

FACILITATING OF CROSS-BORDER ELECTRIC POWER EXCHANGE BY MEANS OF FACTS

ROLF GRÜNBAUM*
ABB UTILITIES AB

(Sweden)

1. INTRODUCTION

Power interconnections are becoming increasingly widespread in the world, as incentives for power exchange between countries as well as parts of countries are growing. Technically, limitations on power transmission capability of a power corridor can in most cases be alleviated by adding of new transmission and/or generating capacity. This, however, may not be practicable or desirable in the real case. Adding of new lines may be too costly and time-consuming. Concessions for right-of-ways may be hard or impossible to come by. And last but not least, environmental aspects today are much more important than they used to be and need to be properly addressed in conjunction with transmission development.

Also, AC power transmission, which normally offers the simplest and most cost effective type of transmission, is not always controllable in a direct way. Things like power flow control as well as dynamic stability need to be properly looked after. Fortunately, there are prospects for handling of such issues thanks to the development of high power electronics, making AC systems more flexible in a cost effective and environmentally friendly way.

2. FACTS

The term "FACTS" (Flexible AC Transmission Systems) covers several power electronics based systems used for AC power transmission. FACTS solutions are particularly justifiable in applications requiring rapid dynamic response, ability for frequent variations in output, and/or smoothly adjustable output. Under such conditions, FACTS is a highly useful option for enabling or increasing the utilization of transmission grids or interties. In green-field projects, AC plus FACTS will likewise in many cases prove attractive and cost-effective in relation to other options. Applications treated in this paper are involving SVC (Static Var Compensators), and Fixed as well as Thyristor-Controlled Series Capacitors (TCSC).

* Power Systems – FACTS, SE-721 64 Västerås

3. INTERCONNECTION OF POWER SYSTEMS

For an HVAC grid interconnector, several kinds of system stability need to be safeguarded:

- (1) Angular stability, manifesting itself in upkept synchronism in the system;
- (2) Synchronous stability, manifesting itself in sufficient electromechanical damping and absence of sustained power oscillations;
- (3) Dynamic voltage stability, manifesting itself in the absence of voltage collapses.

Furthermore, in cases of several parallel circuits in a power transmission corridor, power has to be divided between circuits in such a way that optimum overall transfer capability is obtained, and bottlenecks due to uneven power sharing are avoided. With SVC and series compensation, bulk AC transmission over distances of more than 1.000 km is a reality. With the advent of thyristor-controlled series compensation, further potential as well as flexibility is added to AC power transmission. Uses are found in many places in the world where there are long and weak transmission corridors interconnecting states or remotely separated regions within states, with transfer capability limited due to restrictions in dynamic stability of the links. It is to be expected that further uses will be found in years to come. Minimizing of the environmental impact is a key issue. A very efficient way of doing this is avoiding the building of transmission lines, or, in other words, utilizing existing transmission lines more efficiently. And, of course, avoiding the need to build more transmission lines also leads to a minimizing of investment costs, because transmission lines are very expensive to build, not to mention time-consuming, in comparison with available options. This is where FACTS is coming in. In green-field projects, with FACTS, the amount of transmission lines needed to achieve a specific amount of power transmission can be kept to an absolute minimum.

4. SVC

An SVC is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and filter capacitors (FC). A TCR consists of a reactor in series with a bi-directional thyristor valve. A TSC consists of a capacitor bank in series with a bi-directional thyristor valve and a damping reactor which serves to prevent parallel resonance with the network.

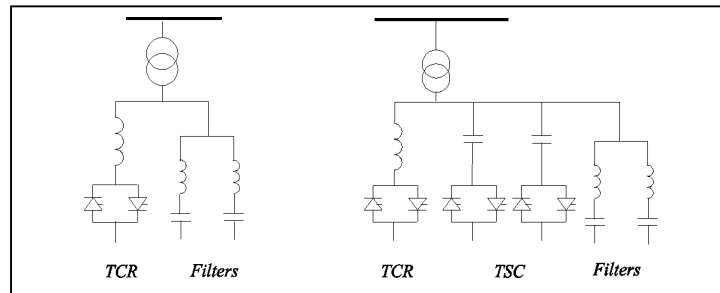


Fig. 1a: TCR / FC configuration. Fig. 1b: TCR / TSC configuration.

