Grid flexibility

FACTS: novel means for enhancing power flow

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Blackouts in the USA and Europe have caused governments, the media, and public to focus ever more closely on the importance of a secure and reliable supply of power. It is now recognized that a significant number of grids are plagued by under-investment. The uncertainty of roles and rules within the electricity supply industry brought about by the on-going de-regulation process has only exacerbated the problem. The rapid increase of wind power in several regions of the world may have a destabilizing effect on the grid as a whole which means more emphasis needs to be placed on the resilience of transmission networks.

Traditionally the strengthening of power grids has involved the construction of new and often costly transmission lines. Cost has not been the only downside – in many cases there have also been substantial public objections.

Over the years, it has become clear that the maximum safe operating capacity of the transmission system is often based on voltage and angular stability rather than on its physical limitations. So rather than constructing new lines, industry has tended towards the development of technologies or devices that increase transmission network capacity while maintaining or even improving grid stability.

Many of these now established technologies fall under the title of FACTS (Flexible AC Transmission Systems). They not only improve the capacity of power transmission systems, but flexibility is also greatly enhanced.

In theory, a transmission system can carry power up to its thermal loading limits. In practice, however, before the thermal limit is reached, the system is most often constrained by transmission stability and voltage limits, and loop flows.

System voltage levels in AC systems may vary moderately but are not allowed to exceed well defined limits of typically 5–10 percent. Transmission stability limits refer to the limits of transmittable power with which a transmission system can ride through major faults in the system with its power transmission capability intact.

Loop flows often occur in a multi-line, interconnected power system as a consequence of basic circuit laws which define current flows by the impedance rather than the current capacity of the lines. In other words, power flow between points A and B in a grid will not necessarily take place along the shortest, most direct route, but will instead go uncontrolled and fan out to take unintended paths available in the grid. This results in overloaded lines with thermal and voltage level problems.

Because of all these constraints, a 400 kV line, for example, will usually not be required to transmit more than 450–500 MW over any "reasonable" distance without very specific safety measures in place. However, from a purely thermal loading point of view, the line is more than capable of transmitting this amount of power.

FACTS can confine or neutralize electrical disturbances such as voltage sags and fluctuations, flicker, harmonic distortion, and phase unbalance in three-phase systems. In addition, improved economy of the process or processes in question will also be achieved.

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FACTS are designed to remove such constraints in a fast and intelligent way so that planners', investors' and operators' goals are met without them having to undertake major system additions.

FACTS devices are integrated in a system for a variety of reasons, such as power flow control, reactive power (var) compensation, loop flows or ancillary functions like damping of oscillations. These devices can be applied in shunt, in series, and in some cases, both in shunt and series. Shunt devices include static var compensators (SVC), and SVC Light® (otherwise known as STATCOM). Series devices include fixed series capacitors (SC) and thyristor-controlled series capacitors (TCSC).

These devices enable a very cost effective increase in power transmission capacity at optimum conditions, ie, at maximum availability, minimum transmission losses, and minimum environmental impact.

Power quality improvement

Power quality includes many aspects: sags, disruptions, harmonics, flicker and fluctuations are just some of the phenomena involved. Voltage sags, for example, result from faults in the grid and may be caused by lightening strikes, insulation breakdowns or flash-over to ground. Whatever the reason, maintaining or improving power quality in transmission and distribution networks is very important. FACTS has more than proven itself when it comes to power quality problems as the following example will illustrate.

Suppose a region or a country decides to build a much needed steel plant. A suitable location is determined in terms of potential GNP growth and employment. However, the ability of the supplying grid is, in many cases, overlooked. The factory is built but the grid is often found to be weak or even insufficient. The result is unsatisfactory plant performance as well as added "pollution" to the grid that spreads and affects other industries connected to it.

In such cases, FACTS can confine or neutralize electrical disturbances such as voltage sags and fluctuations, flicker, harmonic distortion, and phase unbalance in three-phase systems. In addition, improved economy of the process or processes in question will also be achieved.

Long distance AC power transmission

In cases of long distance AC power transmission, maintaining synchronism as well as stable system voltages, particularly in conjunction with system faults is very important. With series compensation, safe bulk AC power transmission over distances of more than 1,000 km are very much a reality today. With the advent of thyristor-controlled series compensation, greater capability as well as flexibility is added to the AC power transmission concept.

TCSC is especially useful where long and weak transmission corridors interconnect states – or widely separated regions within states. In these situations, transfer capabilities are restricted because the dynamic stability of the links is limited. In a power transmission system, TCSC:

- Balances load flows.
- Increases first swing stability, power oscillation damping, and voltage stability.
- Overcomes the problem of sub-synchronous resonance risks (SSR).

Controllable series compensation

A series capacitor in a grid introduces an opposite reactance to that of the inductive line reactance. By this means, the effective transmission reactance of the grid is decreased and the power transmission capability is increased under stable conditions.

