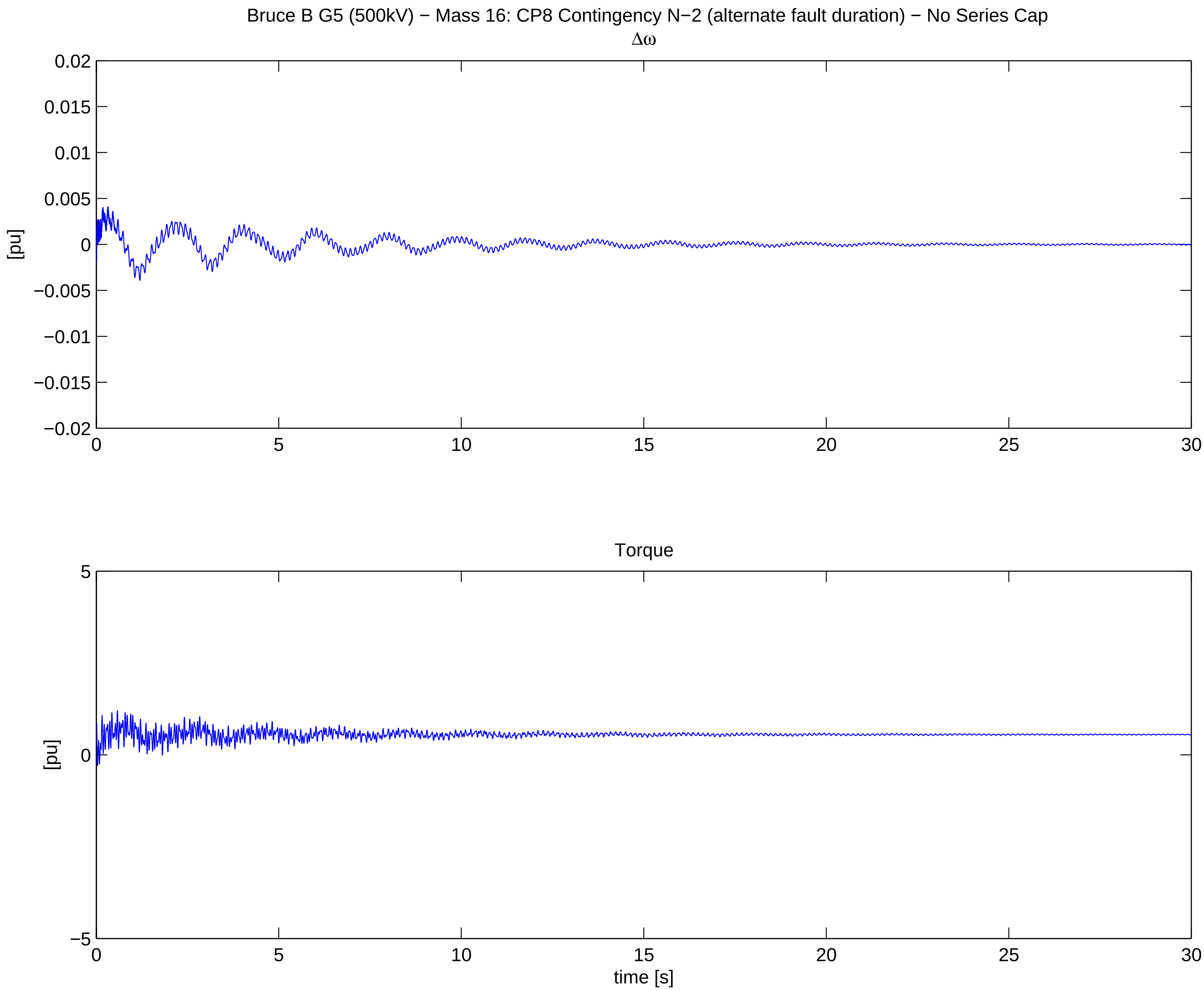

Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

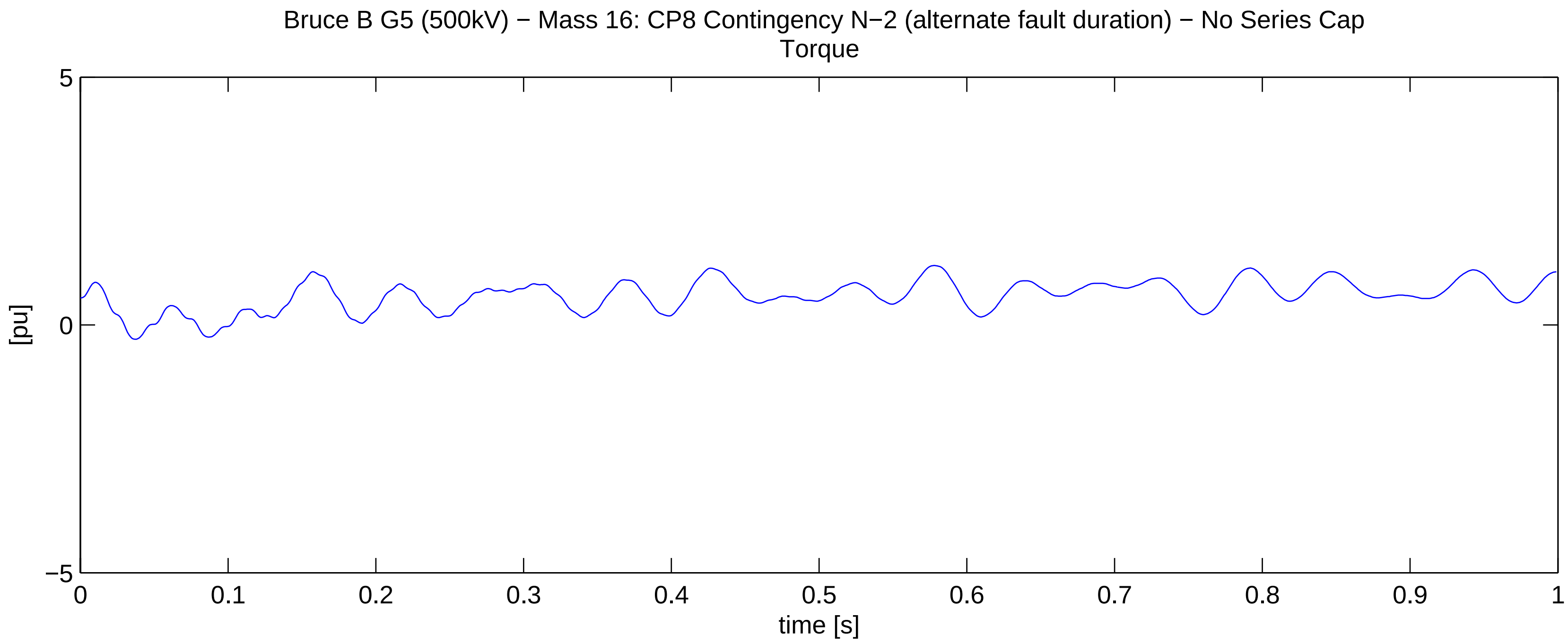


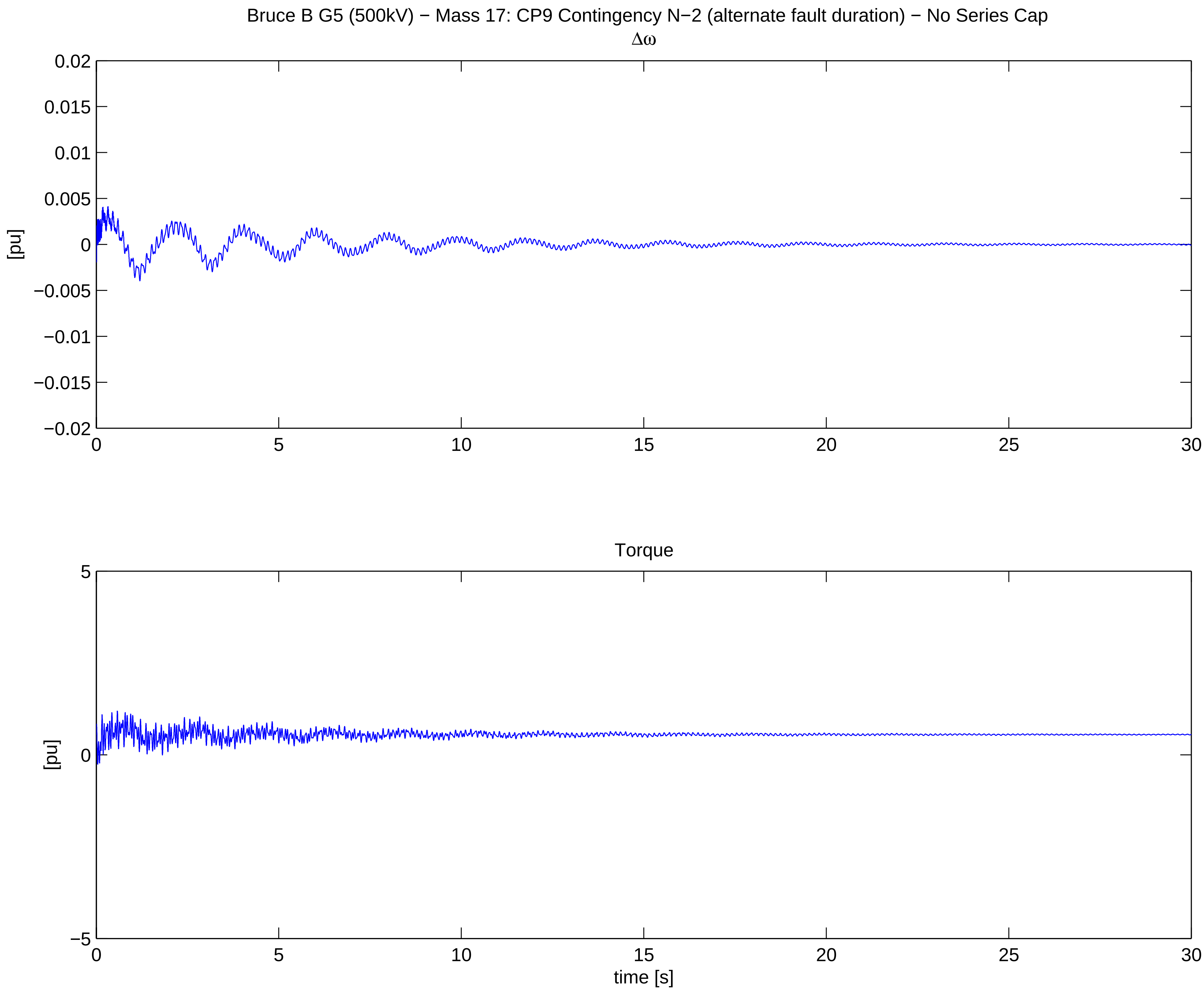
Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

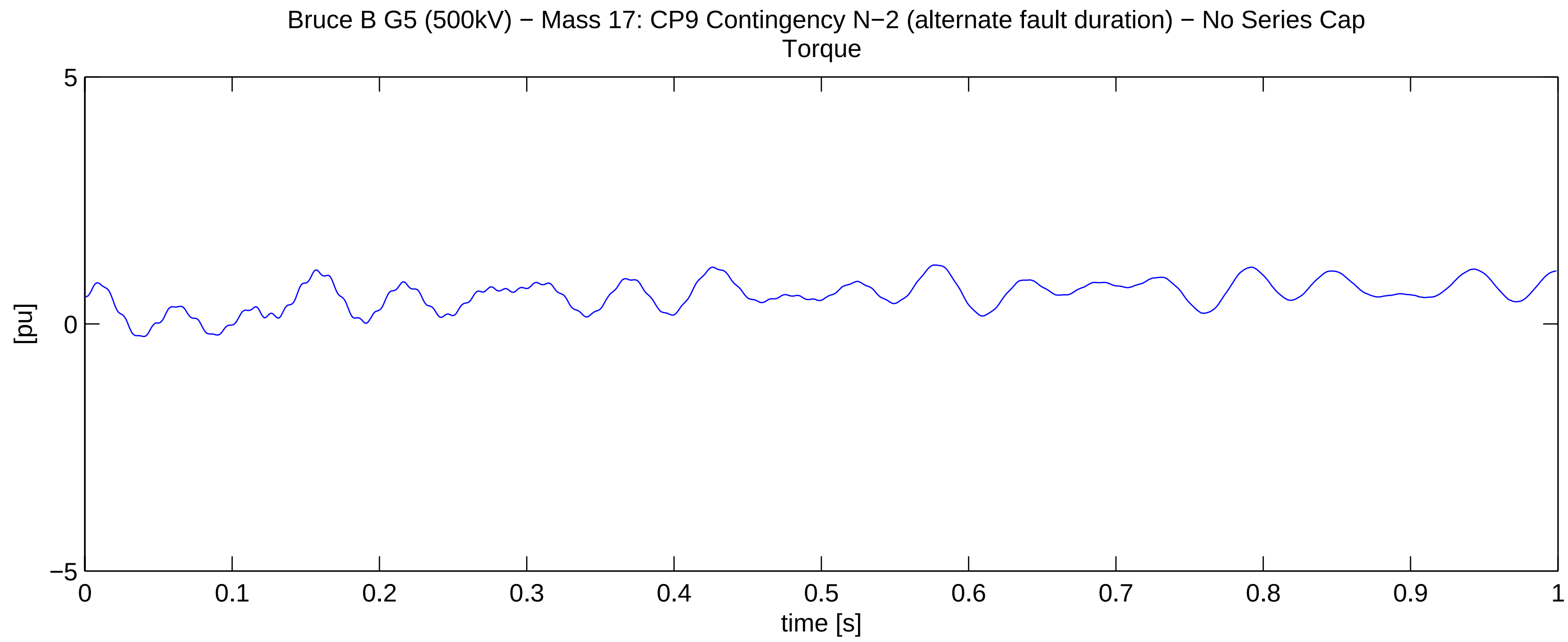

Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

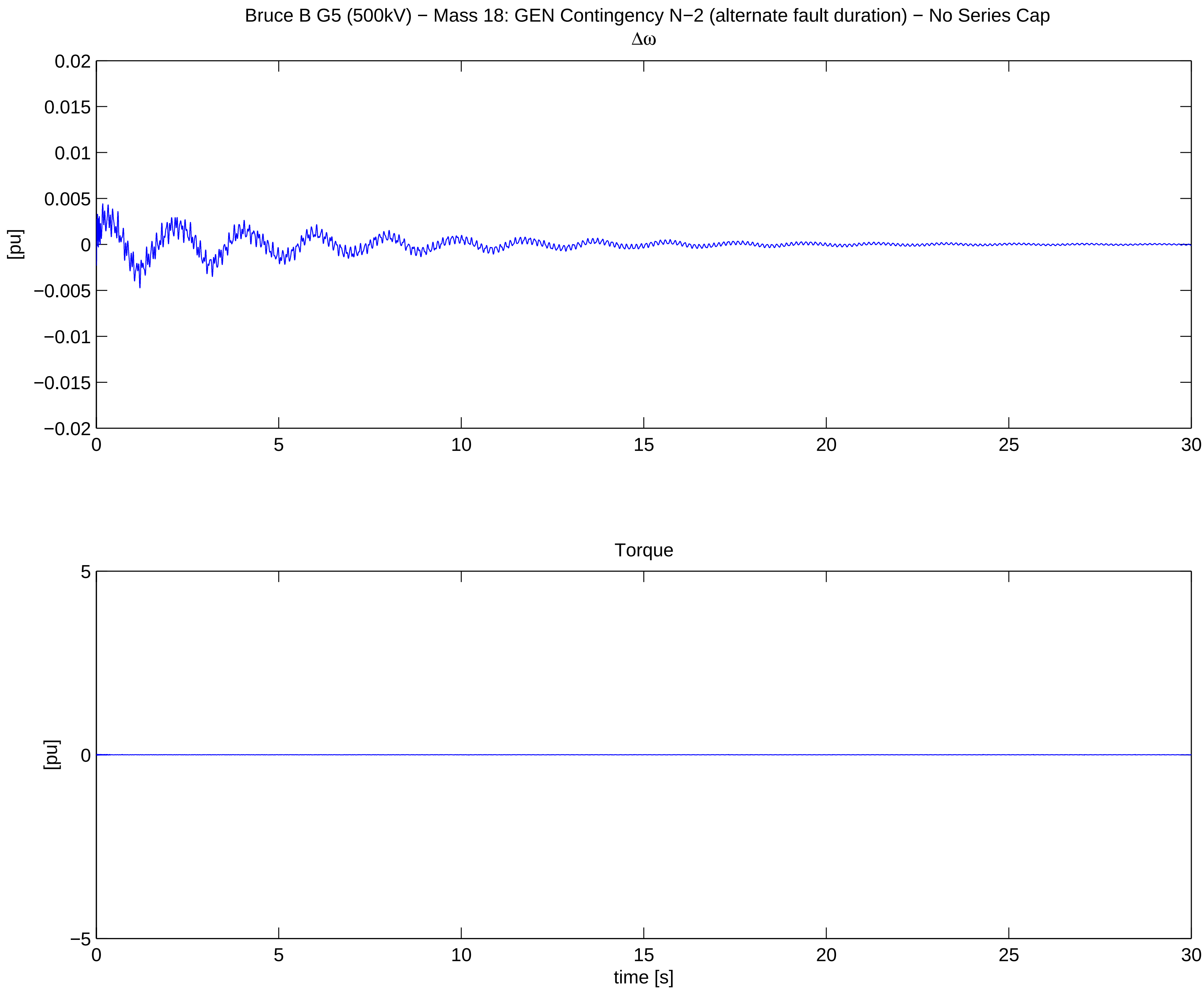


Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

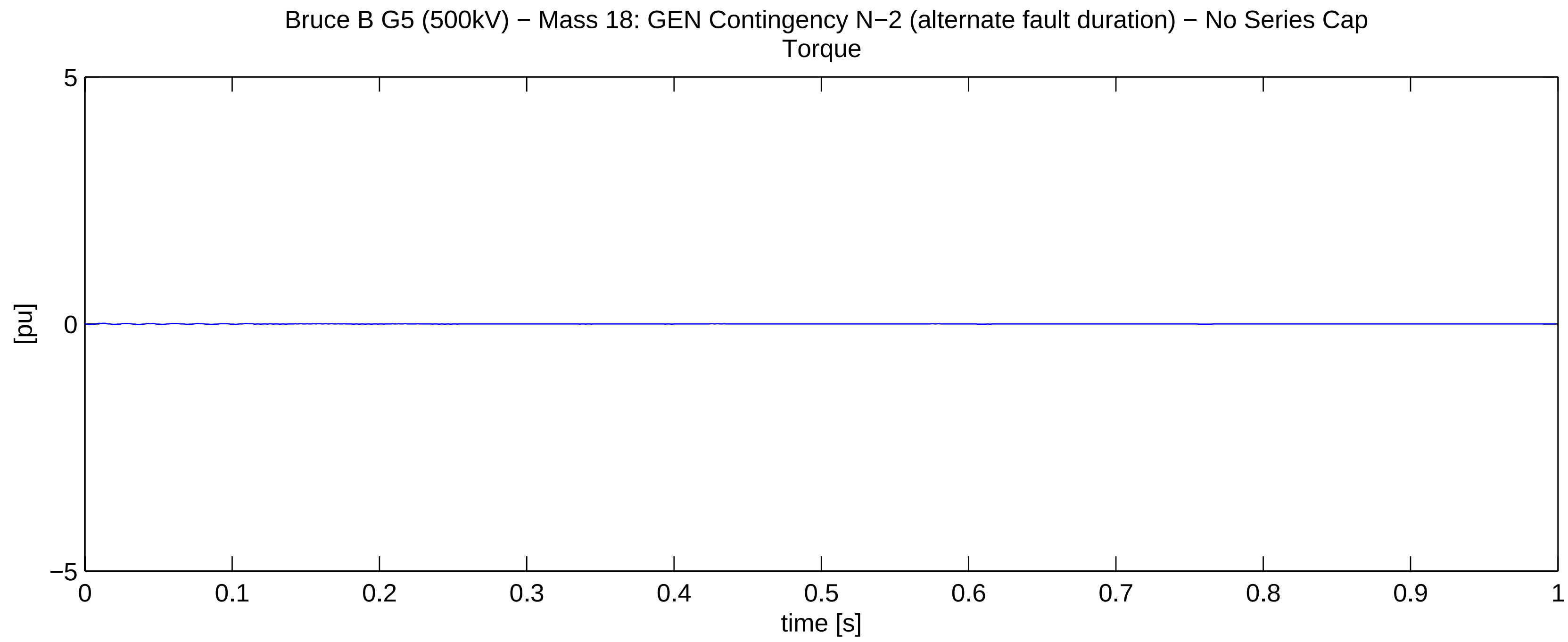

Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

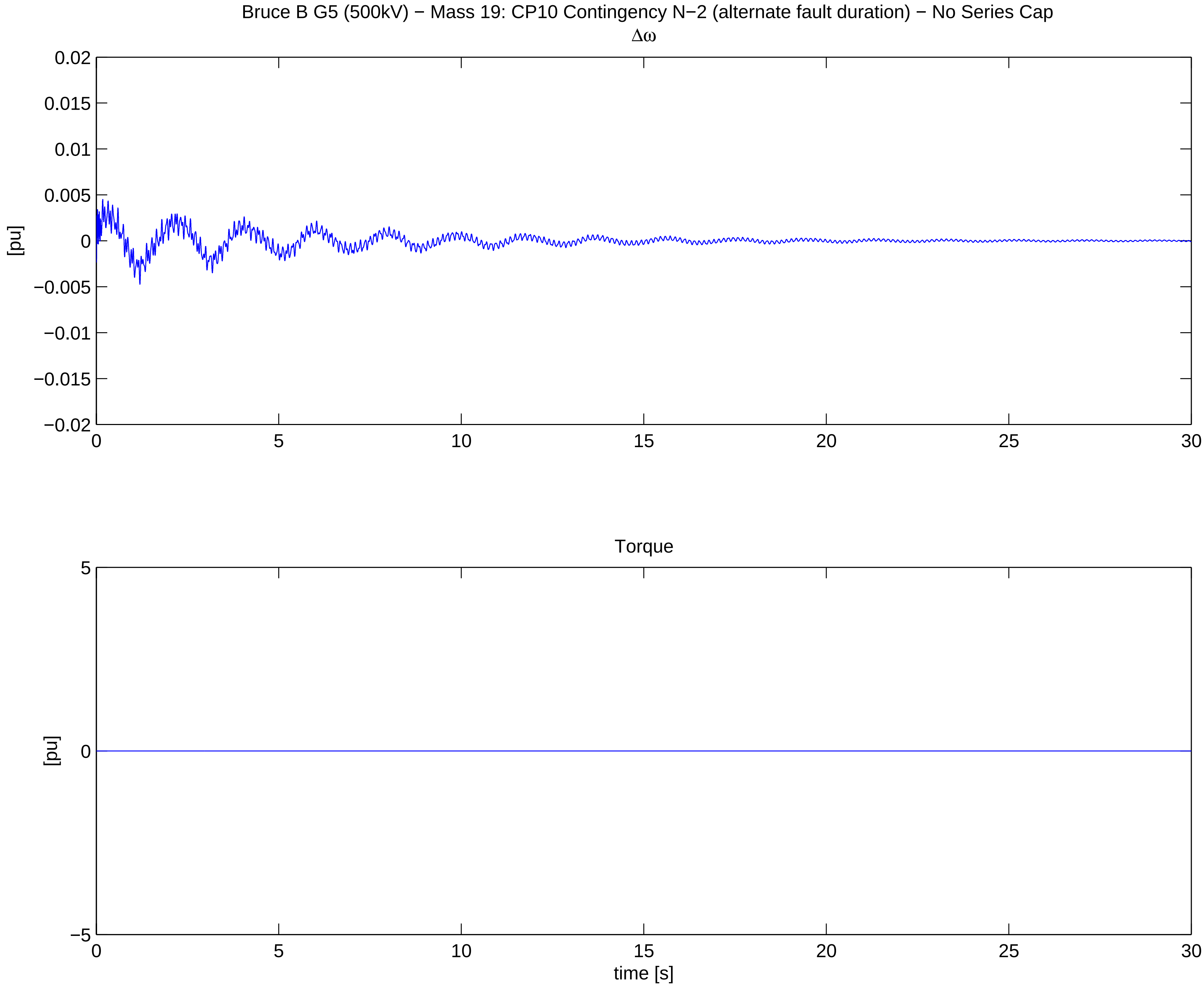

Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

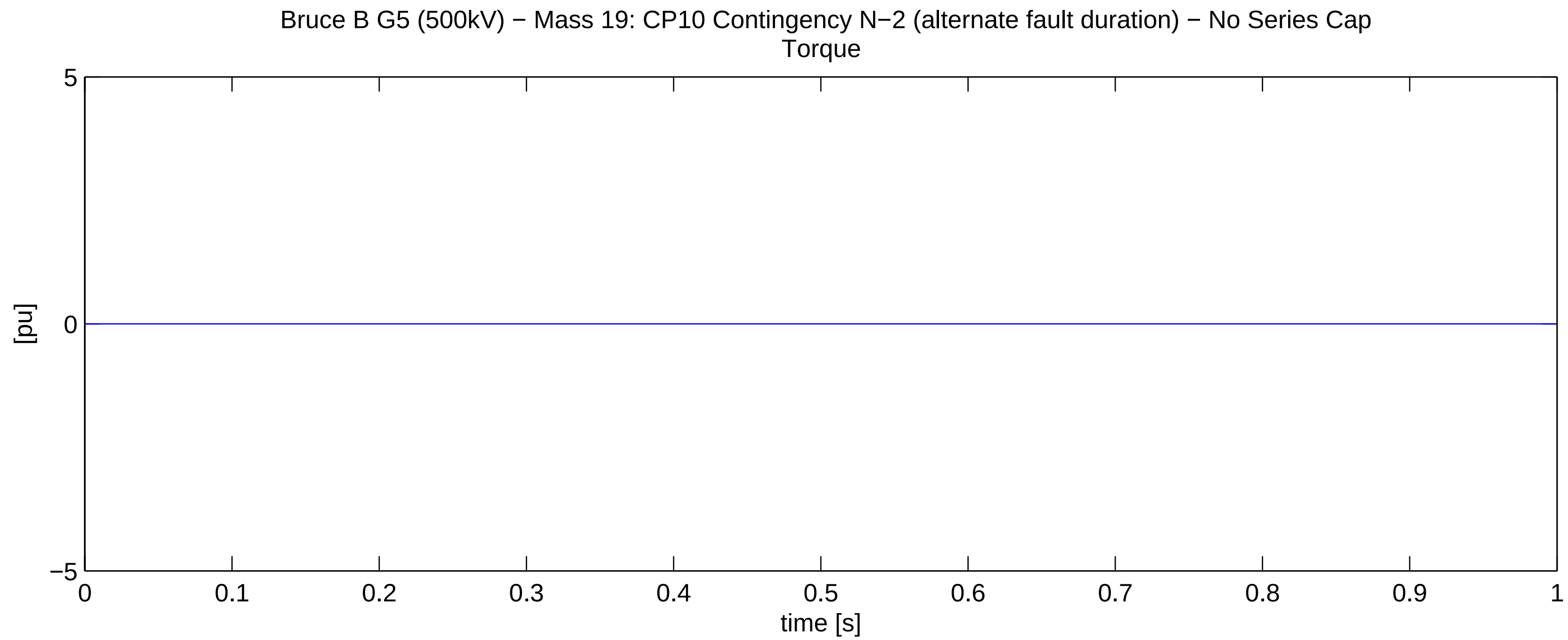

Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



Bruce B G5 (500kV) − Mass 18: GEN Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce B G5 (500kV) − Mass 18: GEN Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−2 (alternate fault duration) − No Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−2 (alternate fault duration) − No Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

APPENDIX T-2: Complete Transient Torque Plots – With Series Cap

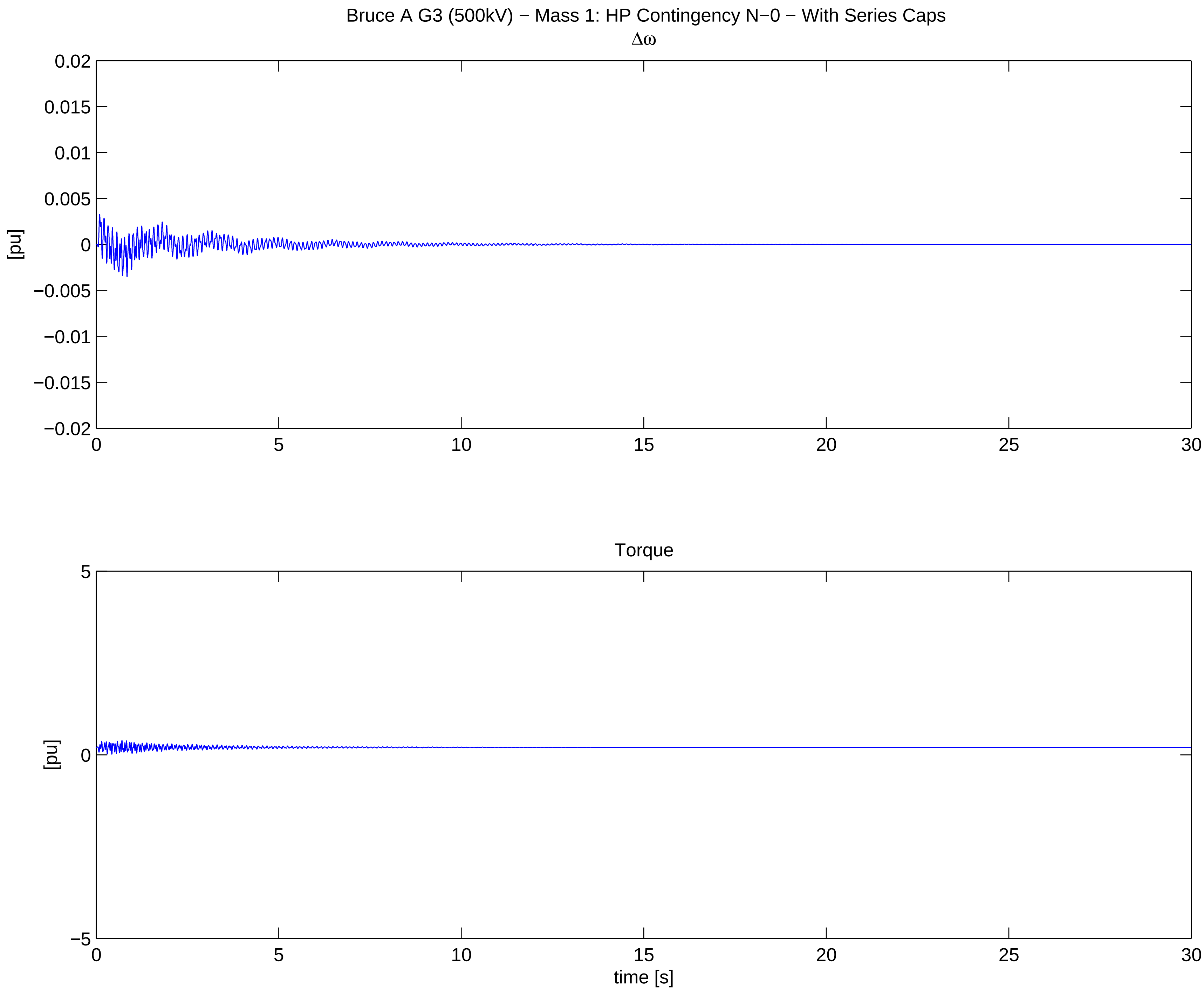
Appendix T2 – Complete Transient Torque Plots – With Series Cap

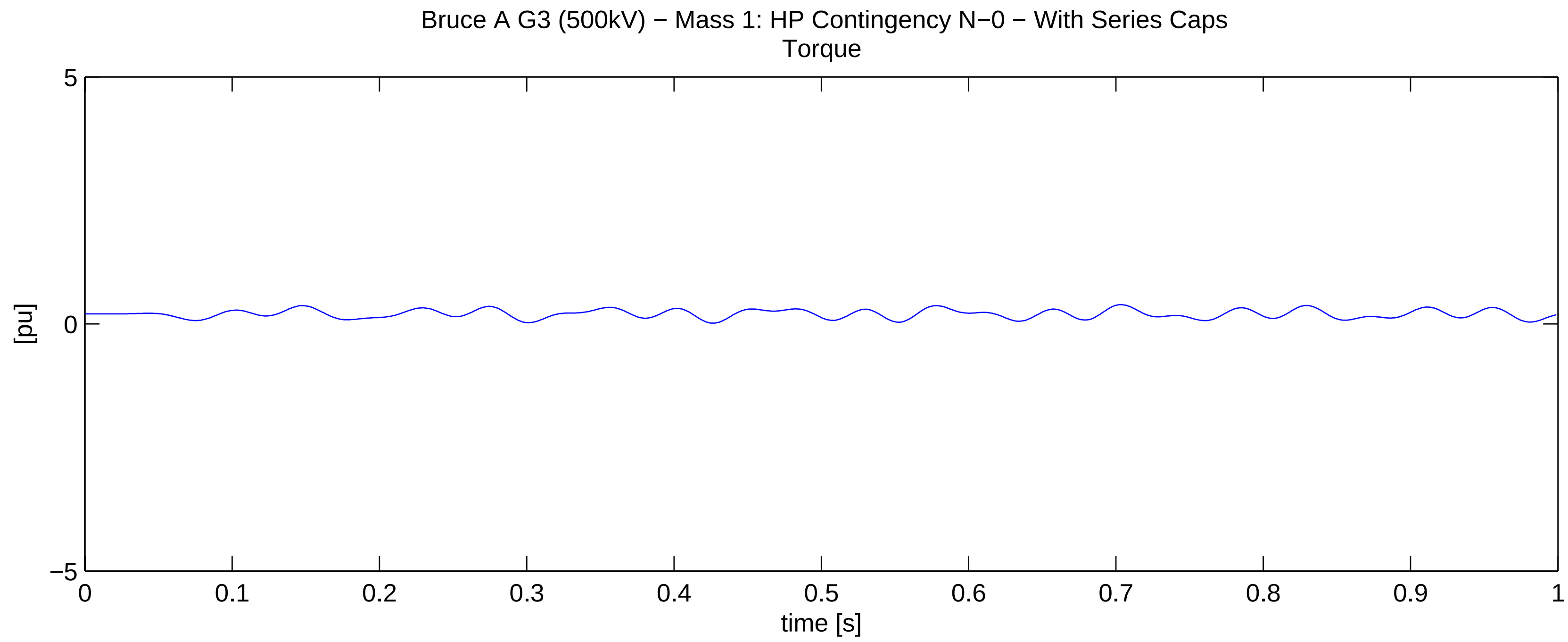
This appendix contains plots of the torques experienced at the various shaft locations for the most critical contingencies at Bruce A and Bruce B units. The descriptions of the contingencies simulated are provided in Table T2-1.

Table T2-1: Contingency Descriptions

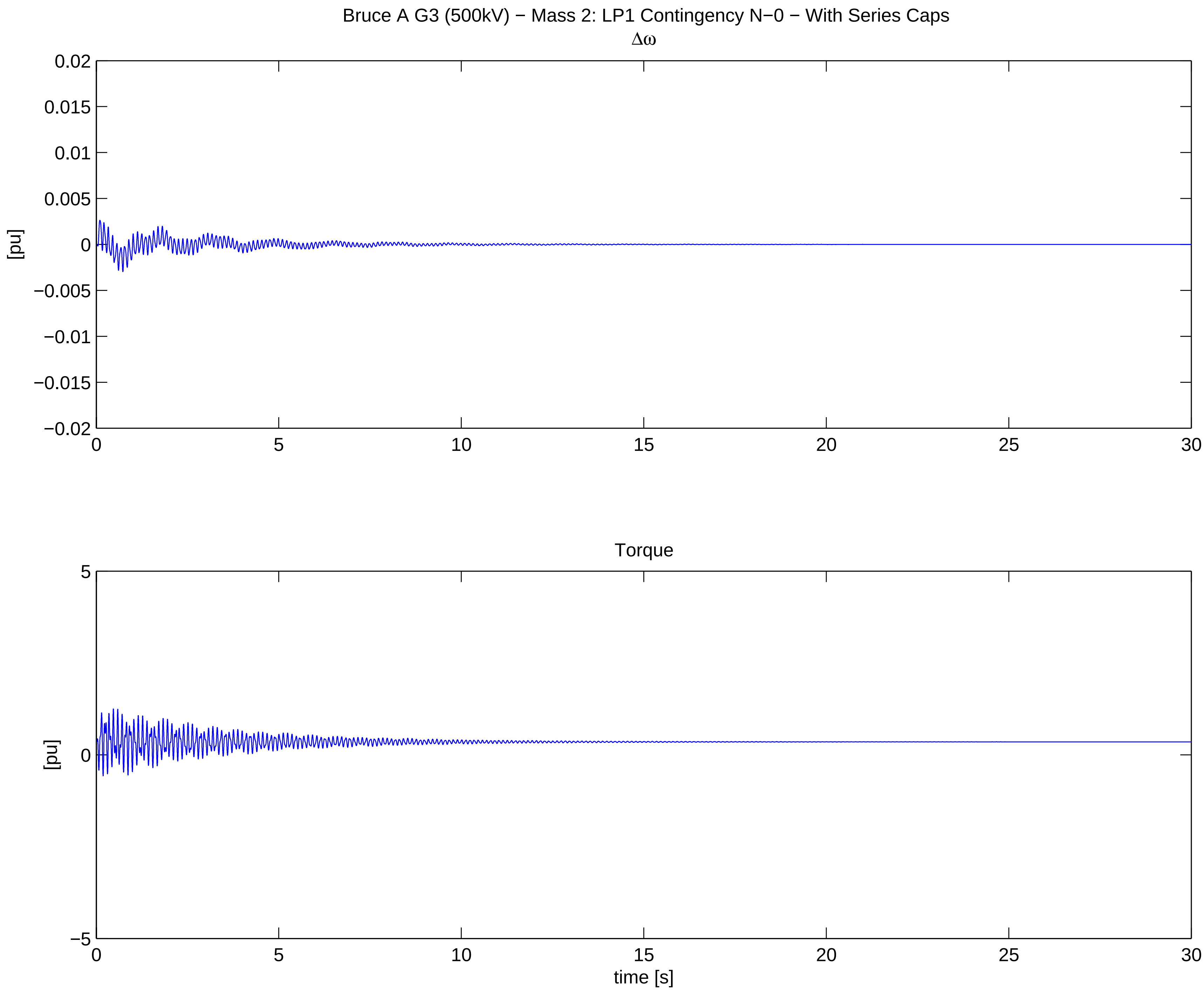
Contingency ID	Bruce A – Clairville 500kV Line 1	Bruce B – Milton 500kV Line 1	Bruce A – Bruce B 500kV Tie	Bruce A 500/230/27.6kV Transformer 25	Bruce A 500/230/27.6kV Transformer 27	Bruce A 500/230/27.6kV Transformer 28	Bruce A – Longwood 500kV Line 1	Bruce A – Bruce B 500kV Tie 1	Bruce B – Milton 500kV Line 1	Bruce B – Longwood 500kV Line 1	
Bruce A 500kV Unit G3											
N-0											
N-1b			X								
N-2	X	X									
N-5d	X		X	X	X	X					
N-5d alternate fault	X		X	X	X	X					Fault duration changed from 5 cycles to 3.768 cycles
Bruce A 230kV Unit G1											
N-2e	X		X								
Bruce B 500kV Unit G5											
N-0											
N-1								X			
N-2								X	X		
N-2 alternate fault								X	X		Fault duration changed from 5 cycles to 6.372 cycles

X – indicates the branch is out-of-service

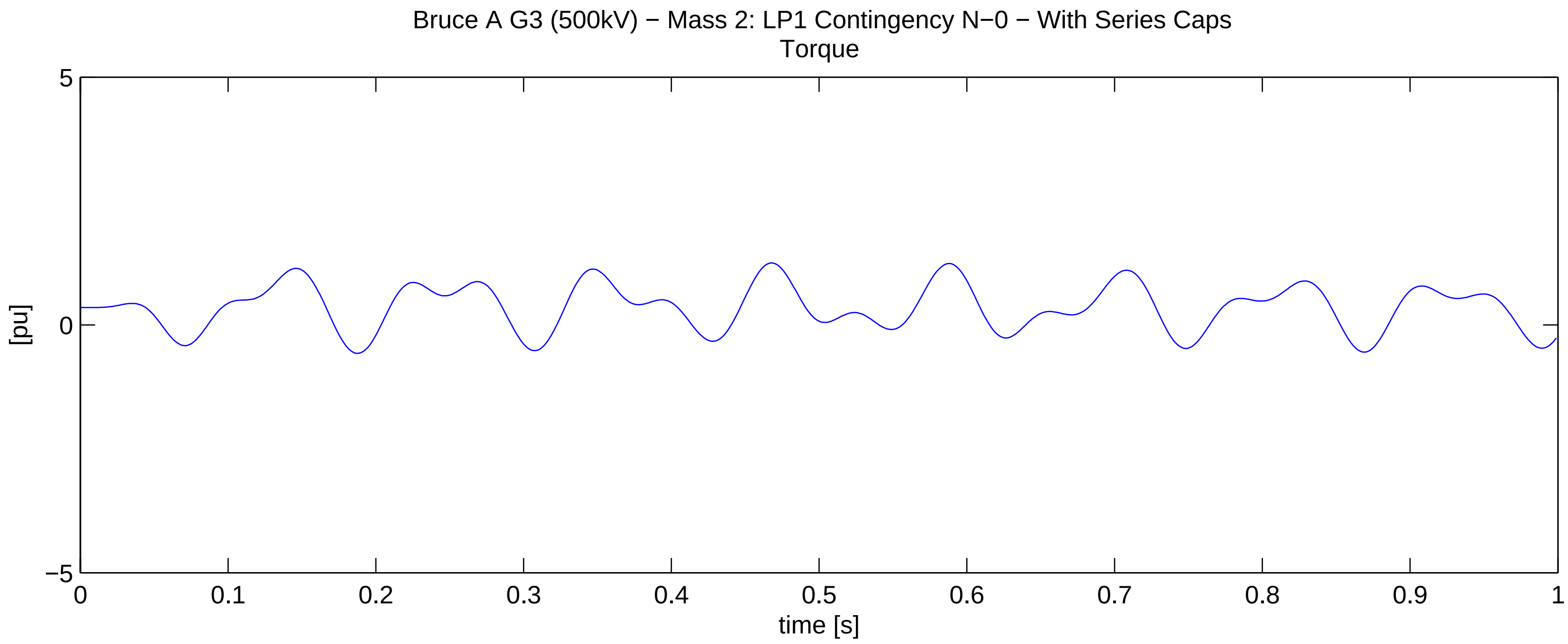

Bruce A G3 (500kV) − Mass 1: HP Contingency N−0 − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



Bruce A G3 (500kV) − Mass 1: HP Contingency N−0 − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

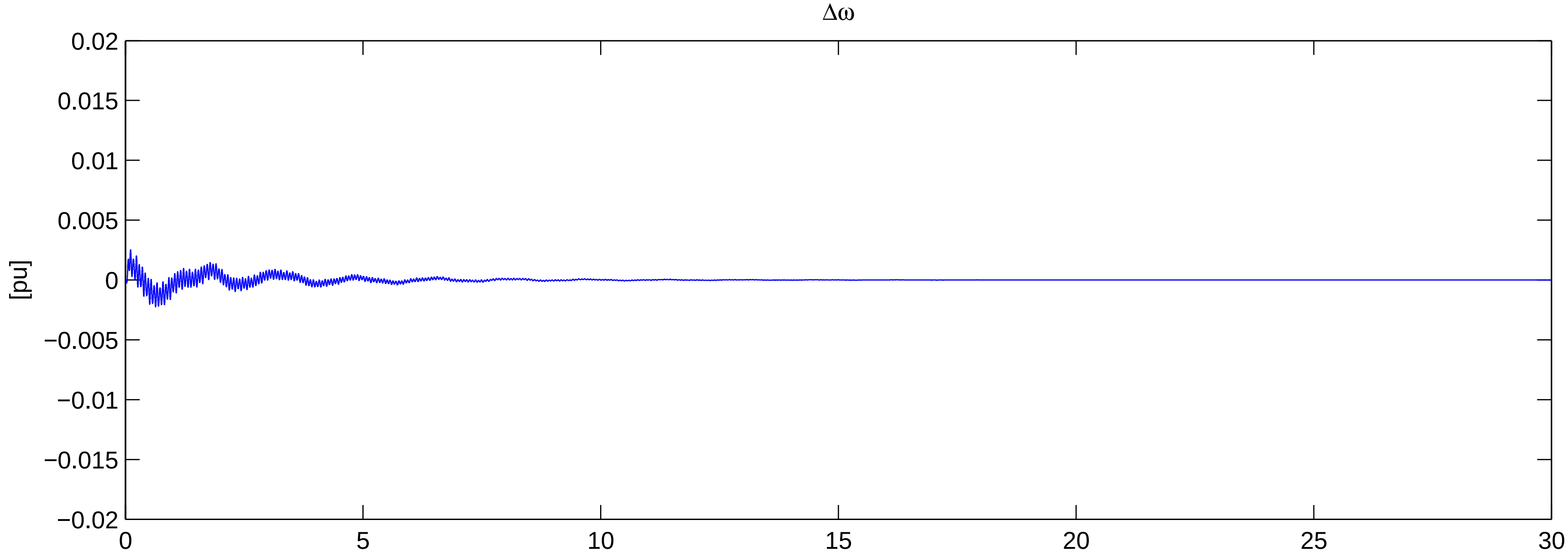


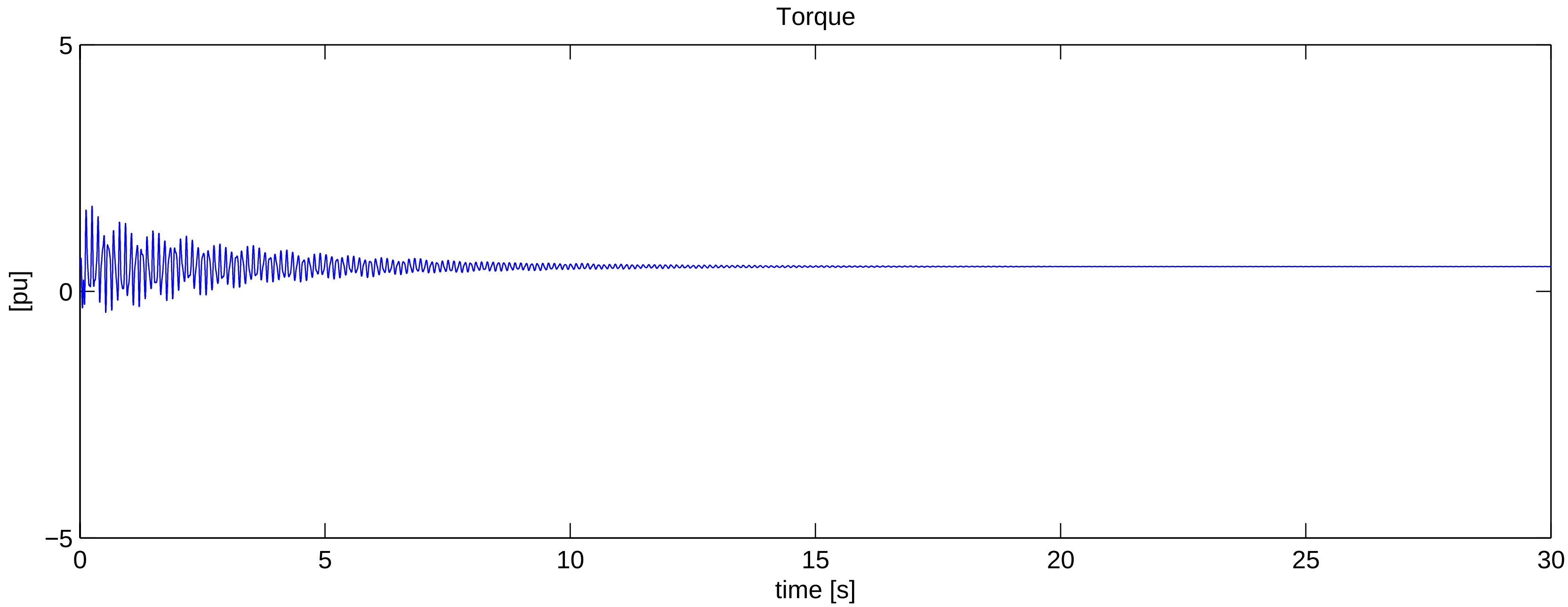
Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−0 − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

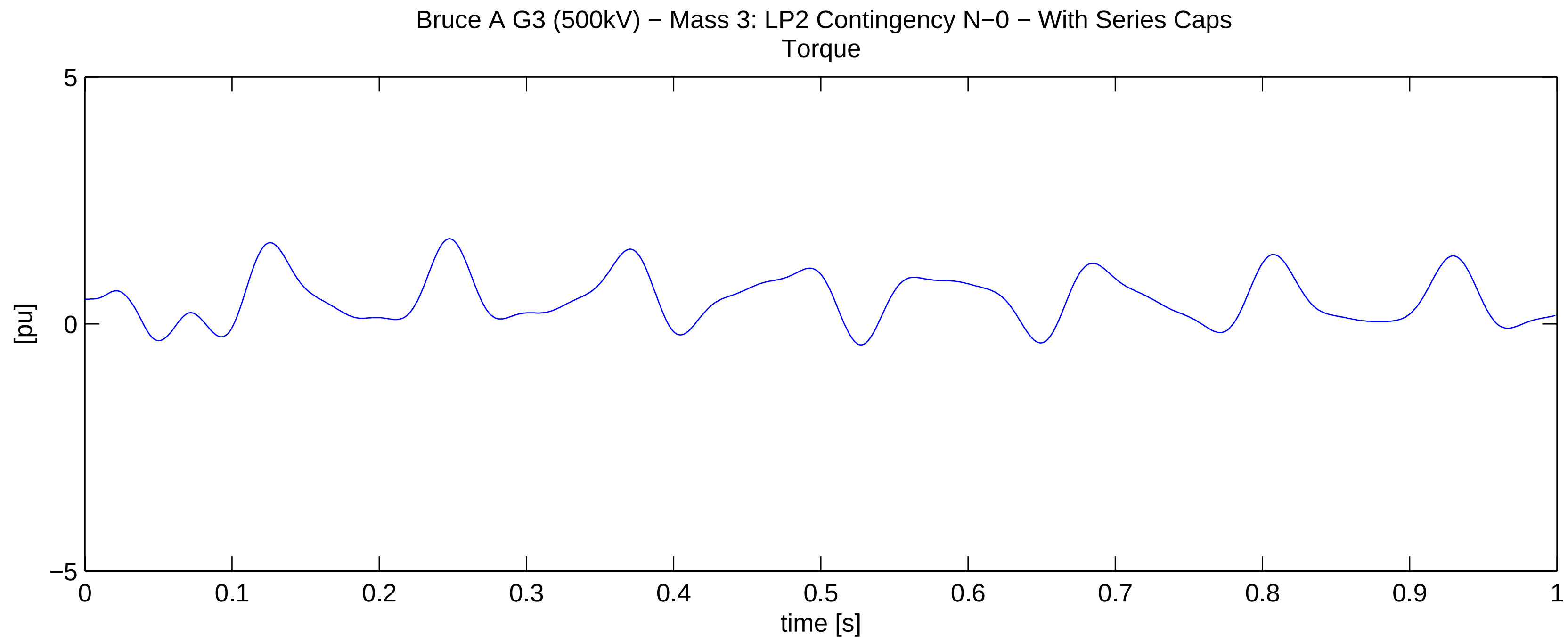


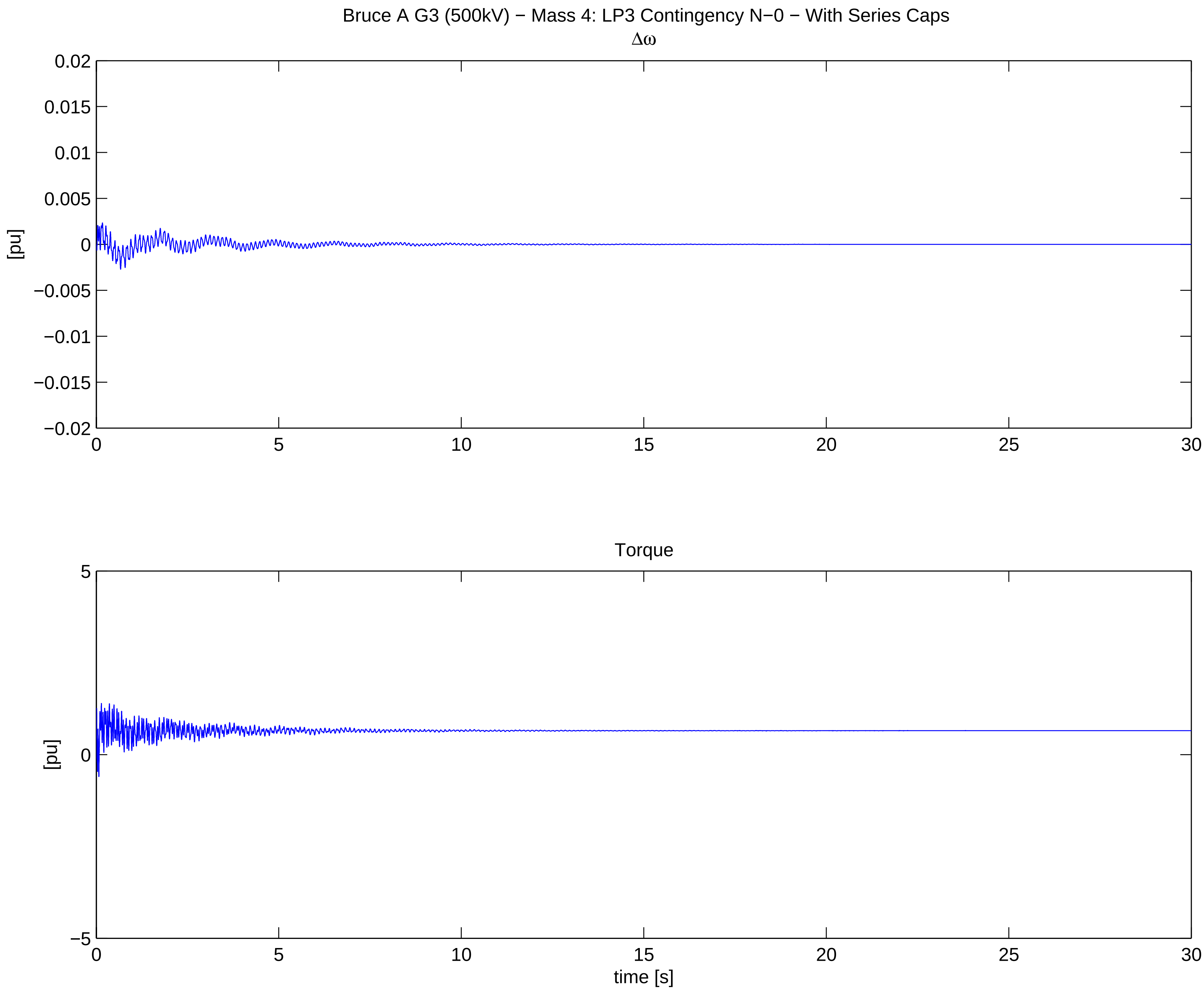
Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−0 − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−0 − With Series Caps

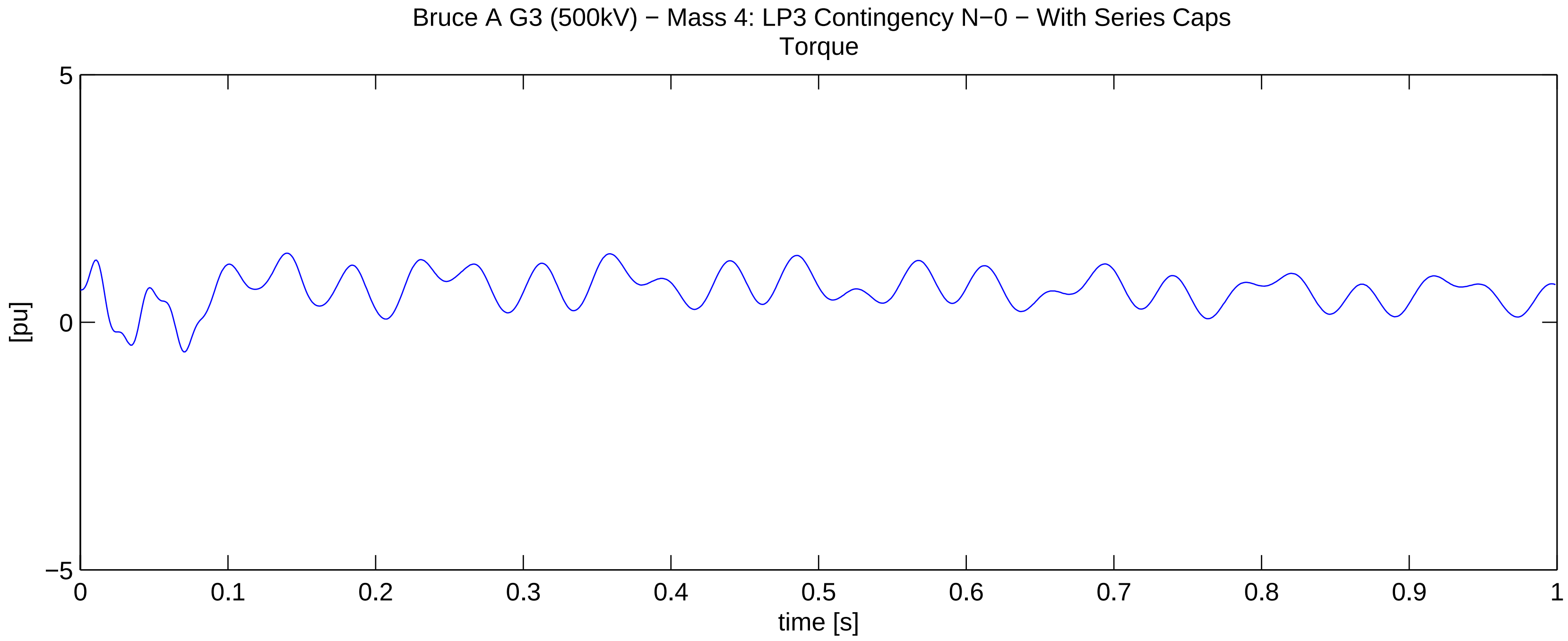


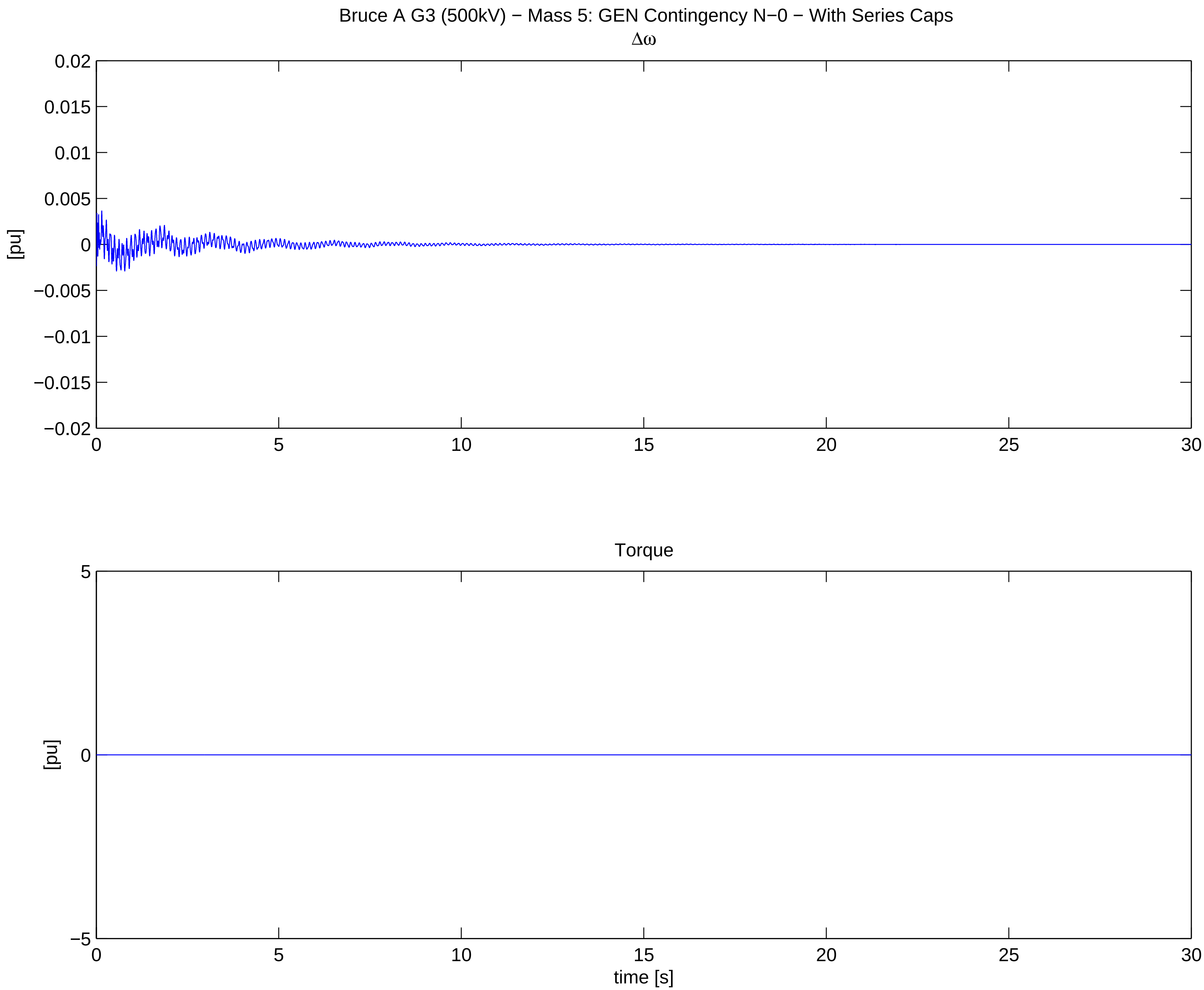



Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−0 − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

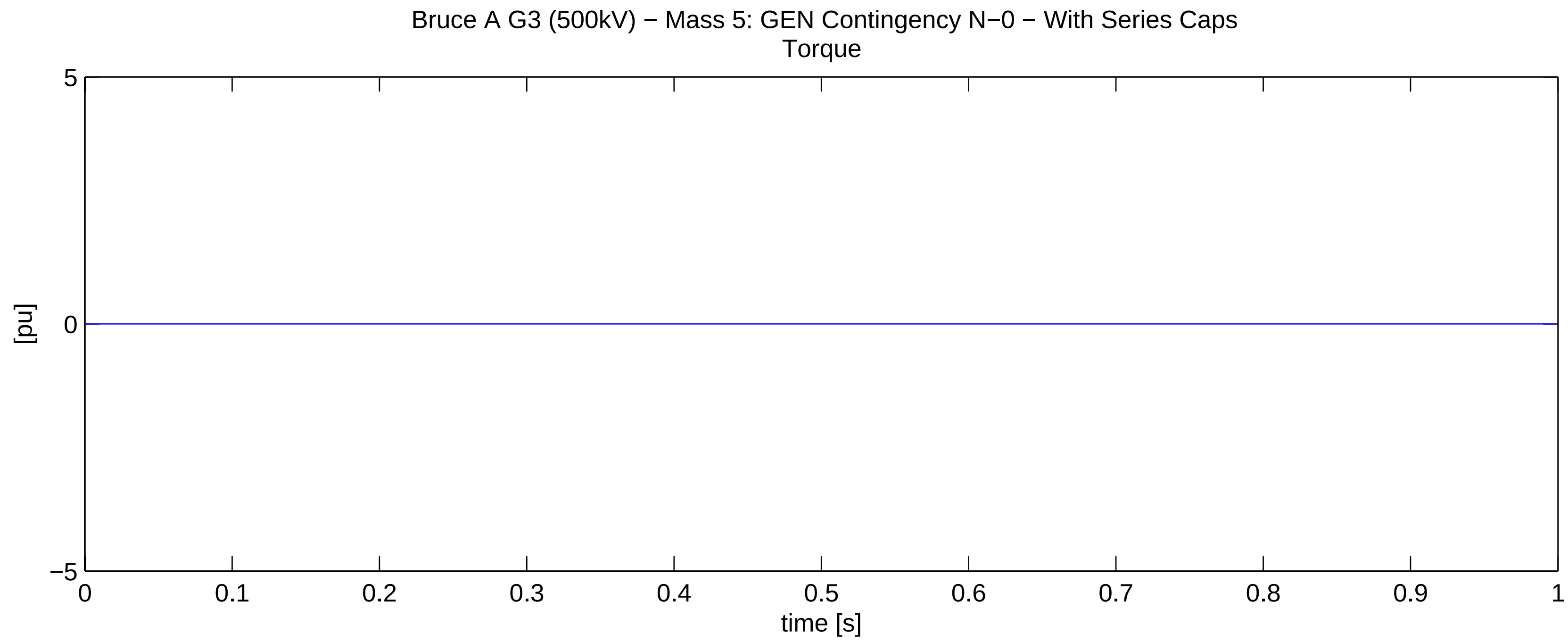


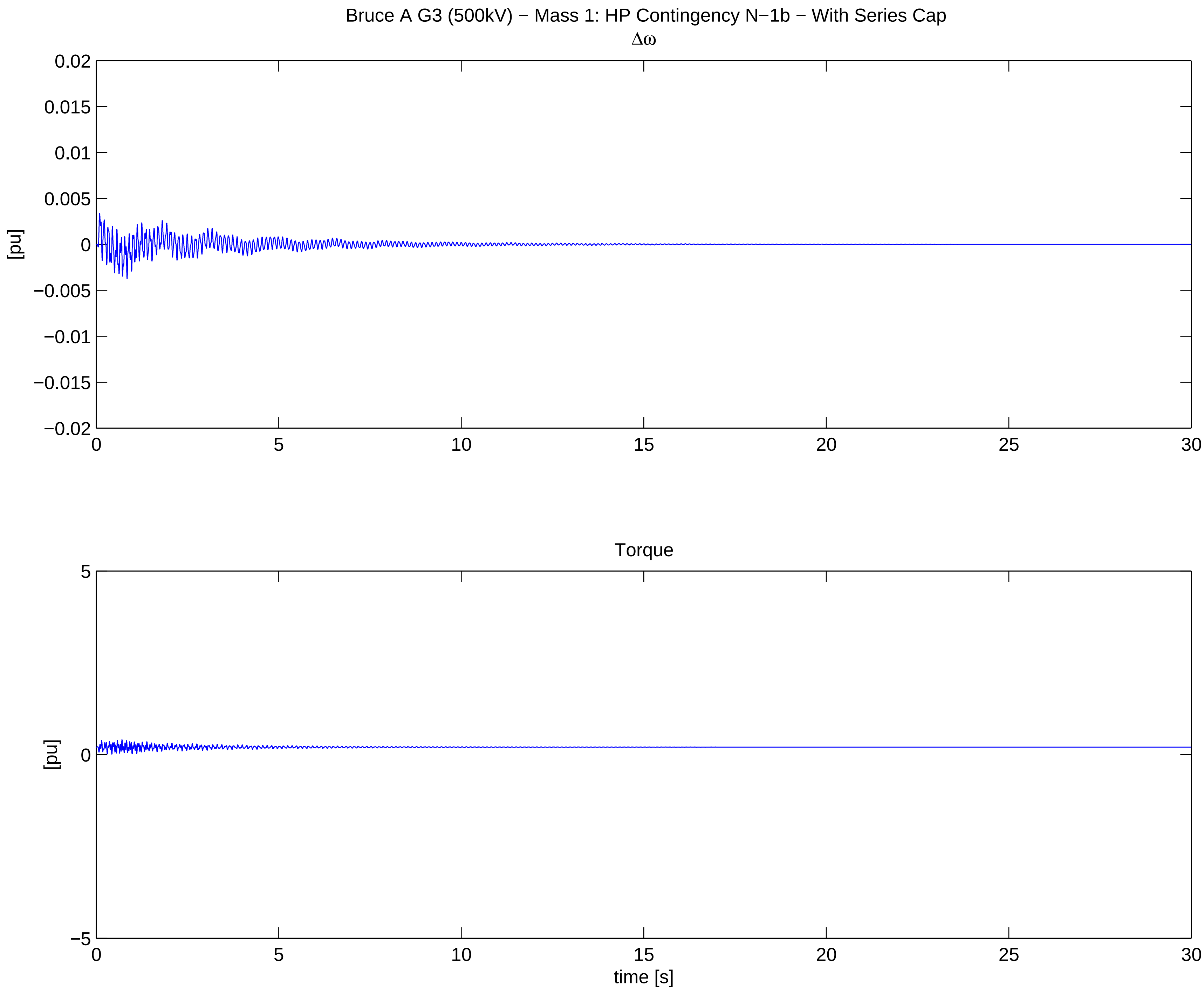
Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−0 − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

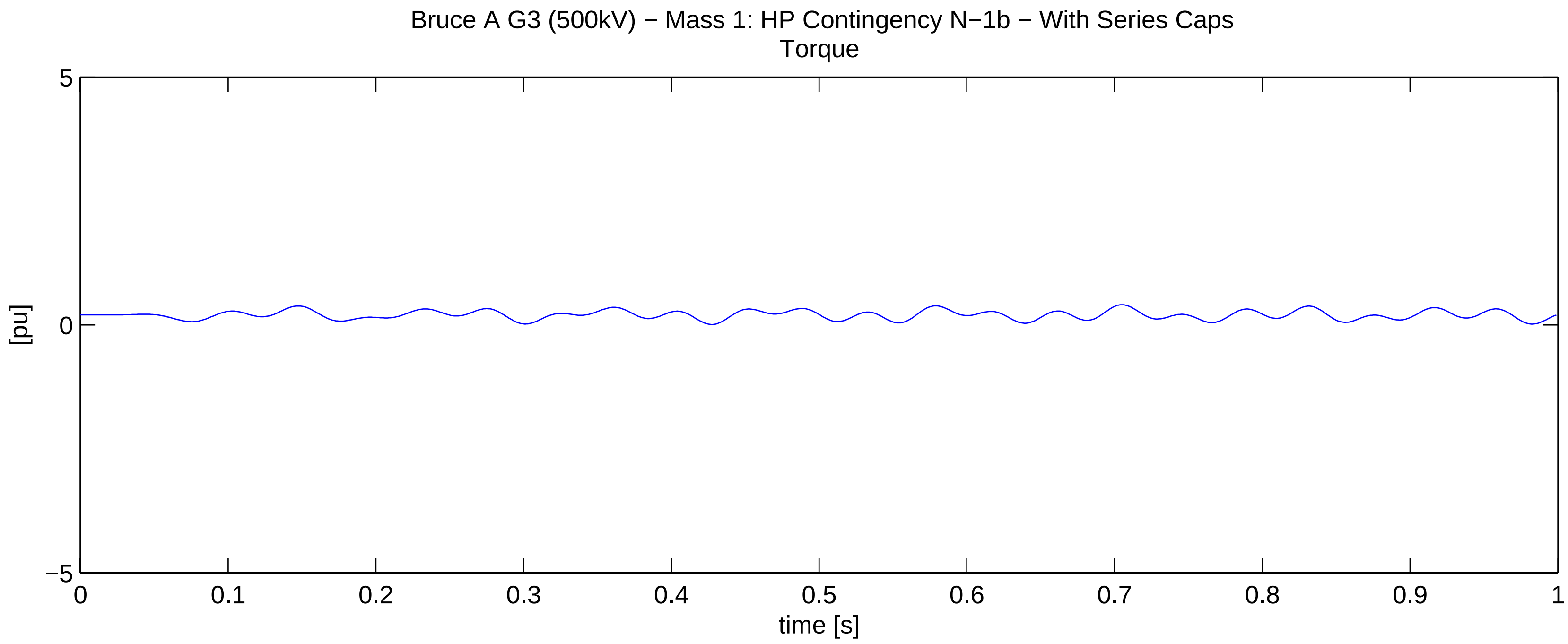

Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−0 − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

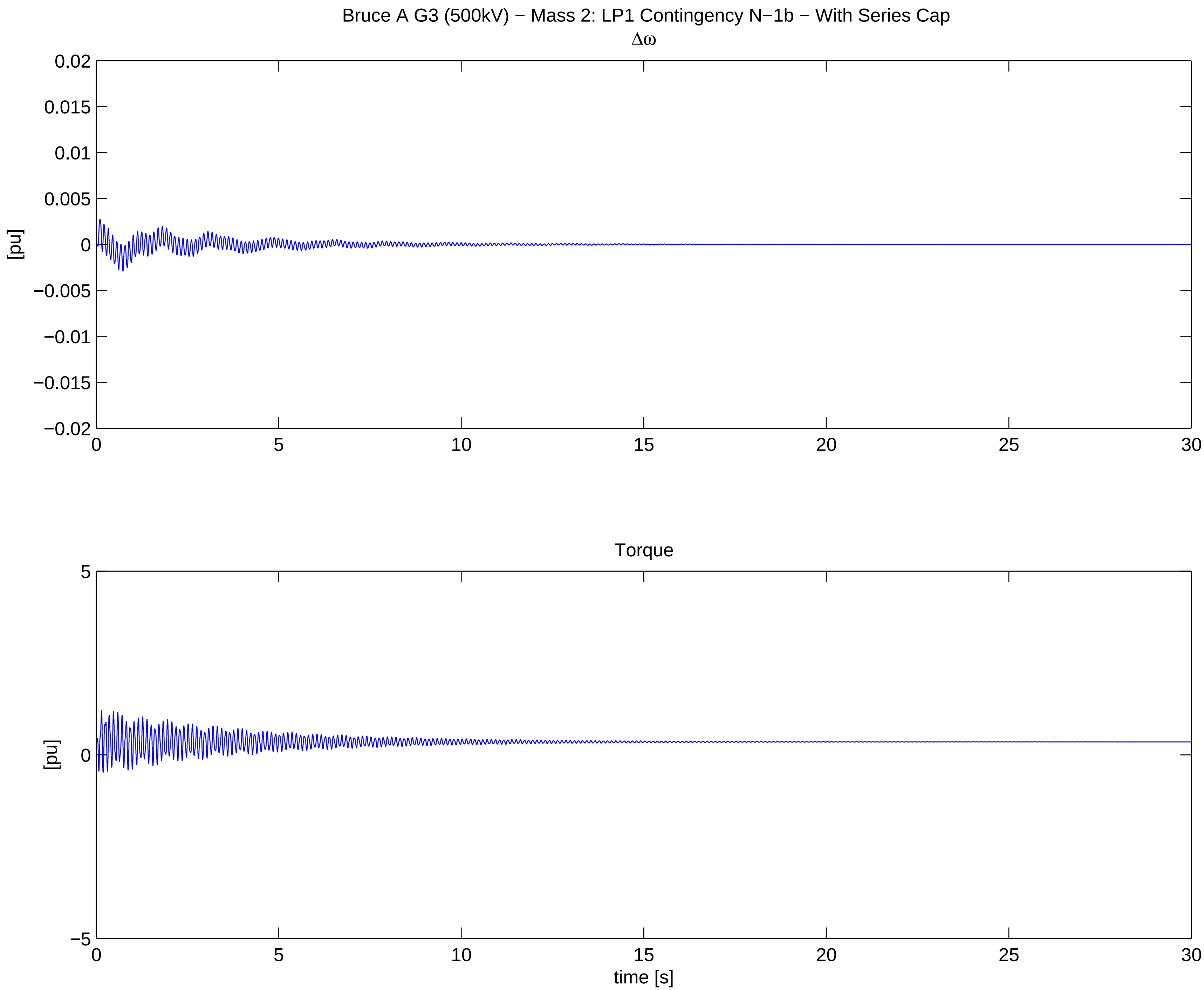


Bruce A G3 (500kV) − Mass 5: GEN Contingency N−0 − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

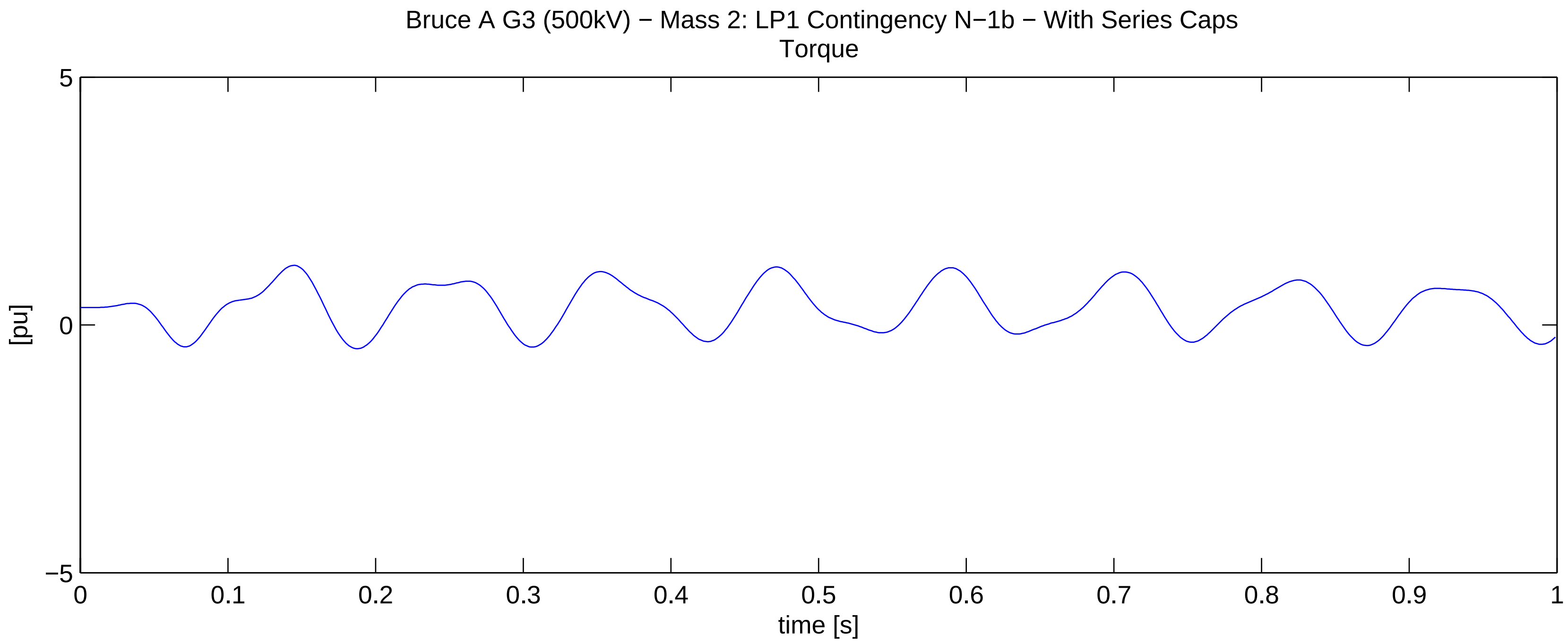

Bruce A G3 (500kV) − Mass 5: GEN Contingency N−0 − With Series Caps
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

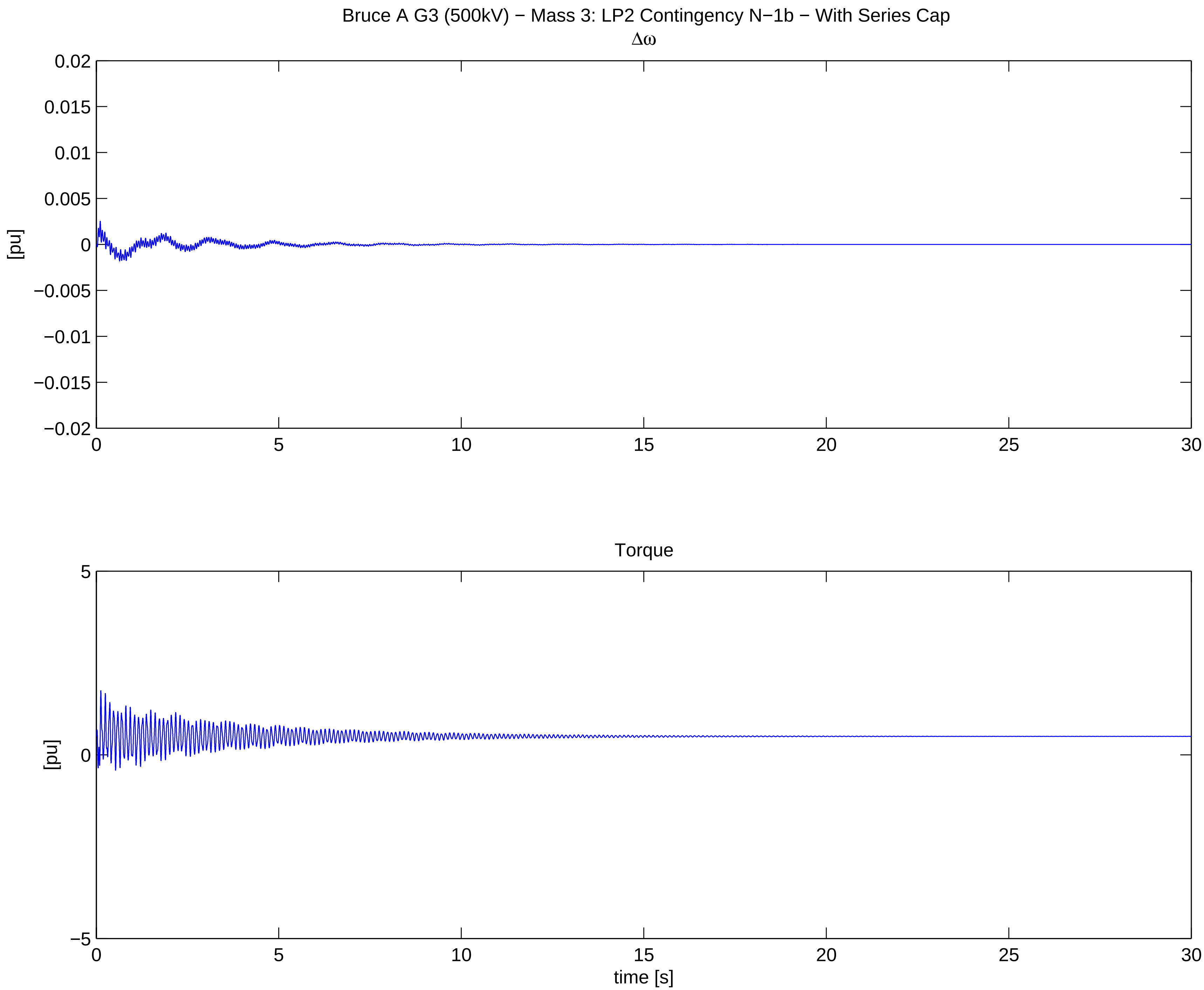

Bruce A G3 (500kV) − Mass 1: HP Contingency N−1b − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce A G3 (500kV) − Mass 1: HP Contingency N−1b − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

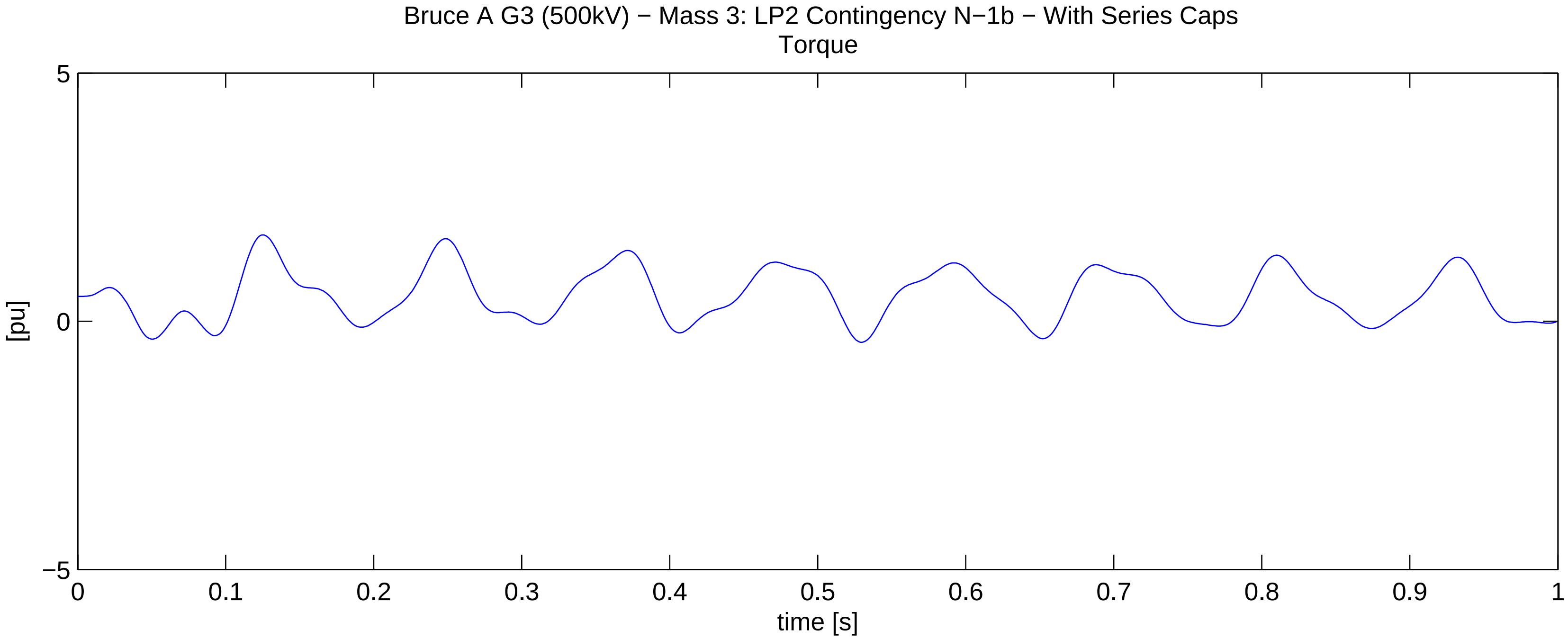


Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−1b − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

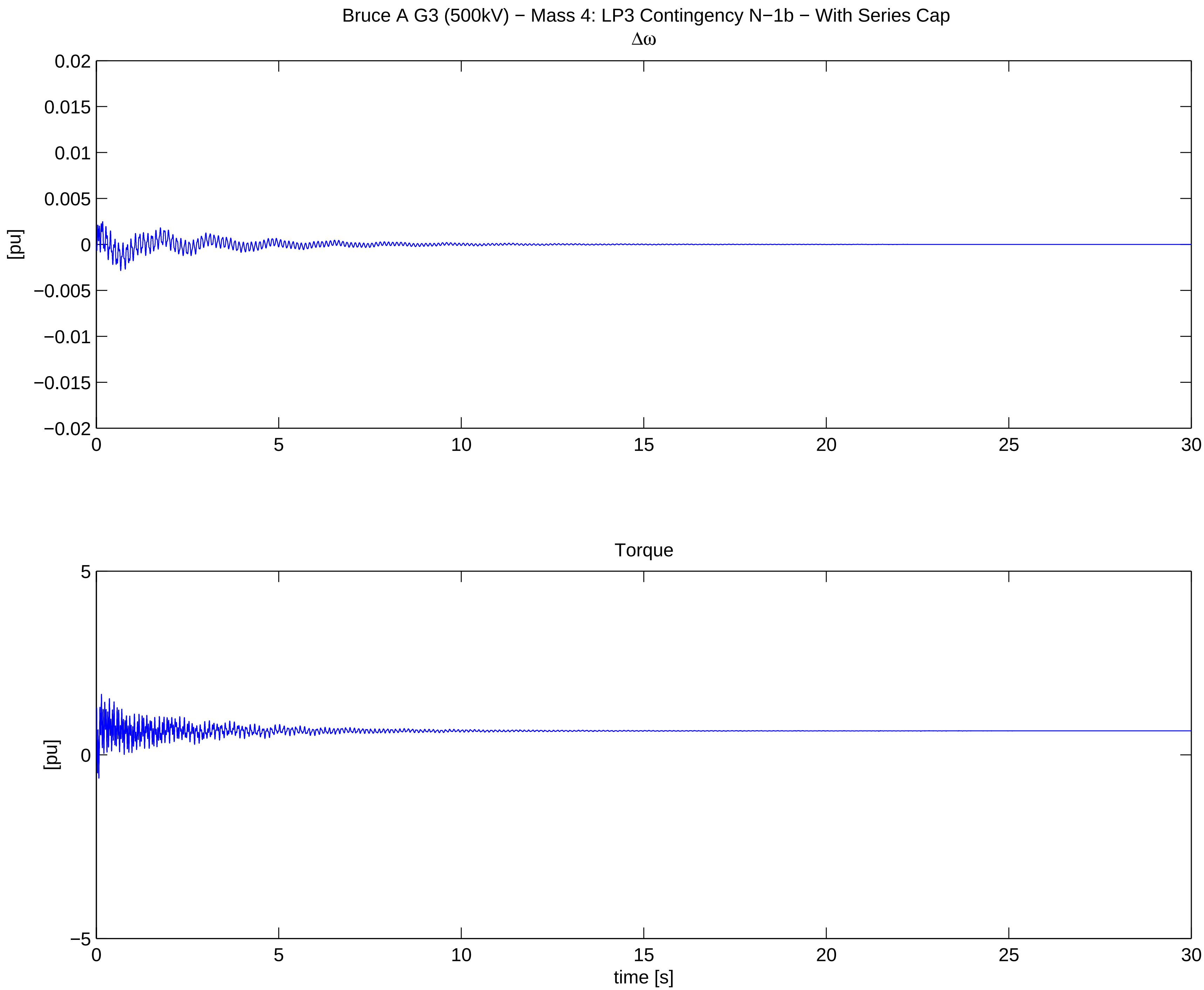

Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−1b − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

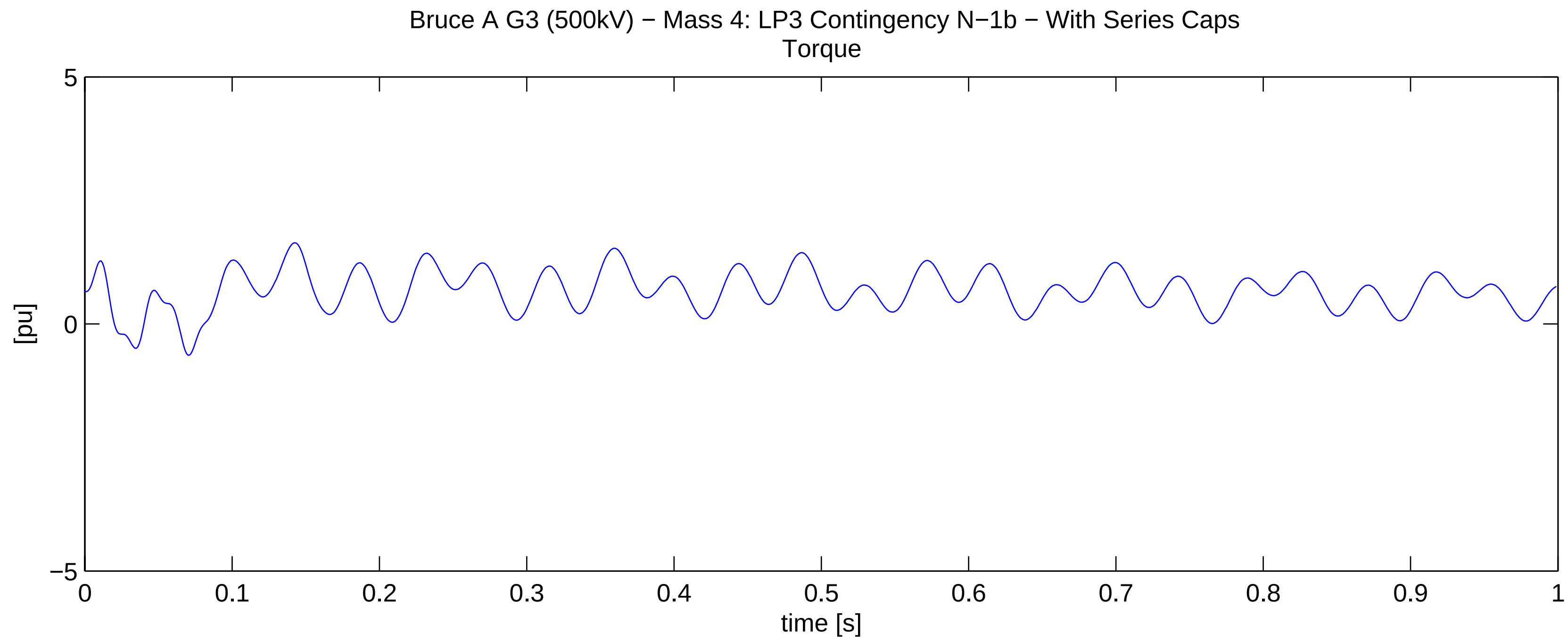


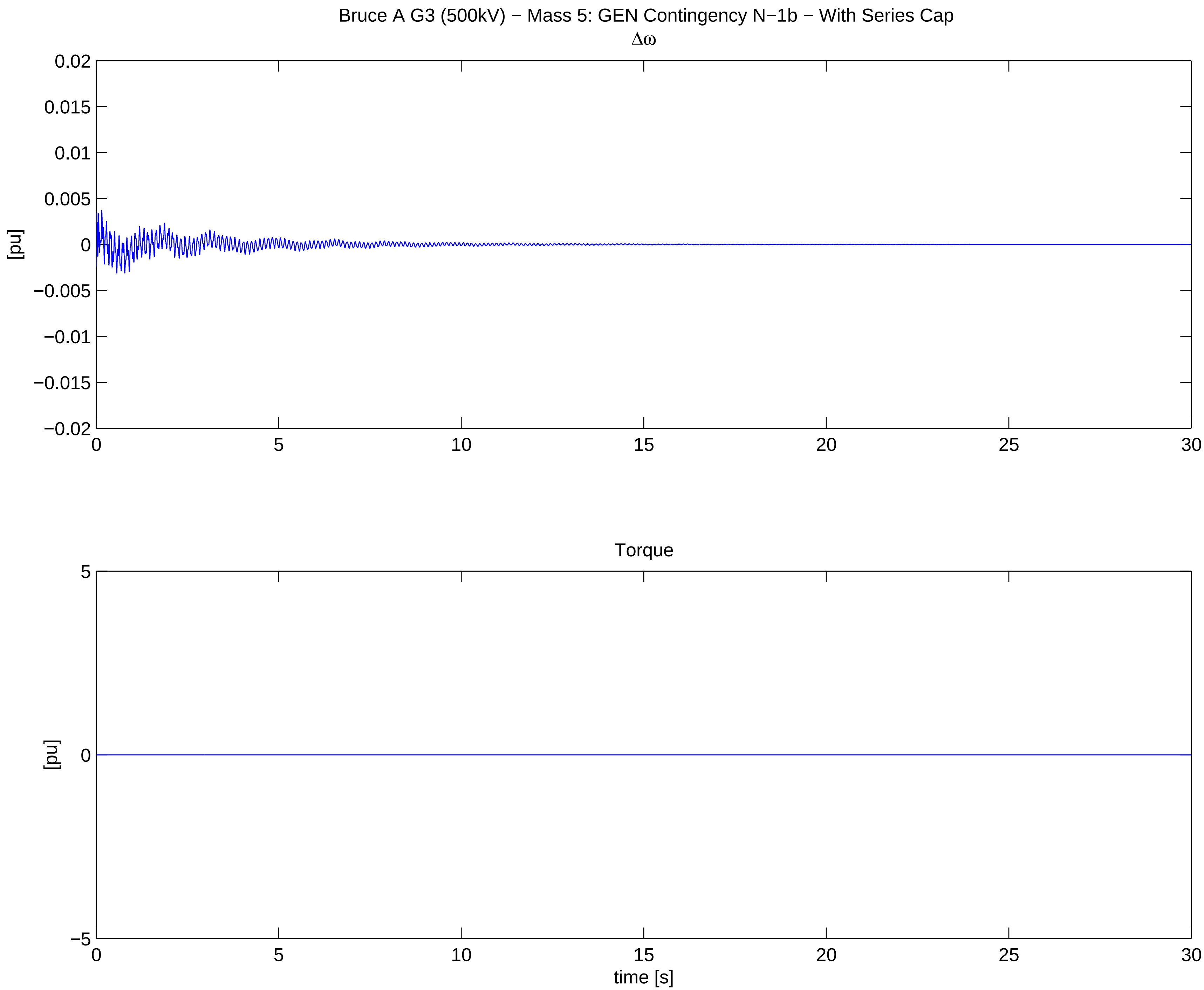
Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−1b − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