Two common design types are shown in Fig. 1. An SVC based on TCR and TSC may be designed in a variety of ways, to satisfy a number of criteria and requirements for its operation in the grid. The fast response of SVC makes it highly suitable for fulfilling functions such as:

- Steady-state as well as dynamic voltage stabilisation, meaning power transfer capability increases and reduced voltage variations.
- Synchronous stability improvements, meaning increased transient stability and improved power system damping.

4.1. Transient Stability Improvement of Power Intertie

The power system in Thailand is undergoing strong expansion. Increased generating capacity in different parts of the system augments demands on the transmission system and on transfer of power over long distances. A weak part of the bulk system is an interconnecting corridor linking Bangkok with a major generating area in the south by means of a twin circuit 230 kV line and a twin circuit 115 kV line. The length of this interconnector is 700 km, and an SVC is located at Bang Saphan, half way in between. Transient stability is a limiting factor for power transmission over this interconnector. The purpose of the SVC is to increase the transient stability, thereby increasing the power transmission capability of the existing system. At the same time, the SVC provides continuous voltage control under various operating conditions. Mechanically-switched capacitor banks were considered but ruled out due to high demands on control dynamics, requiring a response time well below 50 ms. Also, continuous var control efficiently eliminates step-wise voltage changes, which since the system is weak could violate the grid owner's requirement that voltage changes do not exceed 3% at 230 kV. The overall dynamic range of the SVC is 50 Mvar (inductive) to 300 Mvar (capacitive) (Fig. 2).

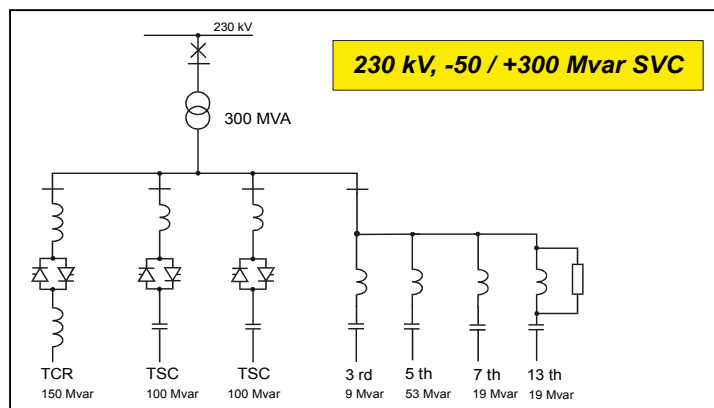


Fig. 2: Single-line diagram, SVC at Bang Saphan.

The SVC at Bang Saphan has enabled considerable increase of the power transmission capability up to Bangkok, with no need for more lines. Without the SVC, the transmission capacity was limited to below 200 MW. With the SVC, the capacity has been raised to well over 300 MW, i.e. a more than 50% increase of transmission capability over the existing lines.

5. SERIES COMPENSATION

Series capacitors offer increase of the transmission capability of new or existing circuits by:

- An improvement of system stability
- Improvement of voltage regulation and reactive power balance
- Improved load sharing between parallel circuits.

The impact of series compensation on power transmission can be illustrated as in Fig. 3:

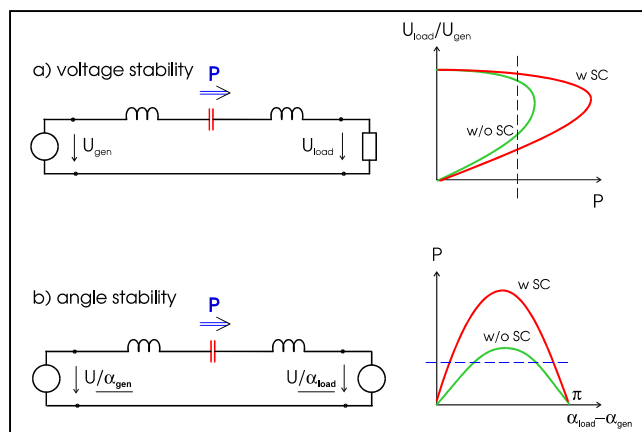


Fig. 3: The impact of series compensation on a) voltage and b) angular stability.

