Joint World Bank / ABB Power Systems Paper

Improving the efficiency and quality of AC transmission systems (Draft3)

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Introduction

The fast-changing electricity supply industry is bringing the users of high voltage transmission systems fresh opportunities as well as challenges. These stem mainly from the strong increase in inter-utility power transfers, the effects of deregulation, and political, economical, and ecological considerations on the building of new transmission facilities.

Likewise, power quality is an item of steadily increasing concern in power transmission and distribution. Since transmission services are now provided under contract, restrictions on voltage and current distortion, sags and fluctuations are coming into force at a scale hitherto unseen in many countries. Light flicker in work places as well as domestic dwellings, and energy and production outages due to poor quality of electrical grids is no longer acceptable.

The traditional approach to overcoming such capacity and quality limitations in power transmission and distribution in many cases is the addition of new transmission and/or generating capacity. This, however, may not be practicable or desirable in the real case, for a variety of reasons. Adding of new lines and/or extending of existing substations may be too costly and time-consuming, concessions for new rights-of-way may be hard or impossible to come by, and last but not least, there may be serious obstacles in the way from an ecological point of view.

This paper will show how other solutions, collectively known as Flexible AC Transmission Systems (FACTS)[1], based on state of the art, high power electronics, may be a superiour option, from technical, economic and environmental points of view.

Constraints in a transmission system

In theory, a transmission system can carry power up to its thermal loading limits. But in practice, to reach the thermal limit, the system meets the following constraints:

-Transmission stability limits
-Voltage limits
-Loop flows

With transmission stability limits are meant the limits of transmittable power with which a transmission system can ride through major faults in the system with its power transmission capability intact.

With voltage limits are meant the limits of power transmission where the system voltage can be kept within permitted deviations from nominal, usually no more than 5-10%. The voltage is governed by a quantity named reactive power (Q). Q in its turn depends of the physical length of the transmission circuit as well as from the flow of active power. So, in simple terms, the longer the line and/or the heavier the flow of active power, the stronger will be the flow of reactive power, as a consequence of which the voltage will drop, until, at some critical level, the voltage collapses altogether.

Loop flows can be a problem as they are governed by the laws of nature which may not be coincident with the interests of man. This means that power which is to be sent from point ”A” to point ”B” in a grid will not necessarily take the shortest, direct route, but will go uncontrolled and fan out to take unwanted paths available in the grid, thereby generating additional losses and possibly also overloading of sections of neighbours´ power systems.

Due to all these constraints, a 400 kV line for example will usually not be required to transmit more than some 450-500 MW over any ”reasonable” distance without very specific measures taken to safely enable it, although from a purely thermal loading point of view it very well could.

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[1] FACTS is the terminology used in the industry.

FACTS are designed to remove such constraints and to meet planners´, investors´ and operators´ goals without their having to undertake major system additions. This offers ways of attaining an increase of power transmission capacity at optimum conditions, i.e. at maximum availablity, minimum transmission losses, and minimum environmental impact. Plus, of course, at minumum investment cost and time expenditure.

Improving or safeguarding of power quality in transmission and distribution is the second very important driving force for the implementing of FACTS in power systems. For instance, the building of a steel plant may be an undertaking of great importance to a country or a region, offering GNP growth as well as employment. In many cases, however, where the supplying grid is weak or insufficient, this added value will also become a nuisance to many due to pollution of the grid, pollution which will spread far and wide over the grid and in the worst case become an impediment to industrial endeavour elsewhere and in any case a source of complaint.

FACTS will offer remedy in such cases, by enabling confinement or neutralizing of electrical disturbances such as voltage sags and fluctuations, harmonic distortion, and phase unbalance in three-phase systems. As a useful added value, improved economy of the process or processes in question will usually also be achieved.

FACTS devices

The term ”FACTS” covers several power electronics based systems used for AC power transmission. Given the nature of power electronics equipment, FACTS solutions will be particularly justifiable in applications requiring one or more of the following qualities:

-Rapid dynamic response
-Ability for frequent variations in output
-Smoothly adjustable output.

Important applications in power transmission highlighted in this paper are involving FACTS devices such as SVC (Static Var Compensators), Fixed* as well as Thyristor-Controlled Series Capacitors (TCSC) and Statcom. Still others are PST (Phase-shifting Transformers), IPC (Interphase Power Controllers), UPFC (Universal Power Flow Controllers), and DVR (Dynamic Voltage Restorers).

