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FACTS AND HVDC LIGHT FOR POWER SYSTEM INTERCONNECTIONS

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Introduction

The deregulation of the electricity market together with increasing constraints resulting from social opposition to the installation of new facilities puts new demands on the operators of transmission and distribution systems. These new trends enhance the need for flexibility, power quality and increased availability of transmission and distribution systems by using tools which can be implemented with limited investments, short delivery times and short planning and decision making horizons. FACTS (Flexible AC Transmission Systems) is a term denoting a whole family of concepts and devices for improved use and flexibility of power systems. Some of these devices have today reached certain maturity in their concept and application, some are as a matter of fact quite established as tools in power systems. This paper will treat benefits of FACTS devices applied in power systems such as increased power transmission capability, improved static and dynamic stability, an increase of a availability and a decrease of transmission losses. Examples will be given of FACTS devices which have reached a more or less commercial degree of applicability in power systems, salient design features of these as well as operational experience. The paper also treats HVDC Light, a new DC transmission system technology, still consisting of well-known components forming the system. HVDC Light is very suitable for DC power transmission for a number of applications, as will be highlighted in the paper.

New approach to development of transmission networks

The traditional way to develop the transmission network in order to achieve better linkage between generation and demand was to reinforce of the grid, mainly by installing new lines and substations.

However, in recent years substantial changes were implemented in the traditional structures of electric power systems throughout the world. The general reason for this is to improve efficiency, and the main tools are deregulation and privatization i.e. the introduction of market rules to the electrical sector. In consequence the transmission system must be adapted to the new conditions of open access and open trading. This adaptation requires the construction of new interconnections between regions and countries. The other important element is the necessity to adapt transmission systems to changing generation patterns.

Manufacturers of electrical equipment must be prepared to meet these new requirements, where relocatability and flexibility will be the critical factors.

The flexibility of the system also means shorter planning and decision-making, with the consequence that shorter delivery times are requested.

Practical examples of how these new requirements can be satisfied by using new types of equipment are described below.

Significance of reactive power compensation

Transmission of electric energy at EHV (extra high voltage) over a long distance by means of alternating current (AC), requires some kind of reactive compensation. This is due to the inherent distributed series reactance and shunt susceptance of the long AC transmission line. If suitable means for reactive compensation are not installed, operation of the EHV power system for different steady state and dynamic conditions becomes difficult and even impossible.

Basically, reactive compensation may be applied to the power system in two ways: series compensation and shunt compensation. Usually, shunt compensation is employed for voltage control and series compensation to control the longitudinal behavior of the network.

The series capacitor is a special case of controlling the power transmission system through control of a longitudinal element, i.e. an element that is placed lengthwise in the transmission line. This is in contrast to shunt element controls, such as the control of generation, of loads or using static var compensators. However, each type of compensation affects, to some extent, both the voltage control and the stability limit. In an actual long distance EHV AC transmission system, means for series and shunt compensation are often combined in order to achieve the optimal result.

Application of Series Capacitors

The property of the series capacitors is that it provides a method of controlling the longitudinal behavior of the network while providing reactive power. This form of compensation is very effective in certain situations. The Series Capacitor reduces the total reactance of a transmission line and thus makes the line electrically shorter.

To summarize, the main reasons for incorporating series capacitors in transmission systems will be:

- To increase the power transfer capability as a result of raising the transient stability limit
- To improve the voltage profile of the system
- To reduce transmission system losses by optimizing the sharing of active power between parallel lines
- To reduce the cost of power transmission by making power transfer with fewer parallel lines and less required shunt compensation possible.

Series compensation in a system improves voltage control and reactive power balance because the reactive power generation in a series capacitor increases as the transmitted power increases. In this respect, the series capacitor is a self-regulating device.

The important features of series capacitors as a part of the transmission system is high reliability and proper protection arrangement. High reliability means that the series capacitor is designed in such a way that its availability is at least as great as that of the other vital parts of the system (lines, breakers, transformers, etc.).

The protection demand implies that the series capacitor has to be provided with a protective system which quickly and safely by-passes the capacitor in a situation where faults in the surrounding parts of the power system give rise to conditions which might cause damage to the series capacitor. However, the same protective system also has to allow the series capacitor to be reinserted into the power system with a minimum of delay as soon as the fault in the surrounding network has been cleared.

The capacitors are often located along the lines, and switched as part of the lines. The choice of location may require a special study in each particular case, with respect to overall economy and system reliability. The degree of compensation usually lies between 20 and 70 %, as referred to the line inductive reactance. EHV series capacitor installation usually range in size between 100 Mvar and 1000 Mvar.

The technology involved in series compensation has undergone dramatic development in recent years. Not only capacitors themselves, which have improved greatly over the years as regards reliability, power density and losses, but also associated equipment such as protective devices, control systems, etc. In the field of protection, zinc oxide (ZnO) technology has brought new possibilities of high reliability and reinsertion speed. The triggered spark gap has enabled more cost-effective design of the ZnO protection at high fault levels. As regards the control system, fiber optic signal communication and computerized control equipment have opened a wide range of features for series capacitor application today and in future.

By utilizing series capacitors, fewer parallel lines are required and construction of new lines can be postponed or made unnecessary altogether. Investing in a series capacitor as an alternative to a new line will often prove profitable, in more than one way:

- Investment cost is only a fraction of the line cost, lead times are much shorter and right of way problems can be avoided

Series capacitor technology is well proved today as part of subtransmission and transmission systems up to 800 kV. More than 100.000 Mvar of series capacitors are in operation or under construction all over the world.