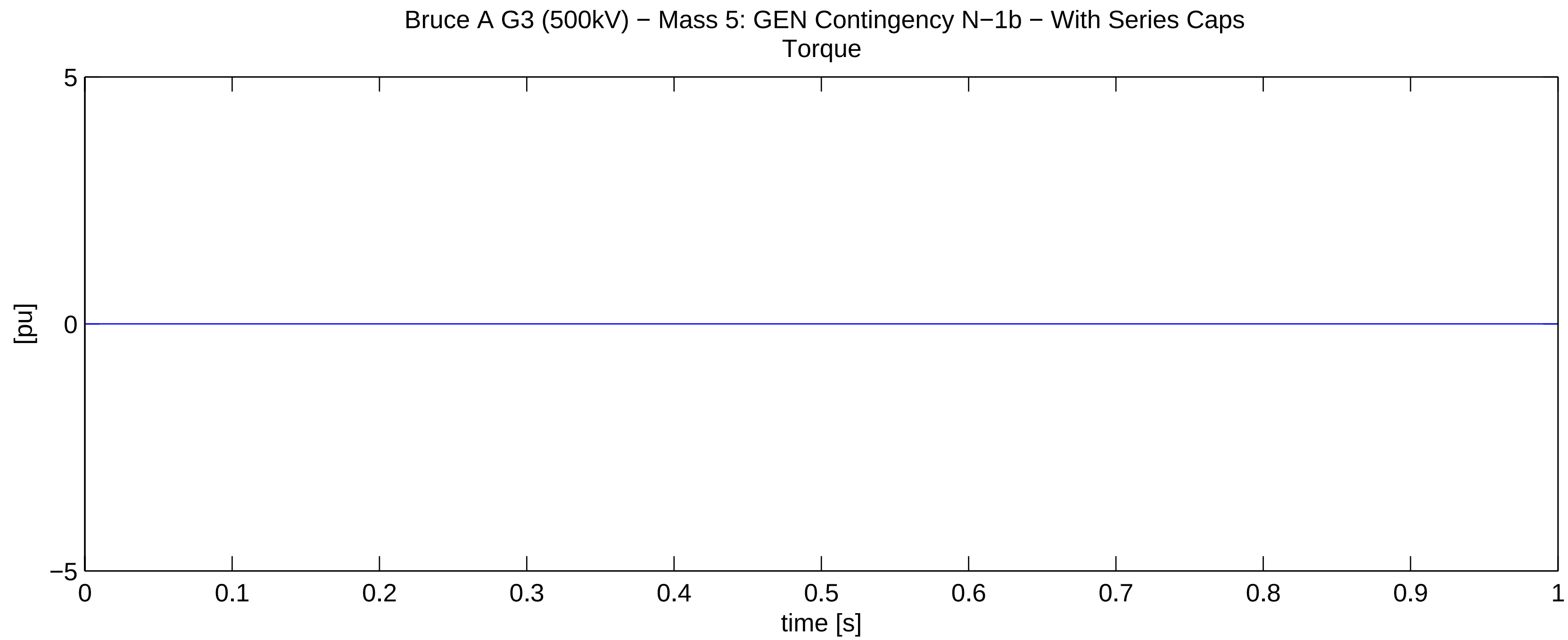
Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−1b − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

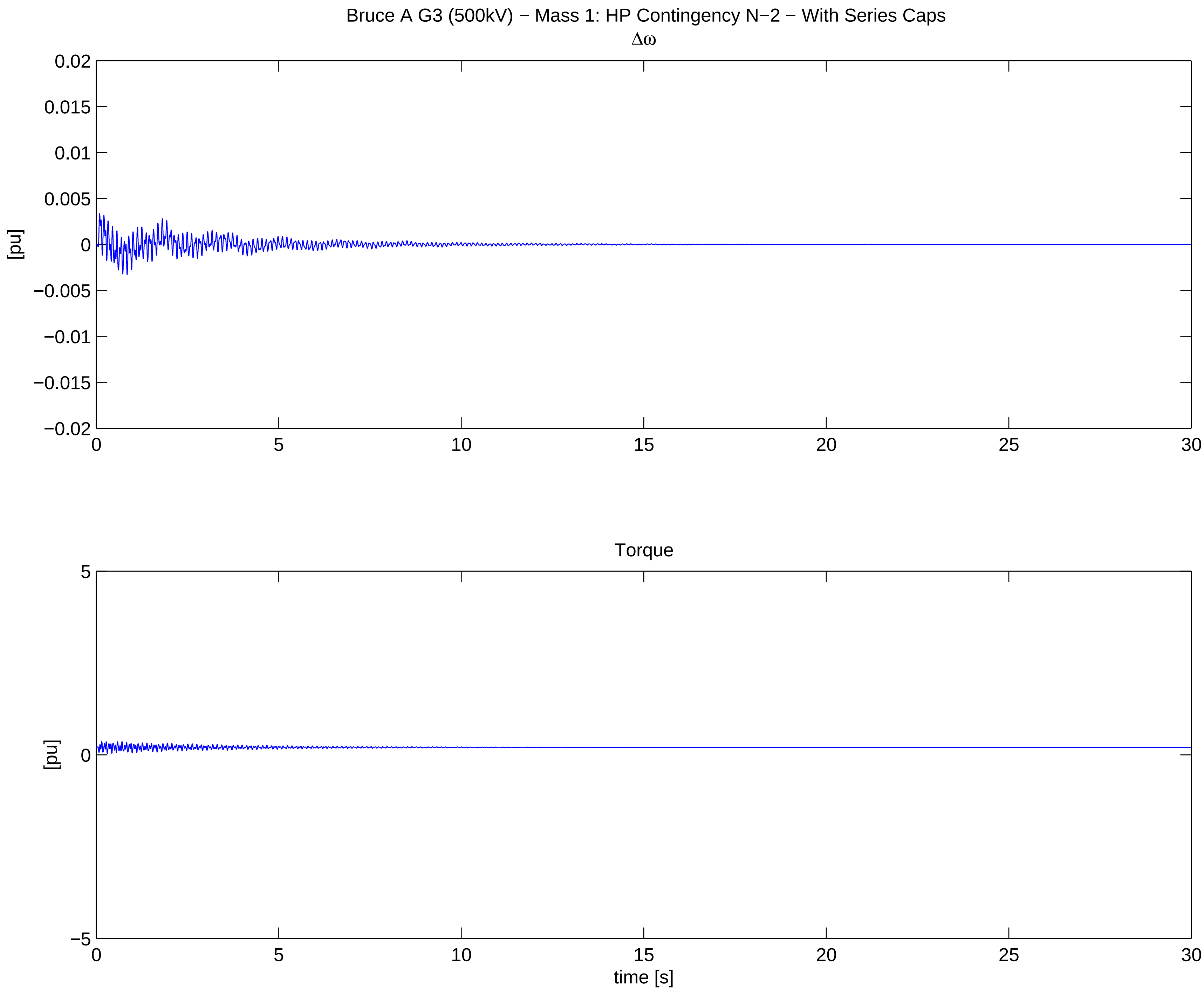

Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−1b − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−1b − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

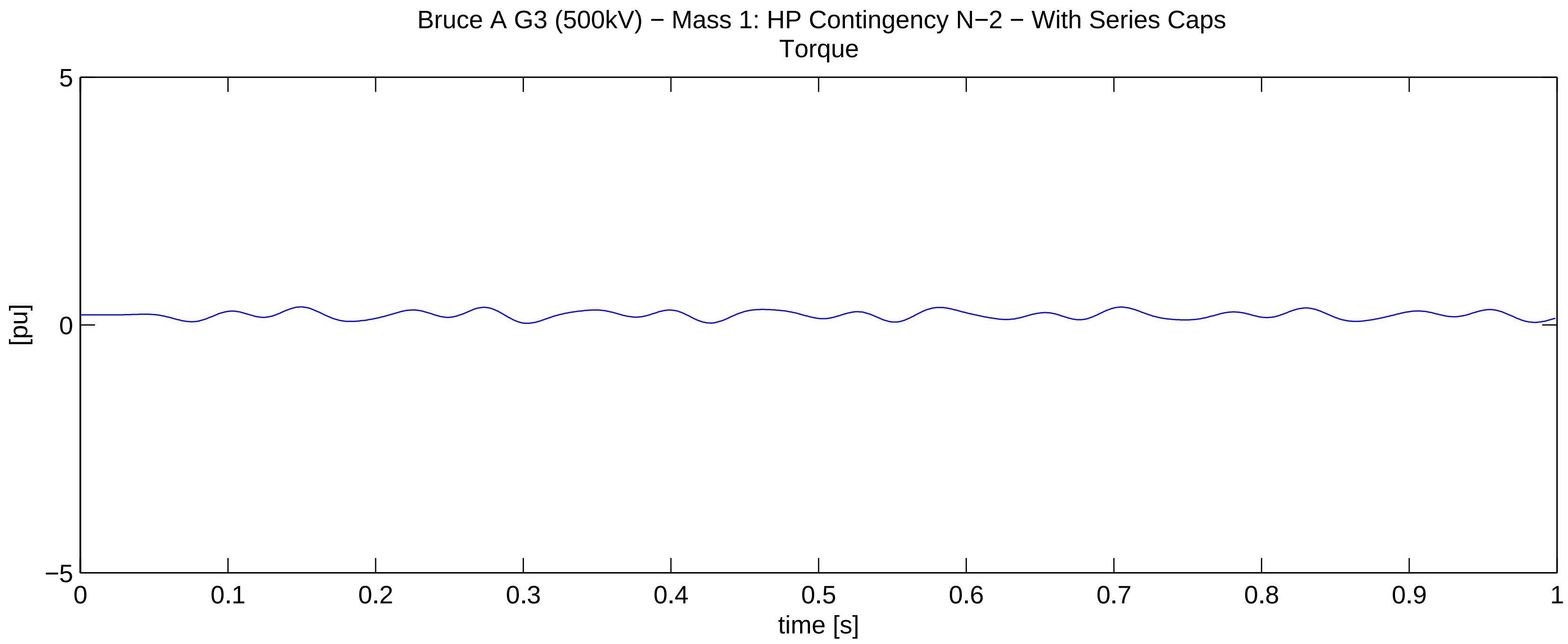


Bruce A G3 (500kV) − Mass 5: GEN Contingency N−1b − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

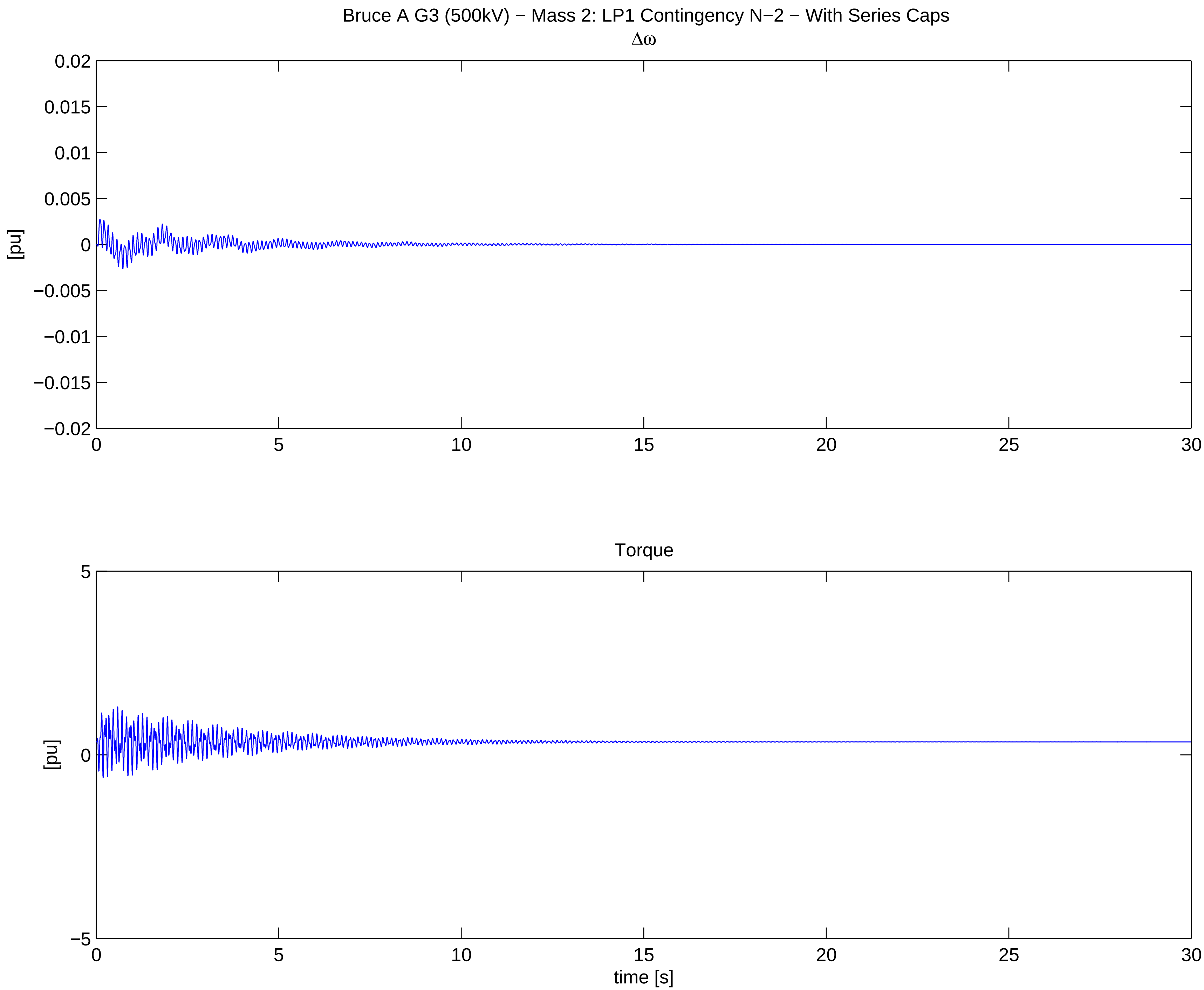

Bruce A G3 (500kV) − Mass 5: GEN Contingency N−1b − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

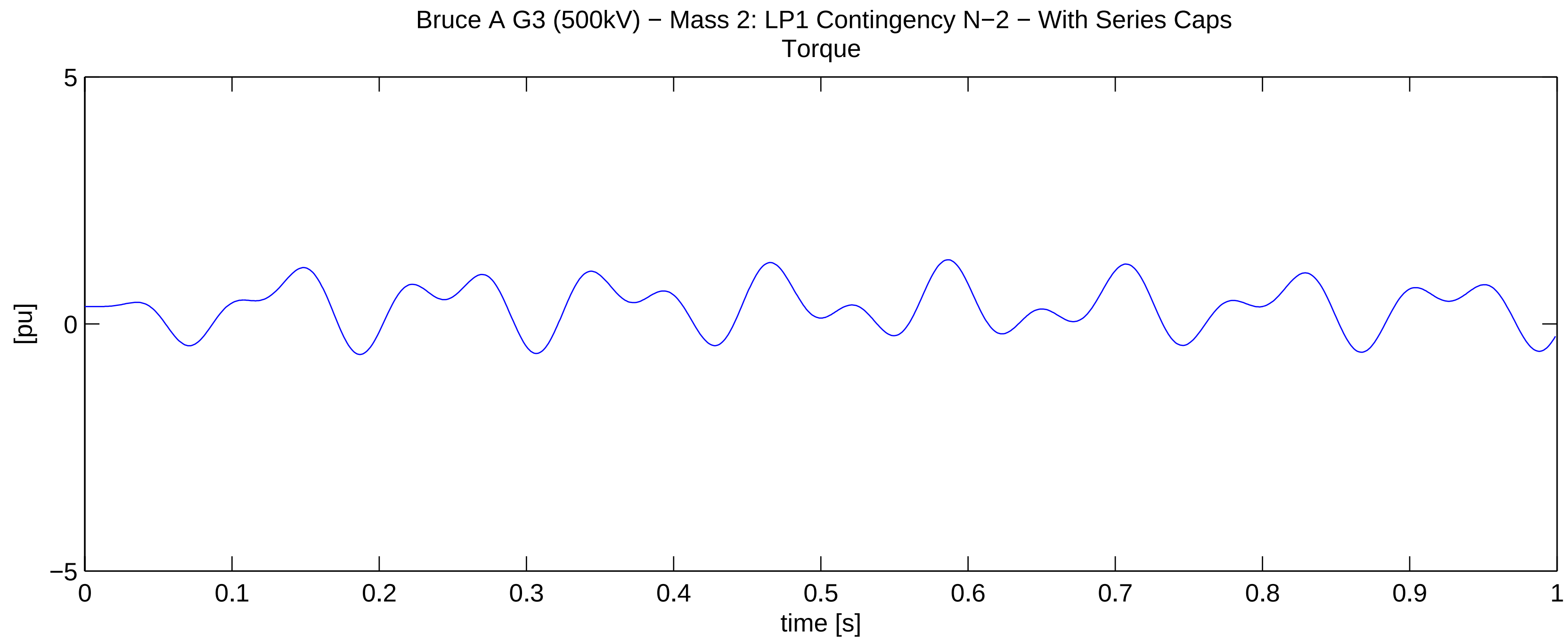


Bruce A G3 (500kV) − Mass 1: HP Contingency N−2 − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

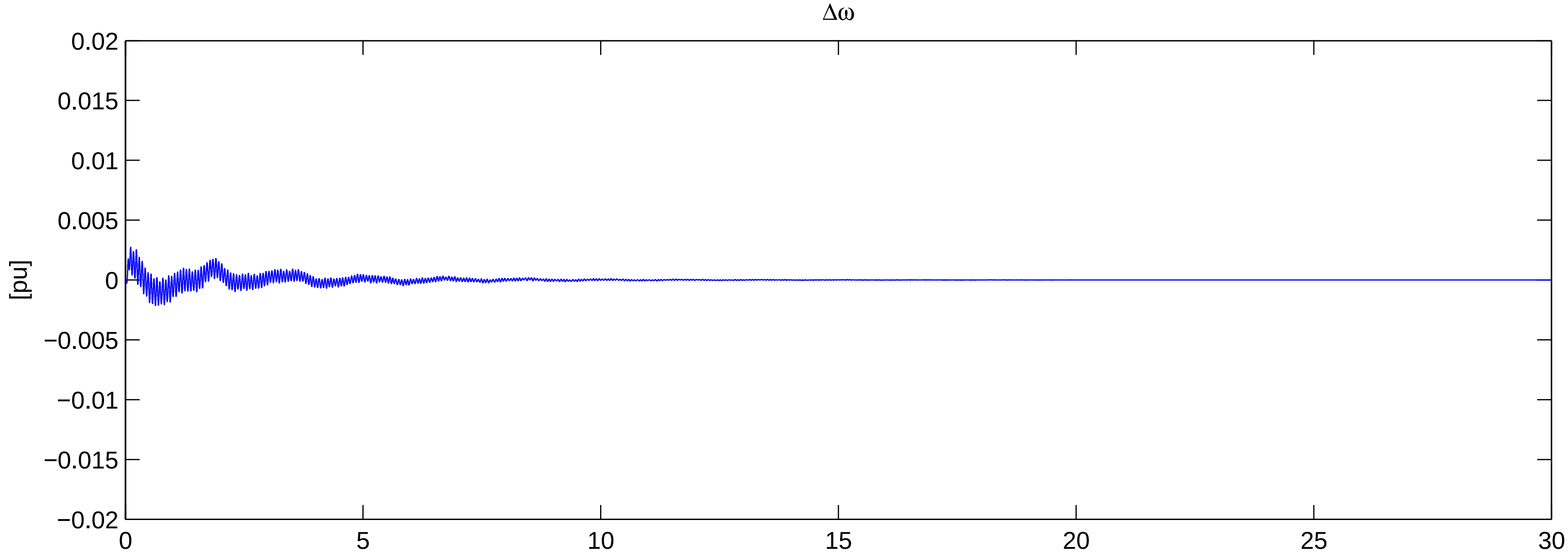


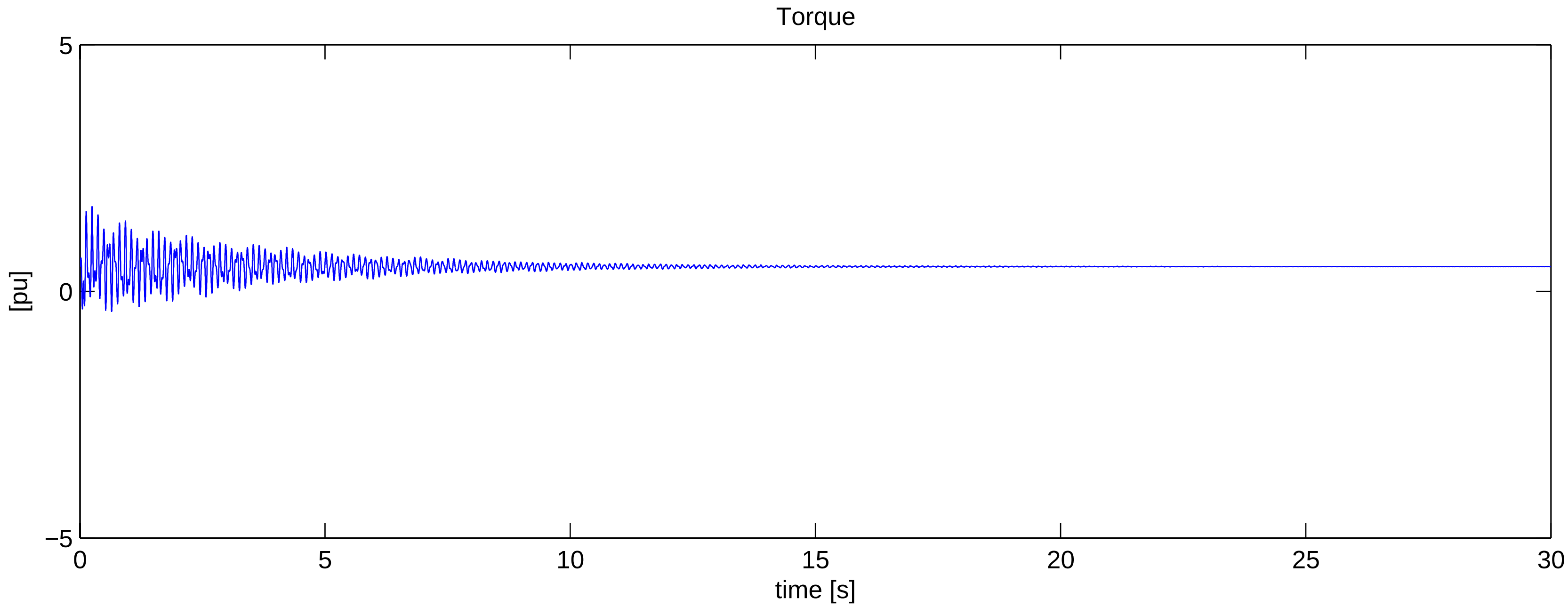
Bruce A G3 (500kV) − Mass 1: HP Contingency N−2 − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

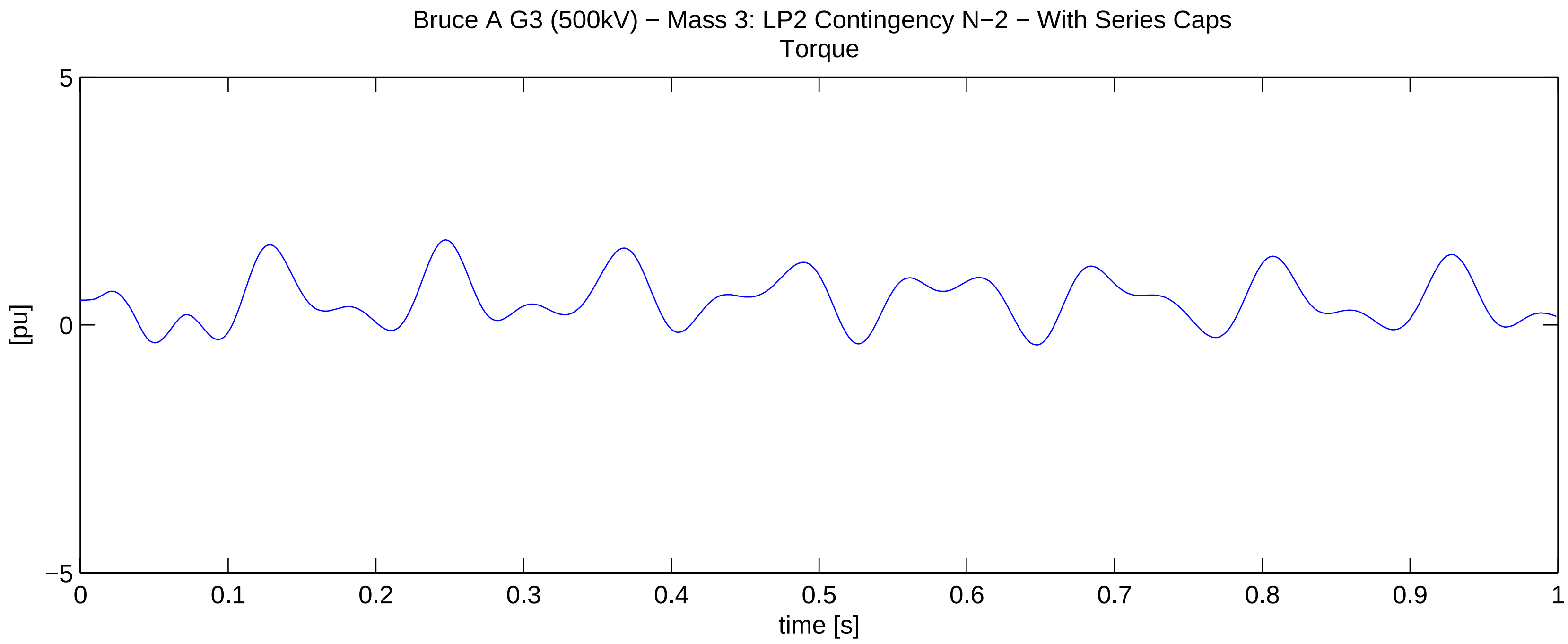

Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−2 − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−2 − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

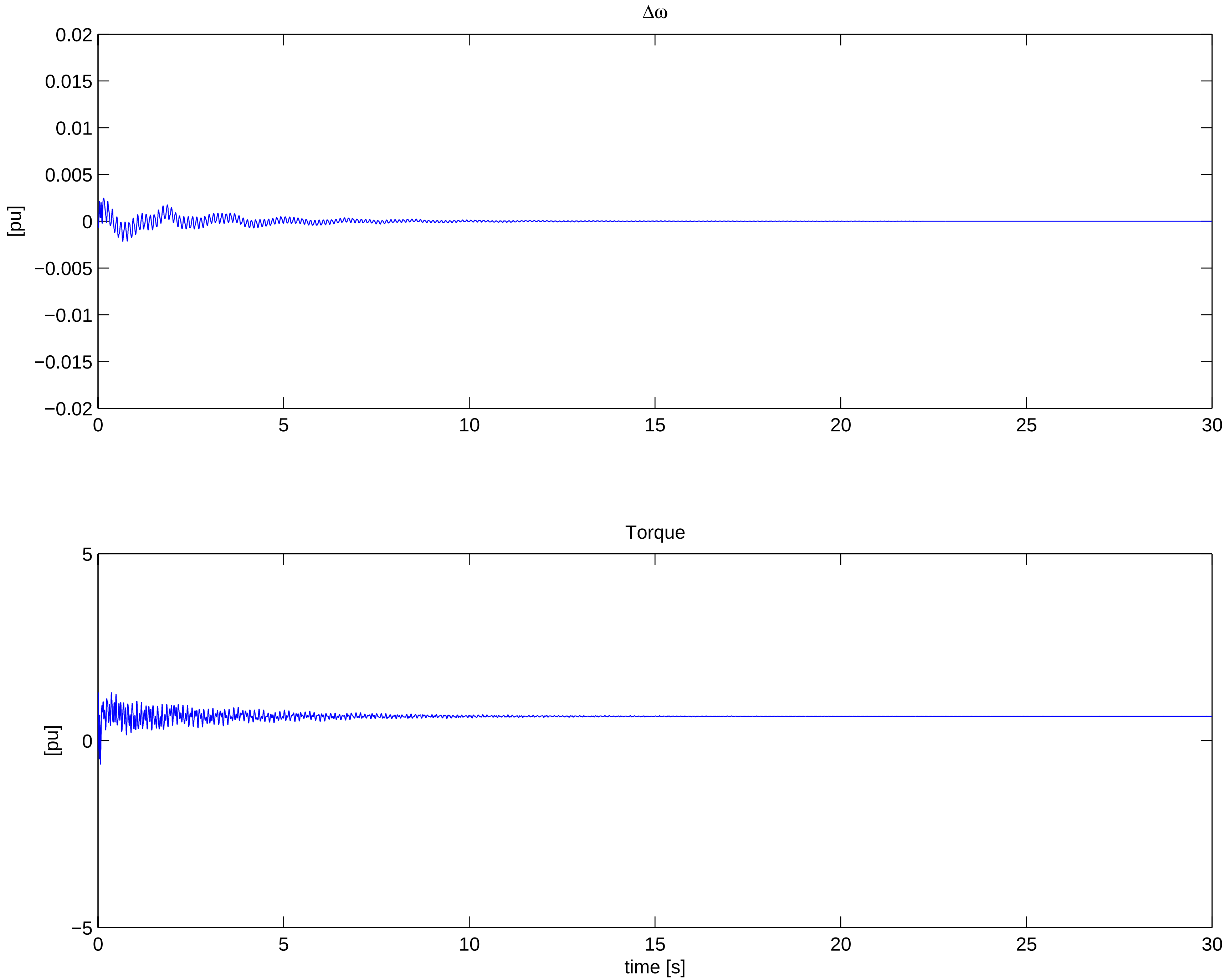
Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−2 − With Series Caps

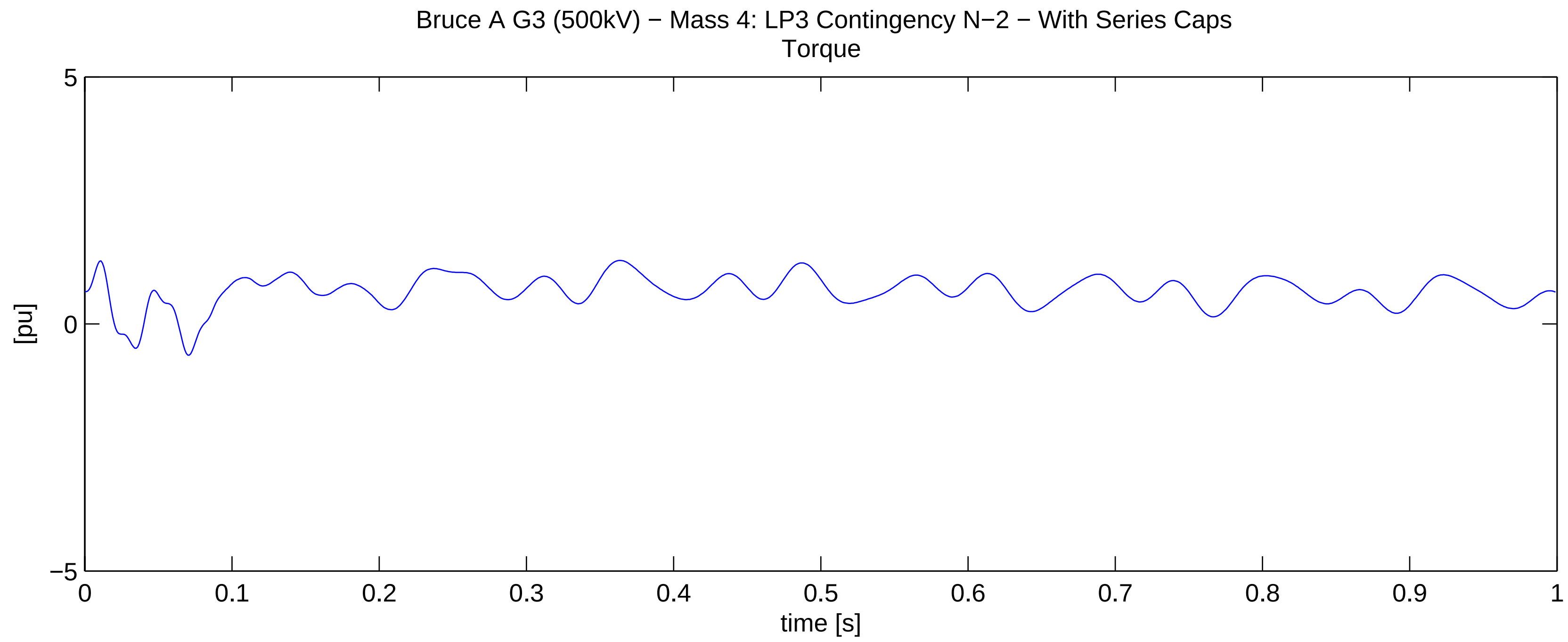


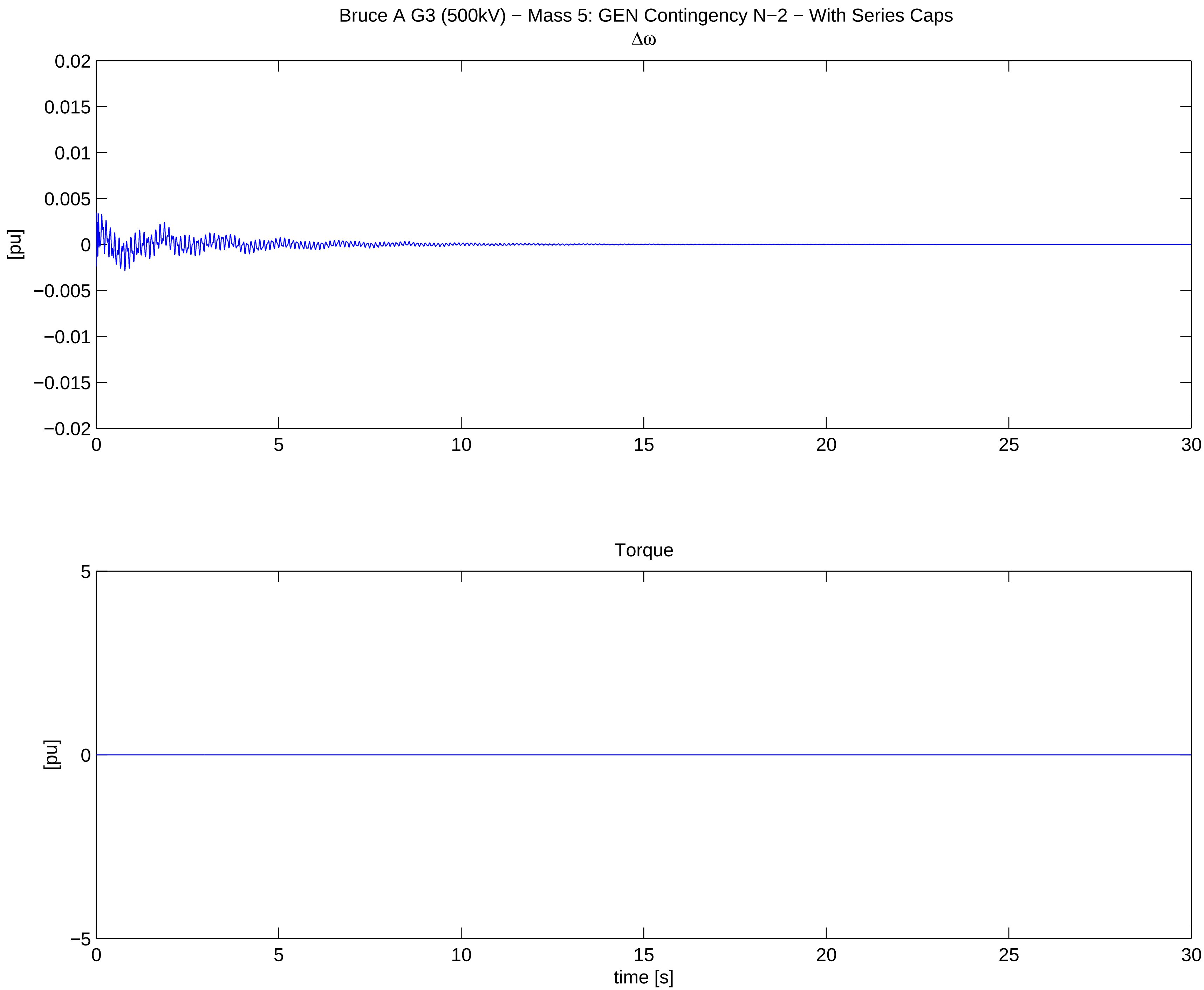



Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−2 − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

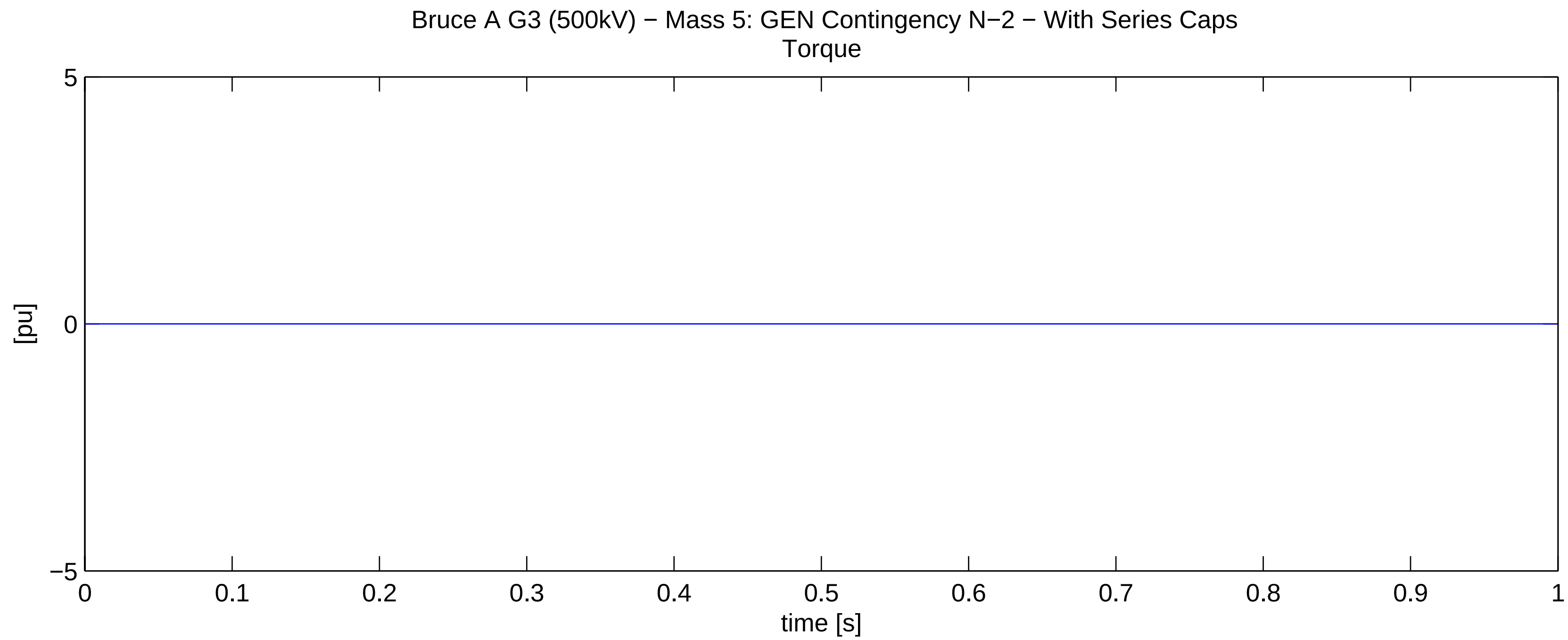
Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−2 − With Series Caps




Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−2 − With Series Caps
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

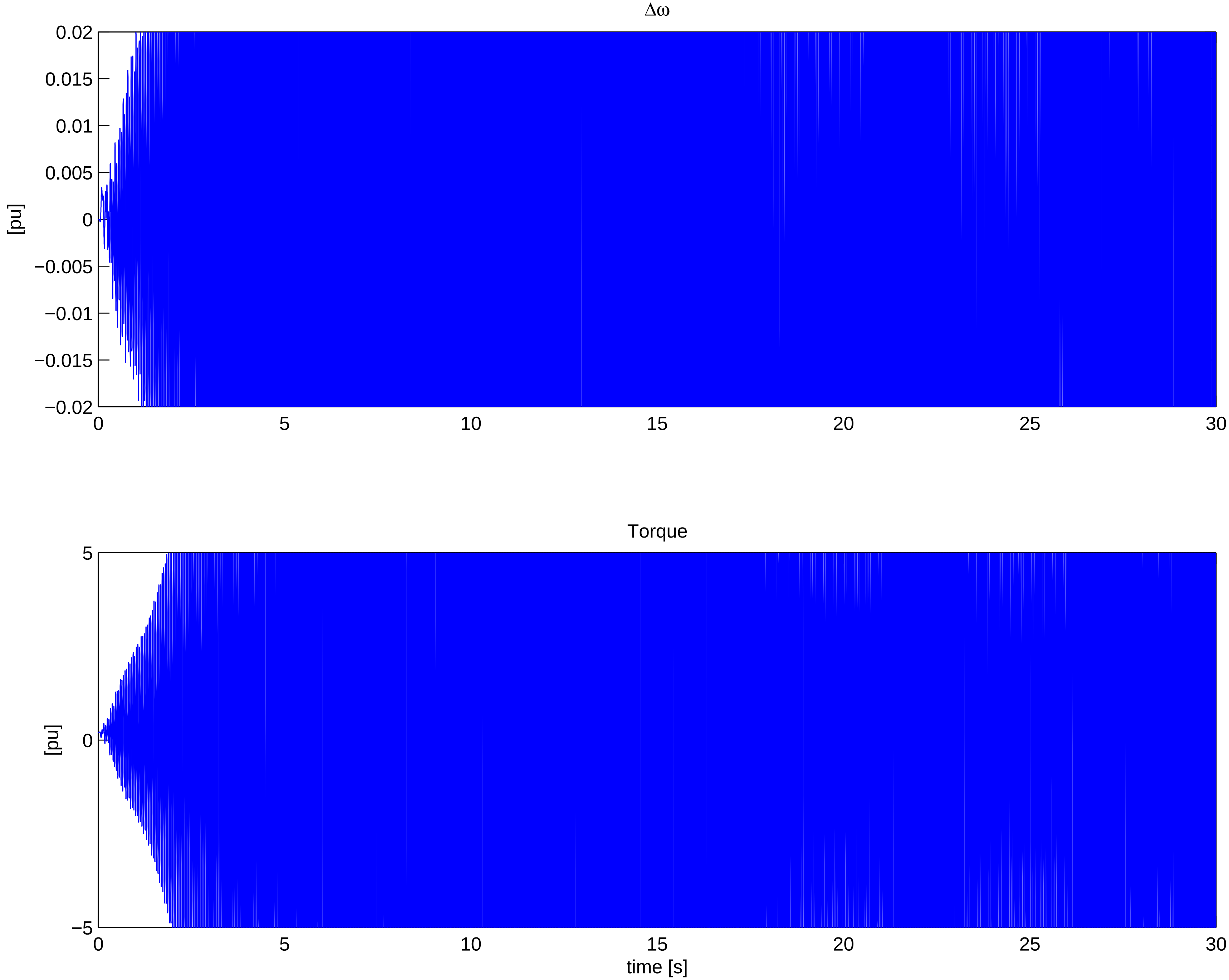


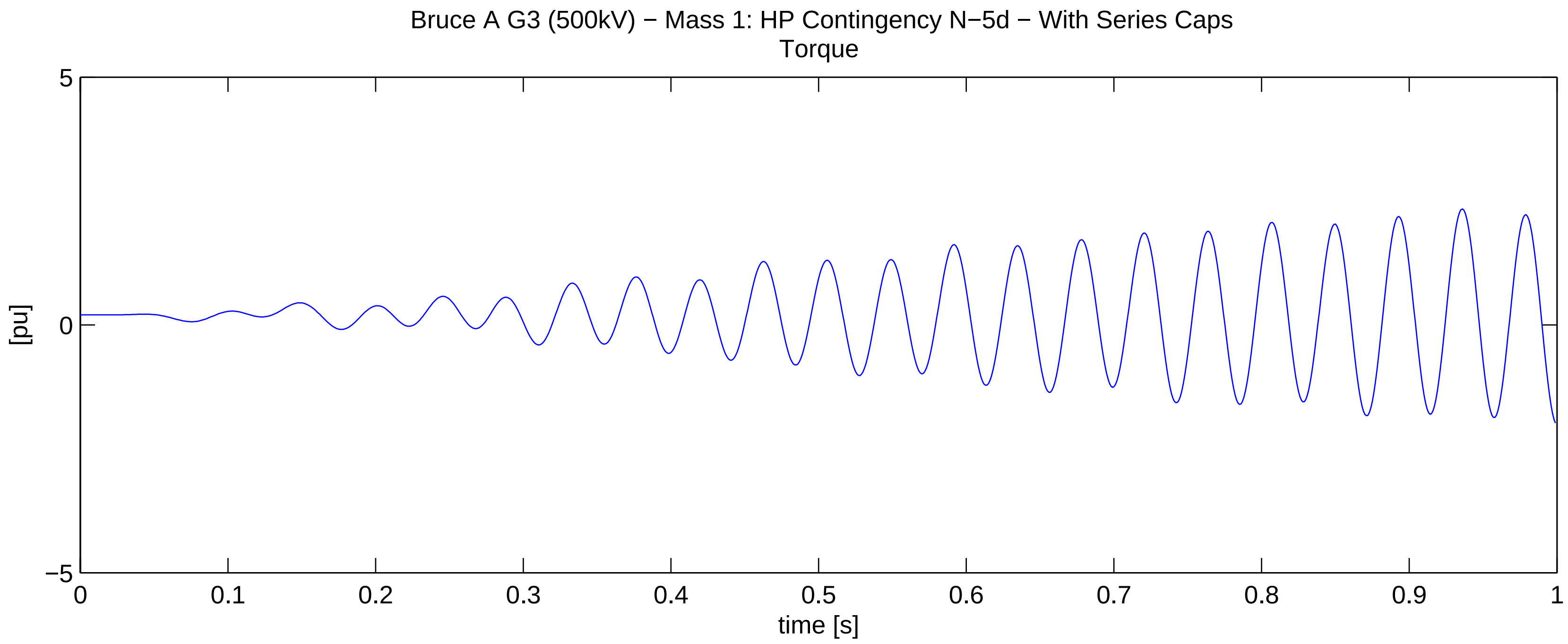
Bruce A G3 (500kV) − Mass 5: GEN Contingency N−2 − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

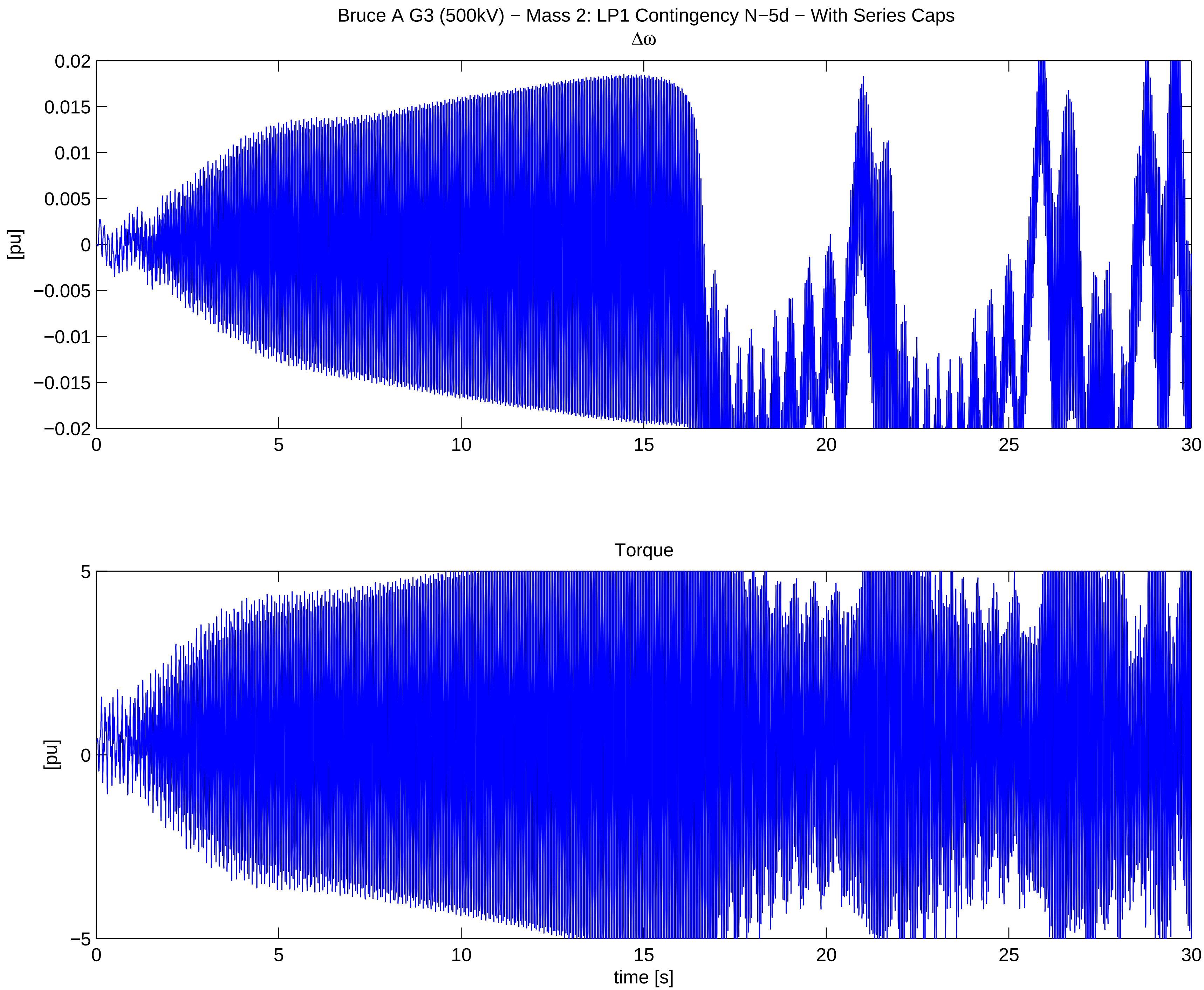


Bruce A G3 (500kV) − Mass 5: GEN Contingency N−2 − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

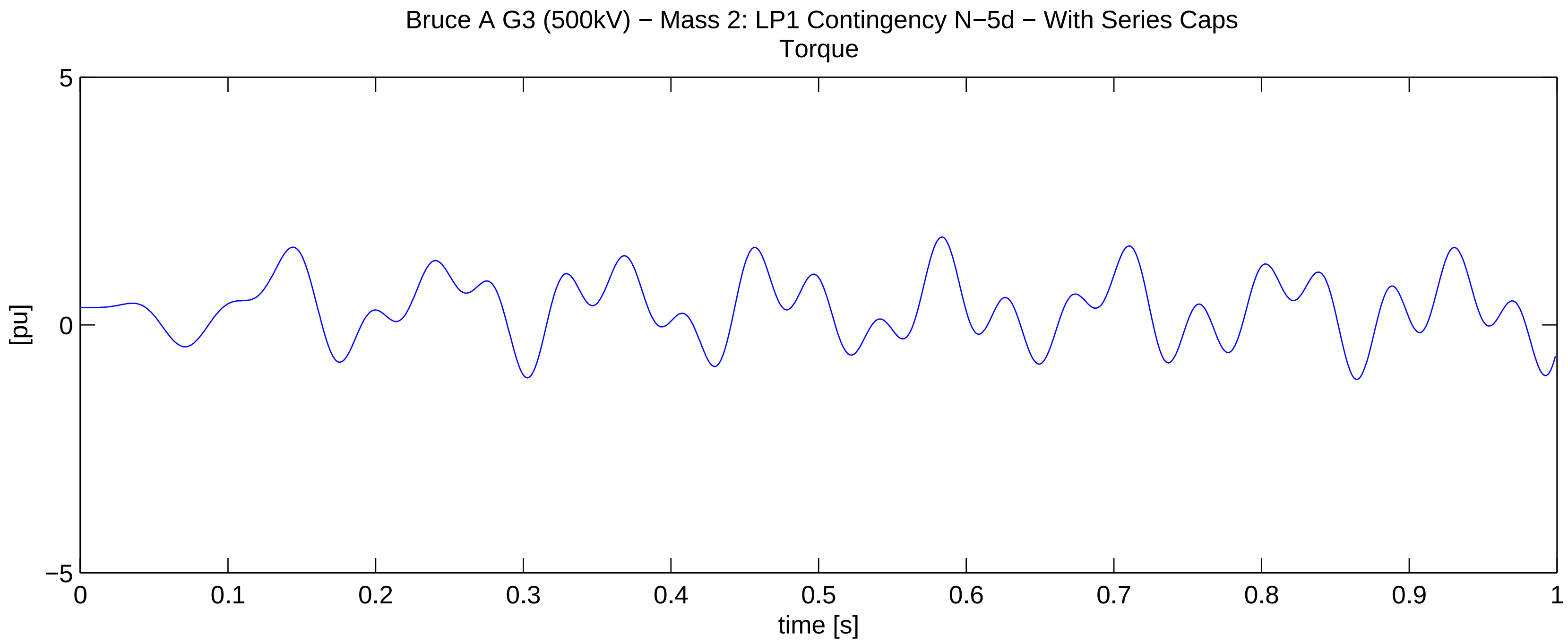
Bruce A G3 (500kV) − Mass 1: HP Contingency N−5d − With Series Caps

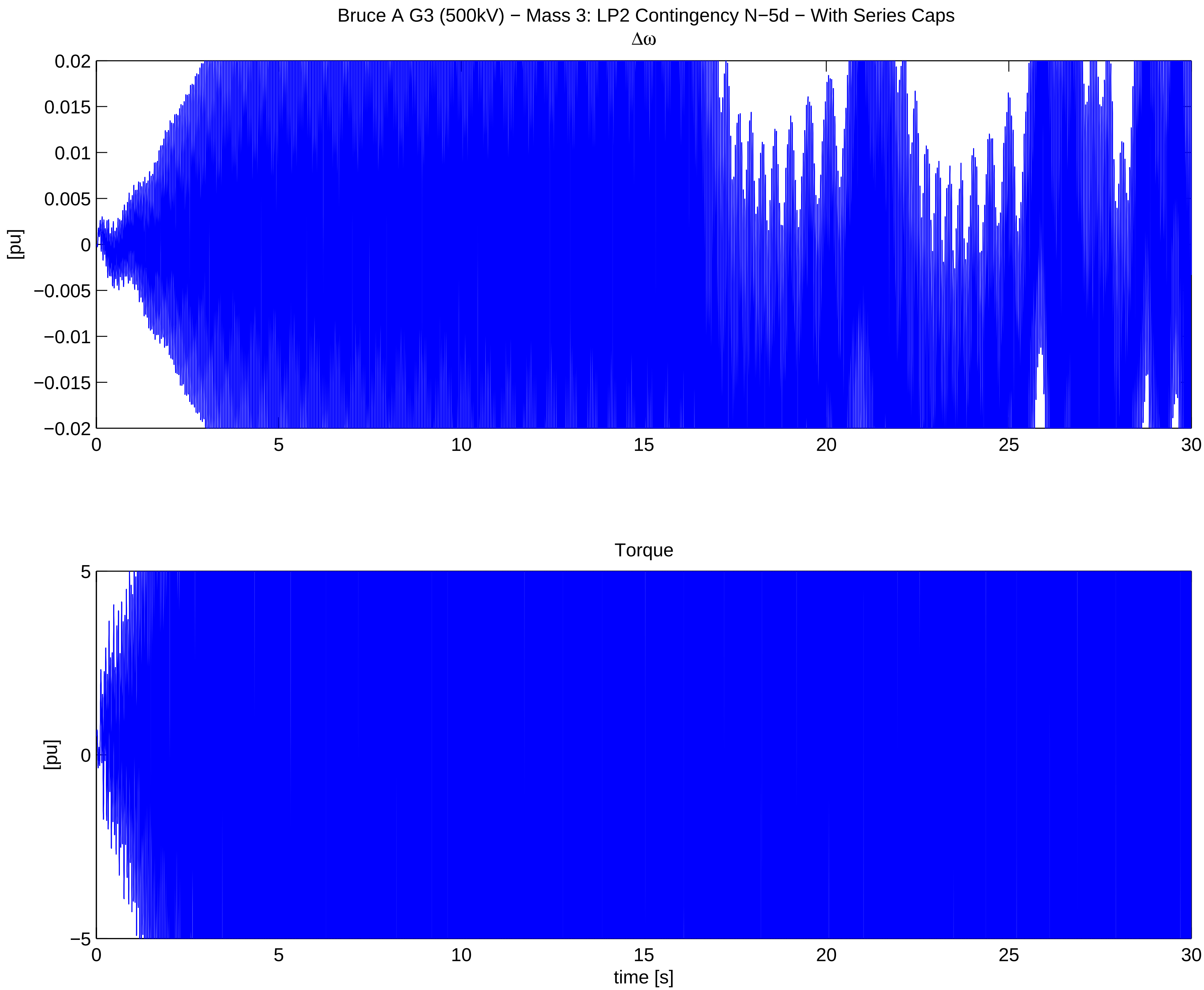


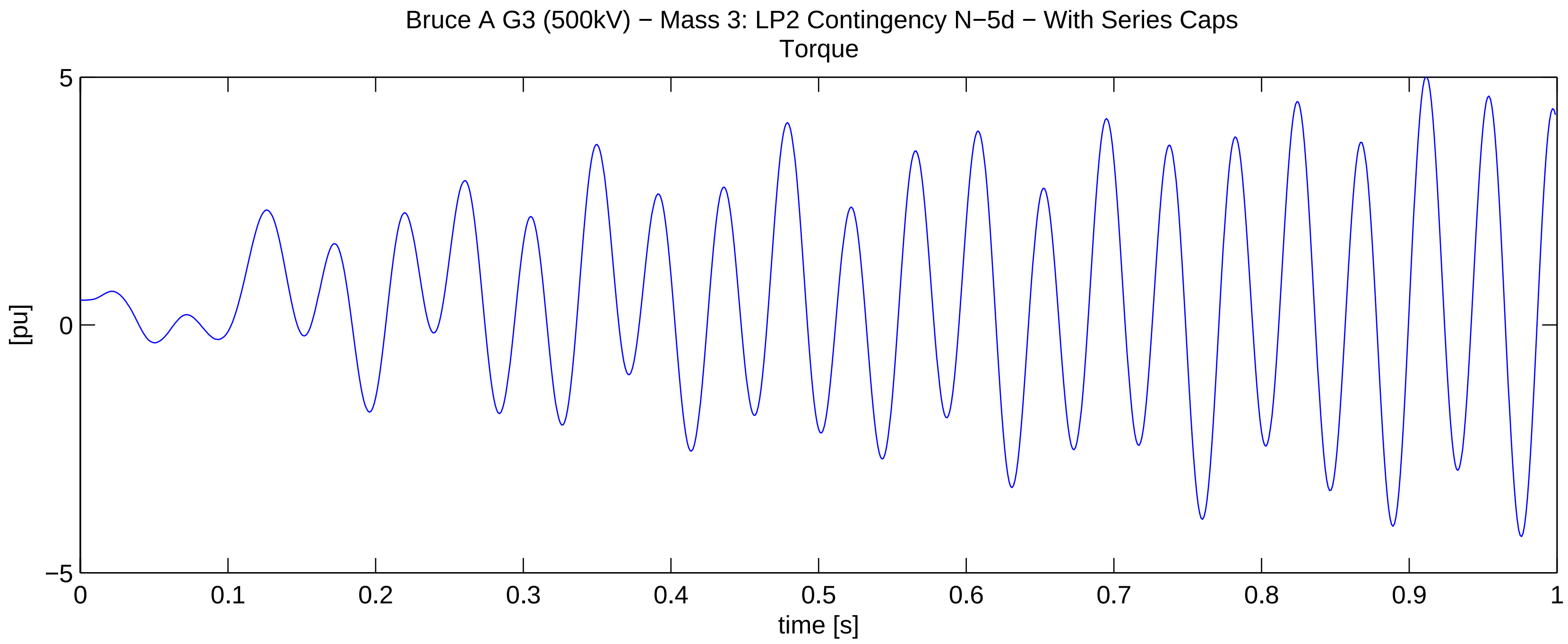

Bruce A G3 (500kV) − Mass 1: HP Contingency N−5d − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

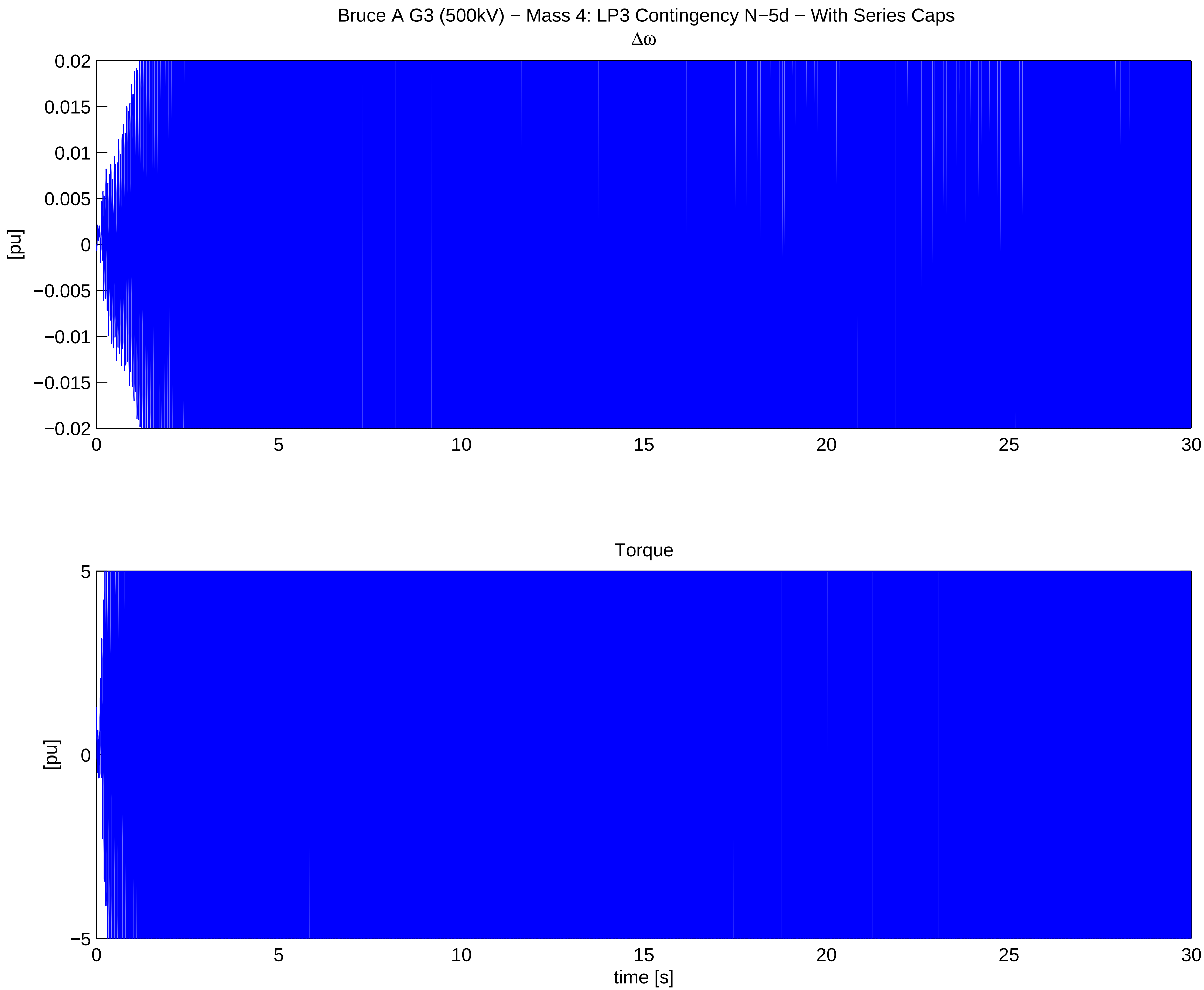


Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−5d − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

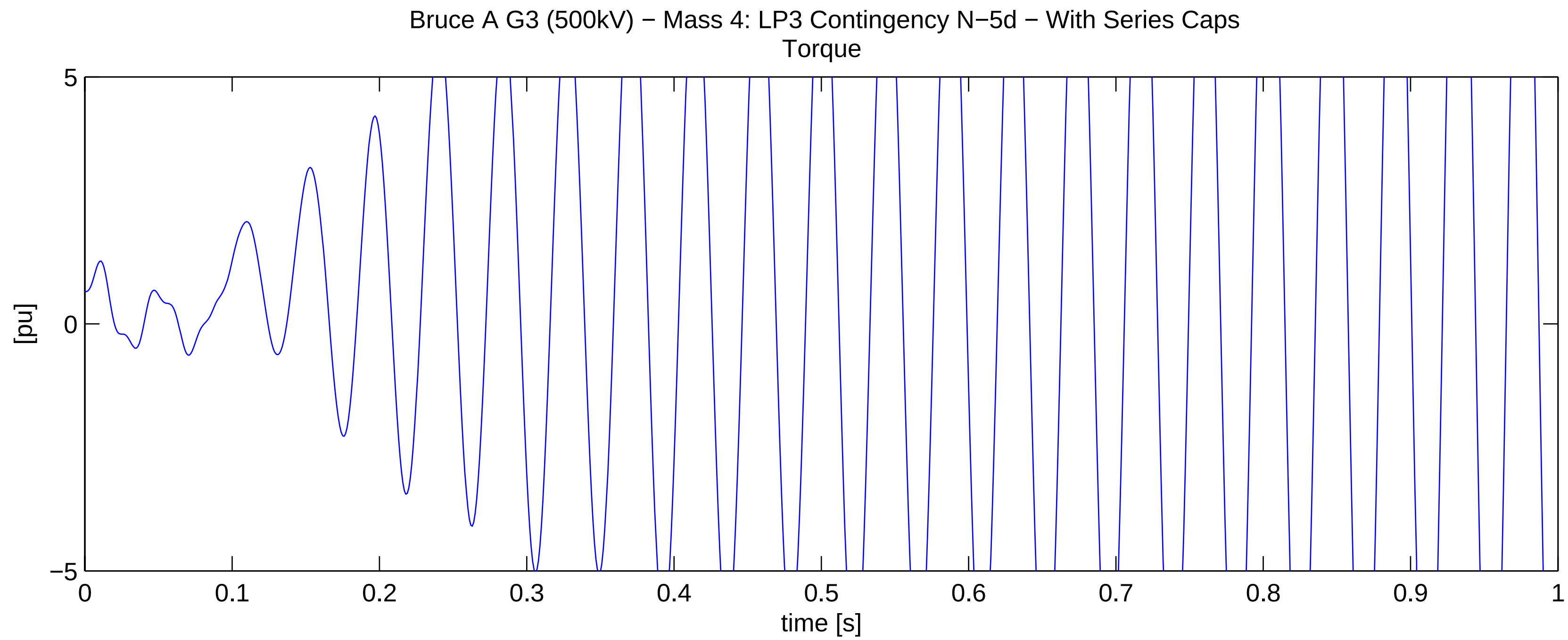

Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−5d − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−5d − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

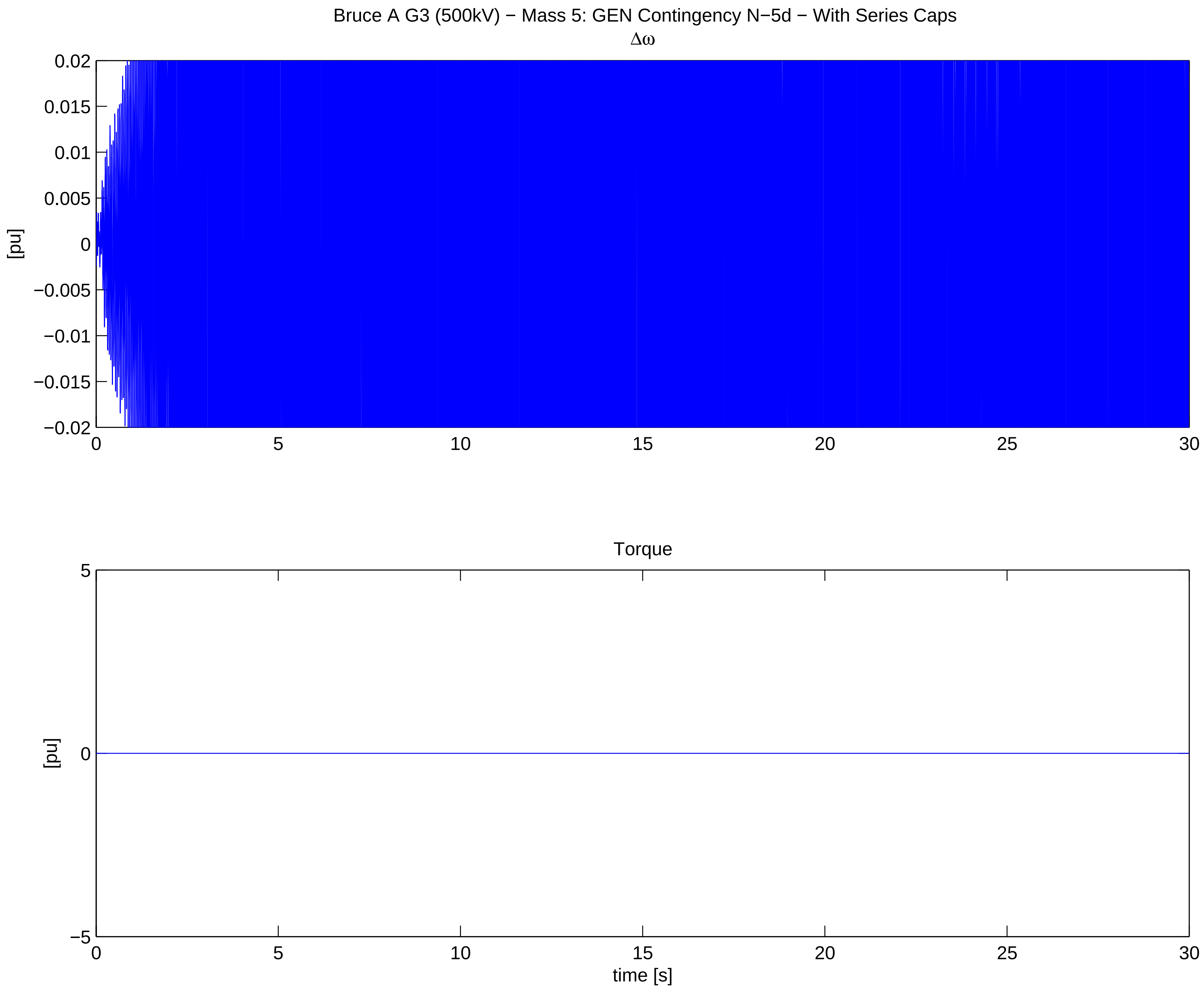

Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−5d − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



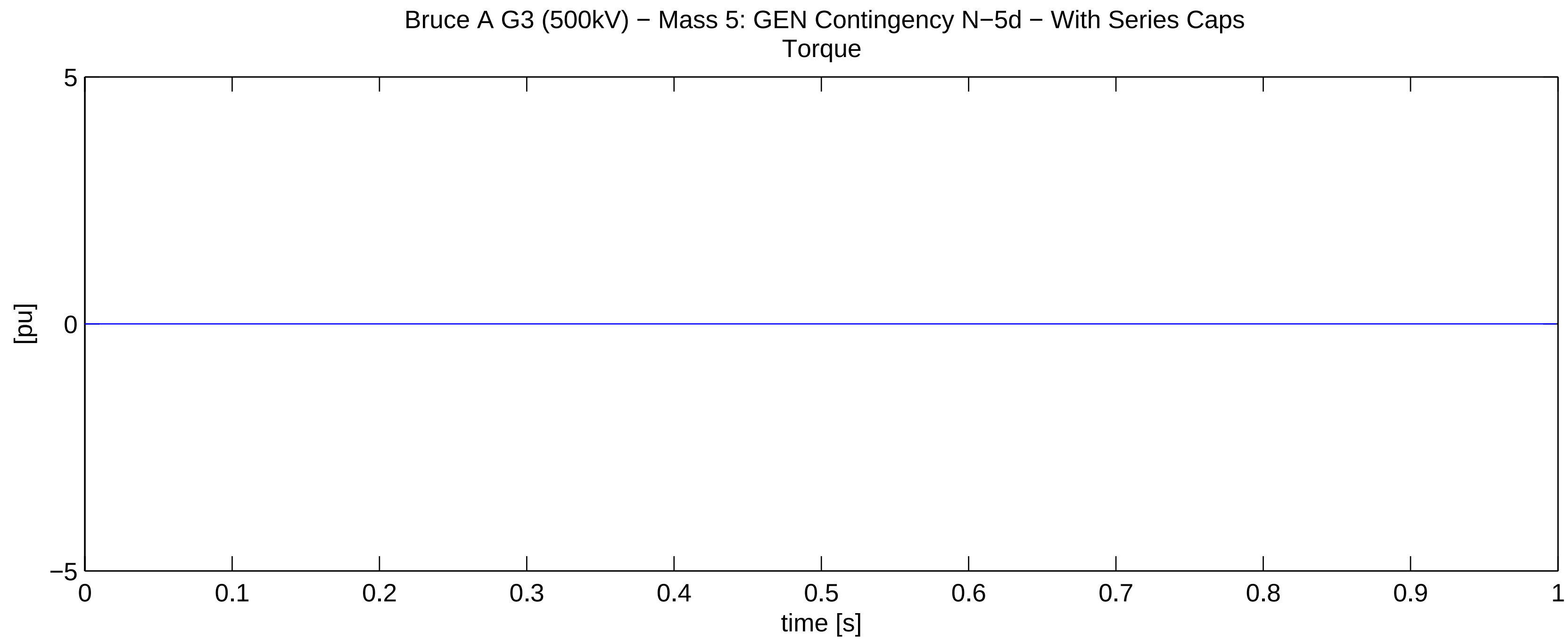
Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−5d − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

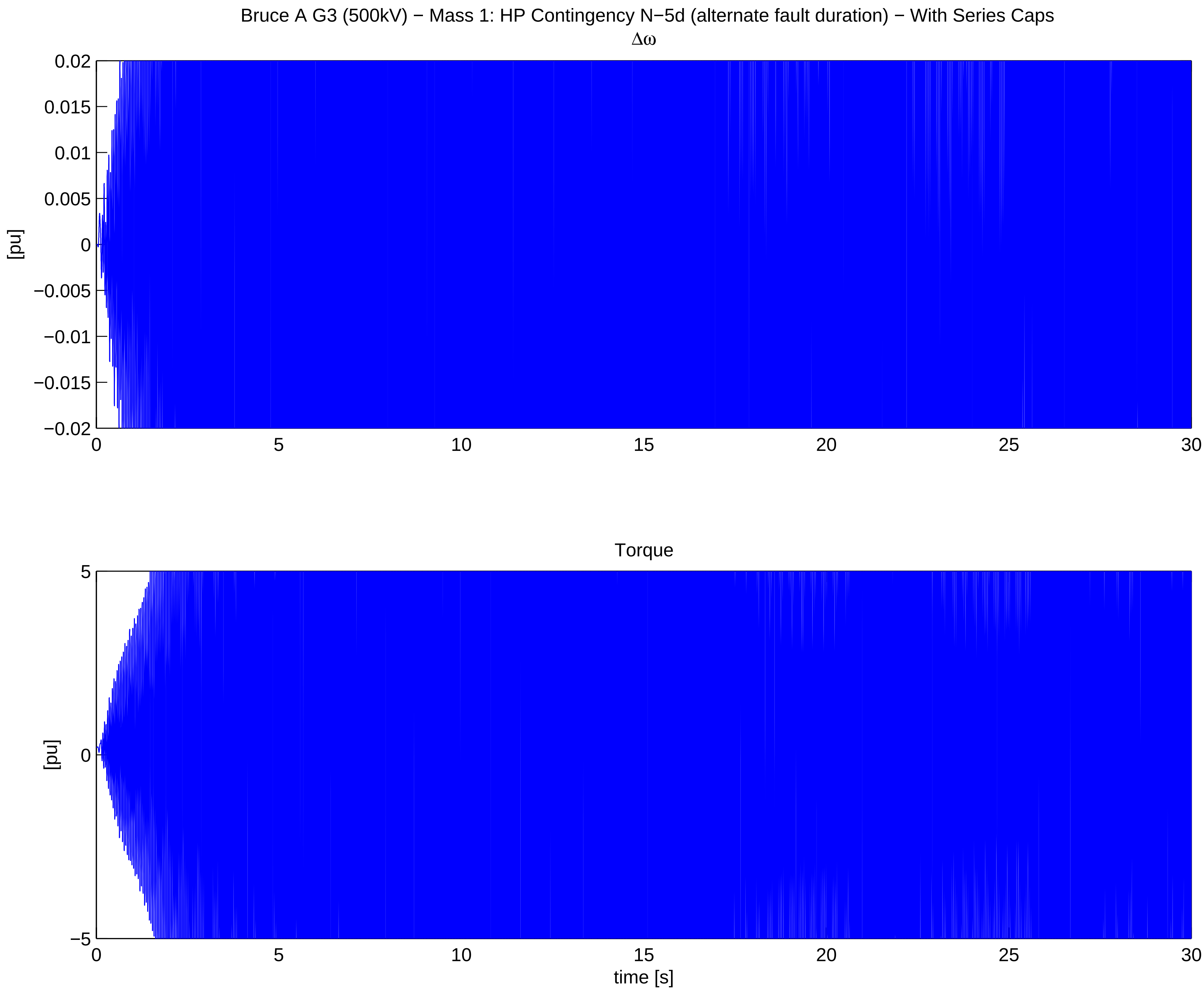


Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−5d − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

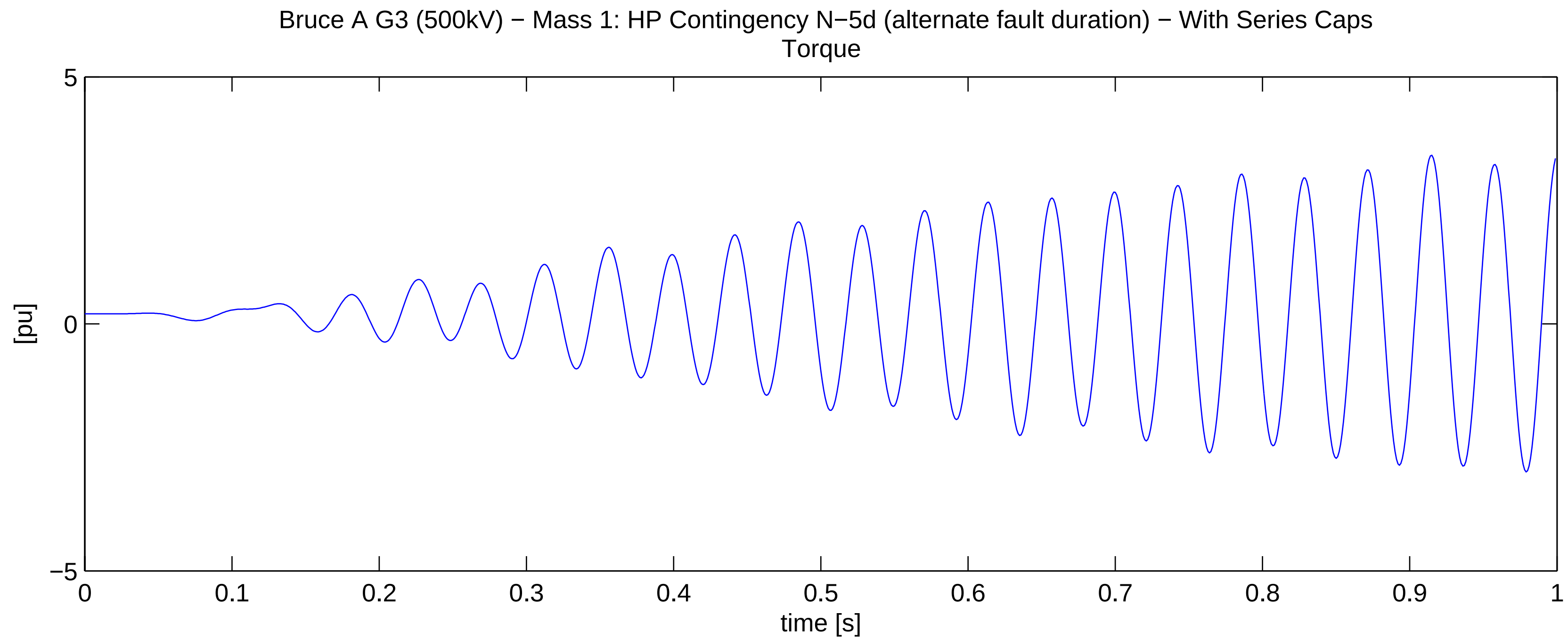


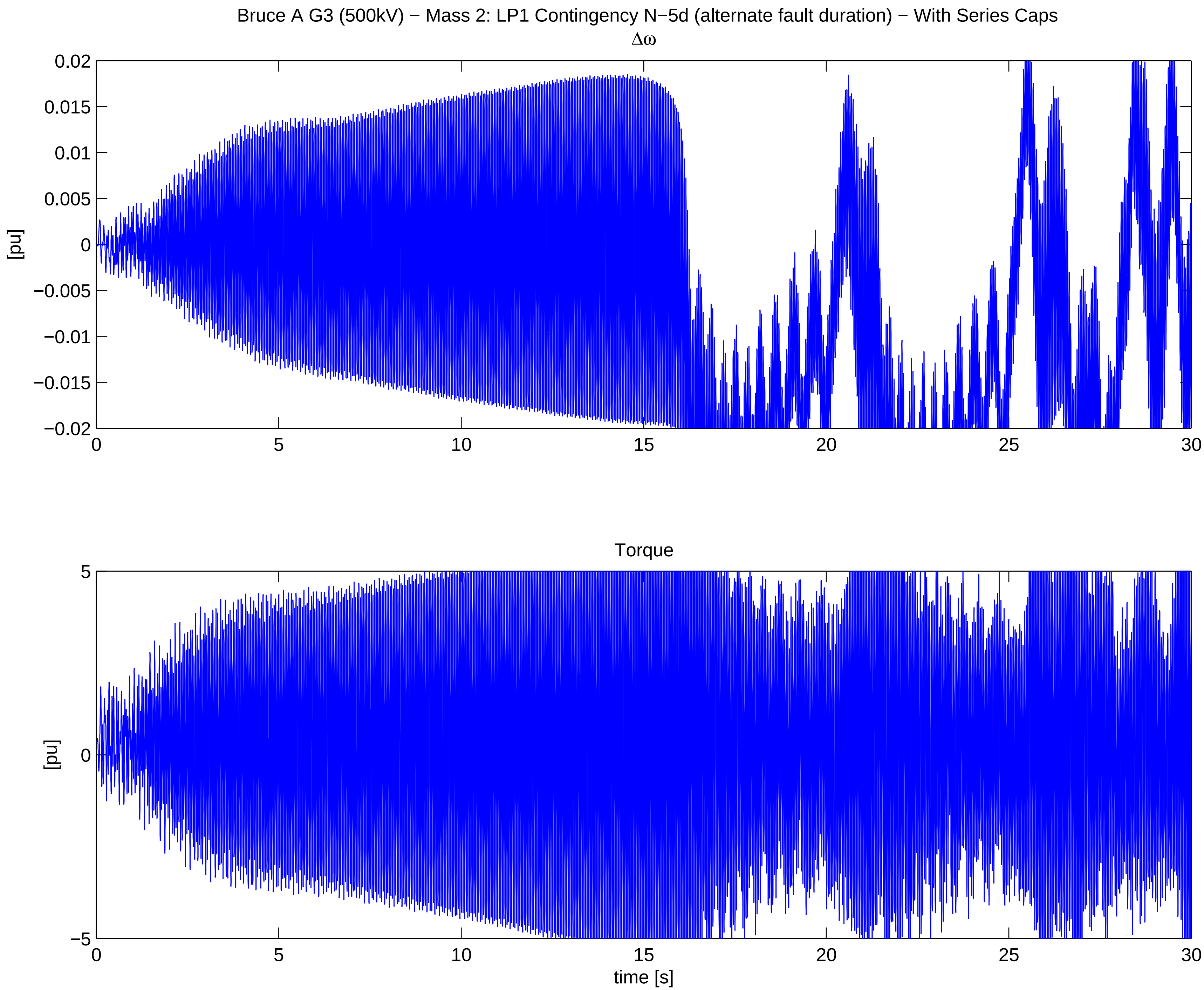
Bruce A G3 (500kV) − Mass 5: GEN Contingency N−5d − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce A G3 (500kV) − Mass 5: GEN Contingency N−5d − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

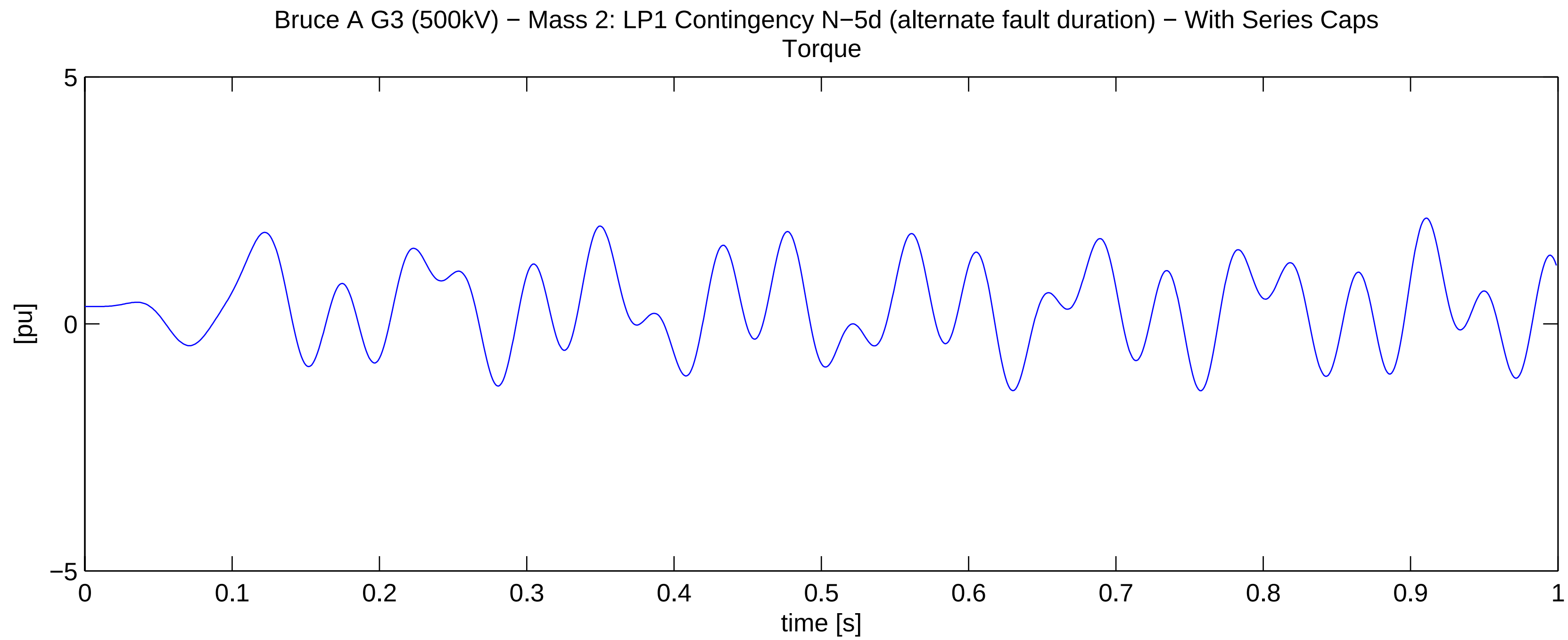


Bruce A G3 (500kV) − Mass 1: HP Contingency N−5d (alternate fault duration) − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

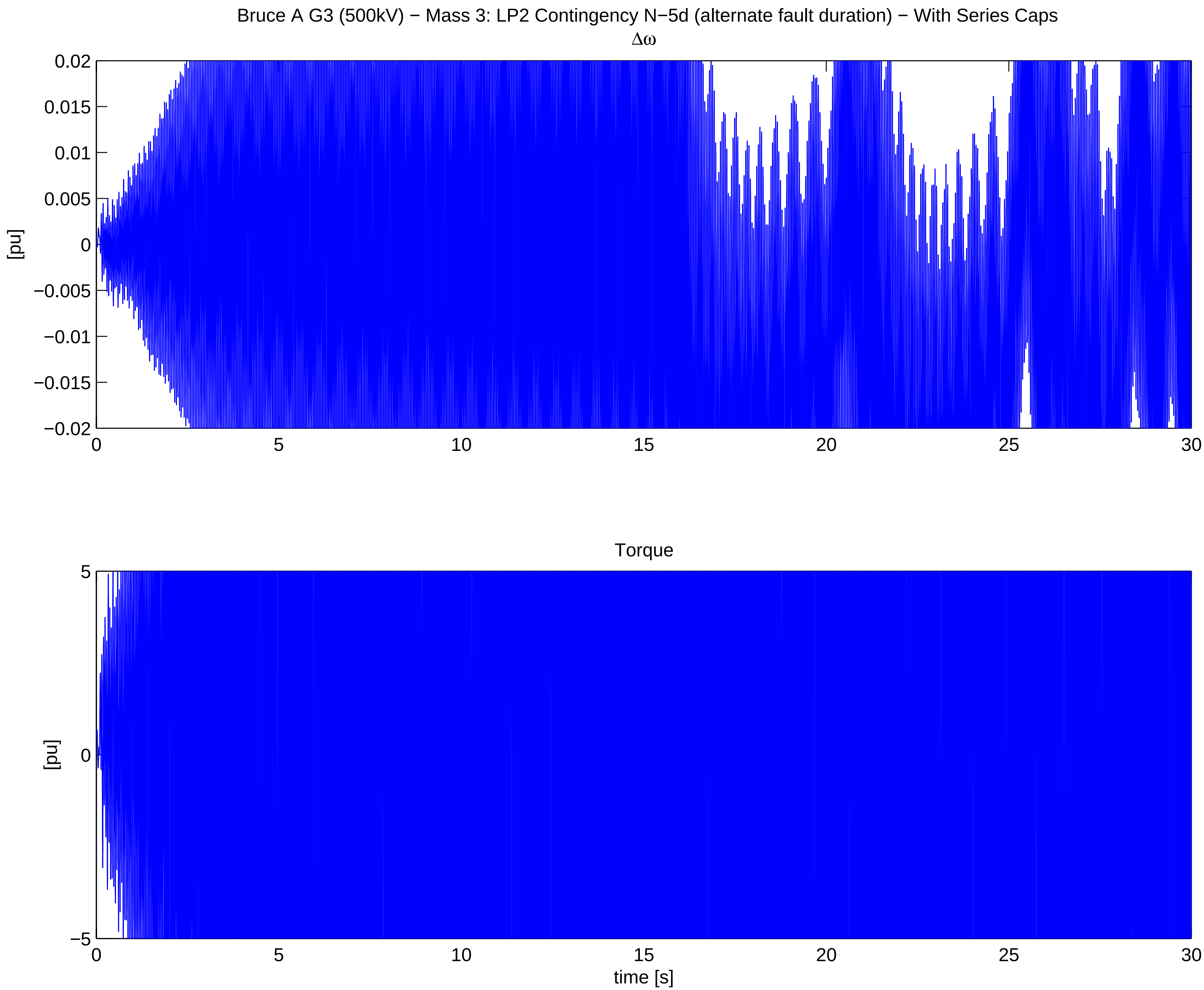

Bruce A G3 (500kV) − Mass 1: HP Contingency N−5d (alternate fault duration) − With Series Caps
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

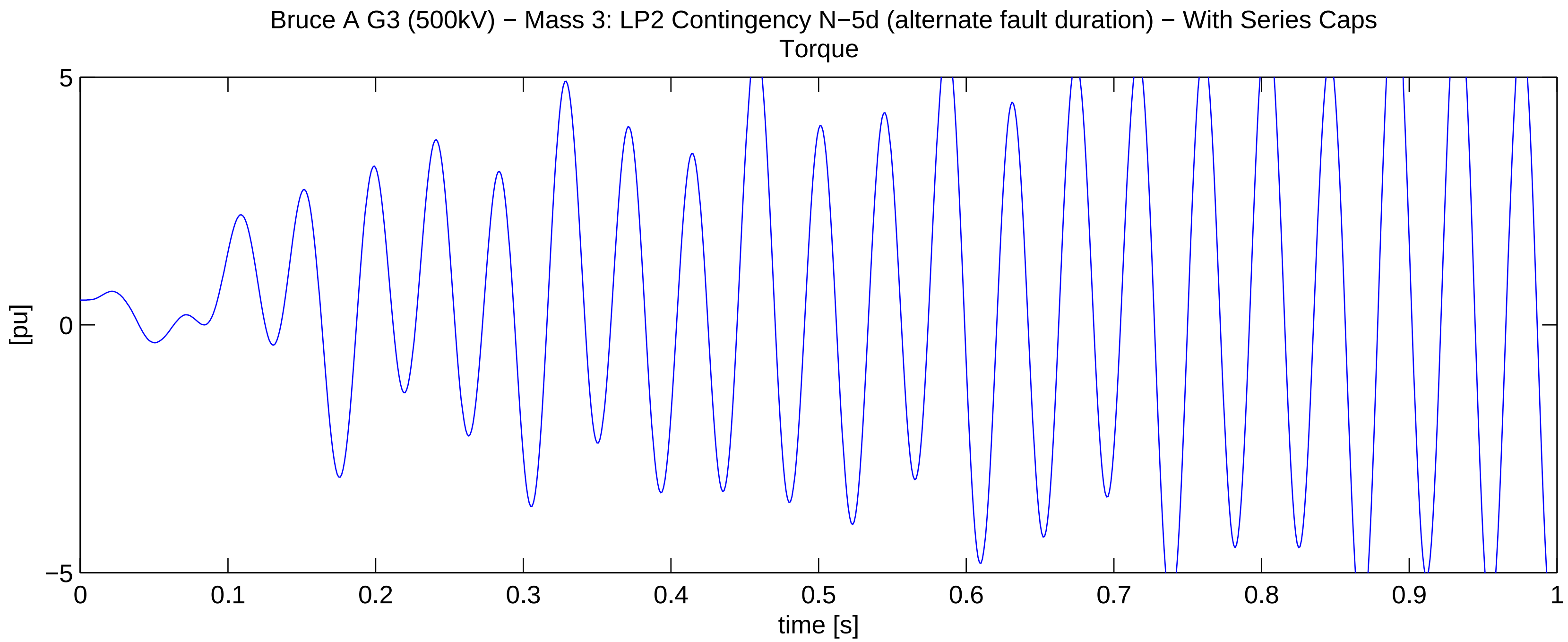


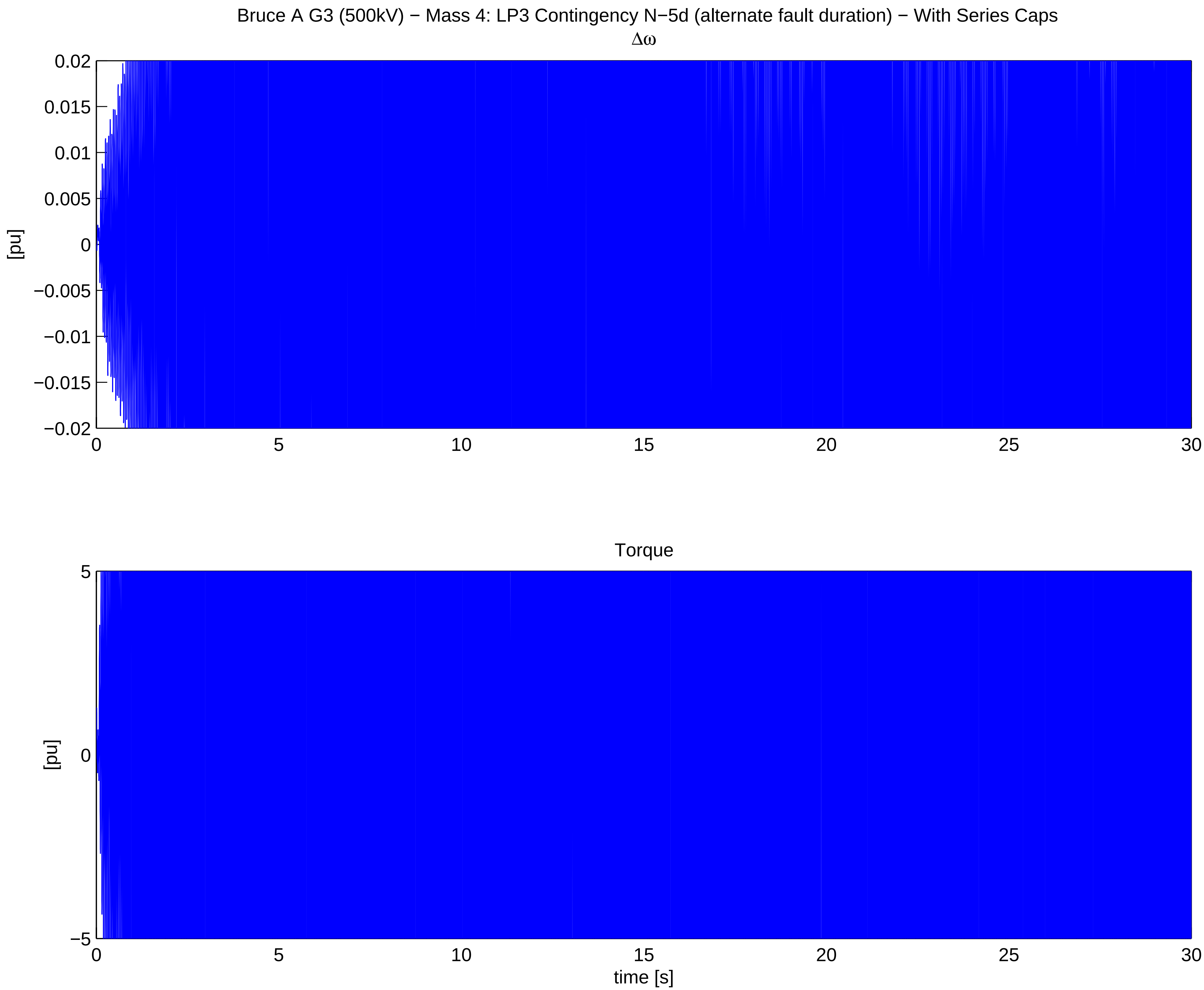
Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−5d (alternate fault duration) − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