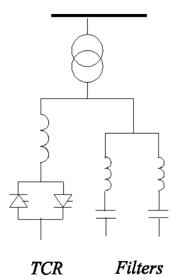
Technology underlying FACTS

SVC

An SVC is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and/or Fixed Capacitors (FC) tuned to Filters. A TCR consists of a fixed reactor in series with a bi-directional thyristor valve. TCR reactors are as a rule of air core type, glass fibre insulated, epoxy resin impregnated.

A TSC consists of a capacitor bank in series with a bi-directional thyristor valve and a damping reactor which also serves to de-tune the circuit to avoid parallel resonance with the network. The thyristor switch acts to connect or disconnect the capacitor bank for an integral number of half-cycles of the applied voltage.

Two very common design types, both having each their specific merits, are shown in Fig. 1a and 1b.



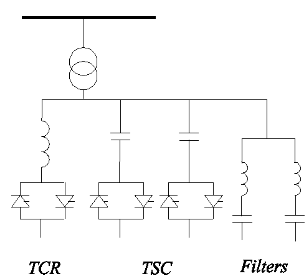


Fig. 1a: TCR / FC configuration.   Fig. 1b: TCR / TSC configuration.

A complete SVC based on TCR and TSC may be designed in a variety of ways, to satisfy a number of criteria and requirements in its operation in the grid.

Series Capacitor (SC)

Of course, a series capacitor is not just a capacitor in series with the line. For proper functioning, series compensation requires control, protection and supervision facilities to enable it to perform as an integrated part

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* Not strictly FACTS but closely related in its application.

of a power system. Also, since the series capacitor is working at the same voltage level as the rest of the system, it needs to be fully insulated to ground.

The main circuit diagram of a state of the art series capacitor is shown in Fig. 2. The main protective device is a varistor, usually of ZnO type, limiting the voltage across the capacitor to safe values in conjunction with system faults giving rise to large short circuit currents flowing through the line.

A spark gap is utilized in many cases, to enable by-pass of the series capacitor in situations where the varistor is not sufficient to absorb the excess current during a fault sequence.

Finally, a circuit breaker is incorporated in the scheme to enable the switching in and out of the series capacitor as need may be. It is also needed for extinguishing of the spark gap, or, in the absence of a spark gap, for by-passing of the varistor in conjunction with faults close to the series capacitor (so-called internal faults).

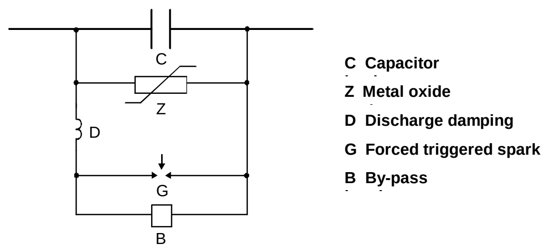

Fig. 2: Main configuration of a Series Capacitor.

Controllable series compensation

Though very useful indeed, conventional series capacitors are still limited in their flexibility due to their fixed ratings. By introducing control of the degree of compensation, additional benefits are gained.

In early types of controllable series capacitors, mechanical circuit breakers are used to switch segments of the capacitor in and out according to need. This is adequate in most situations for power flow control, but for applications requiring more dynamic response, its usefulness is reduced due to the limitations associated with using circuit breakers as switches.

State of the art controllable series compensation is shown in Fig. 3. Here, the introduction of thyristor technology has enabled strong development of the concept of series compensation. Added benefits are dynamic power flow control, possibility for power oscillation damping, as well as mitigation of sub-synchronous resonance (SSR), should this be an issue.

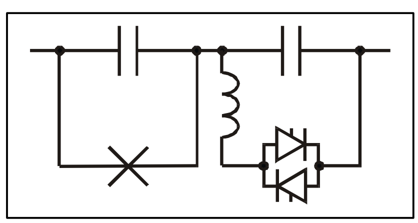

Fig. 3: Controllable Series Compensation.

Statcom

A Static Compensator consists of a voltage source converter, a coupling transformer and controls (Fig. 4). In Fig. 4, I_q is the converter output current and is perpendicular to the converter voltage V_i. The magnitude of the converter voltage and thus the reactive output of the converter (Q) is controllable. If $V_i > V_T$, the Statcom supplies reactive power to the ac system. If $V_i < V_T$, the Statcom absorbs reactive power.

State of the art for Statcom is by the use of IGBT. By use of high frequency Pulse Width Modulation (PWM), it has become possible to use a single converter connected to a standard power transformer via air-core commutating reactors. The core parts of the plant are located inside a prefabricated building. The outdoor equipment is limited to heat exchangers, commutation reactors and the power transformer. For extended range of operation, additional fixed capacitors, thyristor switched capacitors or an assembly of more than one converter may be used.