Application examples

400 kV transmission system in Sweden

The 420 kV transmission system between Northern and Middle Sweden comprises 8 lines with altogether 8 Series Capacitors, having a total rating of 4800 Mvar. See Fig. 1. The degree of compensation k ($k = X_C / X_L$) for the individual Series Capacitor Banks, has been selected in such a way, that the sharing of active load (real power) between the individual 420 kV lines, which are of different designs, and the parallel connected 245 kV network, became most favorable. In the optimum point, minimum losses for the total network is obtained. The reduction in losses, compared to the uncompensated case, has alone paid for the Series Capacitor investment in a few years. Another benefit of the Series Capacitors in the Swedish 420 kV network is the ability to supply reactive power and support the voltage during and after a large disturbance.

The selected degree of compensation is between 30 – 70 % for the individual banks. With this compensation, stable transmission of more than 7000 MW on 8 parallel lines is achieved. This means, that the lines are loaded up to or > 2 x SIL (Surge Impedance Loading). Without Series Compensation five additional lines would have been needed to transmit the same amount of power. This, of course, would have been unpermissible, not only from an investment point of view, but also with respect to the environmental impact, right of way problems, etc.

The operating experience has been very good. The overall failure rate of capacitor units has been less than 0.1 per cent per annum. Other faults have also been insignificant and caused no interruption of service. A simple and reliable design of the protective and supervising system has contributed to this. The capacitor stations are unattended. Inspection and maintenance are carried out at regular intervals by visiting personnel.

Improvement of the transient stability of a long 500 kV AC transmission system in Argentina

In a long, weak EHV AC transmission system, the power transmission capacity is limited by the transient stability requirement. In this case, the property of the series capacitor to reduce the reactance of a long transmission line (i.e. the reduction of the total transfer reactance) offers an effective and economic means of improving the transient stability limit, which permits the lines to transfer more power.

Another typical application which illustrates this is the 500 kV El-Chocon AC transmission system in Argentina. See Figure 2. The El Chocon-Ezeiza system was designed to transfer 1650 MW across1038 km. 500 kV was chosen as it proved to be technically and economically preferable to a higher AC voltage or HVDC. The system was made up of two parallel circuits erected on independent structures.

Originally, two options for the design were considered:

- Option A: Two parallel 500 kV transmission lines with 40 % series compensation
- Option B: Three parallel 500 kV transmission lines without series compensation

After economic considerations, option A was chosen, since the cost of option B was approx. 35 % higher. The cost of the series capacitors was approx. 10 % of the total cost of option A.

The first line was commissioned in 1973 and the second a year later. In 1977, series capacitor banks were installed in the Puelches and Henderson substations, which are located approximately a third of the line length from the two system ends. The banks providing the 40 % series compensation were connected between the station busbars. Without compensation the power transfer capacity would be limited to 800 MW.

The SCs were designed with a continuous current rating of 2056 A, 368 Mvar per 3-phase bank. The overload current rating was according to IEC 143, 1972.

Two additional 500 kV transmission lines, both planned with series compensation, have been subsequently added to the system.

- A third line between El Chocon and Abasto was added in 1986 raising transmission capacity to 2600 MW. This line was compensated in 1994 raising the capacity with another 300 MW, please see Fig.3.

  In 1996 the banks in Puelches and Henderson were replaced with banks having the same compensation level (40 %) but a larger current carrying capacity. The new banks are rated 681 Mvar and 596 Mvar respectively. The new banks secured the increase of transmission capacity with another 400 MW.

- A fourth line between Piedra del Aguila and Abasto is now under construction and will be commissioned in the end of 1999.

The total transmission capacity of the corridor will be thus be established at 4600 MW.

Application of SVC's (Static Var Compensators)

The SVC is a reactive power compensation device based on high power thyristor technology. It is a static shunt reactive device, the reactive power generation or absorption of which can be varied by means of thyristor switches. Unlike the synchronous compensator, it has no moving parts and hence the denomination "static".

Already in the first half of the 1970s the SVC became a well-established device in high-power industrial networks, particularly for the reduction of voltage fluctuation caused by arc furnaces. In transmission systems the breakthrough came at the end of the 1970s. Since then, there has been an almost explosive increase in the number of applications, in the first place as an alternative to synchronous compensators, but also for a more extensive use of dynamic i.e. of easily and rapidly controllable shunt compensation.

At present approximately 300 SVCs with a total control range of about 40 000 Mvar have been installed or are under construction worldwide.

Compensators in use range in size from some tens up to several hundreds Mvar control range with nominal voltages up to 765 kV.

An SVC can improve power system transmission and distribution performance in a number of ways. Installing an SVC at one or more suitable points in the network can increase transfer capability and reduce losses while maintaining a smooth voltage profile under different network conditions. The dynamic stability of the grid can also be improved, and active power oscillations mitigated.

To summarize the application of SVC gives the following benefits.
In power transmission:

- Stabilized voltages in weak systems
- Reduced transmission losses
- Increased transmission capacity, to reduce or remove the need for new lines
- Higher transient stability limit
- Increased damping of minor disturbances
- Greater voltage control and stability
- Power swing damping

In power distribution:

- Stabilized voltage at the receiving end of long lines
- Increased productivity as stabilized voltage better utilizes capacity
- Reduced reactive power consumption, gives lower losses and eliminates higher or penal tariffs
- Balanced asymmetrical loads reduce system losses
- Fewer stresses in asynchronous machinery
- Enables better use of equipment (particularly transformers and cables)
- Reduced voltage fluctuations and light flicker

An SVC typically comprises a transformer, reactors, capacitors and bi-directional thyristor valves. There is a variety of main circuit arrangements. Figures 4 and 5 show two common schemes:

- FC/TCR – Fixed Capacitor (filter) / Thyristor-Controlled Reactor
- TSC/TCR – Thyristor-Switched Capacitors/Thyristor-Controlled Reactor

Application examples

Interconnection Canada - USA

Northern States Power Co. (NSP) of Minnesota, USA are operating an SVC in its 500 kV power transmission network, a part of Manitoba-Minnesota Transmission Upgrade Project, the purpose of which is to increase the power interchange capability between Winnipeg and the Twin Cities on existing transmission lines. See fig. 6.