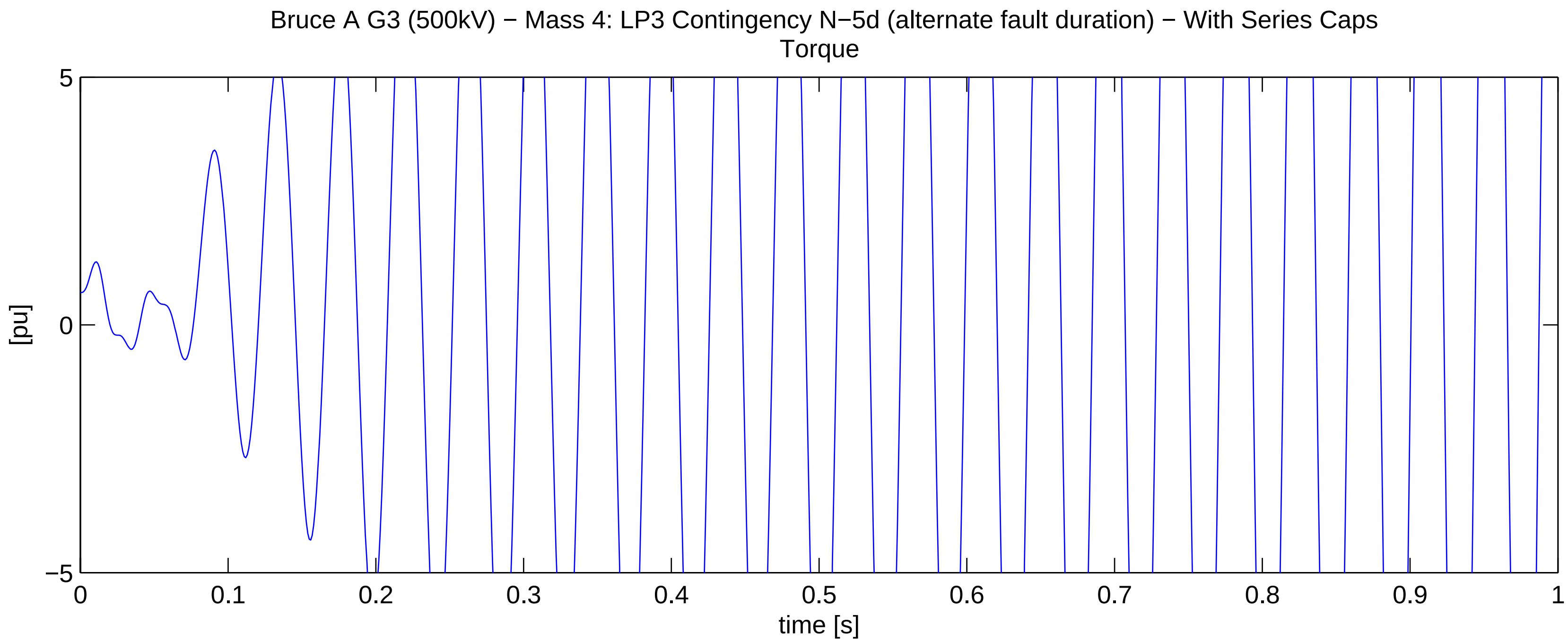
Bruce A G3 (500kV) − Mass 2: LP1 Contingency N−5d (alternate fault duration) − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−5d (alternate fault duration) − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

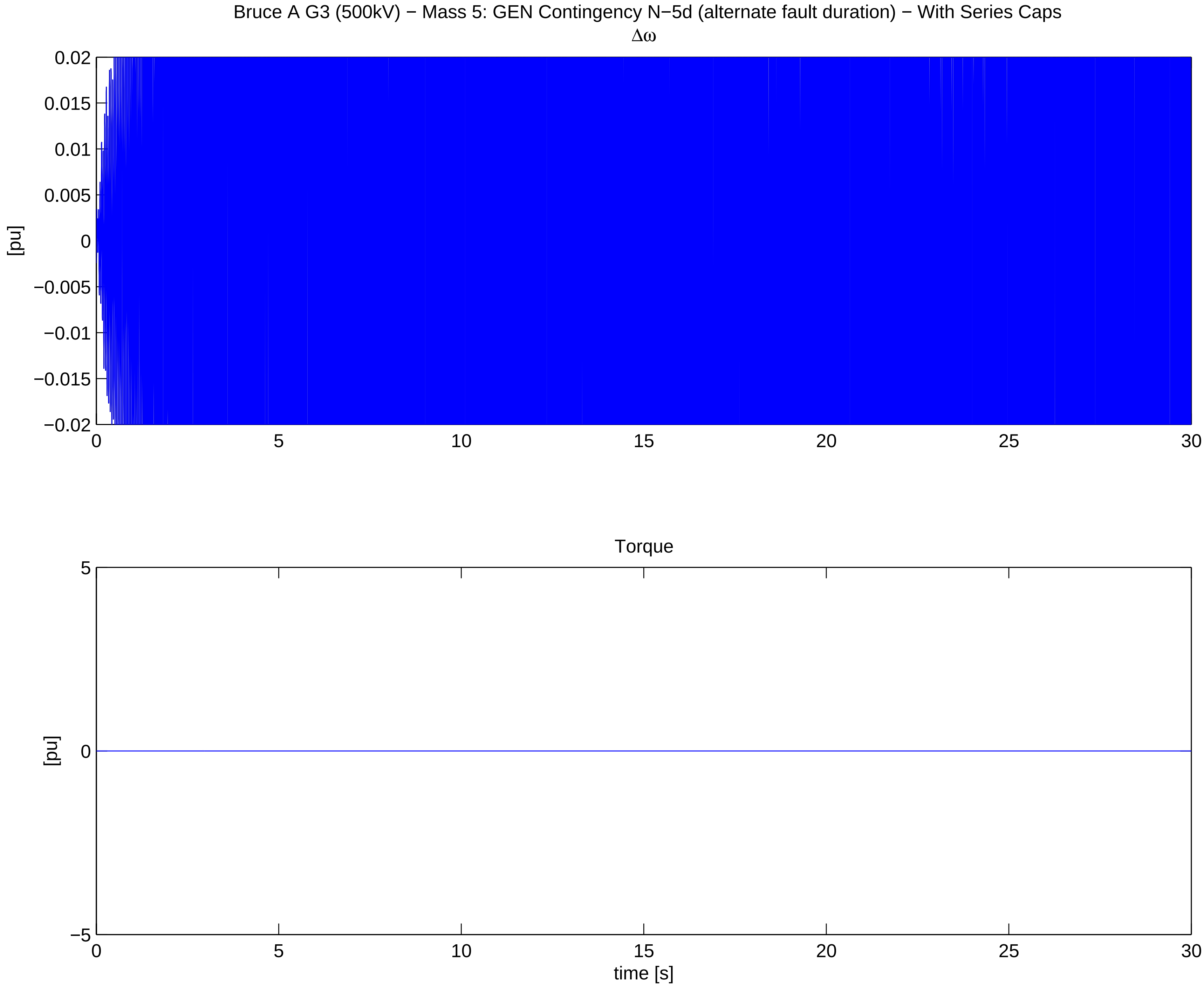

Bruce A G3 (500kV) − Mass 3: LP2 Contingency N−5d (alternate fault duration) − With Series Caps
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

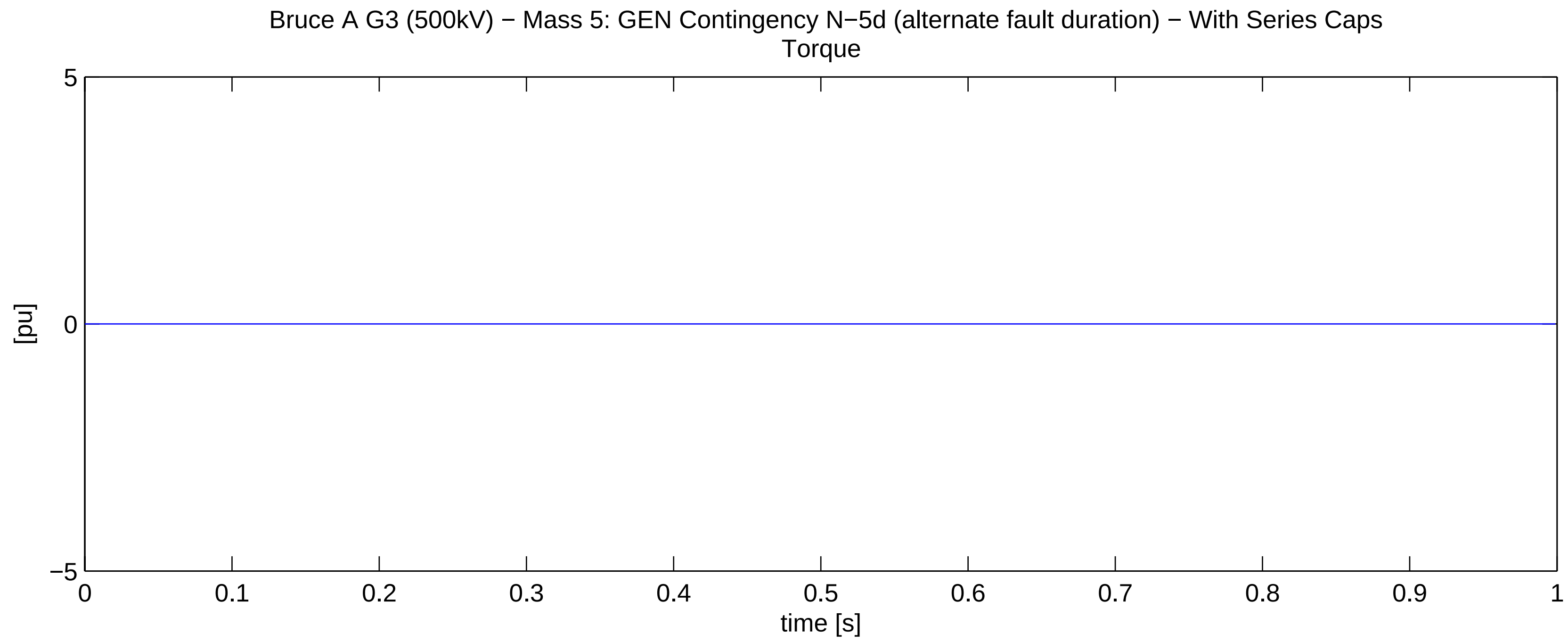


Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−5d (alternate fault duration) − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

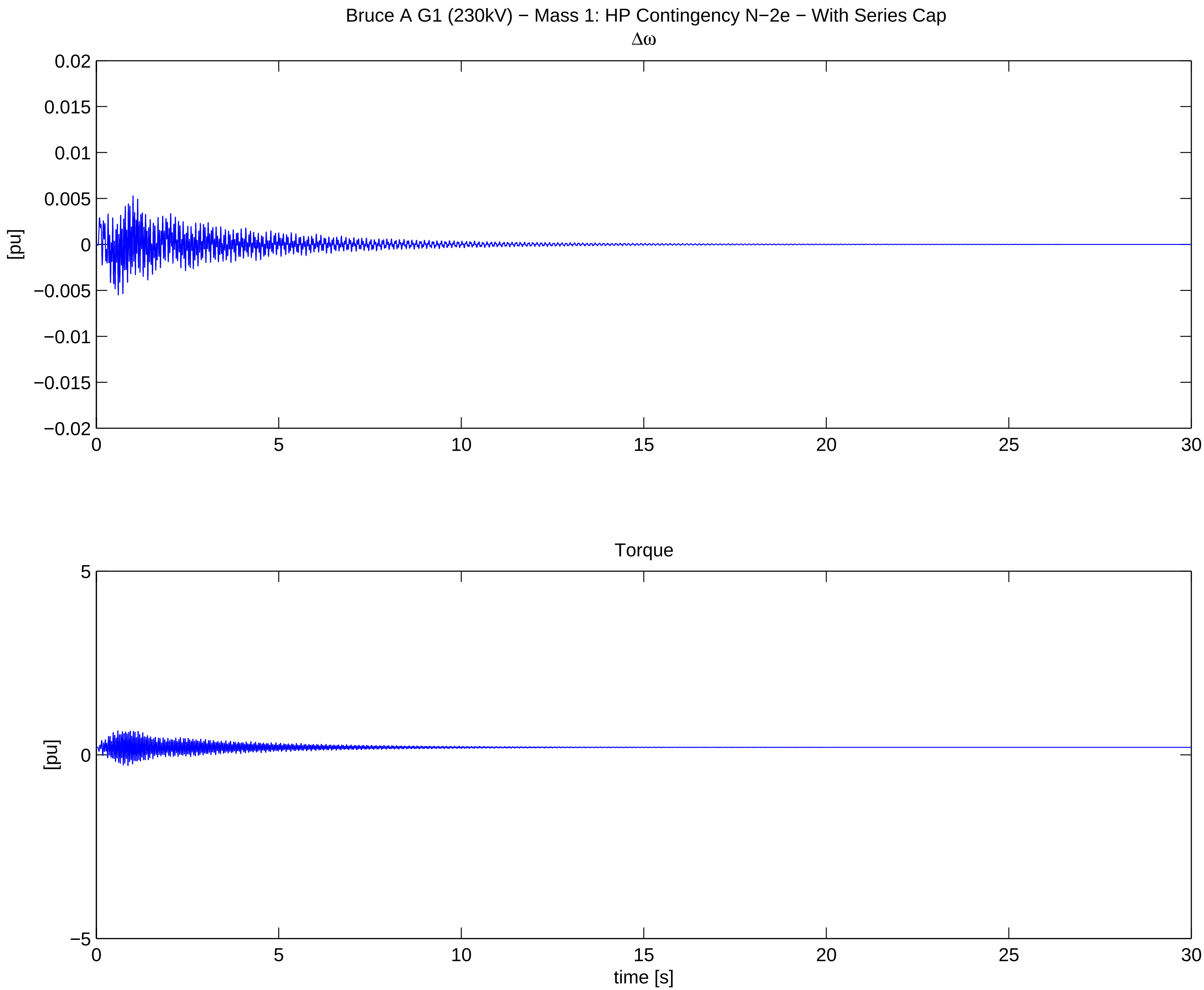


Bruce A G3 (500kV) − Mass 4: LP3 Contingency N−5d (alternate fault duration) − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

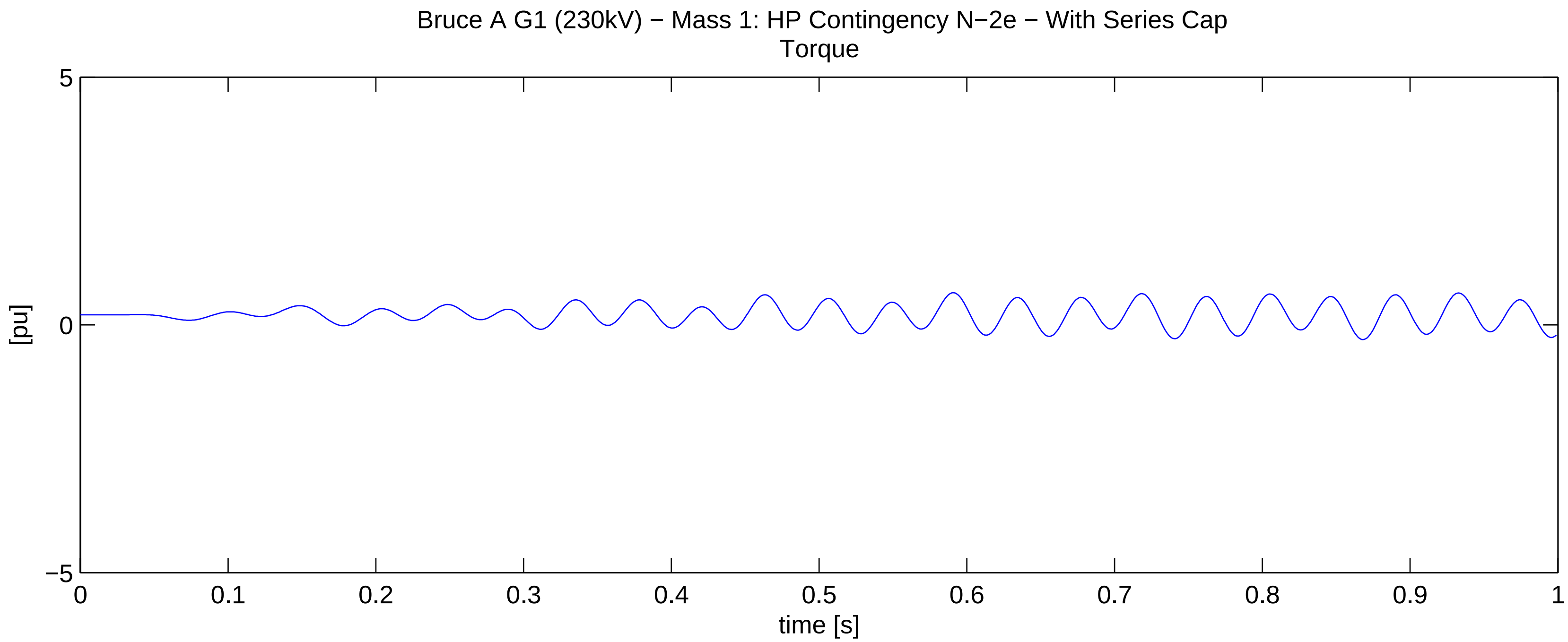

Bruce A G3 (500kV) − Mass 5: GEN Contingency N−5d (alternate fault duration) − With Series Caps
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

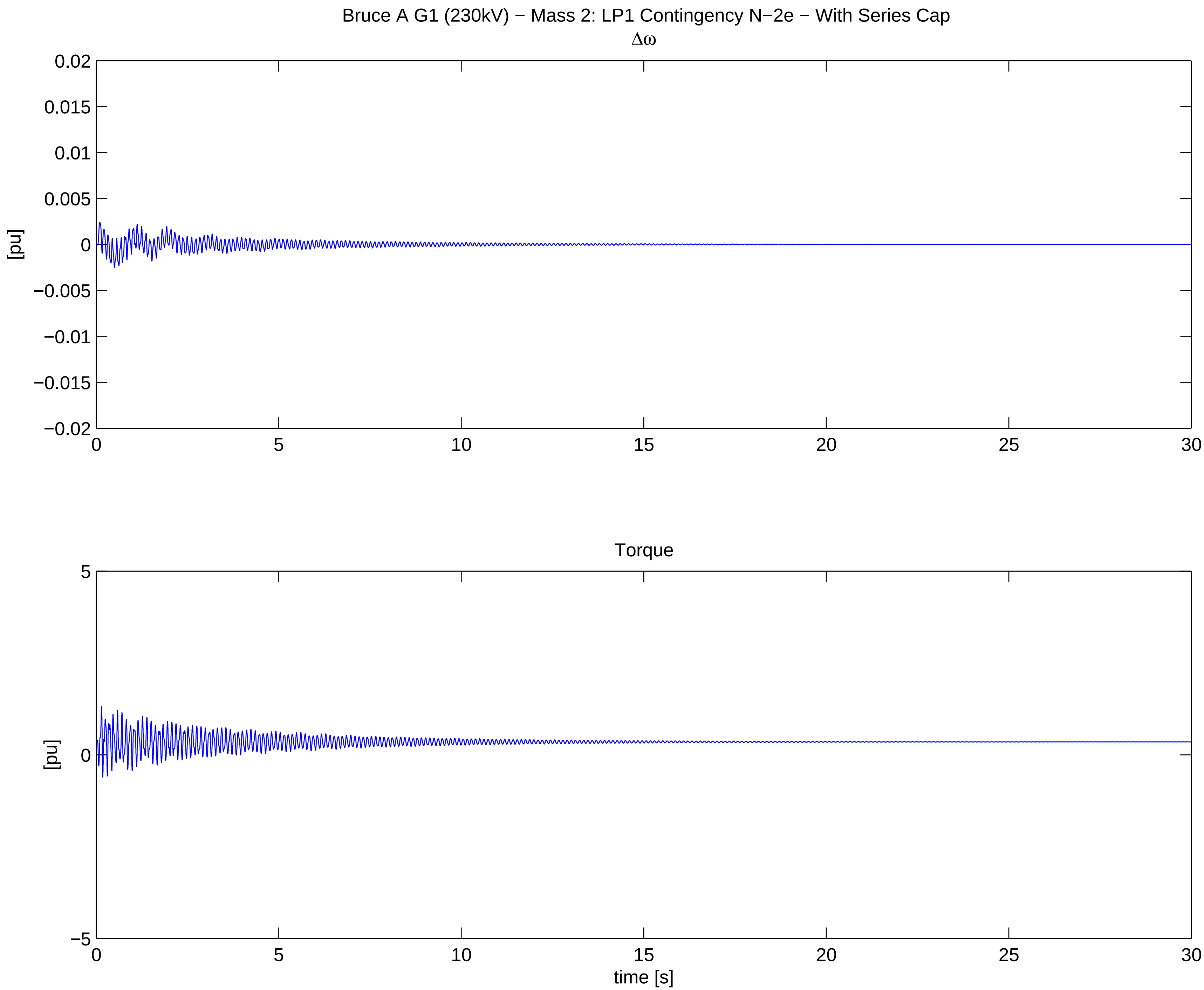


Bruce A G3 (500kV) − Mass 5: GEN Contingency N−5d (alternate fault duration) − With Series Caps
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



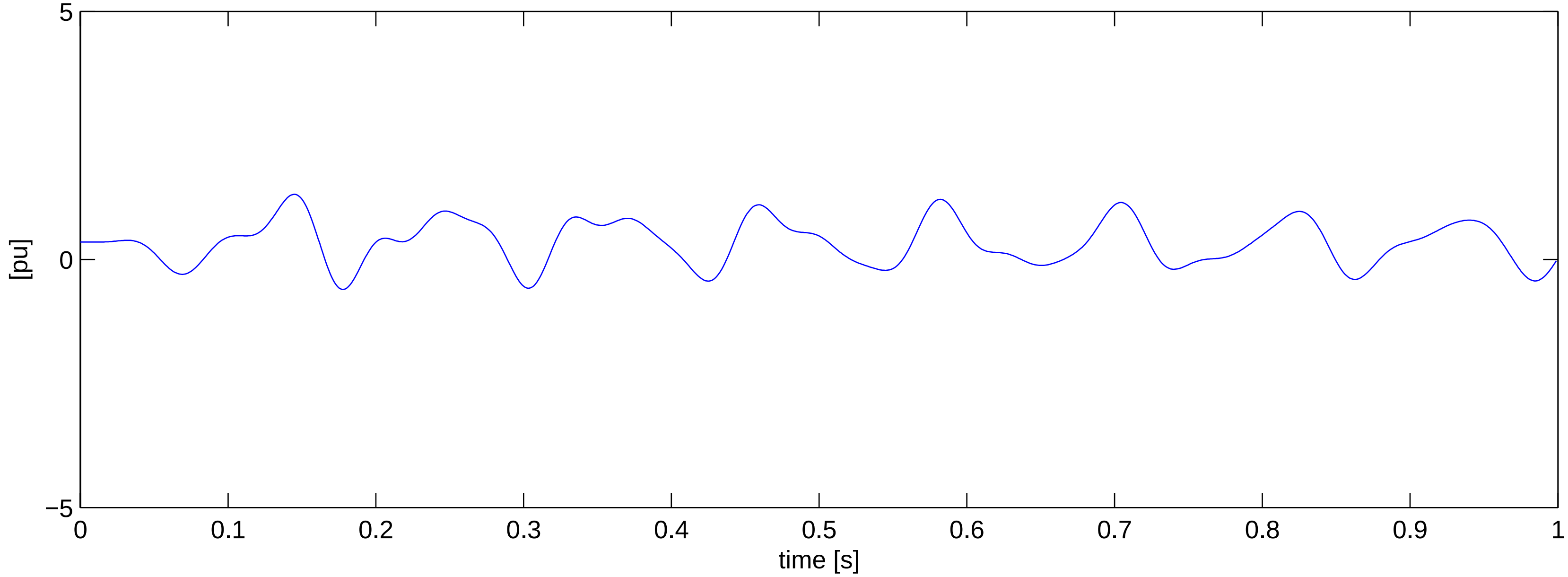
Bruce A G1 (230kV) − Mass 1: HP Contingency N−2e − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
time [s]


Bruce A G1 (230kV) − Mass 1: HP Contingency N−2e − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

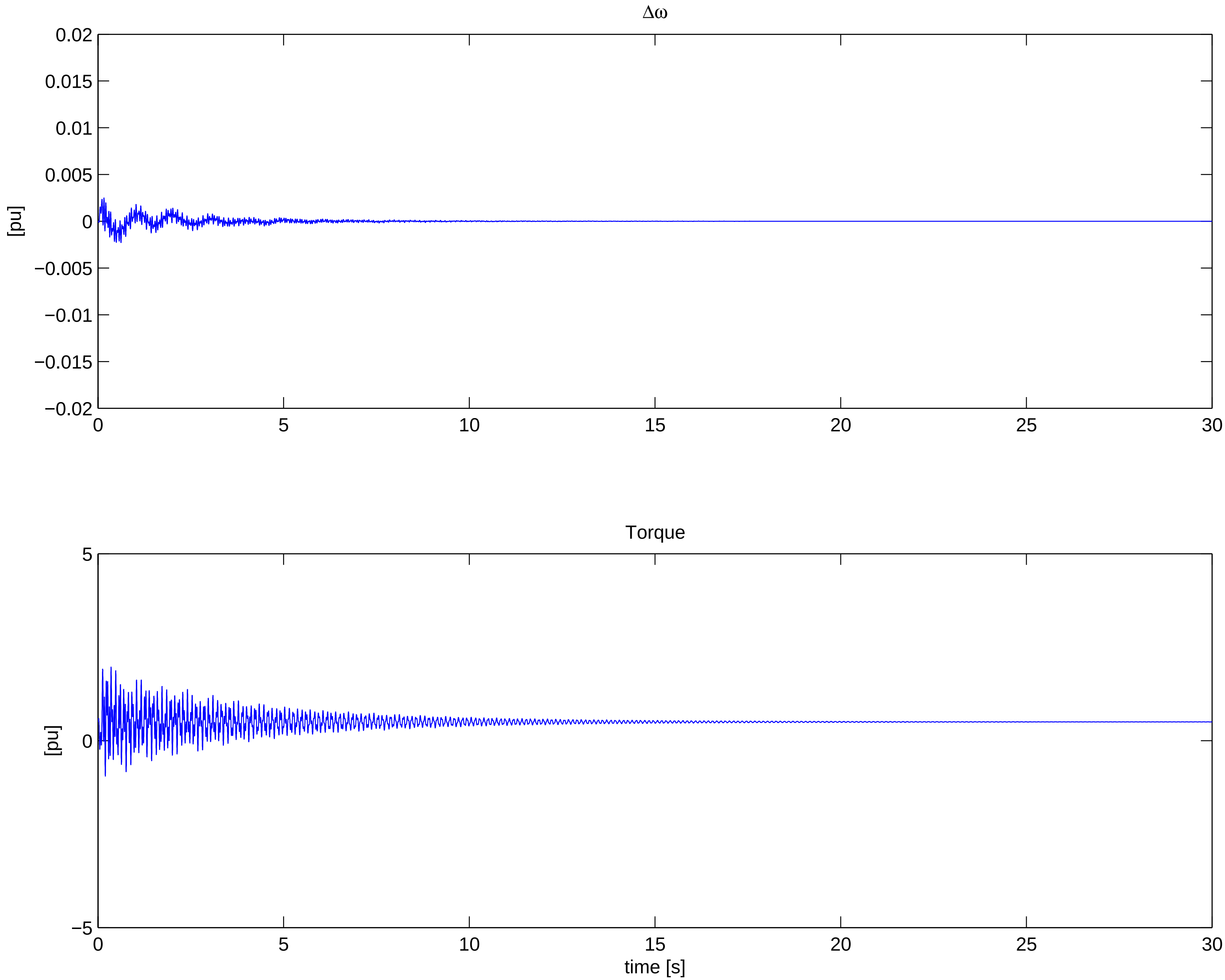


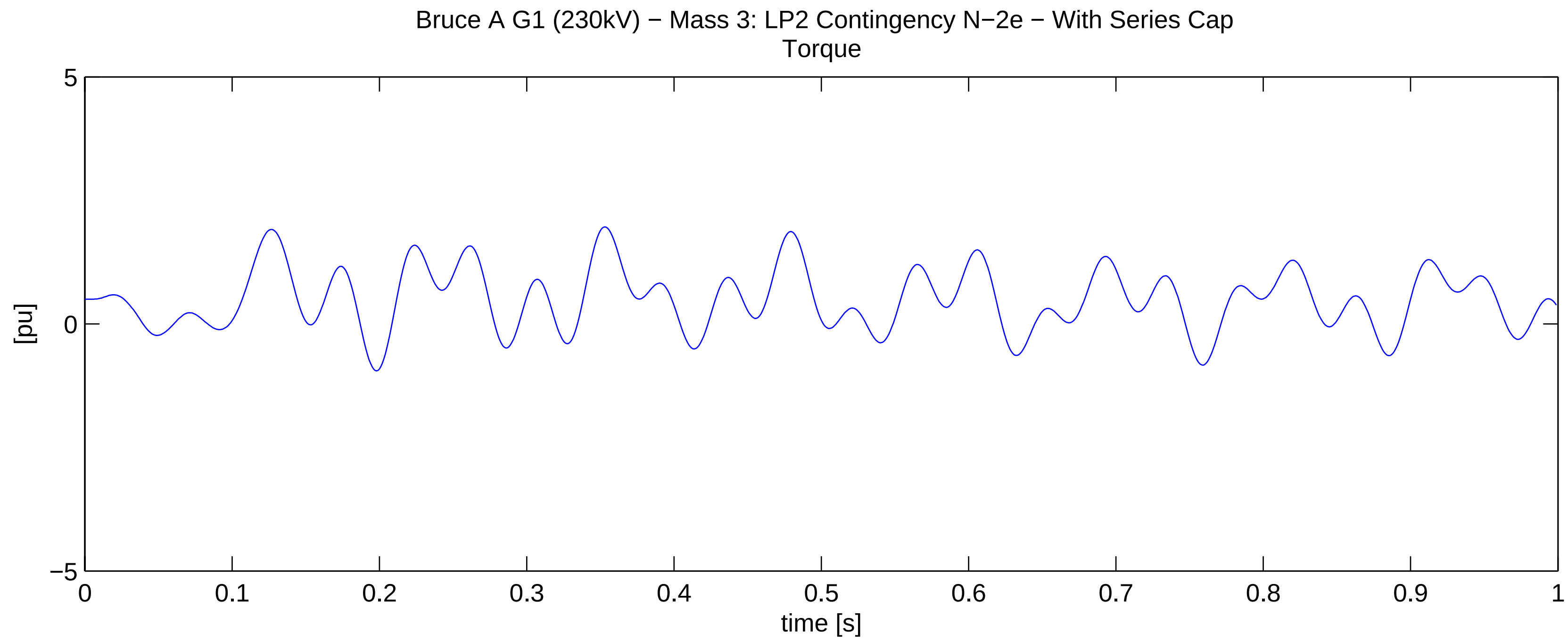
Bruce A G1 (230kV) − Mass 2: LP1 Contingency N−2e − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

Bruce A G1 (230kV) − Mass 2: LP1 Contingency N−2e − With Series Cap
Torque

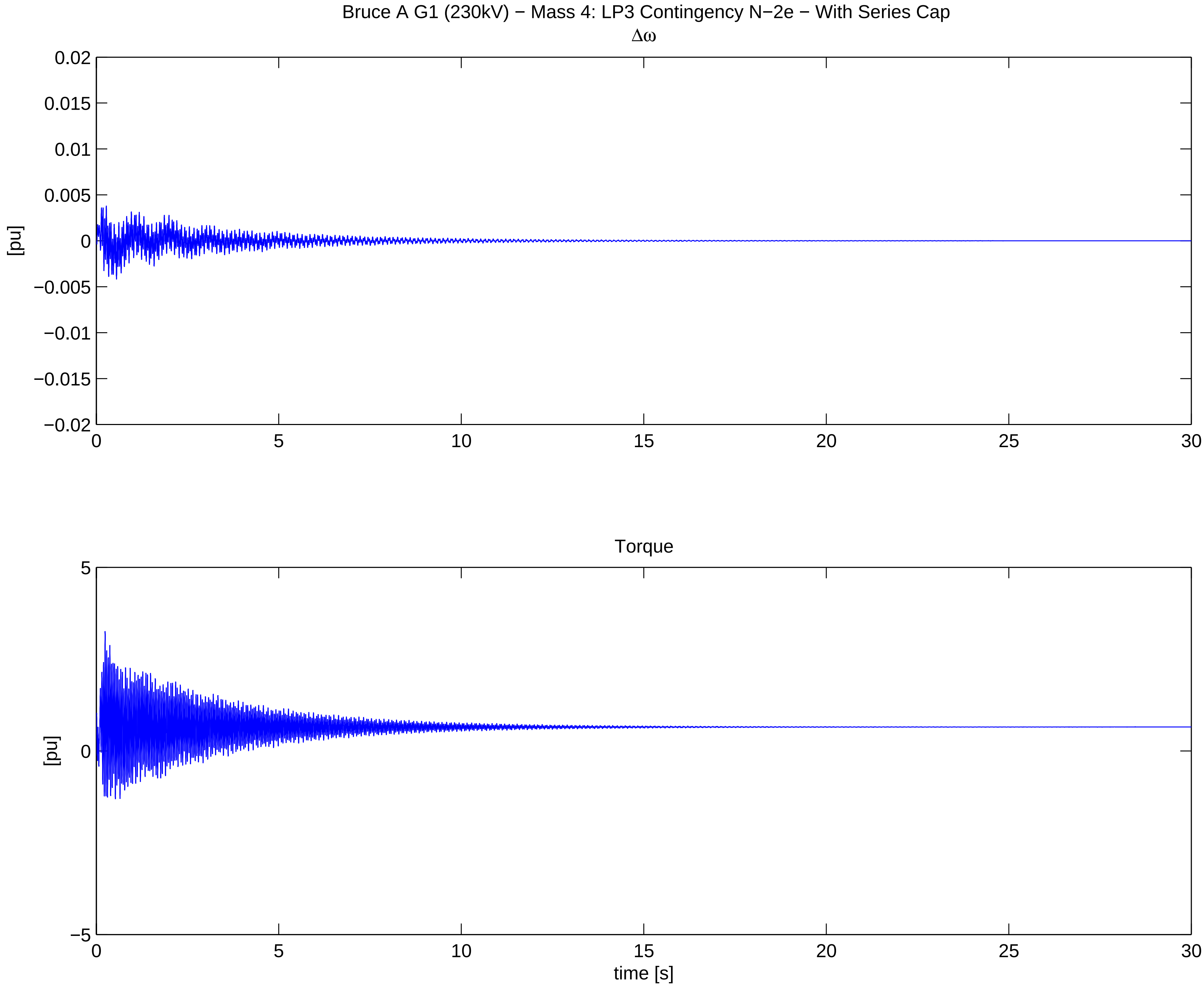


Bruce A G1 (230kV) − Mass 3: LP2 Contingency N−2e − With Series Cap

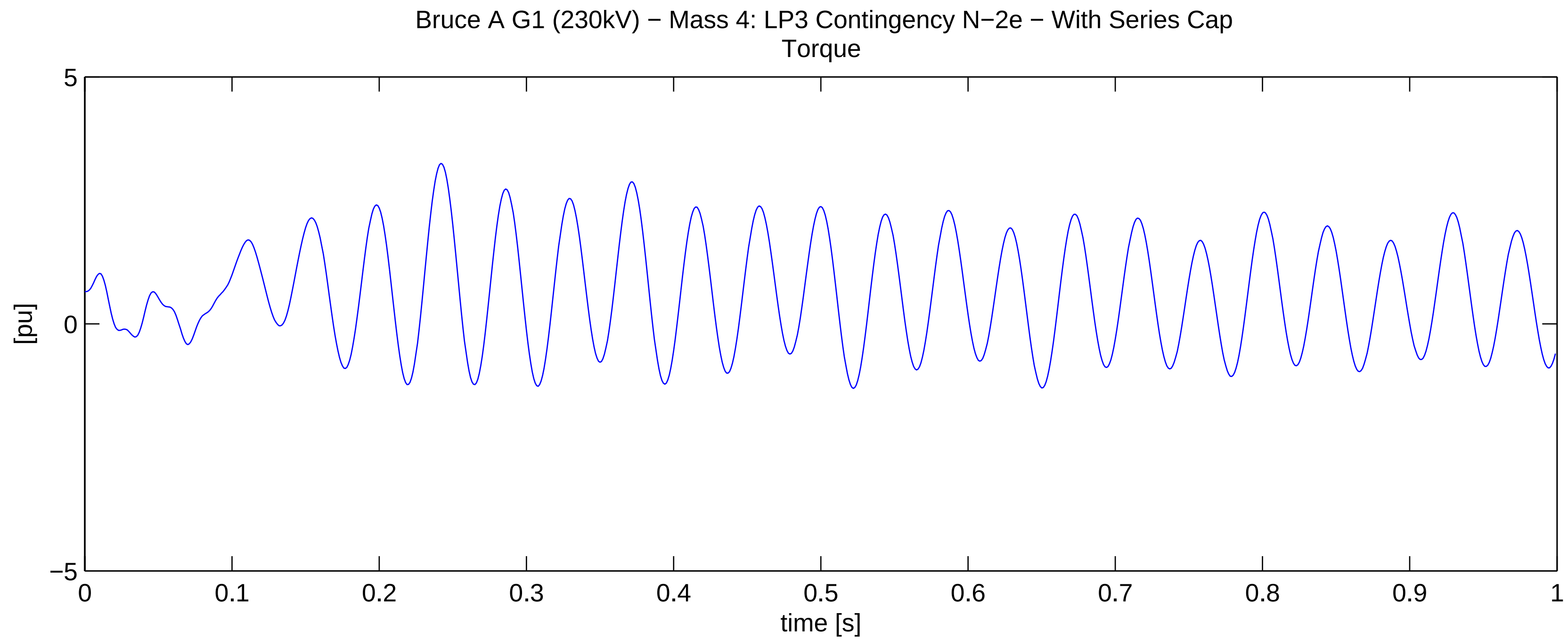




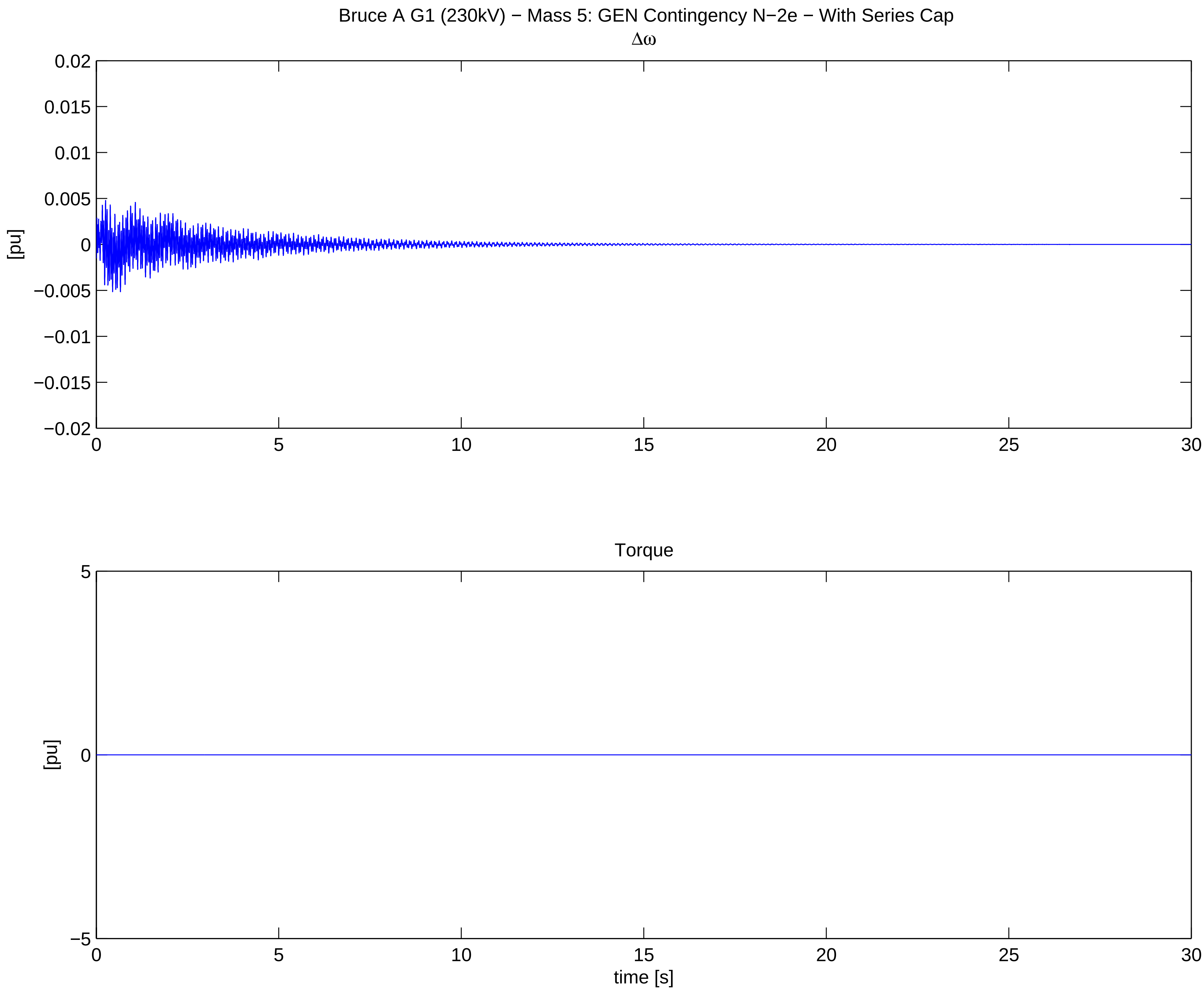
Bruce A G1 (230kV) − Mass 3: LP2 Contingency N−2e − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



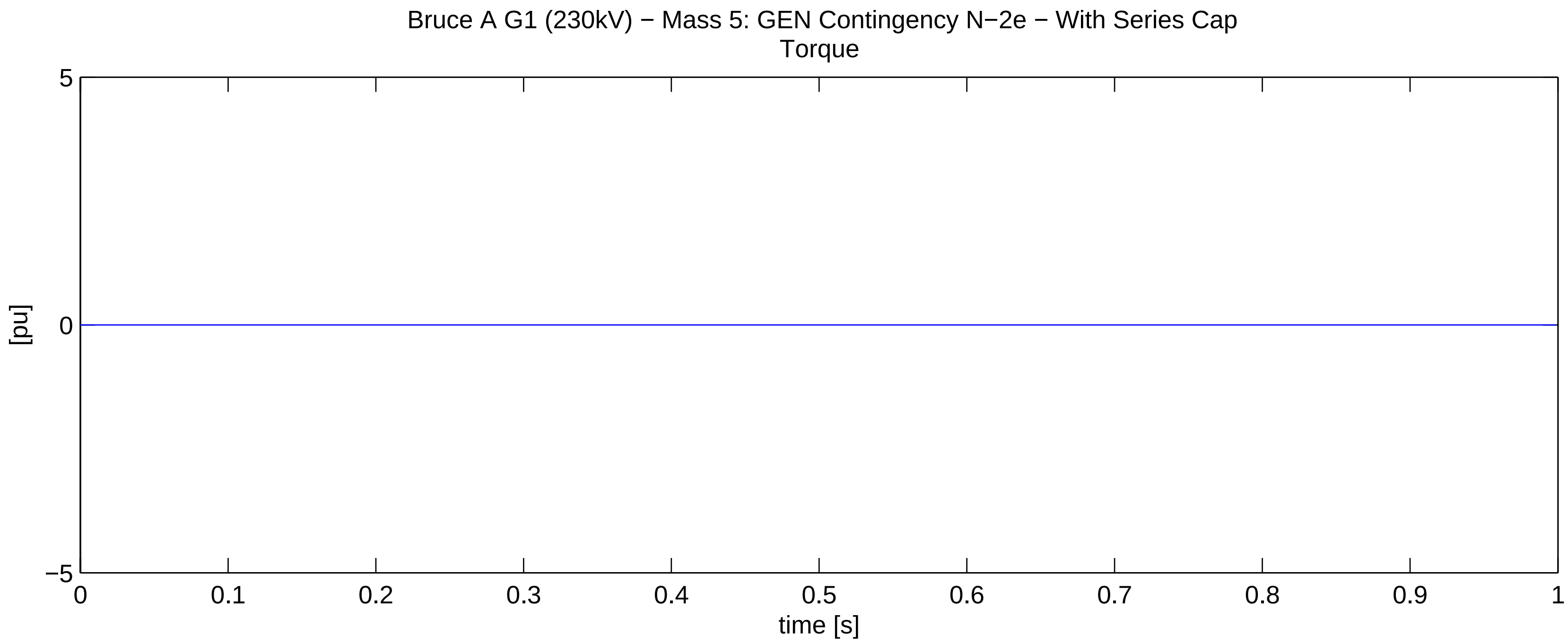
Bruce A G1 (230kV) − Mass 4: LP3 Contingency N−2e − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

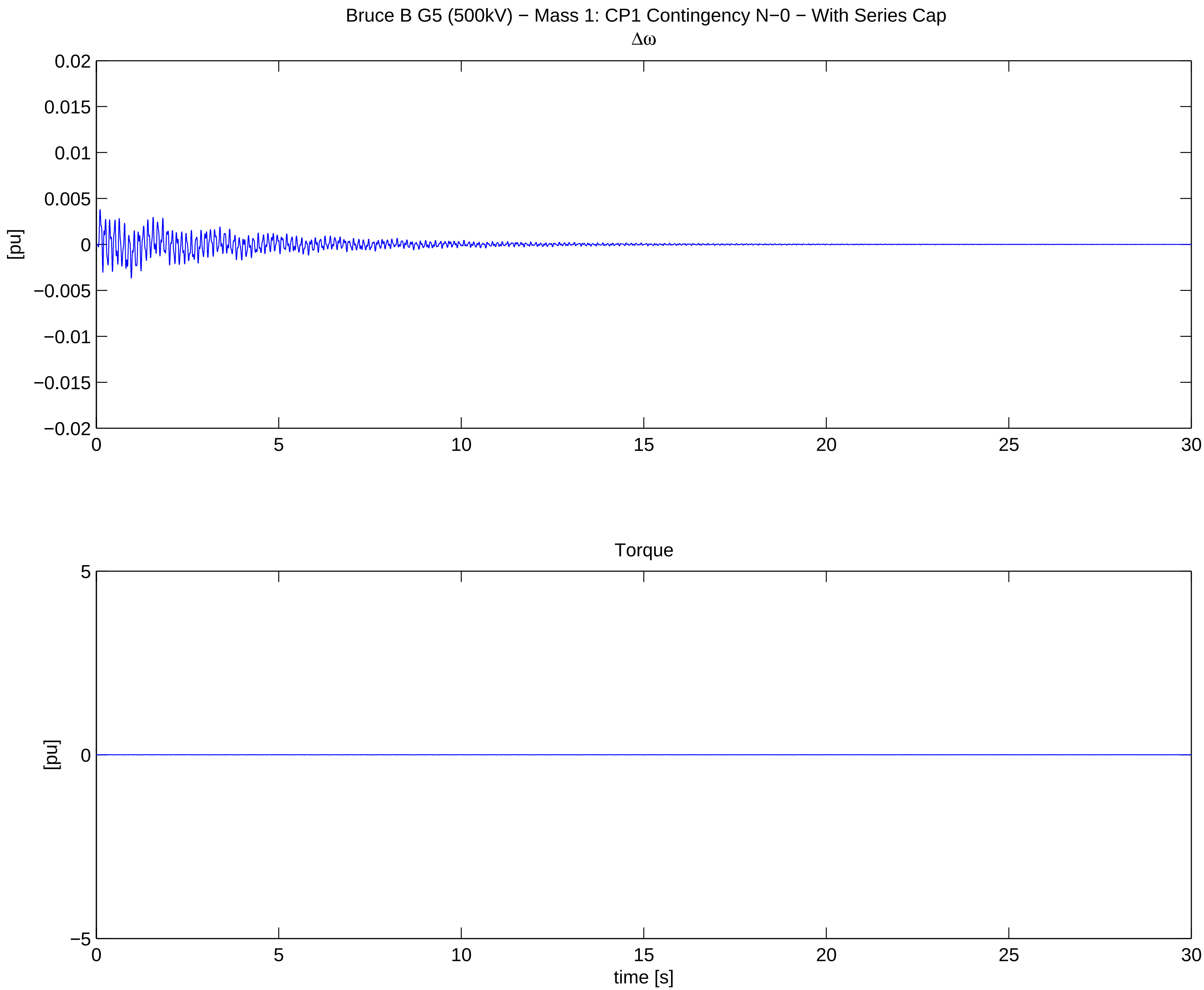


Bruce A G1 (230kV) − Mass 4: LP3 Contingency N−2e − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

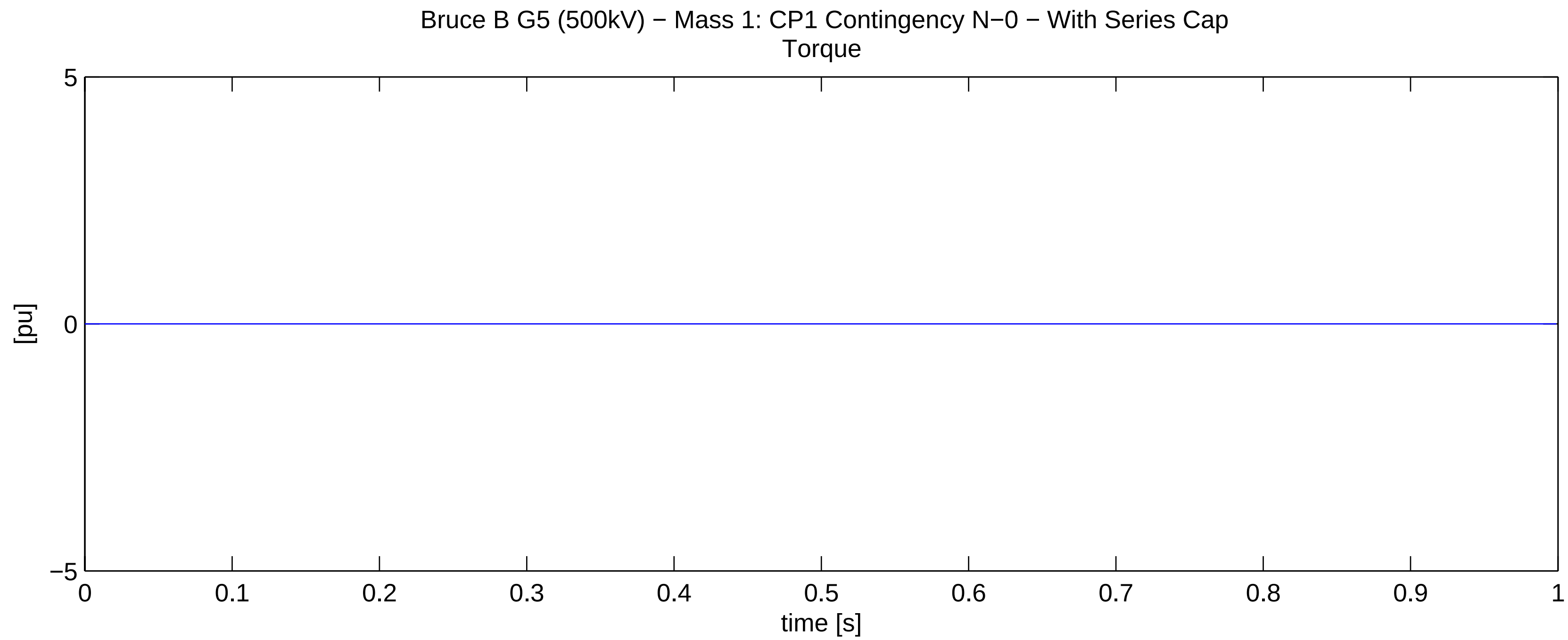


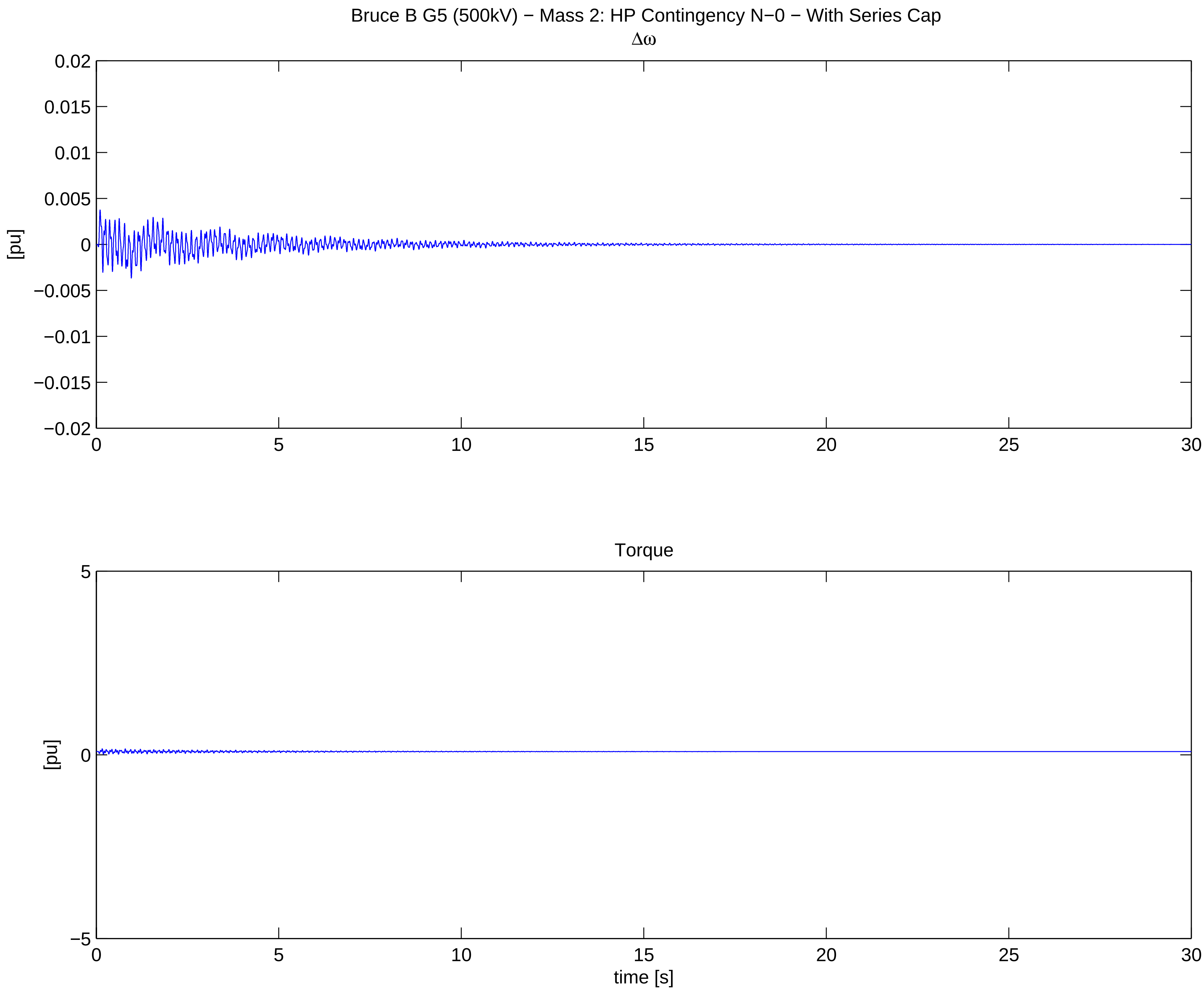
Bruce A G1 (230kV) − Mass 5: GEN Contingency N−2e − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

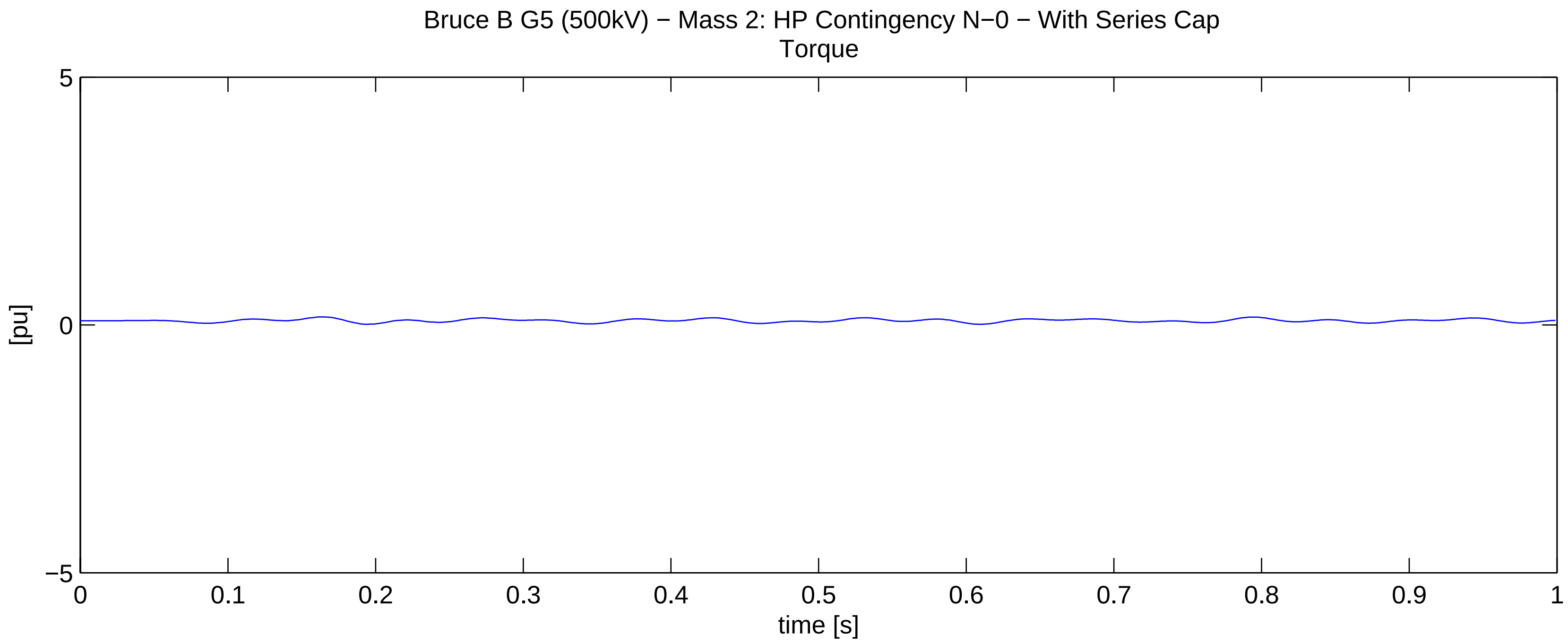

Bruce A G1 (230kV) − Mass 5: GEN Contingency N−2e − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

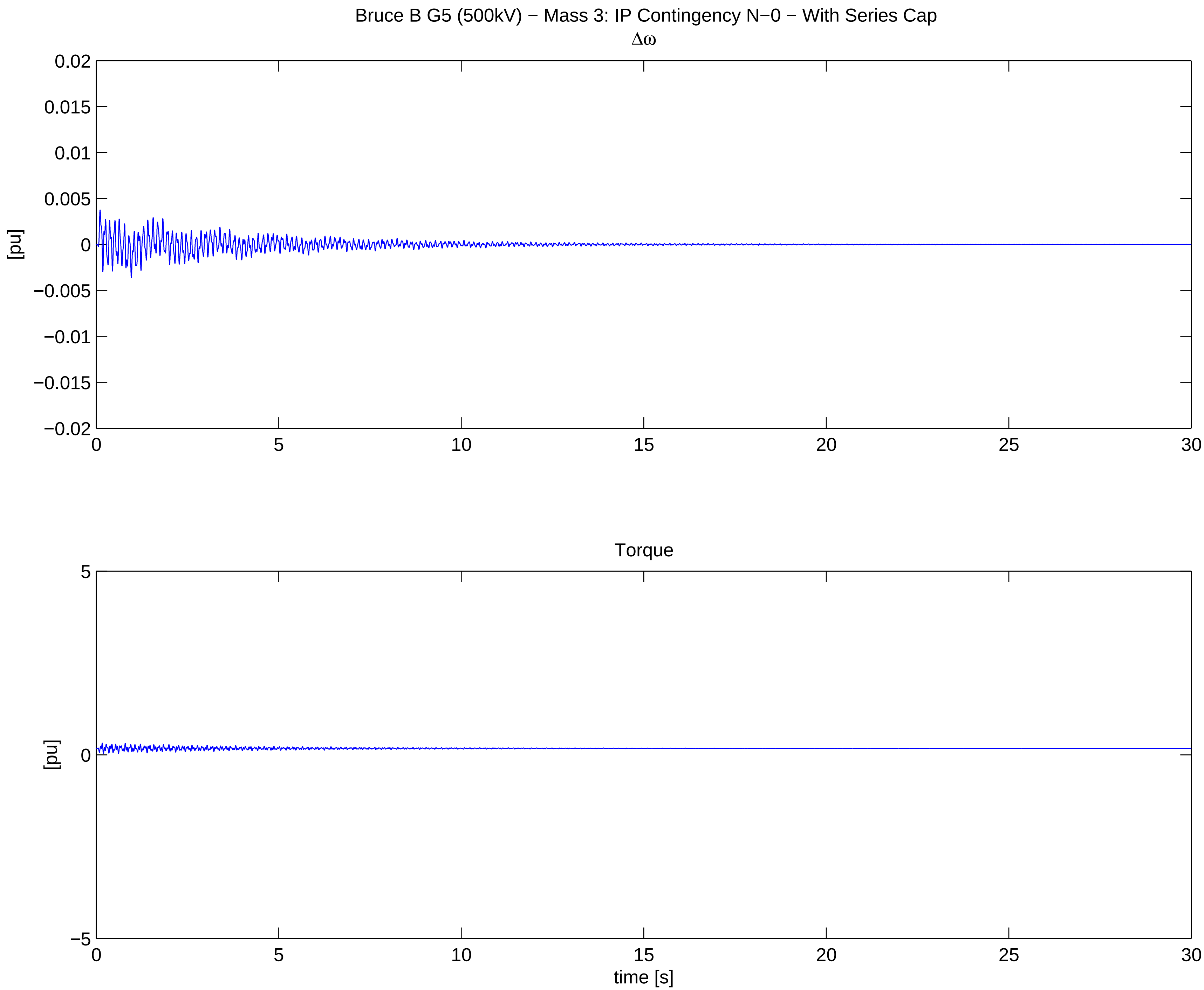


Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−0 − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
time [s]

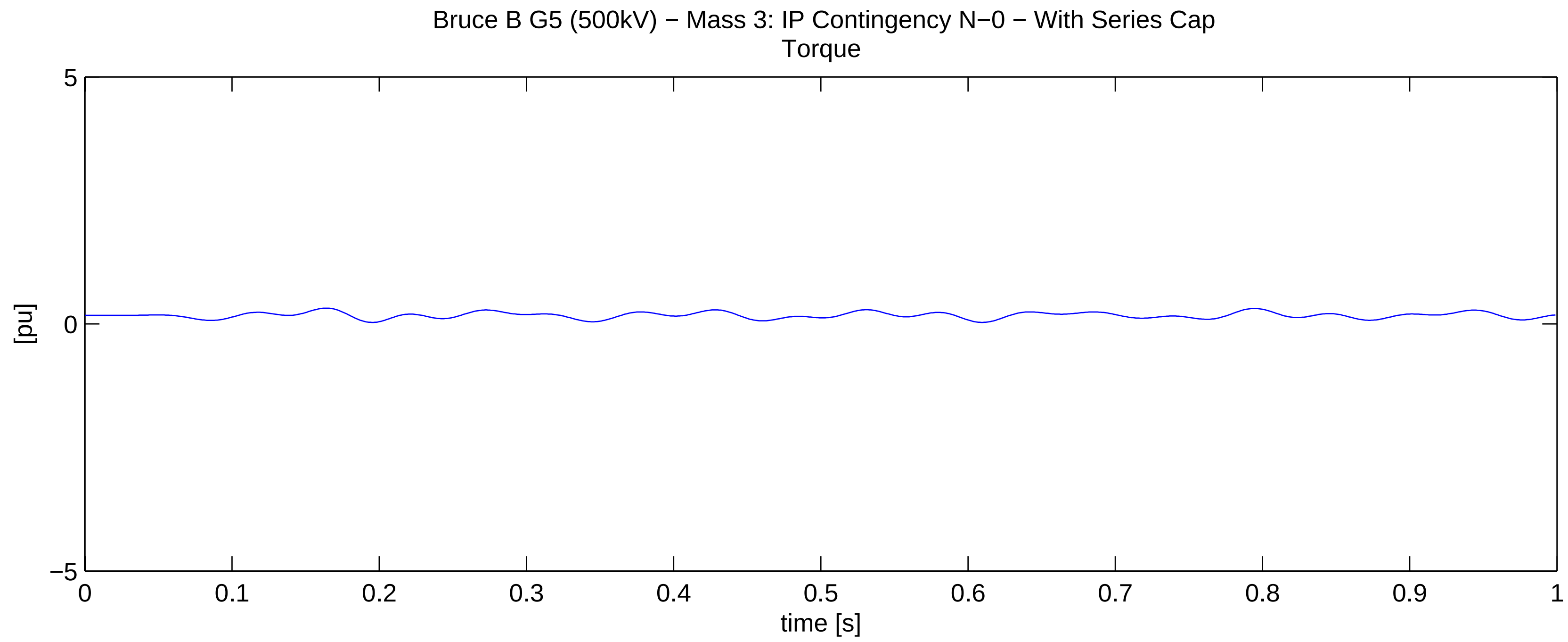

Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−0 − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 2: HP Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

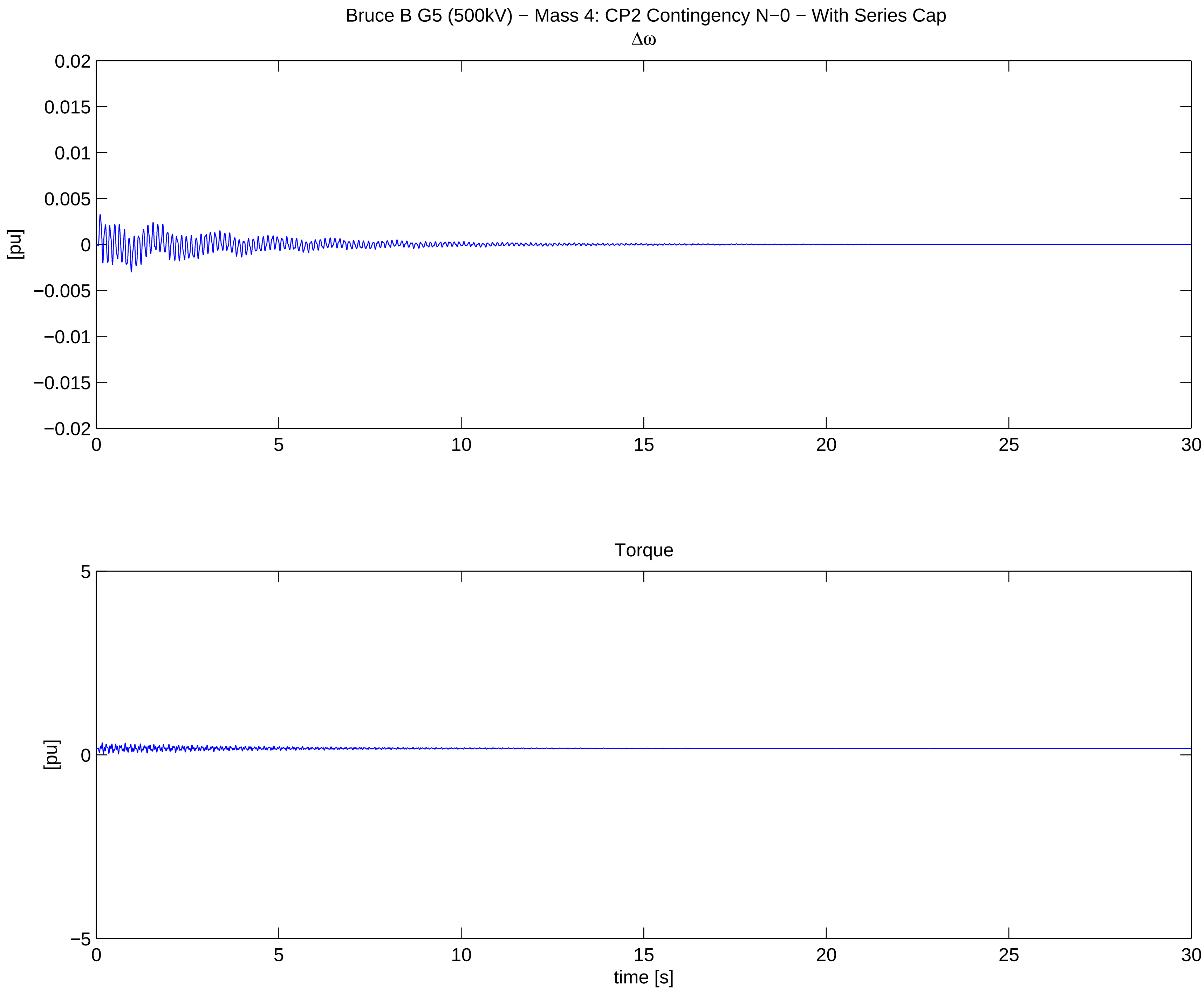

Bruce B G5 (500kV) − Mass 2: HP Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



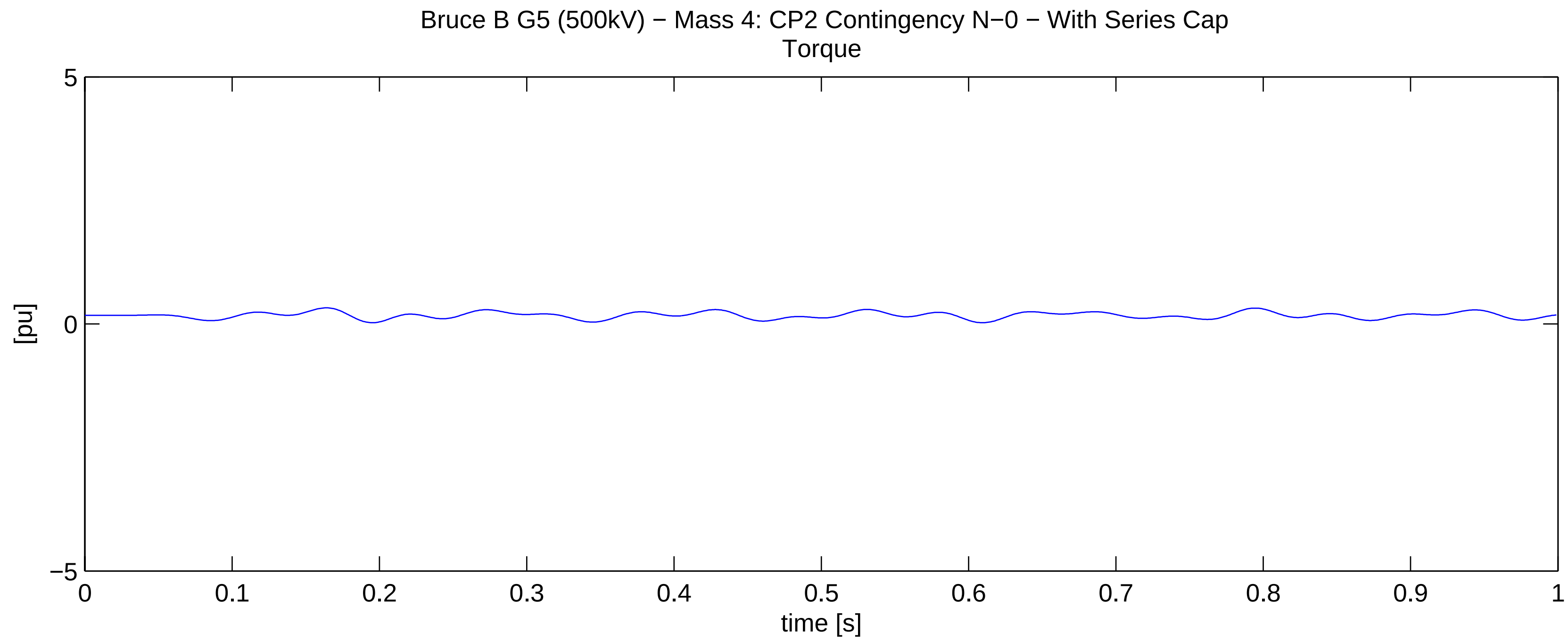
Bruce B G5 (500kV) − Mass 3: IP Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

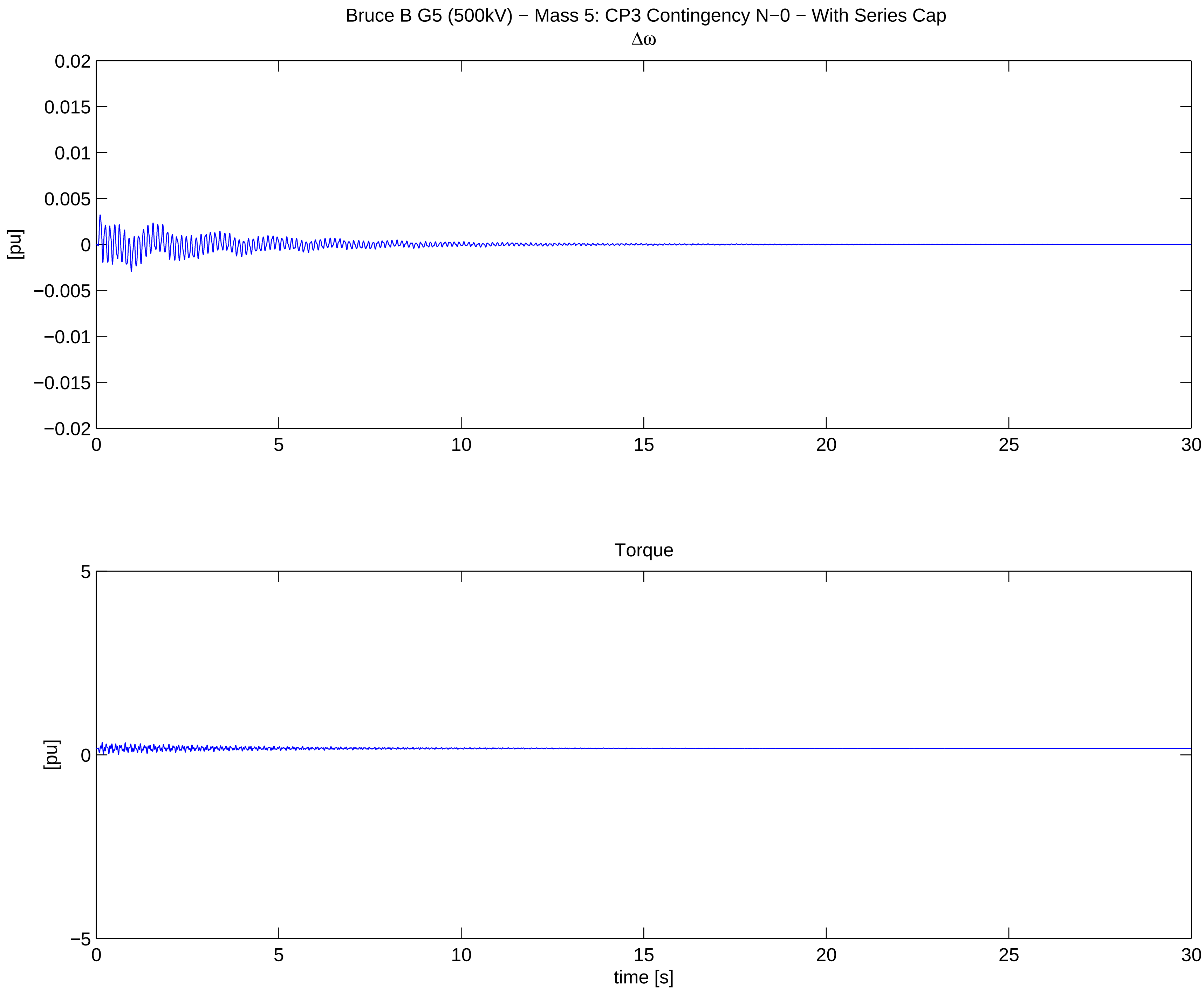


Bruce B G5 (500kV) − Mass 3: IP Contingency N−0 − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

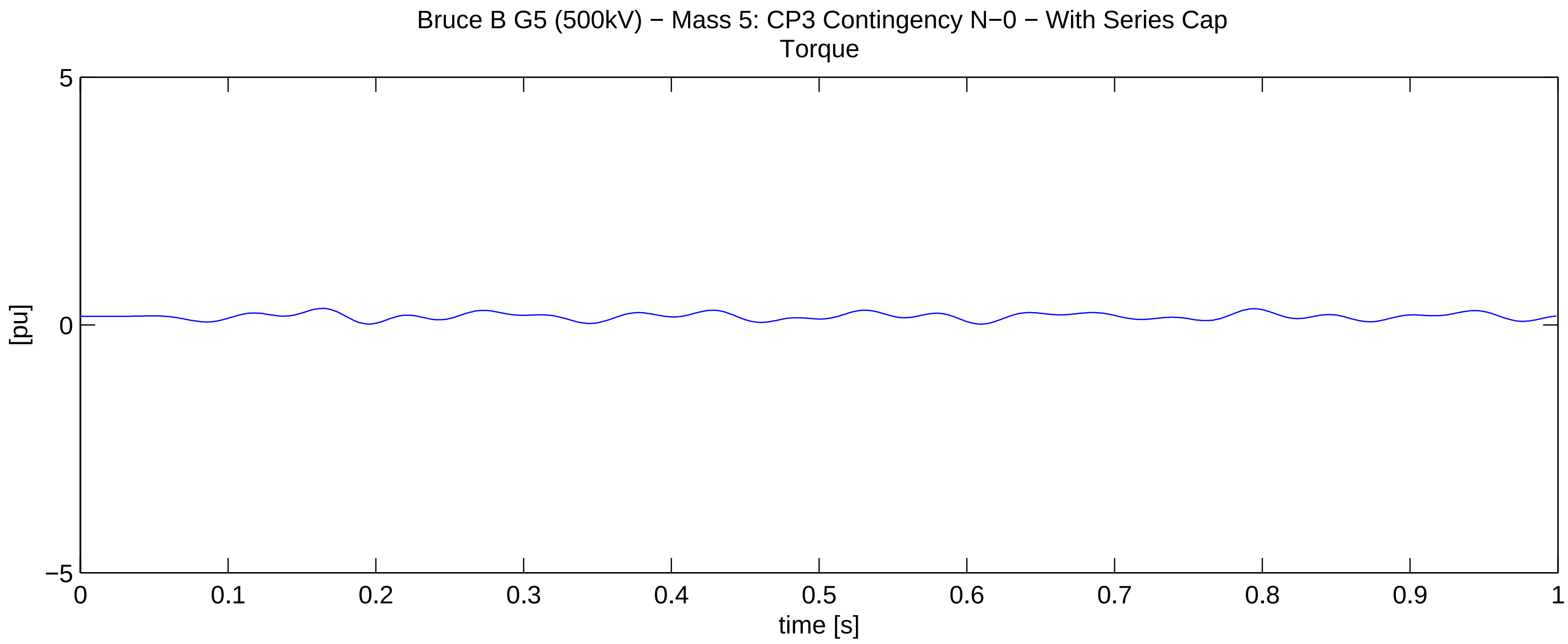


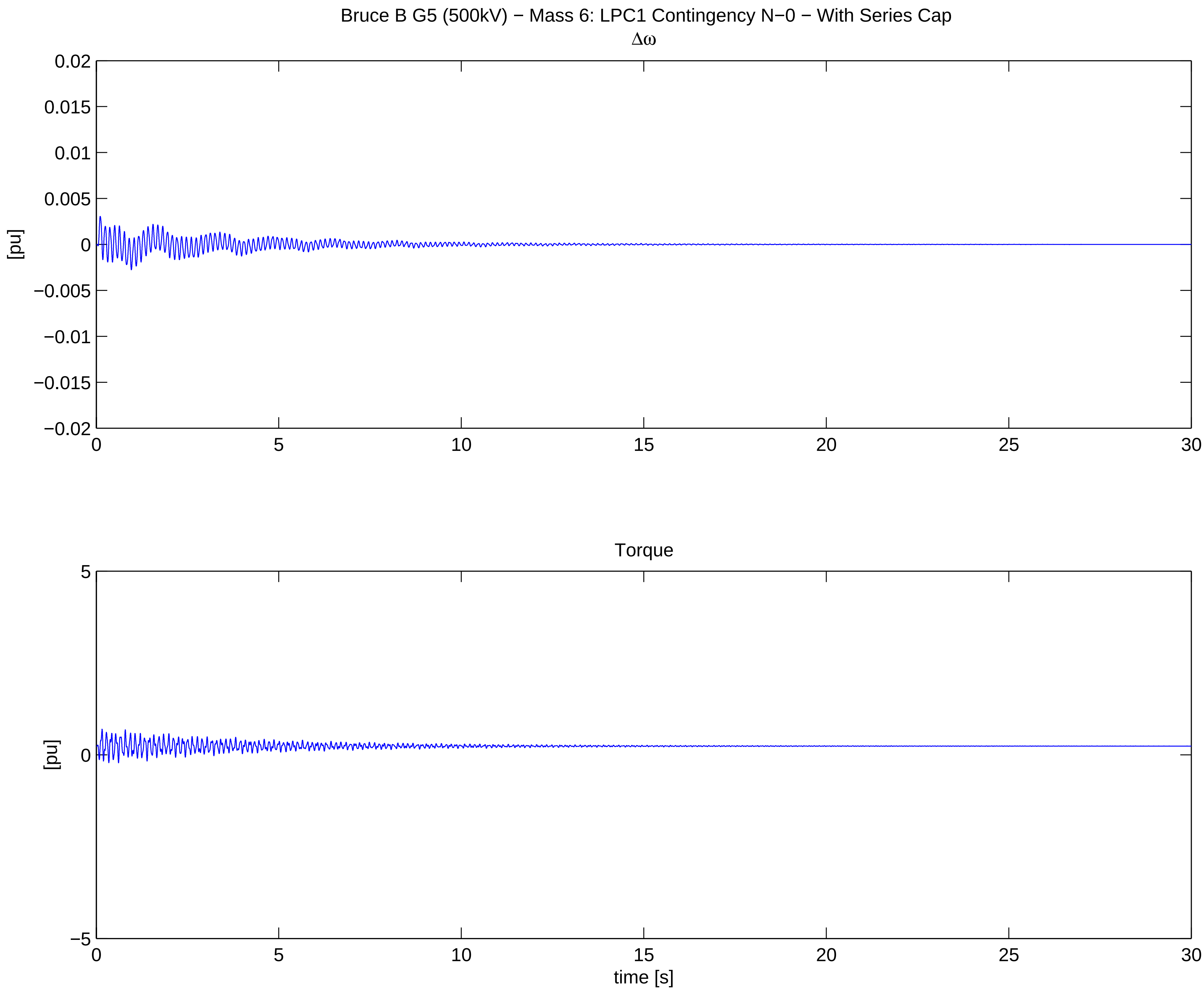
Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

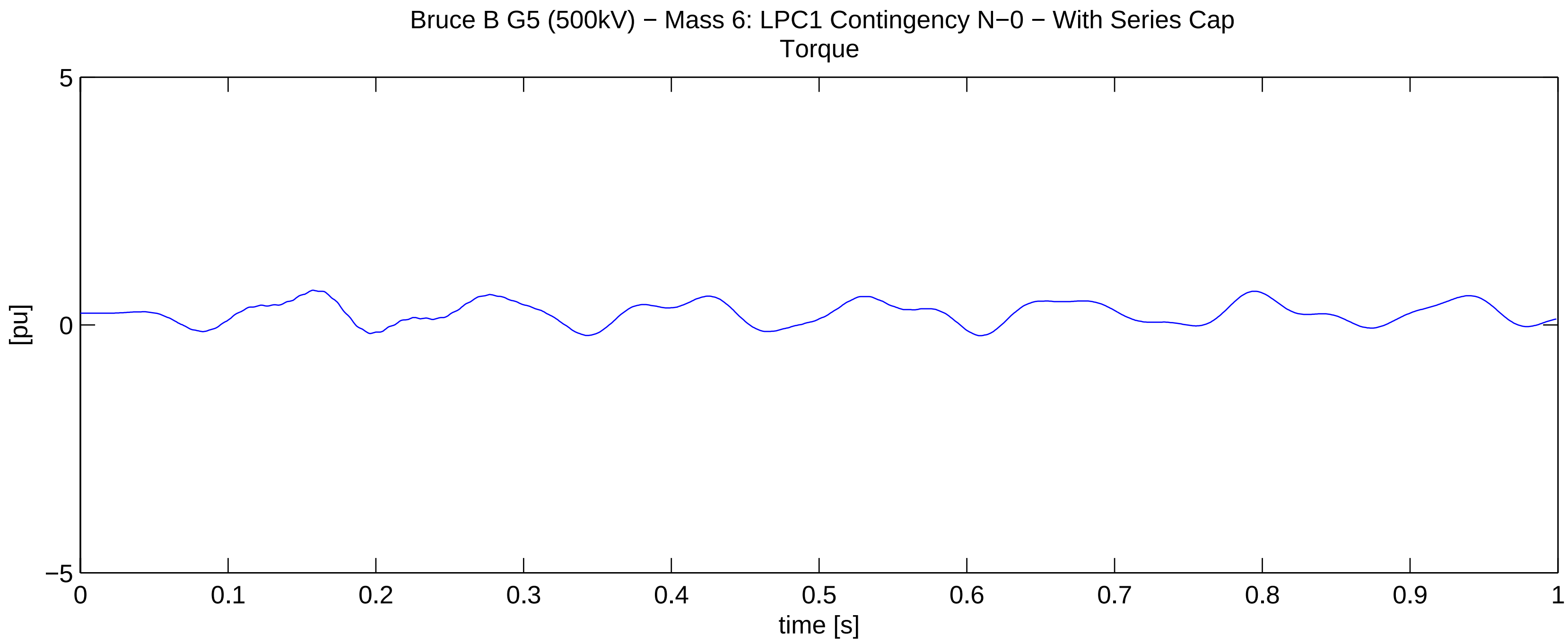

Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



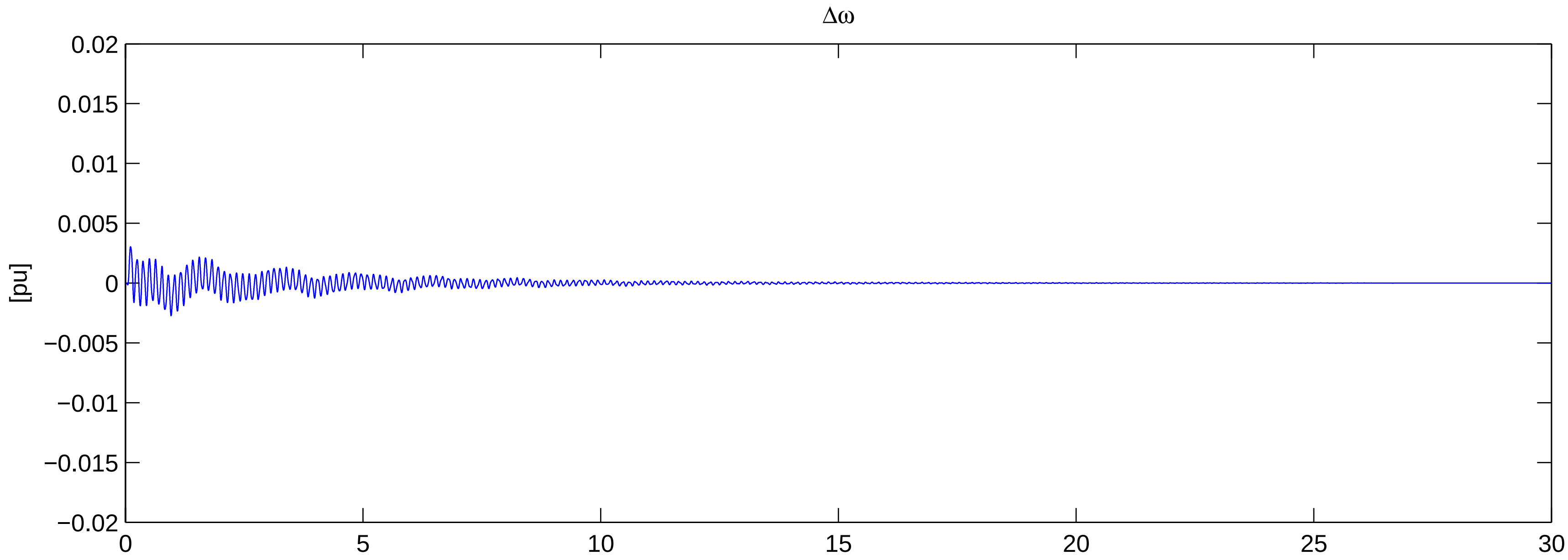
Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

