TCSC

Thyristor Controlled Series Compensation

Keeping grids together

Boosting transmission capacity

Series compensation has been successfully utilized for many years in electric power networks. With series compensation, it is possible to increase the transfer capability of existing power transmission systems at a lower investment cost and with a shorter installation time compared to the building of new, additional lines or generation. This is due to the inherent ability of series capacitors to achieve:

- Increased dynamic stability of power transmission systems
- Improved voltage regulation and reactive power balance
- Improved load sharing between parallel lines

With the advent of thyristor control, the concept of fixed series compensation has been broadened and its usefulness has been increased further.

Introducing controllability

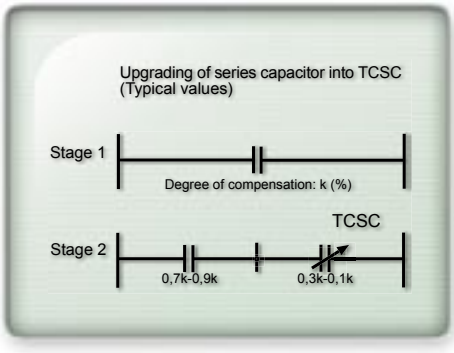
Thyristor-controlled series capacitors (TCSC)

Thyristor-controlled series capacitors (TCSC) introduce a number of important benefits in the application of series compensation:

- Elimination of subsynchronous resonance risks
- Damping of active power oscillations
- Post-contingency stability improvement
- Dynamic power flow control

Increased transfer capacity

The overall result typically appears as increased transfer capacity.



Applicable in new as well as existing systems

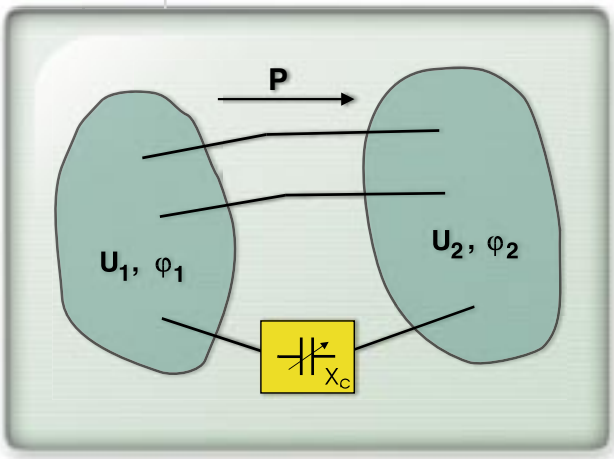
The benefits of thyristor-controlled series capacitors are by no means attainable only for installations starting from scratch. It is fully possible and practicable also to upgrade existing series capacitors by making all or part of them thyristor-controlled, thereby extending their impact and usefulness in the grid most considerably.

Power flow control

In interconnected power systems, the actual transfer of power from one region to another might take unintended routes depending on impedances of transmission lines connecting the areas. TCSC is a useful means for optimizing power flow between regions for varying loading and network configurations.

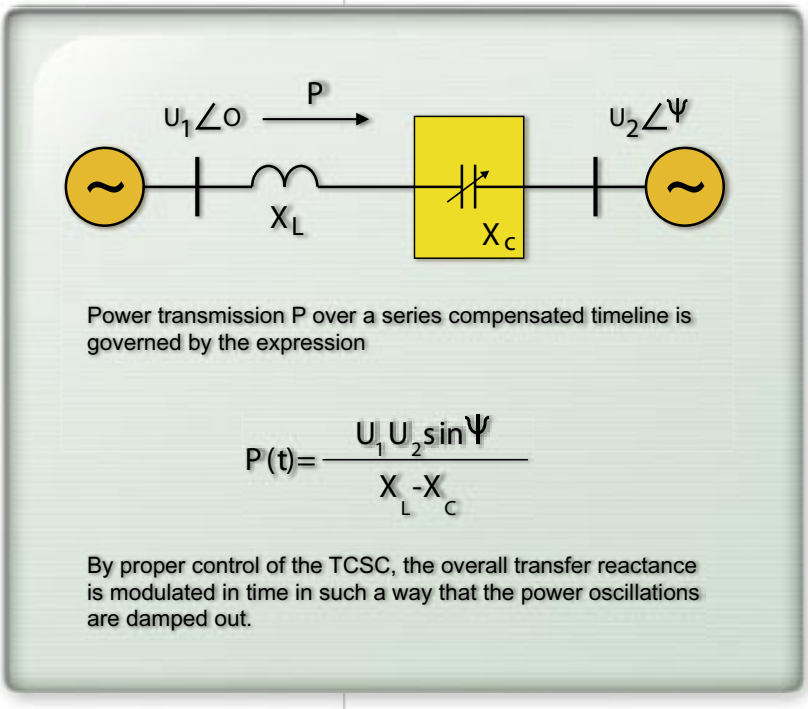
It becomes possible to control power flows in order to achieve a number of goals:

- Minimizing of system losses
- Reduction of loop flows
- Elimination of line overloads
- Optimizing of load sharing between parallel circuits
- Directing of power flows along contractual paths.