5.1. Some Salient Design Features

The main circuit diagram of a series capacitor is shown in Fig. 4. 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 causing large short circuit currents to flow through the line.

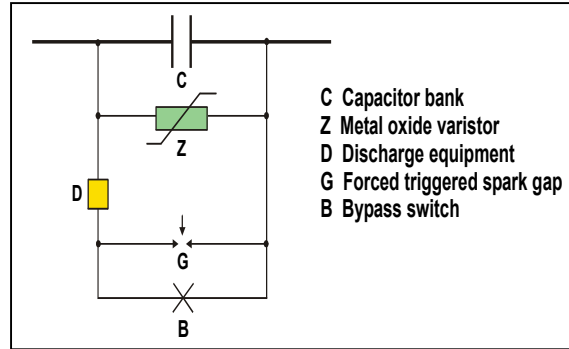


Fig. 4: Main configuration of a series capacitor.

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. Gap-less schemes are frequently chosen, as well. Such schemes rely exclusively on ZnO varistors for overvoltage protection, plus the bypass breaker for bypassing of the series capacitor. This kind of scheme may be the optimum solution in cases where the fault level of the power transmission system is limited, and consequently, no excessive amounts of energy need to be dissipated by the varistor for any foreseeable fault situation.

5.2. Dynamic Stability Improvement in Power Interconnector

In the Nordic countries, cross-border power trade is increasing, motivating to find the quickest and most cost-effective ways of reinforcing cross-border power transmission corridors. The usefulness of series compensation has been shown with the installation of three series capacitors in a twin circuit 400 kV cross-border interconnection between Sweden and Finland (Fig.5), thereby enabling a substantial increase of power exchange between the countries.

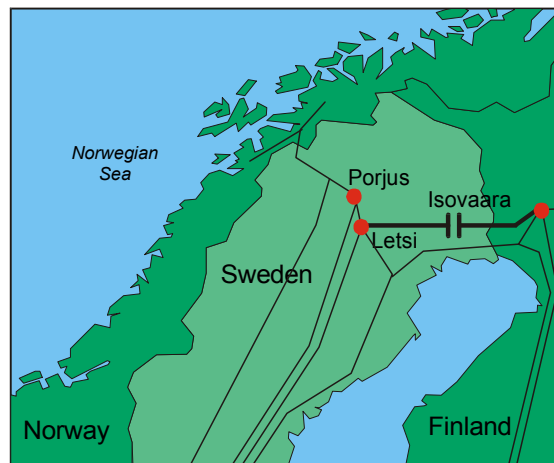


Fig. 5: Swedish-Finnish series compensated 400 kV cross-border interconnection.

With the series capacitors in operation, the power transmission capacity of the existing interconnection has been increased from 900 MW uncompensated to 1.200 MW, without any need for building of an additional line. The impact of the series capacitors in this case is an increase of voltage stability of the interconnection at steady-state as well as transient grid conditions. The series capacitor at Isovaara forms part of a 250 km circuit between Letsi on the Swedish side and Petäjäsoski on the Finnish side. It is rated at 515 Mvar at 400 kV. Its degree of compensation is 70%; its rated current is 1800 A. The main circuit protection is performed by means of ZnO varistors rated around 100 MJ.

6. CONTROLLABLE SERIES COMPENSATION

State of the art controllable series compensation is shown in Fig. 6. 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.

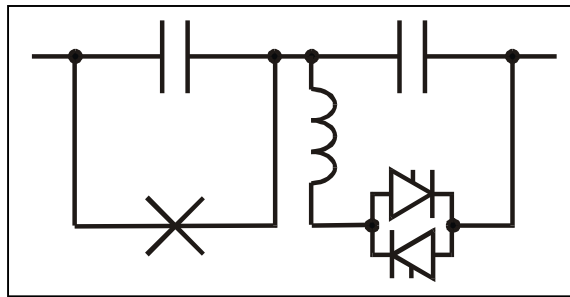


Fig. 6: Controllable Series Compensation.