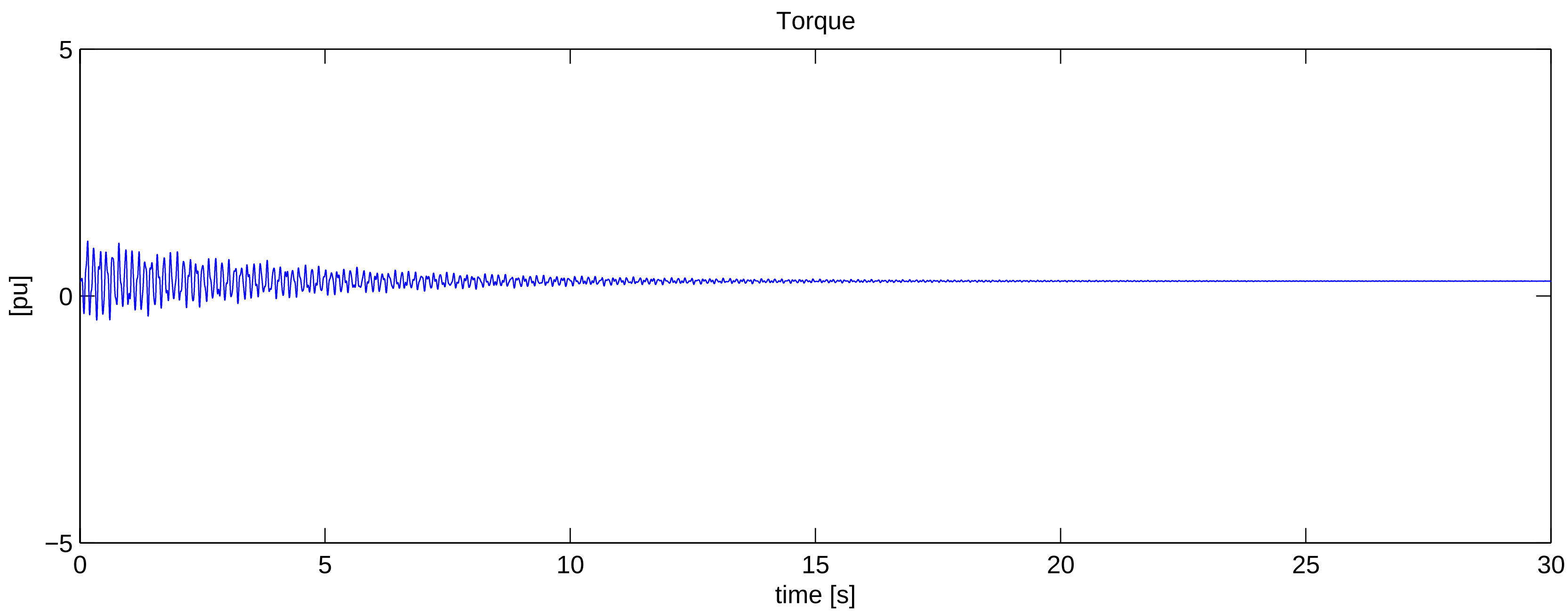

Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

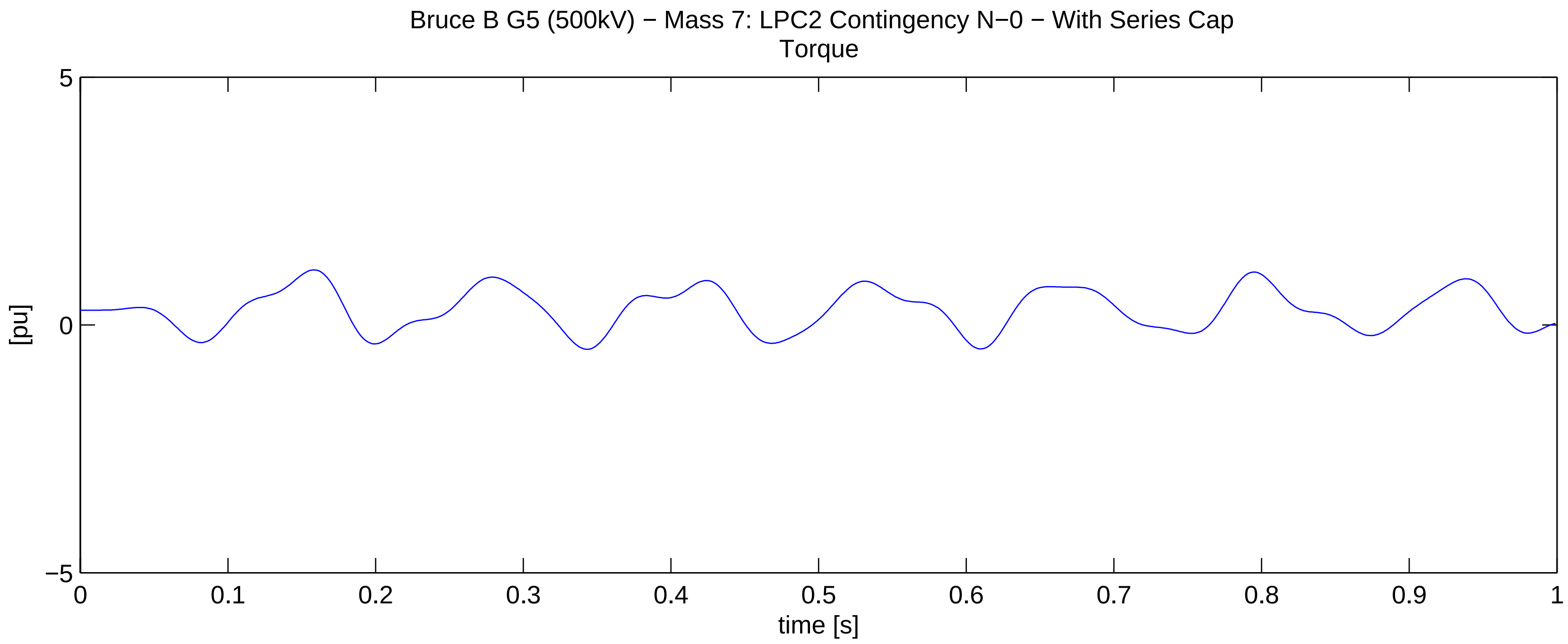

Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

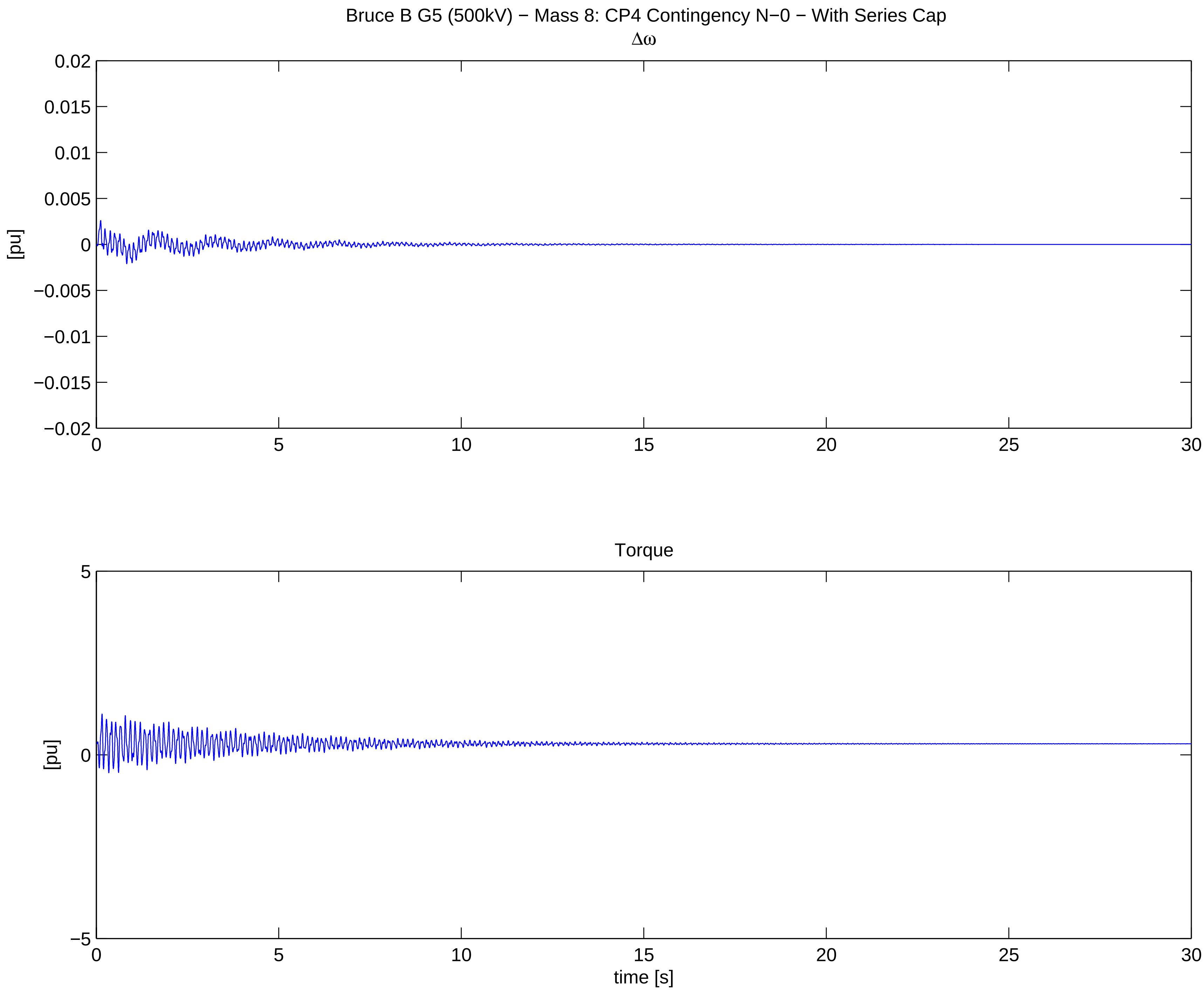

Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

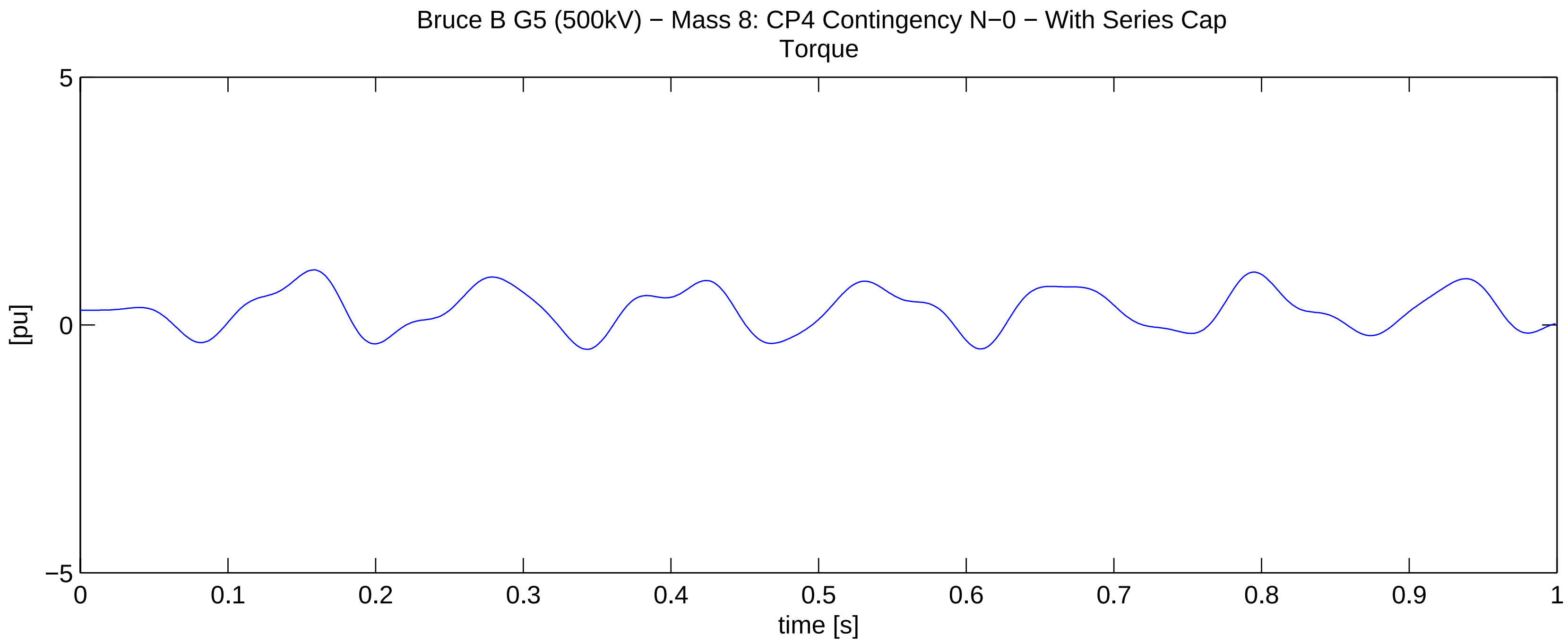
Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−0 − With Series Cap

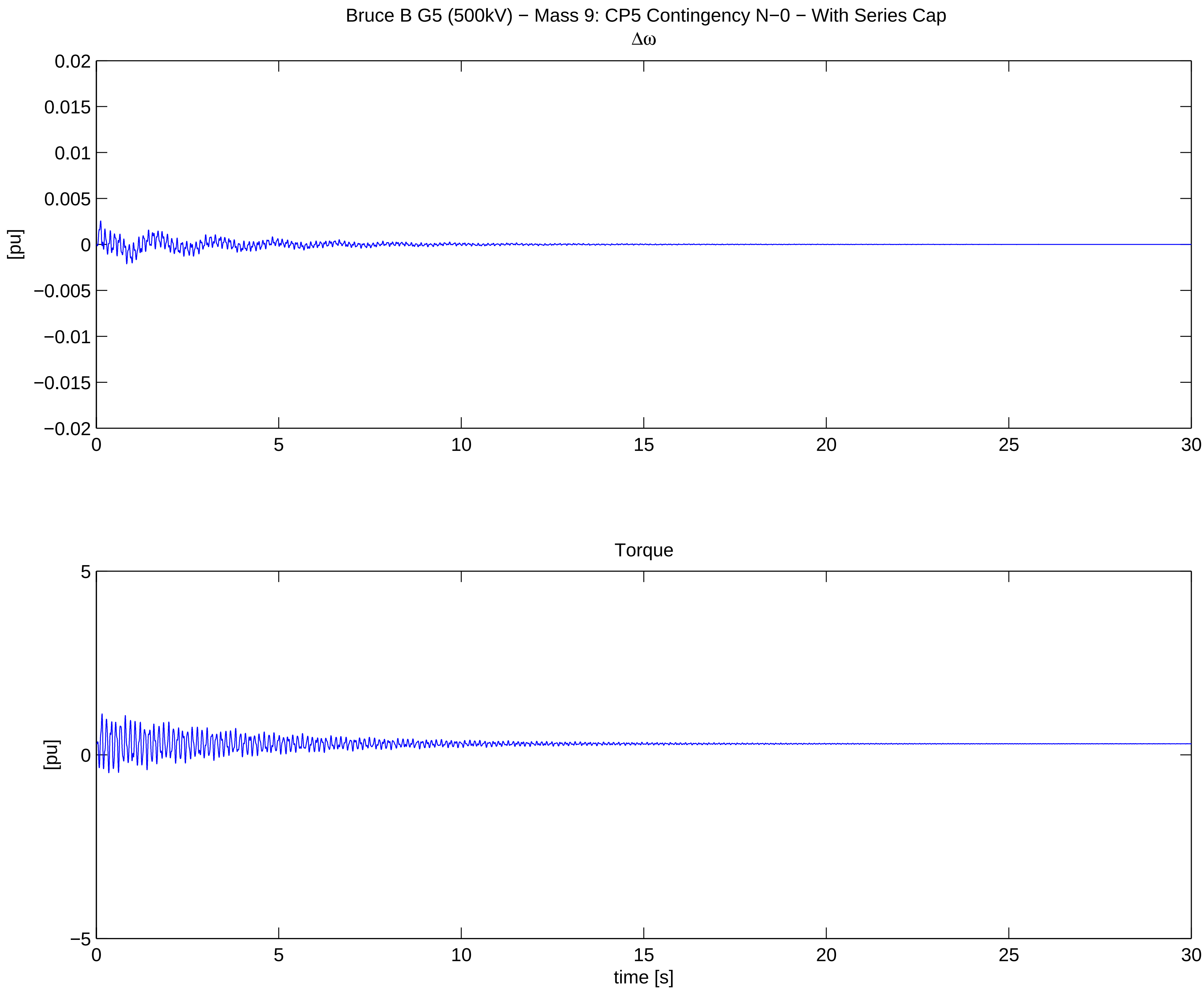




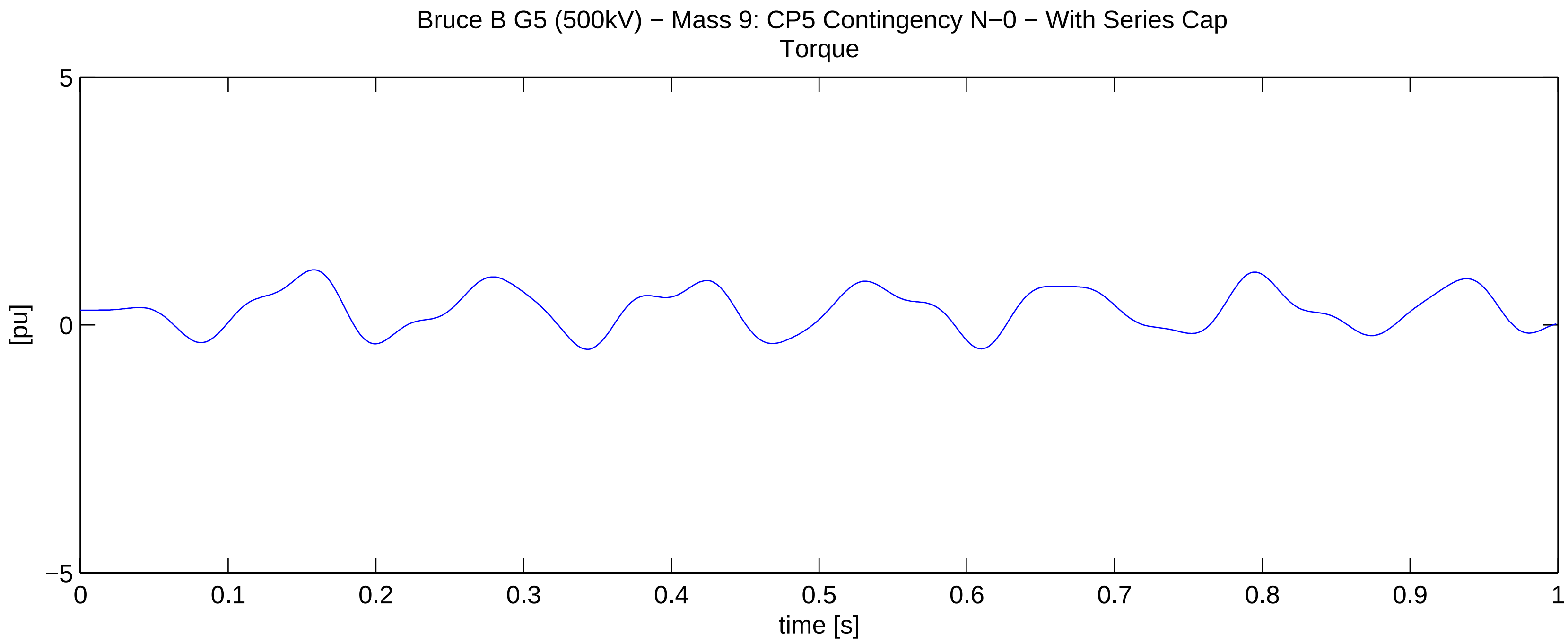

Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

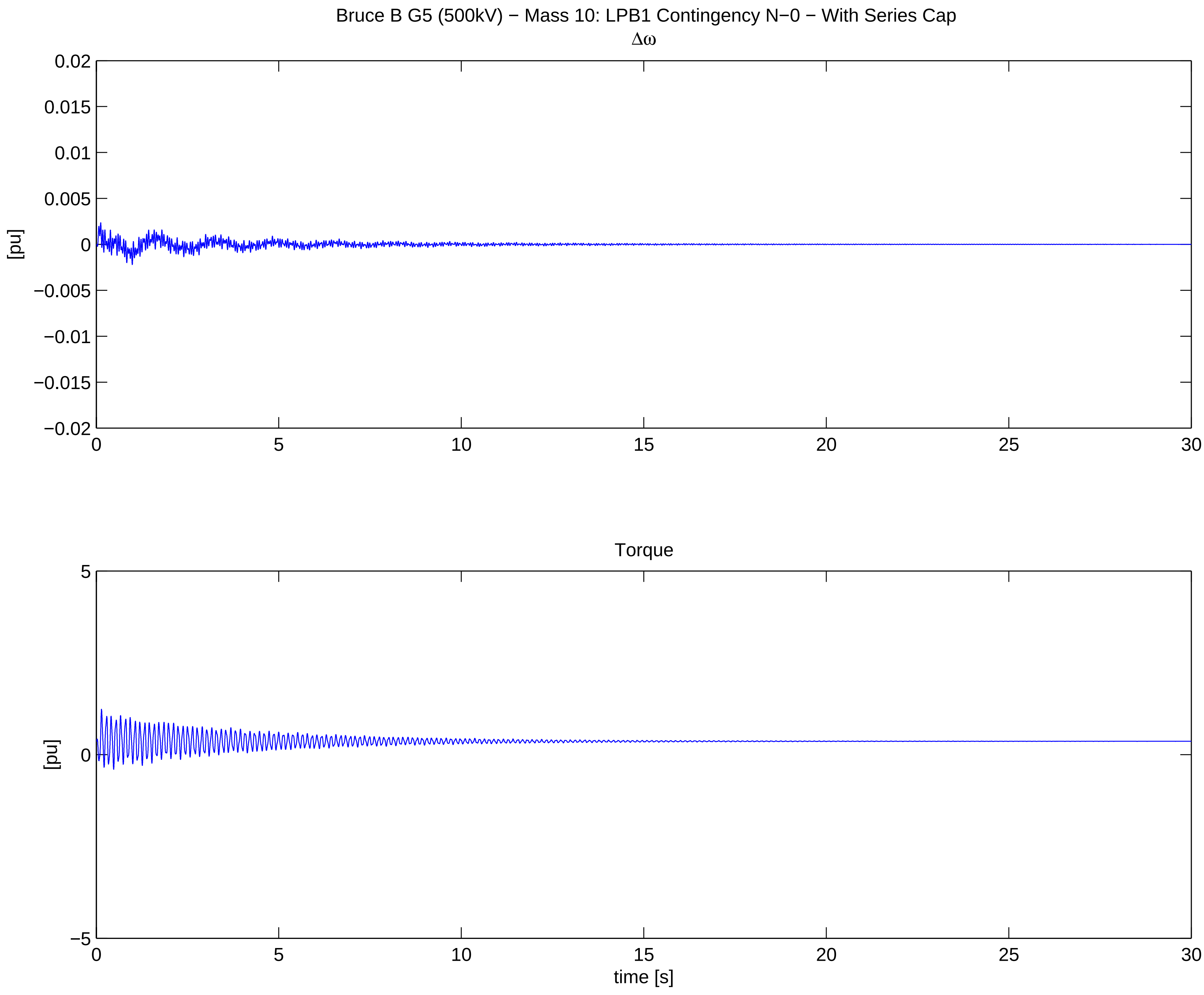

Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

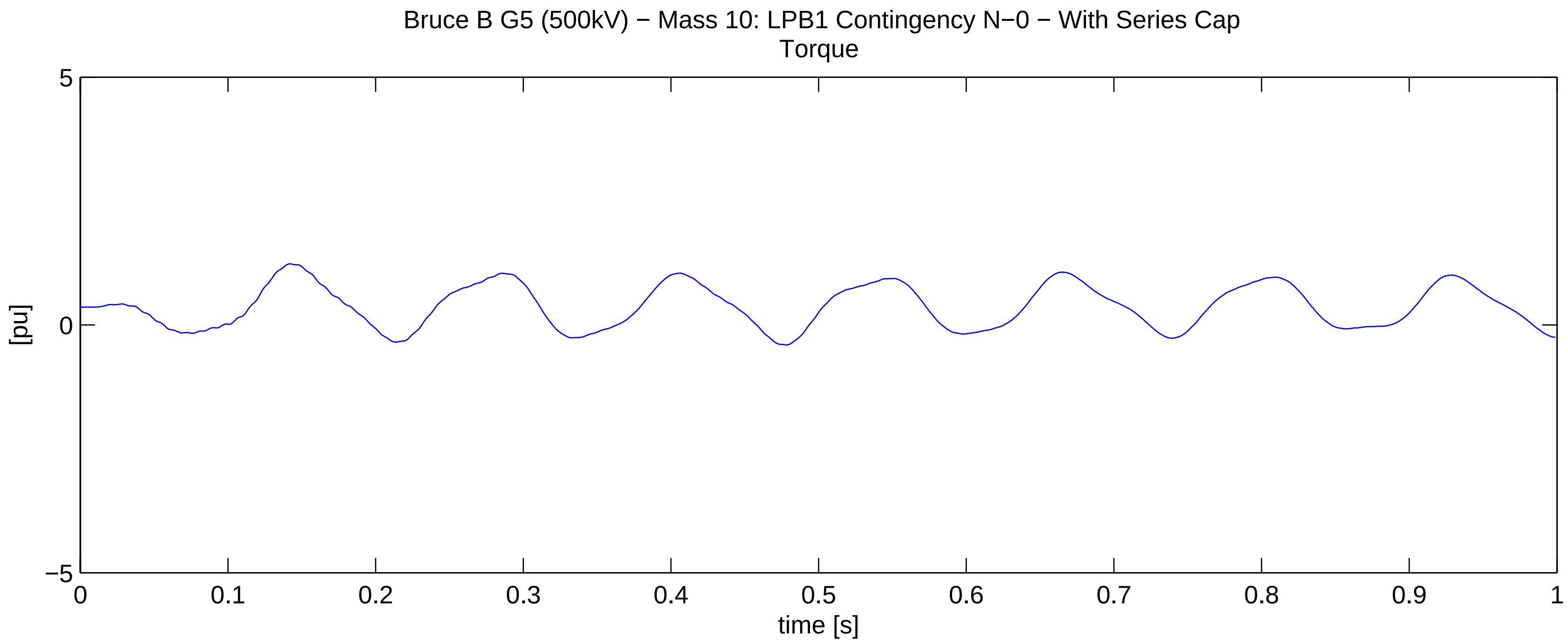


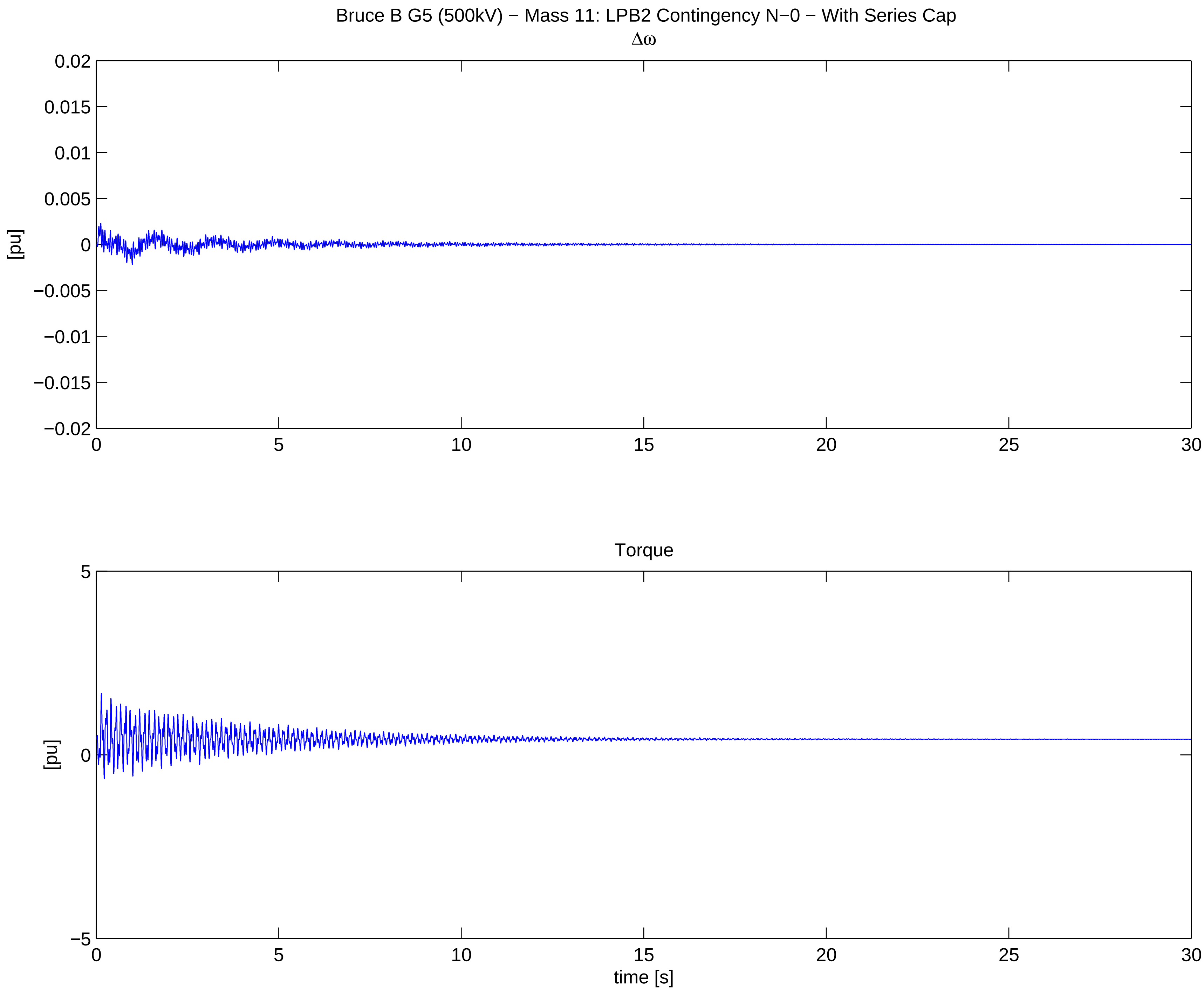
Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−0 − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]



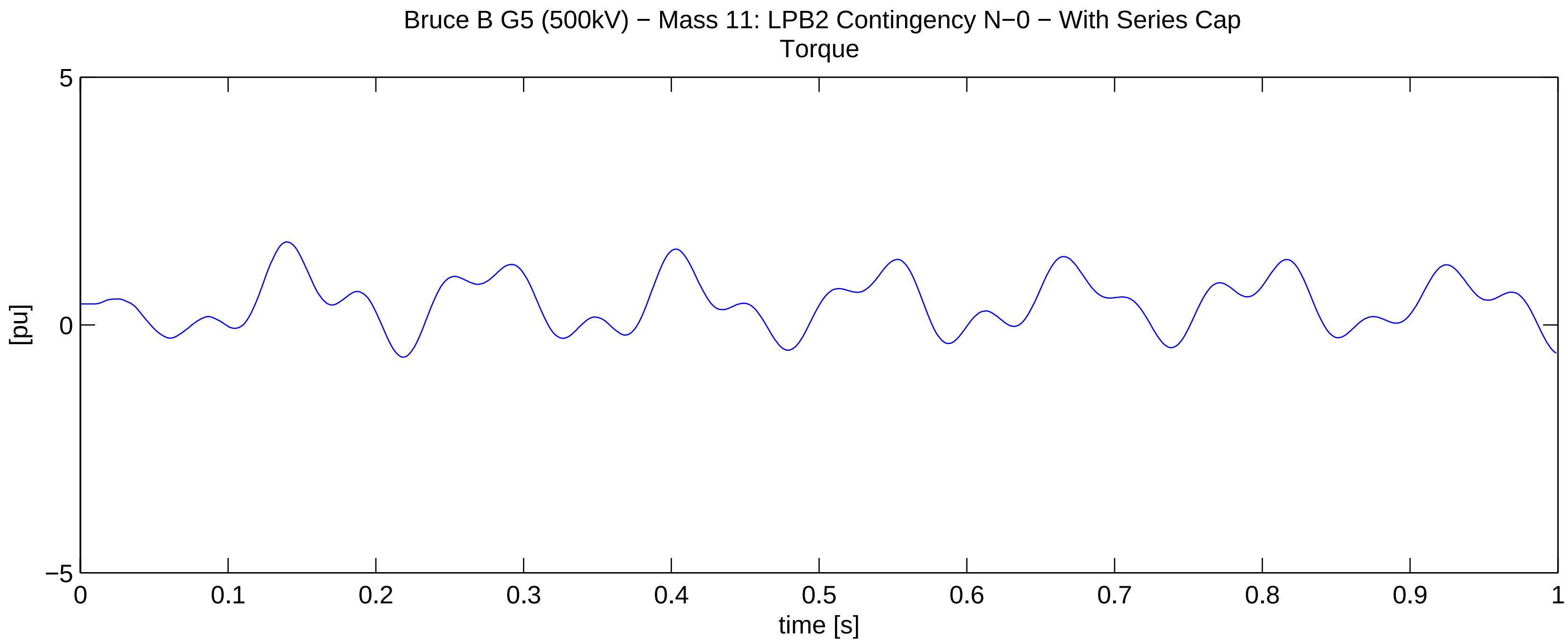
Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

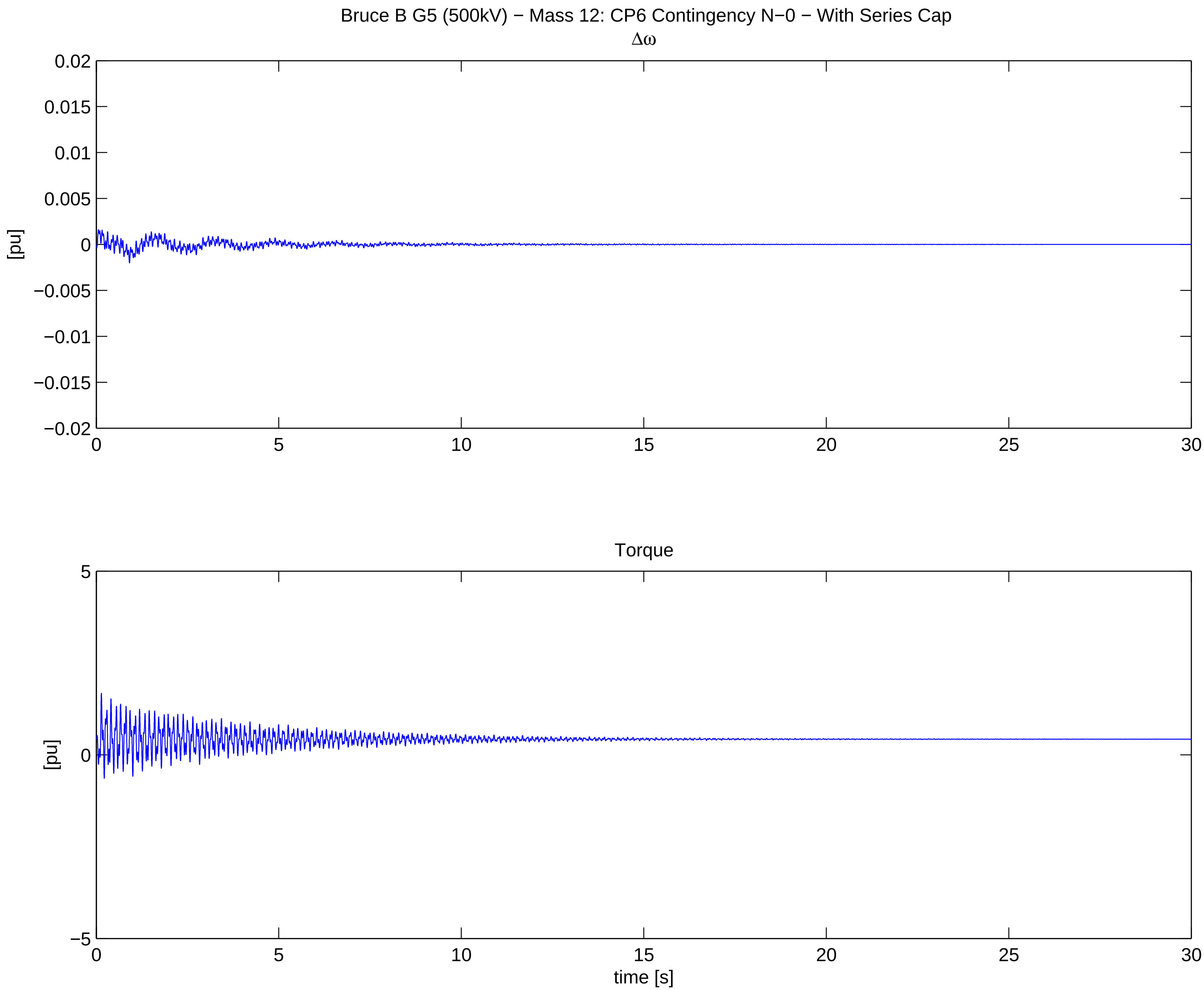

Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

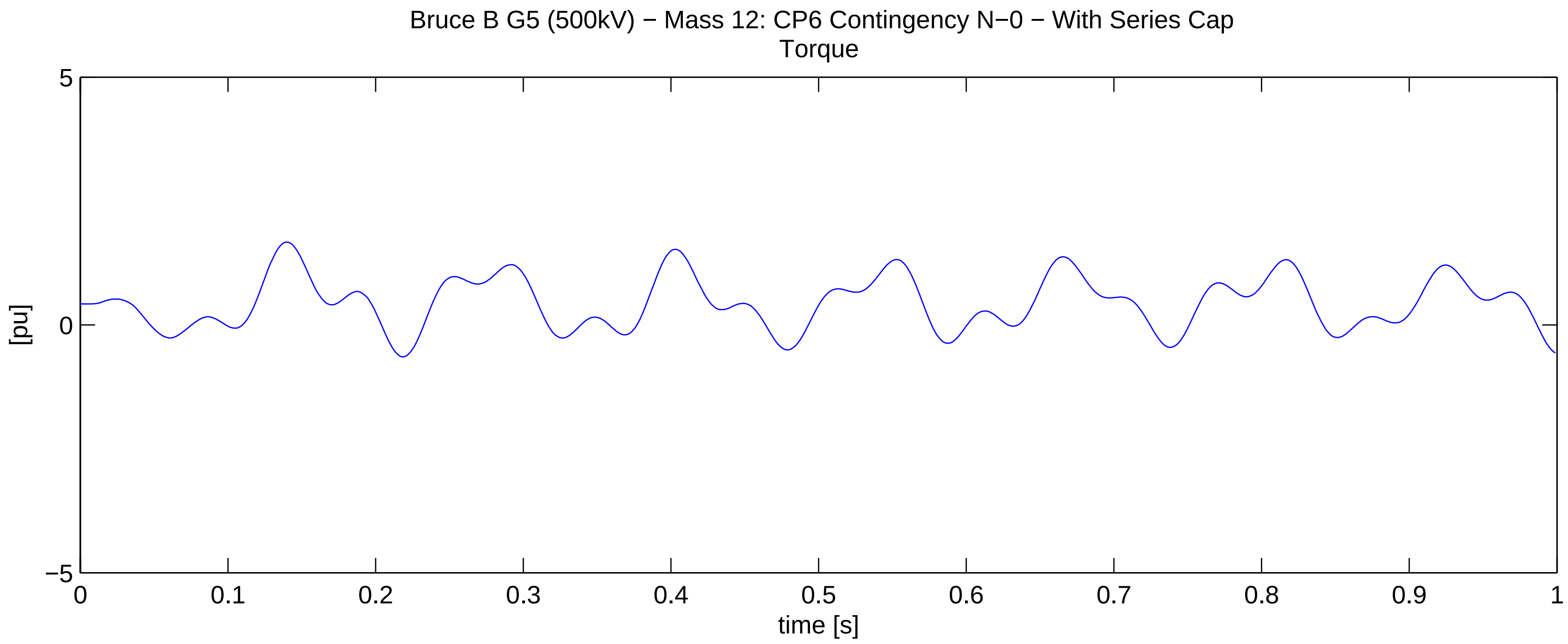


Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

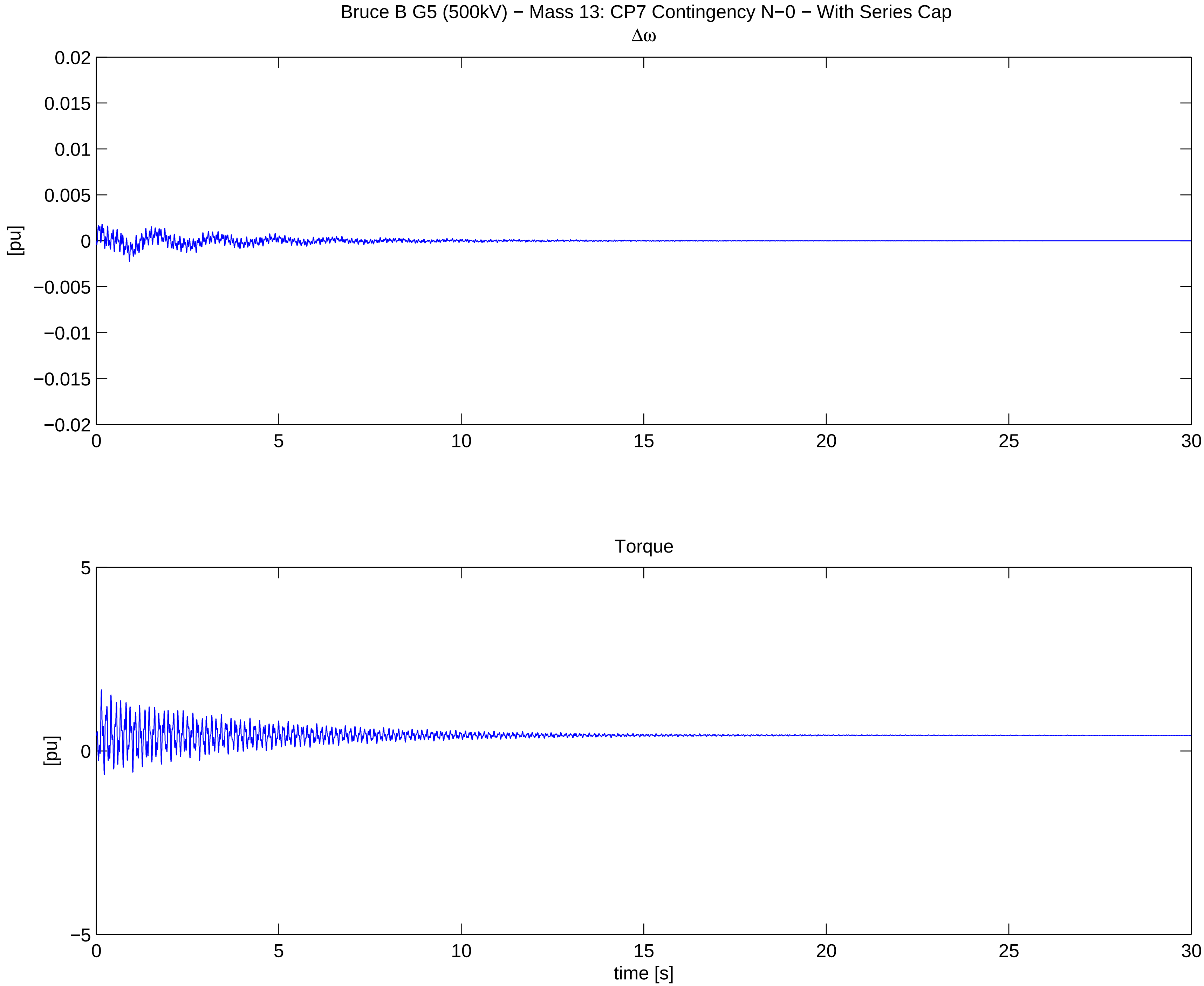

Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



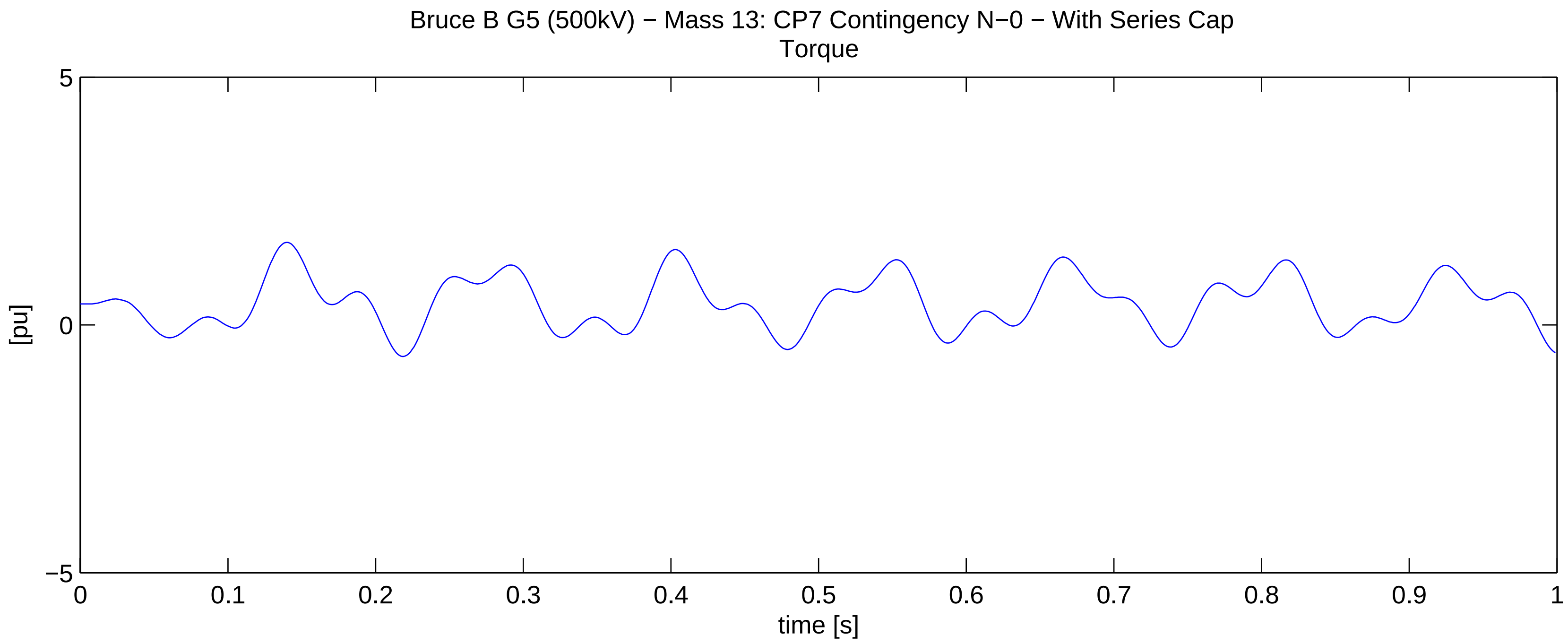
Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−0 − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

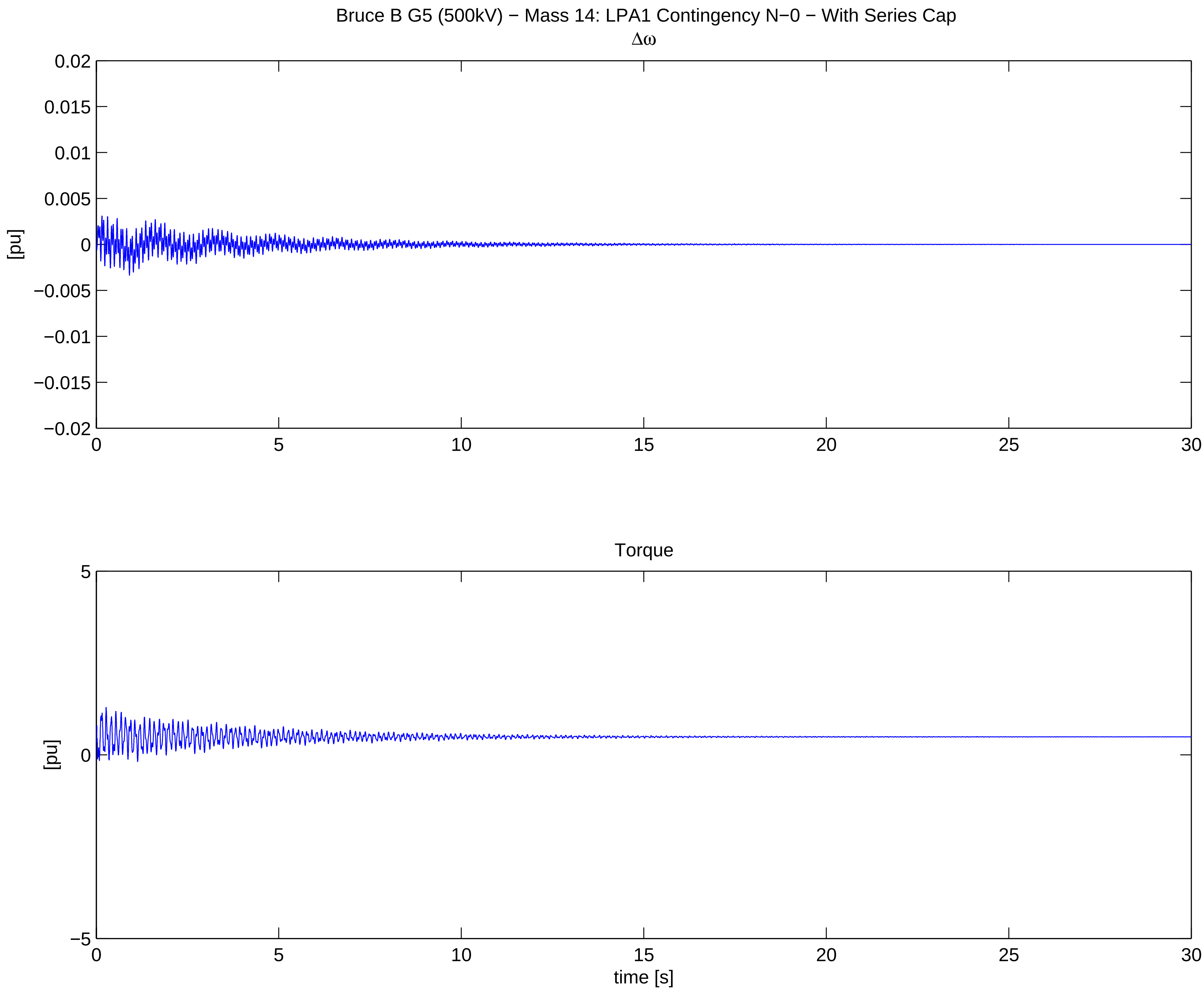


Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

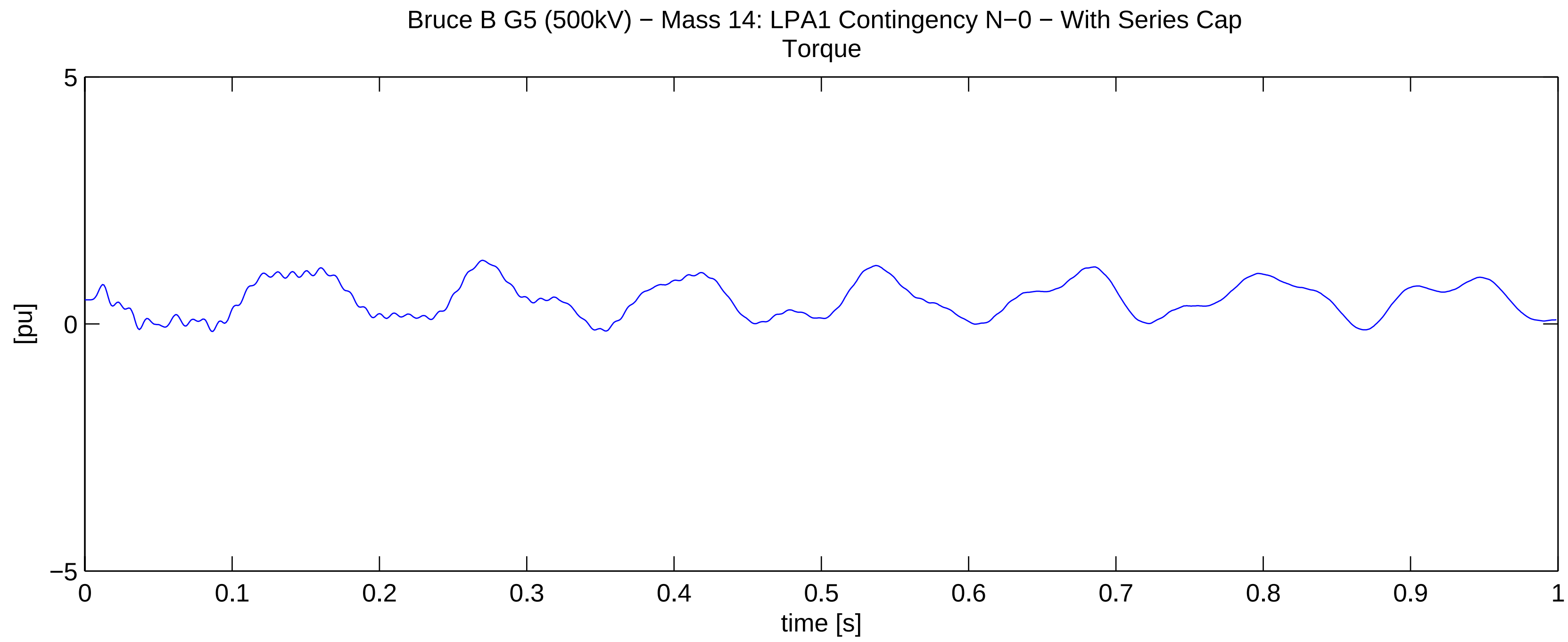


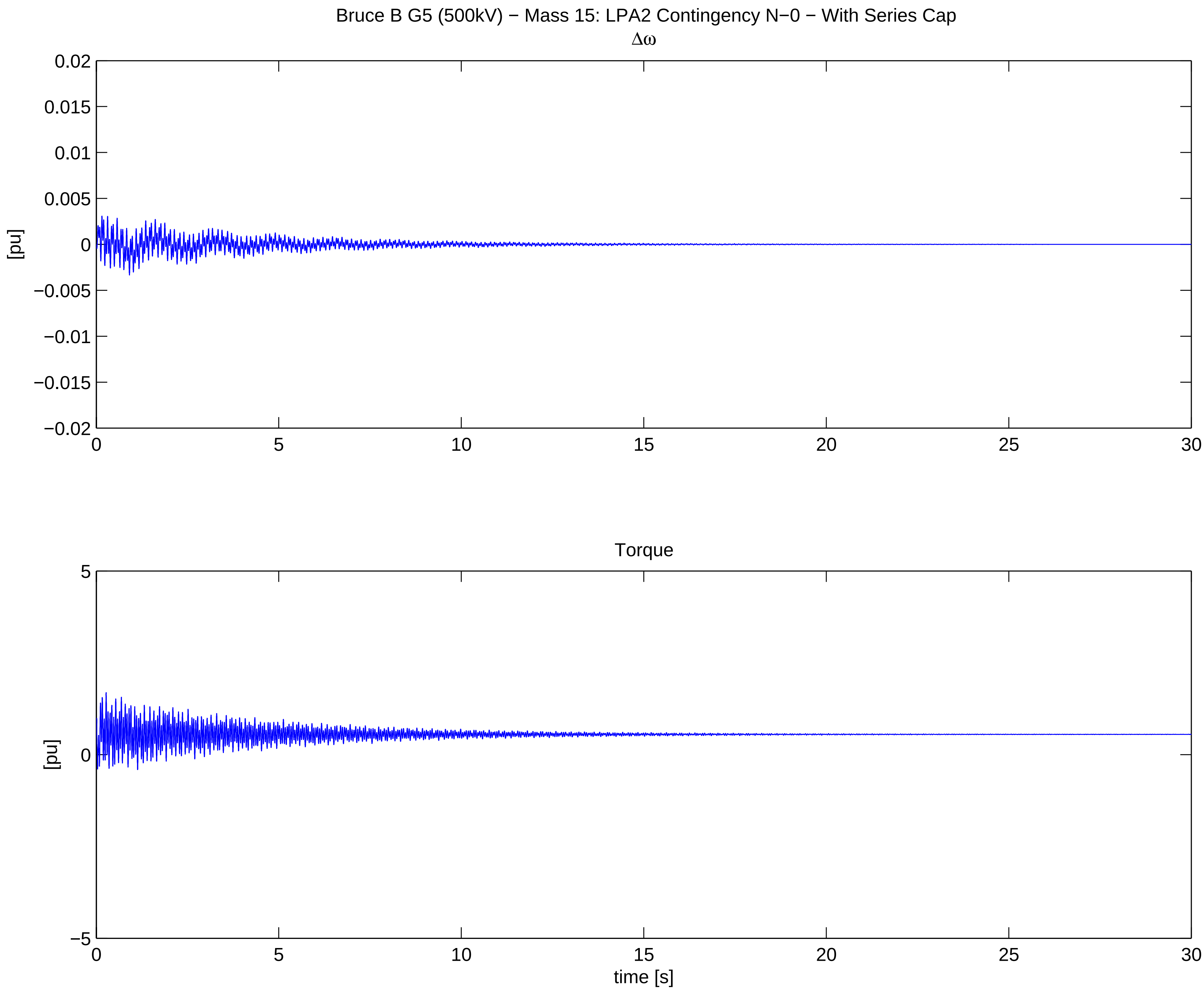
Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

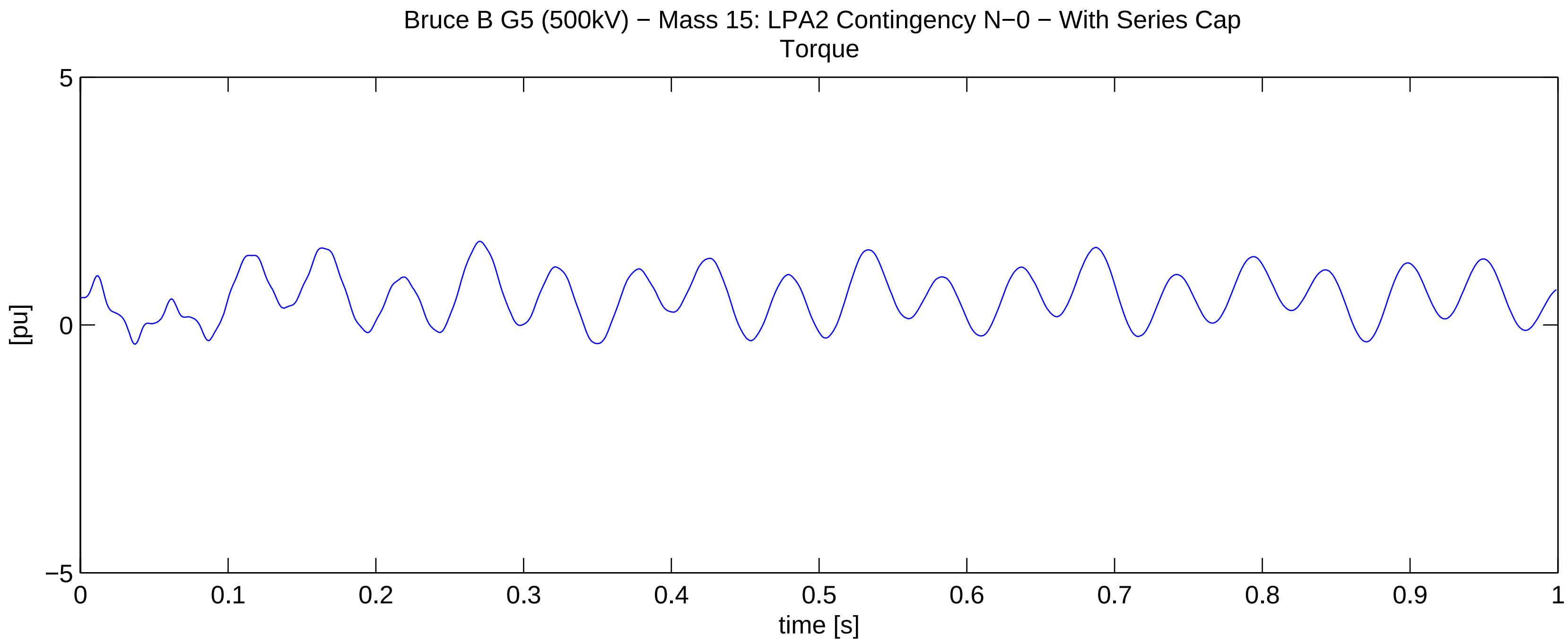

Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



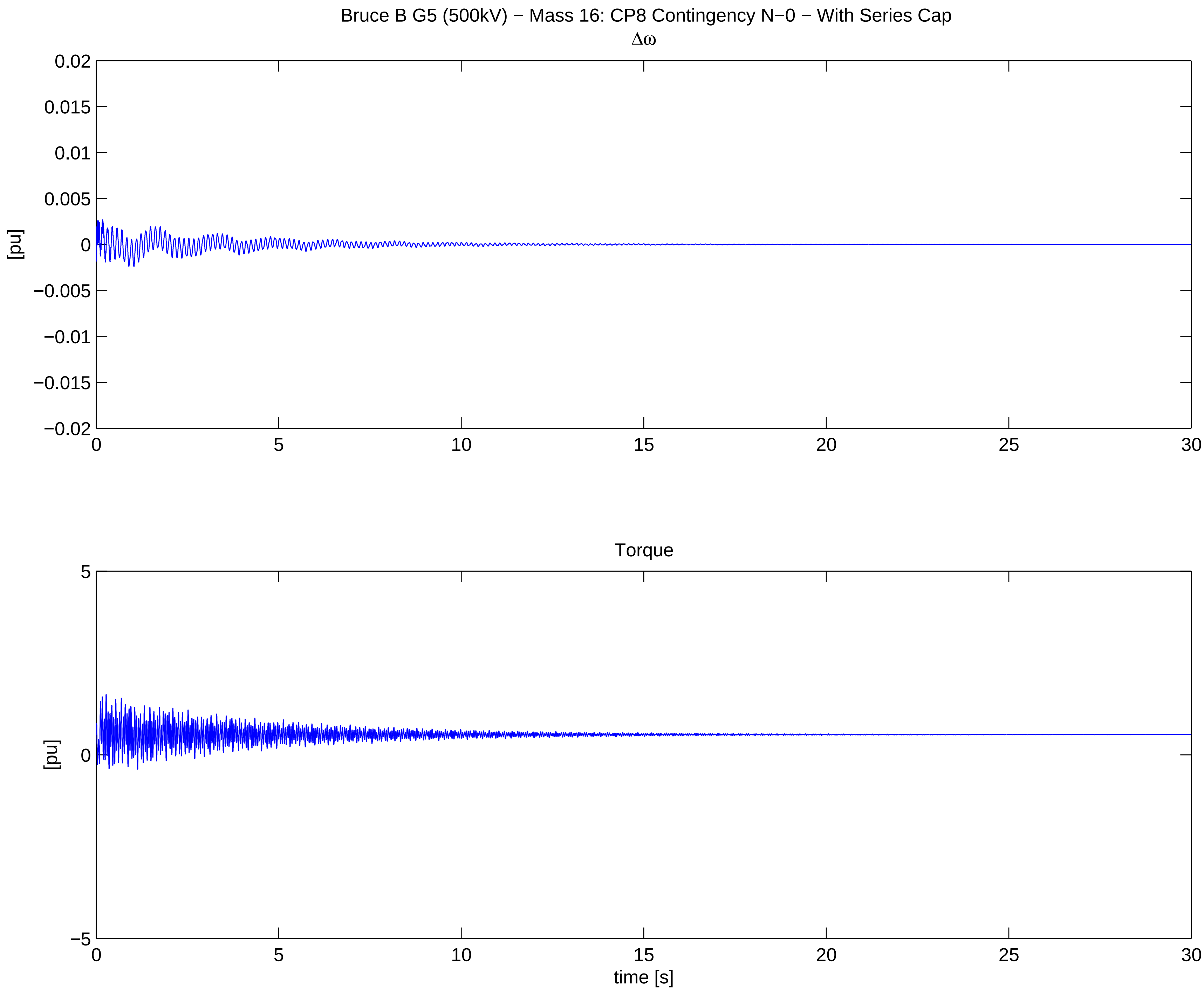
Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

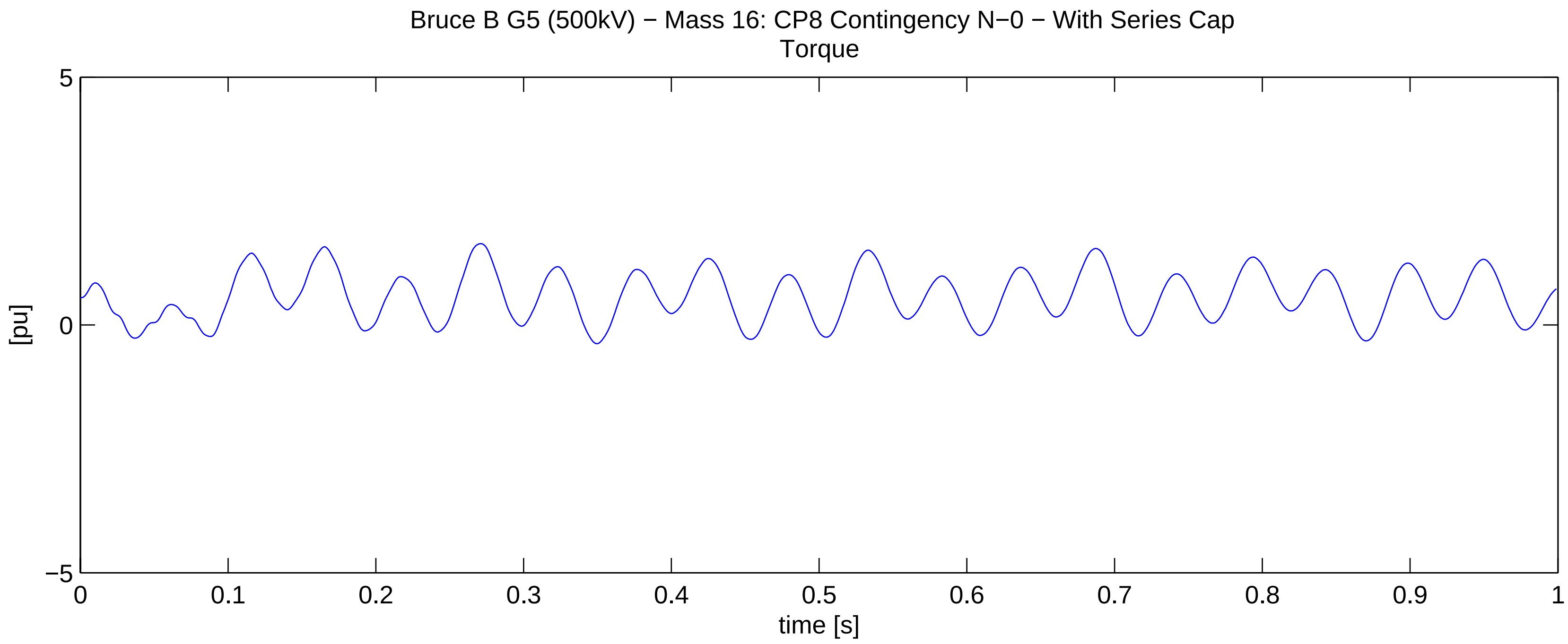

Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

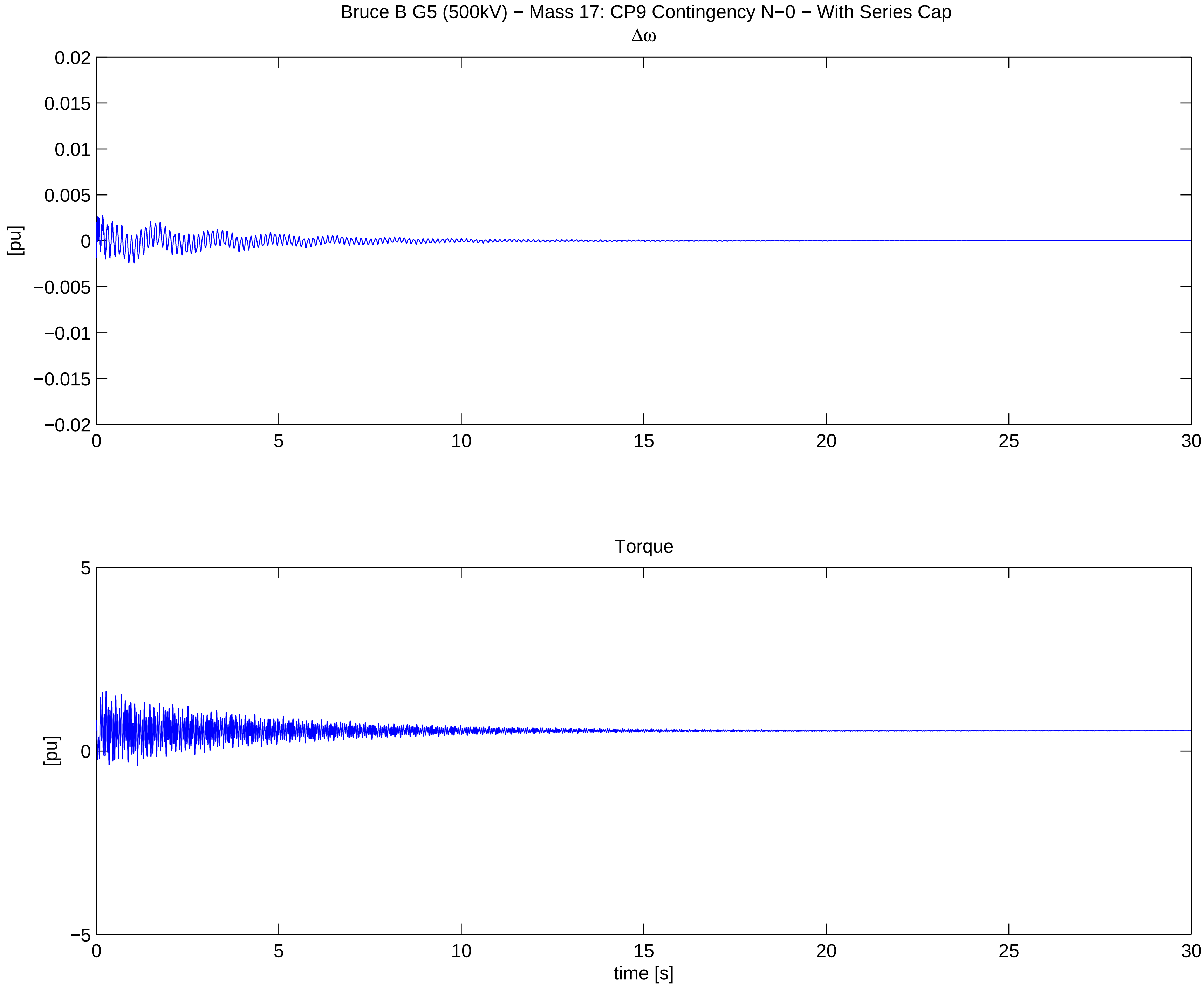


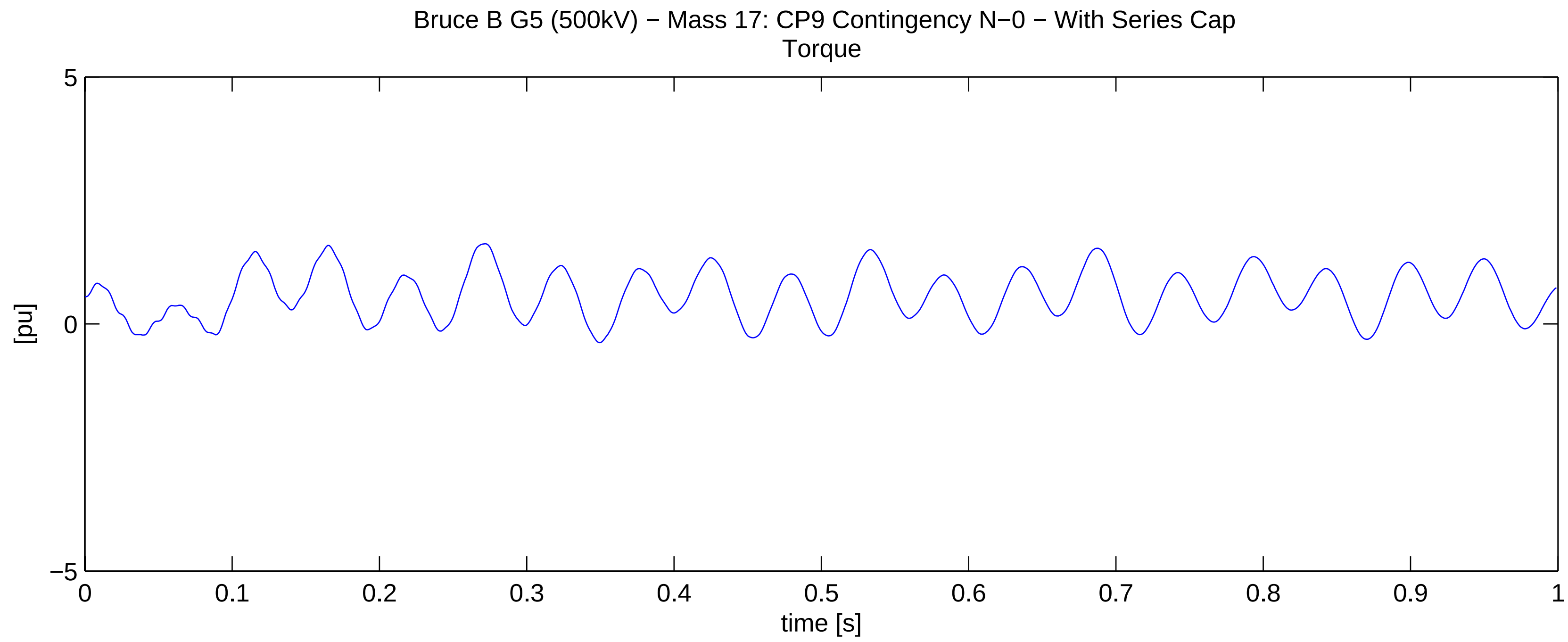
Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



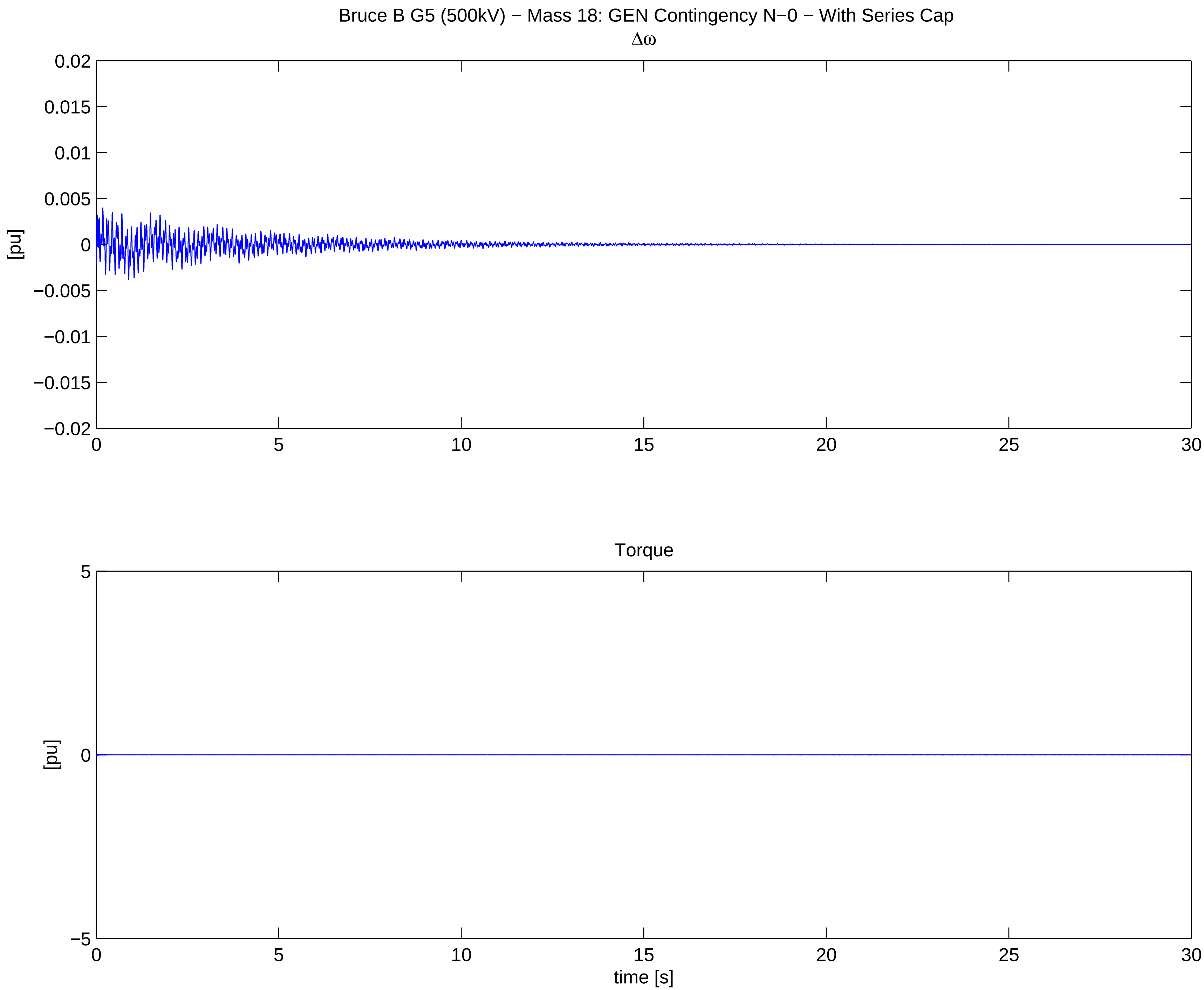
Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

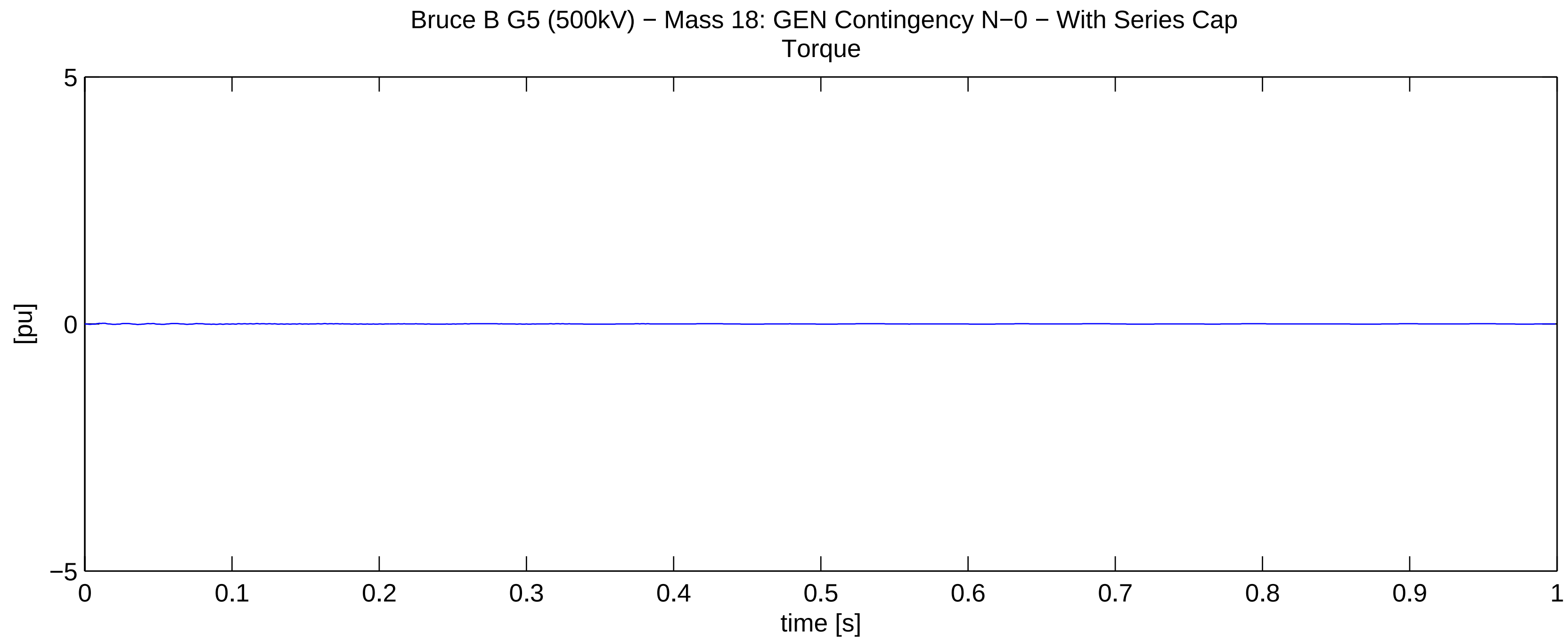

Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

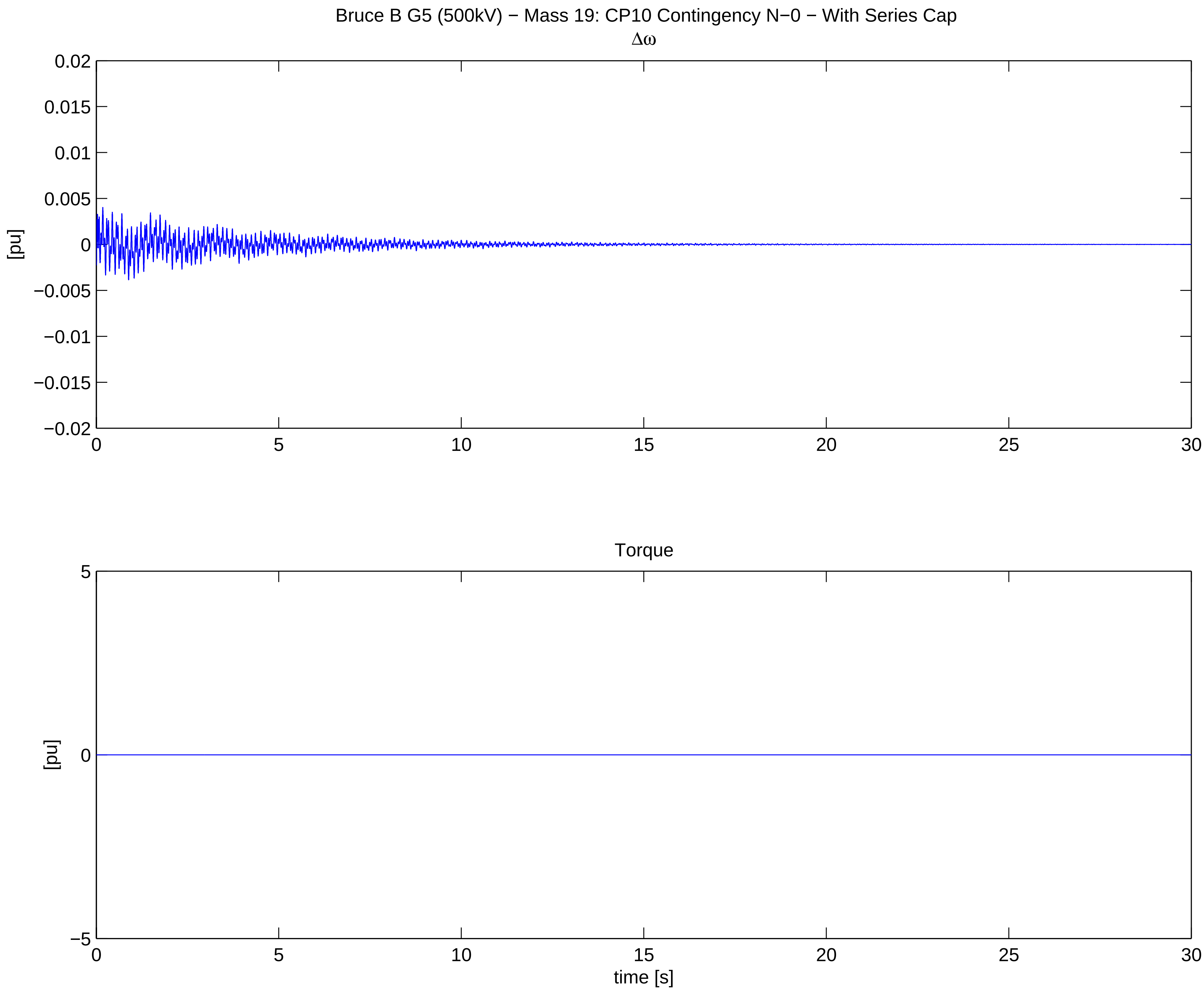


Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

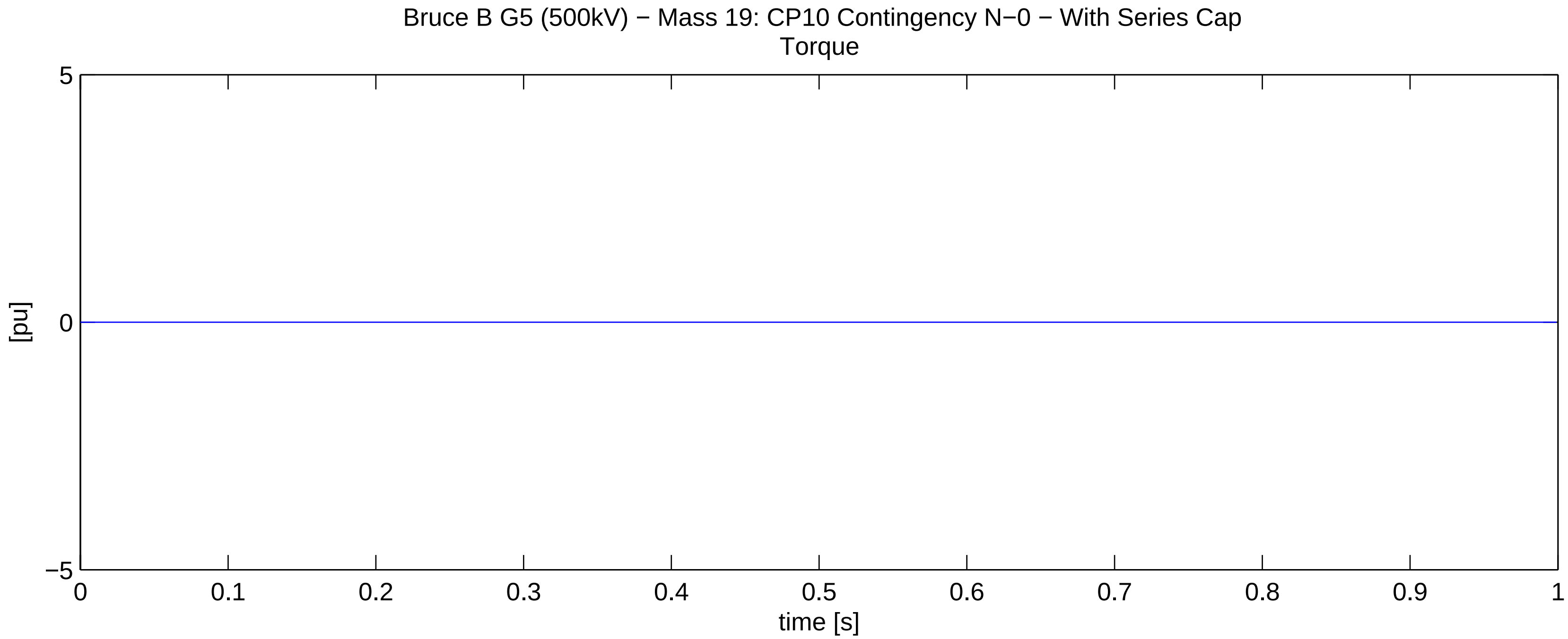


Bruce B G5 (500kV) − Mass 18: GEN Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

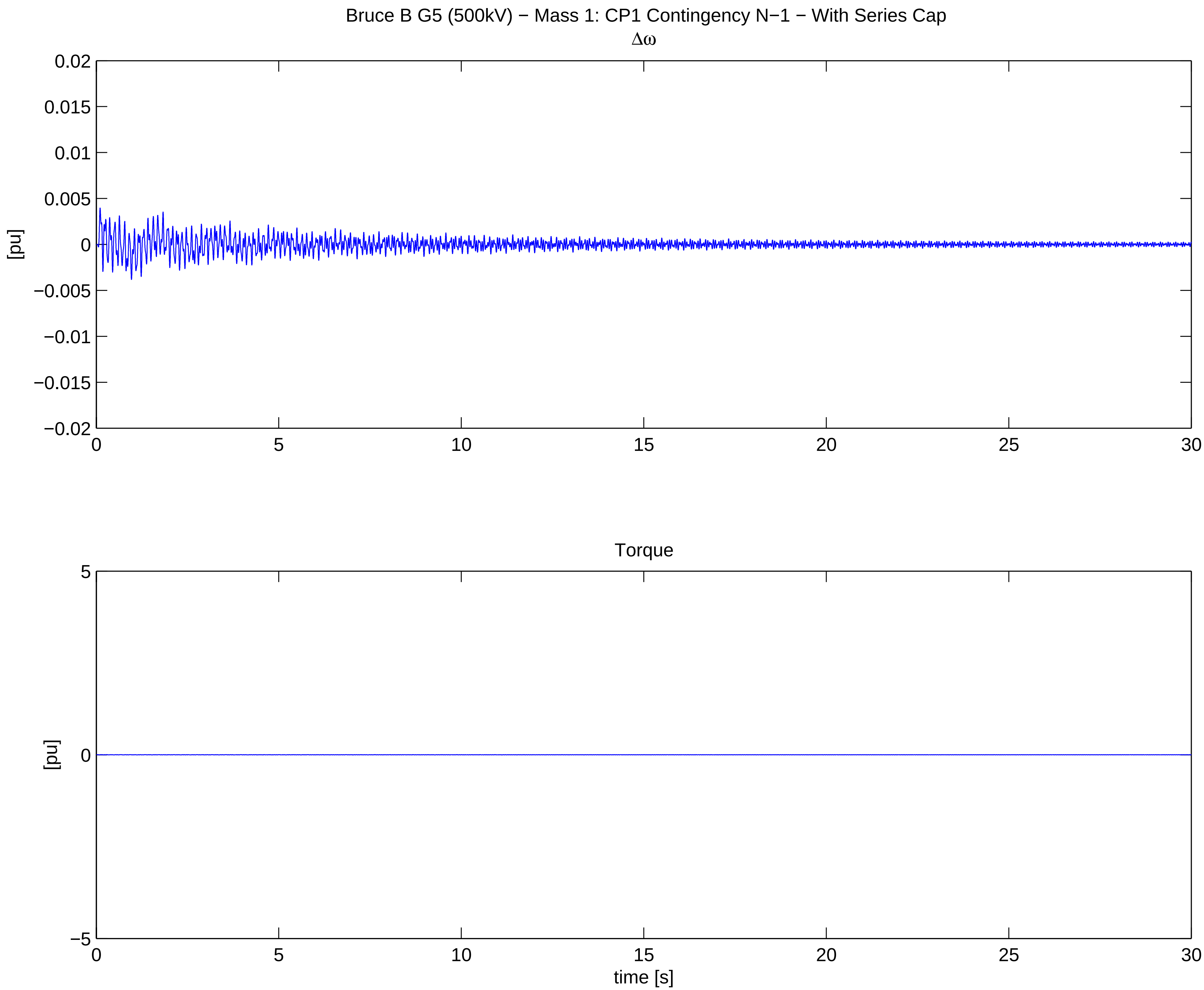

Bruce B G5 (500kV) − Mass 18: GEN Contingency N−0 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



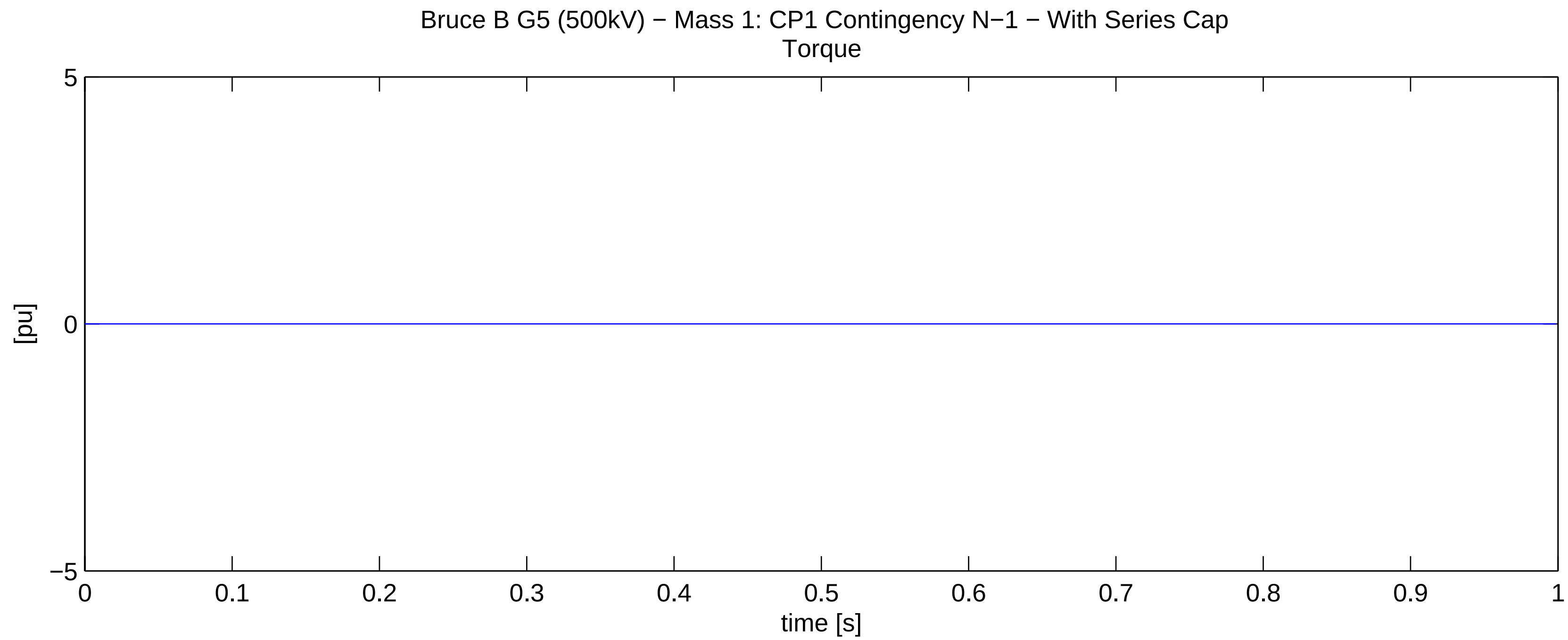
Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−0 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

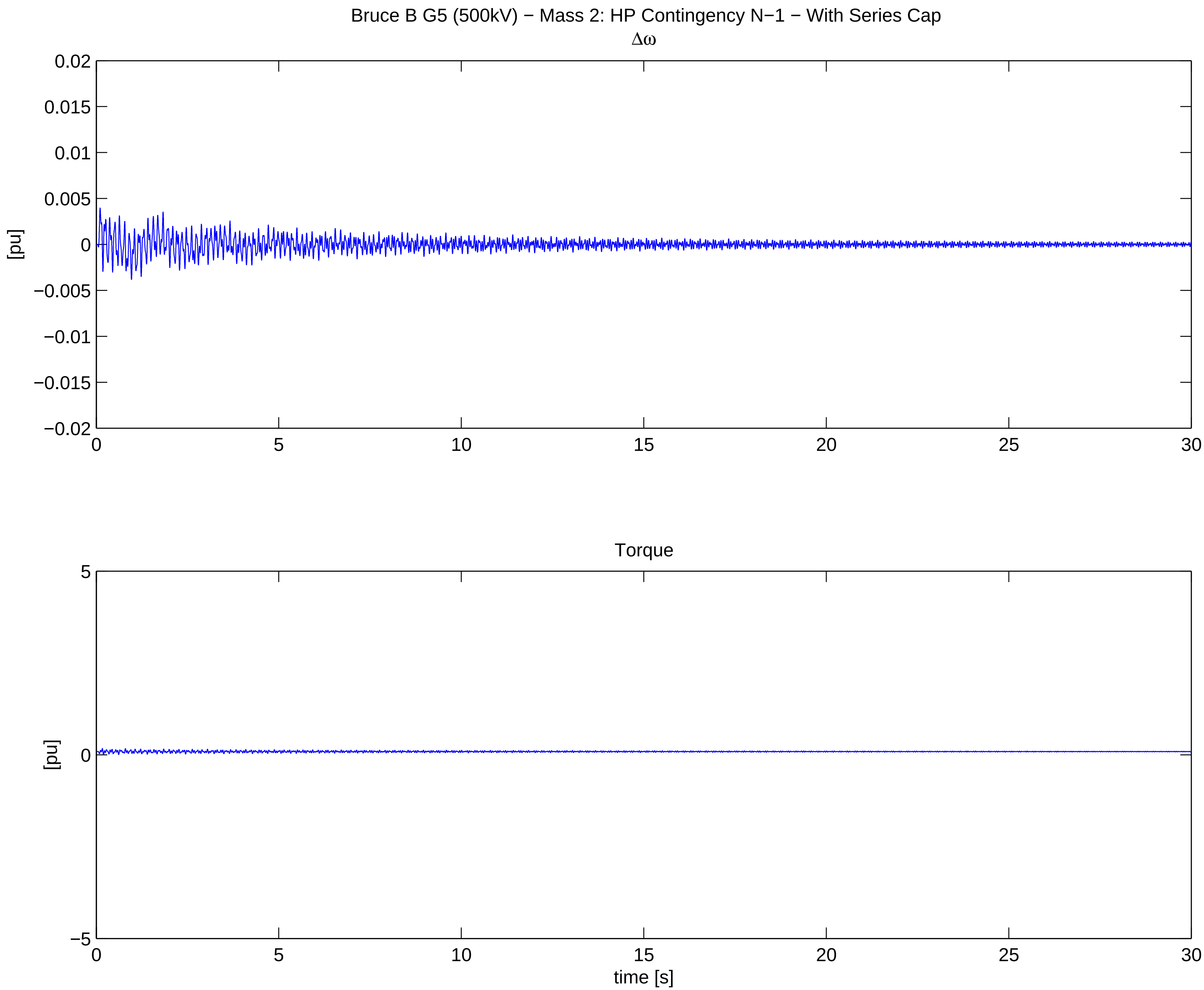


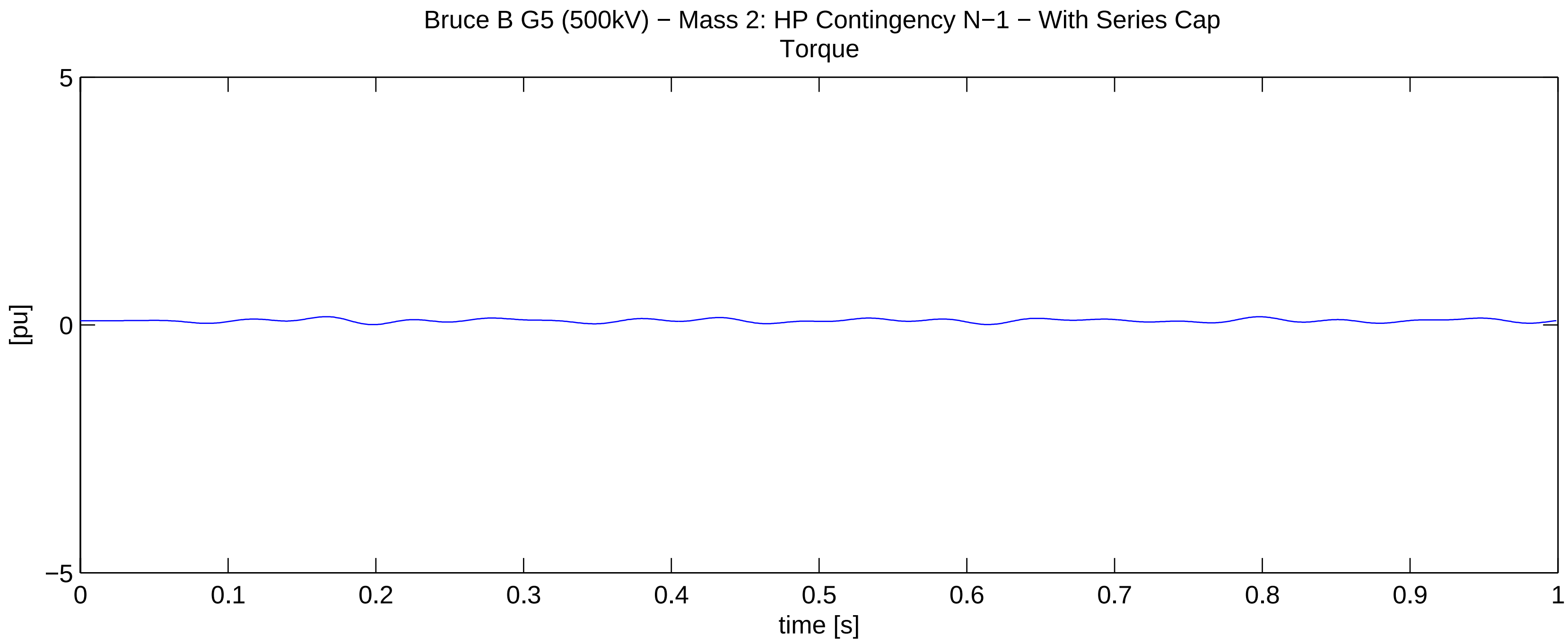
Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−0 − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