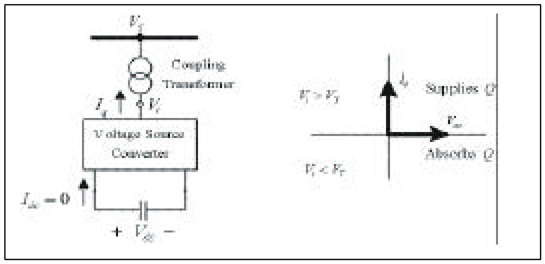

Fig. 4: Static Compensator.

An IGBT based Statcom for power transmission has the appearance shown in Fig. 5.

Fig. 5: Typical Statcom for transmission applications.

The semiconductor valves in a Statcom respond almost instantaneously to a switching order. Therefore the limiting factor for the comple plant speed of response is determined by the time needed for voltage measurements and the control system data processing. A high gain controller can be used and a response time shorther than a quarter of a cycle is obtained.

The plant can in most cases be designed completely without harmonic filters. In some cases where the requirements on high order harmonics are very stringent a small highpass link may be utilized. The risk for resonant conditions is therefore very small. This property makes Statcom suitable for relocation to other sites at changing network conditions.

The high switching frequency used in the IGBT based Statcom concept results in an inherent capability to produce voltages at frequencies well above the fundamental one. This property can be used for active filtering of harmonics already present in the network. The Statcom then injects harmonic currents into the network with proper phase and amplitude to counteract the harmonic voltages.

An IGBT based Statcom for power transmission can be built very compact, see Fig. 5. The area required is no more than approximately 10 times 20 meters.

Phase shifter (PST)

Phase shifters are used to control the flow of electric power over transmission lines. Both the magnitude and and the direction of the power flow can be controlled by varying the phase shift across the PST.

The phase shift is obtained by extracting the line-to-ground voltage of one phase and injecting a portion of it in series with another phase. This is accomplished by using two transformers: the regulating (or magnetizing) transformer, which is connected in shunt, and the series transformer (Fig. 6). The series voltage injected is in quadrature to the line-to-ground voltage.

The angle of the PST is normally adjusted by an on-load tap changer. The series voltage can be varied by the tap changer in steps determined by the taps on the regulating winding. Progress in the field of high power electronics is making it possible now for thyristors to be used in the switching network, thereby making it fast and less subject to mechanical wear.

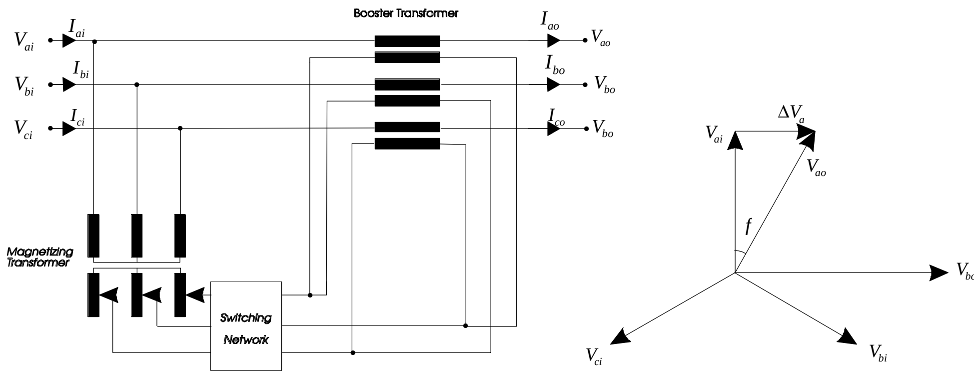

Fig. 6: Phase shifter (PST).

IPC

The PST concept, carried a bit further, leads directly into the Interphase Power Controller (IPC). The topology of an IPC, or as it is also called in this particular shape, APST (Assisted Phase Shifting Transformer) is shown in Fig. 7. The nature of the reactive element in parallel with the PST depends on the quadrant in which the PST is called upon to operate. The two branches function in unison, enabling the APST to force higher power transfer through a circuit than is obtained by the PST alone. The susceptance of the reactive element is chosen many times smaller than that of the PST. Hence, the behaviour of the APST is mainly dictated by the PST, meaning that the controllability of the PST is preserved in the APST.

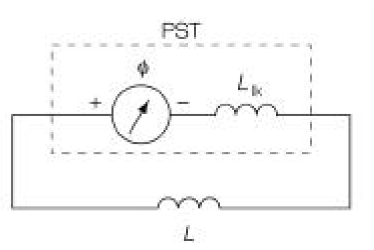

Fig. 7: APST topology.