With TCSC, it is possible to vary the degree of compensation of the line at the mains frequency (50/60 Hz). The speed at which this can be achieved is limited only by the response time of the electronics used in the TCSC. This means TCSC can now be used in applications previously not encountered in series compensation, such as post-contingency power flow control and damping of active power oscillations.

TCSC configurations are comprised of controlled reactors in parallel with sections of a capacitor bank 1. This combination allows smooth control of the fundamental frequency capacitive reactance over a wide range. The capacitor bank of each phase is mounted on a platform to ensure full insulation to ground. The thyristor valve contains a string of high power thyristors connected in series. The inductor uses an air-core design.

A metal-oxide varistor (MOV) is connected across the capacitor to prevent over-voltages.

Power oscillation damping in India

In India, two TCSCs have been installed on a double circuit 400 kV power transmission interconnector between the Eastern and Western regions of the grid. The total interconnector length is 412 km. This AC interconnector is needed so that surplus energy is exported from the Eastern to the Western regions of India during normal operating conditions and during contingencies.

The use of TCSC ensures that inter-area power oscillations between the regions are damped. Without it, it is highly probable that power transfer over the interconnector would be limited. Dynamic simulations proving the effectiveness of the TCSC as power oscillation dampers were performed during the design stage and these were subsequently confirmed at the commissioning and testing stage. A site view of the TCSC is shown in the title picture of this article.

Static var compensation

A static var compensator (SVC) is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and/or fixed capacitors (FC) tuned to filters. Two very common design types are shown in 2a and 2b.

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, are glass fibre insulated, and epoxy resin impregnated.

A TSC consists of a capacitor bank in series with a bi-directional thyristor valve and a damping reactor, which also acts as a circuit detuner so that parallel resonance with the network is avoided. The thyristor switch connects and disconnects the capacitor bank for an integral number of applied voltage half-cycles. The TSC is not phase controlled, ie, it does not generate any harmonic distortion.

A complete SVC based on TCR and TSC may be designed in a variety of ways so that specific criteria and requirements in the grid are satisfied. In addition, slow vars (by means of mechanically switched capacitors, MSC) can easily be incorporated into the schemes if required.

SVCs located in load centres are primarily installed to mitigate the effect of disturbances in the grid.

The fast var capabilities of SVC make it highly suitable for:

- *Steady-state as well as dynamic voltage stabilization.* This means that power transfer capability is increased and voltage variations are reduced.
- *Synchronous stability improvements.* This in turn leads to increased transient stability and improved power system damping.
- *Dynamic balancing of unsymmetrical loads.*

An SVC example: voltage control of a load centre

SVCs located in load centres are primarily installed to mitigate the effect of disturbances in the grid (eg, short circuits and/or loss of important power lines) on sensitive loads. The load centres may be located at the end of a radial network or in a meshed system. In either location, they are located far away from large capacity power stations. An example of an SVC installation in a meshed network can be found close to Oslo in the southern part of Norway. This plant is rated at ± 160 MVAr and is connected to a 420 kV system at a substation south-west of the city.

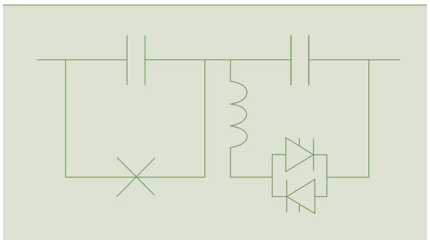
During a transmission network incident, the SVC detects the resulting voltage depression on the 420 kV system. During and following the fault the inclusion of SVC ensures that loads in the city area hardly notice any voltage change. In other words the SVC isolates the city from the impact of remote system faults.

SVC Light®

SVC Light® is a STATCOM (STATic COMpensator) type of device. In it, voltage source converter (VSC) and insulated gate bipolar transistor (IGBT) technologies have been brought together to ensure that power quality and power transfer are optimized over existing sub-transmission and distribution circuits. In the grid it is characterized by a small footprint, a very high dynamic response, and the ability to actively filter out unwanted harmonics and phase unbalance.

A VSC is a fully controllable voltage source which matches the system voltage in phase and frequency. It has an amplitude which can be continuously and rapidly controlled, enabling it to be used as the tool for reactive power