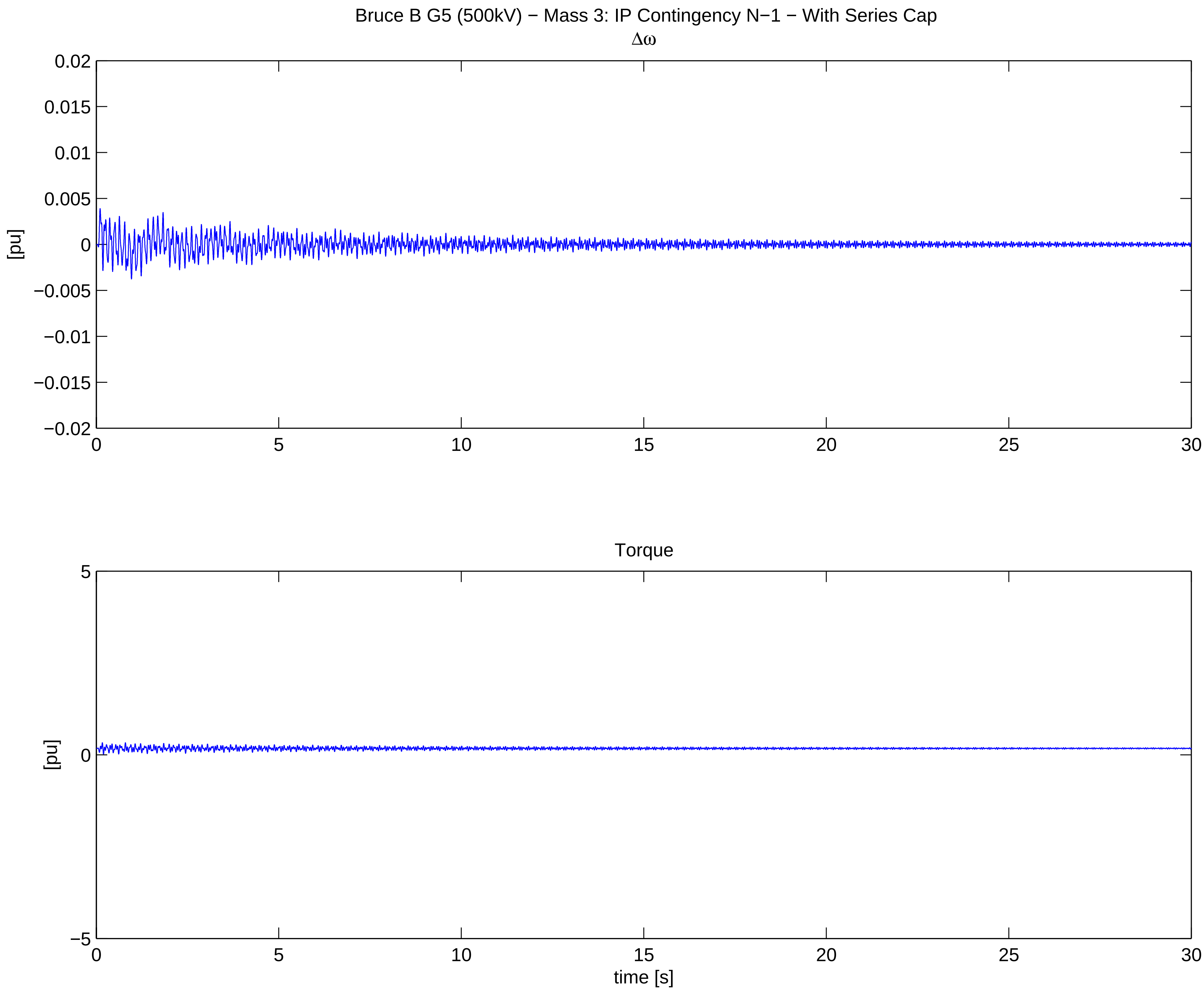
Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−1 − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

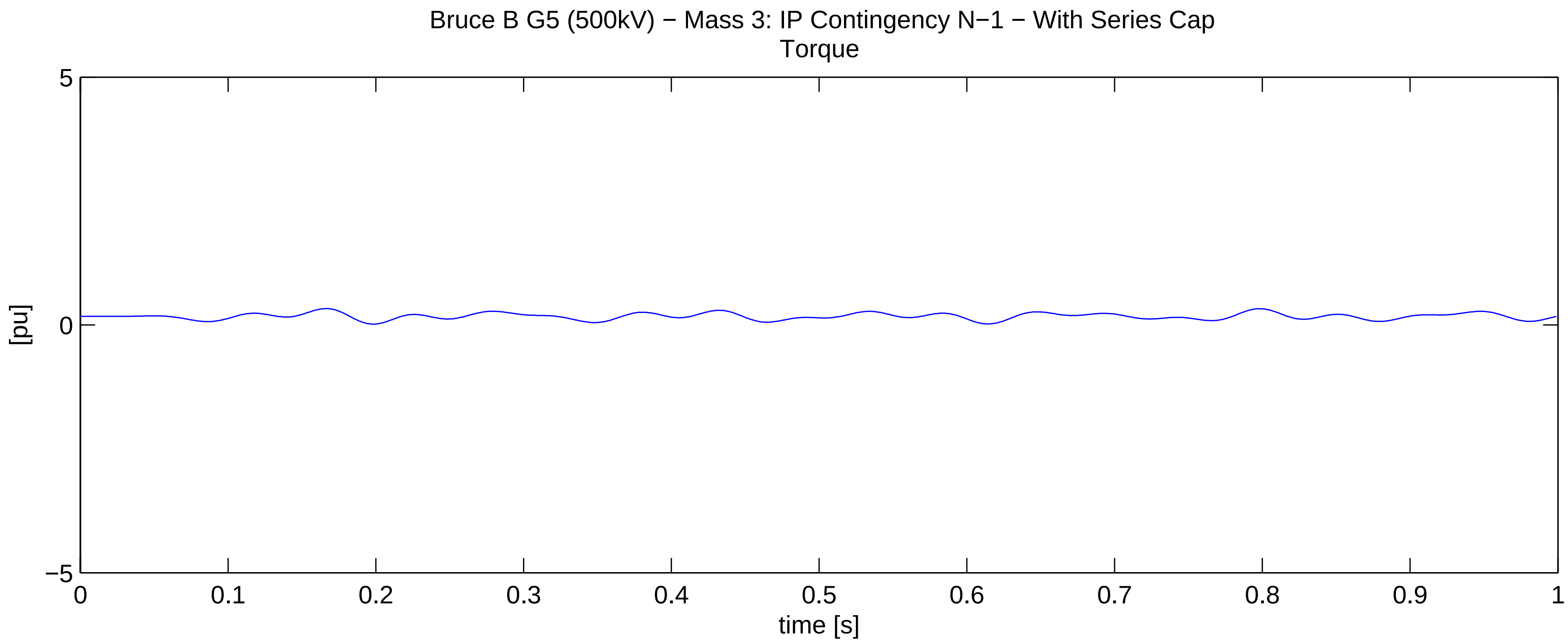

Bruce B G5 (500kV) − Mass 2: HP Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



Bruce B G5 (500kV) − Mass 2: HP Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

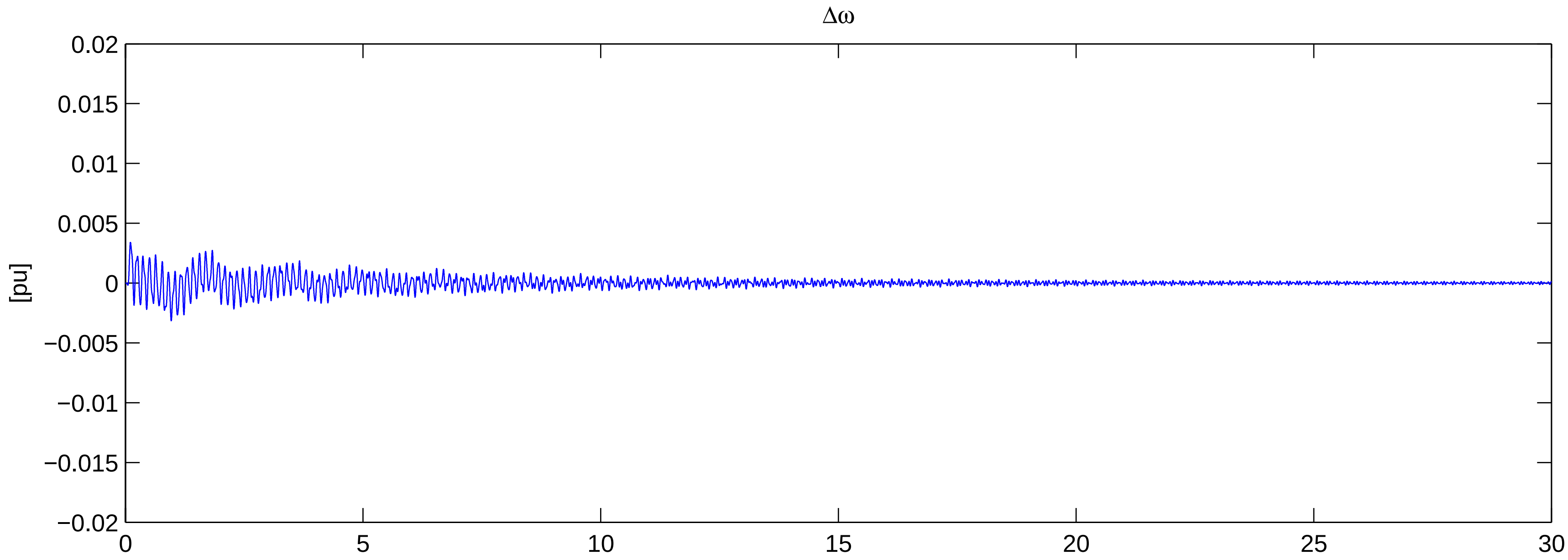


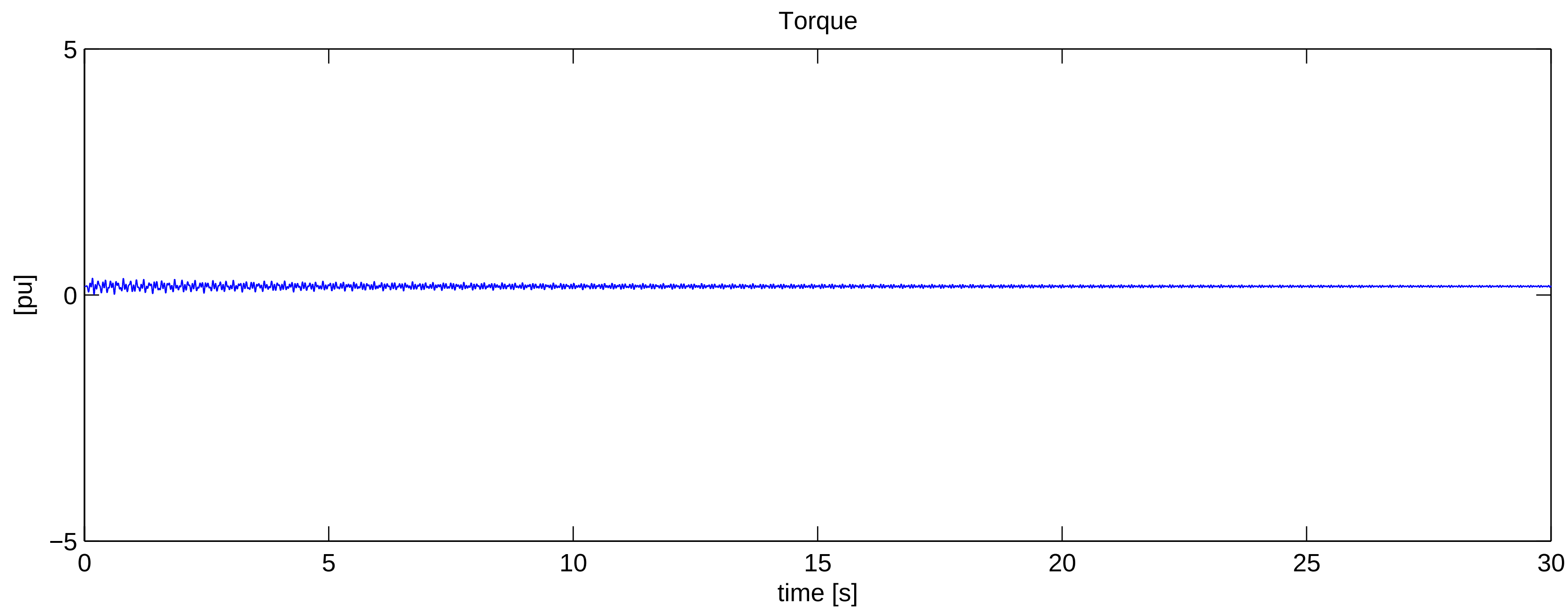
Bruce B G5 (500kV) − Mass 3: IP Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

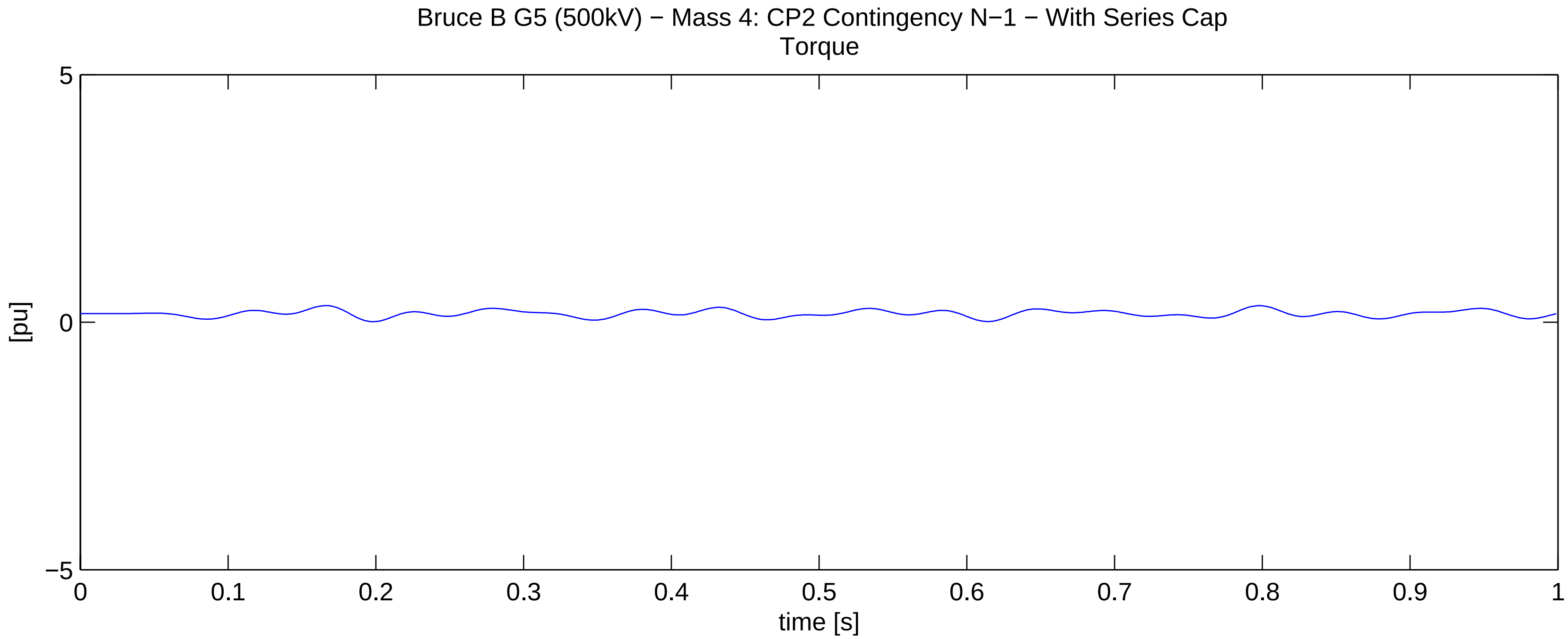


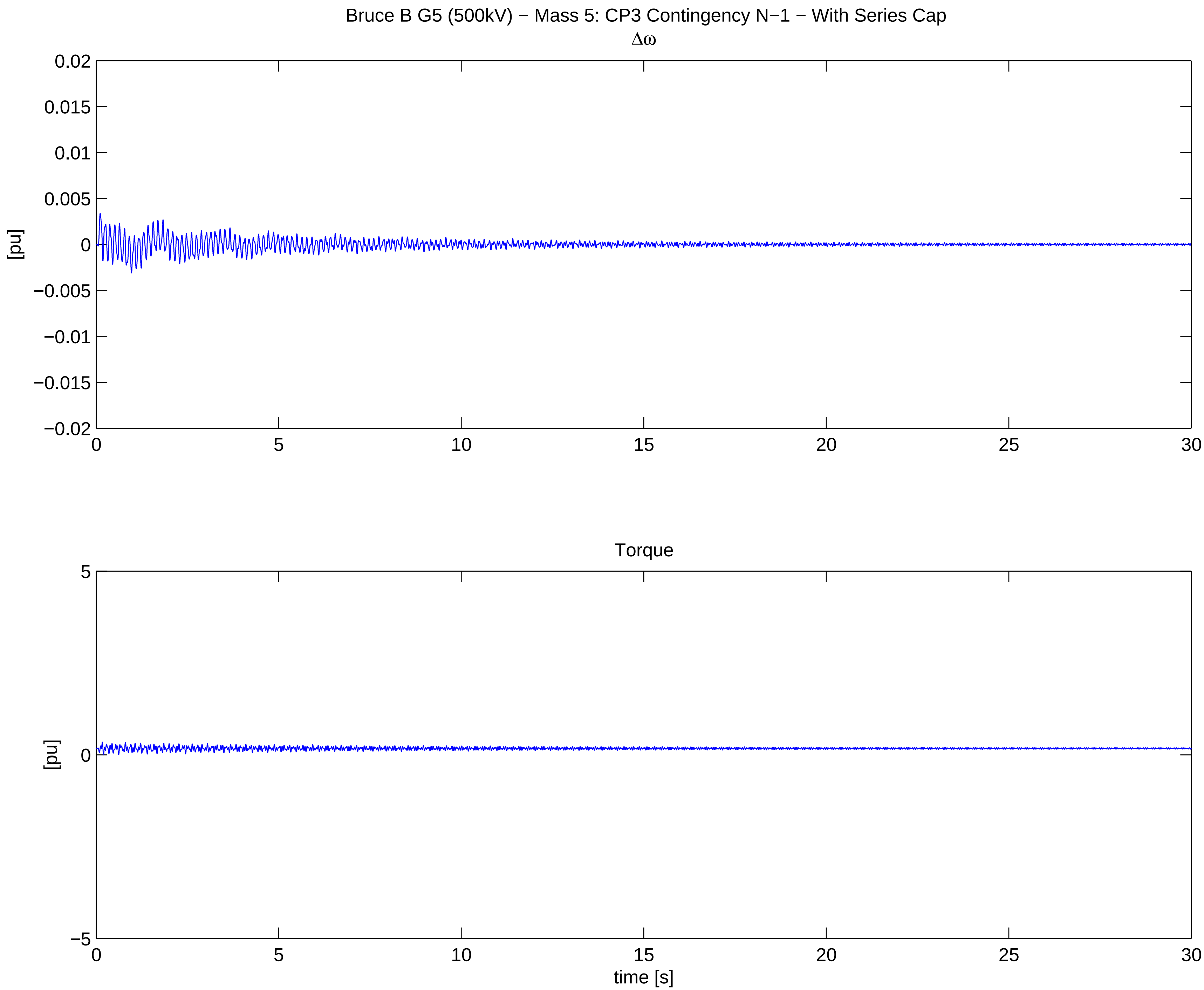
Bruce B G5 (500kV) − Mass 3: IP Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−1 − With Series Cap

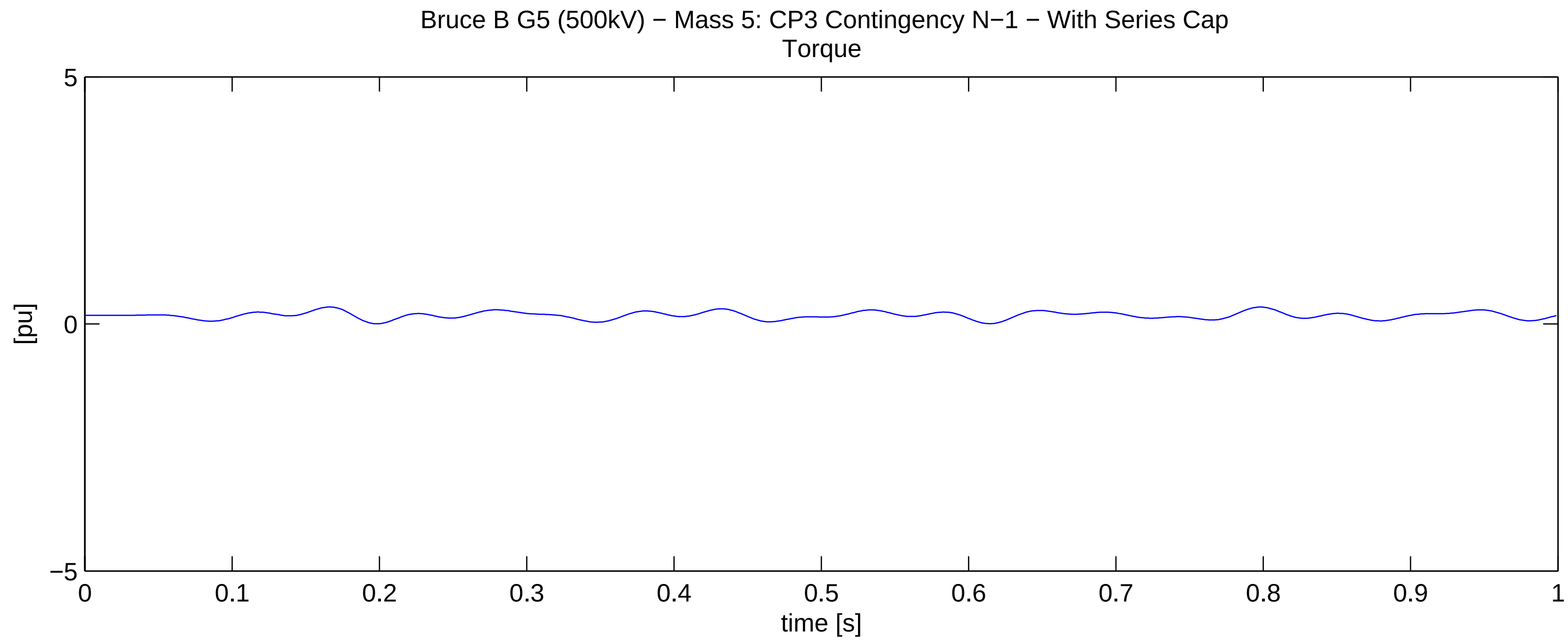


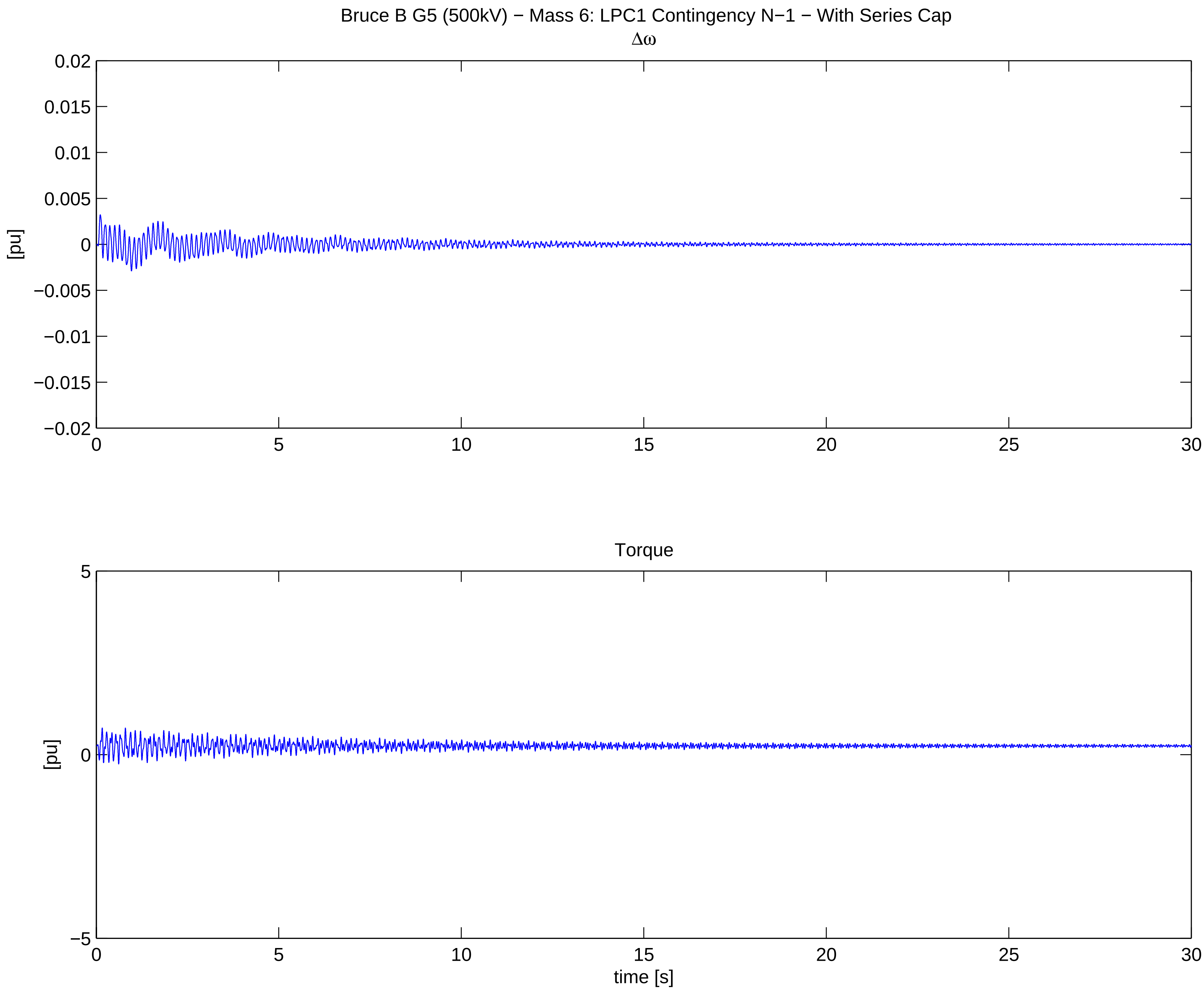


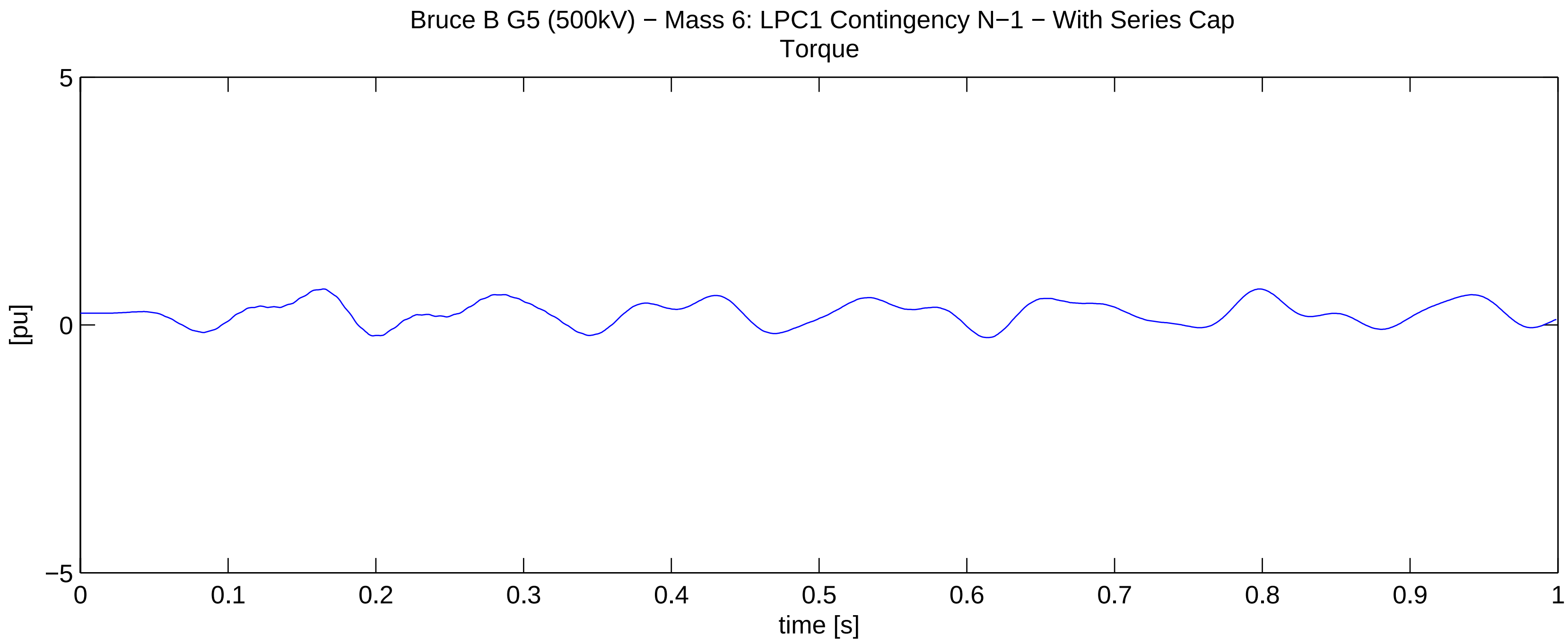

Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

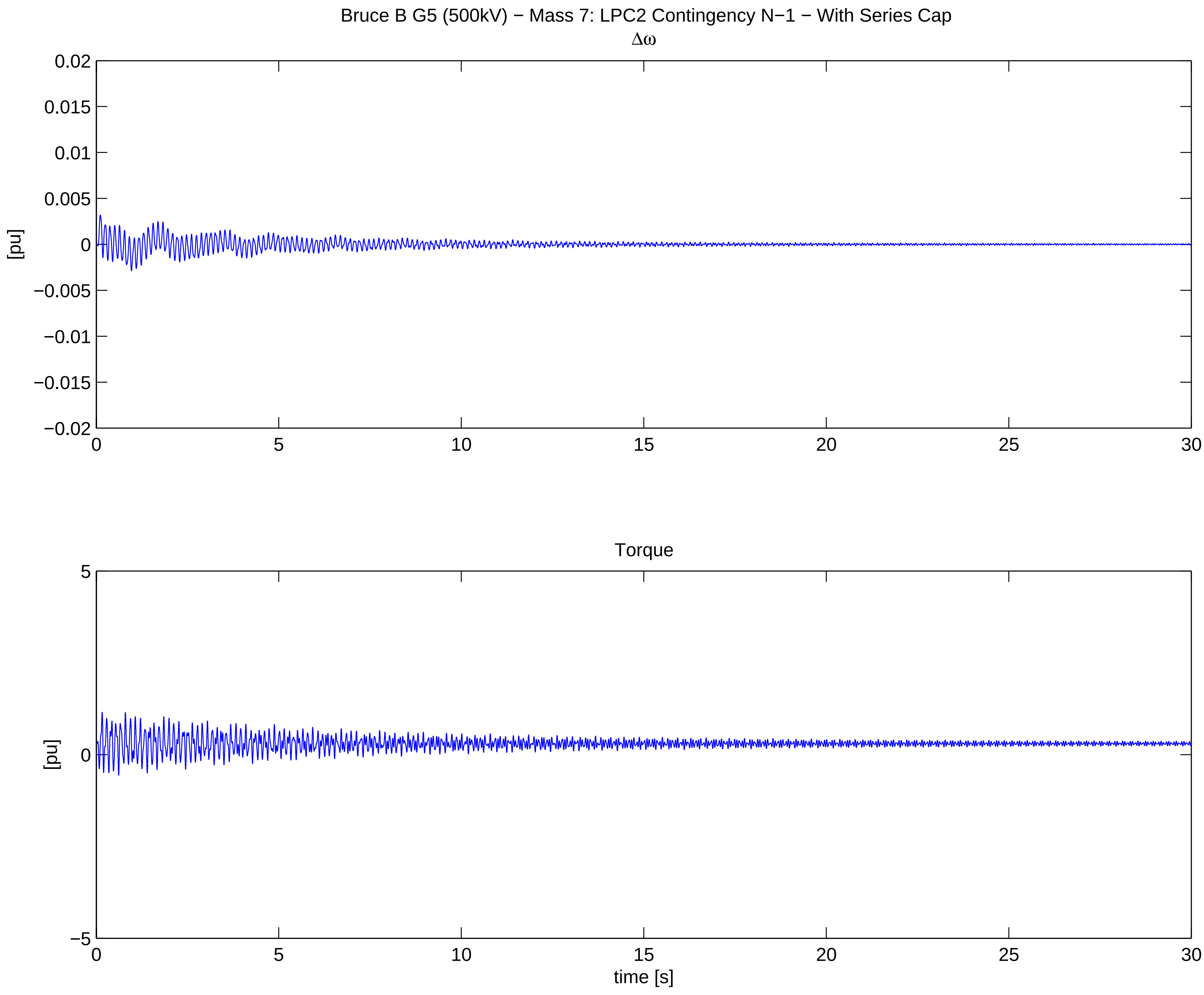


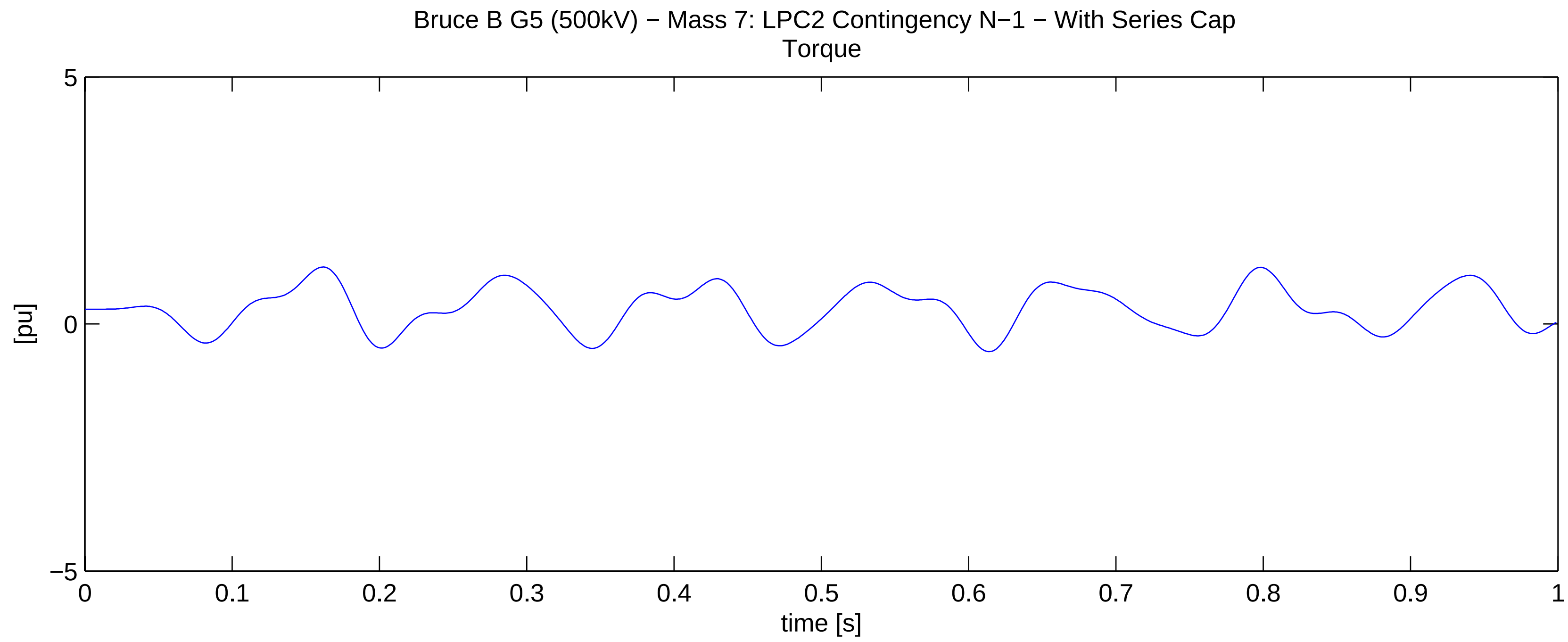
Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−1 − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

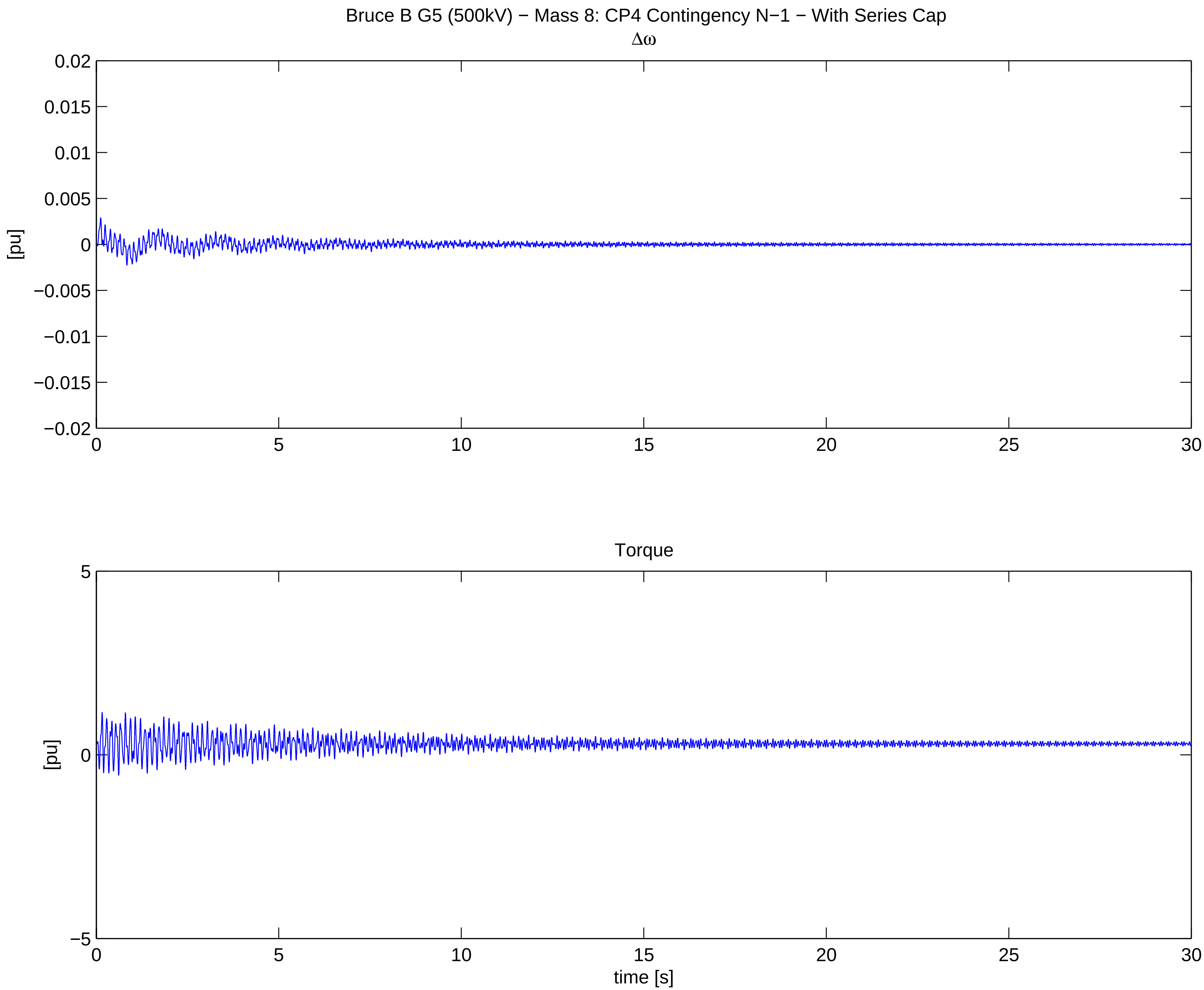

Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

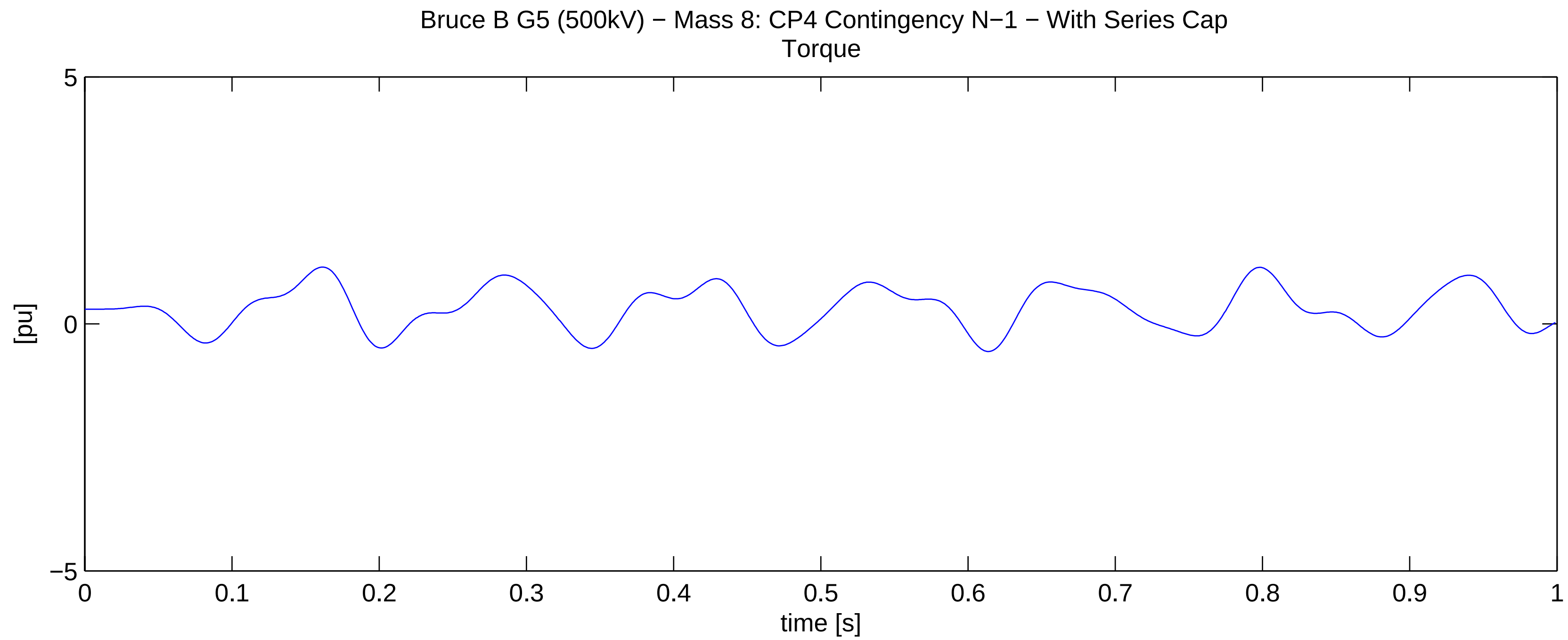

Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

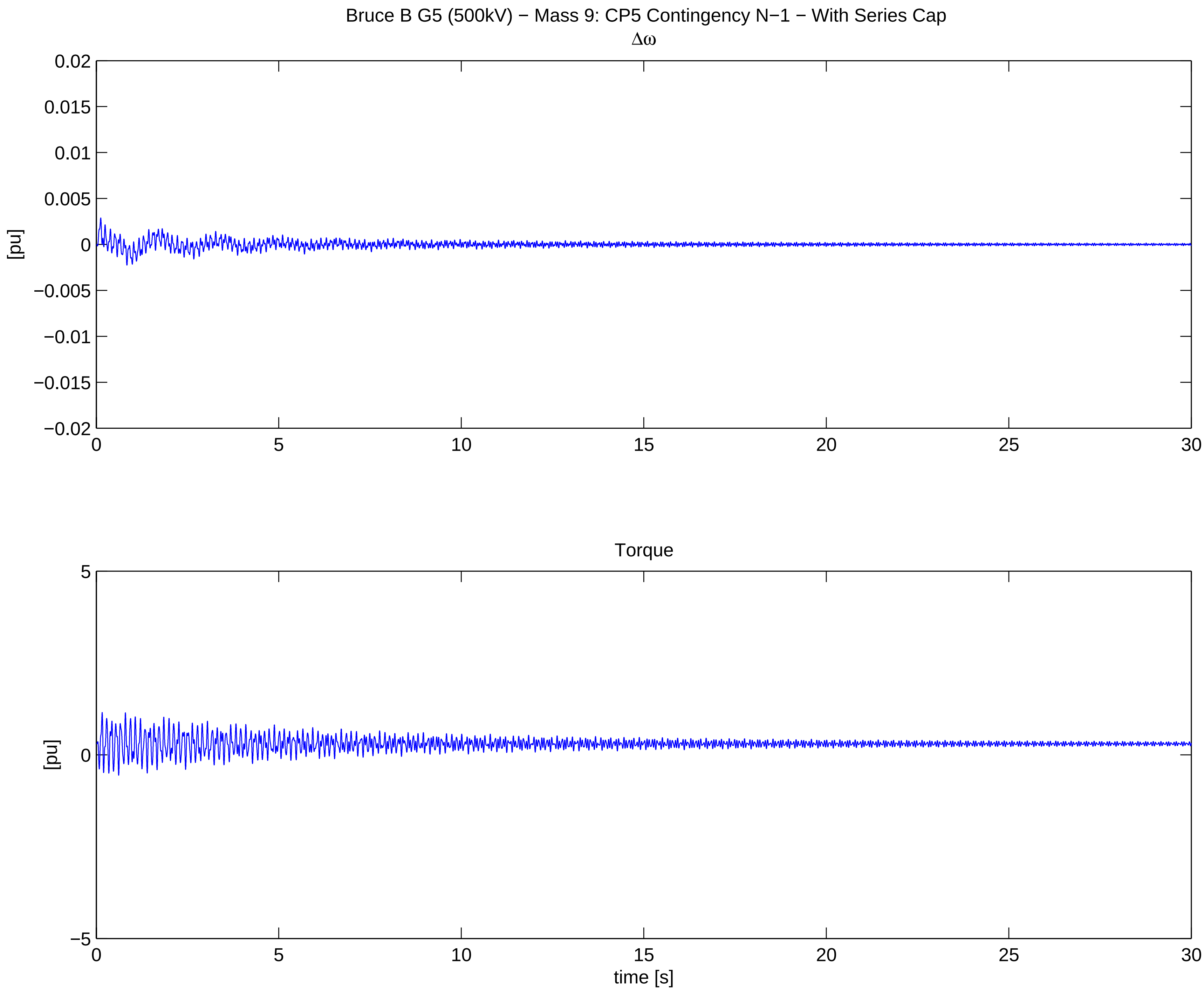

Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

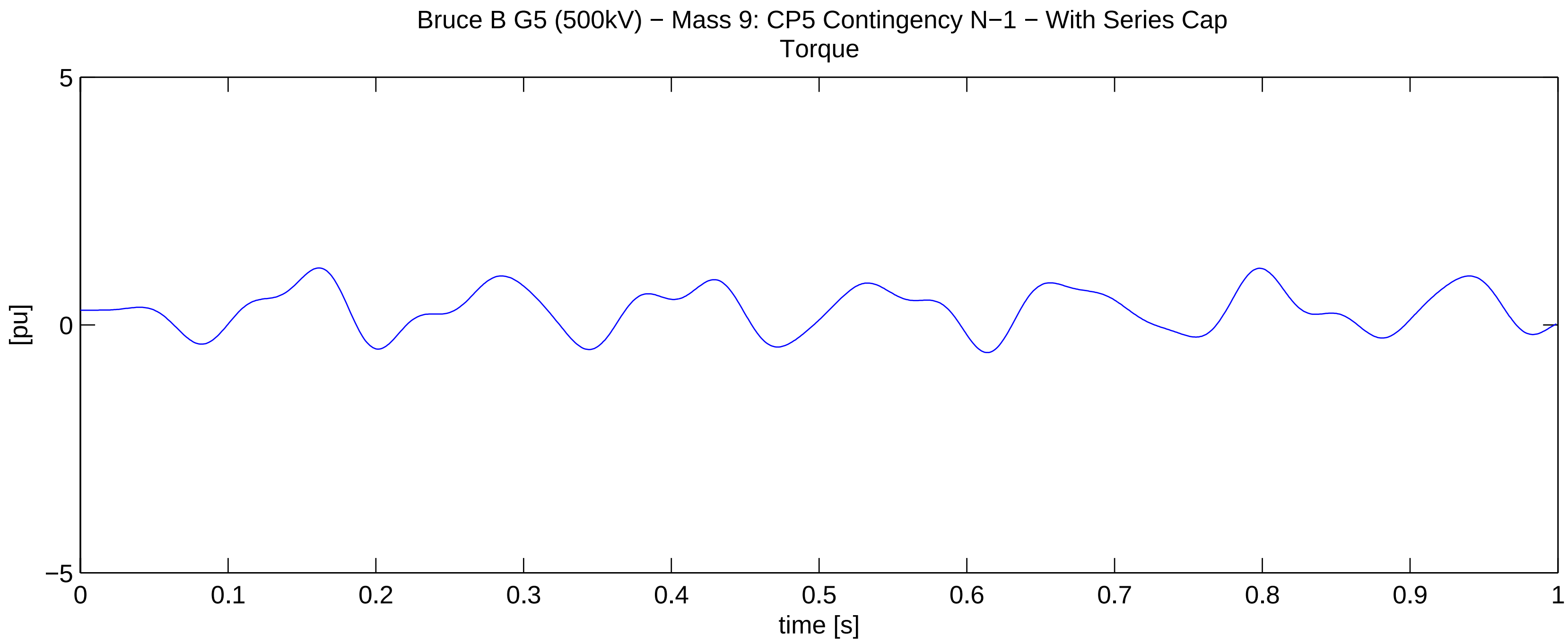

Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

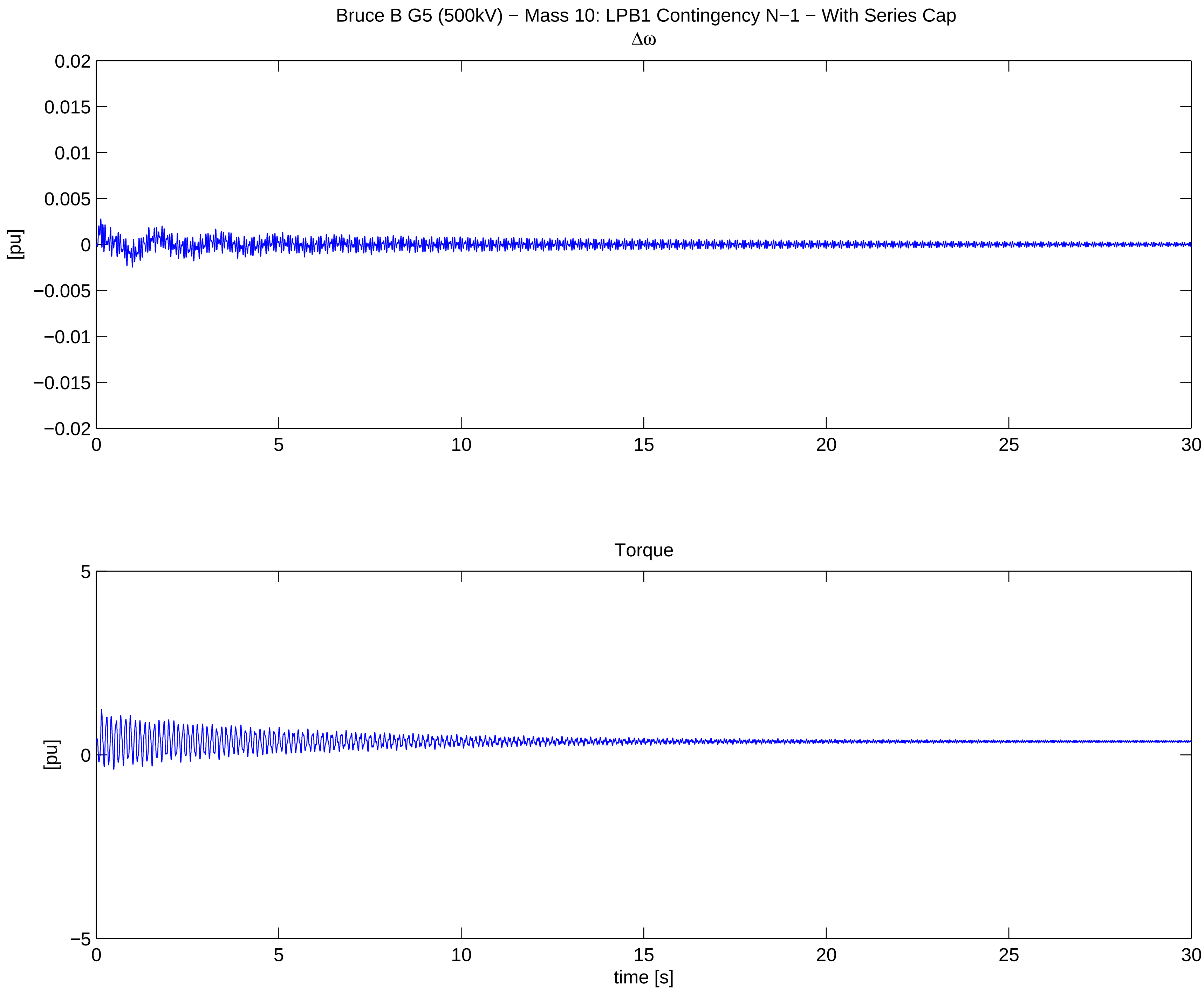


Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−1 − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

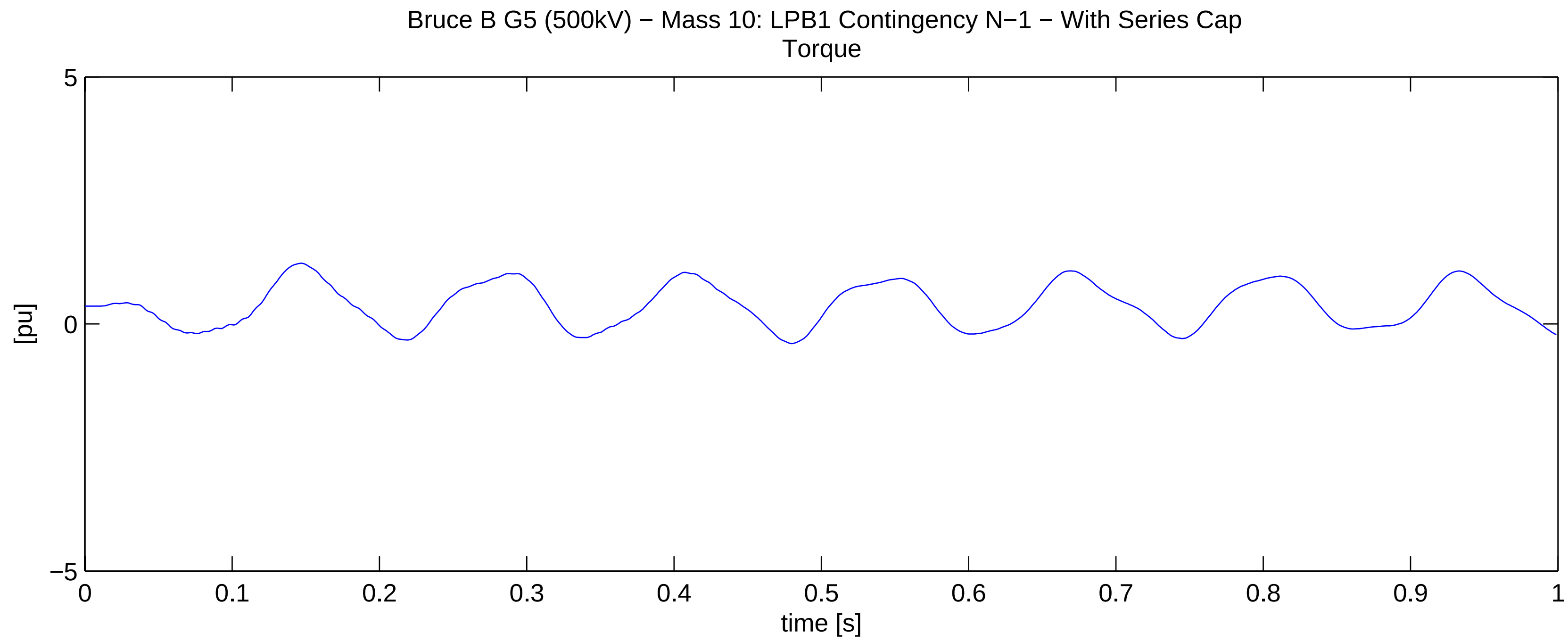

Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

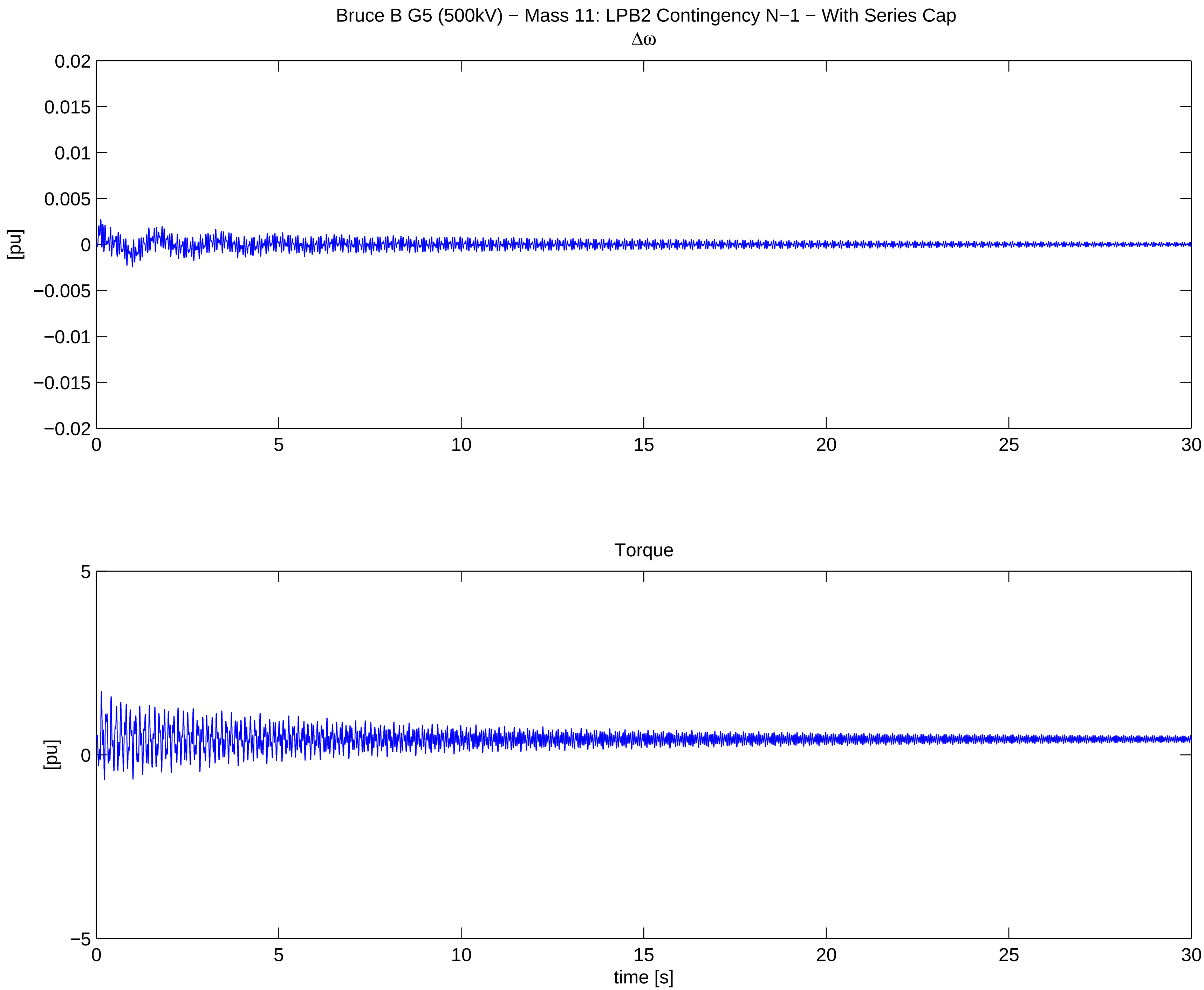

Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



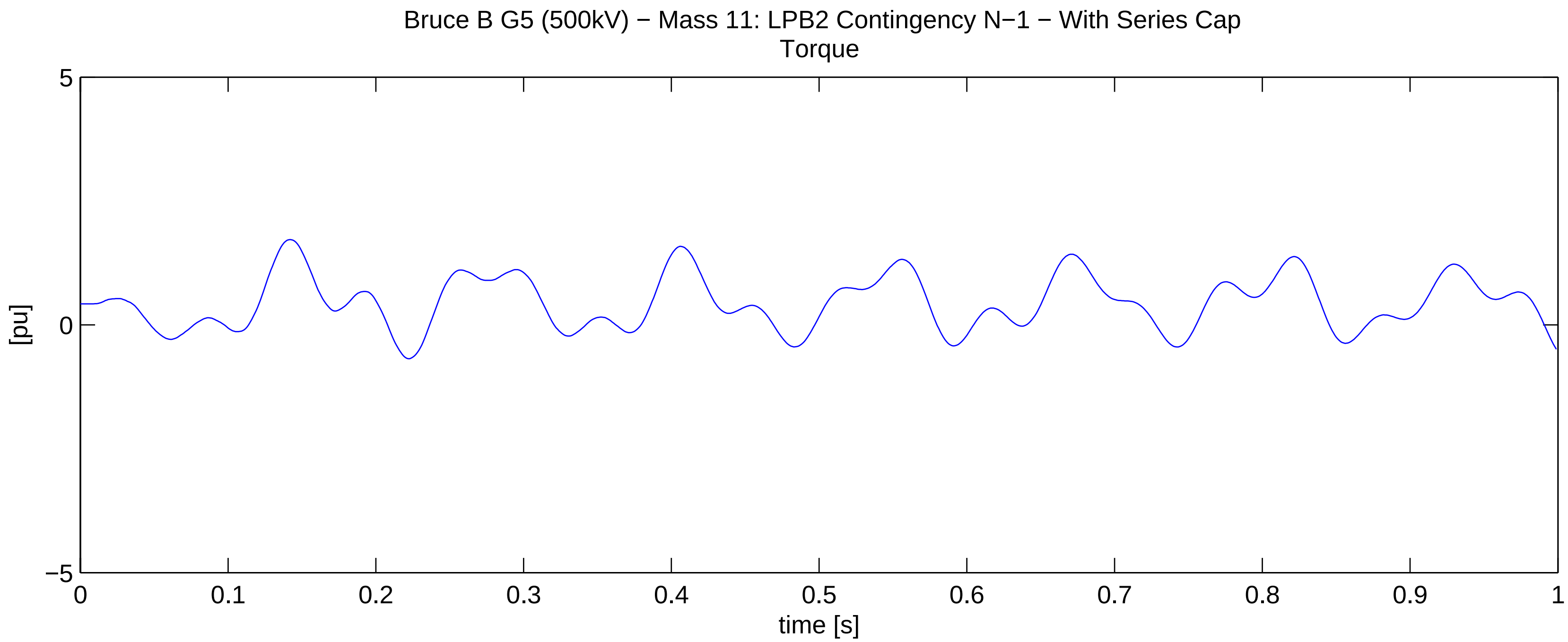
Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



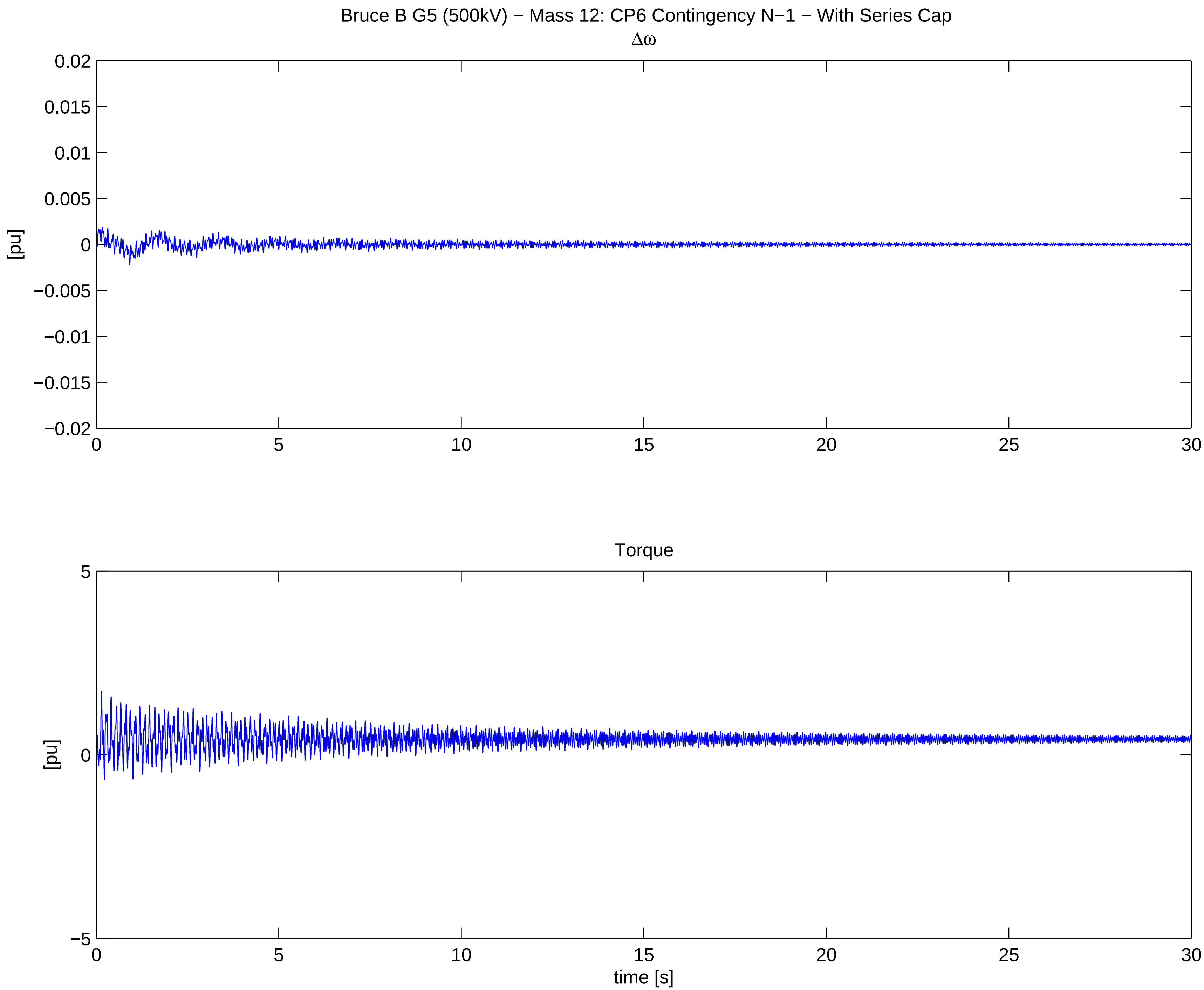
Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

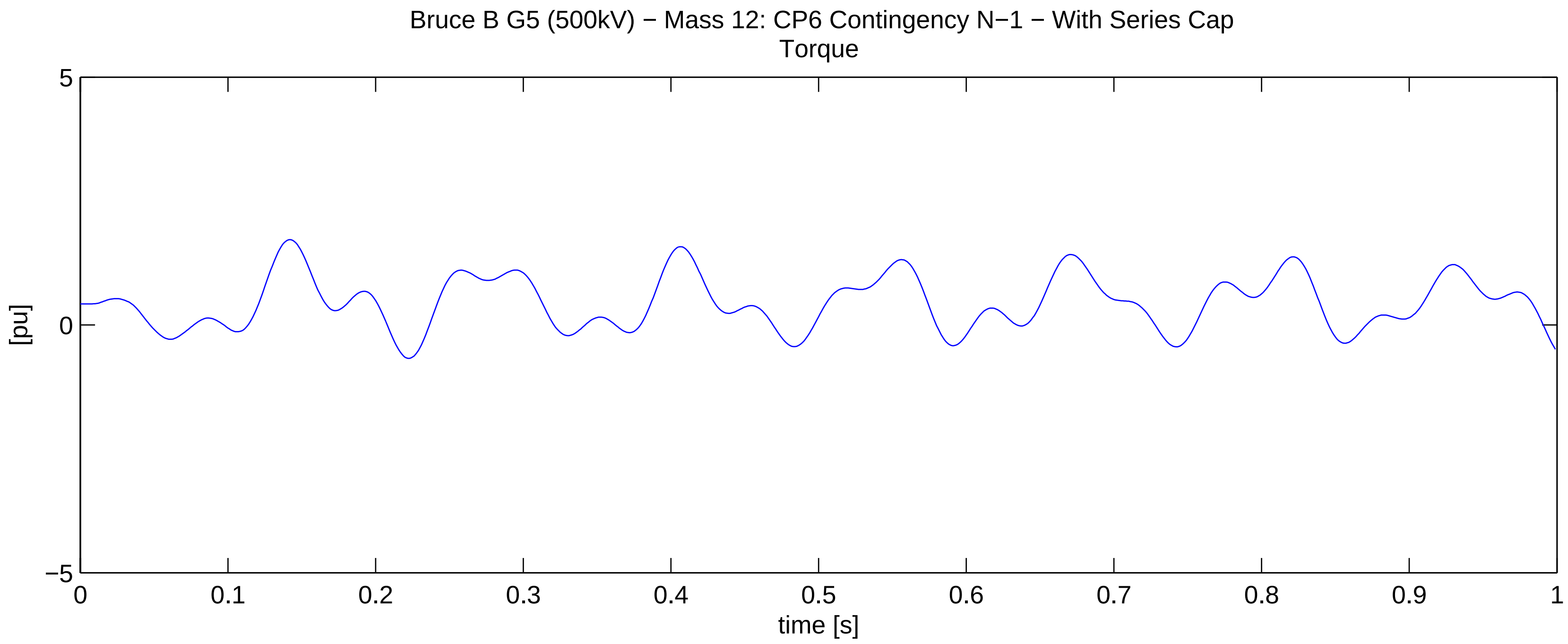


Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



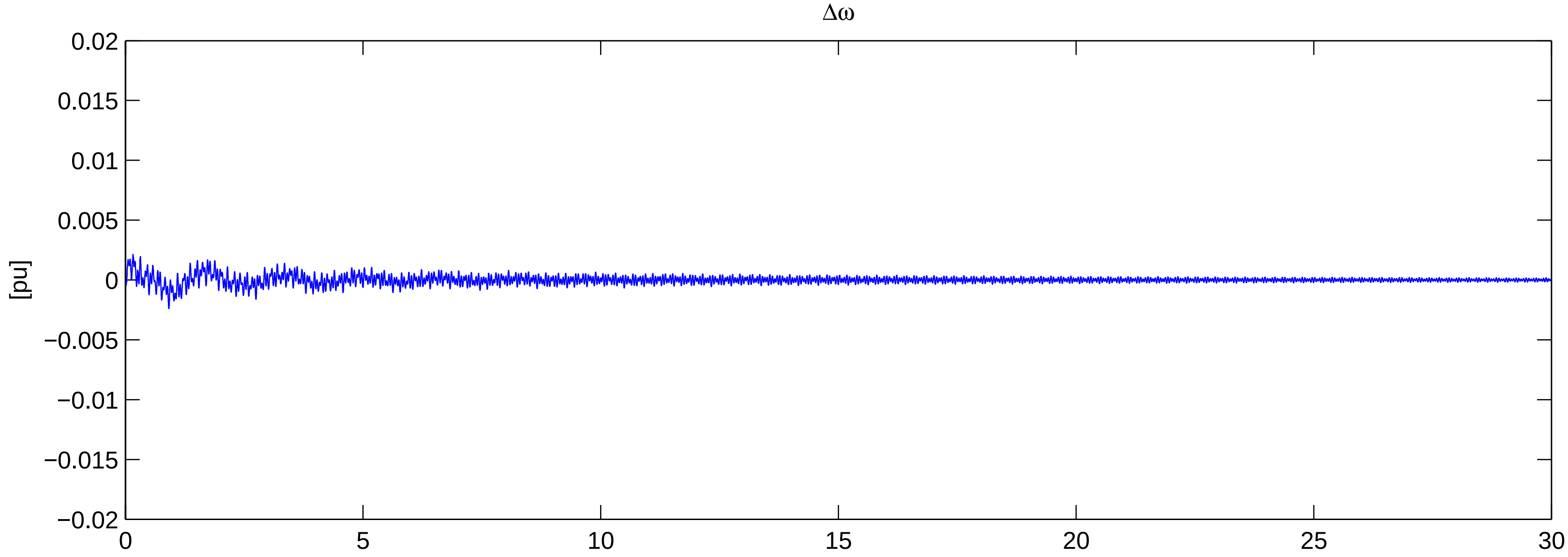
Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

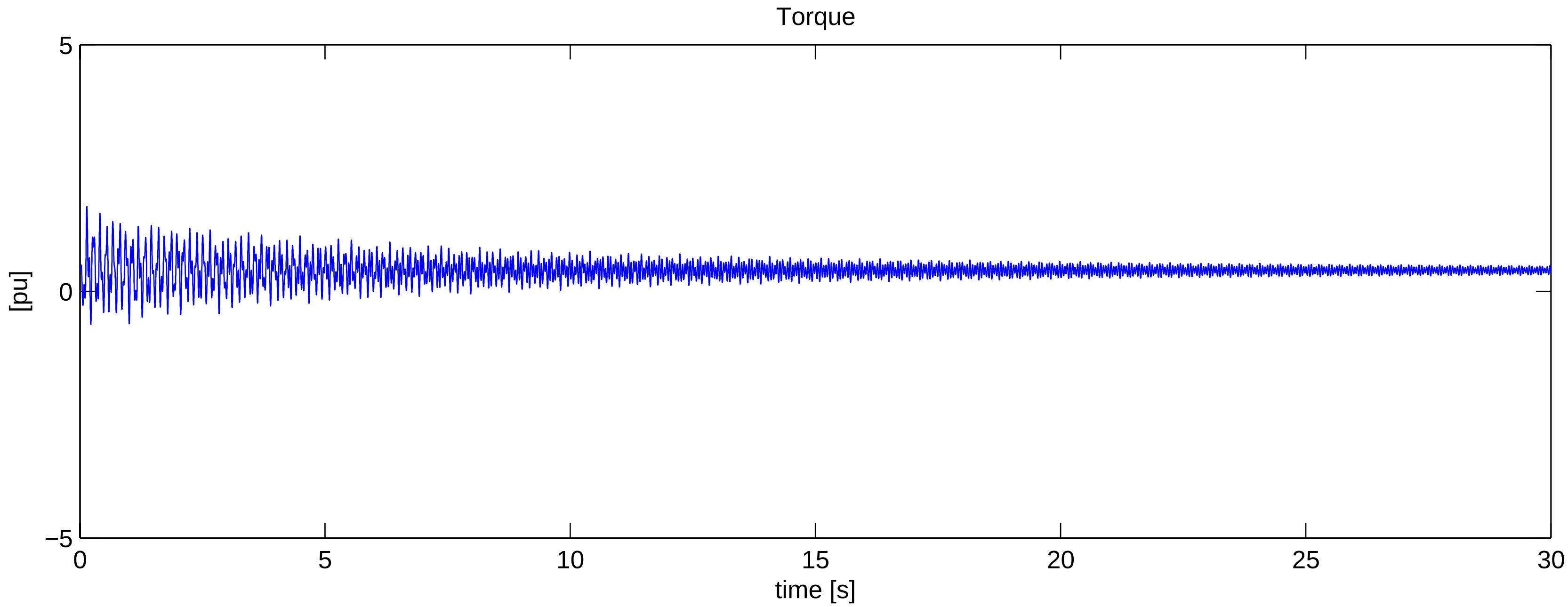

Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

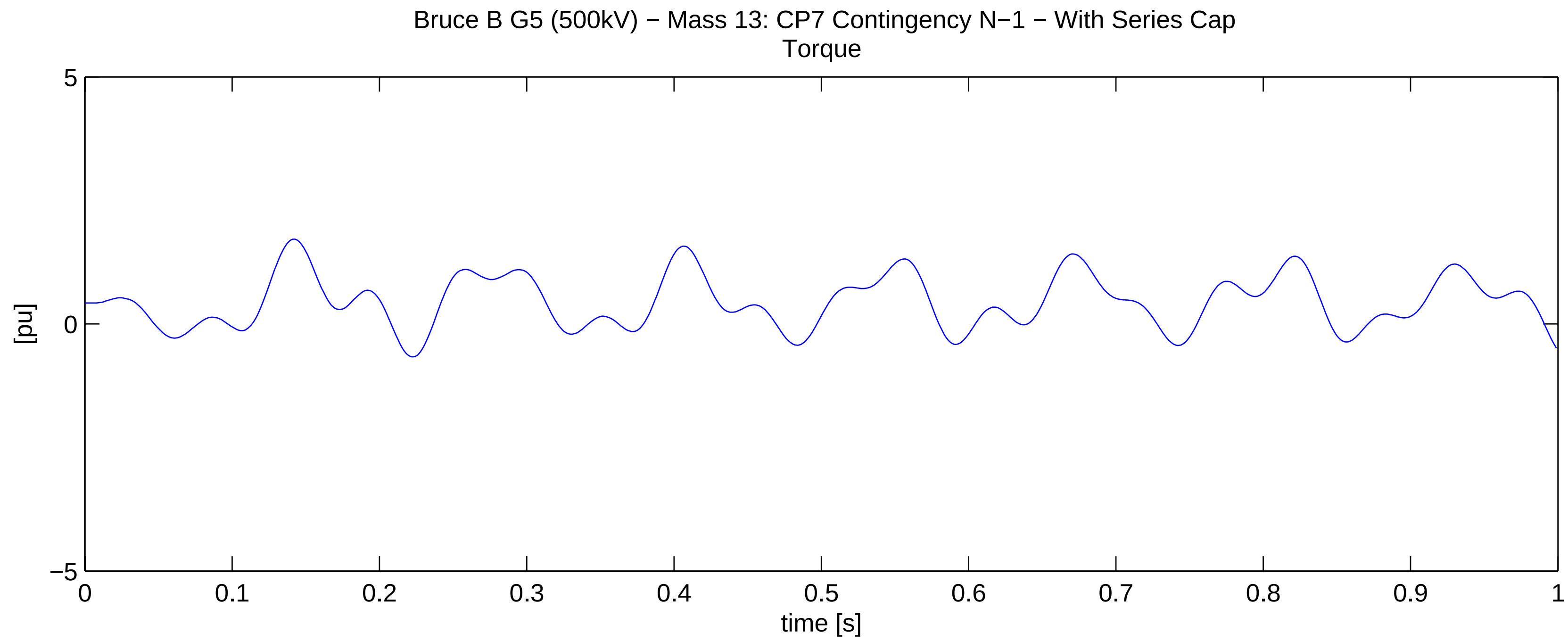


Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

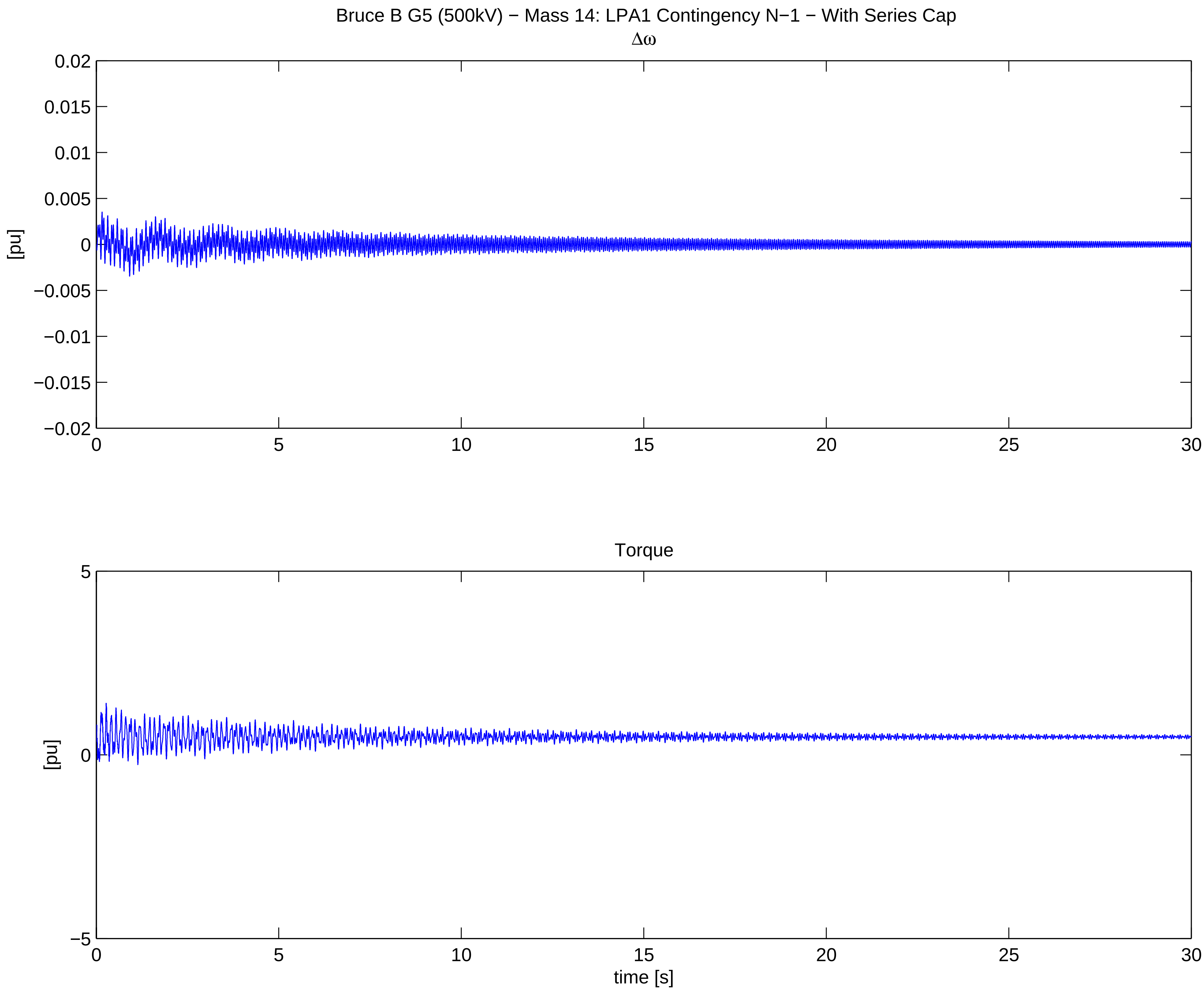
Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−1 − With Series Cap

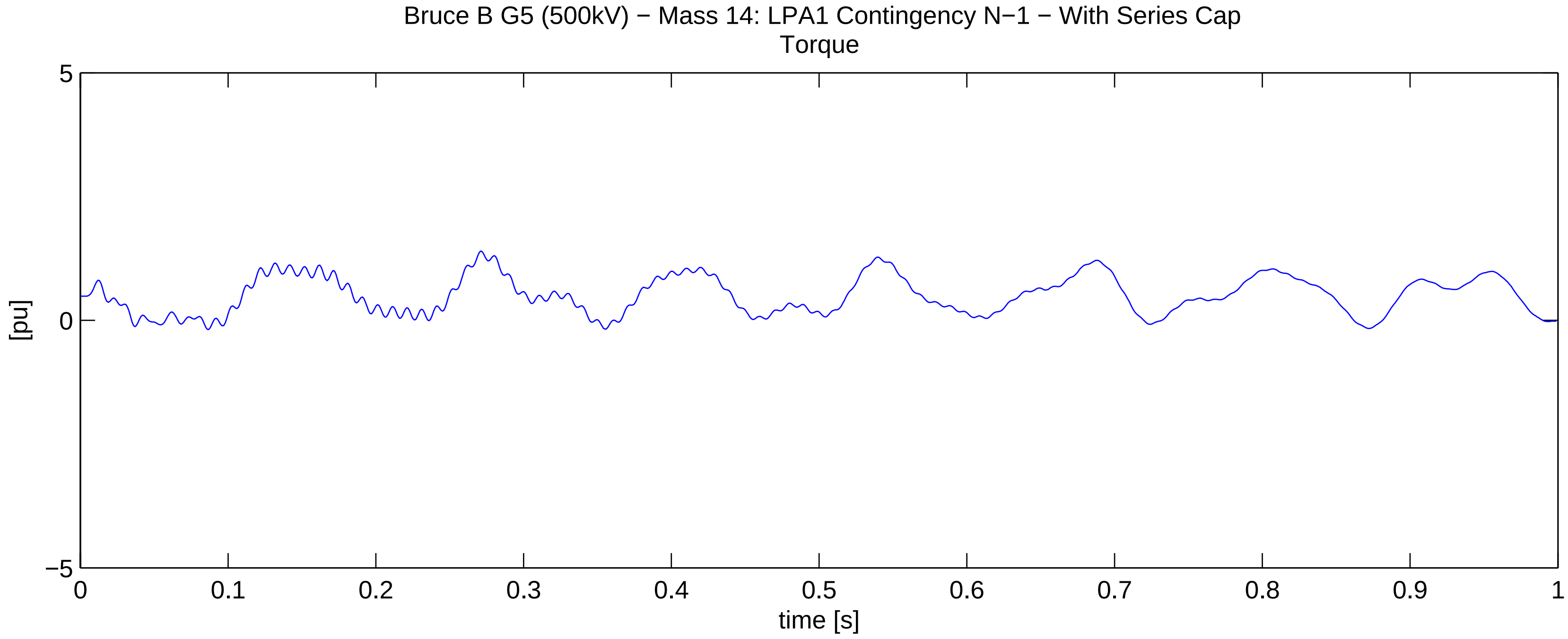




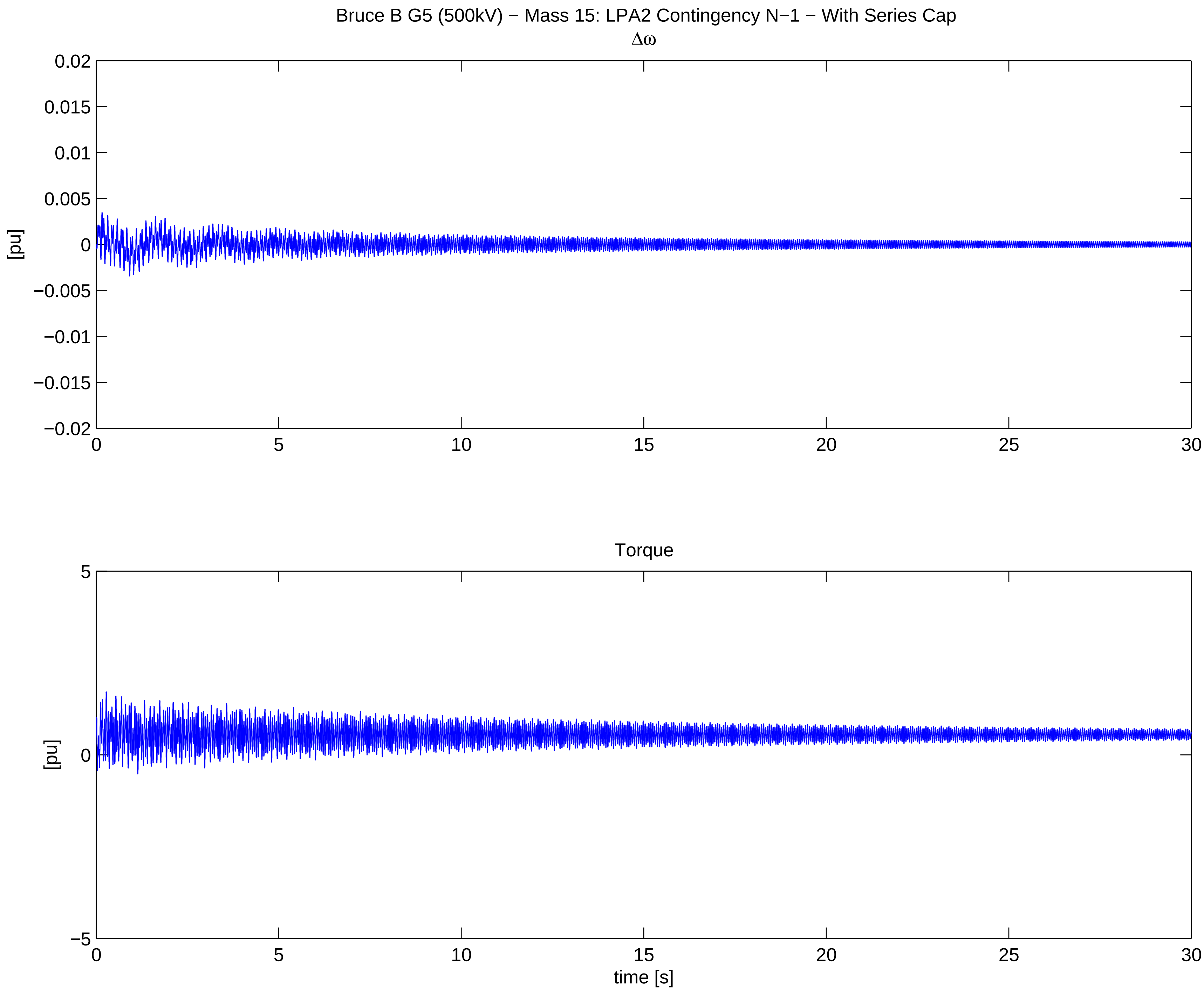


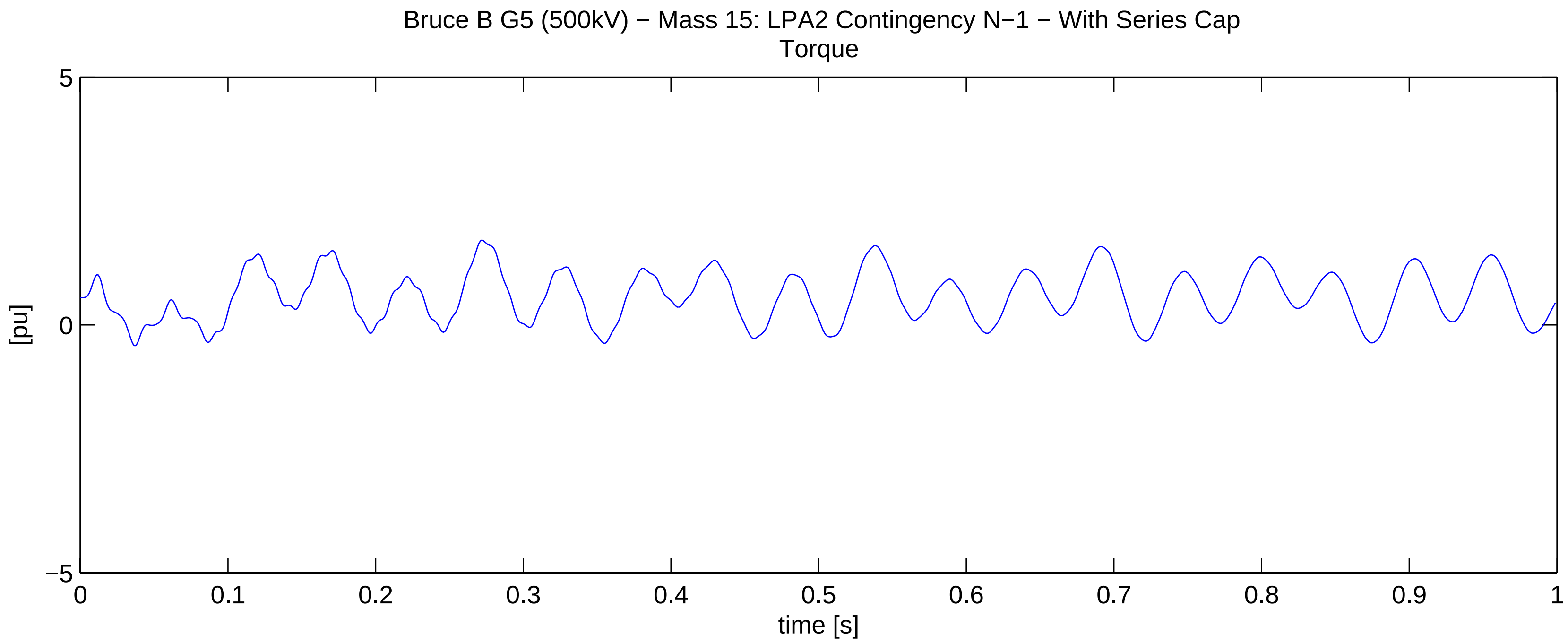
Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

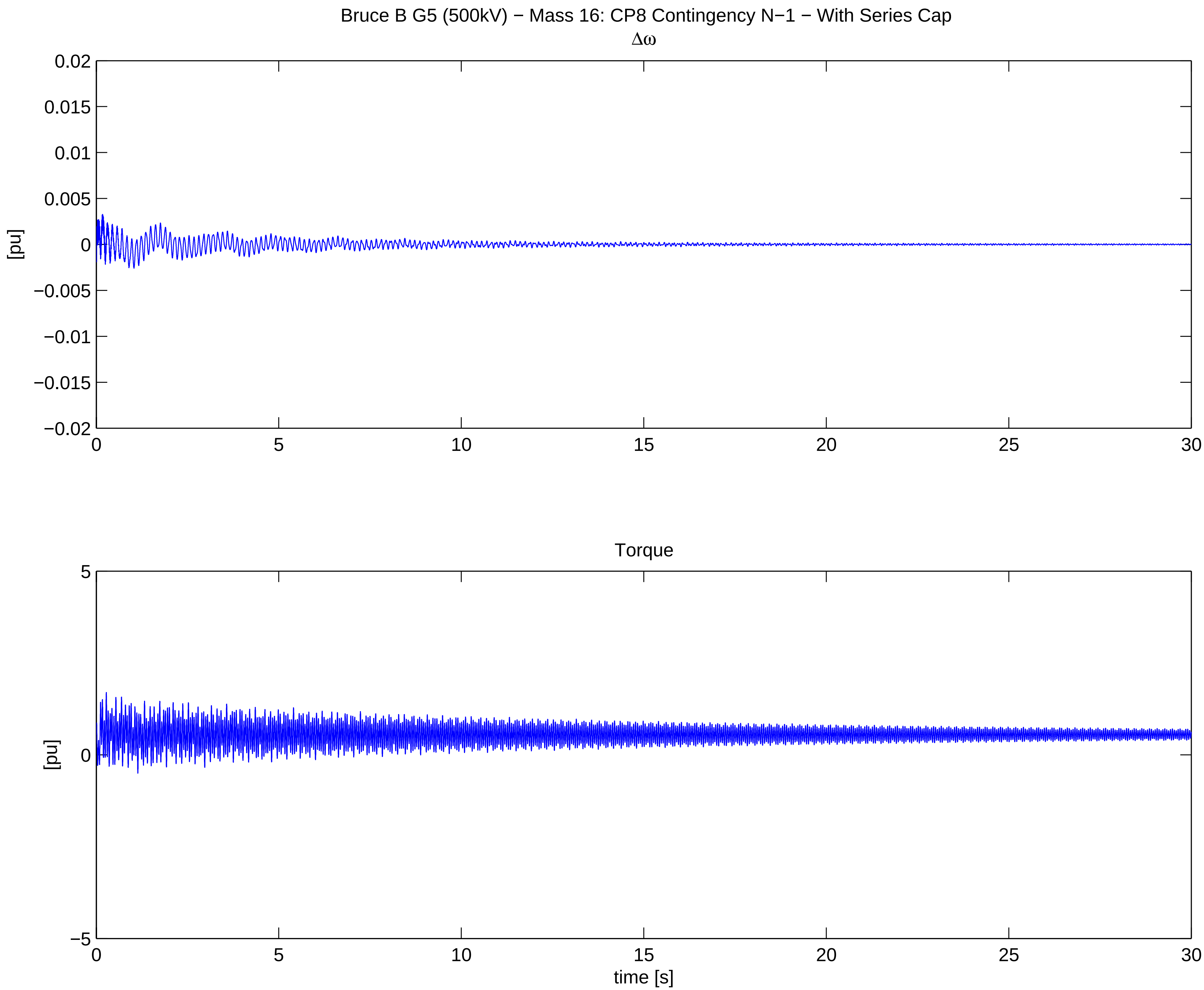

Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

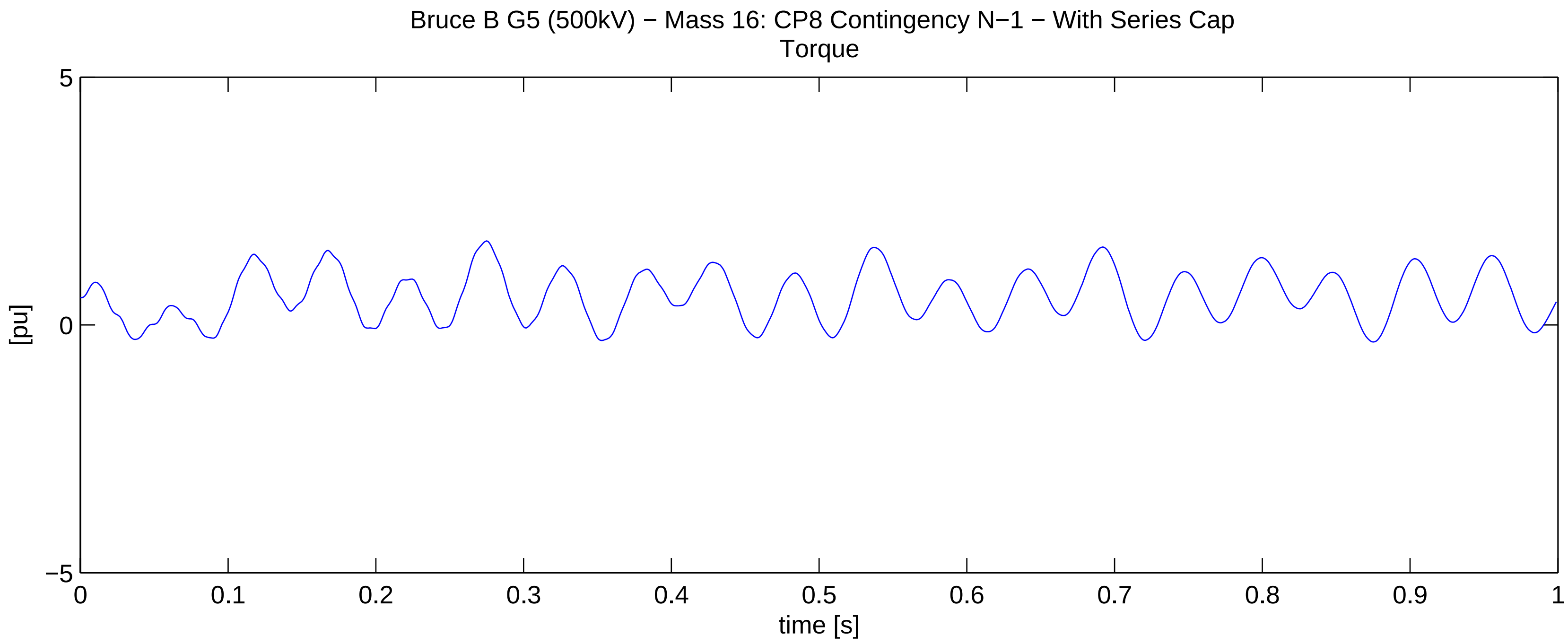


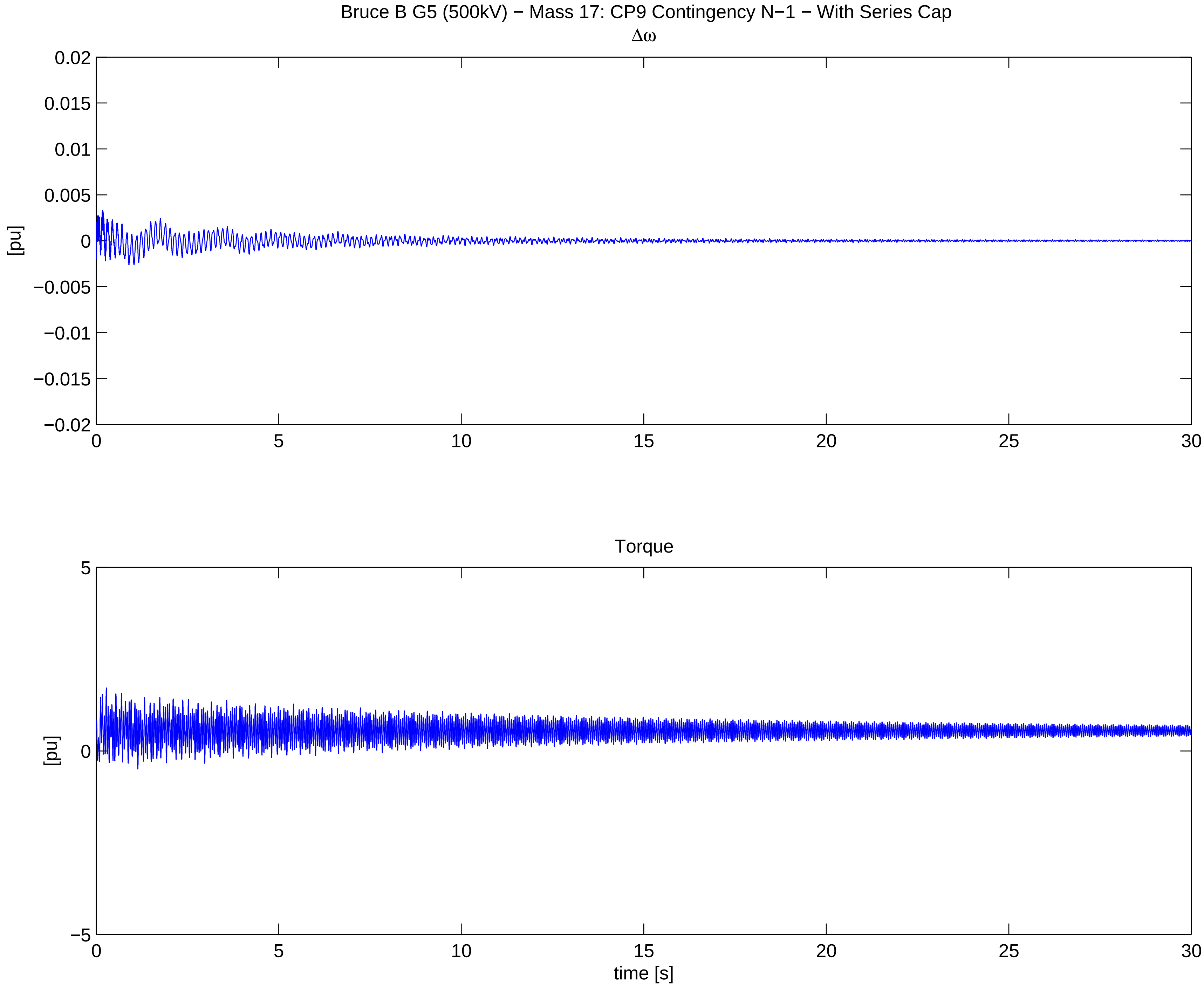
Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