Unified power flow controller (UPFC)

The Unified Power Flow Controller consists of two switching converters operated from a common DC link, as shown in Fig. 8. In the figure, Converter 2 performs the main function of the UPFC by injecting an AC voltage with controllable magnitude and phase angle in series with the transmission line. The basic function of Converter 1 is to supply or absorb the active power demanded by Converter 2 at the common DC link. It can also generate or absorb controllable reactive power and provide independent shunt reactive compensation for the line.

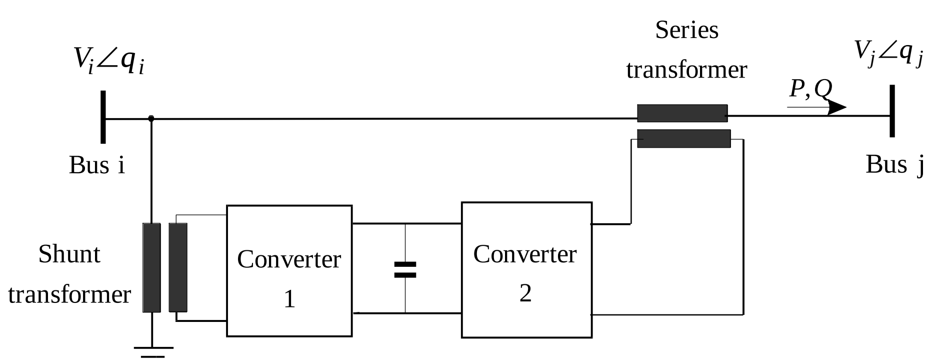

Fig. 8: Unified Power Flow Controller (UPFC).

A UPFC can regulate active and reactive power simultaneously. In principle, a UPFC can perform voltage support, power flow control and dynamic stability improvement in one and the same device.

Dynamic voltage restorer (DVR)

The function of a Dynamic voltage Restorer (DVR) is illustrated in Fig. 9. In the event of a voltage dip, the power electronic converter injects the appropriate voltage required into the supply bus to compensate for the sag. Rapid control cycles and millisecond switching speed of the converter enable accurate control of the voltage experienced by the load. This can be critical in sensitive manufacturing processes, where a single voltage sag may cause the loss of production, and with it, very high costs.

A DVR will typically have sufficient energy storage capacity to compensate a 50 per cent three-phase voltage dip for up to 10 cycles, the period normally required for fault clearance. Although a DVR may be rated to compensate up to a 90 per cent voltage dip, it does not support complete outages. Capacitors serve as energy storage device.

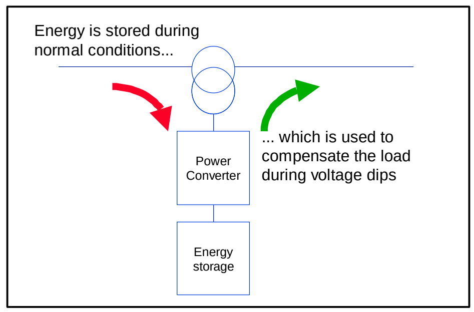

Fig. 9: Dynamic Voltage Restorer.

A typical power range to be covered by DVR is from 3 MVA up to 50 MVA.

From project conception to implementation

When a customer identifies a problem in his grid which he wants to have solved, how should he go about it? Step one, of course, is to analyze the problem and pinpoint what needs to be attained as a solution. For example, there could be a bottleneck in the power transmission system which needs to be dealt with, to enable sufficient flow of power as the demand increases. For this analysis, the customer may want to use skills at hand in his own house, or he may want to employ an independent consultant.

The said analysis should result in a report which can form the base for a functional specification, in which the problem is described and the desired improvement(s) in the grid is (are) spelled out (for example, a certain voltage improvement or stabilization under various, likewise specified operational conditions of the grid). For facilitating of this procedure, generic specifications or guidelines for the specifying of FACTS devices are available, which will serve as starting points for the writing of a project specification. This specification is then made the base of a tendering procedure, where quotations are requested from manufacturers for systems and equipment suitable for solving the grid problem(s). If financing is not available by the customer´s own means, a financing institution, bilateral or multilateral, will need to be involved in the procedure, as well. This institution may require the nomination of his own consultant to evaluate the project and the specification as part of the procedure.

In the tendering process, manufacturers will propose equipment and solutions (type(s), location(s) and and rating(s) of FACTS) based on each manufacturer´s design, following his conception of the problem and required solution(s). Often, the best answer to a design challenge may be a combination of FACTS devices, for example SVC and SC. Each proposal will then need to be evaluated, technically as well as commercially, either by the customer himself, or by his nominated consultant.