The solution for increased power transmission capability was chosen instead of building a new line as it was found superior with respect to increased asset utilization as well as minimized environmental impact.

The main purpose of the SVC is to improve the generation and transmission system's dynamic response to network disturbances. It also provides improvement during steady-state conditions by supplying adequate reactive power support. With the SVC in operation, the power transmission capability of the transmission system has been increased by some 200 MW.

Without the SVC power transmission capacity of the NSP network would be severely limited, either due to excessive voltage fluctuations following certain fault situations in the underlying 345 kV system, or to severe overvoltages at loss of feeding power from HVDC lines coming from Manitoba.

The system has a dynamic range of 450 Mvar inductive to 1000 Mvar capacitive at 500 kV, making it one of the largest of its kind in the world. It consists of a Static Var Compensator (SVC) and two 500 kV, 300 Mvar Mechanically switched Capacitor Banks (MSC). The large inductive capability of the SVC is required to control the overvoltage during loss of power from the incoming HVDC at the northern end of the 500 kV line.

The SVC consists of two Thyristor-switched Reactors (TSR) and three Thyristor-switched Capacitors (TSC), Fig.7. The overall dynamic range of the SVC as seen from the 500 kV side is presented in Fig. 8.

The short-time ratings are utilized only during severe disturbances in the 500 kV network. Additionally, the SVC has been designed to withstand brief (<200 ms) overvoltages up to 150 % of rated voltage.

Transient stability improvement in the Mexican 400 kV system

An SVC with a dynamic range of 600 Mvar is operating since 1982 in Temascal substation of CFE Mexico. The compensator was installed in order to increase the transmission capacity and ensure secure power supply in the 400 kV transmission system between the hydro-power generating stations in the south of the country and the large consumer district of Mexico City.

The compensator consist of four thyristor-switched capacitor groups (TSC) and four thyristor-controlled reactors (TCR), each rated 75 Mvar. This permits continuous regulations of reactive power from 300 Mvar inductive to 300 Mvar capacitive. The actual range of operation is further extended by control of 9 mechanically-switched reactors having a total rating of 490 Mvar.

The TCR:s eliminate the excessive voltage rise which can occur when operating on light load and during abnormal conditions in the power system, and in addition reduce surges during switching operations. The TSC: s stabilize the system during heavy and peak load periods.

The increase of power transmission capacity due to installation of the SVC is close to 200 MW. See fig. 9.

Thyristor controlled series compensation

With the advent of thyristor control, the usefulness of series compensation has been augmented further. Applications not spoken of hitherto in conjunction with series compensation such as active power flow control, damping of power oscillations, and last, bust not least, mitigations of sub-synchronous resonance, are all now a practical reality. The latter item, in particular, had for a long time been in search of a good and practicable solution, and with sub-synchronous resonance no longer an obstacle, it can be expected that the usefulness of series compensation will be appreciated even more than before and the technology put to even more widespread use.

The evolution of controllable series compensation can be illustrated as in Fig. 10. Whereas Mechanically Switched Series Capacitors (MSSC) offer versatility for power flow control, the introduction of thyristor technology brings the concept of series compensation still a large step further. Important added benefits are:

- Post-fault dynamic stability improvement
- Damping of active power oscillations
- Mitigation of sub-synchronous resonance (SSR) risks.

If damping is poor over a transmission line, minor system disturbances can get active power oscillations started between generator systems at either ends of the line. These oscillations, usually appearing at low frequencies (<1 Hz), as a rule are more pronounced at higher loads than at lower loads and as a matter of fact act as a limitation on effective power transmission capability of interconnections between generating areas. This could be a serious drawback for instance in conjunction with power corridors between countries or between regions within countries.

By inserting a time varying capacitive element in series with the inductive line reactance (TCSC), the overall reactance can be modulated in time to counter active power oscillations over the line.

Brazil: North-South Interconnection

A current example of AC interconnection of separate power systems within one country is found in Brazil. There are two main power systems in the country that were previously not interconnected, the North System and the South System. These are mainly hydroelectric, 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 favor of the AC option. It consists of a single 500 kV compact circuit (to be doubled at a later stage), more than 1.000 km long and series compensated in several places along the line. Start of operation was early in 1999.

The AC option is highly attractive as 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. Several hydroelectric plants are expected to be built along the same route in the coming two decades, to be connected to 500 kV AC.

A total of six 500 kV series capacitors have been supplied for the project, five of which fixed and one thyristor-controlled (Fig.11). 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 constitute a hazard to power system stability.

The boost level of the TCSC is a key factor. It is a measure of the amount by which the reactance of the series capacitor can be virtually augmented in order to counteract system power oscillations. The boost level can be varied continuously between 1 and 3, which is equivalent to a range of 5% to 15% of the degree of line compensation. At rated line current, the nominal boost level has been set to 1,20.