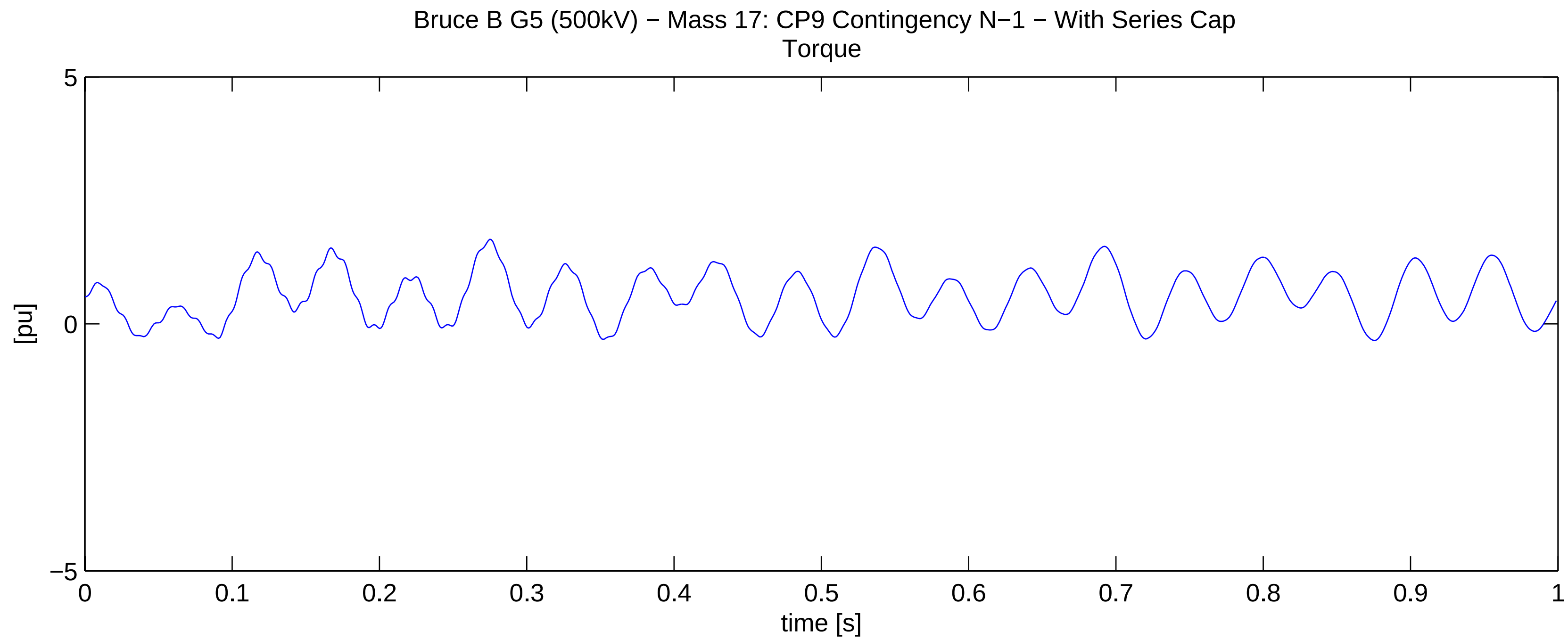

Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

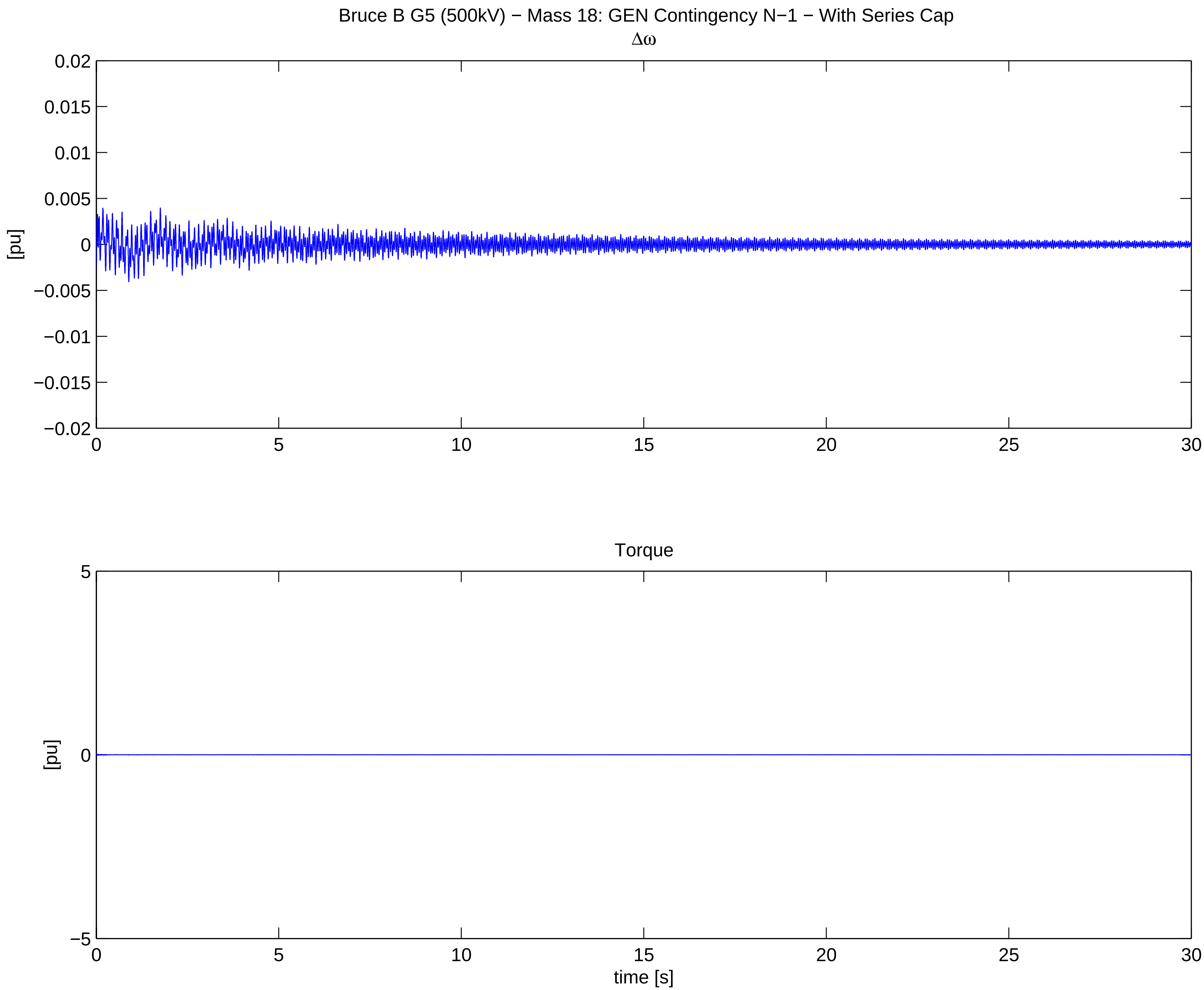

Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

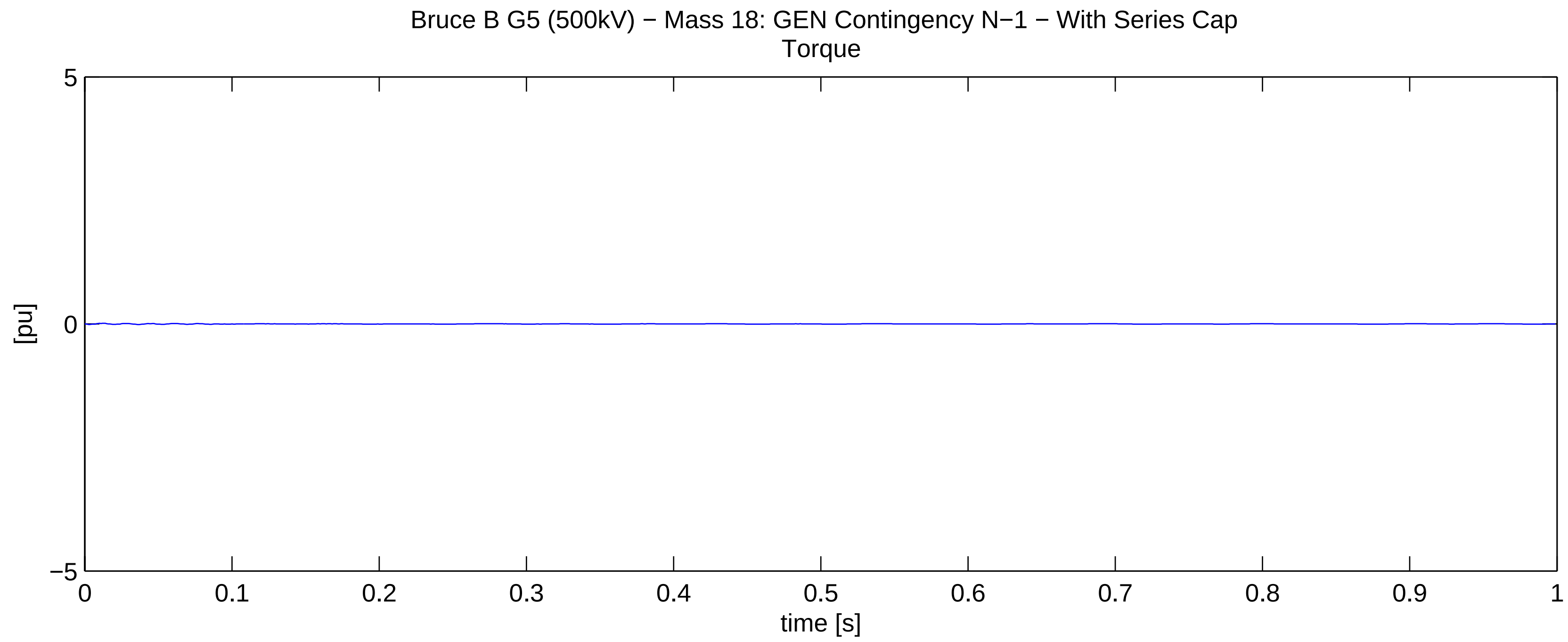

Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



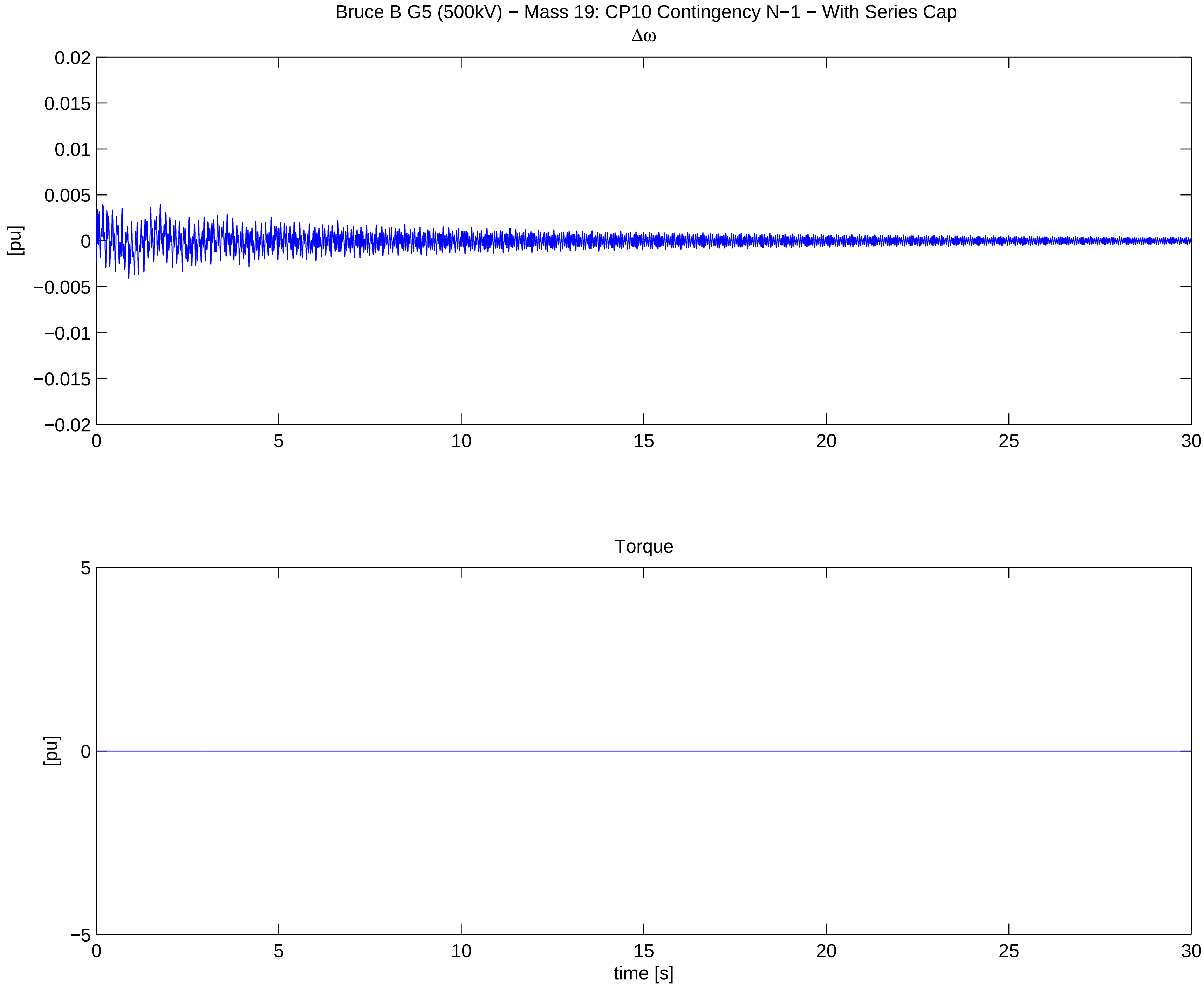
Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

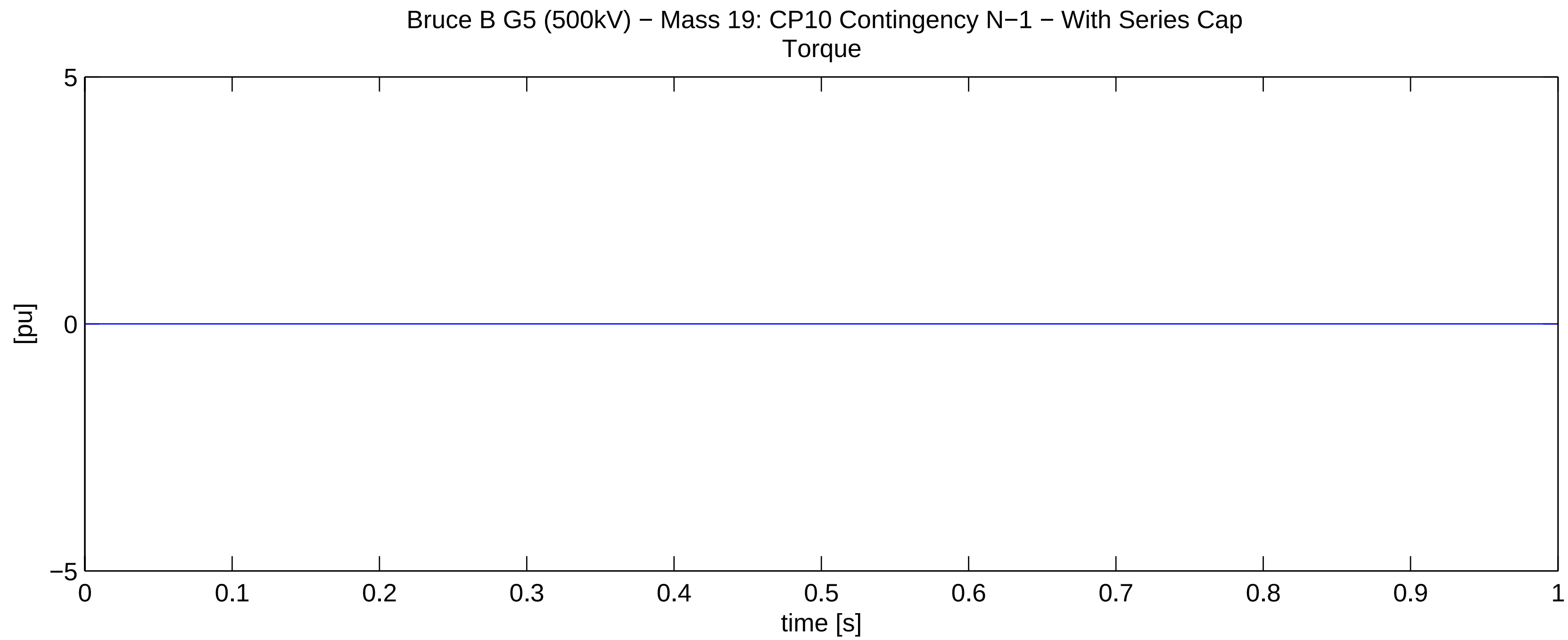

Bruce B G5 (500kV) − Mass 18: GEN Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]



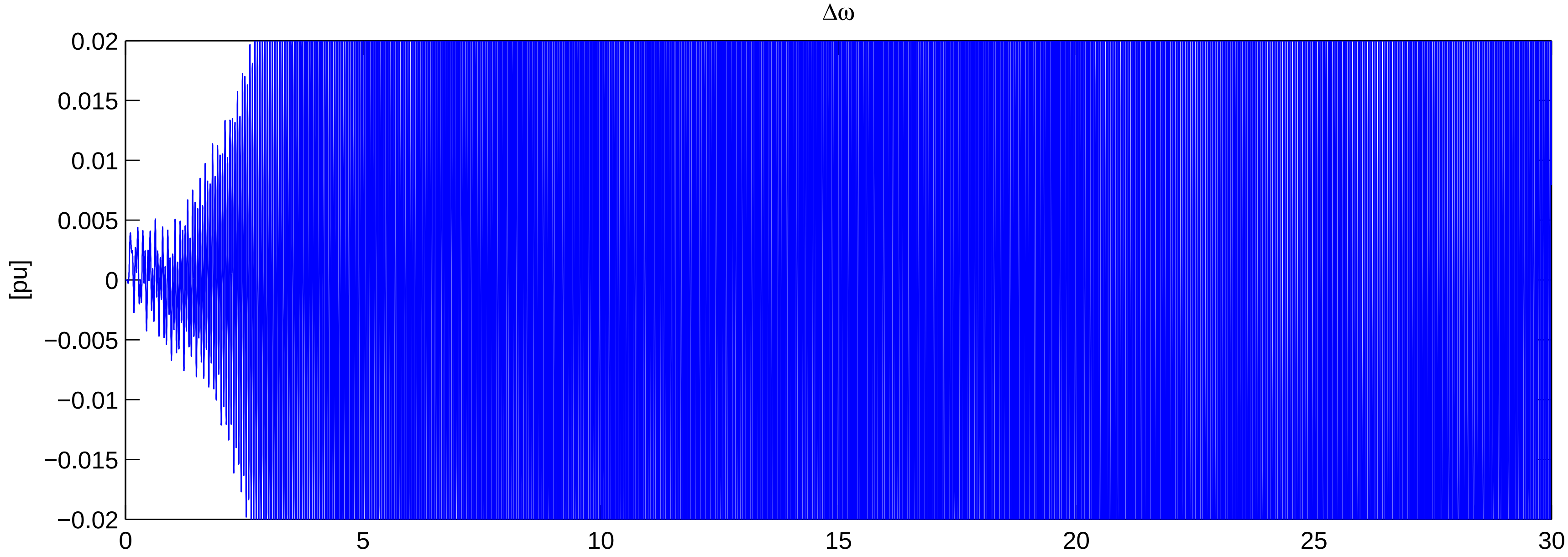
Bruce B G5 (500kV) − Mass 18: GEN Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

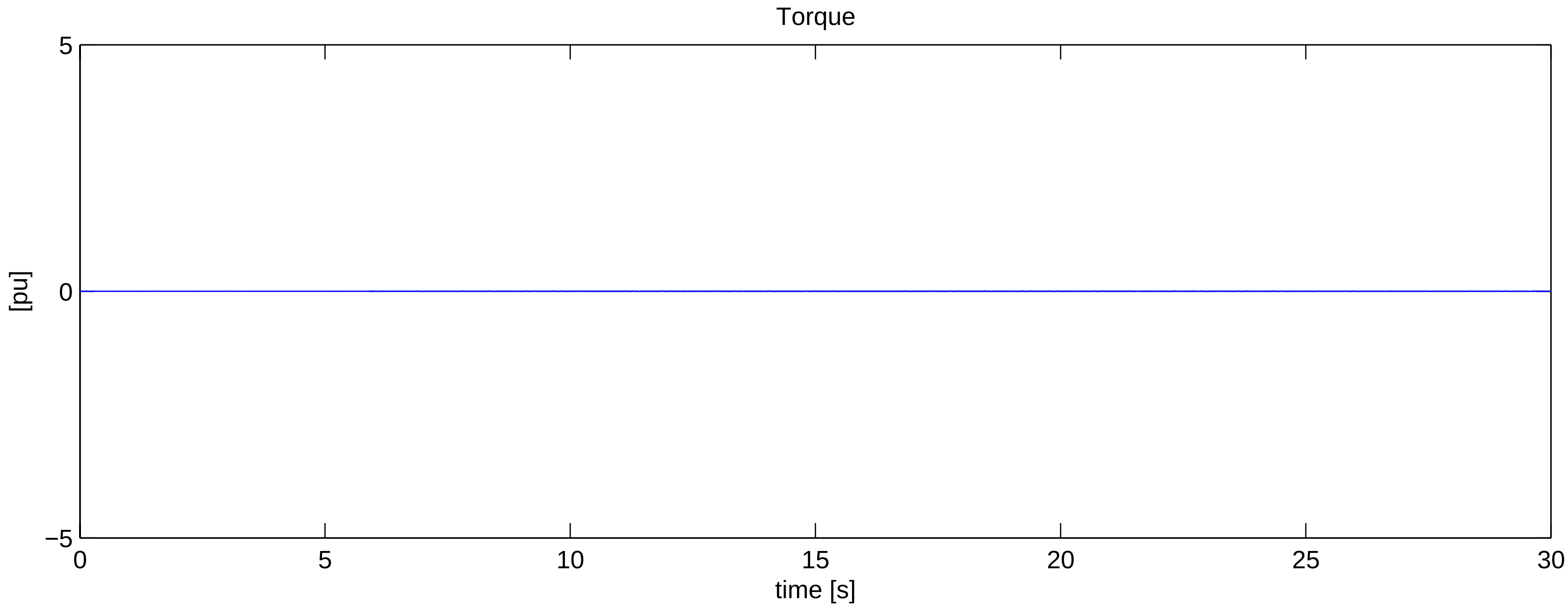


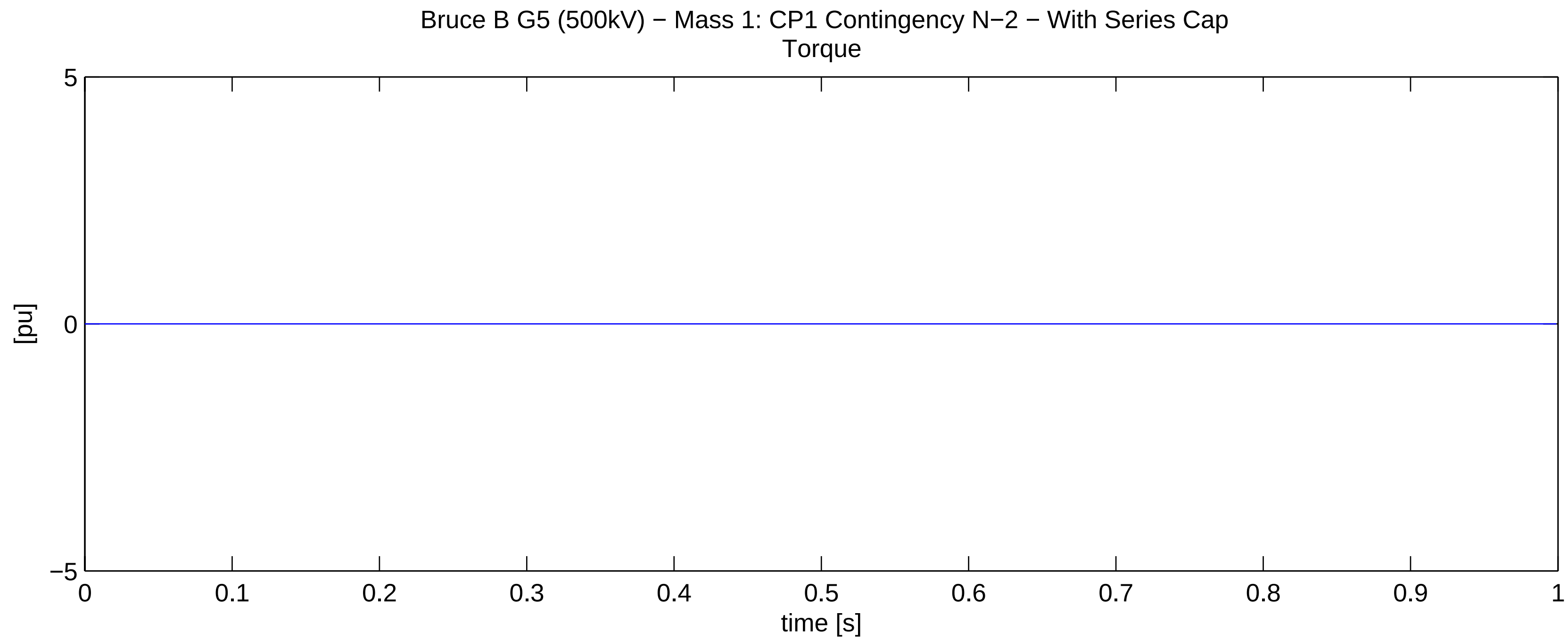
Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−1 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−1 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

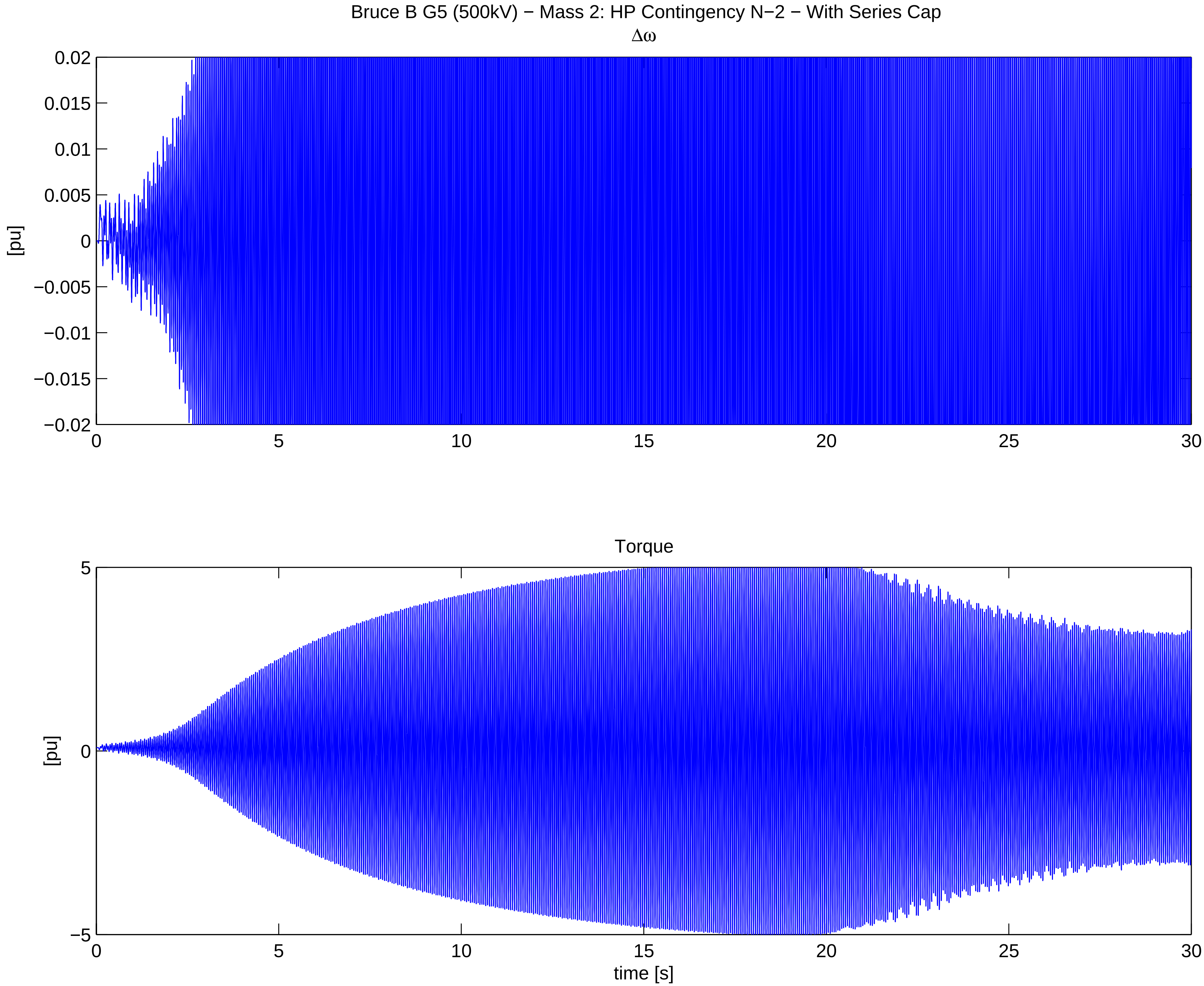
Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−2 − With Series Cap



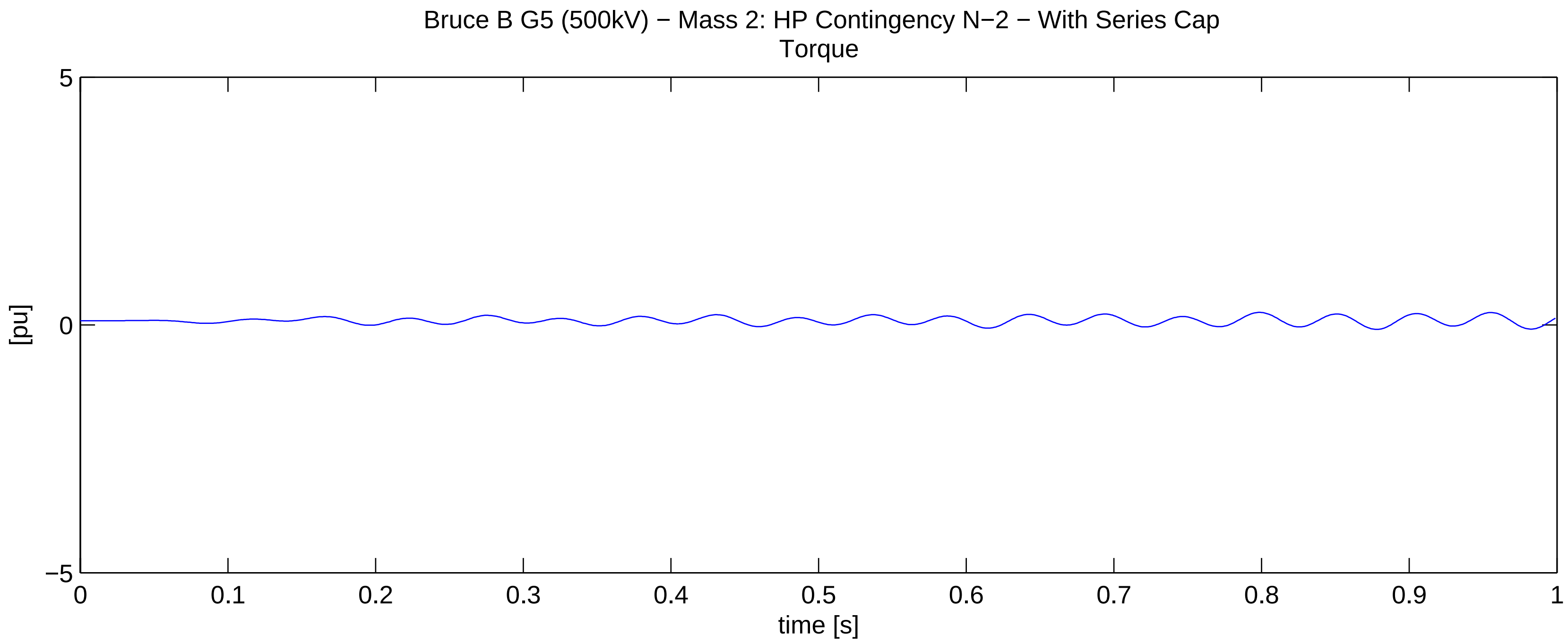


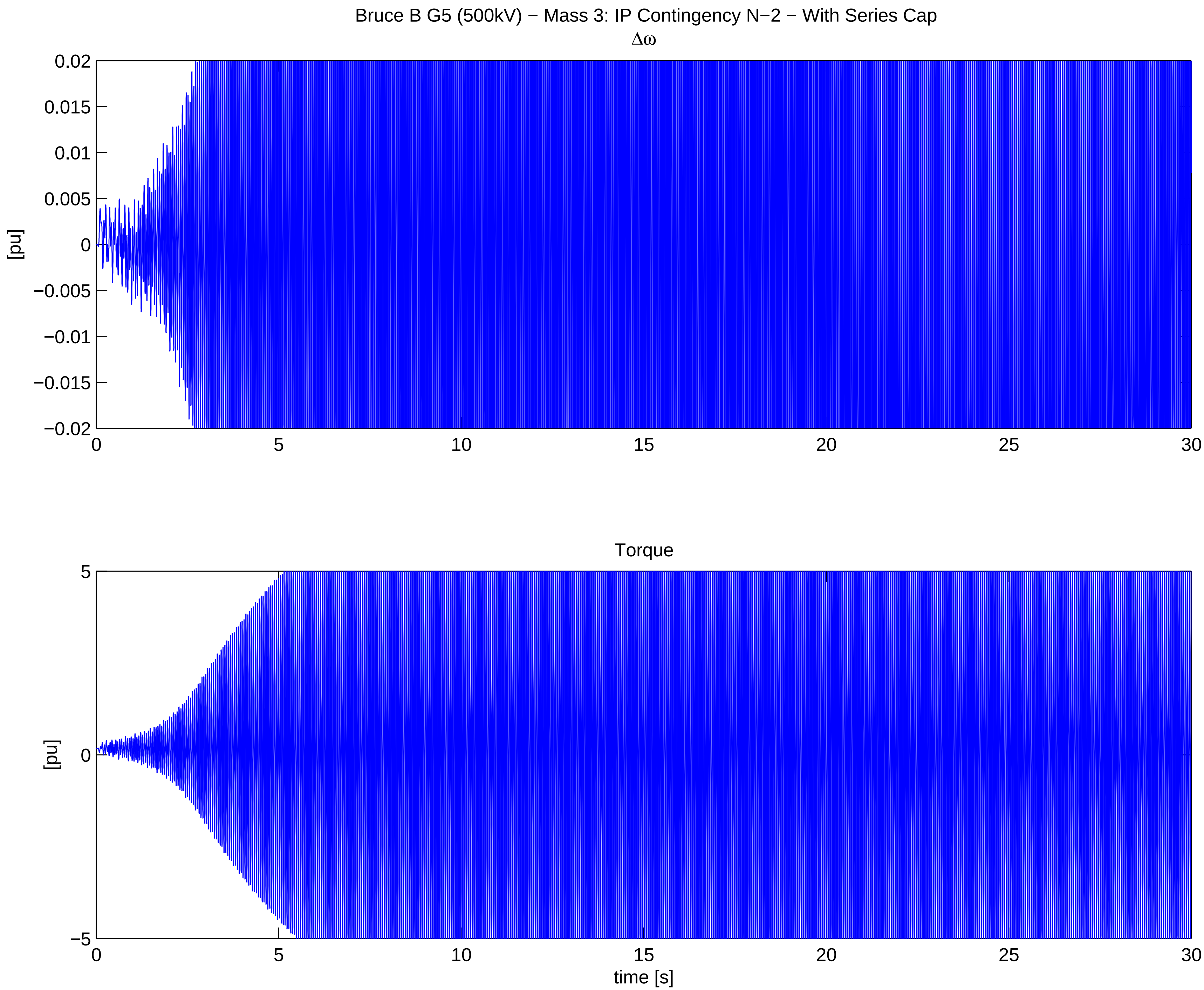


Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−2 − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

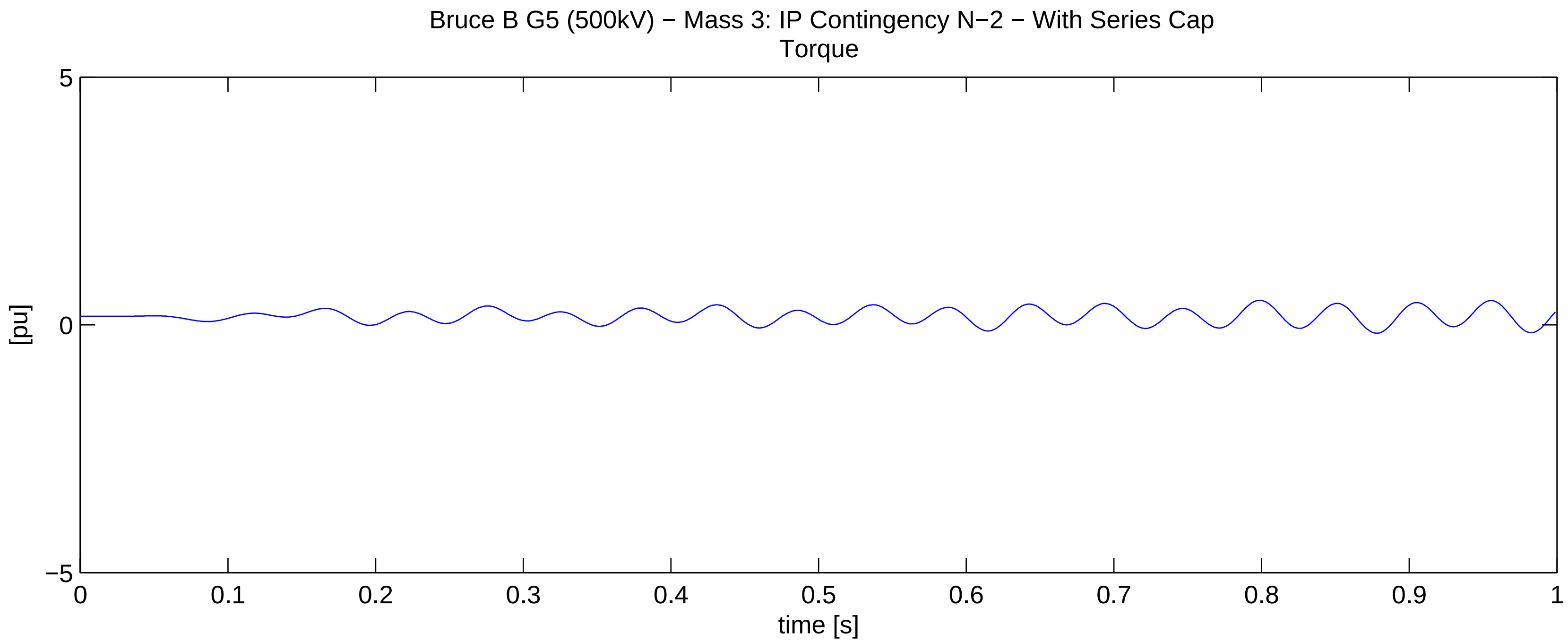


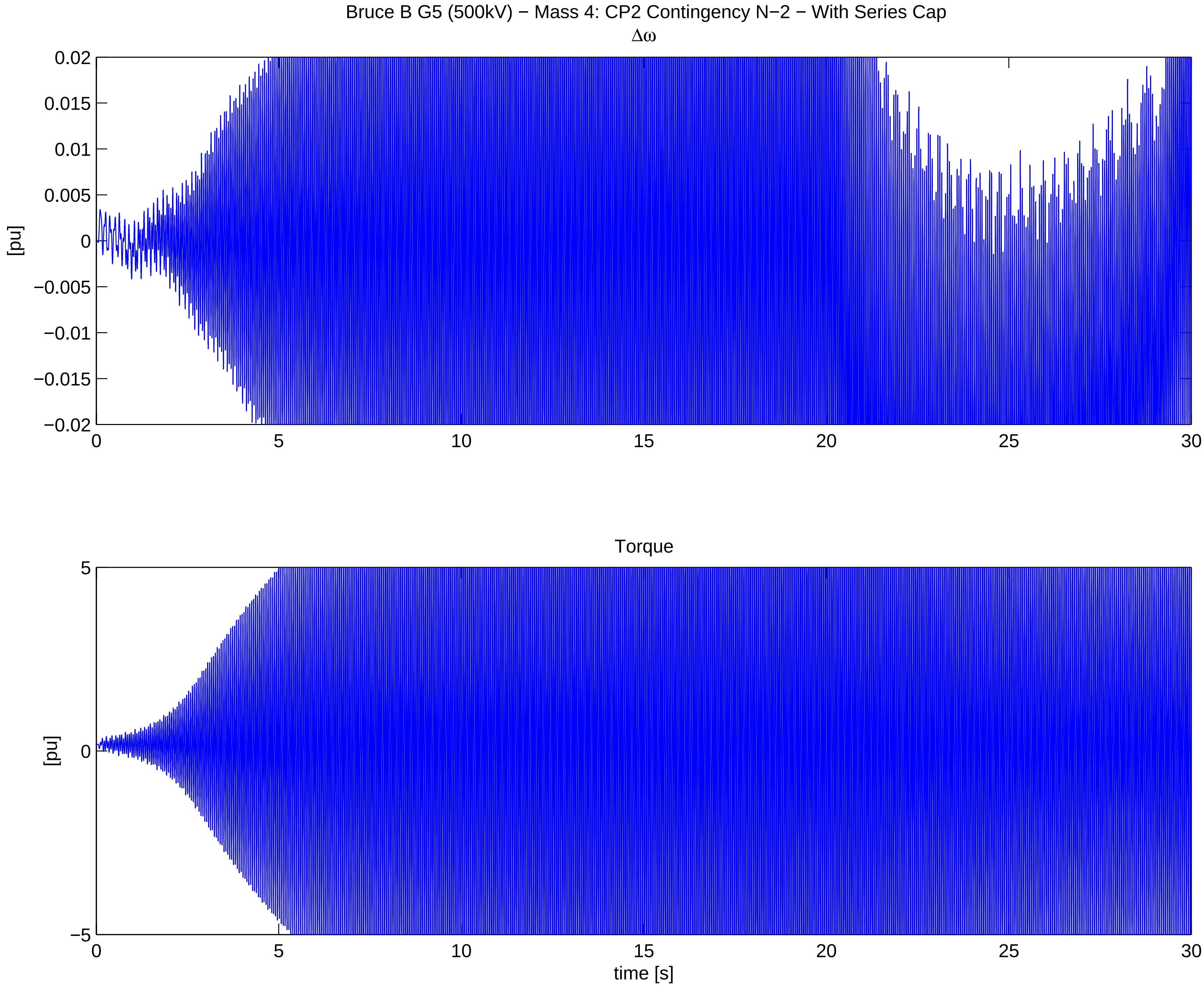
Bruce B G5 (500kV) − Mass 2: HP Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce B G5 (500kV) − Mass 2: HP Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

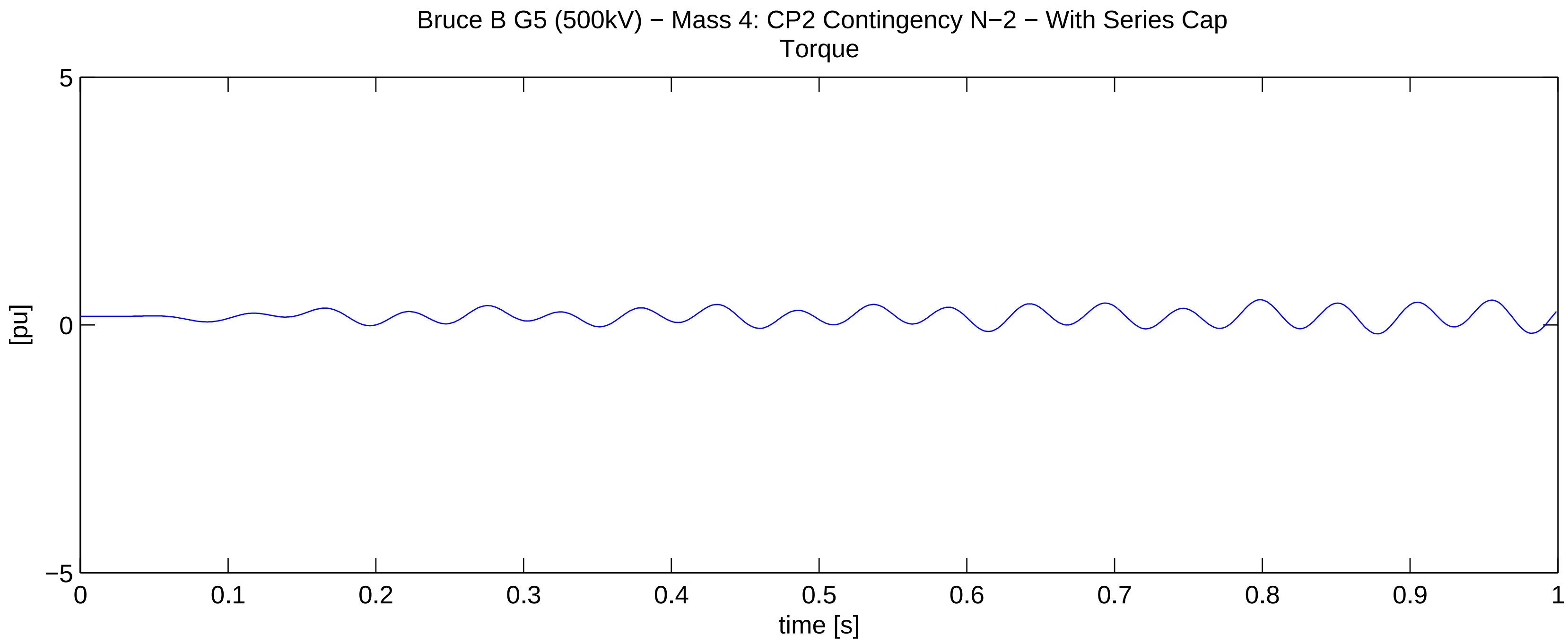


Bruce B G5 (500kV) − Mass 3: IP Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

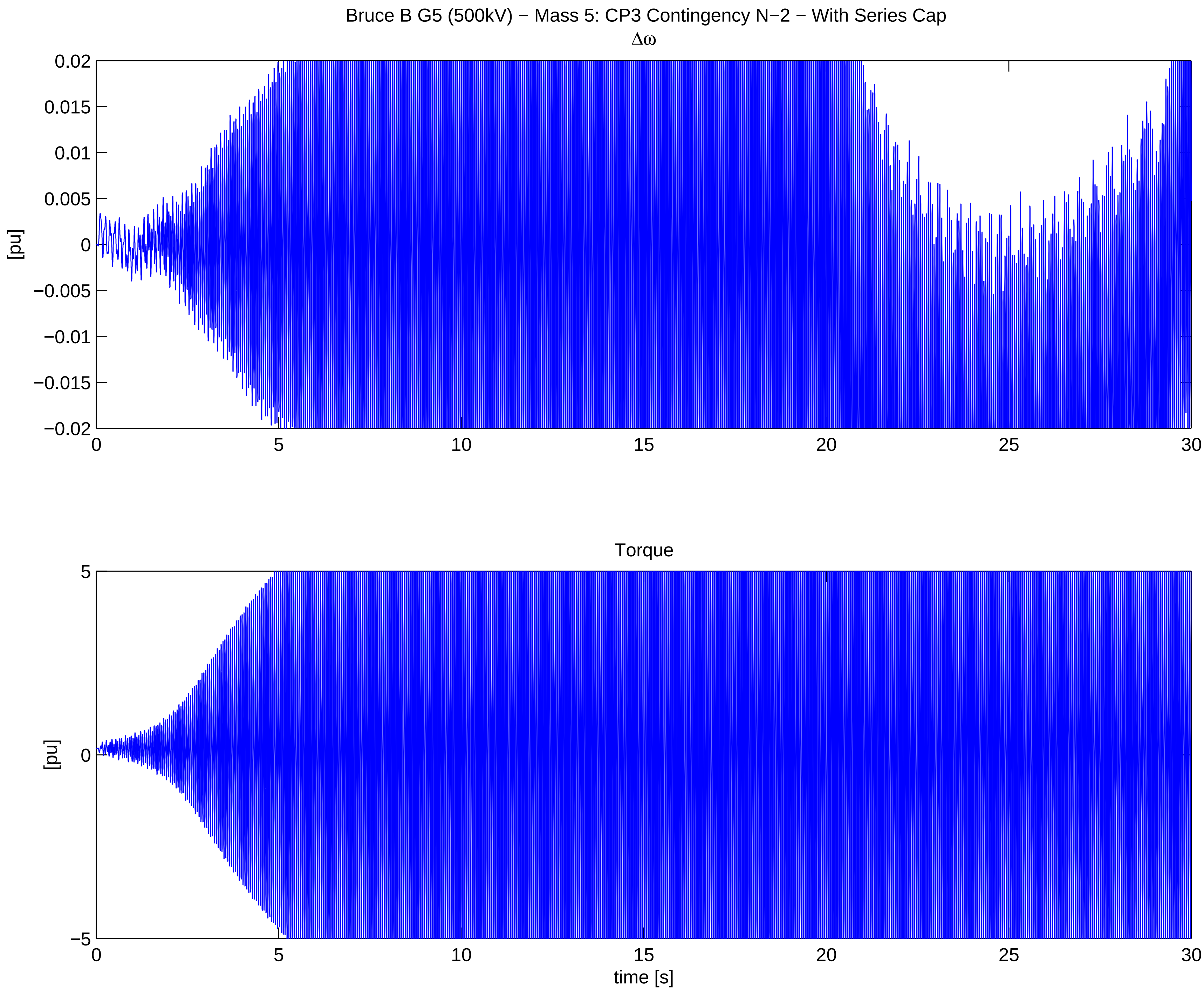

Bruce B G5 (500kV) − Mass 3: IP Contingency N−2 − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

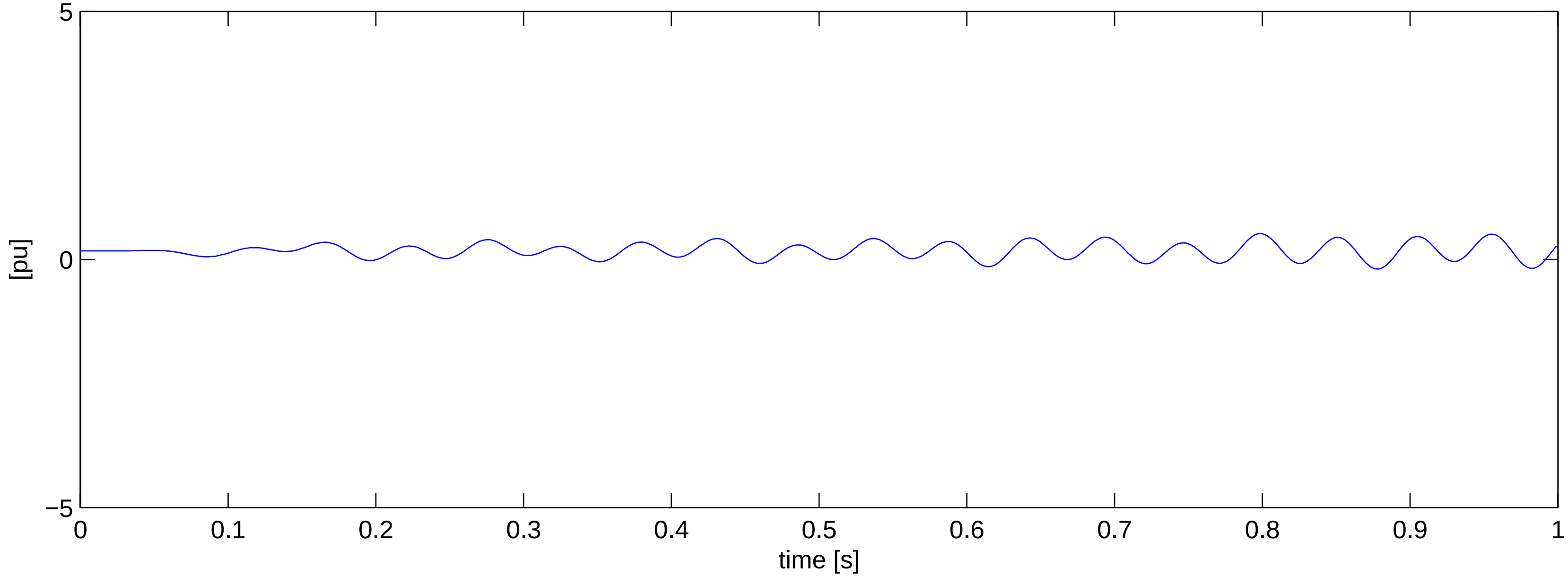


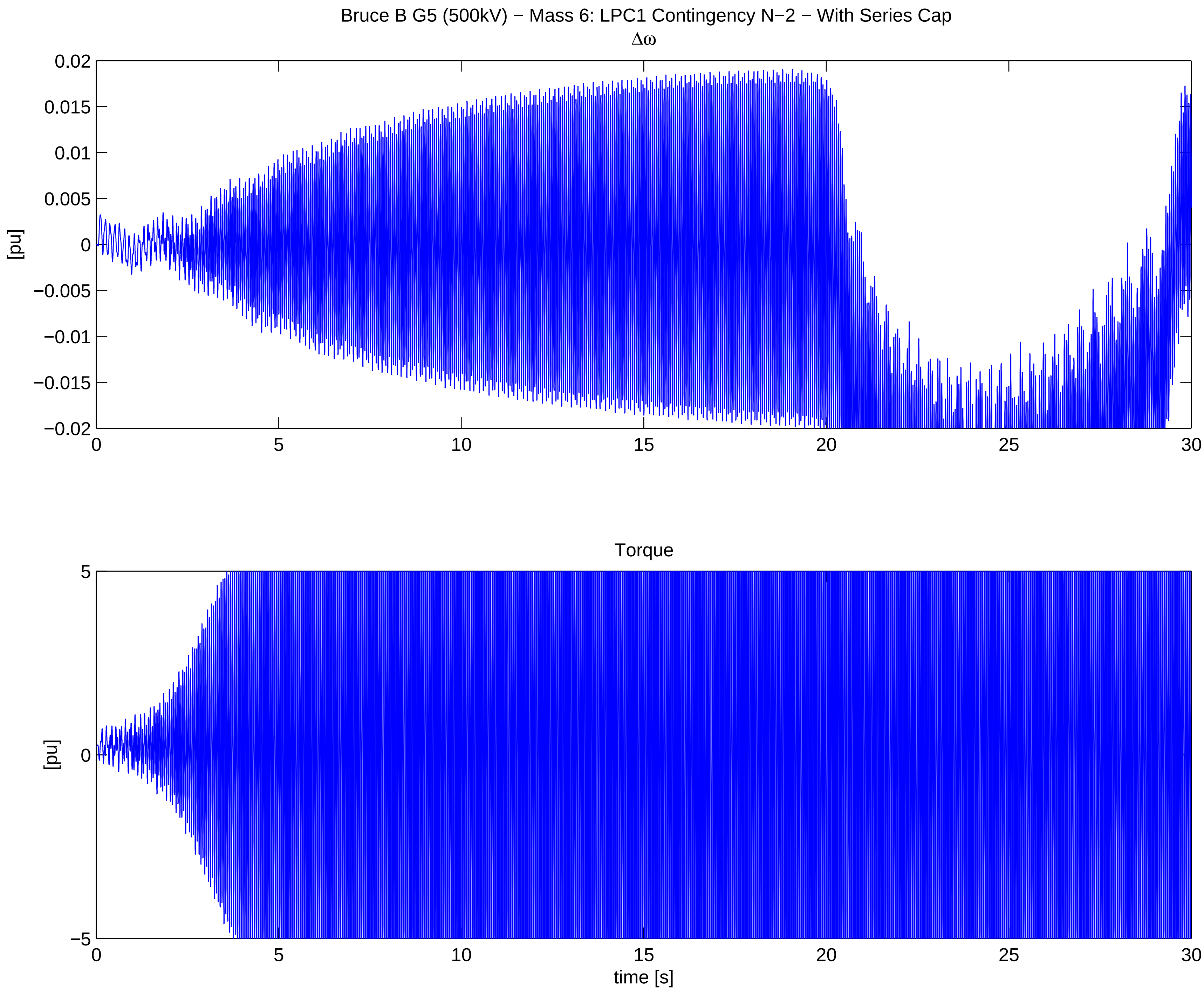
Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



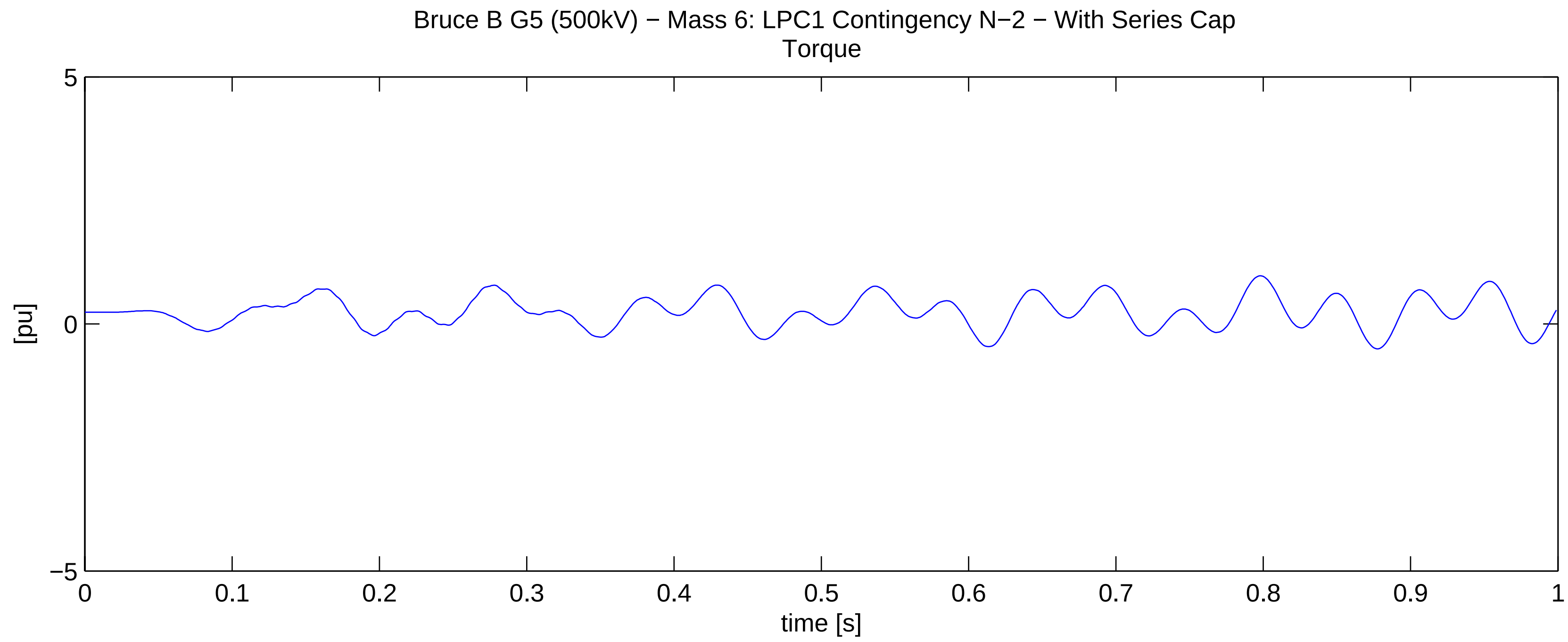
Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

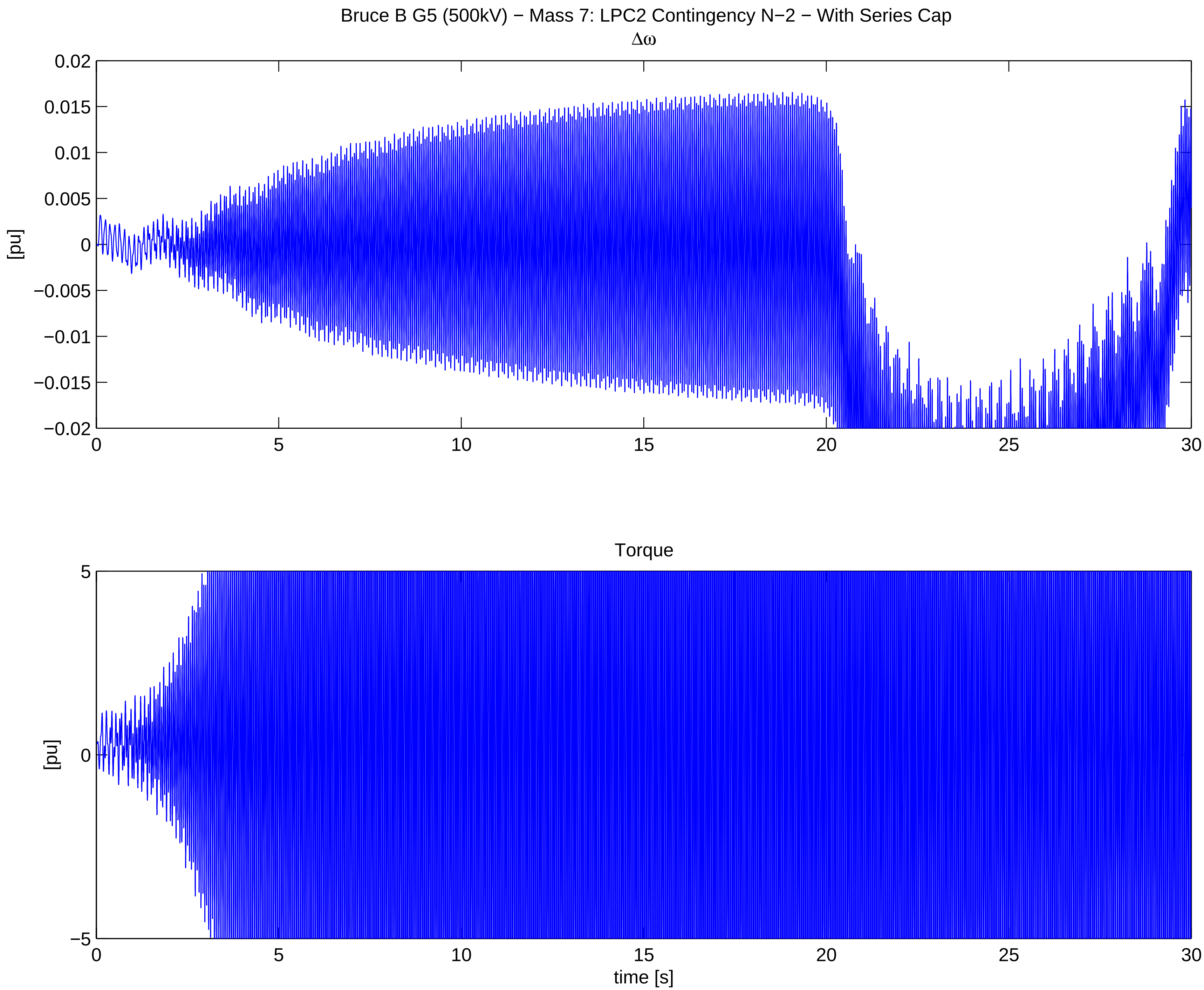
Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−2 − With Series Cap
Torque

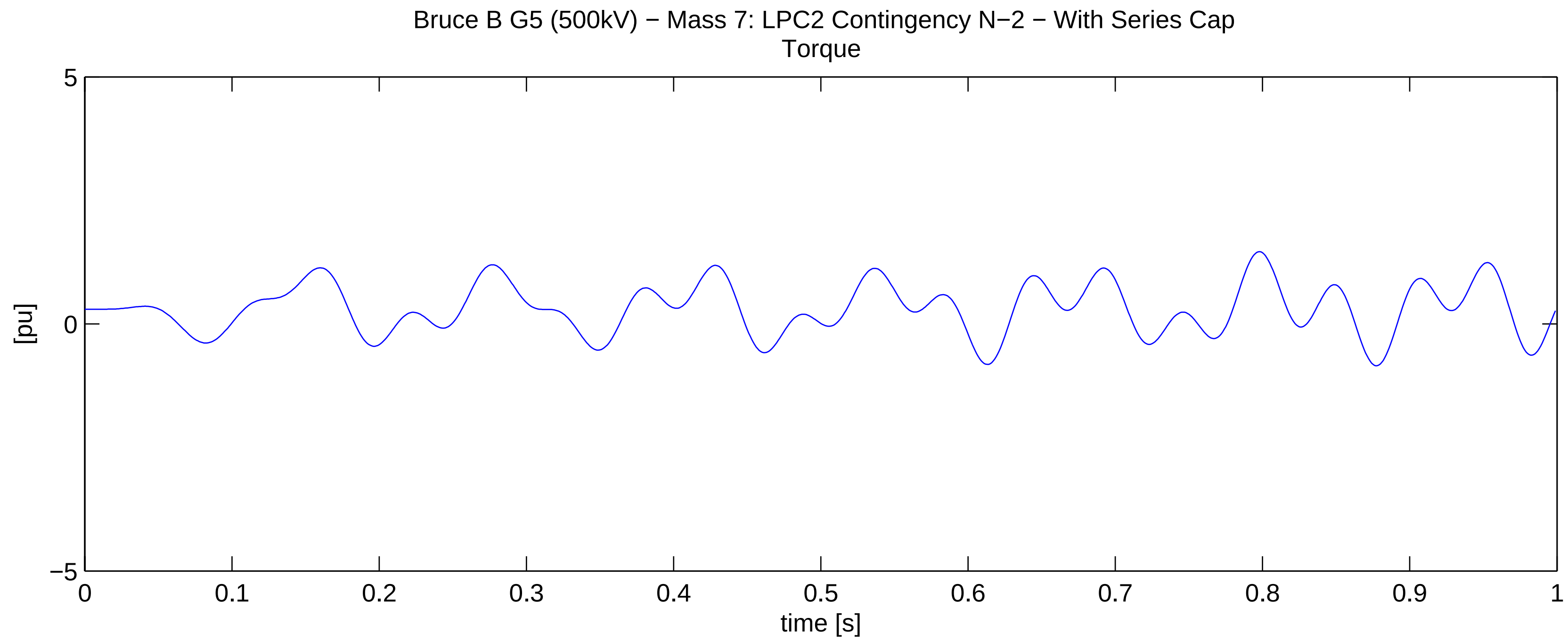


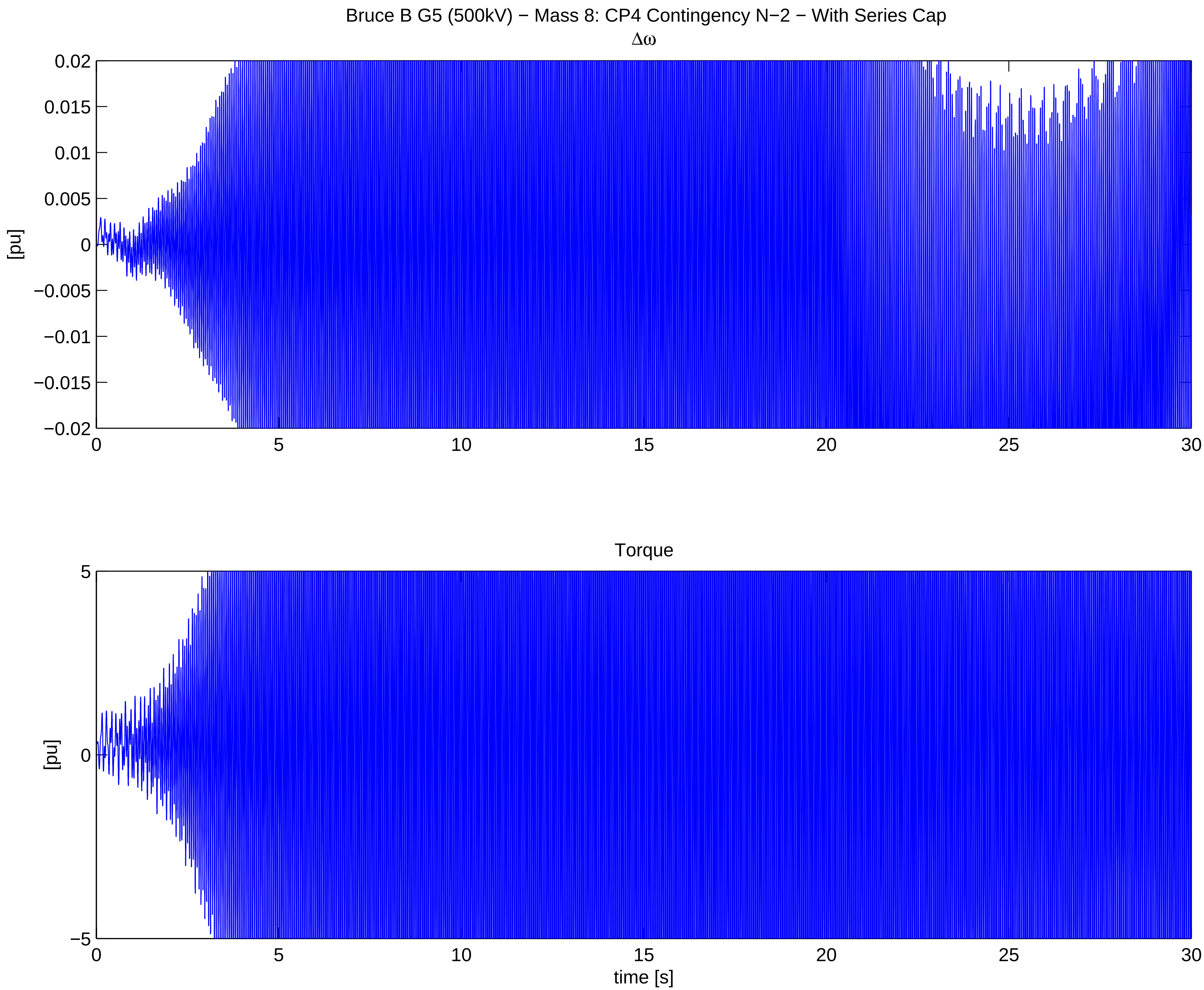


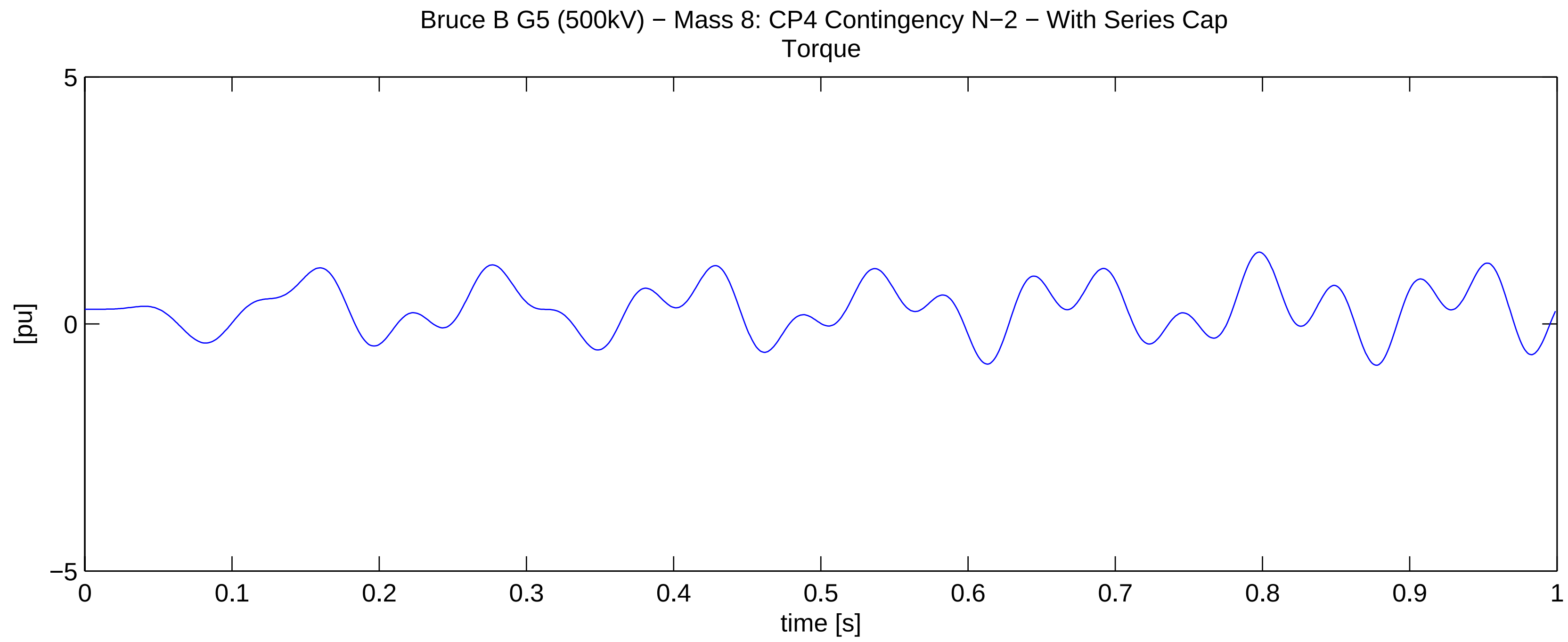
Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

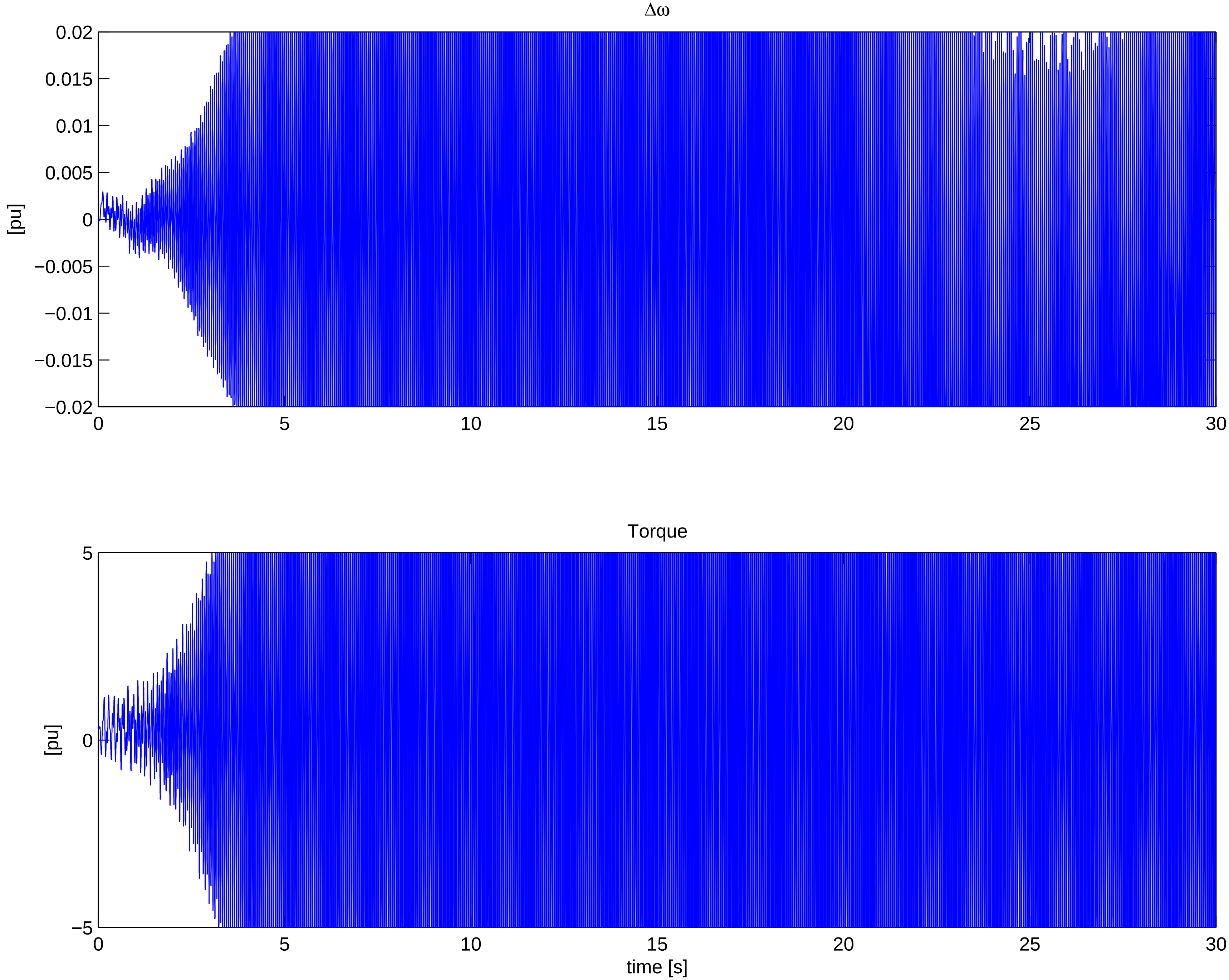

Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−2 − With Series Cap
Δω
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
[pu]
0
5
10
15
20
25
30
Torque
5
0
−5
[pu]
0
5
10
15
20
25
30
time [s]

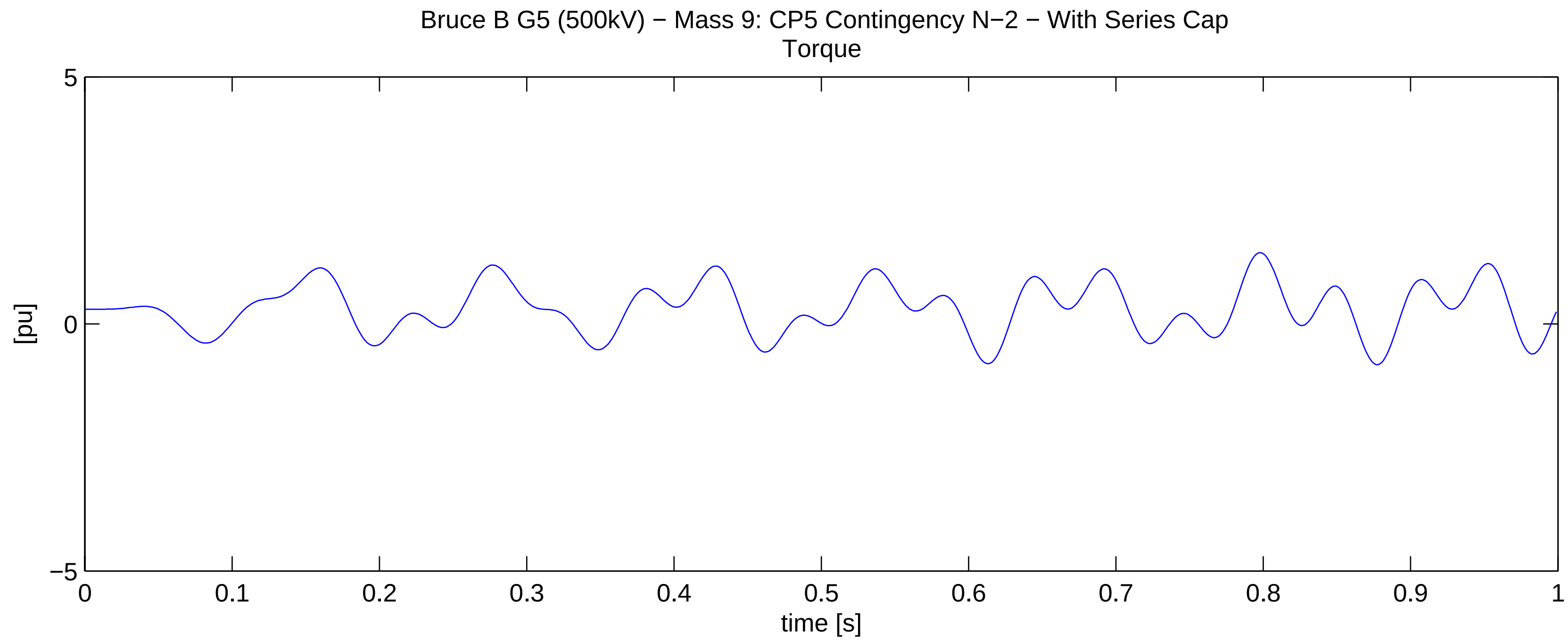

Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

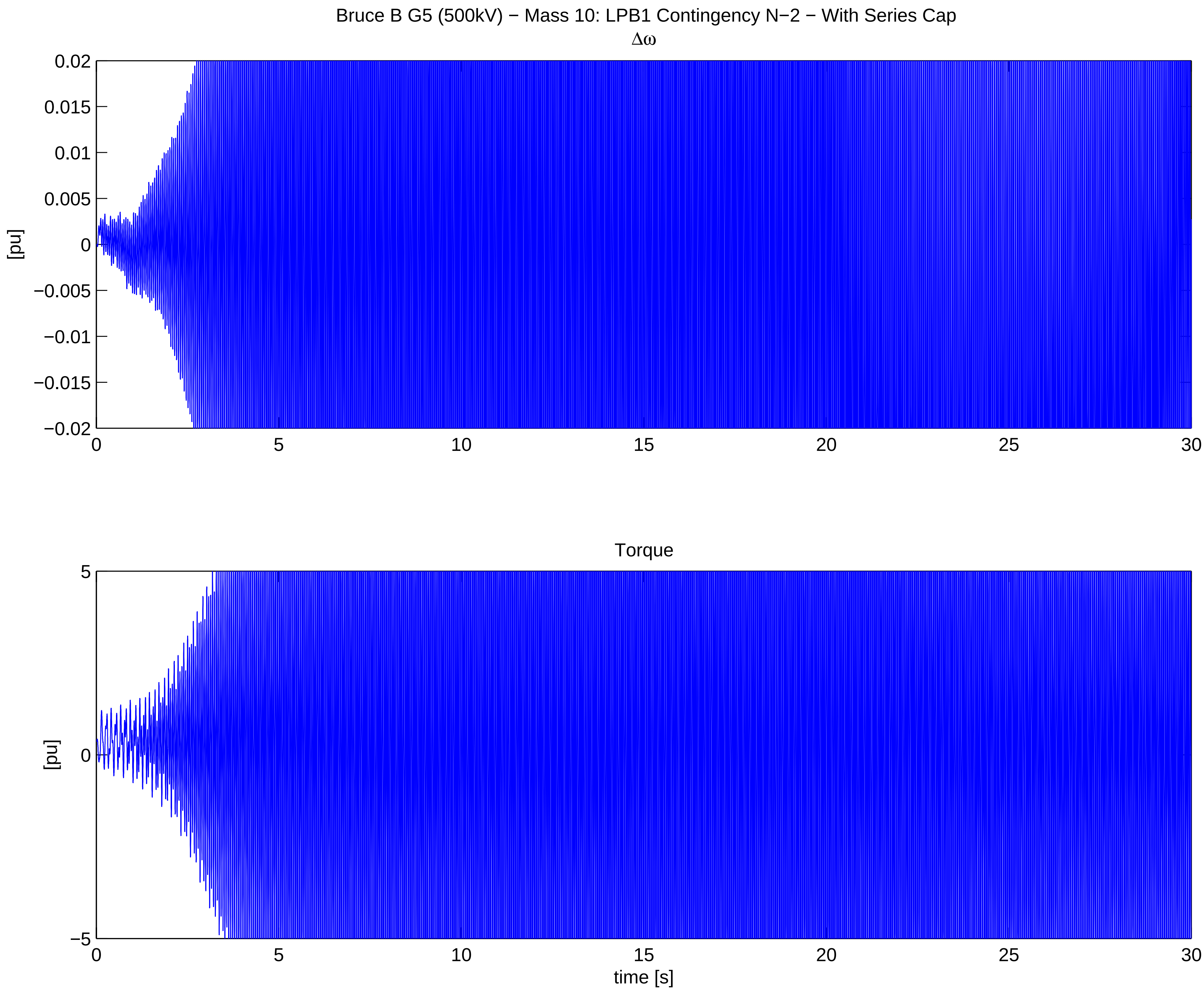

Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−2 − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

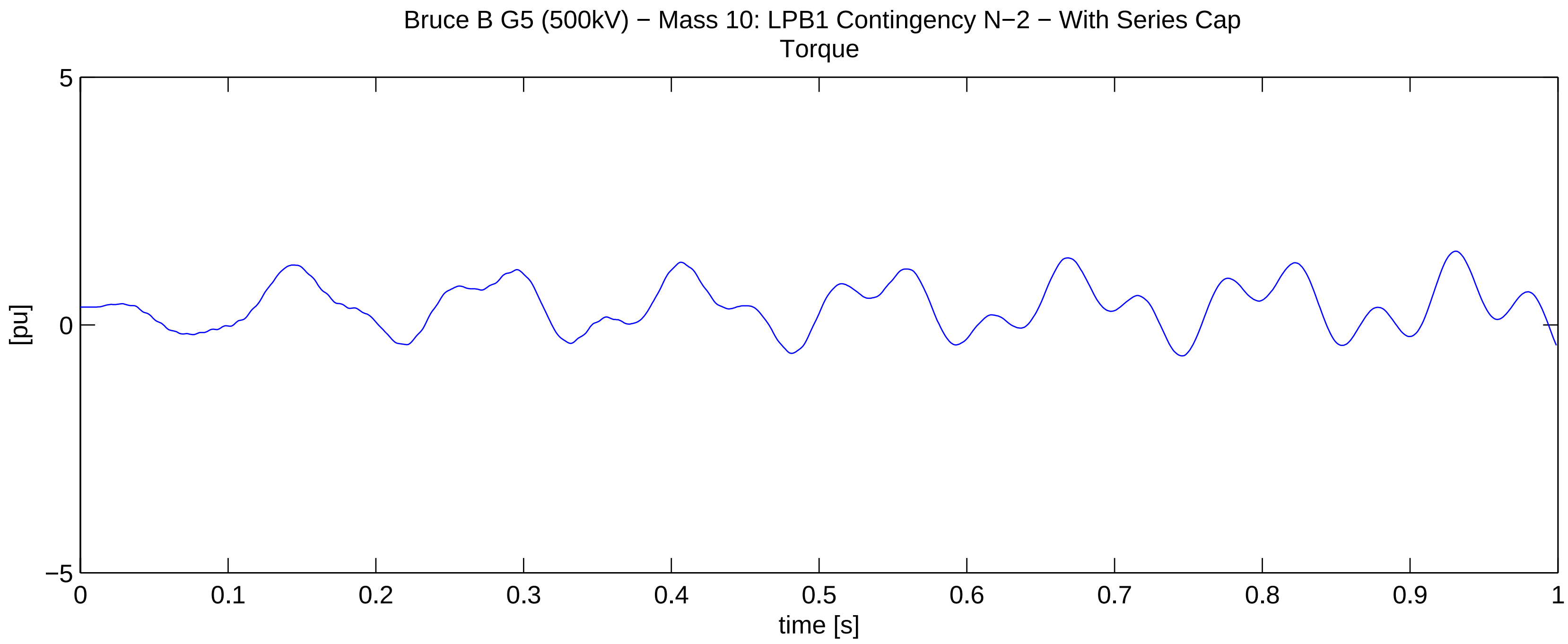
Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−2 − With Series Cap