Design and construction

The winning bidder will then make a detailed, final design of his equipment or solution, based on detailed data on the customer´s grid and requirements supplied by the customer or customer´s consultant. Based on this final design, construction starts, in accordance to a time schedule which will have been agreed upon as part of the tendering procedure and contract negotiations. This construction phase will embrace manufacturing of the equipment in the manufacturer´s workshop, supply of the equipment to site, installing of the equipment, testing and commissioning.

All this takes time, of course, a fact which should be taken into consideration very early in the customer´s planning procedure. To give a rough idea, the time it takes to supply for example an SVC for power transmission purposes will typically amount to some 14-16 months from the signing of contract till the end of testing and commissioning. A Series Capacitor can as a rule be put into operation in 12-14 months or thereabouts.

A continuously ongoing process of standardization and modularization of systems and equipment will enable continuously shorter lead times in the installing of FACTS in grids. Increasing amounts of equipment are being supplied ready-made in pre-fabricated houses, which simplifies civil construction and installation work (site works) as well as cuts down on the need for testing of equipment on site. All this saves time as well as money.

Operation and maintenance

Operation of FACTS in power systems is coordinated with operation of other items in the same system, for smooth and optimum function of the system. This is achieved in a natural way through the Central Power System Control, with which the FACTS device(s) is (are) communicating via system SCADA. This means that each FACTS device in the system can be operated from a central control point in the grid, where the operator will have skilled human resources available for the task. The FACTS device itself is normally unmanned, and there is normally no need for local presence in conjunction with FACTS operation, although the device itself may be located far out in the grid.

Maintenance is usually done in conjunction with regular system maintenance, i.e. normally once a year. It will require a planned standstill of typically a couple of days. Tasks normally to be done are cleaning of structures and porcelains, exchanging of mechanical seals in pump motors, checking through of capacitors, checking of control and protective settings, and similar. It can normally be done by a crew of 2-3 people with engineer´s skill.

Impact of FACTS in interconnected networks

The benefits of power system interconnection are well established. It enables the participating parties to share the benefits of large power systems, such as optimization of power generation, utilization of differences in load profiles and pooling of reserve capacity. From this follows not only technical and economical benefits, but also environmental, when for example surplus of clean hydro resources from one region can help to replace polluting fossil-fuelled generation in another.

For interconnections to serve their purpose, however, available transmission links must be powerful enough to safely transmit the amounts of power intended. If this is not the case, from a purely technical point of view it can always be remedied by building additional lines in parallel with the existing, or by uprating the existing system(s) to a higher voltage. This, however, is expensive, time-consuming, and calls for elaborate procedures for gaining the necessary permits. Also, in many cases, environmental considerations, popular opinion or other impediments will render the building of new lines as well as uprating to ultrahigh system voltages impossible in practice. This is where FACTS comes in.

Examples of successful implementation of FACTS for power system interconnection can be found among others between the Nordic Countries (Nordel), and between Canada and the United States. In such cases, FACTS helps to enable mutually beneficial trade of electric energy between the countries.

Other regions in the world where FACTS is emerging as a means for AC bulk power interchange between regions can be found in South Asia as well as in Africa and Latin America. In fact, AC power corridors equipped with SVC and/or SC transmitting bulk power over distances of more than 1.000 km are a reality today. Some examles are given below.

Cost structure

The cost of a FACTS installation depends on many factors, such as power rating, type of device, system voltage, system requirements, environmental conditions, regulatory requirements etc. On top of this, the variety of options available for optimum design renders it impossible to give a cost figure for a FACTS installation. Nevertheless, a typical cost structure for FACTS could be laid out as in Fig. 10.

It is strongly recommended that contact is taken with a manufacturer in order to get a first idea of costs and alternatives. The manufacturers should be able to give a budgetary price based on a brief description of the transmission system along with the problem(s) needing to be solved and the improvement(s) needing to be attained.

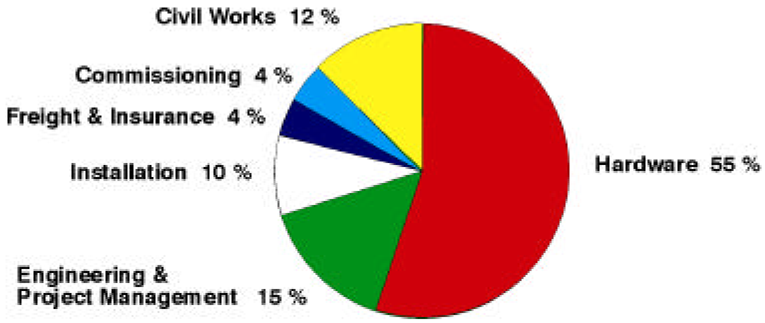

Fig. 10: Typical cost structure of FACTS installation.