Control of power flow between regions.

Damping of power oscillations

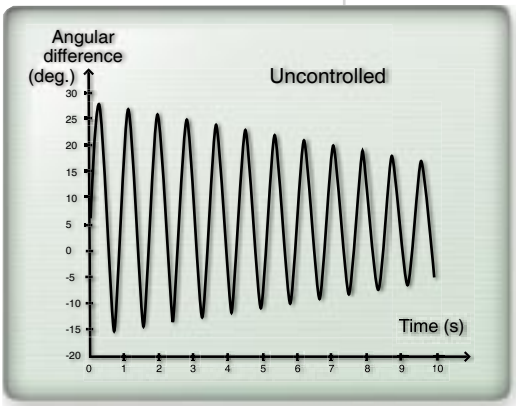


Oscillations of active power in power transmission systems may arise in corridors between generating areas as a result of poor damping of the interconnection, particularly during heavy power transfer. Such oscillations can be excited by a number of reasons such as line faults or a sudden change of generator output.

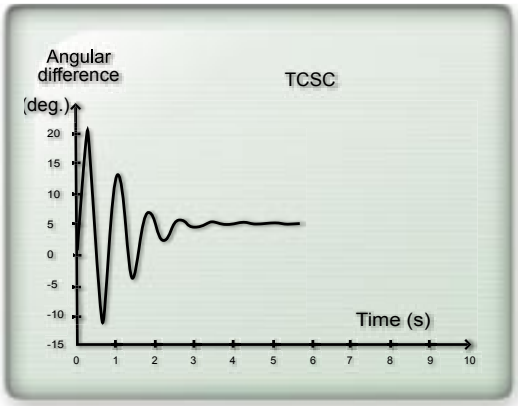
The presence of active power oscillations acts to limit the power transmission capacity of interconnections between areas or transmission regions. It is often possible to find remedy by building additional lines or upgrading existing lines, but this costs a lot of money and takes a lot of time, if not rendered impossible altogether by lack of the necessary permits. In some cases, it may also be possible to introduce Power System Stabilizers (PSS) on generators, but this will not always work, particularly not for inter-area power oscillations which tend to be of a low frequency (typically 0,2 Hz to 0,7 Hz).

In either case, TCSC will be an attractive alternative to consider. It offers a cost-effective, robust power oscillation damper, insensitive to its location in the system and non-interacting with local oscillation modes. In a number of cases, it will turn out to be the best practicable solution.

ABB has developed and patented an ingenious control strategy that enhances the TCSC damping performance compared to conventional technology. We call it Phasor Estimation Technique.



Power oscillations on a 500 kV intertie excited by a temporary short circuit. Power flow through the intertie: 2000 MW.

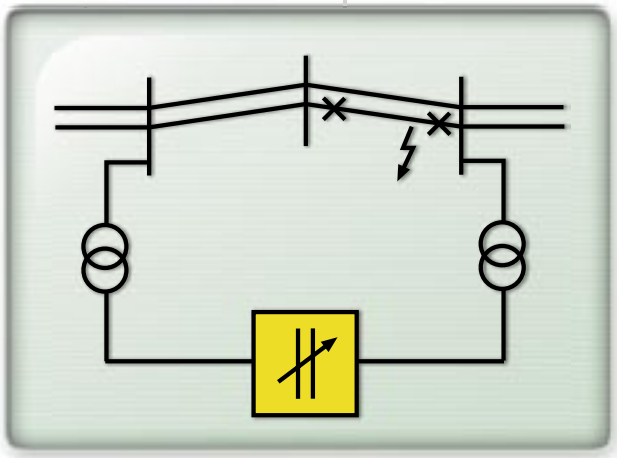


Power oscillations damped out by means of TCSC.