1 Thyristor-controlled series capacitor (TCSC).

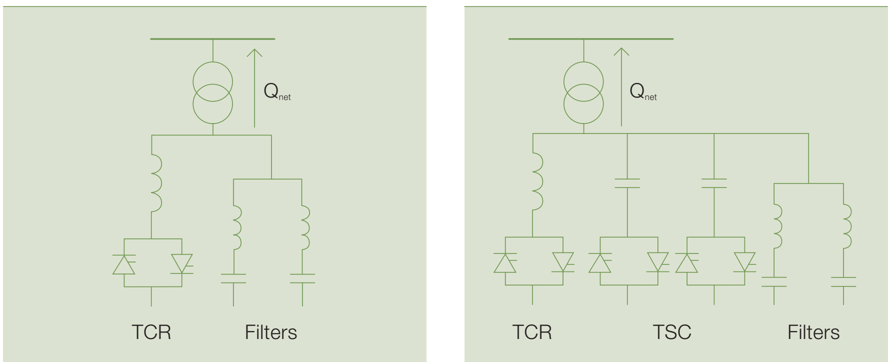


2 SVC configurations used to control reactive power in electric power systems.

Q_{net} = Net reactive power flow to network

a TCR configuration

b TCR-TSC configuration



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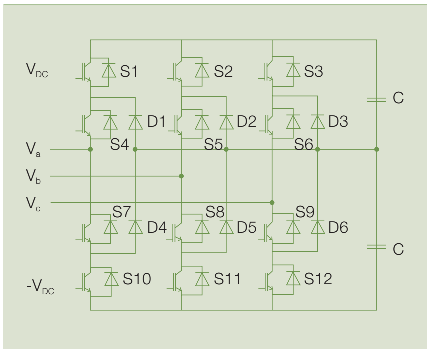
control. The VSC is connected to the system bus via a small reactor.

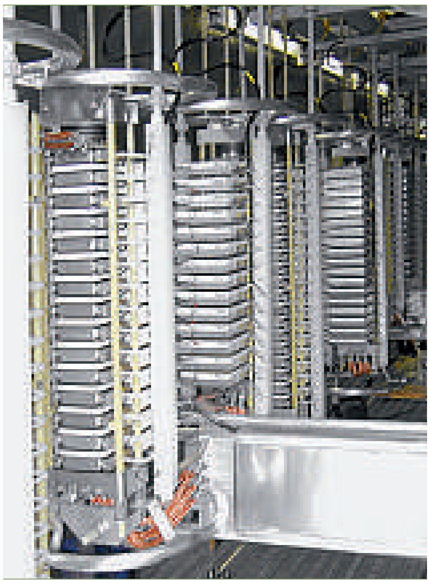
A three-level VSC configuration is shown in 3. One side of the VSC is connected to a capacitor bank, which acts as a DC voltage source. The converter produces a variable AC voltage at its output by connecting the positive pole, the neutral, or the negative pole of the capacitor bank directly to any of the converter outputs.

3 Basic three-level VSC configuration.

S1-12 = IGBT stacks
D1-6 = Diode stacks



4 SVC Light valve assembly.



5 Austin Energy plant (Texas) with SVC Light® rated at ±95 MVAr.

Using Pulse Width Modulation (PWM), an almost sinusoidal AC voltage can be produced without the need for harmonic filtering. This not only makes the design more compact, but also robust from a harmonic interaction point of view.

In the converter, there are four IGBT valves and two diode valves in each phase leg. The valves are constructed by stacking devices with interposing coolers and then applying an external pressure to each stack 4.

Project implementation times are shorter, and investment costs are lower when compared with the alternative of building new transmission lines or power generation facilities.

SVC Light®: enhancing grid flexibility

Austin Energy planned to decommission an old oil- and gas-fired plant near downtown Austin in Texas. The four-unit Holly plant had been kept in operation to stabilize the voltage on the transmission system as well as to provide generation capacity. However, retiring the power plant without a reliable dynamic reactive source would have had a negative impact on the transmission system voltage stability. A solution had to be found that tackled this problem and other requirements, such as the ability to recover quickly from voltage dips at low voltages. It must also take into consideration site limitations, low electromagnetic field requirements, and audible noise.

FACTS technology was considered as a possible solution to this problem.

An initial study had shown that the above requirements could be met using a compact STATCOM application. A STATCOM is specially suited for supplying full compensating current at very low voltages (eg, during a voltage dip), and it can also compensate for any unbalances. It also comes with a small footprint and is relatively easy to screen. In the end, SVC Light®, rated at ±95 MVAr 5 was deemed the best answer.

The SVC Light® control system has inherently the capability of automatically switching in and out three mechanically switched capacitor banks connected to the 138 kV system in the neighborhood. This operation strategy forces the fixed capacitor banks to be the major producer of reactive power support during slow varying conditions in the system, leaving the SVC Light® ready to rapidly respond with dynamic reactive power support to any system disturbances.

The power of the SVC Light® system was clearly evident during the severe thunderstorms that hit the east Texas area in November 2004. Several events suppressed the system voltage significantly, thus forcing the SVC Light® to operate at maximum output, thereby giving much needed support to the system voltage.

FACTS solutions enable power grid owners to increase existing transmission network capacity while maintaining or improving the operating margins necessary for grid stability. As a result, more power can reach consumers with very little impact on the environment, project implementation times are shorter, and investment costs are lower when compared with the alternative of building new transmission lines or power generation facilities. Flexibility is provided as FACTS can quickly and simultaneously influence several parameters in the grid, such as active and reactive power flows.

ABB is the worldwide leader in the field of FACTS.

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