The thyristor valve is mounted at platform level. It is water-cooled and utilizes indirect light triggered thyristors. The valve is rated at 1500 A continuous current and at 3000 A for 10 seconds. Furthermore, since the valve has to perform as back-up protection of the TCSC in extreme situations where the main ZnO overvoltage protection is reaching its rated thermal limit, it needs to be able to withstand fault currents of up to 40 kA (peak) for about 60 ms, equal to the time it takes for the by-pass breaker to close and take over the fault current.

A view of the TCSC is displayed in Fig.12. The main data of the Imperatriz TCSC can be summarized as follows:

Maximum system voltage	550 kV
Nominal reactive power	107 Mvar
Physical capacitor reactance	13,3 Ω
Nominal boost	1,20
Nominal degree of compensation	5%
Boost level range	1-3
Rated current	1500 A
Rated continuous voltage	23,9 kV

Application of TCSC for mitigation of subsynchronous resonance

The introduction of series compensation improves the transmission system behavior with respect to voltage stability and angular stability. However, under adverse conditions, at the same time an electrical resonance might be introduced in the system. Experiences have shown that such an electrical resonance may under certain circumstances interact with mechanical torsional resonances in turbine-generator shaft systems in thermal generating plants. This phenomenon is known as (one form of) Subsynchronous Resonance (SSR). Today the SSR problem is well understood and taken into account when series compensation is planned and designed.

Sometimes SSR conditions may limit the degree of compensation needed for a better power system performance. The use of TCSC will alleviate such restrictions.

Static Synchronous Compensator (STATCOM)
The Static Compensator is based on a solid-state synchronous voltage source that is analogous to a synchronous machine which generates a balanced set of (three) sinusoidal voltages, at the fundemental frequency with controllable amplitude and phase angle. This machine, however, has no inertia and can internally generate or absorb reactive power.

Voltage Source Converter (VSC)
A principal three-phase circuit configuration of a three level voltage source converter is shown in Fig.13. It consists of 12 self-commutated semiconductor switches, each of which is shunted by a reverse parallel connected diode, and six diode branches connected between the midpoint of the capacitor and the midpoint of each pair of switches. By connecting the dc source sequentially to the output terminals, the converter can produce a set of three quasi-square voltage forms of a given frequency.

The frequency, amplitude and the phase of the ac voltage can be varied by proper control. Thus, the voltage source converter can be considered as a controllable voltage source.

Principle of Operation
A Static Compensator consists of a voltage source converter, a coupling transformer and controls. In this application, the dc energy source can be replaced by a dc capacitor and hence, the steady-state power exchange between the Static Compensator and the ac system can only be reactive as illustrated in Fig.14. Here, 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 is controllable. If $V_i > V_T$, the Static Compensator supplies reactive power to the ac system. If $V_i < V_T$, the Static Compensator absorbs reactive power.

Applications
- Dynamic voltage stabilisation: power transfer capability increase, reduced voltage variations.
- Steady-state voltage support.
- Synchronous stability improvements: increased transient stability, improved power system damping, damping of SSR.
- Dynamic load balancing.
- Power quality improvement.

SVC Light
SVC Light is a product name for an IGBT based STATCOM. The Light technology is based on the principle that the plant topology should be simple. A minimum of conventional apparatus should be used. These components are replaced by high technology devices such as IGBT valves and high performance computer systems. By use of high frequency switching PWM (about 2 kHz), 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 have been located inside a container. In it, the IGBT valves, DC capacitors, control system and the valve cooling system reside. The outdoor equipment is limited to heat exchangers, commutation reactors and the power transformer. Today, a rating of +/- 100 Mvar per converter is available. In case a wider range is required additional fixed capacitors, thyristor switched capacitors or an assembly of more than one converter may be used. An utility SVC Light has the appearance shown in Fig.15.

Voltage and current characteristics
The operating area for the new type of SVC is defined by the maximum voltage that can be set up on the converter terminals and by the maximum converter current. At undervoltage conditions a constant current equal to the maximum converter current can be maintained. This implies that the Mvar production decreases linearly

with the voltage. During overvoltage conditions the maximum current can be maintained up to the ceiling for the converter terminal voltage.

Response time
The semiconductor valves in an SVC Light 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.

Harmonic interaction with the network
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 necessary. The risk for resonant conditions is therefore negligible. This property makes the SVC Light suitable for easy relocation to other sites at changing network demands.

The high switching frequency used in the SVC Light 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 SVC Light then injects harmonic currents into the network with proper phase and amplitude to counteract the harmonic voltages.

Footprint and layout
SVC Light for power utility can be built very compact, see Fig.15. The area required is no more than approximately 10 times 20 meters.

HVDC LIGHT for power system interconnections

HVDC Light is a new DC transmission system technology, still consisting of well known components forming the complete system.

HVDC Light is very suitable for DC power transmission as well as for reactive power generation and consumption. One HVDC Light unit is capable of transmitting up to about 200 MW, as of today.
The same unit can also be used to generate or consume up to about 200 MVAr. These properties are controlled independently of each other, and this is one of many features with HVDC Light.

As can be seen from the Single Line Diagram, Fig.16, the Converter station consists of only a few components, i.e. the valve bridge and the capacitors on the DC side, the phase reactors and the harmonic filter bank on the AC side. In most applications a three phase step-up transformer is added. One modular housing is including the Control & Protection system, as well as the Station Control and Monitoring system. The valve cooling system together with the auxiliary power system are located in another dedicated module.