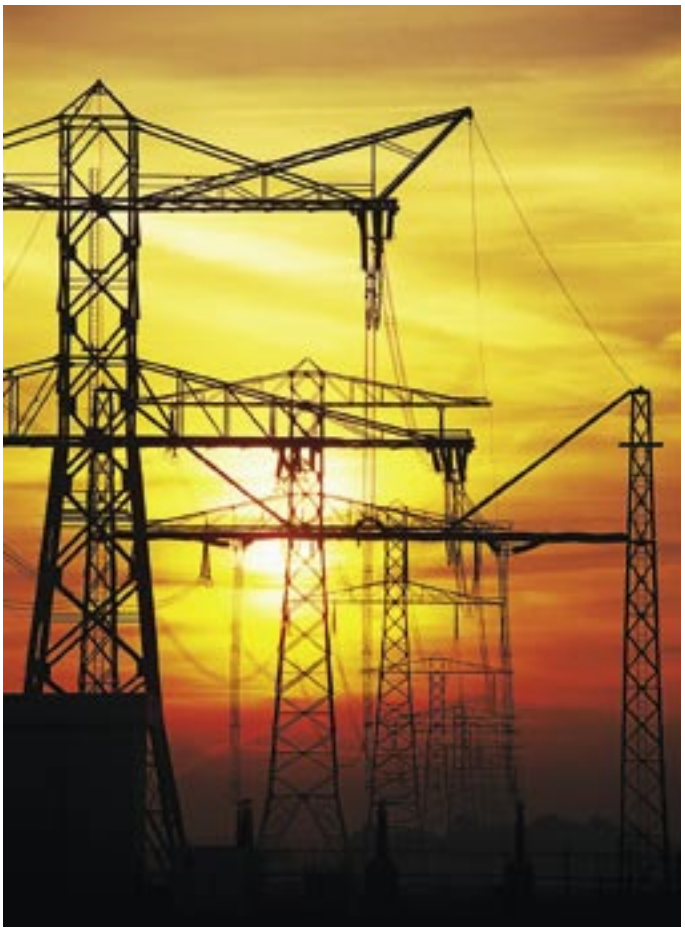
Post-contingency stability improvement and loadability control

An important benefit of TCSC is its ability for quick boosting of its degree of compensation, making it very useful as a tool for improving the post-contingency behaviour of networks. By means of this quality of the TCSC, the degree of compensation of a series capacitor can be increased temporarily following upon a network contingency, thereby adding to the dynamic stability of the network (voltage and angle) precisely when it is needed. By this feature, the series capacitor can be lower rated for steady-state conditions, thereby keeping transmission losses smaller.

For instance, in many applications it is desirable to enable an underlying transmission system to carry a higher amount of power under contingency conditions where a circuit is tripped in higher voltage transmission paths. Series compensation is not needed during normal operation as it would only influence overall system losses in an unfavourable way. In order to meet both objectives, i.e. safeguarding power transmission capability during contingencies and at the same time keeping transmission losses as low as possible during normal operating conditions, TCSC can be advantageously utilized.



TCSC for post-contingency stability improvement and loadability control.