FACTS for minimizing of grid investments
It has been mentioned that an important incentive for considering of FACTS in grid planning is its being an economically as well as politically and environmentally attractive alternative to larger, more costly and more time-consuming investments in extended transmission networks, i.e. basically more lines. Thus, for instance, it can be shown that the cost of installing series capacitors as means for improving the power transmission capacity of existing lines amounts to only a fraction of the cost for installing one or several new lines. This is valid for all existing transmission voltages and for all transmission distances where series compensation comes into consideration.

By considering series compensation from the very beginning, power transmission between regions can be planned with a minimum of transmission circuits, thereby minimizing costs as well as environmental impact from the start.

Summary: choice of option
So how should power system planners, investors in power infrastructure (both public and private), and financiers of such infrastructure be guided with respect to choosing between FACTS and a traditional approach of building of (a) new line(s) and/or a generation facility? The answer is to let the "market" decide. In other words:

- the planners, investors and financiers should issue functional specifications for the transmission system to qualified contractors, as opposed to the practice of issuing technical specifications, which are often inflexible, and many times include older technologies and techniques) while inviting bids for a transmission system.
- The functional specifications could lay down the power capacity, distance, availability and reliability requirements; and last but not least, the environmental conditions.
- The bidders should be allowed to bid either a FACTS solution or a solution involving the building of (a) new line(s) and/or generation; and the best option chosen.

Four cases of FACTS installations
<u>1. SVC:</u>
<u>SA-Zimbabwe interconnection</u>
Since 1995, an SVC rated at 100 Mvar inductive to 200 Mvar capacitive at 330 kV has been in operation in the Matimba-Insukamini 600 MW power interconnecting corridor between South Africa and Zimbabwe. It is located at the ZESA Insukamini 330 kV substation in Zimbabwe, close to the coupling point for the 400 kV interconnection to South Africa. This 405 km long line forms part of an AC connection running in parallel with the Cahora Bassa HVDC link (Fig. 11).

The single 400 kV interconnection between Matimba and Insukamini is relatively weak, and unless proper measures are taken, poorly damped, low frequency (‹ 0,5 Hz) active power oscillations tend to appear between South Africa and Zimbabwe. The SVC is there to mitigate these power oscillations. With the SVC in operation, stability and power transfer margins have been increased by approximately 150 MW in the existing power corridor, without any need for additional power lines.

It should be pointed out in this context that the alternative to the SVC, i.e. the building of an additional line, would have taken longer as well as cost considerably more money. Additionally, the eliminating of the need for an additional line has brought benefits to the environment which cannot so easily be quantified, but which nevertheless are very important, as well.

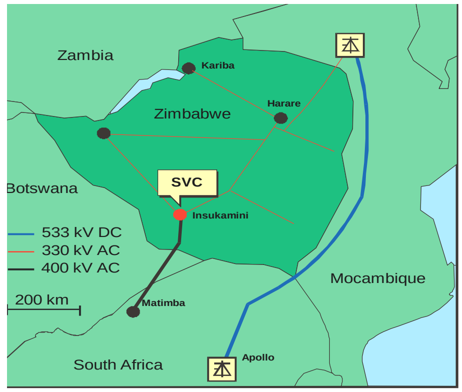

Fig. 11: Matimba-Insukamini 600 MW power interconnection.

The SVC (Fig. 12) consists of a TCR rated at 150 Mvar, a TSC rated at 150 Mvar and Harmonic Filters rated at 50 Mvar. By proper control of these branches, the desired operating range of the SVC is achieved. The Power Oscillation Damper is activated if large power oscillations or a large power derivative appear in the transmission system. The SVC can be operated from three different locations: the local SVC control room, the ZESA control house at Insukamini and remotely via a SCADA system in the ZESA control centre.

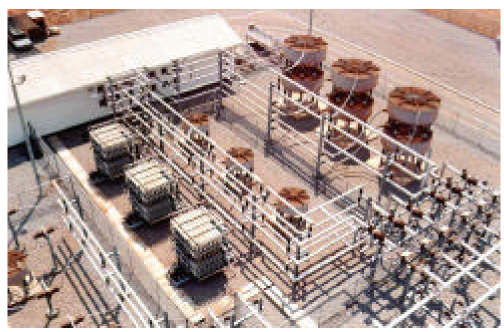

Fig. 12: The Insukamini SVC.

2. SC:
The Argentina case

Striking examples of growth are found in Latin America at present. As economy is developing at an increasing pace all over the continent, electric power demand is naturally growing, as well. Large amounts of electricity need to be transported over vast distances, between regions of countries as well as between countries. Here, series compensation is the natural option for safeguarding of comprehensive and reliable power transmission, and the technology is coming to ever more extensive use.