HVDC Light is based on the Voltage Source Converter, VSC, technology, where the valves are built by Insulated Gate Bipolar Transistors, IGBT's. This type of converters are able to switch off the DC current independent of the AC voltage. The ± DC voltages are kept constant to an ordered value by high frequency switching of the rectifier valves, which thereby charges the DC side capacitors. Furthermore, the VSC inverter can create its own AC voltage in case of a black AC network, through high frequency switching between the ± DC voltages. This is known as Pulse Width Modulation, PWM, technique, Fig.17. As mentioned above active and reactive power are separately controlled. The active power is controlled by adjusting the difference between the phase angles of the AC voltage output from the converter valves and the AC system voltage, measured across the phase reactors. Reactive power is controlled by adjusting the AC voltage amplitude out from the converter valves.

Application areas

Bulk power transmission
The facility can be used for normal active bulk power transmission with or without imposed modulations, e.g. frequency control.

Reactive power generation/consumption
HVDC Light can be set to consume or generate reactive power, independent of the level of active power, which even can be set to zero, still having full reactive power control capability at both ends.

Small scale generation
Development of remote small scale generation, such as wind and hydro, will be economically justified, by utilising HVDC Light for transmission of the electricity.

Feeding of local loads, like islands
The HVDC Light transmission concept makes it feasible, in many cases, to connect remote local loads or islands to a main grid, thereby enable such loads to benefit from the less costly electricity available from the main grid.

City centre infeed
Increasing the capacity of electricity into city centres by adding new AC over head lines, could be very costly, and in many cases impossible due to the permit requirements. By using the cost effective HVDC Light DC cables the energy can be brought into the city centre by underground cables, or connected on existing poles or towers, instead.

Multiterminal DC grid
VSC converters are very suitable for creating a DC grid with a large number of converters, since very little co-ordination is needed between the interconnected HVDC Light converters.

Interconnection of asynchronous AC networks
Due to the high frequency switching of the IGBT's, the frequency of the AC networks are of no importance. HVDC Light can handle any frequency up to several hundred of Hz.

Off-shore generation
Transmission of electricity derived from excess gas at oil platforms, or from wind mills at sea, becomes economically feasible by using HVDC Light for the transmission to the main grid.

Converting existing AC transmission into DC
In areas where permits for building new AC transmission lines are hard or impossible to get, the transmission capacity of existing distribution systems can be increased in a very cost effective way, by converting the AC lines into HVDC Light DC lines.

Power quality by isolation of disturbing loads
Loads like smelters, normally causes a lot of problems to other loads in the main grid.
HVDC Light is very immune to disturbances on the AC systems. This feature makes the VSC converter very suitable to feed such a disturbing load, thereby isolate the disturbing load from the main grid, preventing other loads from being damaged.

Advantages with the HVDC Light.

- Possible to feed totally islanded and passive AC networks
  The VSC converter is able to creates its own AC voltage at any predetermined frequency, without the need for rotating machines, thanks to the PWM technique.

- Separately control of active and reactive power
  Active power transmission and reactive power consumption/generation orders can be set independently of each other by the operator. The active power can even be set to zero, while maintaining full reactive power modulation of the AC systems.

- No contribution to short circuit currents
  At AC system ground faults or short circuits, whereupon the AC voltage drops, the power transmitted by the HVDC is automatically reduced to a predetermined value, hence the contribution to the fault current is decided by whether the receiving system is isolated or synchronised with the main grid.

- Intercommunication not needed
  From technical point of view, telecommunication between the rectifier and the inverter is not needed, since the rectifier keeps the DC voltage constant at the desired value, independent of the power order set at the inverter(s) hooked up to the DC system. The inverter(s) has its own power order, where upon the corresponding amount of DC current is consumed from the DC side.
  From convenience point of view for the operators, a telecommunication link might be desired in order to have the status of the involved converter stations displayed, and to be able to control the entire system from one location and by one operator or from a dispatch centre.

- Environmental-friendly
  Compact design requires a minimum of open space.

- Underground cables instead of OH lines
  The visual impact is minimised. No towers or gantries needed for connecting the DC side.

The extruded DC cables can be buried all the way between the converter modules of the stations.

- Short overall delivery time
  The complete system is modularised, standardised, and pretested at the factory, resulting in a minimum of commissioning time at site. Furthermore, the site preparation required is fairly simple, due to the low weight of the included modules, forming the converter station.

- Relocateable
  The modularised design makes the relocate-ability possible, should the conditions and requirements change in the future.

- Low maintenance requirements
  The only moving parts are the fans and pumps of the valve cooling system.
  All units are supervised by the redundant MACH 2 control system, from which all necessary information will be obtained to ensure safe and reliable operation of the facility.

HVDC Light Cables

The Cables used in HVDC Light applications are a new developed type, where the insulation is made of an extruded polymer that is particularly resistant to DC voltage. Polymeric cables are the preferred choice for HVDC, mainly because of their excellent mechanical strength, flexibility, and low weight.
Magnetic fields are eliminated in this facility, which operates in bipolar mode, since the DC current flows in opposite directions in the two cables, the one with a positive voltage and the other with a negative voltage. These cables are manufactured both for sea (copper), and land (aluminium) applications.

HVDC Light Converter modules

IGBT valves

The converter bridge consists of three phases, with two IGBT valves per phase. The corresponding AC phase is connected between the two valves, which enables the three phases to create a symmetrical DC voltage with opposite polarities, with respect to the midpoint grounded DC capacitors.

Each valve consists of a number of IGBT's, determined by the DC voltage level, which in turn is directly proportional to the DC power level. The IGBT's are switched on and off with a constant frequency of about 2 kHz.

Phase reactors

These are standard single phase air cooled reactors. They are used for controlling both the active and the reactive power flow, as well as for smoothing of the current, and reducing the inrush currents upon energization from the AC side. The reactors are essential for both the active and reactive power flow, since these properties are determined by the power frequency voltage across the reactors.