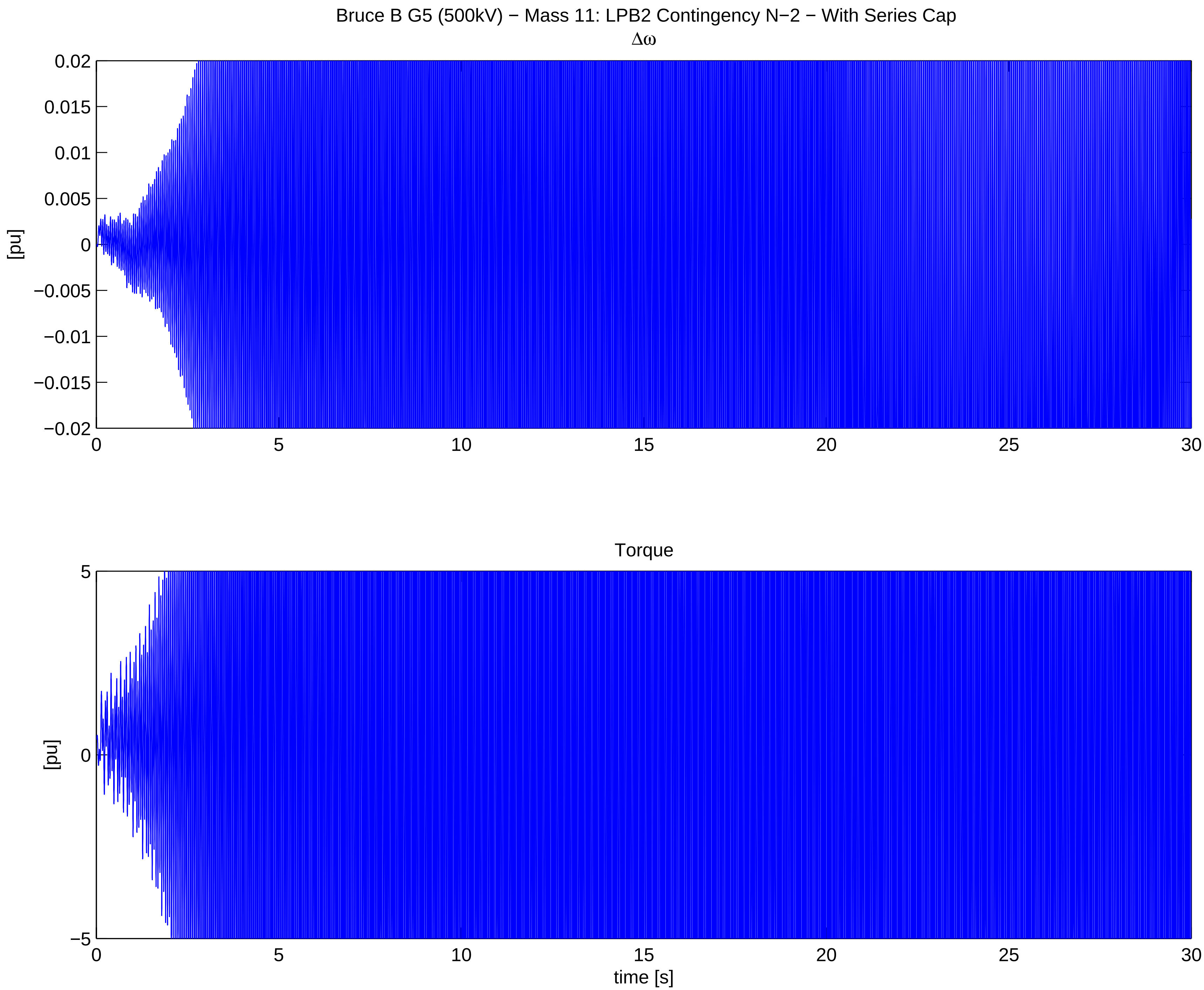



Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

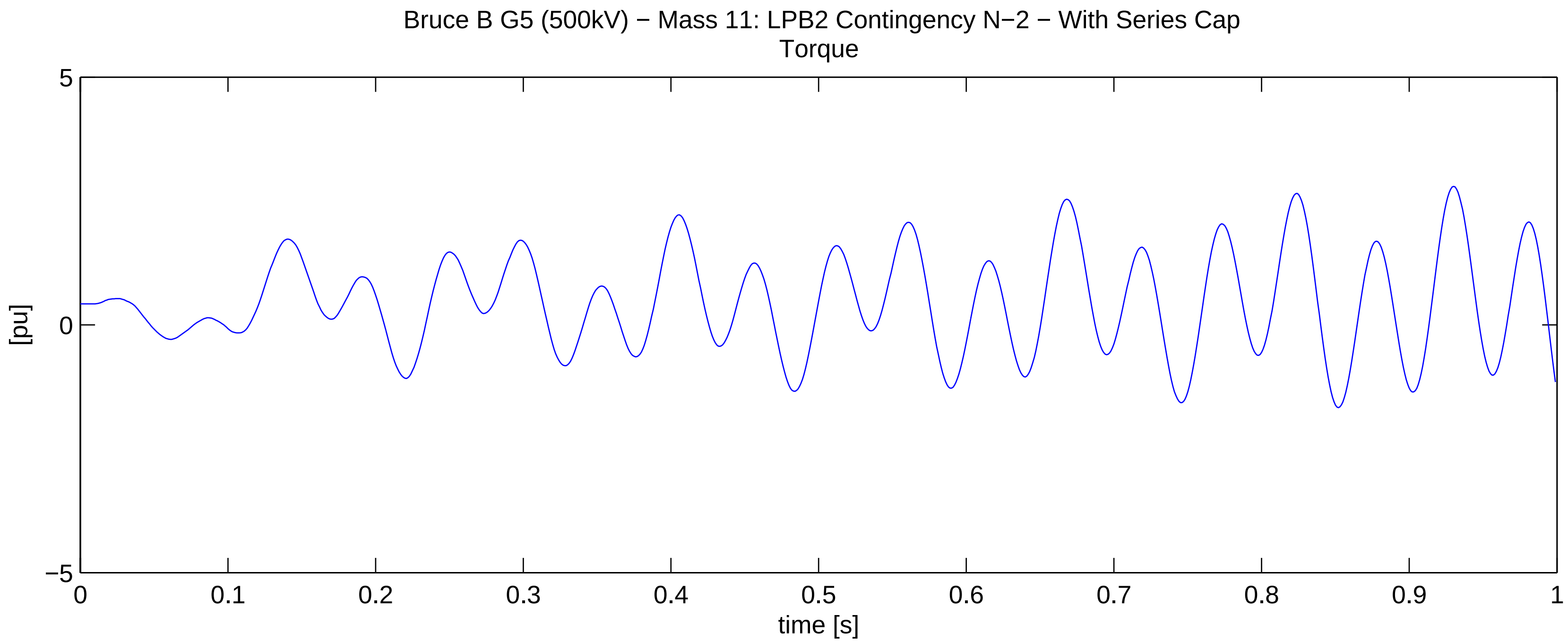


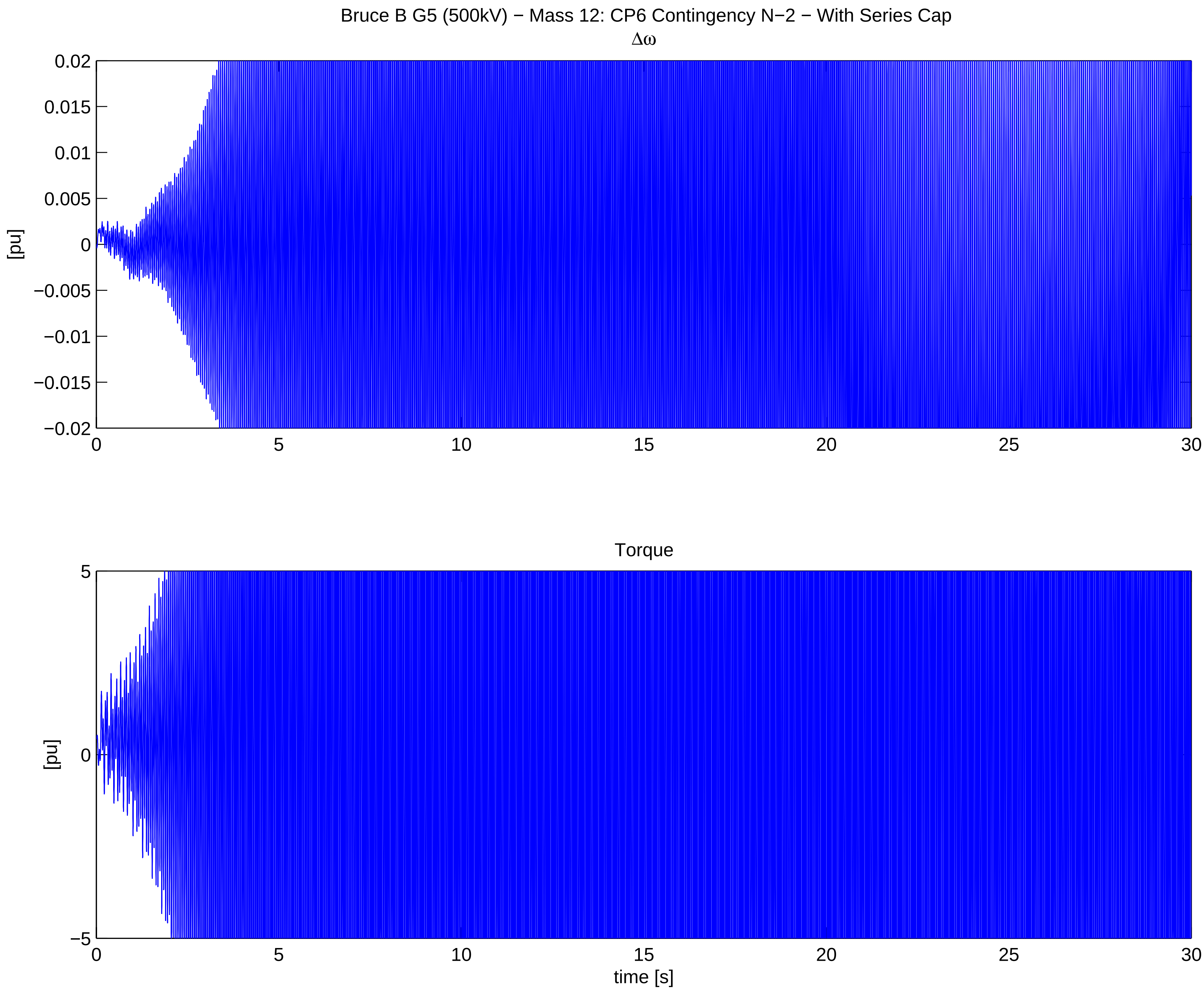
Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

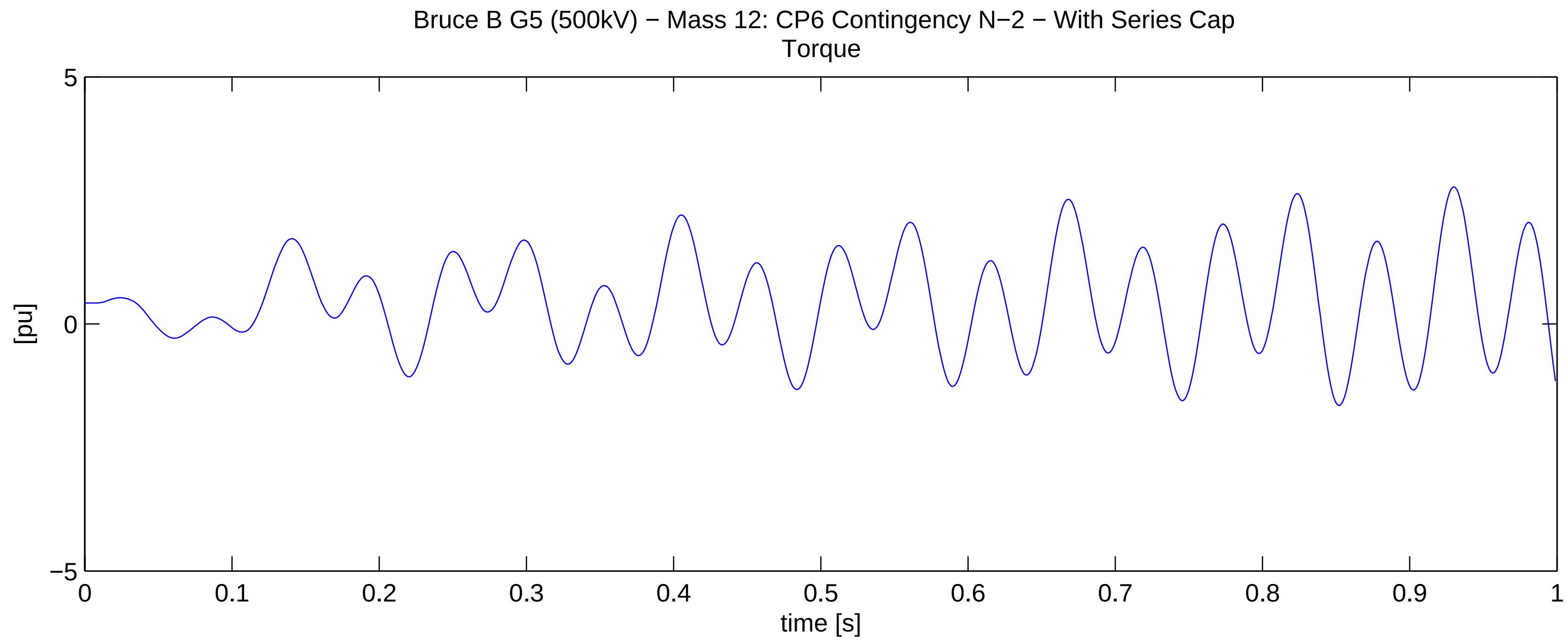

Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

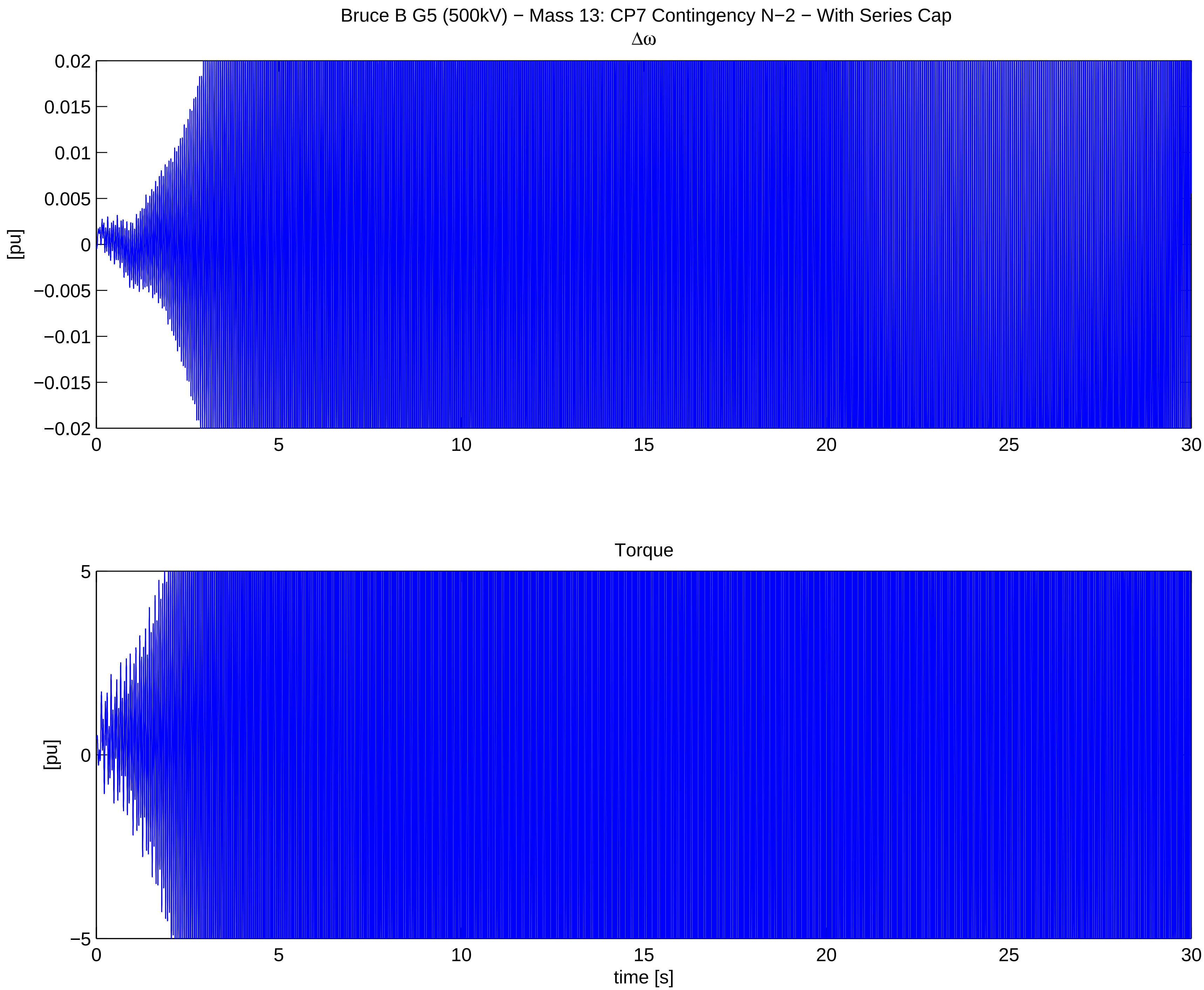


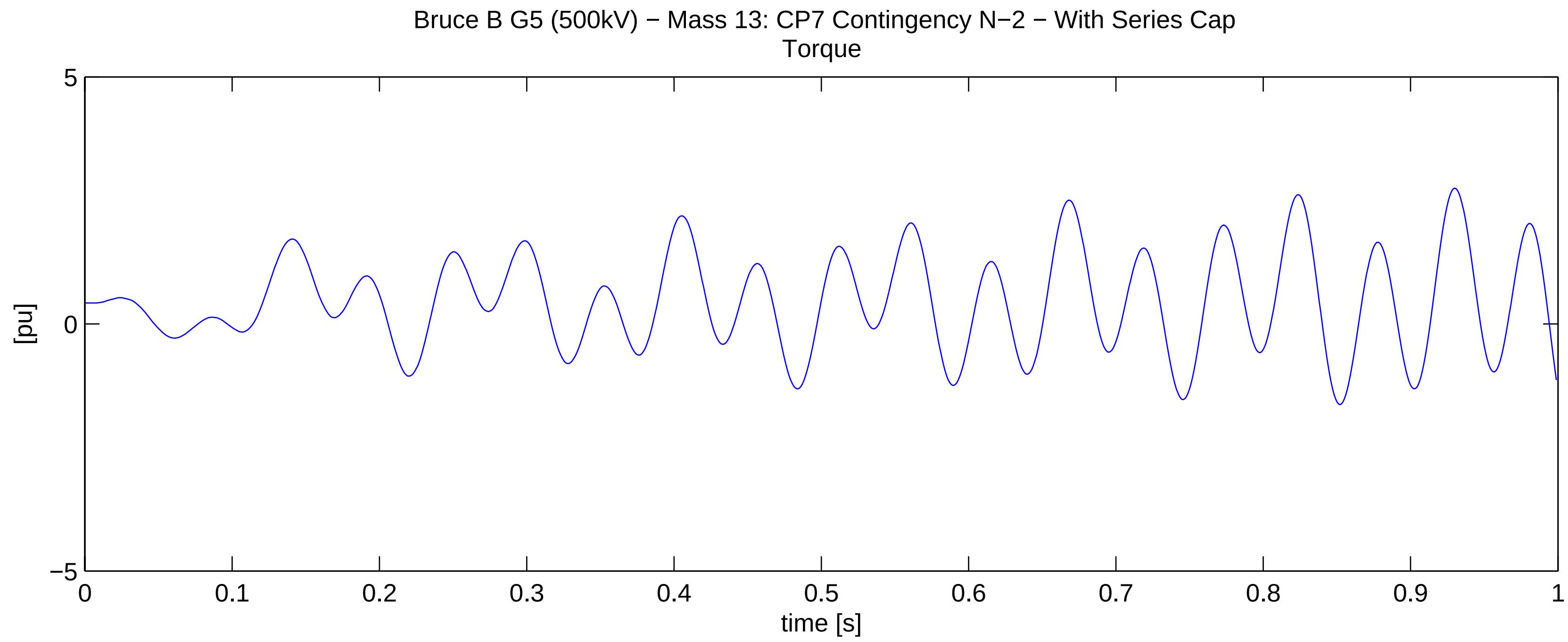
Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

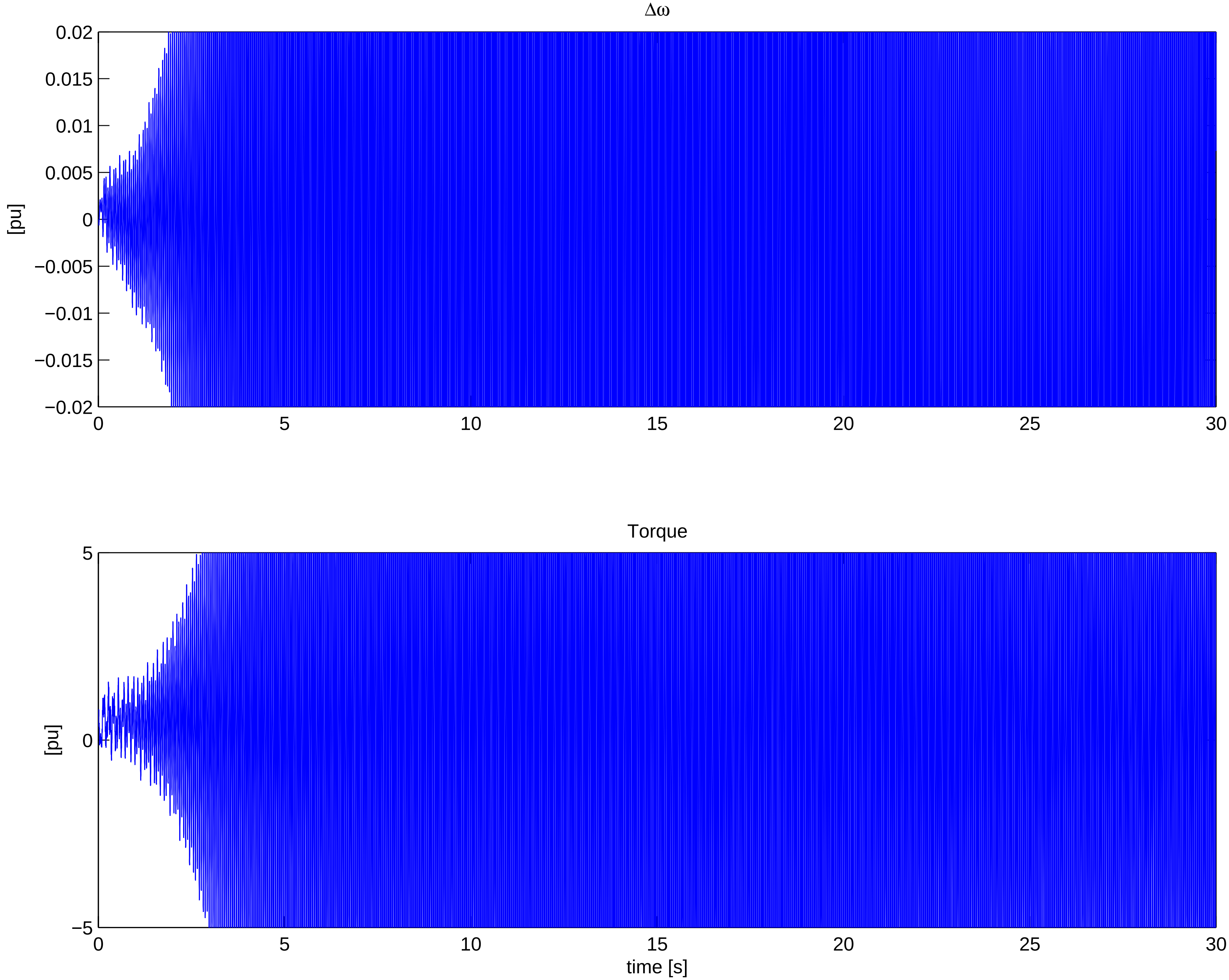

Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

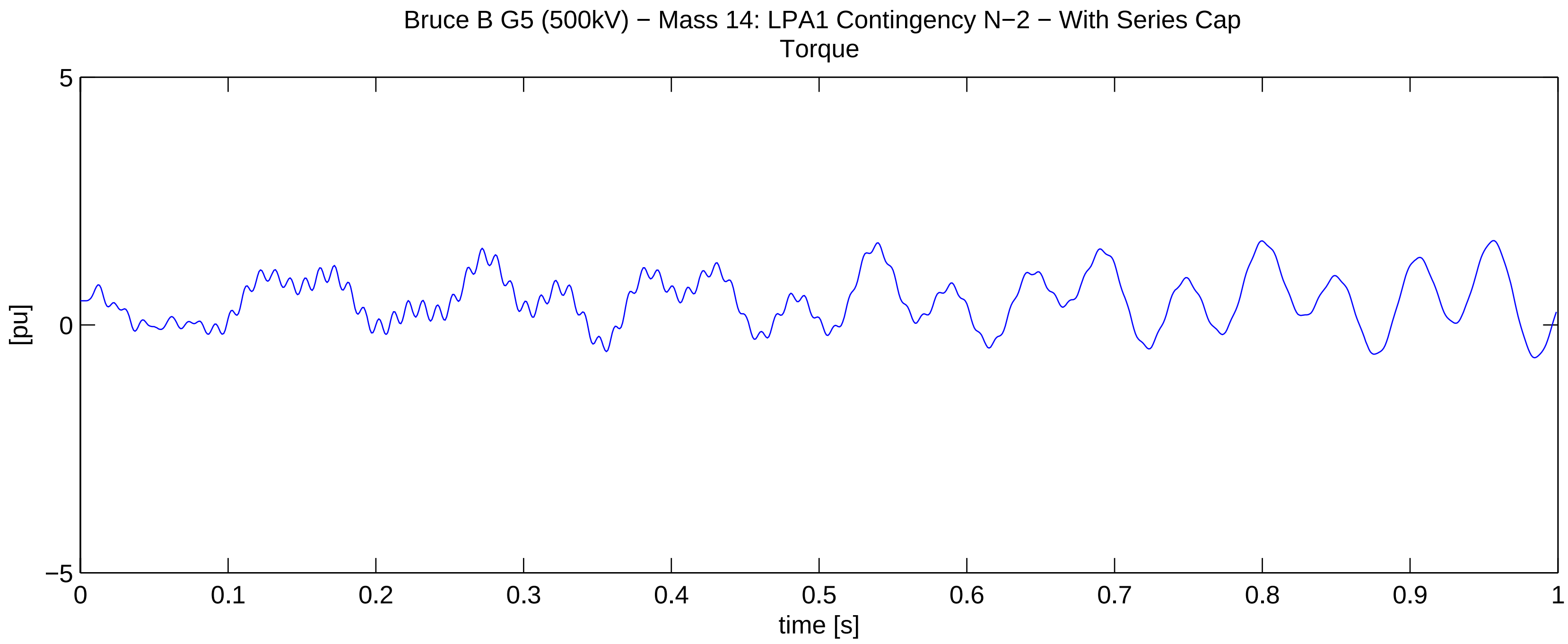

Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

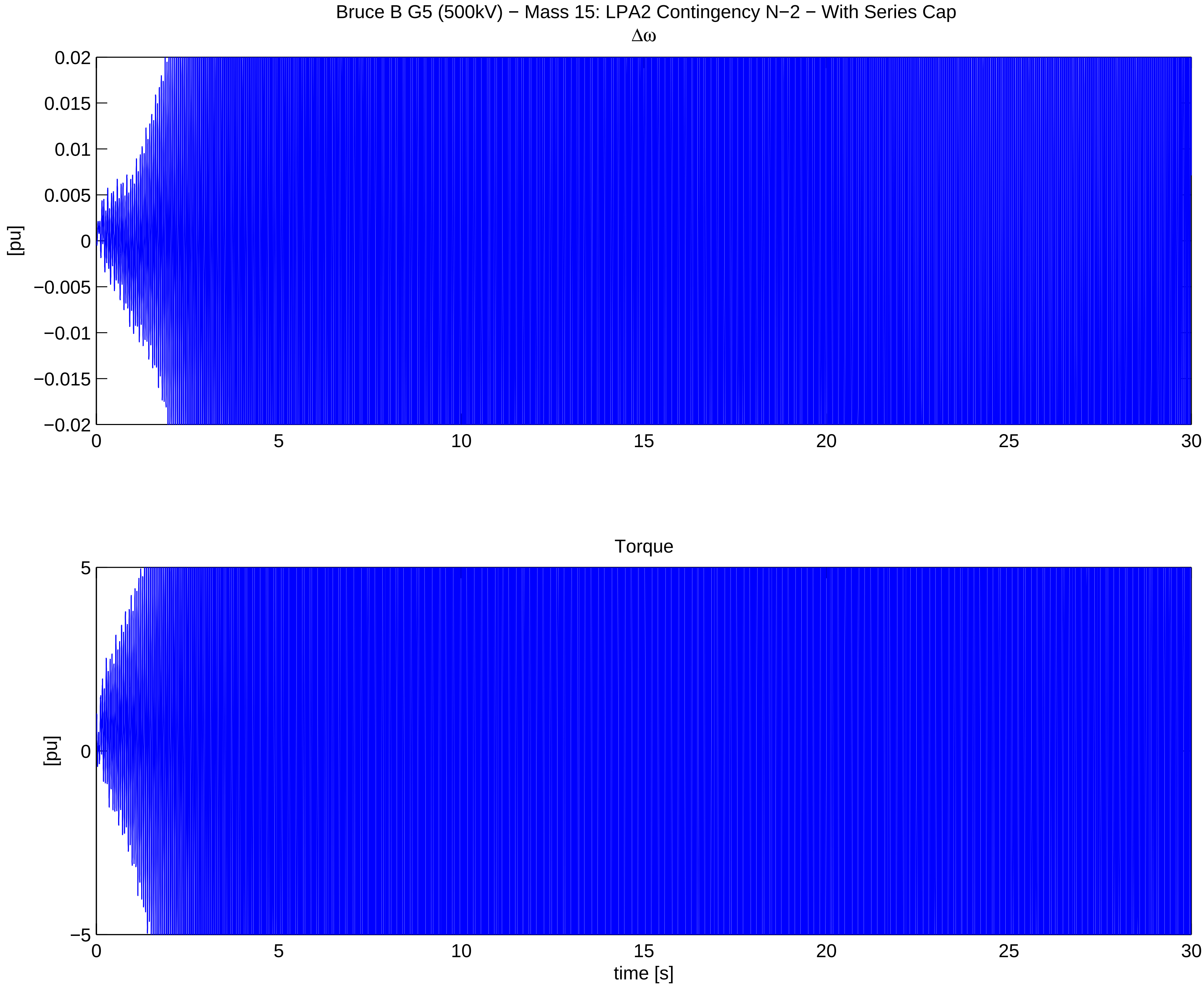

Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−2 − With Series Cap

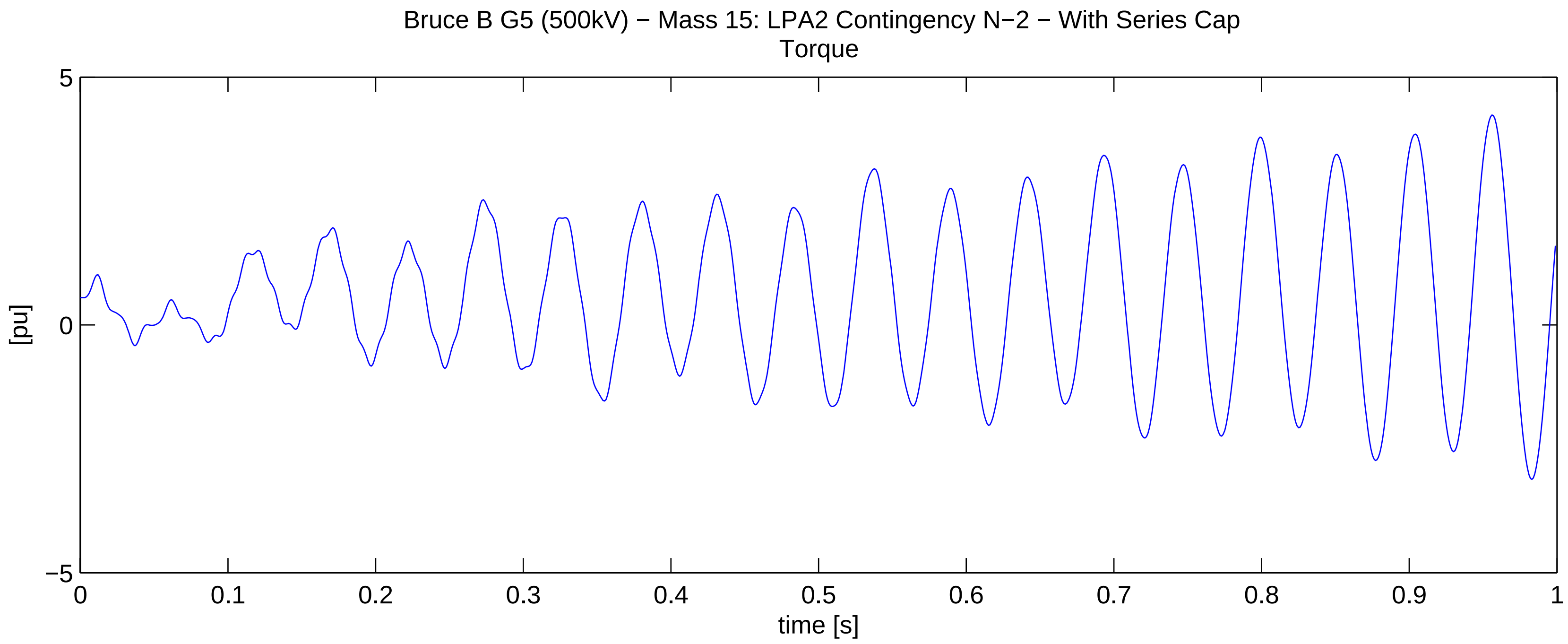


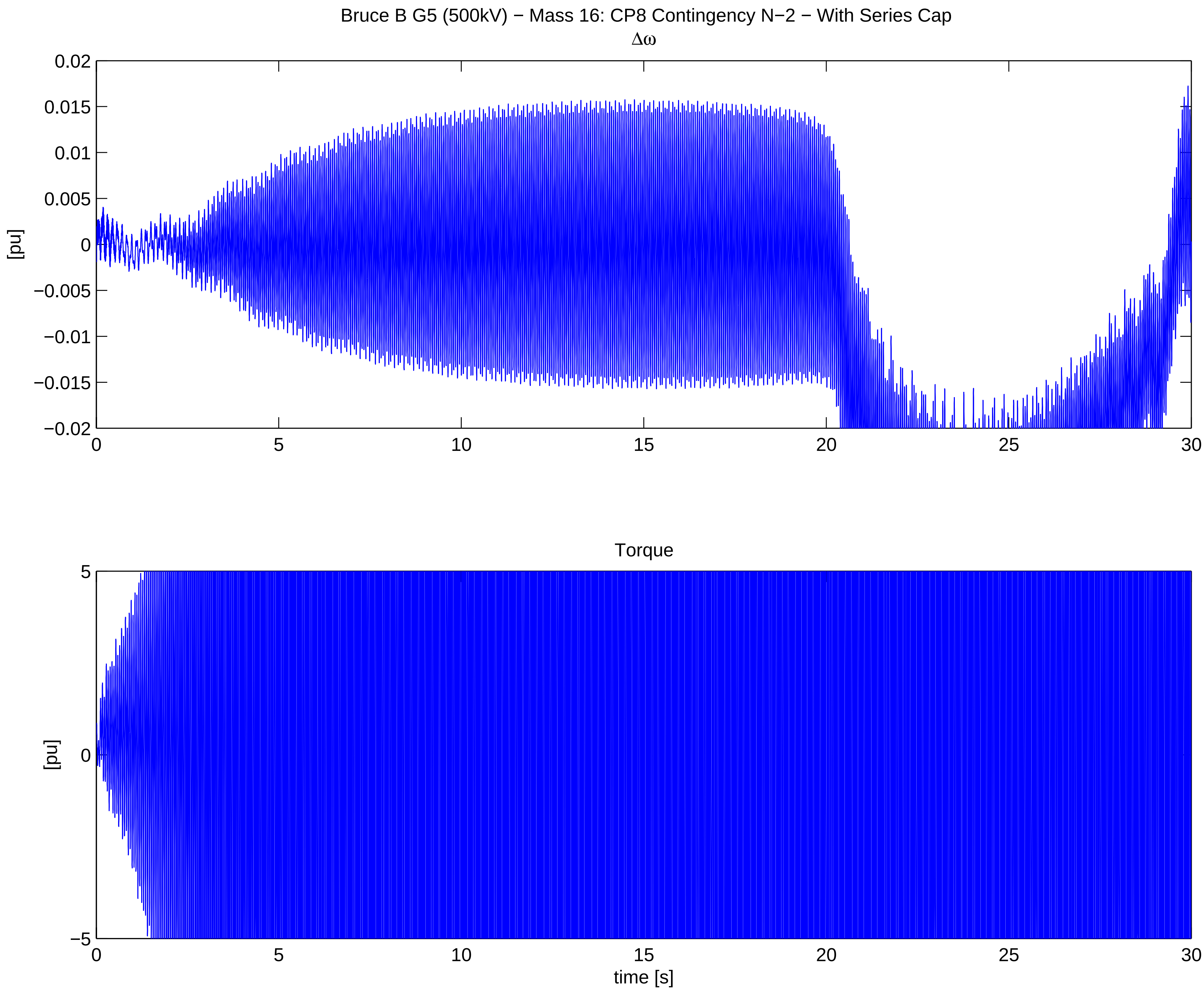


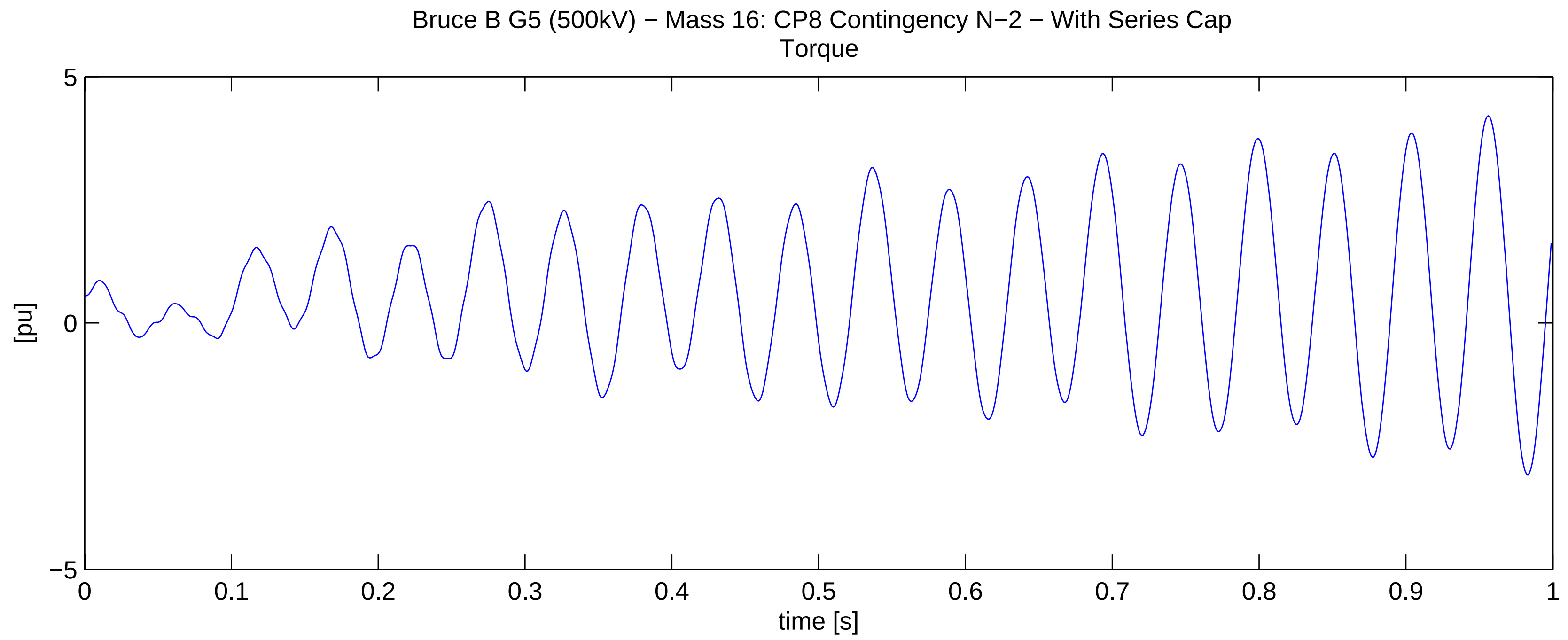
Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

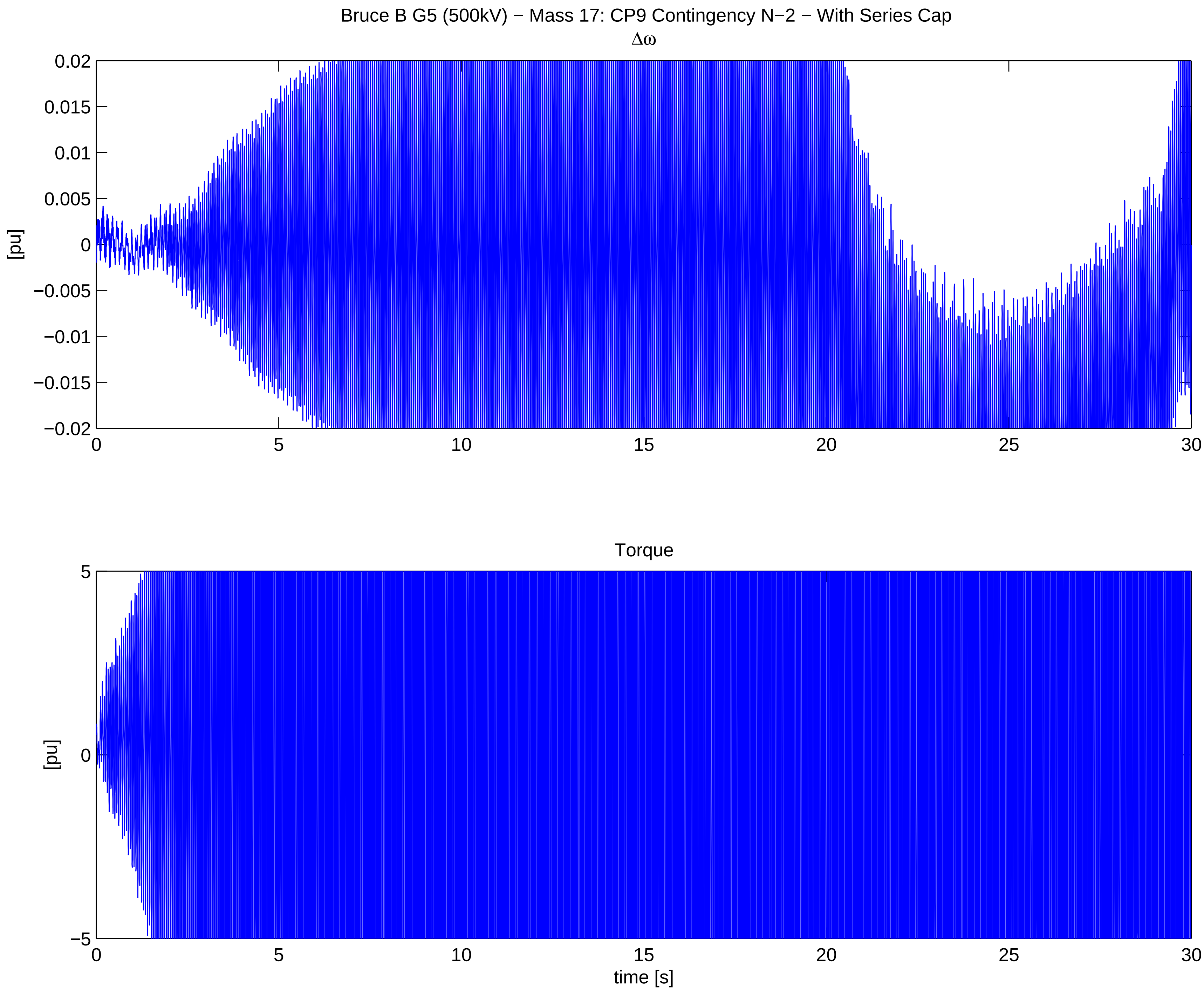


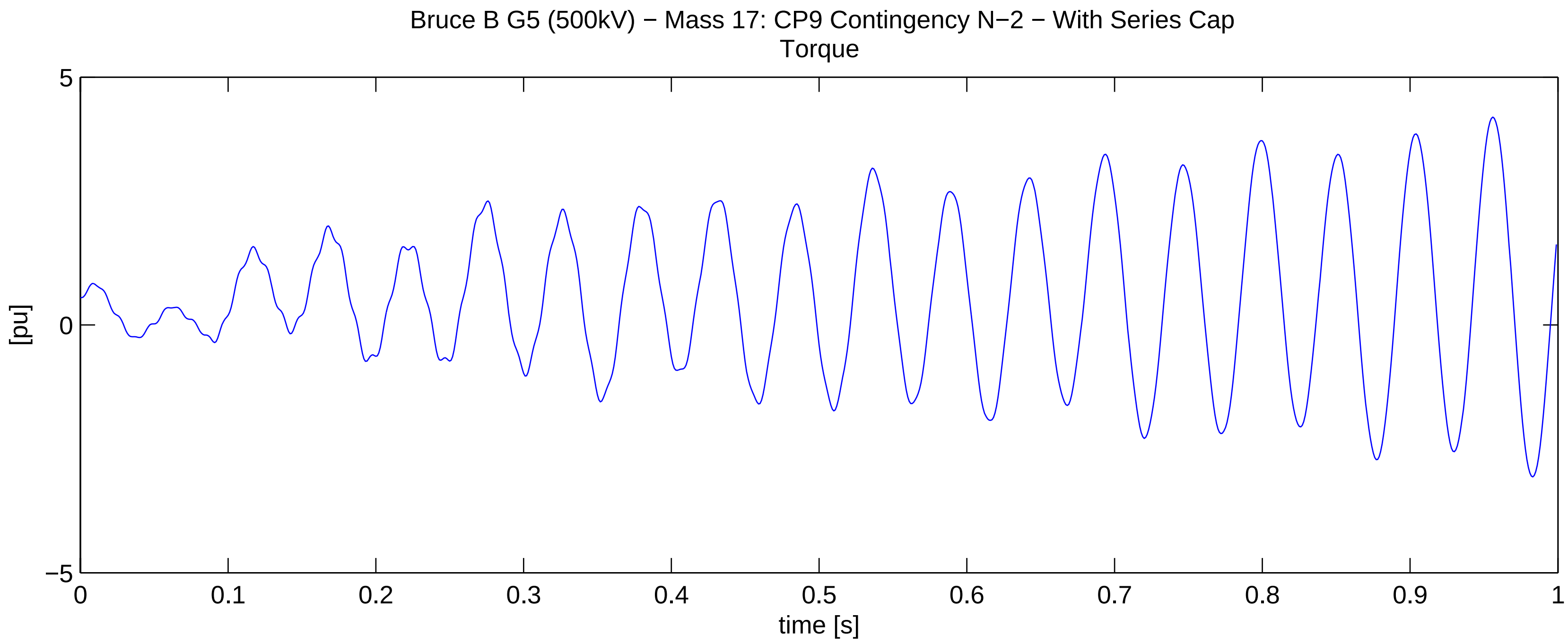
Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

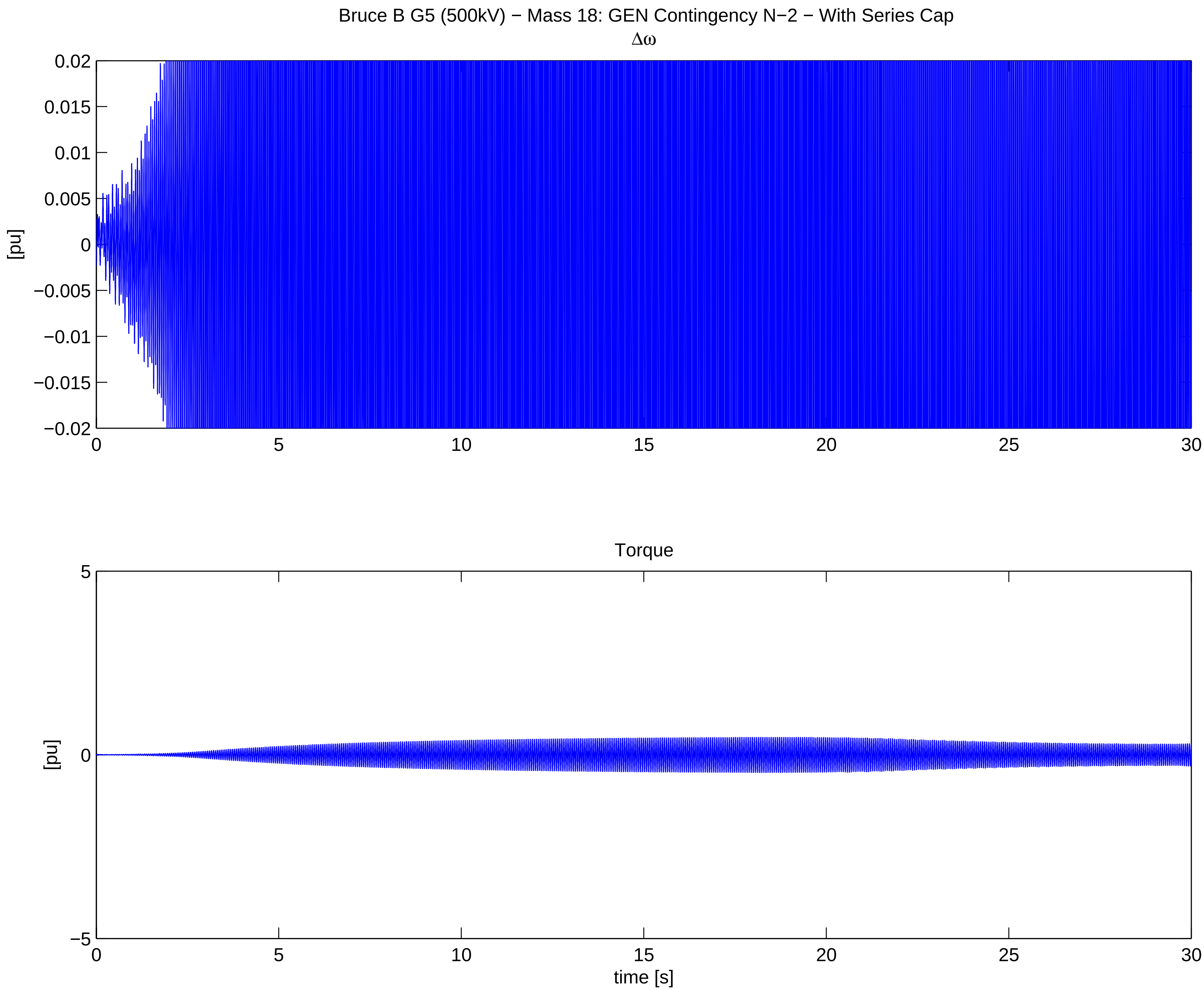

Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

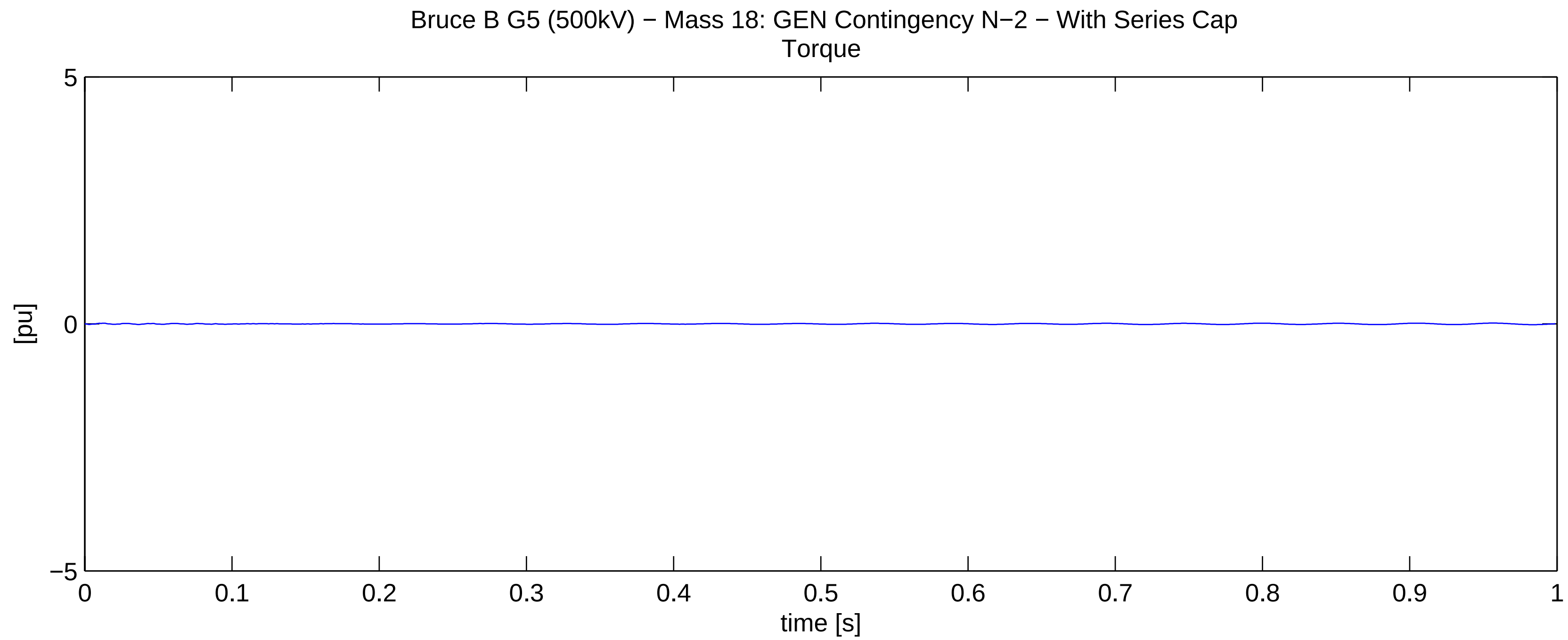

Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

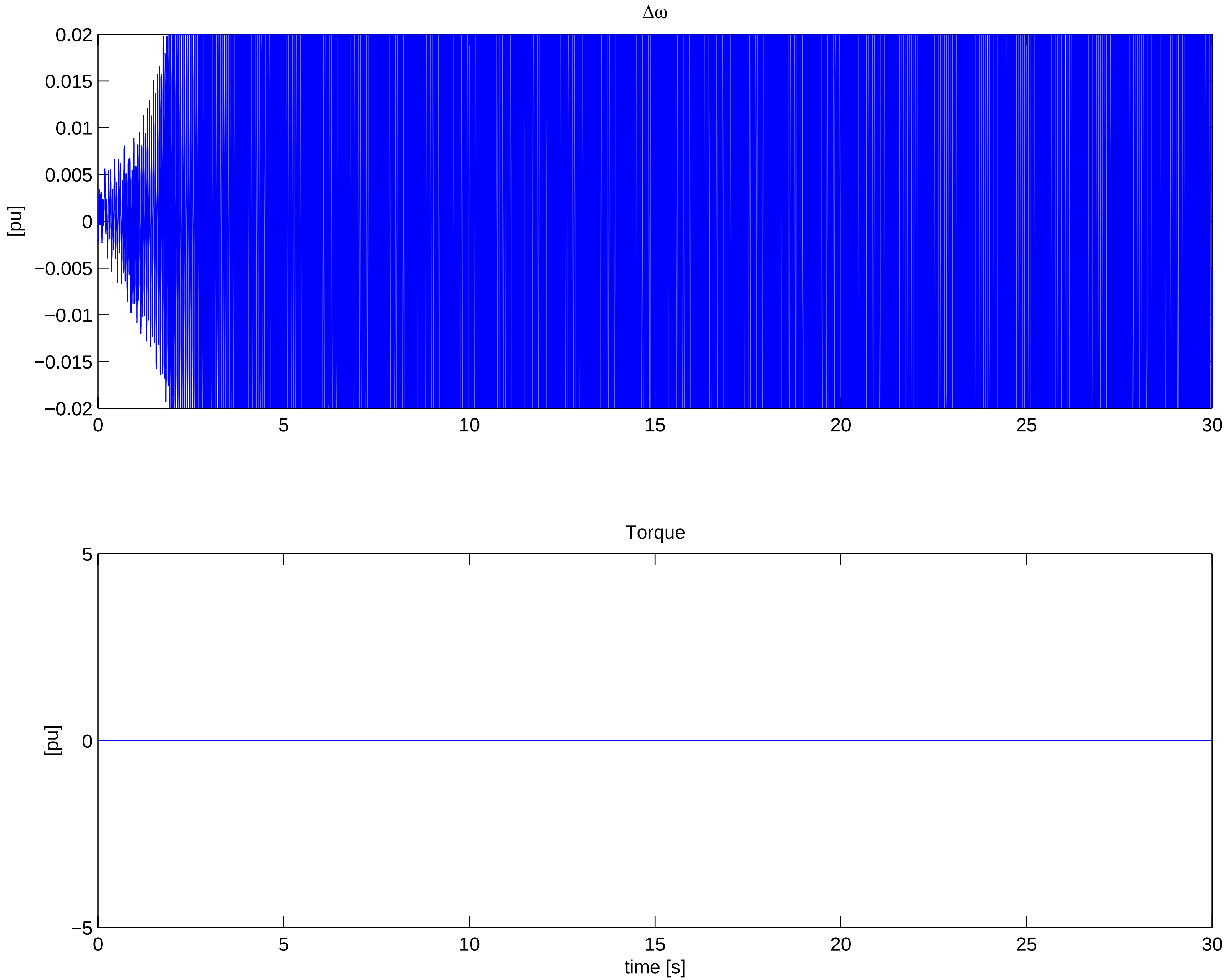

Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

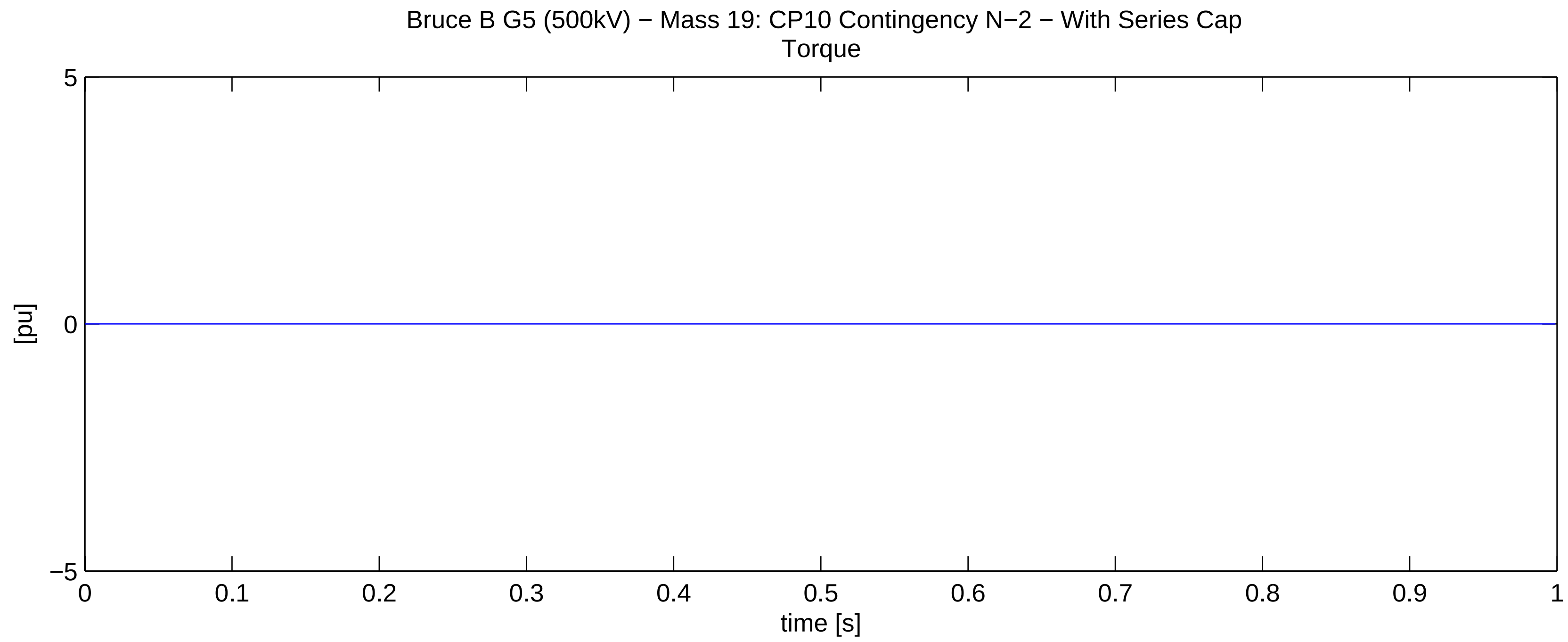


Bruce B G5 (500kV) − Mass 18: GEN Contingency N−2 − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

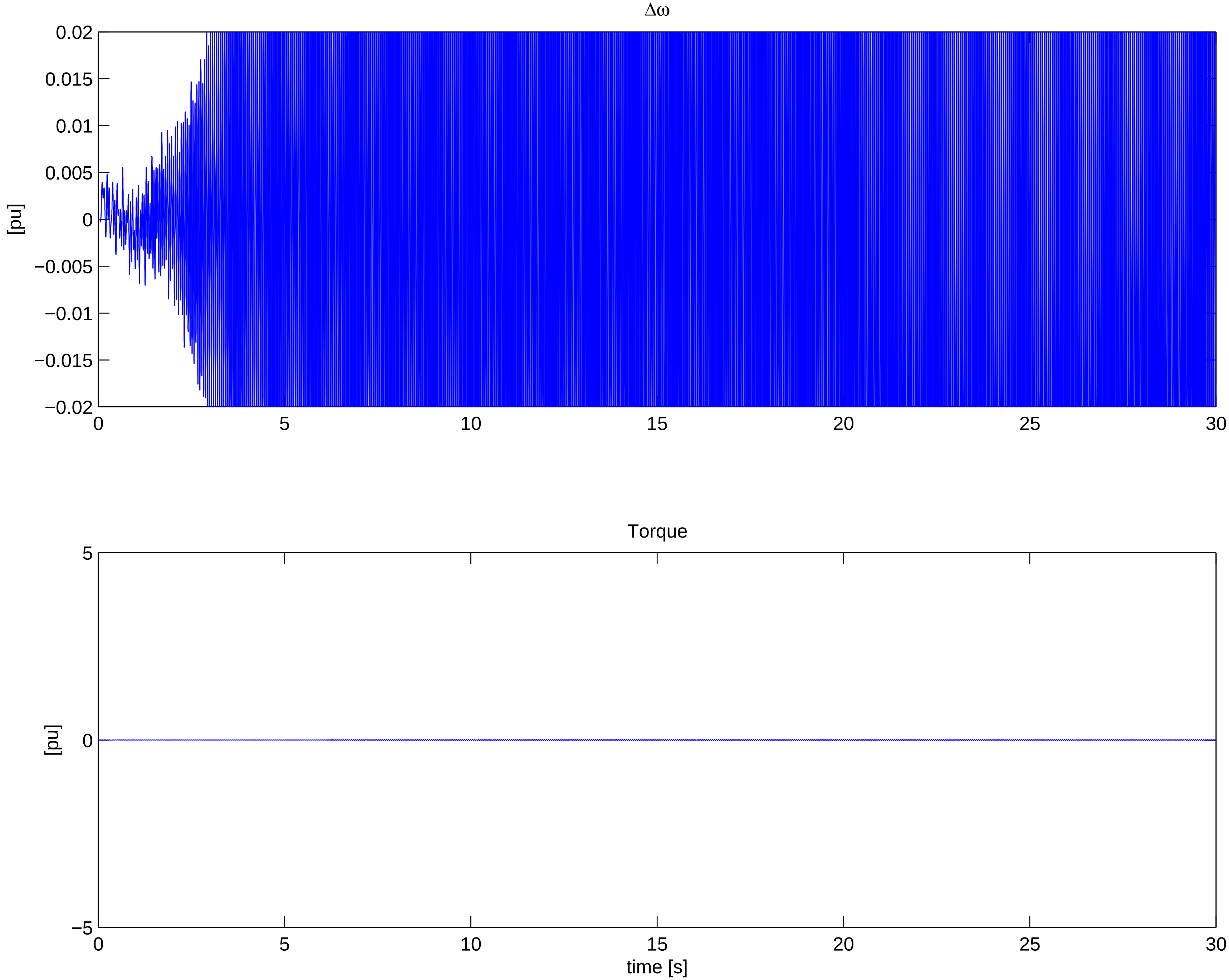

Bruce B G5 (500kV) − Mass 18: GEN Contingency N−2 − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

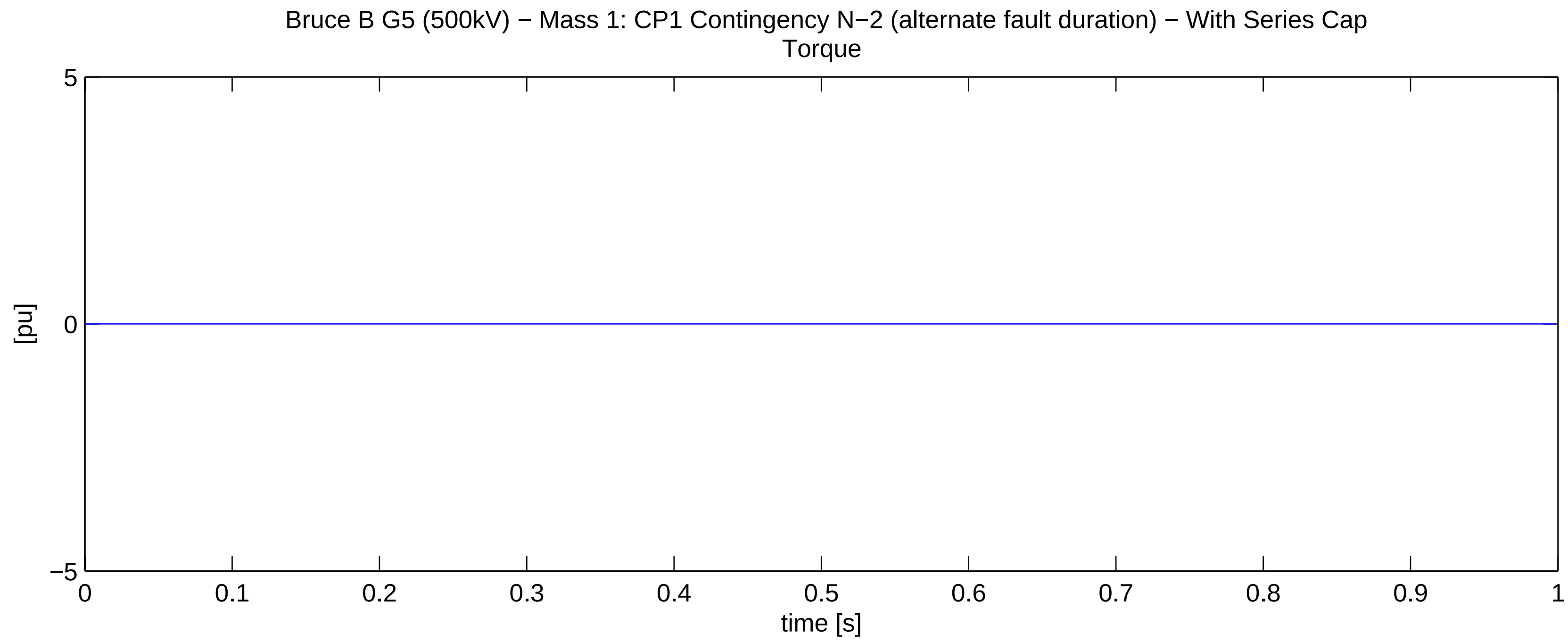
Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−2 − With Series Cap



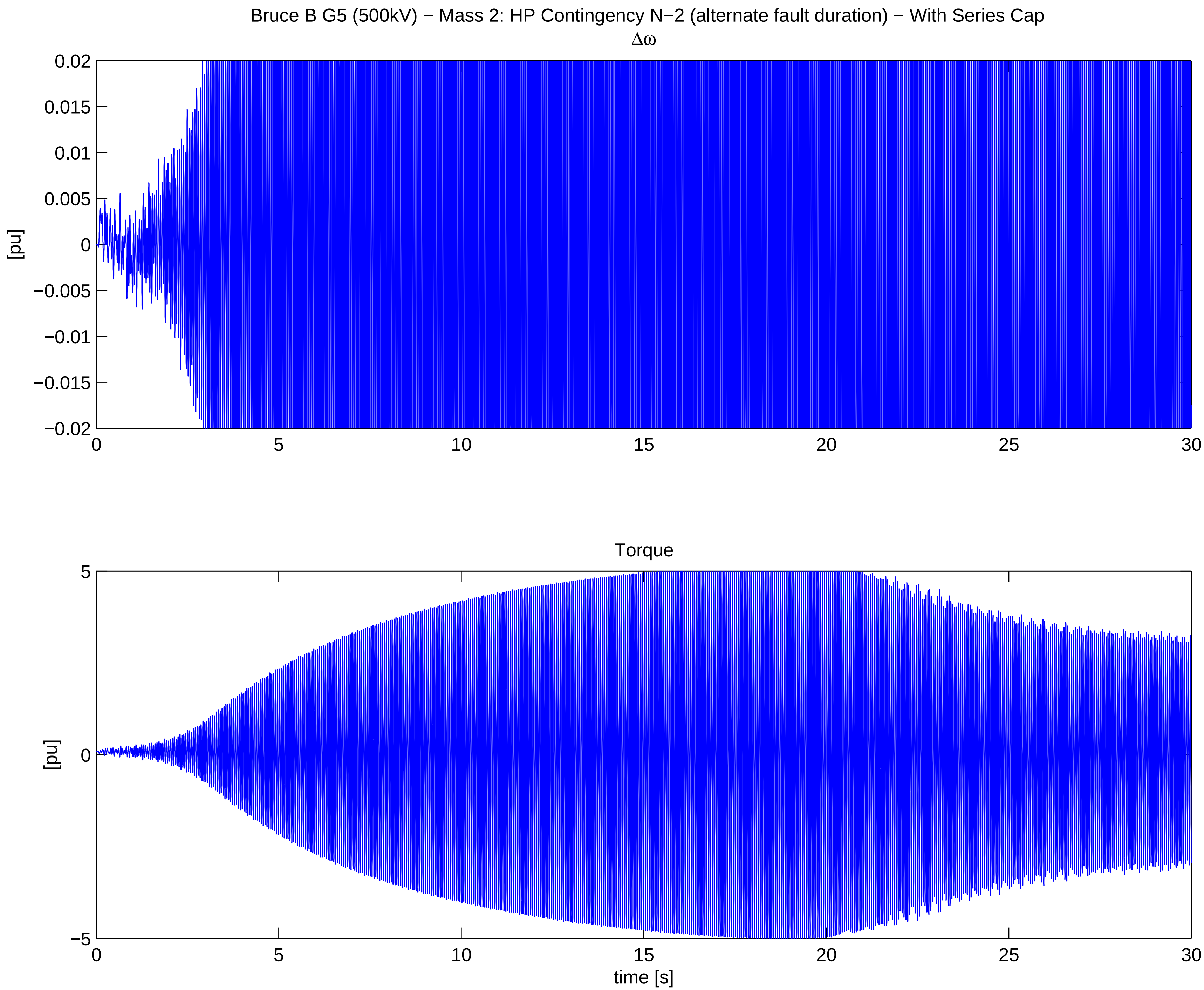

Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−2 − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

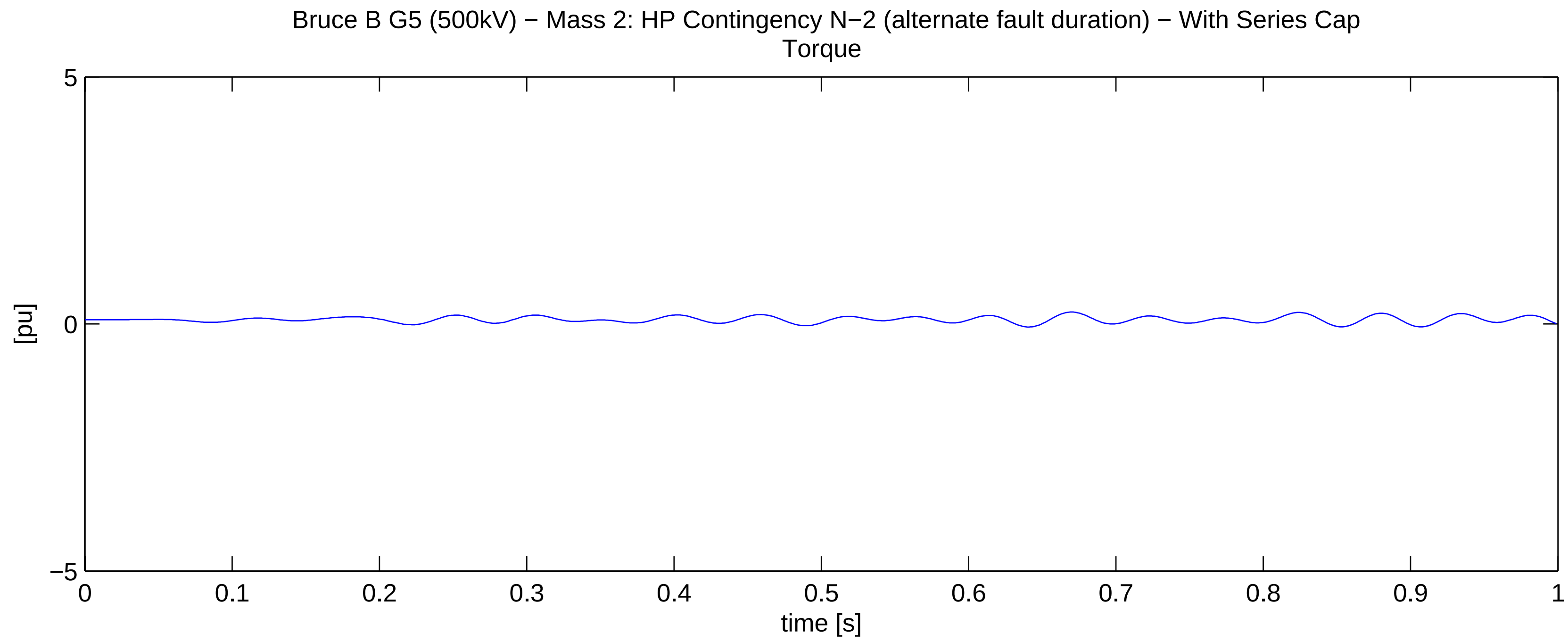
Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−2 (alternate fault duration) − With Series Cap



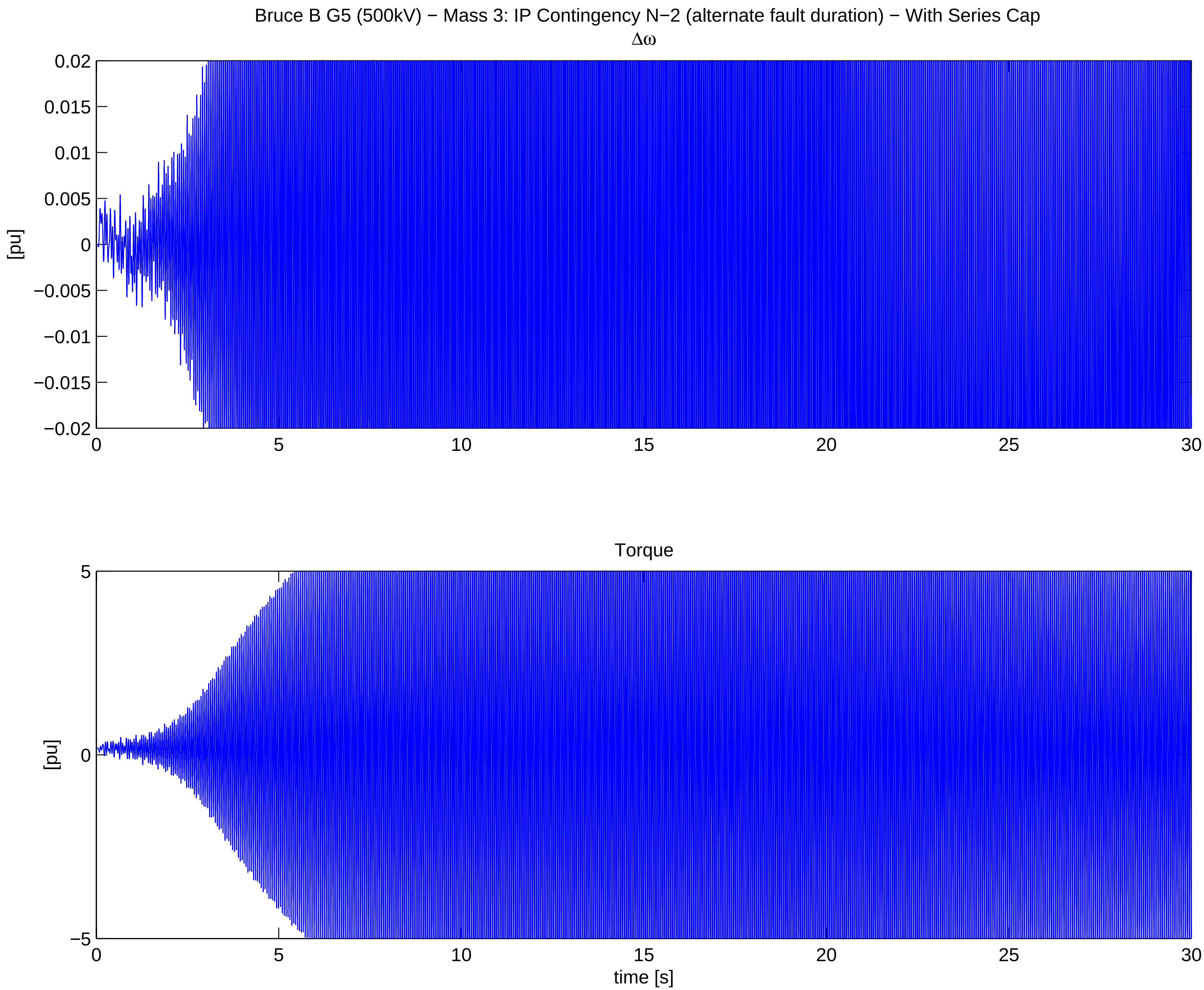


Bruce B G5 (500kV) − Mass 1: CP1 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
[pu]
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

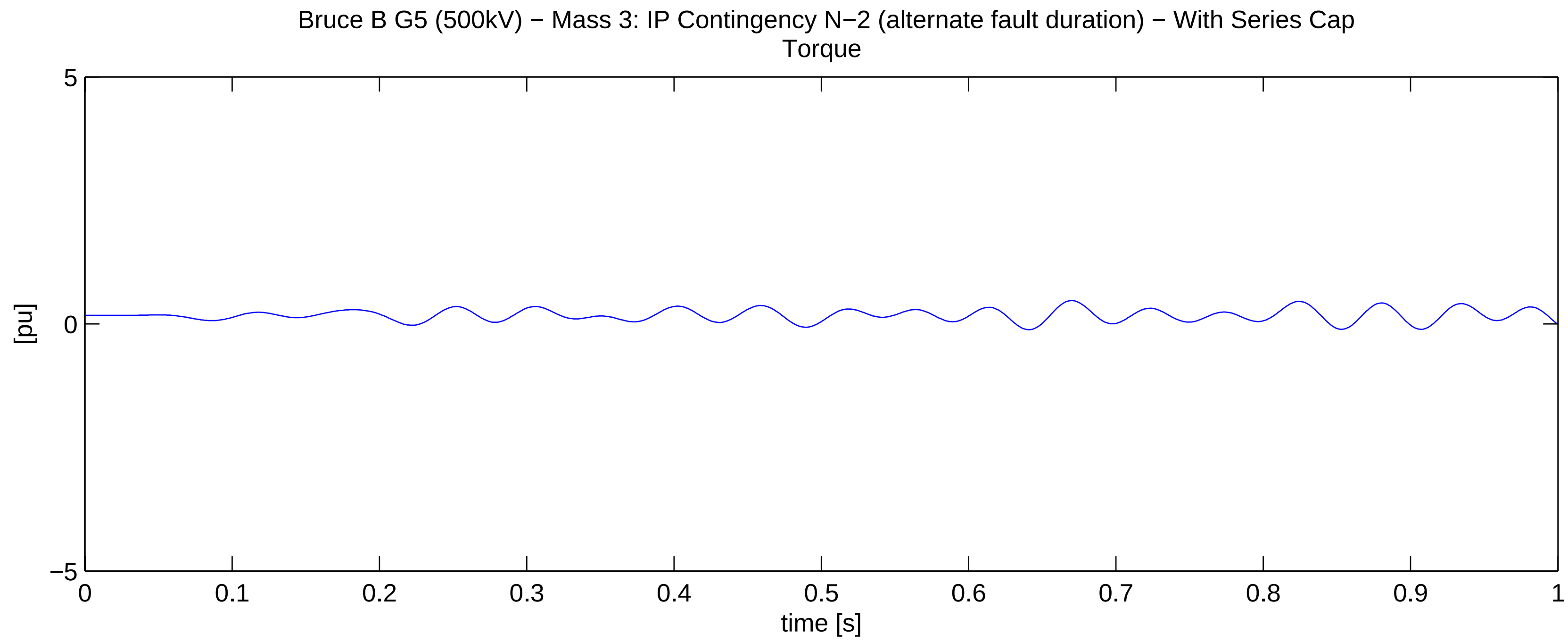

Bruce B G5 (500kV) − Mass 2: HP Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

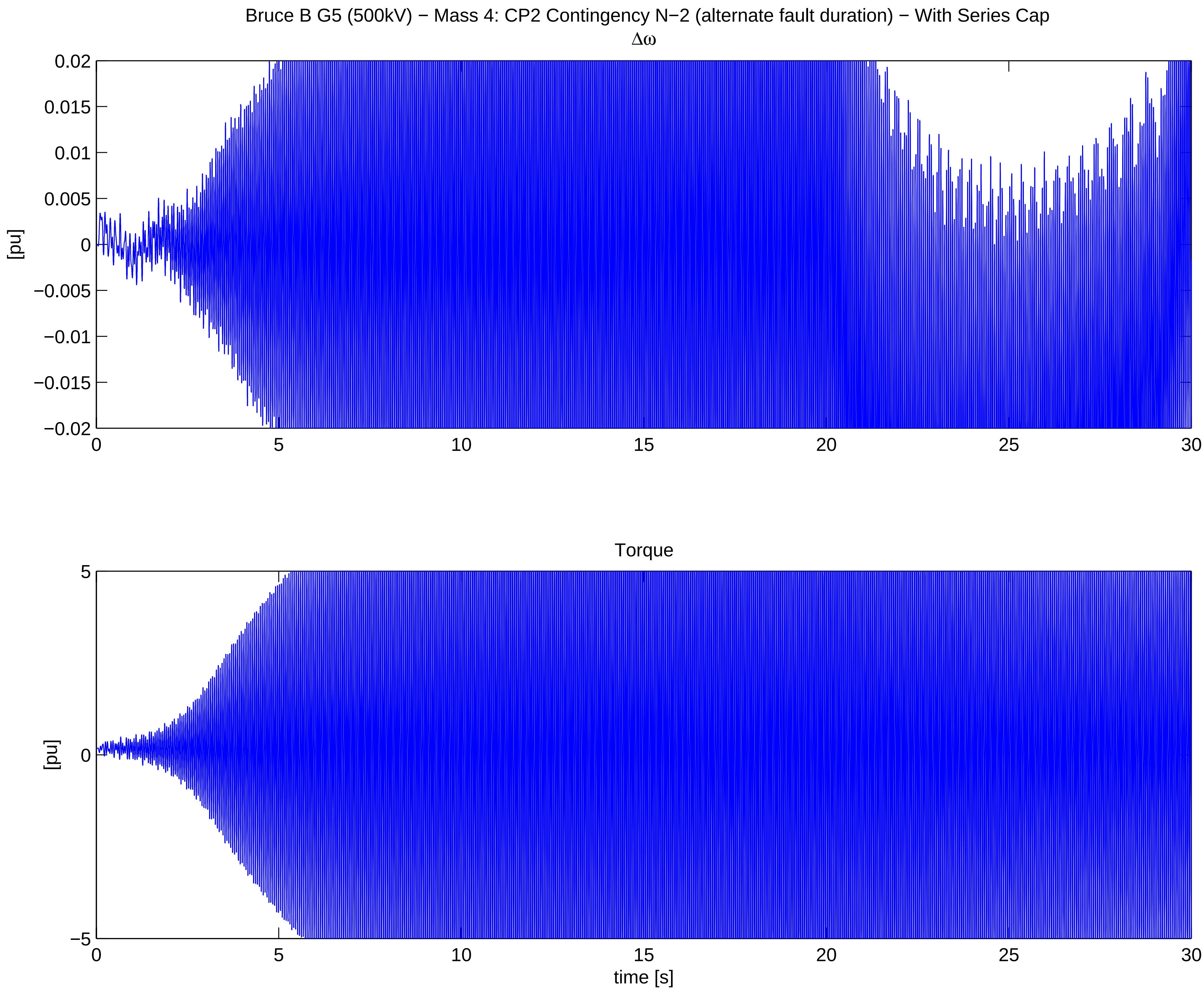


Bruce B G5 (500kV) − Mass 2: HP Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

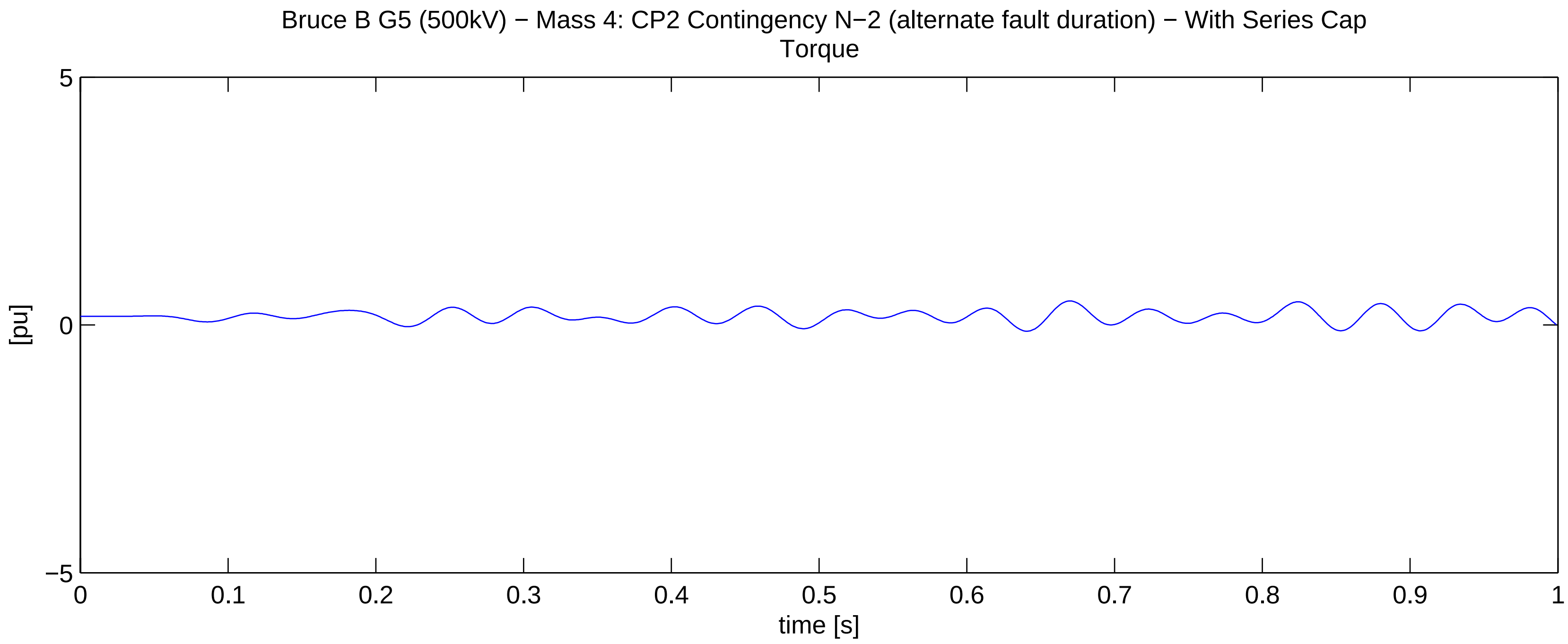


Bruce B G5 (500kV) − Mass 3: IP Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

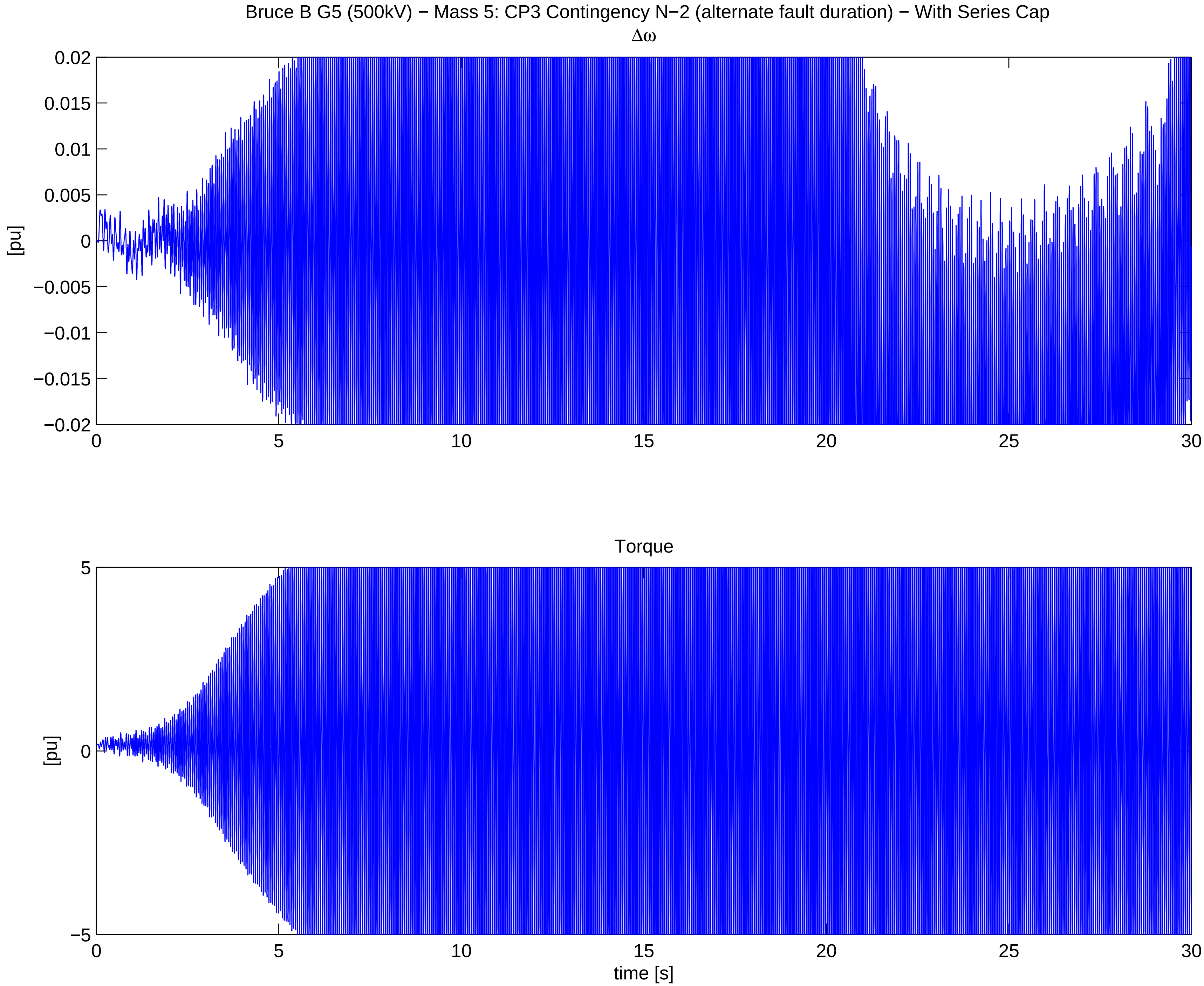

Bruce B G5 (500kV) − Mass 3: IP Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



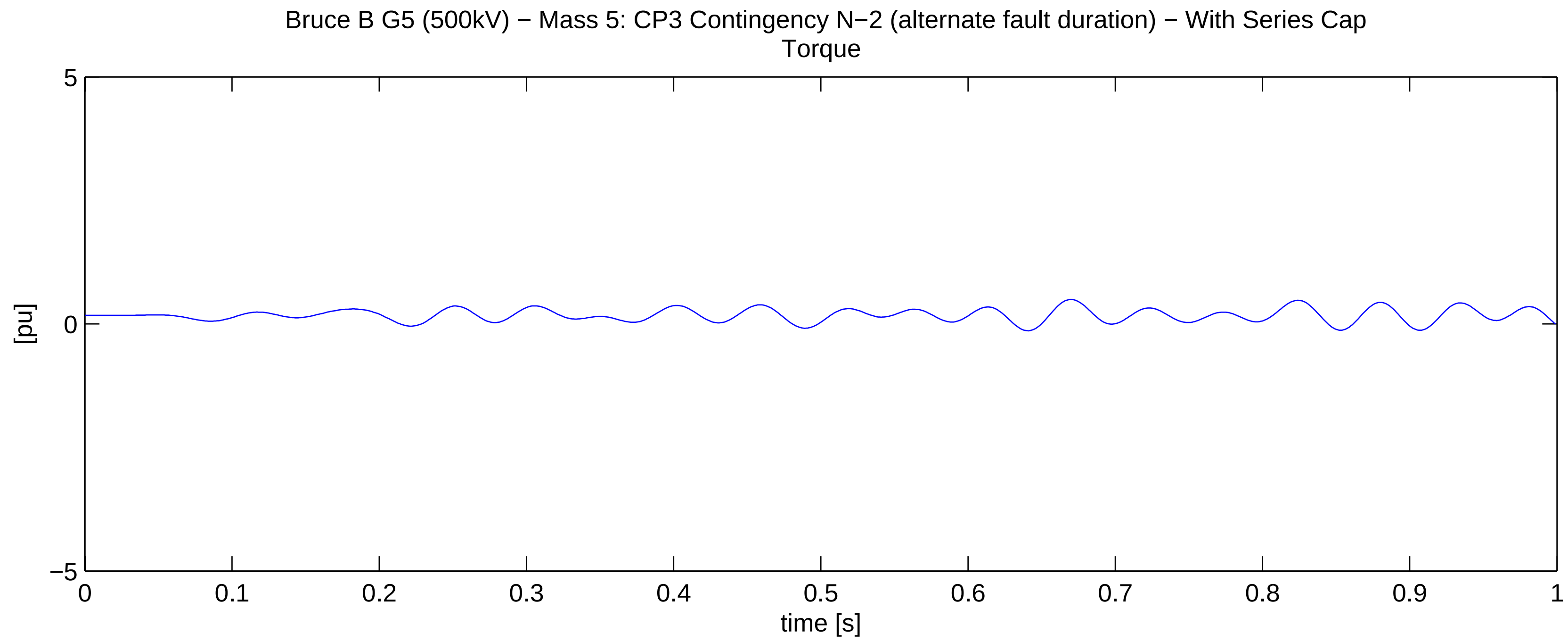
Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

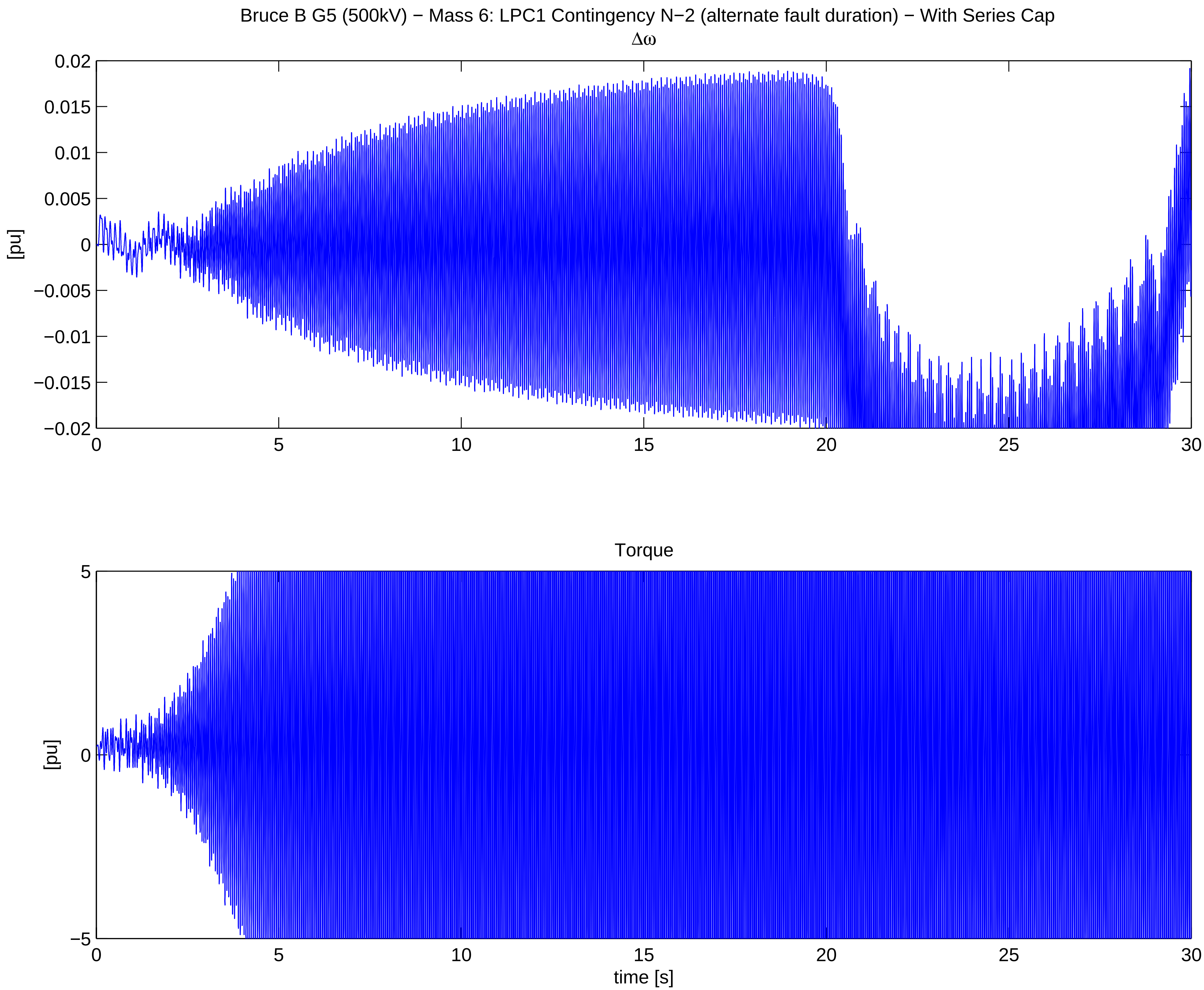


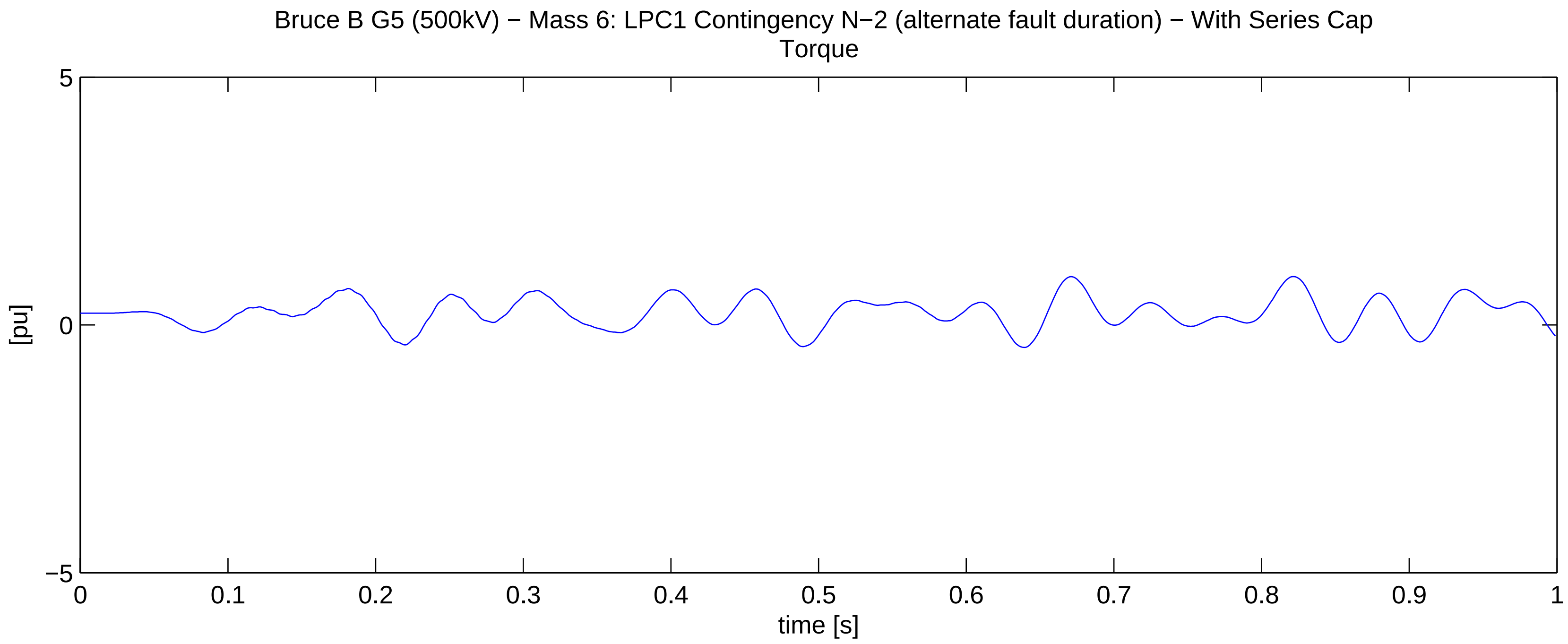
Bruce B G5 (500kV) − Mass 4: CP2 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