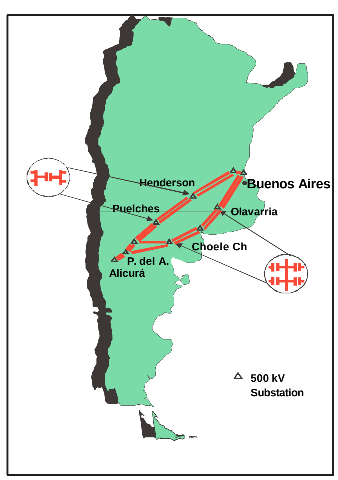

Fig. 13: Comahue-Buenos Aires 500 kV series compensated power corridor.

All in all, there are 10 series capacitors in operation in the power corridor, altogether rated at close to 2.400 Mvar at 500 kV (Fig. 14). The purpose of the series compensation of the four lines is to enable an increase of the active power transmission capability of the power corridor, a task which is fulfilled in several ways:

By raising the transient stability limit of the lines;
By improving the reactive power balance and voltage regulation of the lines;
And by improving the active power sharing between the lines.

Without the series capacitors, several additional 500 kV lines would have had to be added to enable stable transmission of the same amount of power through the corridor. It is not difficult to imagine how much more that would have cost, in time, money, and environmental impact. In fact, it would have been quite impossible, from the concessional, environmental, as well as economical point of view.

As a matter of fact, the benefits of series compensation as an alternative to building more lines were established from the very start, when an evaluation was made between initially two series compensated 500 kV lines and three uncompensated lines, for transmission of the initial 1650 MW of power. The series compensated alternative came out as about 30% less costly from a pure investment point of view. On top, as mentioned previously, there were environmental benefits which counted in an important way, as well. With this, the series capacitor option was firmly established for the continued development of the power corridor.

Fig. 14: 500 kV series capacitors.

3. TCSC:
Brazil North-South Interconnection
A current example of AC interconnection of separate power systems is found in Brazil. There are two main power systems in the country which were previously not interconnected, the North System and the South System. These are mainly hydro-electric, comprising more than 95% of the nation´s total volume of power generation and consumption. Feasibility studies were performed regarding an interconnection of the two systems, and a decision was made to go ahead and build the transmission corridor. Both AC and DC alternatives were assessed, and decided in favour of the AC option. It consists of a single 500 kV compact circuit (to be doubled at a subsequent stage), more than 1.000 km long and series compensated in several places. Operation began early in 1999.

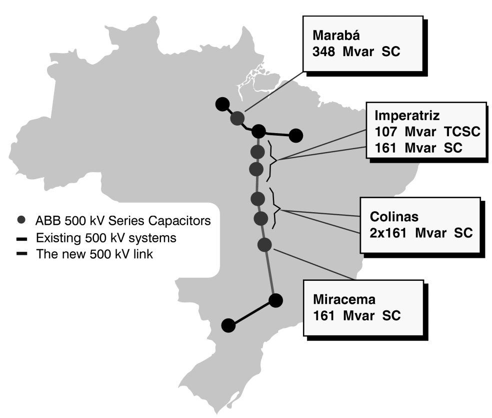

Fig. 15: Brazil North-South Interconnection.

The AC option with FACTS came out less costly than the DC alternative. Furthermore, it is attractive from the point of view that it facilitates the making of inexpensive hydro energy available to a rapidly growing federal economy as well as to future development over a vast area having great economical potential. In other words, it enables the connecting to the North-South Link in a simple and economical fashion of several hydroelectric plants expected to be built along the same route in the coming two decades.

A total of six 500 kV series capacitors have been supplied for the project, five of which fixed and one thyristor-controlled (Fig. 15). All in all, about 1100 Mvar of series capacitors have been supplied.

The thyristor-controlled series capacitor is located at the Imperatriz substation at the northern end of the interconnection. It has the task of damping low frequency inter-area power oscillations between the power systems on either side of the interconnection. These oscillations (0,2 Hz) would otherwise have constituted a hazard to power system stability.

A view of the TCSC is displayed in Fig. 16. The main data of the Imperatriz TCSC can be summarized as follows:

Maximum system voltage	550 kV
Nominal reactive power	107 Mvar
Rated current	1500 A

Fig. 16: View of the Imperatriz 500 kV TCSC.

4. IPC:
Vermont-New York Intertie

In Eastern USA, the New York Power Authority (NYPA) system interconnects with the Vermont Electric Company (VELCO) system via a 115 kV tieline. The tie is a critical link which is necessary to provide both local reliability of service as well as bulk power transfer between the two systems. In order to optimize operation, a PST with a nominal rating of 115 kV, 175 MVA located at Plattsburgh, N.Y. is used to control the tie. During summer operation, this PST constitutes the thermally limiting piece of equipment of the interconnection, limiting pre-contingency loading during summer months to 105 MW.