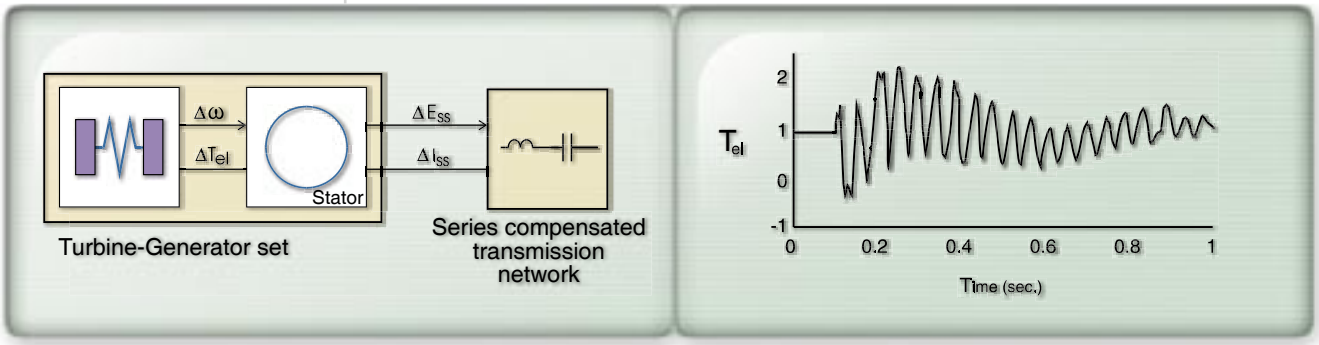
Elimination of SSR

SSR scenario

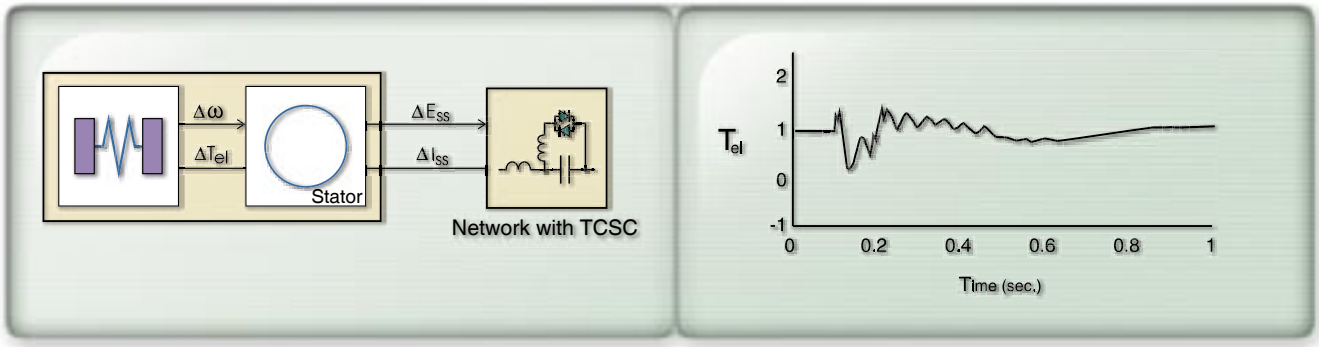
The phenomenon of subsynchronous resonance (SSR) has caused concern in the past in situations where the risk for occurrence of SSR has acted as an impediment to the use of series compensation; cases where the technology would otherwise have offered the best and most economical solution. With the advent of TCSC, no such concerns need to be entertained any longer, and series compensation can be used to its fullest merit.

The SSR risk used to be linked to the utilization of series compensation of transmission lines fed by thermal generation, particularly in cases of high degrees of compensation, where analysis showed that the complementary series resonance frequency of the compensated line(s) co-incided with some poorly damped torsional vibration frequency of the turbo-generator shaft, and could hence induce increased mechanical stresses in the shafts. The TCSC acts to eliminate this risk for co-inciding resonance frequencies by making the series capacitor(s) act inductive in the subsynchronous frequency band, thereby rendering the occurrence of series resonance in the transmission system for subsynchronous frequencies altogether impossible.

This inductive character of the TCSC is made possible by the use of a thyristor-controlled inductor in parallel with the series capacitor. The system is governed by an elegant, patented control scheme called SVR (Synchronous Voltage Reversal, see page 9).



Subsynchronous resonance: shaft torsional vibrations sustained due to resonant behaviour of the electric system.



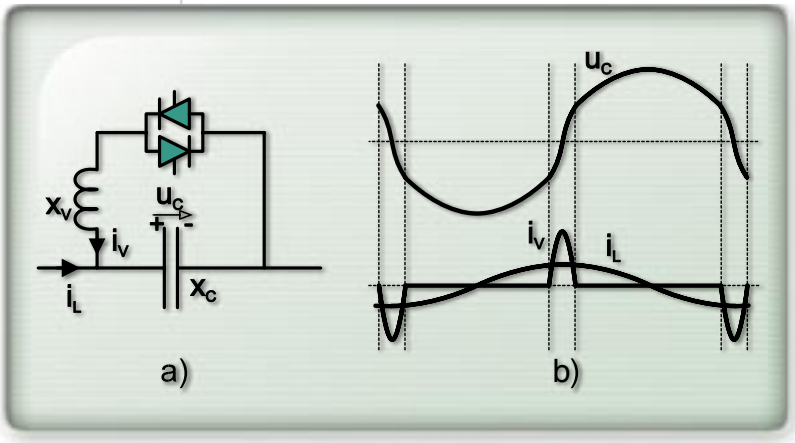
SSR mitigation: with TCSC, torsional vibrations die out due to elimination of the resonant behaviour for SSR frequencies in the electric system.

Thyristor control

Thyristor-controlled segment of a series capacitor.