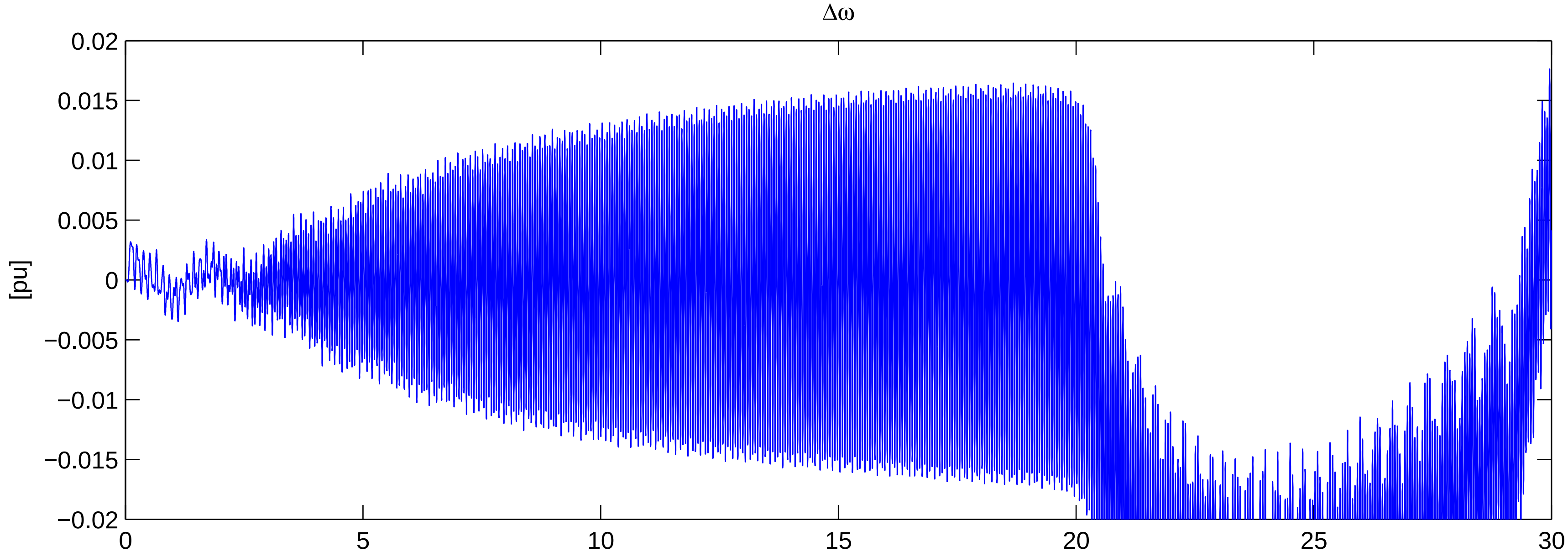
Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

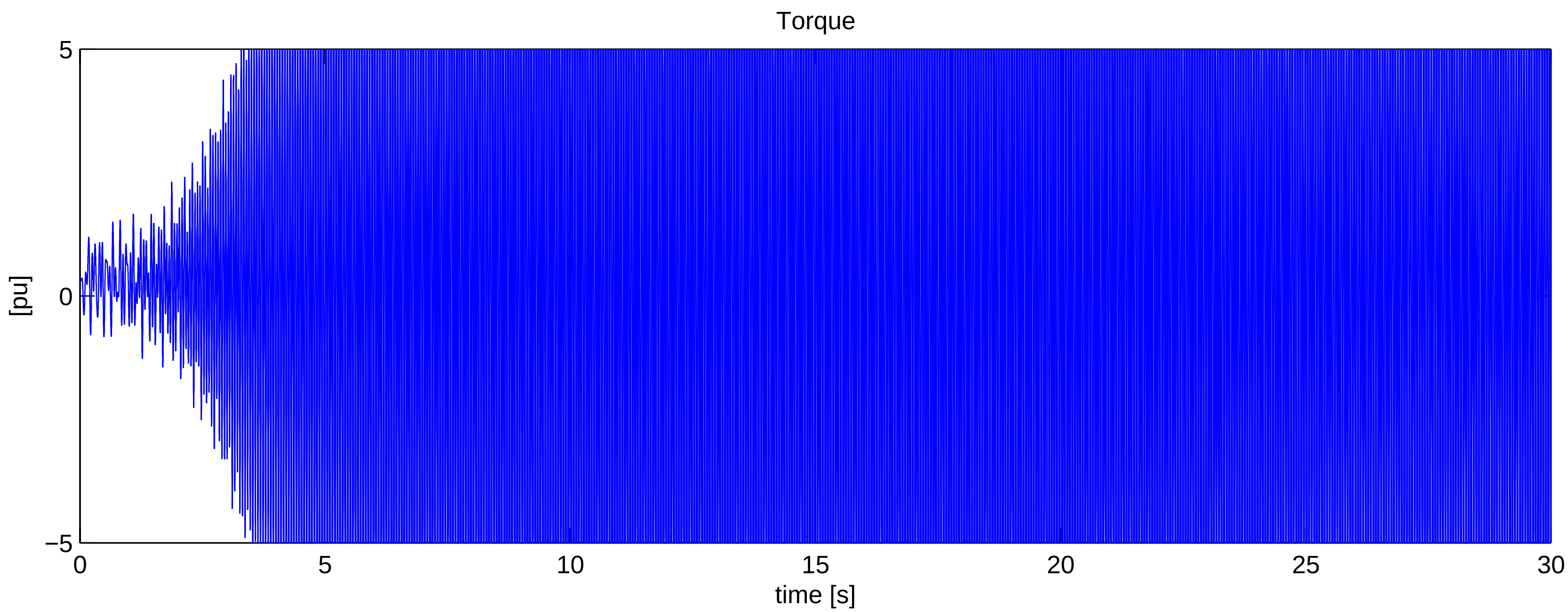

Bruce B G5 (500kV) − Mass 5: CP3 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

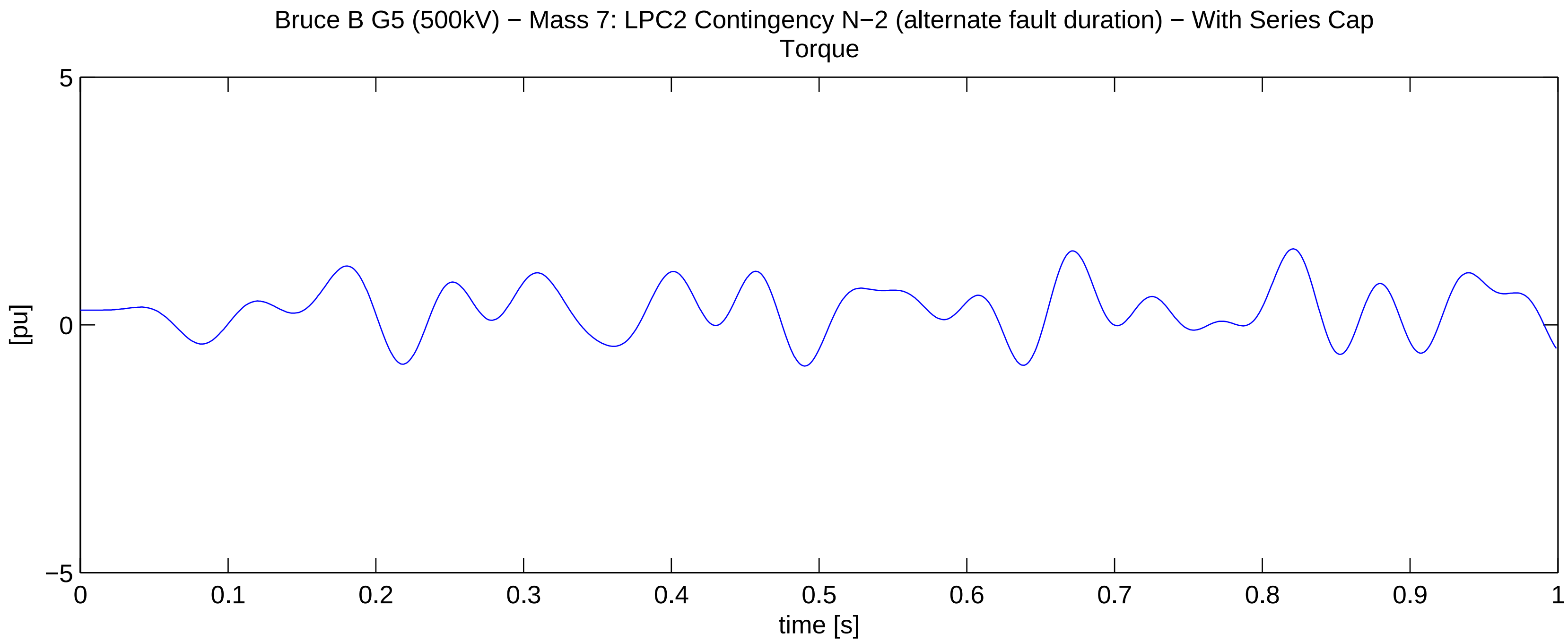

Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 6: LPC1 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−2 (alternate fault duration) − With Series Cap

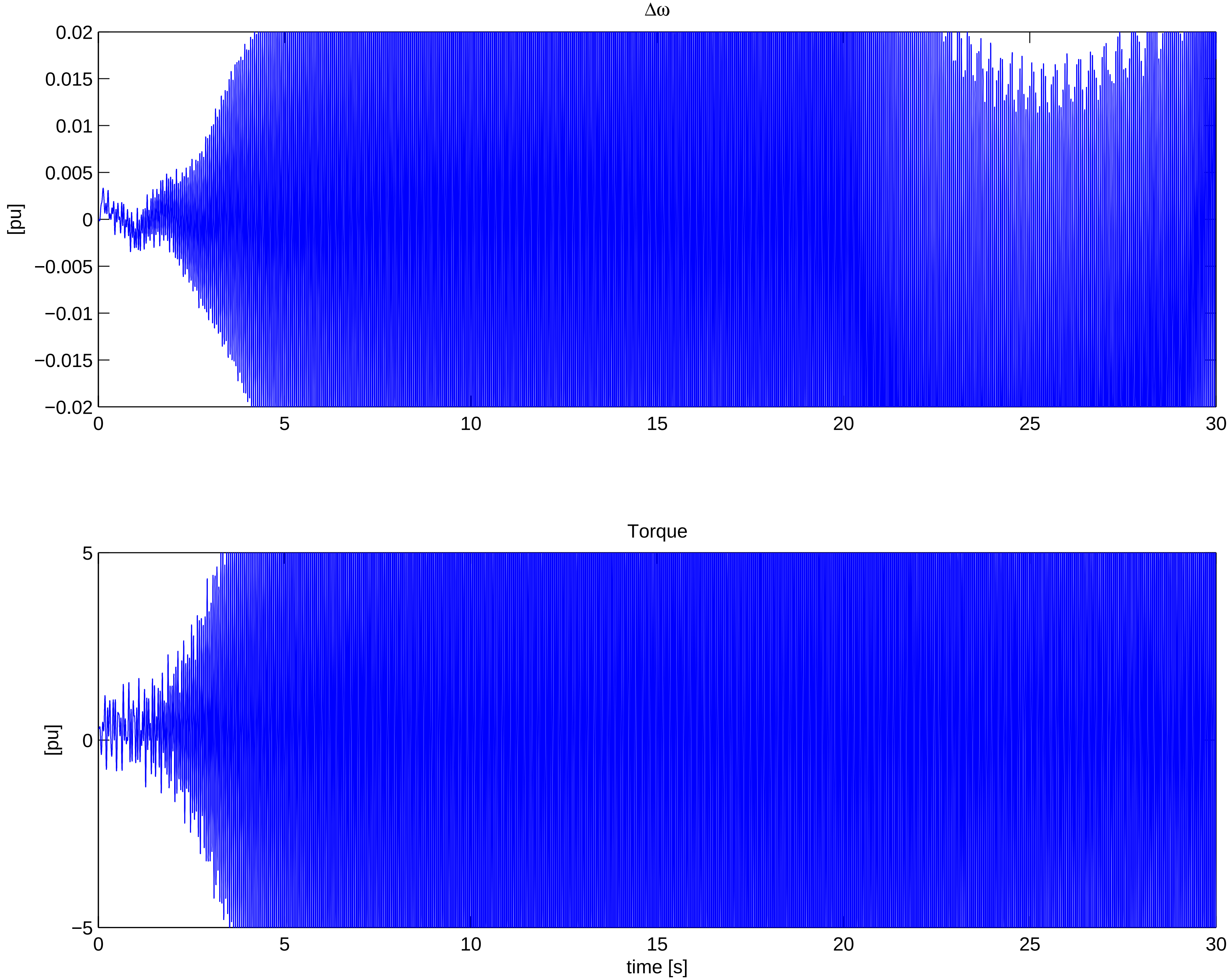


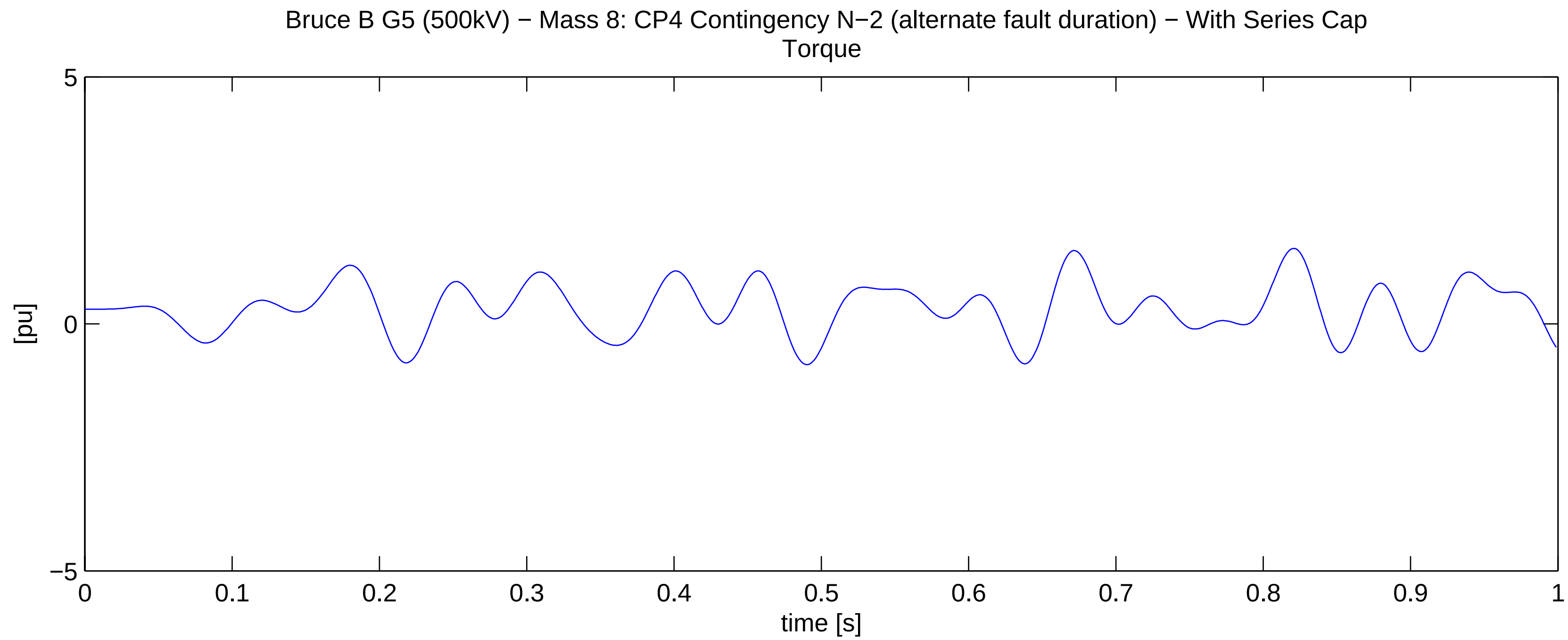




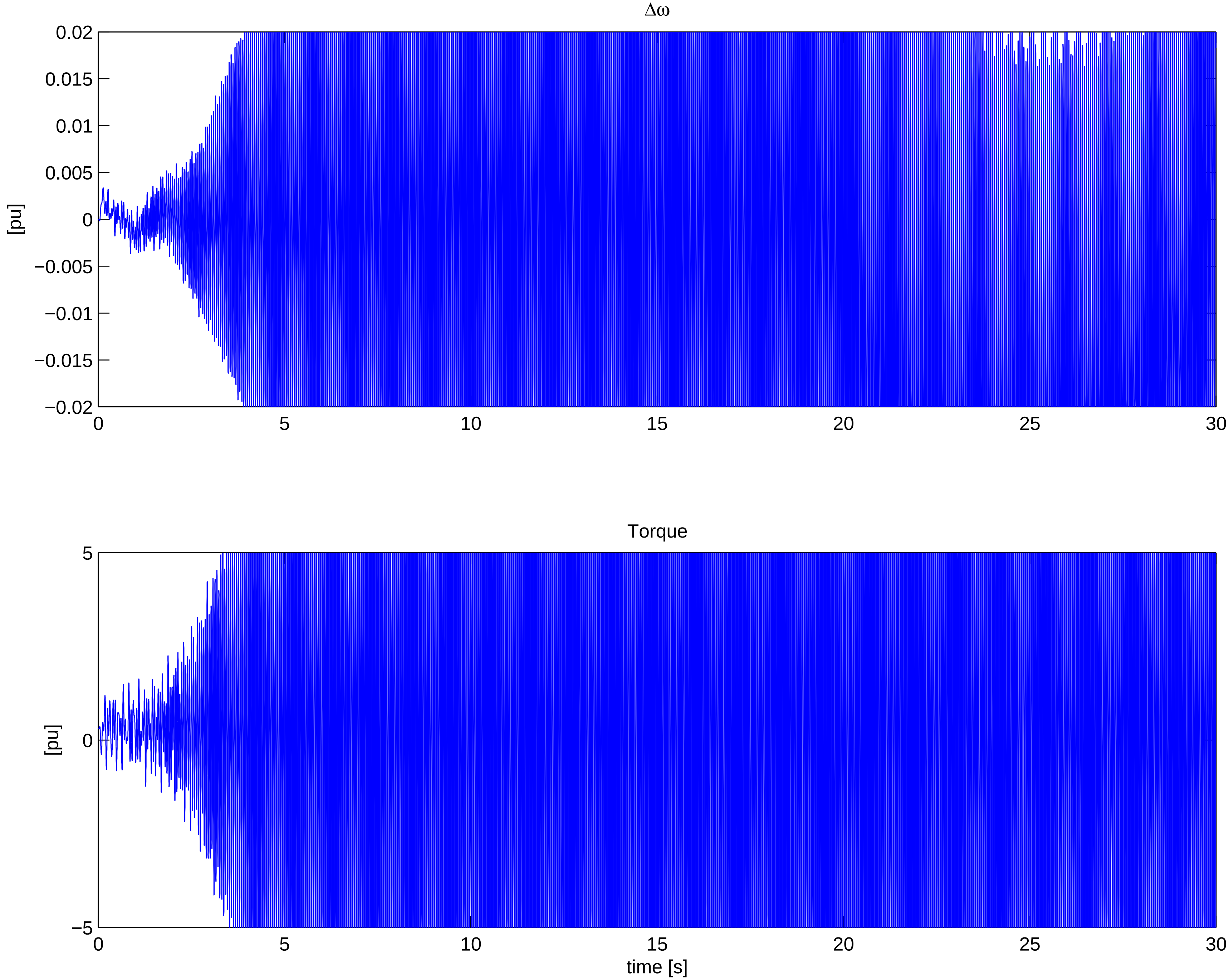
Bruce B G5 (500kV) − Mass 7: LPC2 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

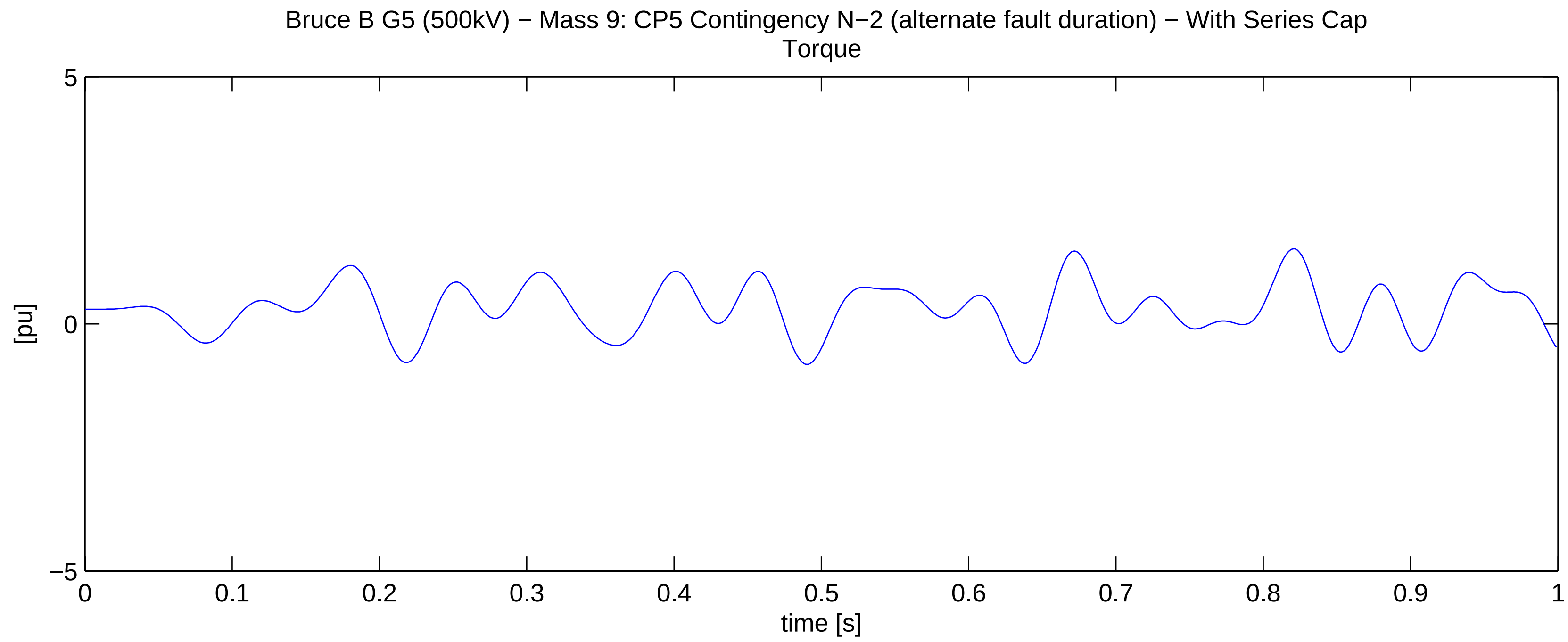
Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−2 (alternate fault duration) − With Series Cap

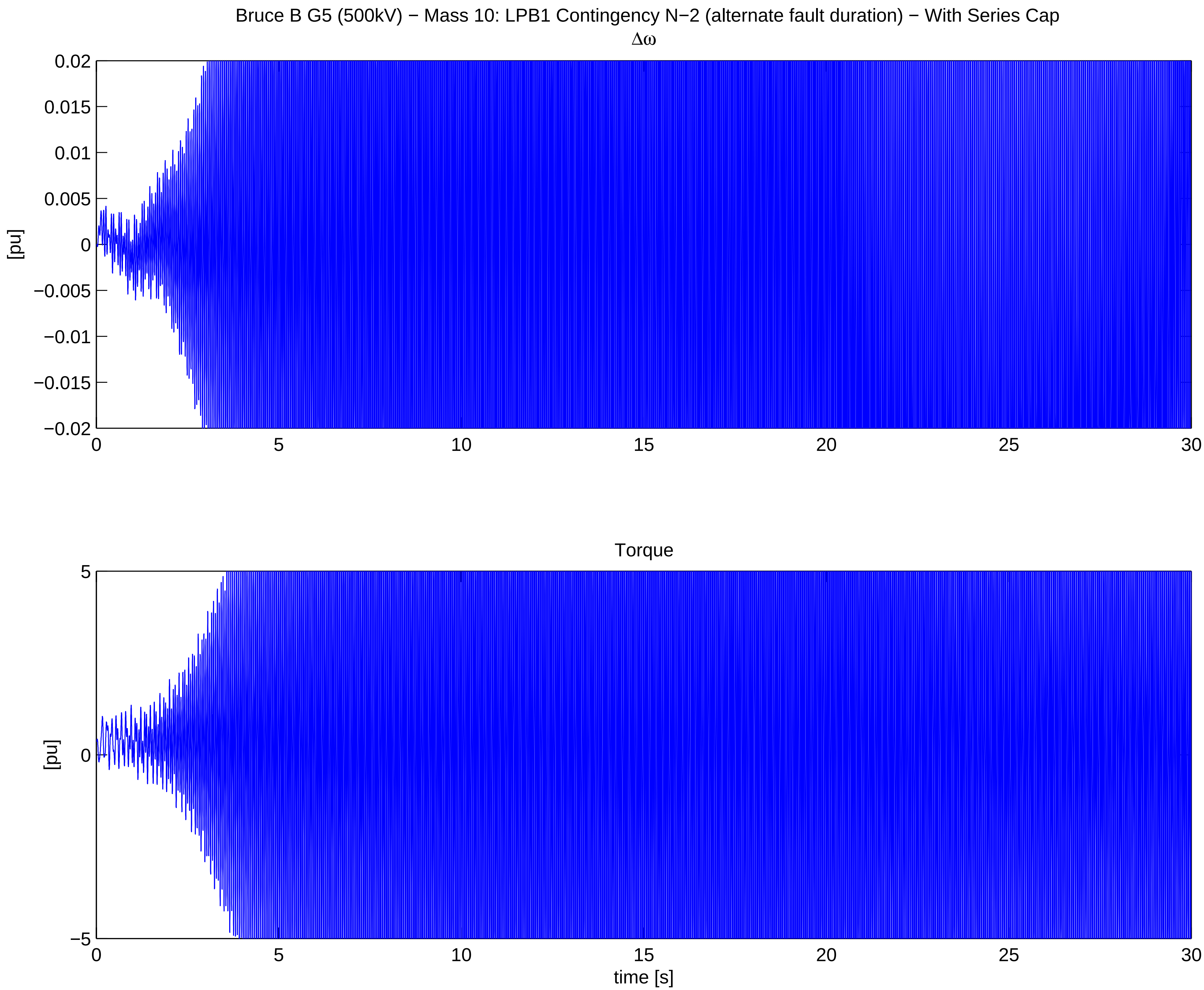



Bruce B G5 (500kV) − Mass 8: CP4 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

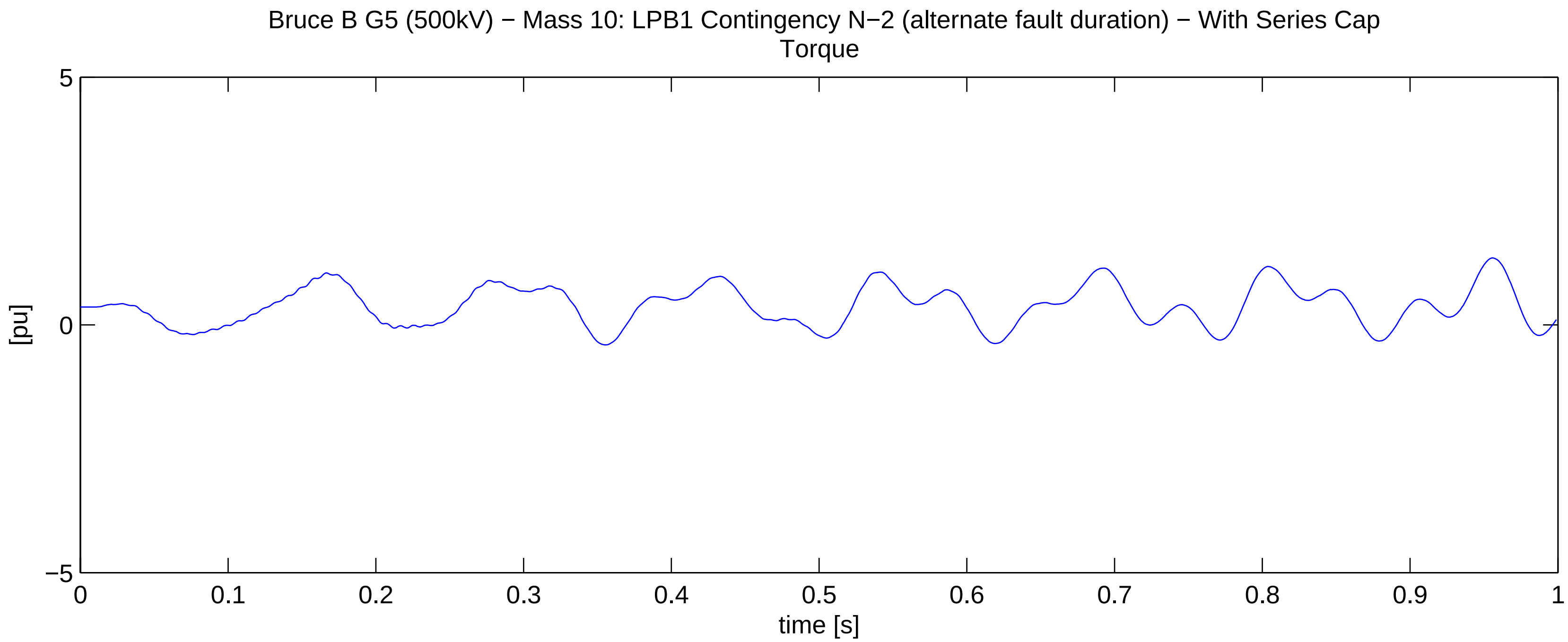
Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−2 (alternate fault duration) − With Series Cap

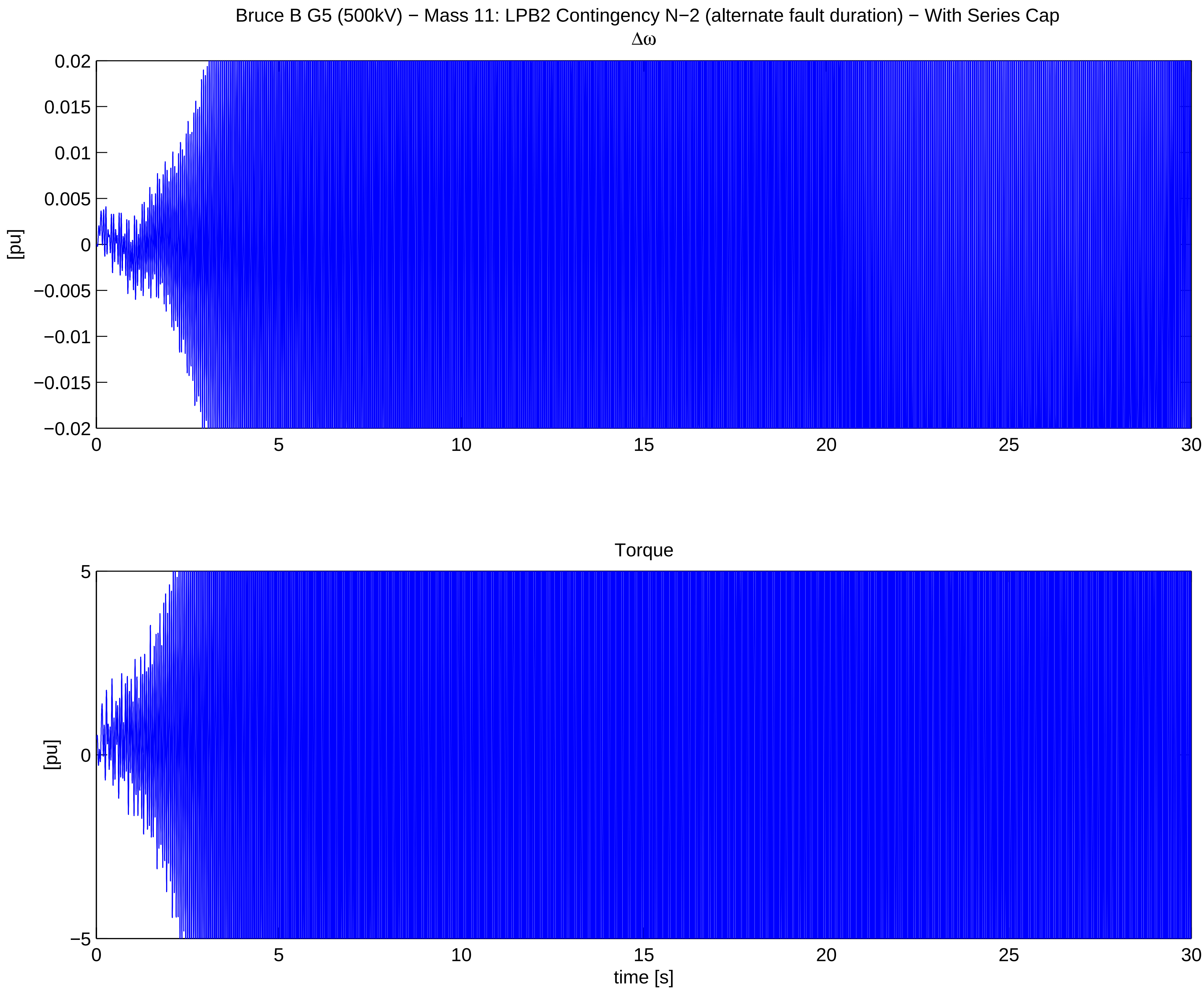



Bruce B G5 (500kV) − Mass 9: CP5 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

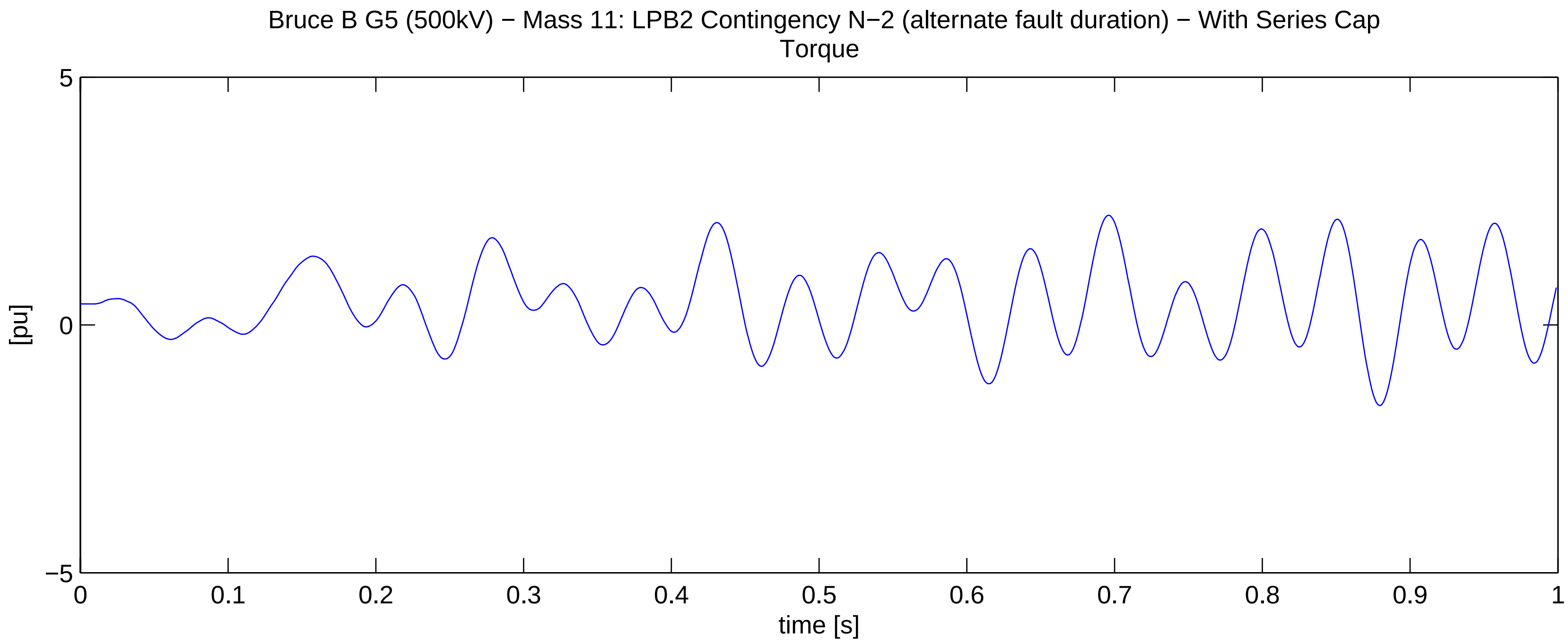


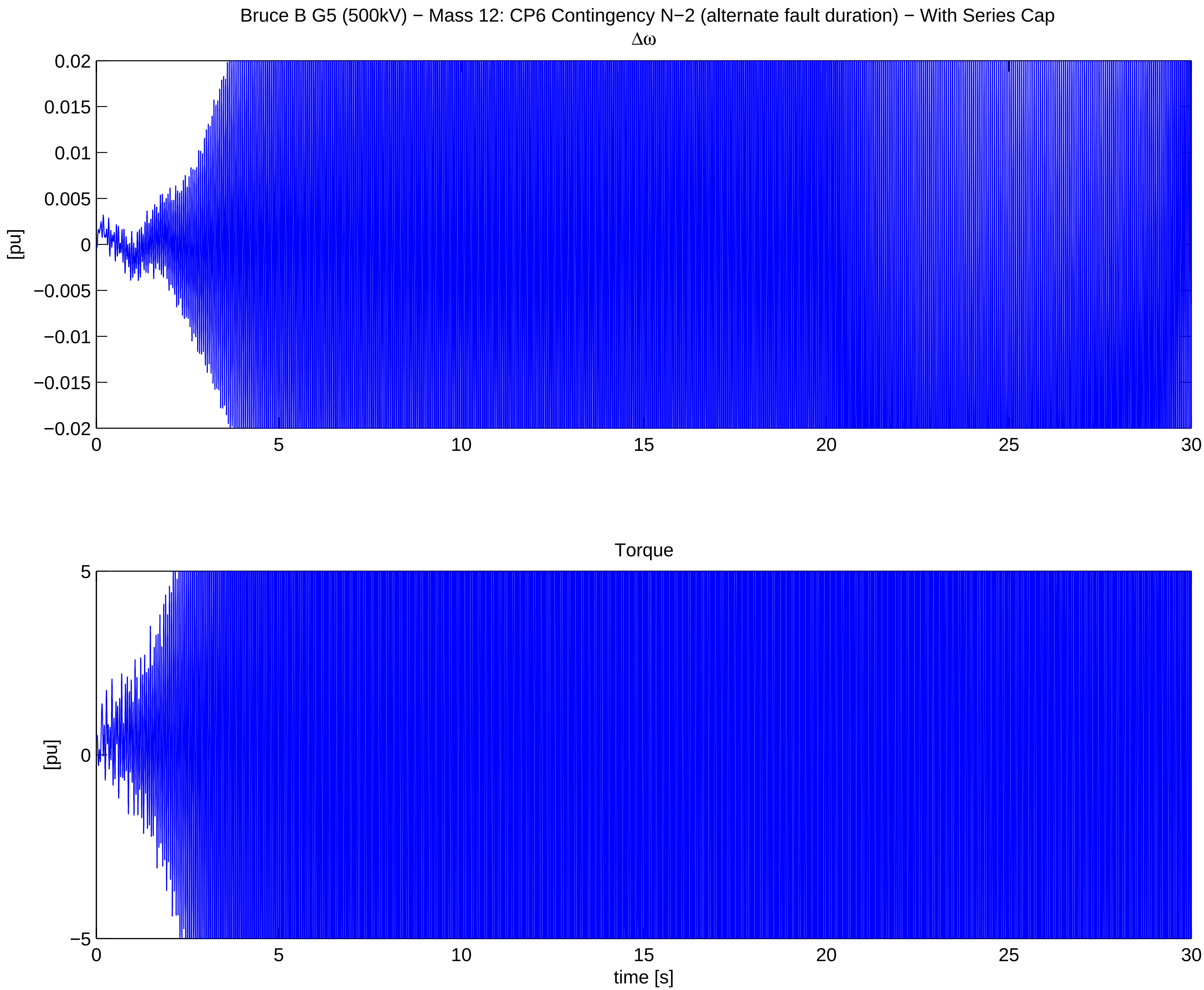
Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 10: LPB1 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

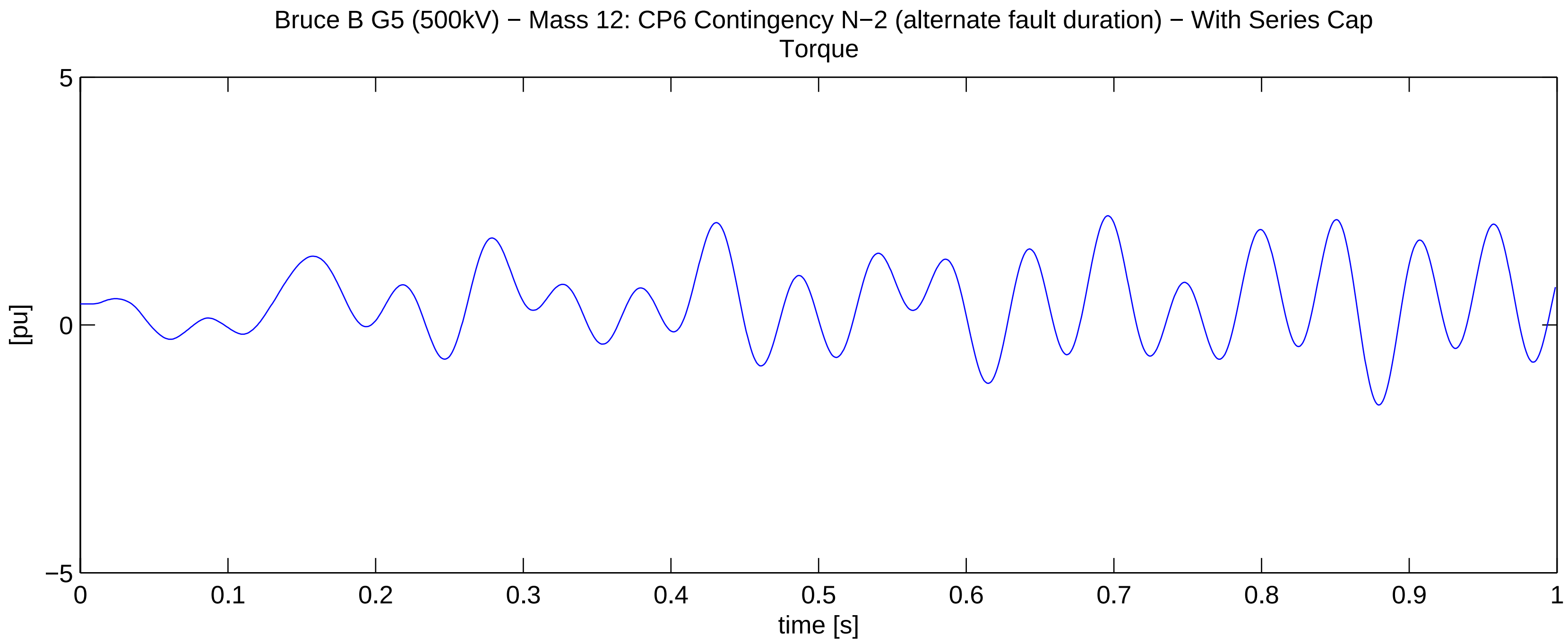


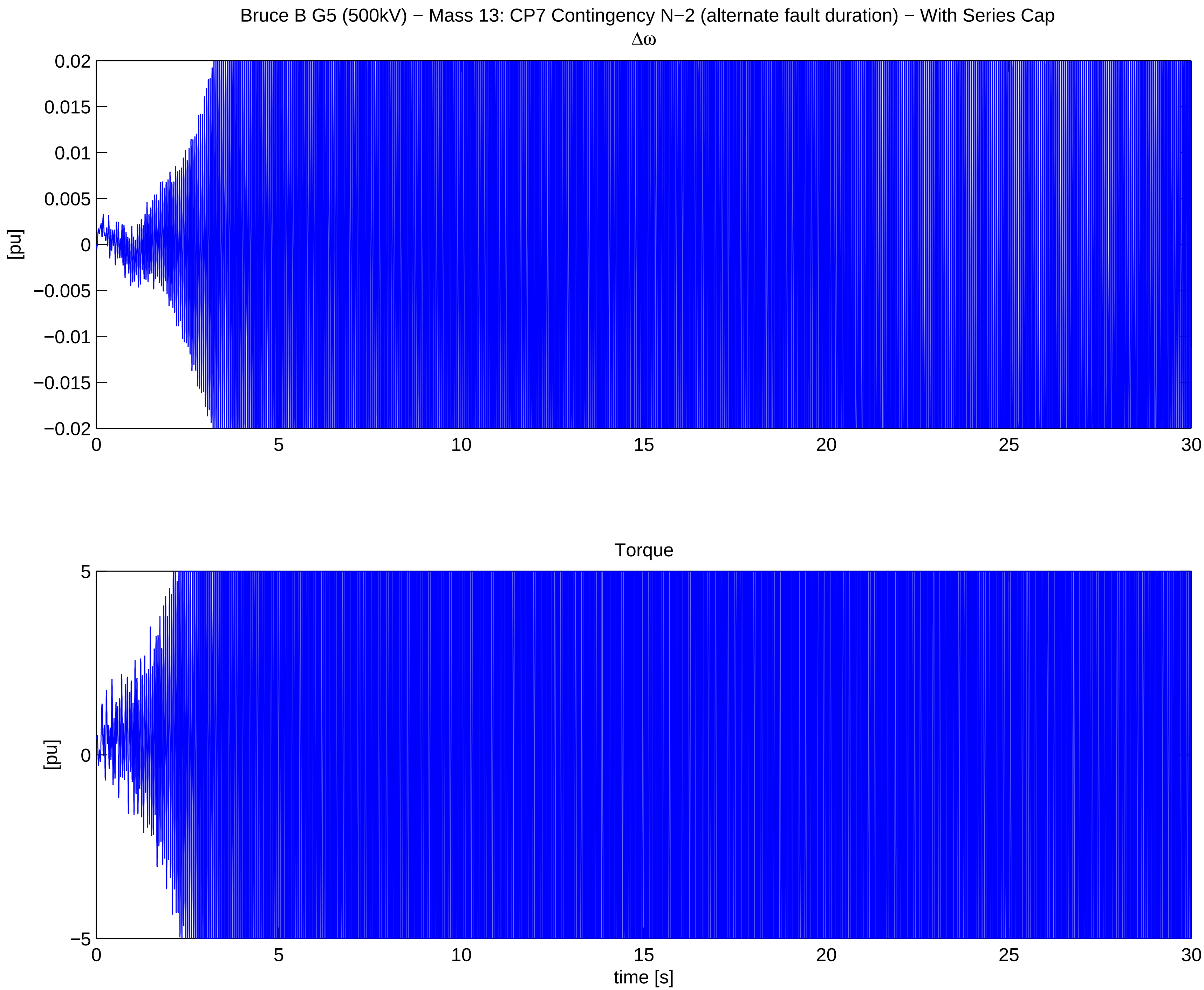
Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

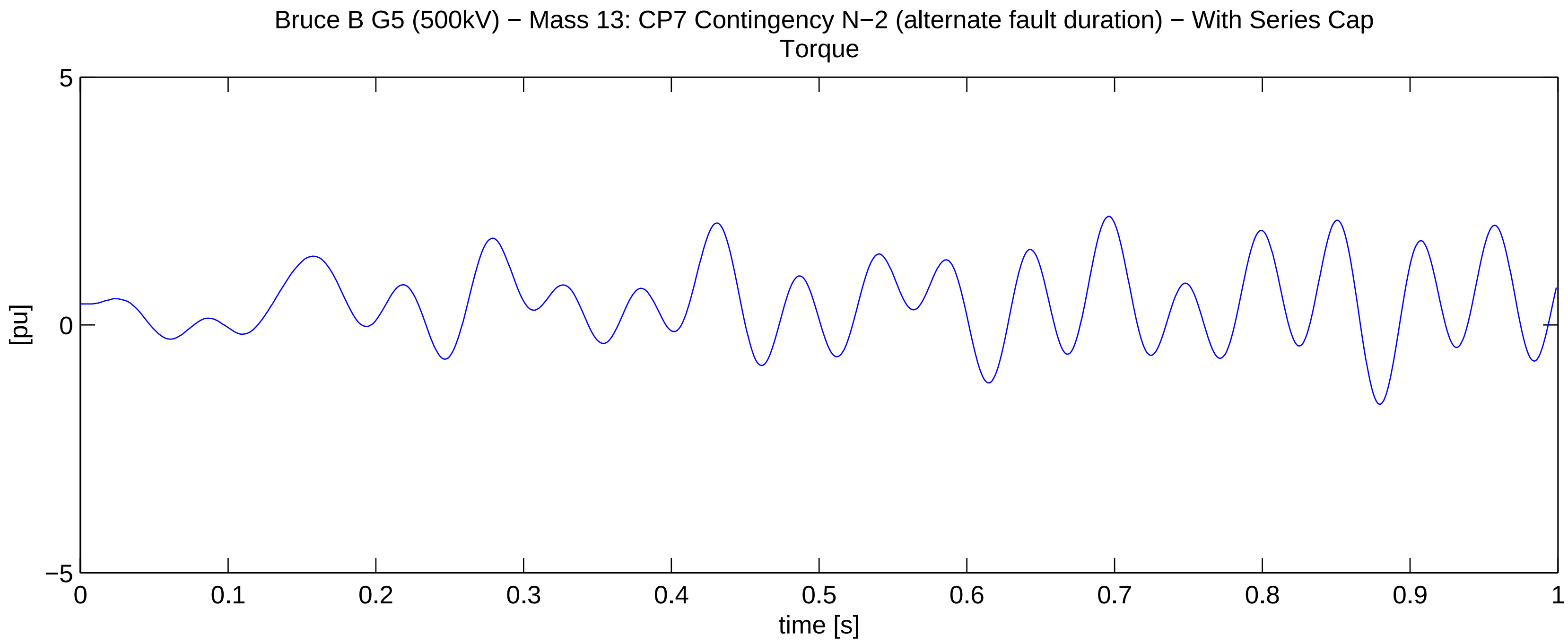

Bruce B G5 (500kV) − Mass 11: LPB2 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

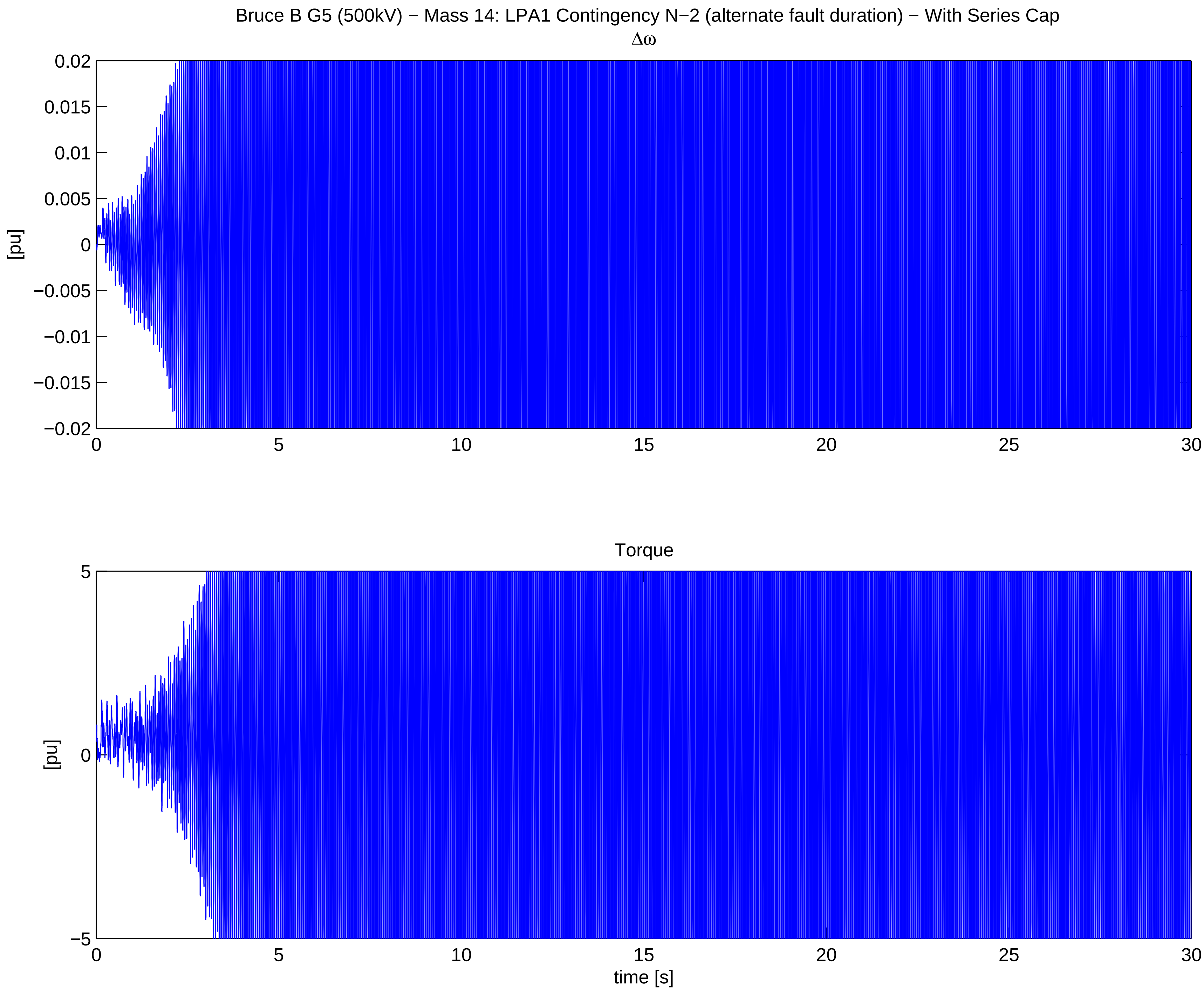


Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

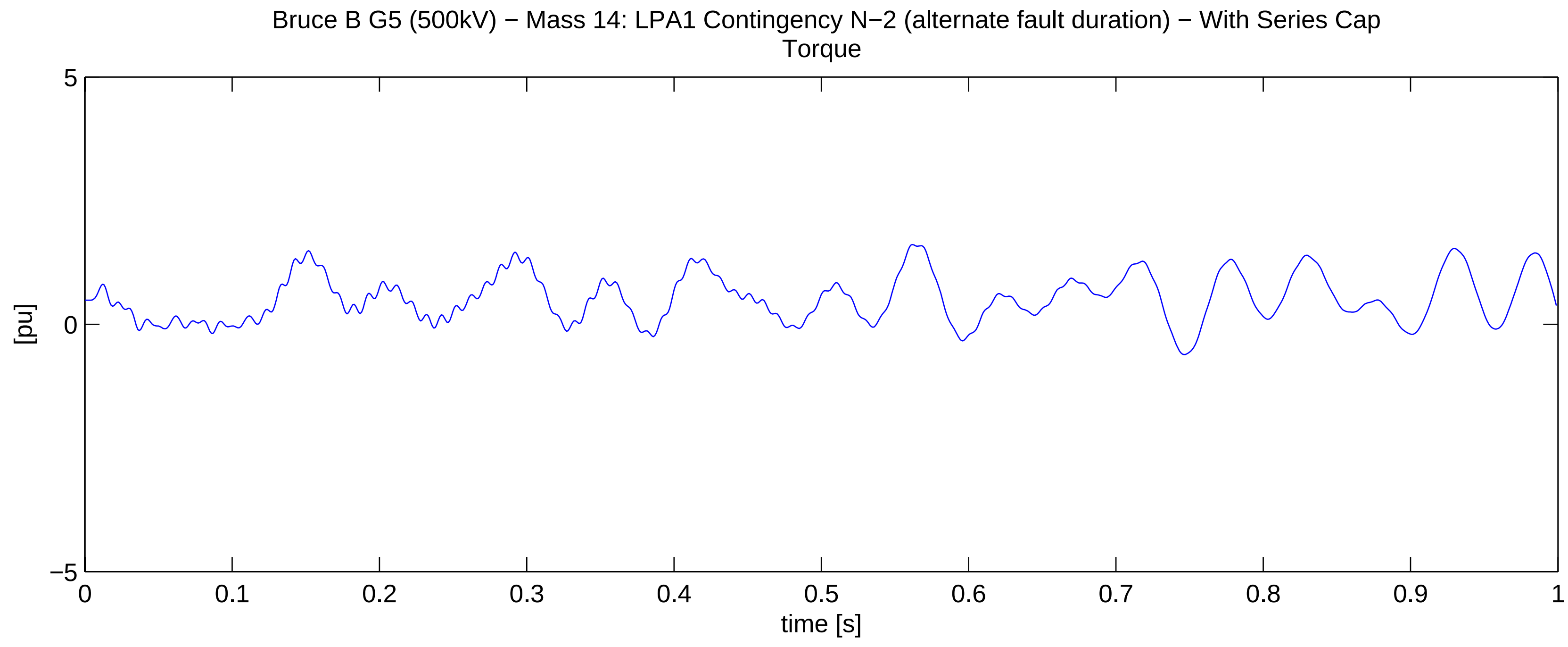

Bruce B G5 (500kV) − Mass 12: CP6 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

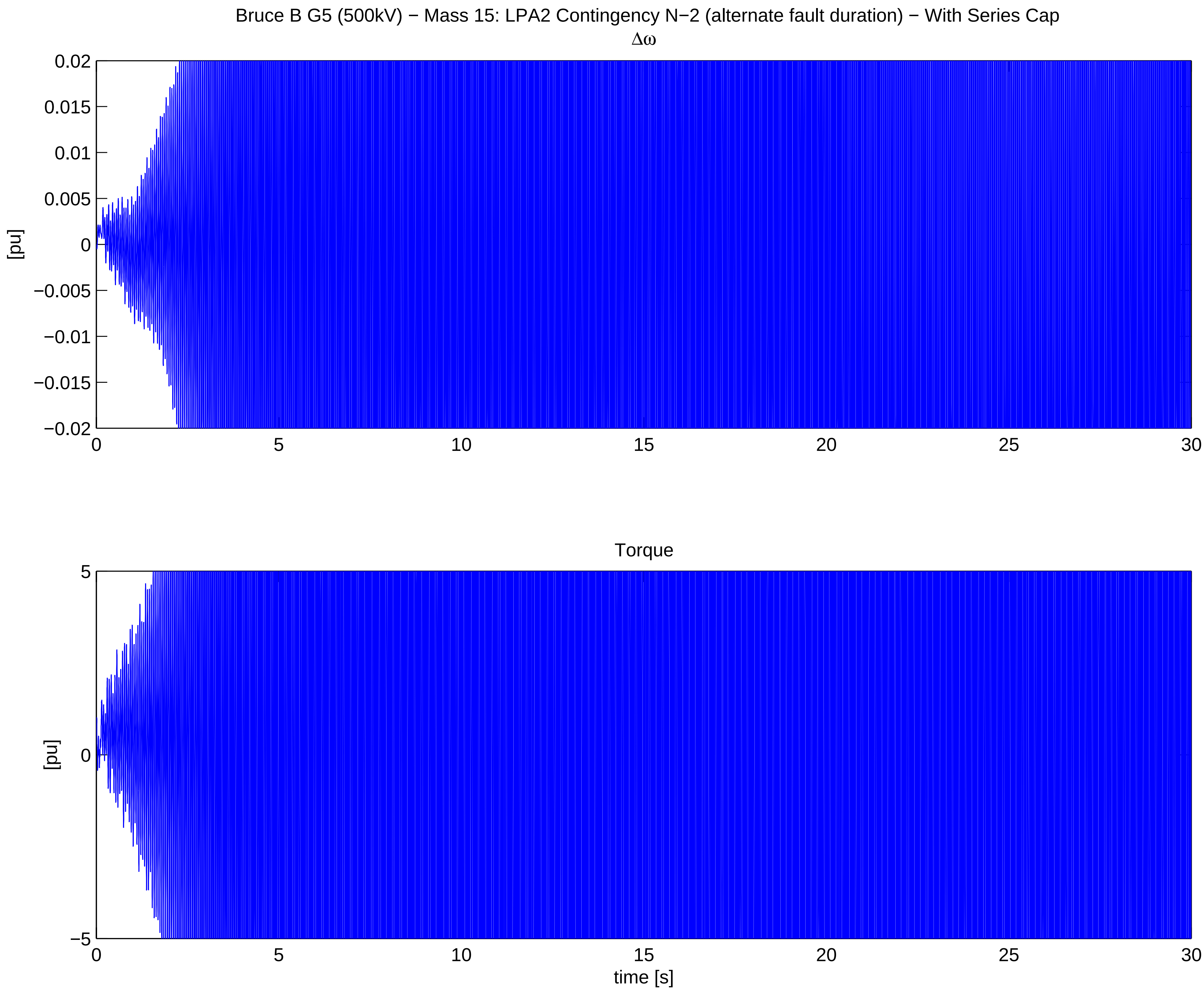

Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]


Bruce B G5 (500kV) − Mass 13: CP7 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

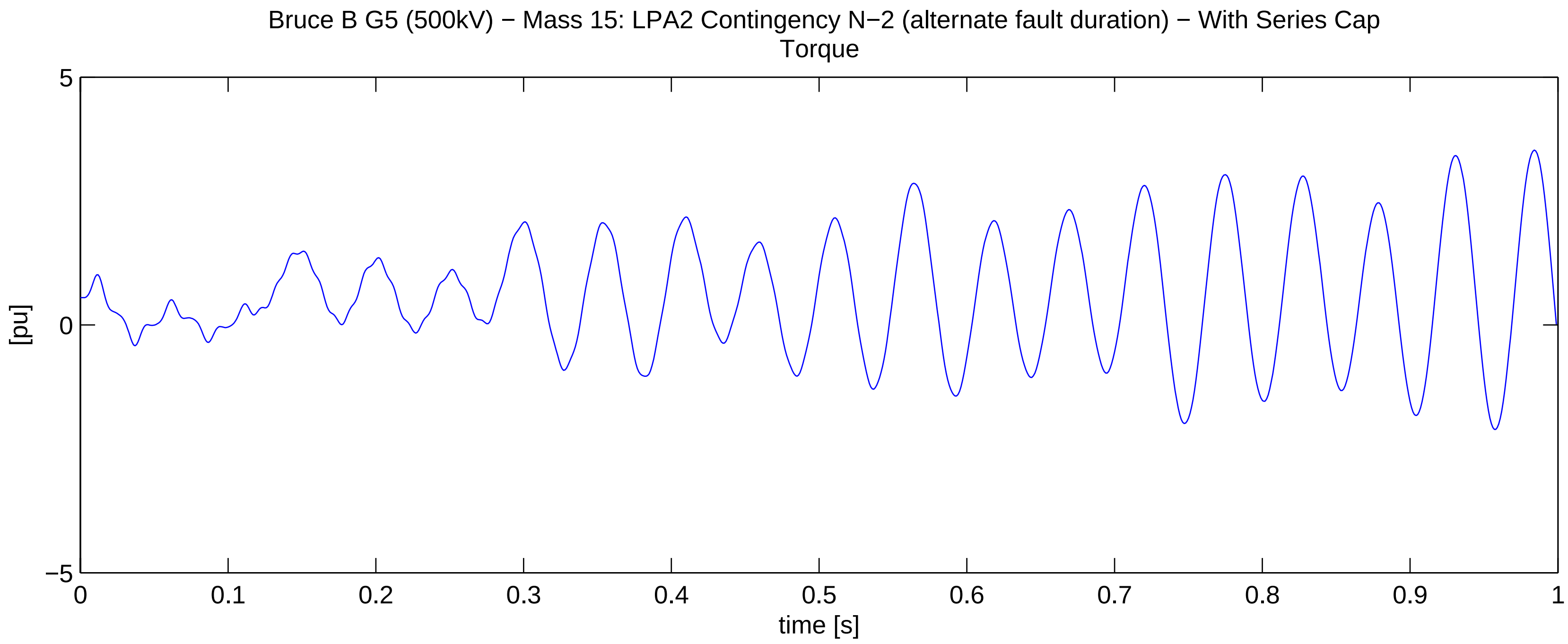


Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

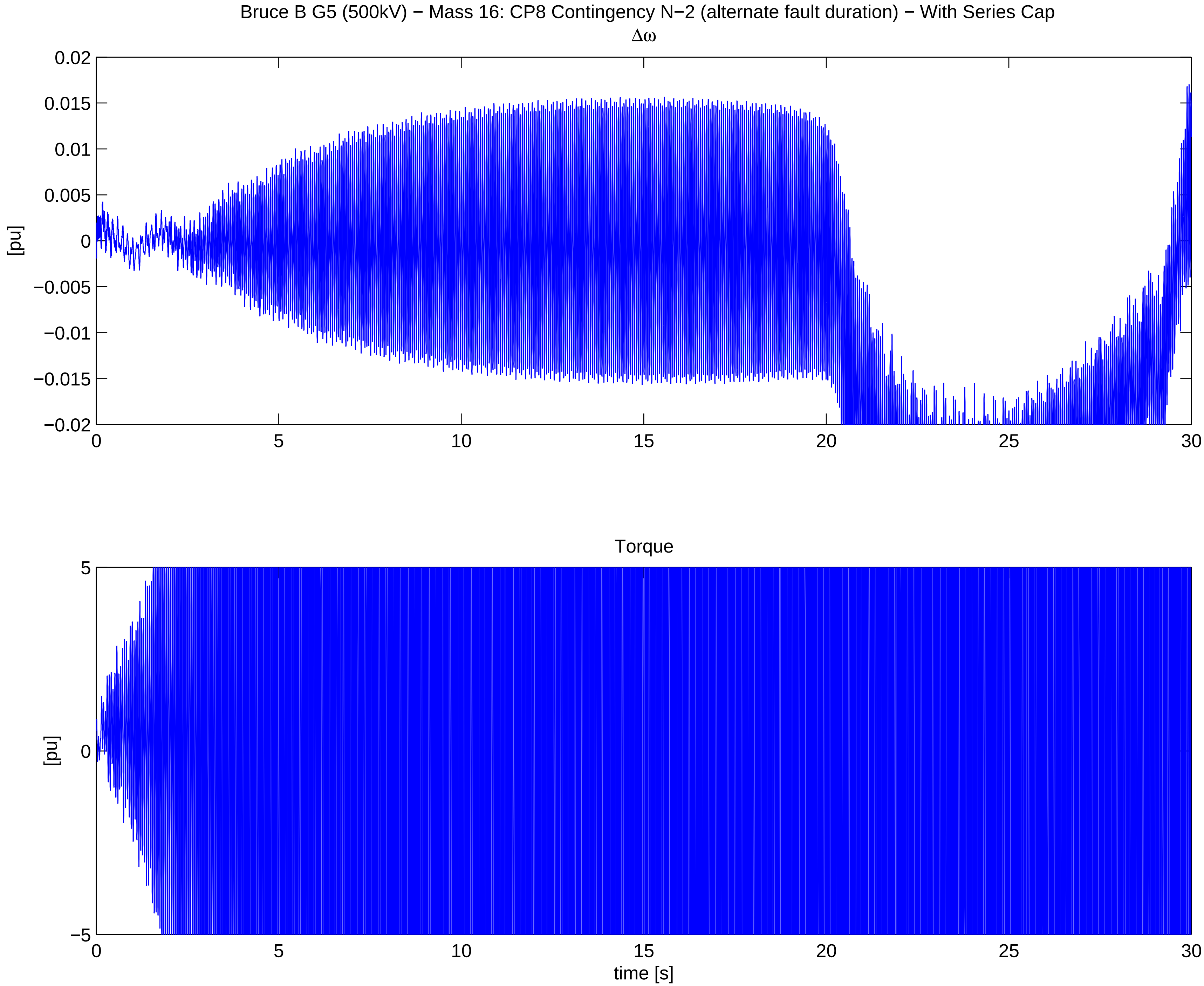

Bruce B G5 (500kV) − Mass 14: LPA1 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

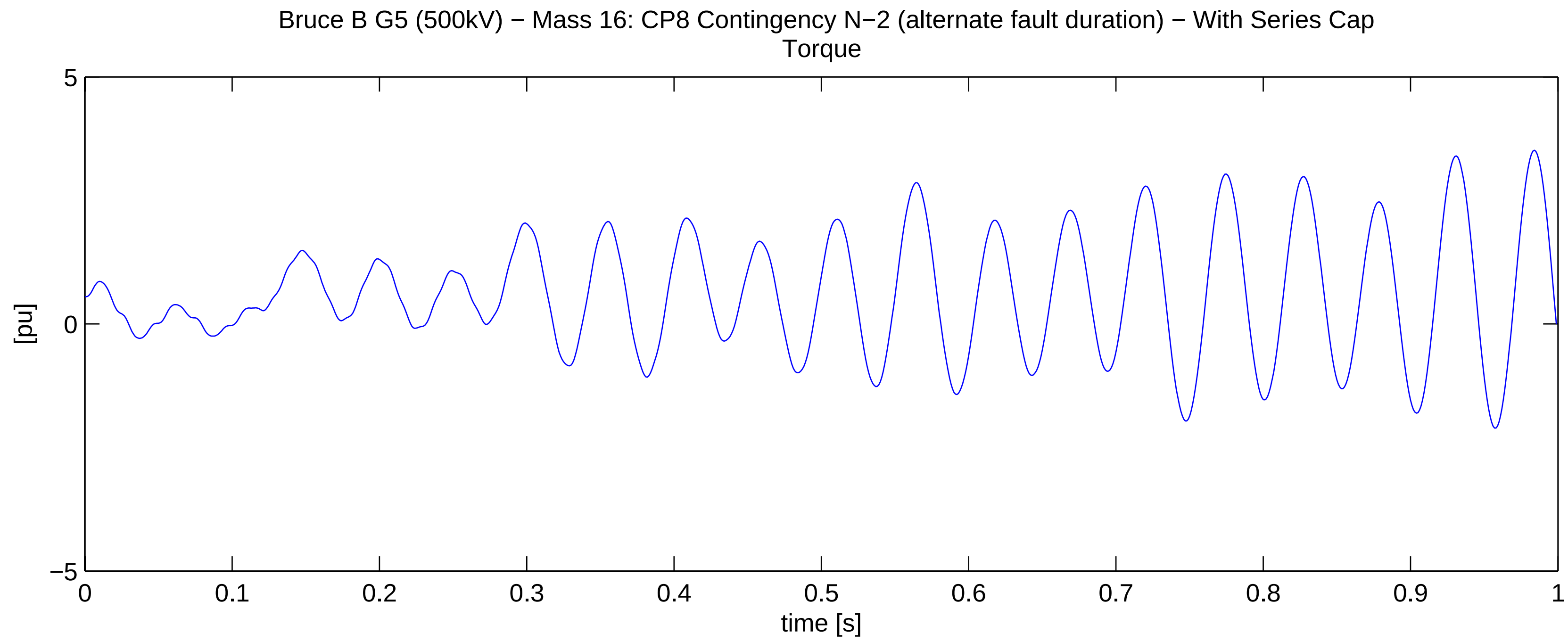


Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]

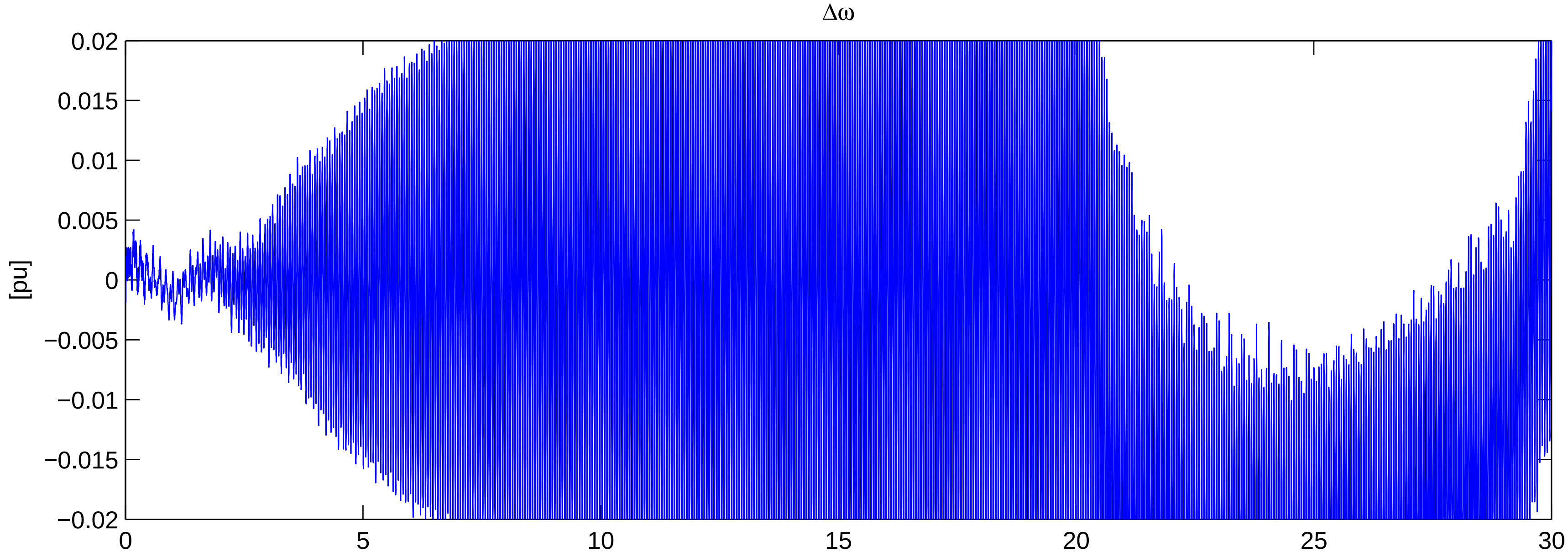


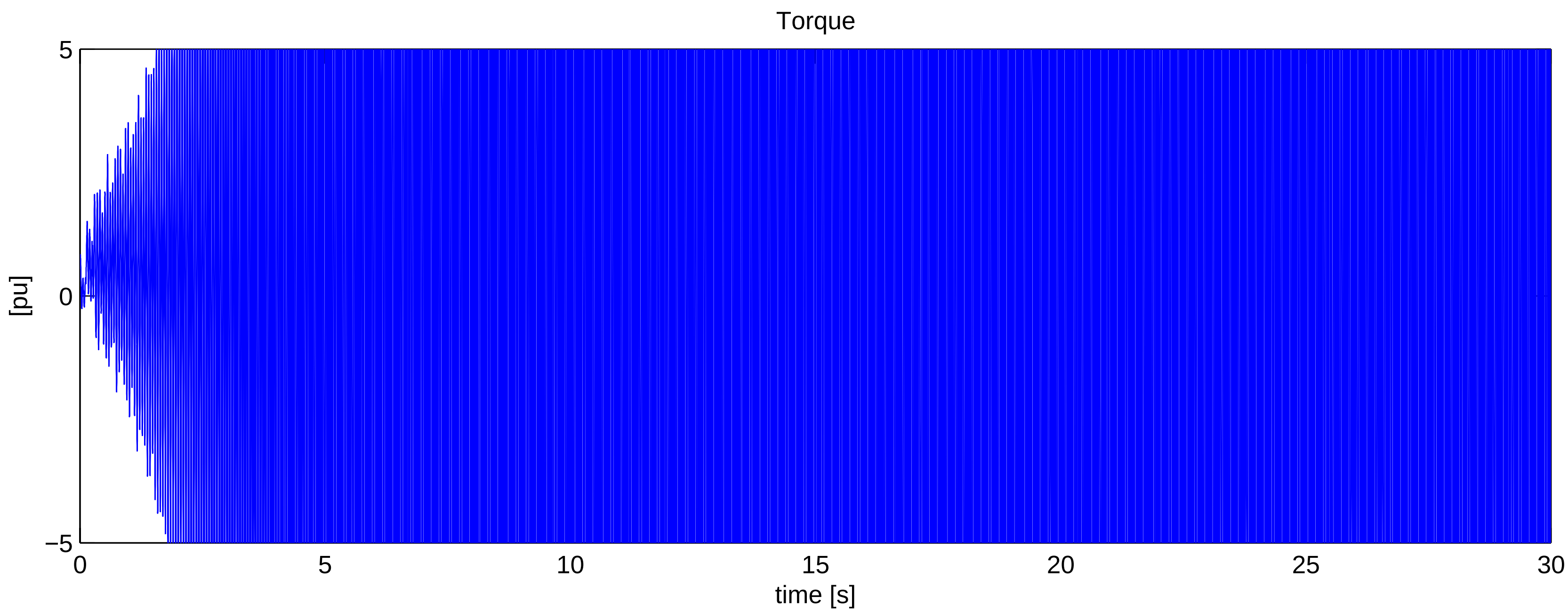
Bruce B G5 (500kV) − Mass 15: LPA2 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

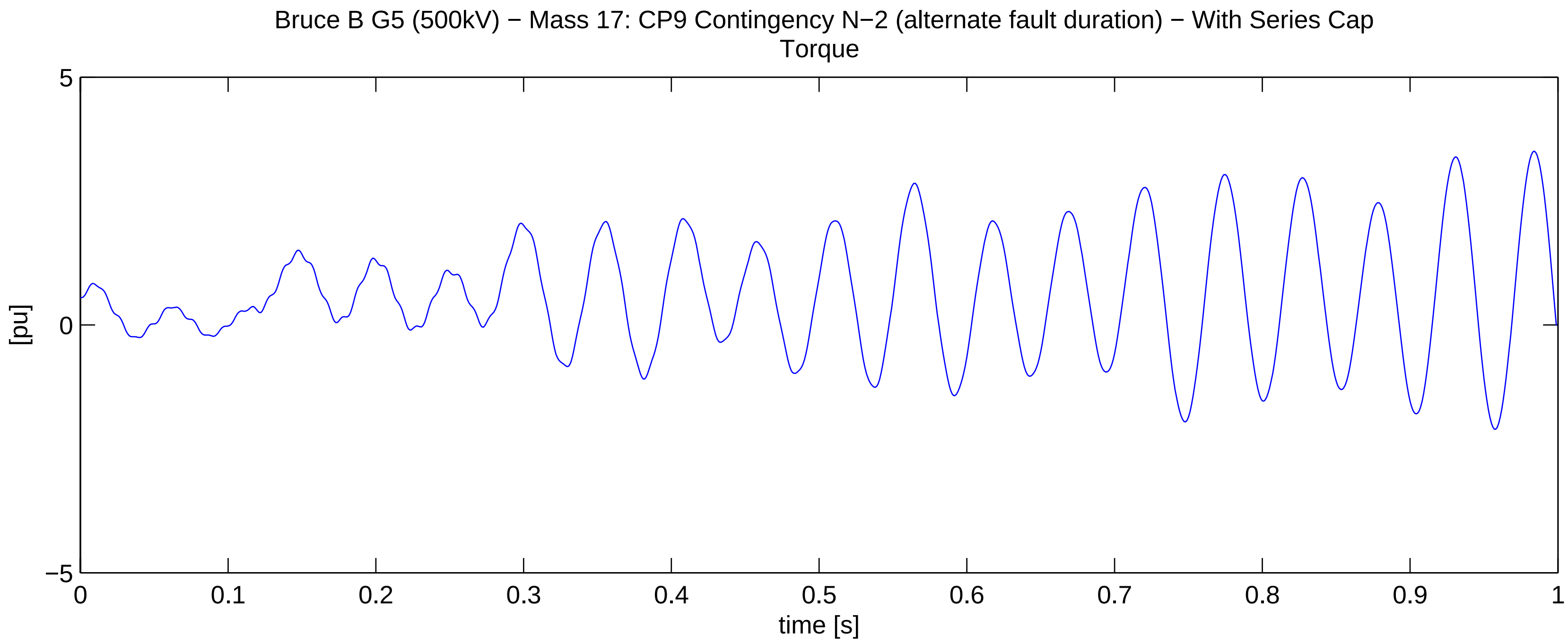

Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]

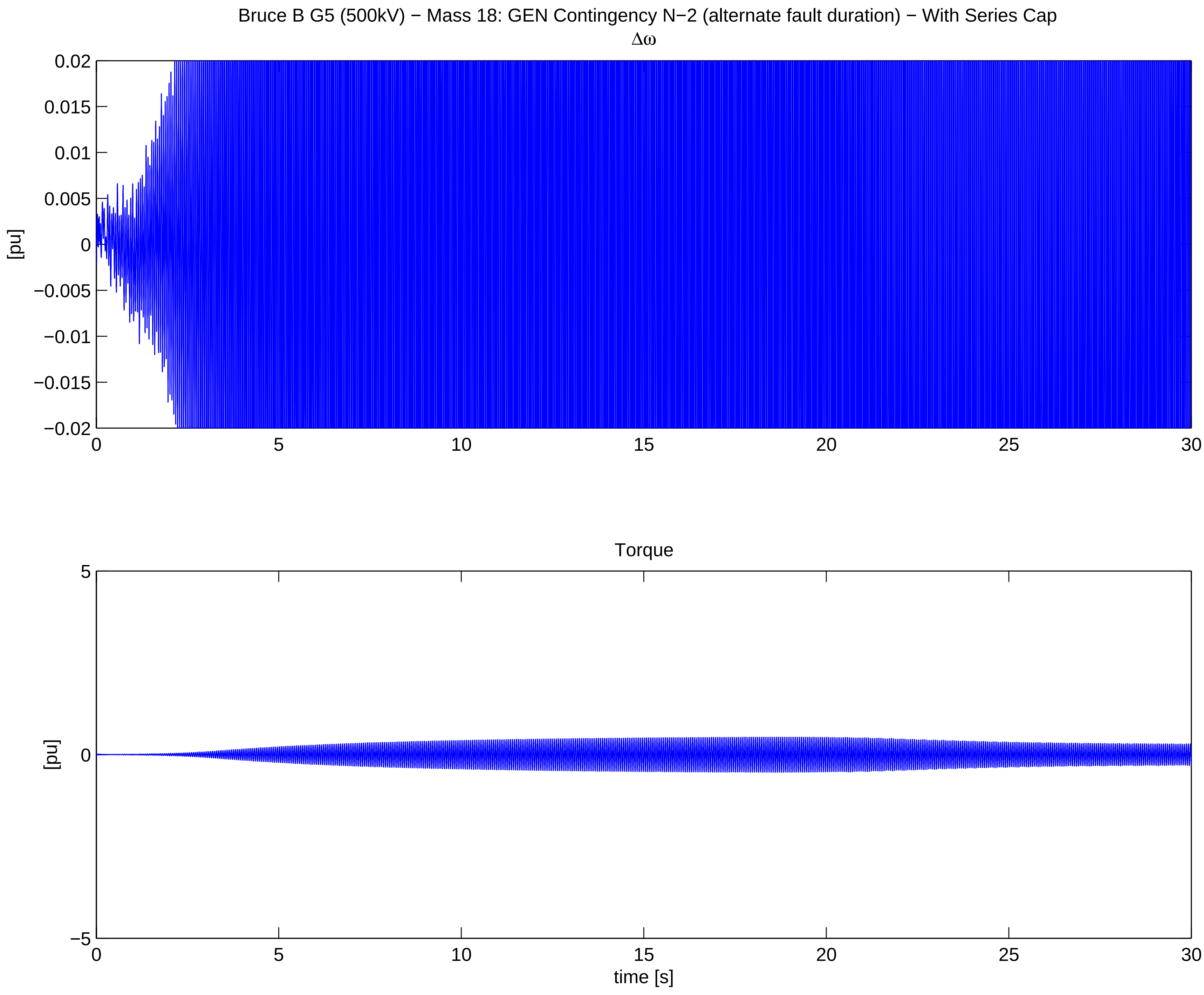

Bruce B G5 (500kV) − Mass 16: CP8 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−2 (alternate fault duration) − With Series Cap

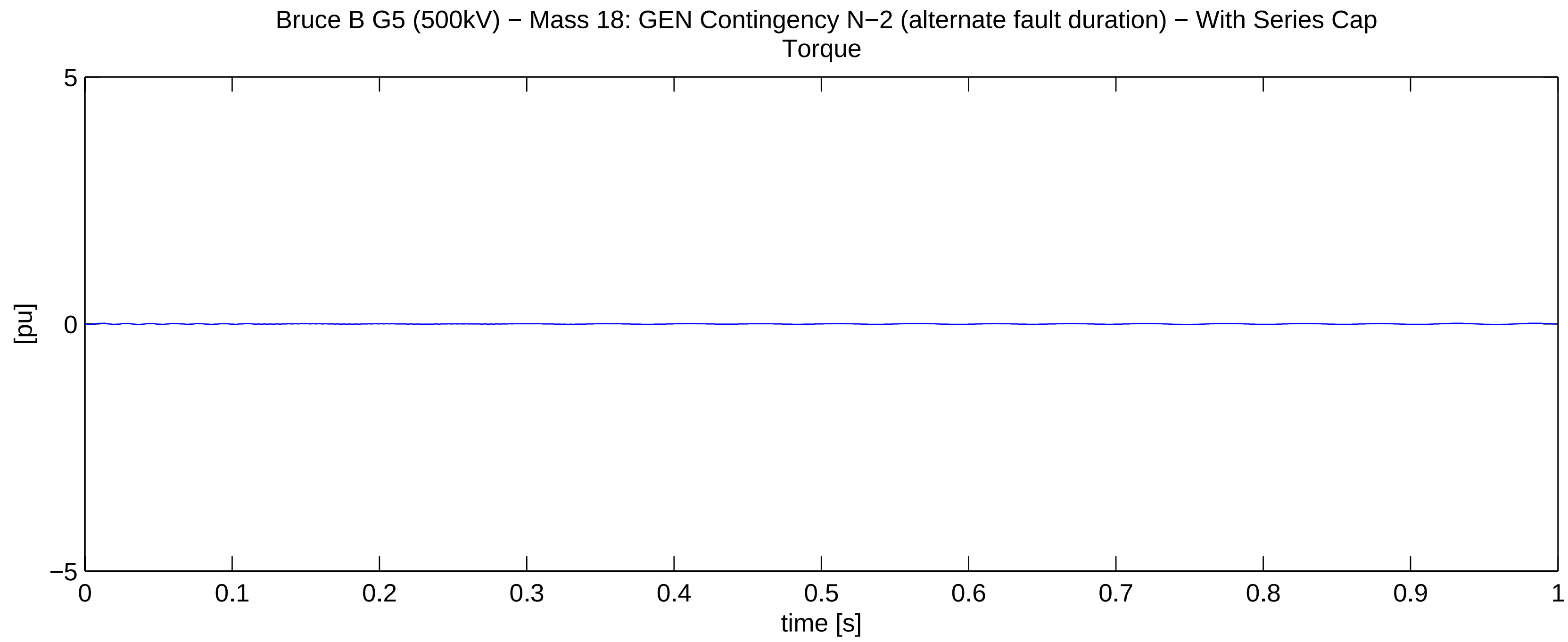


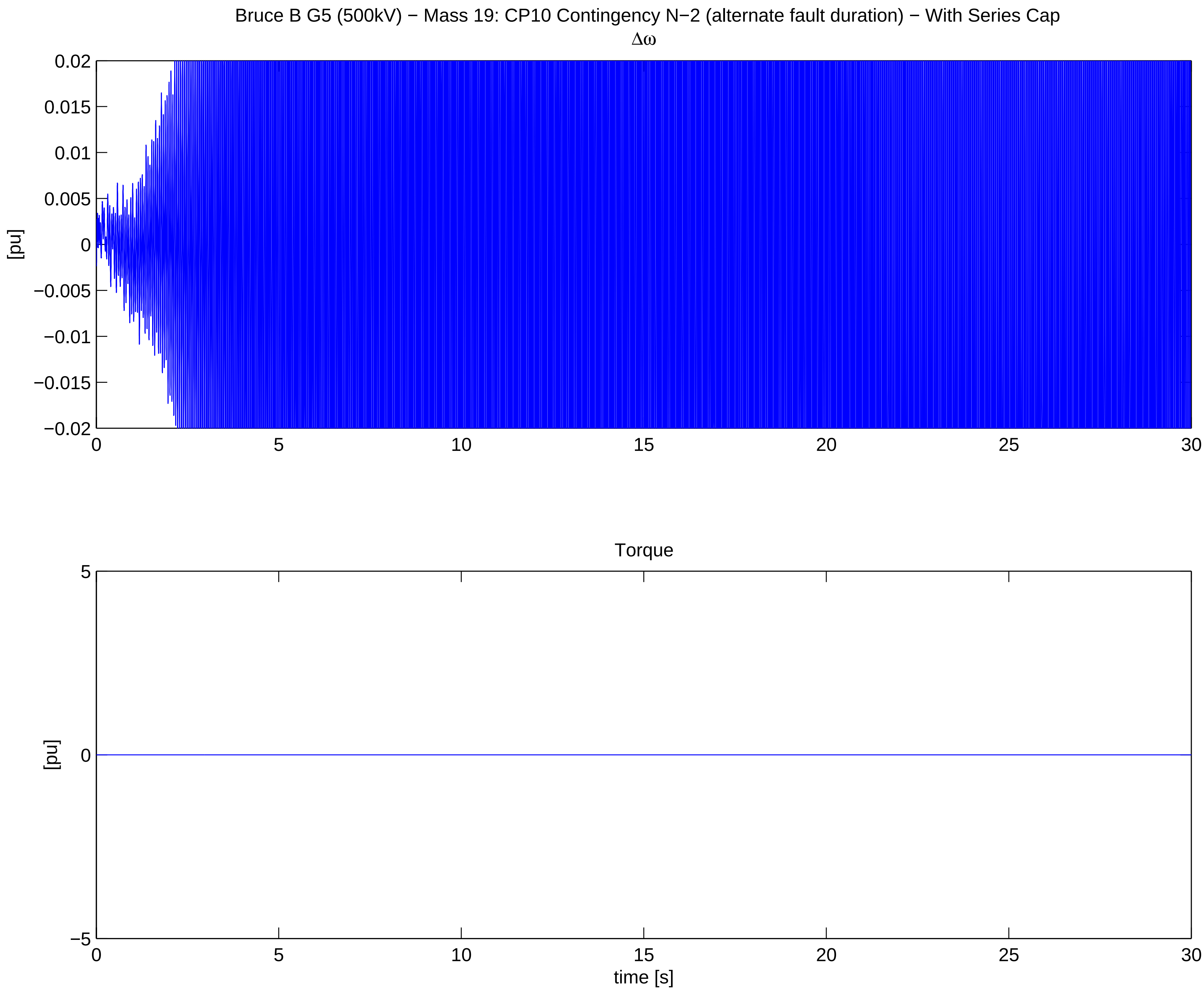


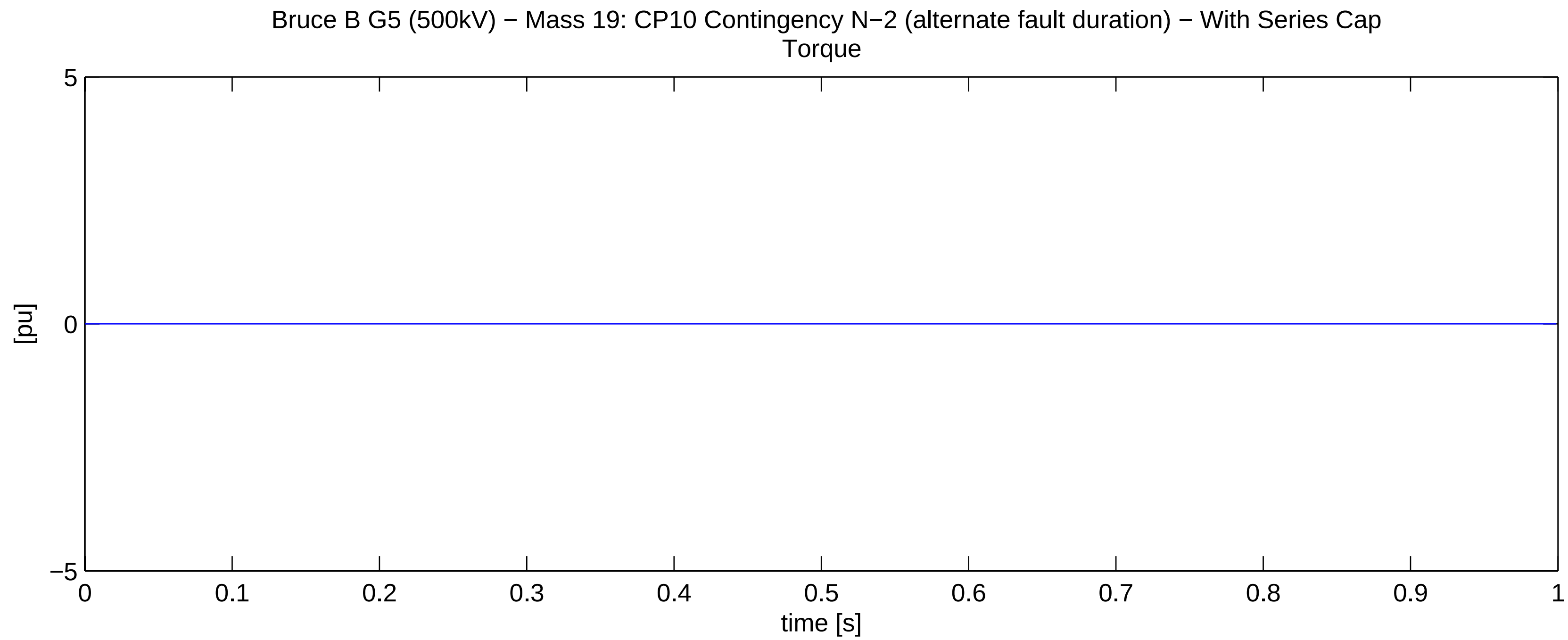

Bruce B G5 (500kV) − Mass 17: CP9 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]



Bruce B G5 (500kV) − Mass 18: GEN Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
time [s]


Bruce B G5 (500kV) − Mass 18: GEN Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]


Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−2 (alternate fault duration) − With Series Cap
Δω
[pu]
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
0
5
10
15
20
25
30
Torque
[pu]
5
0
−5
0
5
10
15
20
25
30
time [s]



Bruce B G5 (500kV) − Mass 19: CP10 Contingency N−2 (alternate fault duration) − With Series Cap
Torque
5
0
−5
[pu]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time [s]

APPENDIX U: Short Circuit Comparison Between Full and Simplified System Model

The table below shows the comparison (as calculated in PSS/E®) between the original full system model (all of Ontario) and the simplified model (shown in Figure 3-5) for short circuit currents at key buses in the system. Note: although the zero sequence data was also used for the lines explicitly modeled, for the transfer and source impedances typical ratios between positive and zero sequence were assumed. This is not a concern since all of the analysis (e.g. transfer function calculations, 3-phase faults in time domain etc.) performed here focuses on positive sequence phenomenon. The positive sequence source and transfer impedances were calculated using the PSS/E® databases supplied by IESO and Hydro One. As shown in section 3.4 (Figure 3-6 and Appendix O), the network frequency response for torsional frequencies are in good agreement between the simplified and full system model. This validates the model for use in analysis related for subsynchronous torsional interaction.

Bus Number	3-ph fault current (A rms) for simplified model	3-ph fault current (A rms) for full system model	% diff
6400	27842	28153	-1.1
7000	16613	16759	-0.9
7108	34727	34619	0.3
6500	29426	30425	-3.3
4000	39996	39886	0.3
4100	57505	59249	-2.9
5105	44316	47685	-7.1