DC side capacitors

On the DC side there are two capacitor stacks of the same size, one from each one of the poles to ground. The size of these capacitors are depending on the required DC voltage.

The purpose is to keep a stable DC voltage at the desired level. The capacitors stacks are being charged to opposite polarities by the high frequency switching IGBT's.

AC filters

The AC voltage output contains harmonic components, derived from the switching of the IGBT's.

These harmonics have to be taken care off, preventing them from being emitted into the AC system or the air, causing malfunctioning of AC system equipment or radio and telecommunication disturbances.

One single HP filter branch is enough to take care off these low energy harmonics.

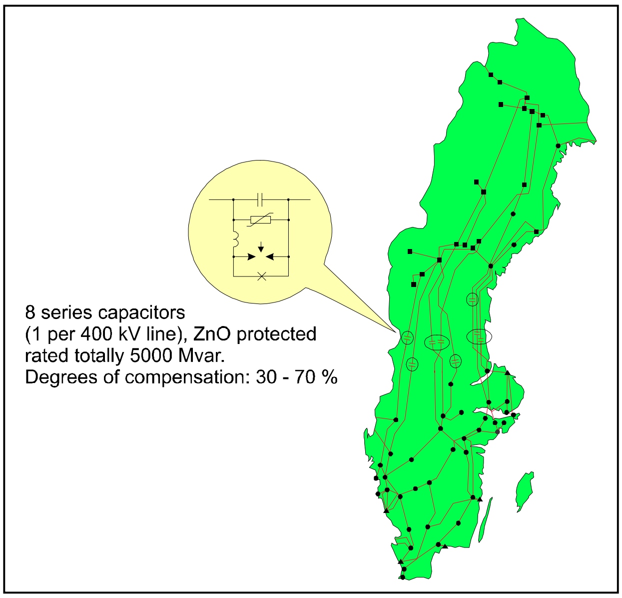

Fig. 1: 400 kV SC - Swedish National Grid

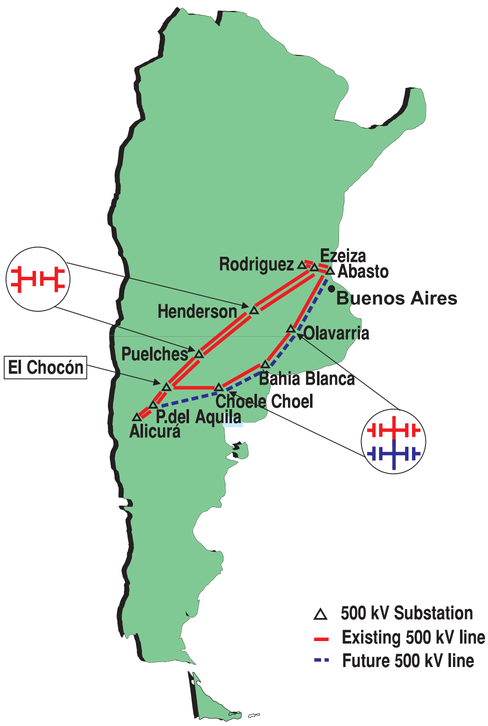

Fig. 2 : The 500 kV power transmission system in south – west Argentina

Fig.3 : View of the 500 kV SC- Olavaria- Argentina

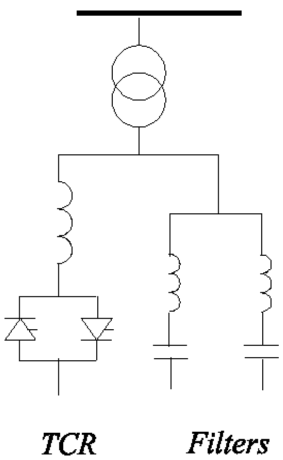

Fig.4:SVC of the TCR / FC type.

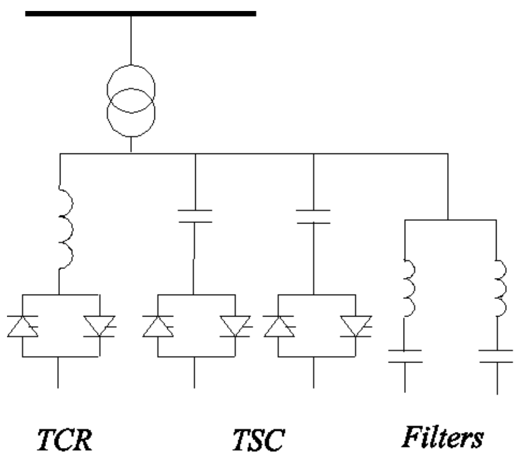

Fig.5: SVC of the TCR / TSC type.