In a TCSC, the whole capacitor bank or alternatively, a section of it, is provided with a parallel thyristor controlled inductor which circulates current pulses that add in phase with the line current so as to boost the capacitive voltage beyond the level that would be obtained by the line current alone. Each thyristor is triggered once per cycle and has a conduction interval that is shorter than half a cycle of the rated mains frequency. By controlling the additional voltage to be proportional to the line current, the TCSC will be seen by the transmission system as having a virtually increased reactance beyond the physical reactance of the capacitor.

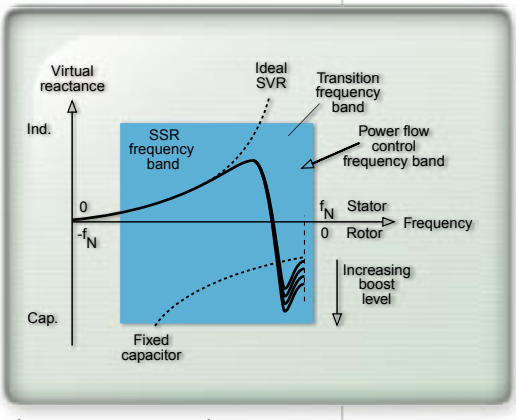
The thyristor valve is integrated in the capacitor overvoltage protection scheme. It replaces the spark gap and allows a reduction of the rating of the protective parallel varistor.



TCSC in steady-state a) circuit b) waveforms

SVR Control scheme

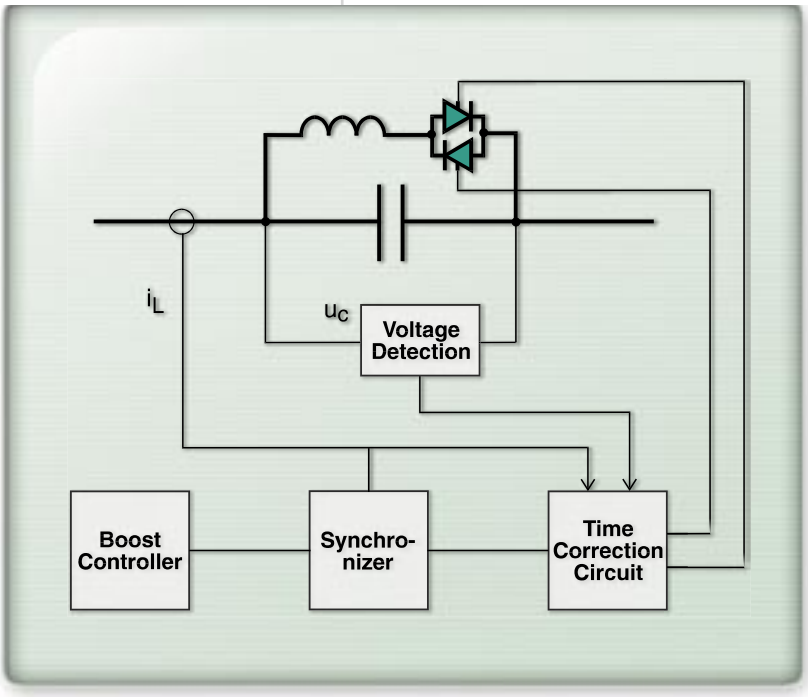
The control algorithm, SVR, has been developed by means of which the TCSC exhibits an inductive virtual impedance in the complete frequency range of concern for SSR. As a consequence of this property of the series capacitor, SSR is efficiently ruled out.



Apparent reactance characteristic of TCSC.

The SVR approach to controlled series compensation offers a number of benefits to the user:

- No resonance risk throughout the SSR frequency range.
- Robust performance of the TCSC, without any need for specific tuning to meet varying network configurations and various rotating machine modes.
- Additionally variable voltage boost can be utilized for system related control purposes, such as power oscillation damping.