6.1. TCSC for Damping of Electromechanical Oscillations

Damping of electromechanical power oscillations has been utilized as an important issue in electric power system operation. Application of Power System Stabilisers (PSS), with increasing transmission line loading over long distances, may in many cases not provide sufficient damping for inter-area power swings. In such cases, other solutions for power oscillation damping are needed. TCSC has proved to be very robust and effective as a means to improve damping of such power oscillations.

The damping effect of TCSC has the following benefits:

- The effectiveness of the TCSC for controlling of power swings increases with higher levels of power transfer.
- The damping effect of a TCSC on an intertie is unaffected by the location of the TCSC.
- The damping effect is insensitive to the load characteristic.
- When a TCSC is utilized to damp inter-area modes, it does not excite any local modes in the process.

6.2. TCSC for Stabilizing of Interregional Power Exchange

In Brazil, two large, geographically separated generating areas have been interconnected by means of a more than 1.000 km, 500 kV AC power corridor, rated to transmit 1.300 MW of attractive and environmentally friendly hydro power in either direction between the areas. The gains by this are considerable, from an economical as well as environmental point of view, as it allows increased utilization of the country's vast hydro power resources, thereby contributing actively to the country's development (Fig. 7).

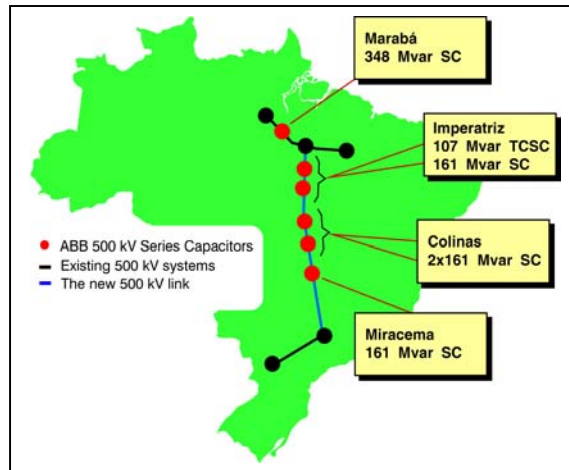


Fig. 7: North-South Interconnection, Brazil.

To safeguard stable and reliable power transmission over this long and weak interconnector, Series Capacitors as well as TCSC have been applied. The TCSC performs the task of damper of active power oscillations (0,2 Hz), which otherwise would tend to build up over the line, and thereby act as a restriction on the power transmission capability of the intertie.

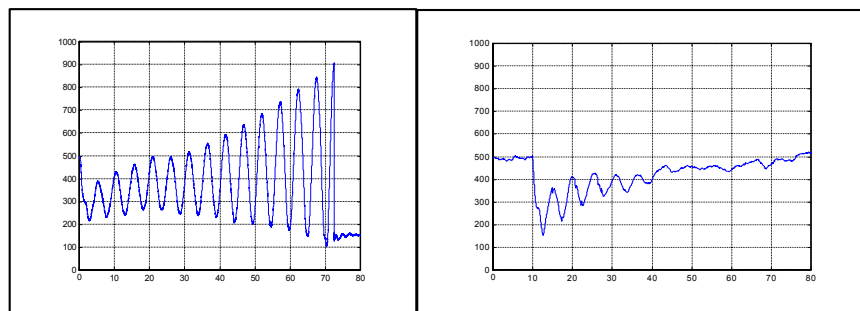


Fig. 8: Power oscillation damping (POD). Left graph: no POD. Right graph: with POD.

Tests were conducted in order to prove the effectiveness of the TCSC. A hydro generator was tripped when the network was intentionally weakened. The result is shown in Fig. 8. The registrations show that the system is unstable without the power oscillation damper, while the TCSC is able to successfully keep the system in synchronism during the disturbance.

7. SUMMARY

With FACTS, the applicability of synchronous interconnection of grids is widened to a substantial degree. Previously limiting factors such as angular and voltage stability can be addressed and alleviated in an efficient and cost-effective way.

By proper choice of devices from the FACTS family, optimum AC grid interconnection will be enabled, meaning:

- Increased power transmission capability,
- Increased availability of power,
- Shorter lead times in comparison with “traditional” solutions such as building of more lines,
- A saving of transmission losses, which is the same as a saving in transmission costs,
- And last, but by no means least, lower investment costs compared to more transmission lines.