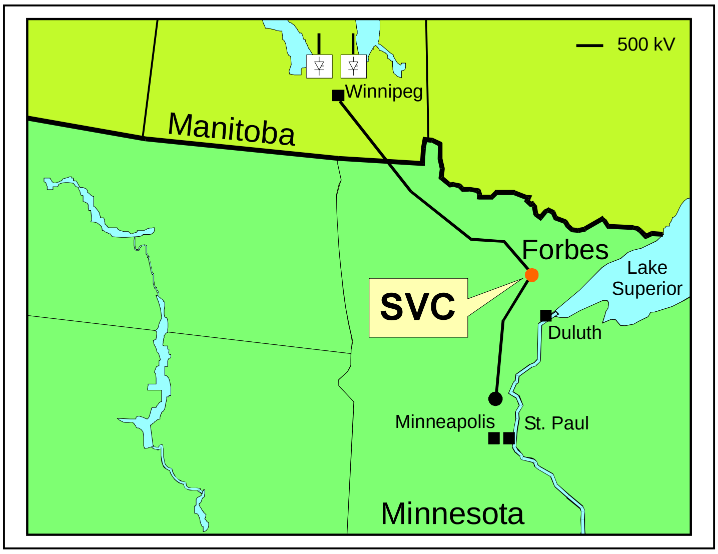

Fig. 6 : Manitoba – Minnesota 500 kV Interconnection

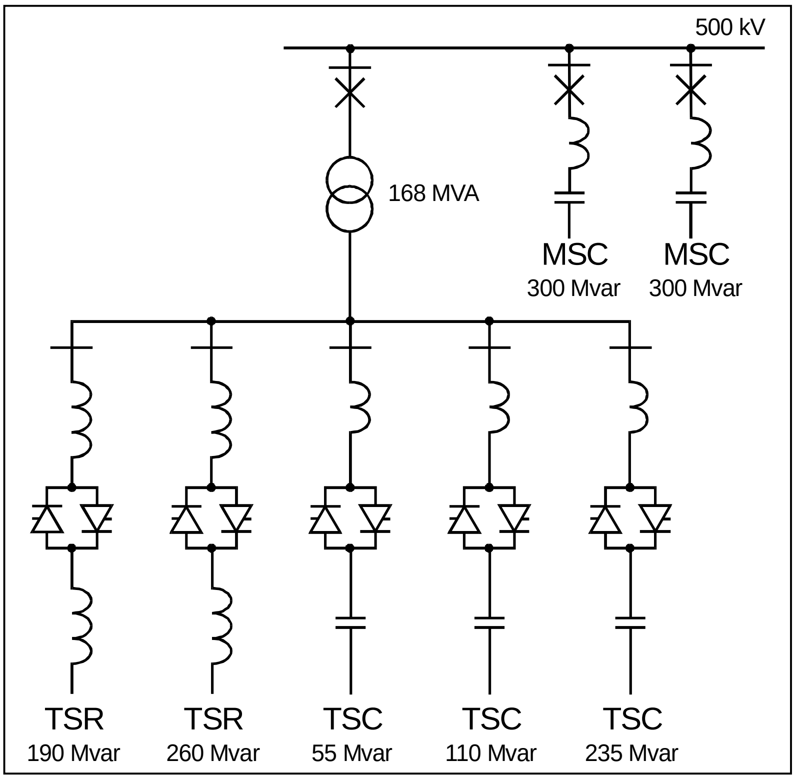

Fig. 7: Single-Line Diagram of the SVC

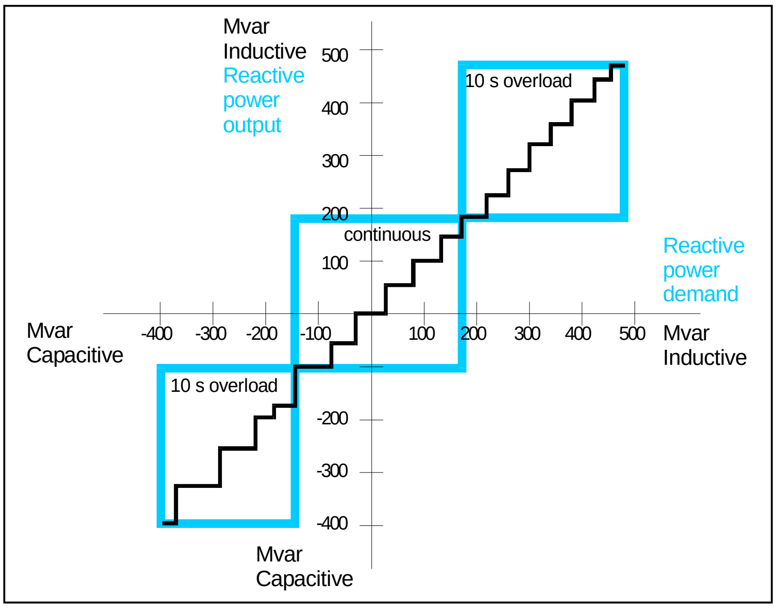

Fig. 8: Dynamic Operating Characteristics of the SVC

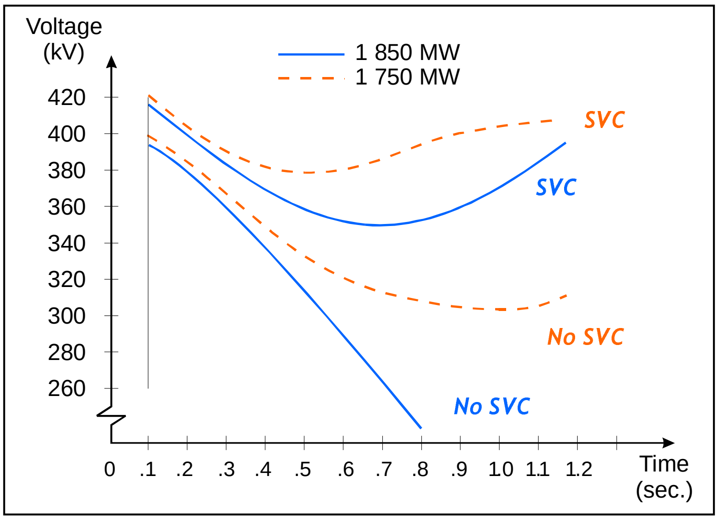

Fig. 9: Transient stability improvement by SVC in post – fault conditions

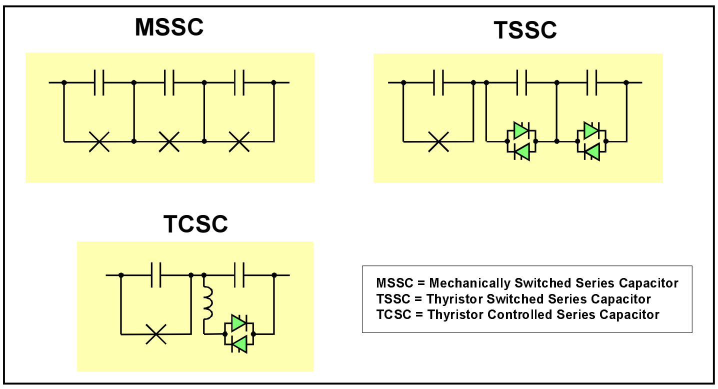

Fig.10 : Evolution of Controllable Series Compensation.

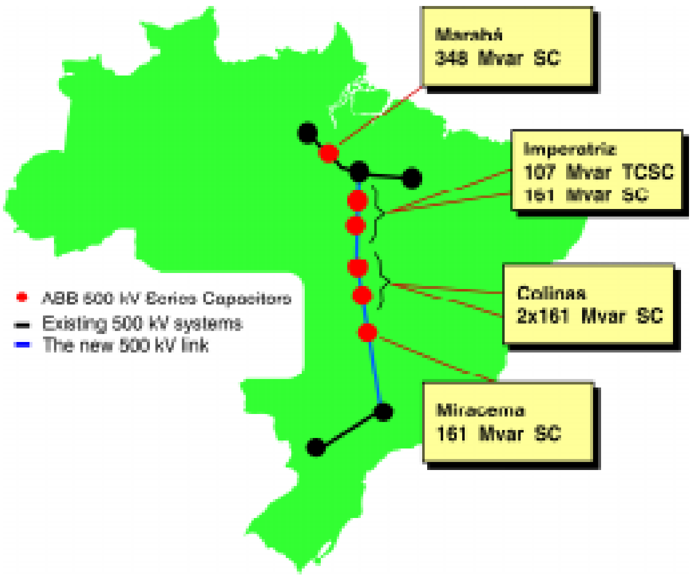