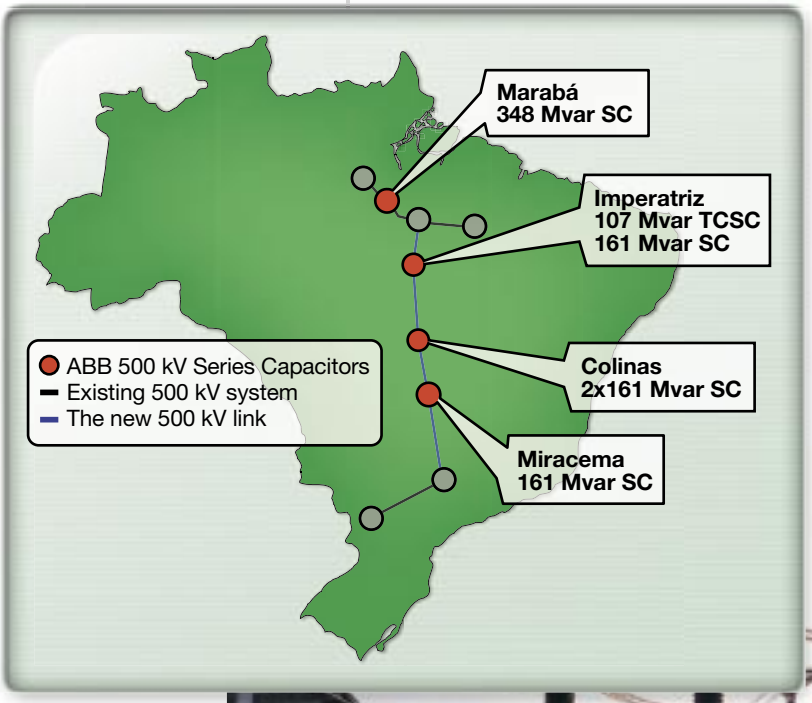
Control scheme, SVR

Power oscillation damping

A Brazilian case

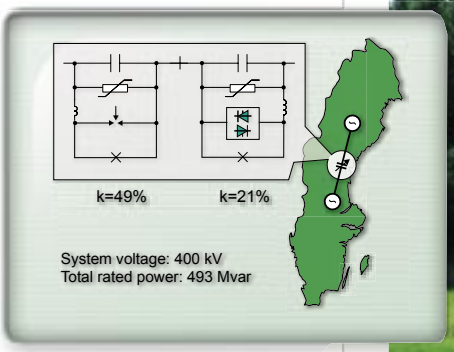
Since 1999, Eletronorte of Brazil has been operating a TCSC and five fixed Series Capacitors supplied by ABB in Eletronorte´s 500 kV interconnector between its northern and southern power systems. In all, about 1.100 Mvar of series capacitors have been installed by ABB. The TCSC is located at Imperatriz at the northern end of the power corridor connecting the two systems which were previously not connected.

The series capacitors installed in the North-South Interconnection have the task of raising the steady-state and dynamic stability of the interie. The TCSC at Imperatriz, the first of its kind to be installed in Latin America, has the task of damping low-frequency inter-area power oscillations between the power systems on either side of the interconnection. These oscillations (at 0,2 Hz) would otherwise have constituted a restrictive hazard to power system stability. The TCSC efficiently eliminates this obstacle to power transmission.



Technical data, Eletronorte TCSC + SC

System voltage:	500 kV
Rated continuous current:	1500 A
Rated overall power:	1100 Mvar
Degree of compensation:	
Total:	54 %
Thyristor controlled:	5-15 %
TCSC control mode:	Phasor Estimation Technique



Swedish National Grid TCSC at Stöde.

A Swedish case

In Sweden, electric power generation is based chiefly on hydro power in the north and nuclear power in the middle and south of the country. Power transmission is performed on 400 kV over interconnecting lines of considerable lengths. To improve power transmission capacity of these lines and thereby keep their needed number to a minimum, series compensation is used throughout.

Technical data, Stöde TCSC

System voltage:	400 kV
Rated continuous current:	1500 A
Rated overall power:	493 Mvar
Degree of compensation:	
Total:	70 %
Thyristor controlled:	21 %
TCSC control mode:	SVR

The Forsmark nuclear power plant situated in mid-Sweden is interconnected with the north of the country by means of a number of 400 kV lines of varying lengths, all series compensated. However, one of the generator units at Forsmark, rated at 1300 MW, is subject to SSR risk in conjunction with certain conditions in the power grid. To counteract this, one of the series capacitors, located at Stöde, previously used to be bypassed upon SSR indication, which meant loss of power transmission capability of the system. In case of failure of the series capacitor SSR protection, the generator was tripped, with subsequent loss of generation. Such measures, however, have now become unacceptable, as demands on availability of power have steadily grown.

Part of the existing series capacitor at Stöde (30 % of its totally installed reactance) has consequently been rebuilt into a TCSC. The series capacitor thus equipped was commissioned in 1997.

Increased availability of power

With the TCSC in operation, the SSR risk is eliminated for all possible system operating conditions. The benefits will be increased availability of power from Forsmark as well as a preserved high level of power transmission over the system, thanks to series compensation.

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