It was recognized as a common interest of NYPA and VELCO to increase the permissible summer transfers over the tieline. An IPC of the APST type was decided upon as the most attractive way of meeting all the system objectives. Placing a high impedance inductor in parallel with the existing PST would reduce flow through it while maintaining essentially full controllability of the tie (Fig. 17). In addition, shunt capacitor banks were required for local supply of the reactive power consumed by the inductor.

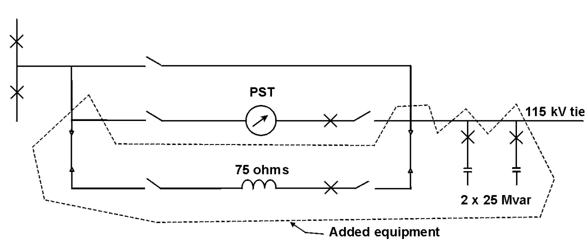

Fig. 17: Single-line diagram of the Plattsburgh IPC.

The Plattsburgh IPC was commissioned in June 1998 (Fig. 18). With it in operation, permissible summer transfer over the tieline in question has been increased to 140 MW, an increase by 35 MW or 33%. An assessment of costs revealed that the IPC cost only about half of what it would have cost to replace the existing PST by a new unit, sufficiently rated for the higher summer transfer.

Fig. 18: Plattsburgh APST.

Conclusion

Power supply industry is undergoing dramatic change as a result of deregulation and political and economical détente in many parts of the world. This new market environment puts growing demands for flexibility and power quality into focus. Also, trade between countries of electric power is gaining momentum, to the benefit of all involved. This calls for the right solutions as far as power transmission facilities between countries as well as between regions within countries are concerned.

As indicated by the acronym, FACTS stands for flexibility in AC power systems. Properly utilized, this offers benefits to users of a variety of kinds:

Without the need to reinforce the grid by means of additional or upgraded existing lines and/or substations FACTS brings about:

-An increase of synchronous stability of the grid;
-An increased voltage stability in the grid;
-Decreased power wheeling between different power systems;
-Improved load sharing between parallel circuits;
-Decreased overall system transmission losses;
-Improved power quality in grids.

The choice of FACTS device in each given case is usually not obvious but needs to be made the subject of system studies, taking all relevant requirements and prerequisites of the system into consideration, so as to arrive at the optimum technical and economical solution. In fact, the best solution may often be lying in a combination of devices.

From an economical point of view, more power can be transmitted over existing or new transmission grids with unimpeded availability at an investment cost and time expenditure lower, or in cases even far lower than it would cost to achieve the same with more extensive grids. Also, in many cases, money can be saved on a decrease of power transmission losses.

From an environmental point of view, FACTS enables the transmission of power over vast distances with less or much less right-of-way impact than would otherwise be possible. Furthermore, the saving in transmission losses may well bring a corresponding decrease in need for generation, with so much less toll on the environment.

All these things help to enable active, useful power to reach out in growing quantities to growing populations under safe and favourable conditions all over the world, to the benefit of all, in LDCs just as well as in highly developed countries. Also, individual countries´ own border lines no longer constitute any limit to power industry. With FACTS, power trade to the benefit of many can be established to a growing extent across borders, by making more efficient use of interconnections between countries, new as well as existing.

Finally, a rough and quick guideline to the use of FACTS in various applications:

Issue	**Device**	**Comment**
Steady-state voltage control	MSC SVC SC	Stepwise, infrequent ctrl. only Continuous control inherent Continuous control inherent
Dynamic and Post-contingency voltage support	SVC Statcom	 Compact design
Improvement of steady-state load sharing	PST IPC SC	 Easily expandable rating Very low losses
Post-contingency load sharing	PST TCSC	 Faster
Transient stability improvement	SC SVC Statcom	Inherently self-regulating Compact design
Power oscillation damping	SVC TCSC	Location critical Insensitive to location and load type
Power quality improvement	SVC Statcom DVR	Voltage fluctuation mitigation Flicker mitigation Voltage sag mitigation

Terminology:

MSC	Mechanically-switched Capacitor*
SVC	Static Var Compensator
SC	Series Capacitor*
Statcom	Static Compensator
PST	Phase-shifting Transformer
IPC	Interphase Power Controller
TCSC	Thyristor-controlled Series Capacitor
UPFC	Unified Power Flow Controller
DVR	Dynamic Voltage Restorer

* Not strictly FACTS but closely related in its application.

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