Fig.11.: Brazil North-South Interconnection.

Fig.12 : View of the Imperatriz 500 kV TCSC.

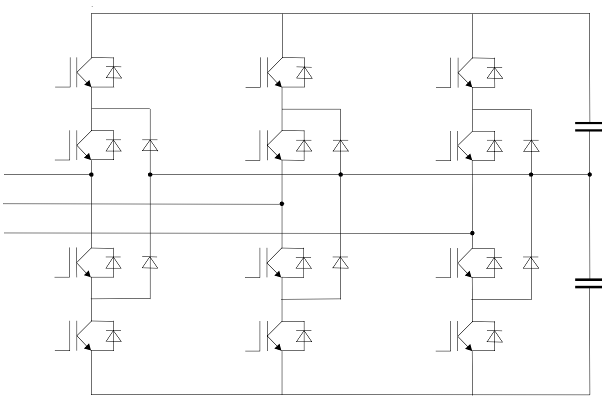

Fig.13 Basic three-level voltage source converter.

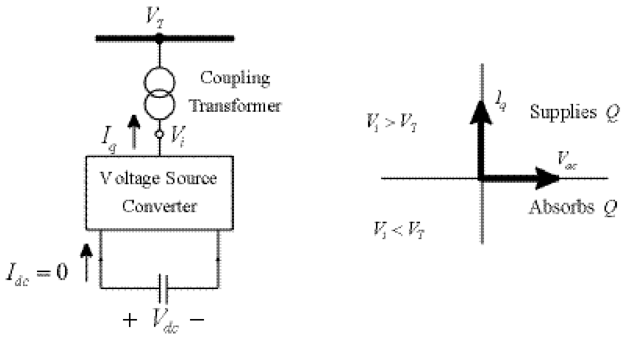

Fig.14 : Static Compensator.

Fig.15 : Typical SVC Light for utility applications.

Figure 16 .
Shows the main equipment of a typical transmission

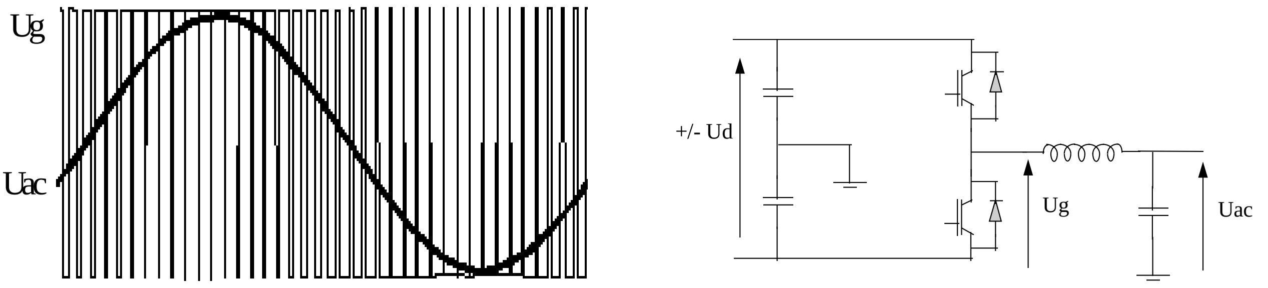

Figure 17 .

Pulse width modulation (PWM) pattern and the fundamental frequency voltage in a voltage sourced converter (VSC)