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Conventional/Non Linear TCSC Control Strategy for Power System Stability Enhancement

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Abstract

One of the most important challenges facing the utility industry is the more efficient utilization of the existing transmission network. In view of the many difficulties involved in adding new transmission capacity and additional power flow control requirements anticipated as a result of the extensive integration of non-utility generation. The power transfer capability and the transient performance of the existing transmission network can be considerably enhanced by introducing more flexible power flow control capabilities; minimizing undesired loop flows; achieving higher loading levels for long transmission lines; and introducing fast real and reactive power modulation capabilities. Such enhanced transmission capabilities can be achieved through the integration of power electronics systems into strategic locations of the transmission network. The general acceptance of power electronics technologies as the means for enhancing the capabilities of the transmission network is demonstrated by the Flexible AC Transmission Systems (FACTS) initiative launched by EPRI to advance research and development in this direction. Thyristor controlled series compensation (TCSC) is one of such electronics systems. It is known that the TCSC can be used to increase stability and power transmission capability for large distance transmission systems, and to damp power oscillation and sub synchronous resonance. This paper focuses on TCSC and its role in power system stability enhancement.

Keywords: FACTS, TCSC.

1. Introduction

FACTS devices are increasingly being used as cost effective measures to increase power system transmission capability, to improve first swing margin, to actively damp oscillations, and to help stabilize weakly coupled systems in the event of critical faults. Power system engineers are currently facing challengers to increase the power transfer capability of existing transmission systems. Flexible Transmission System (FACTS) controllers offer an economical solution to accommodate that need while maintaining sufficient steady-state and transient stability margins. Due to fast and flexible actions of FACTS devices, many relevant benefits can be achieved such as the utilization of transmission capability, efficient power flow control, transient stability improvement, power oscillation damping, sub-synchronous resonances (SSR) mitigation, and fault current limitation [1-2]. Now, these devices are a reality and changing the way engineers plan and operate power systems.

Thyristor Controlled Series Compensation (TCSC) becomes now as a key device in the FACTS family, and widely recognized as an effective and economical means to solve following problems exhibiting in long transmission systems:

- Transient stability problems exhibited by loss of synchronism following major disturbances
- Dynamic instability characterized by negatively damped low frequency oscillation, caused by transferring a high level of power over a weak transmission link.
- Steady state stability due to overloading of transmission lines,
- Voltage stability problems exhibited by a slow decline of the voltage profile with increases in power loading of the transmission systems, etc.

2. TCSC

A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance. The TCSC is based on thyristors without the gate turn-off capability. It is an alternative to SSSC above and like an SSSC, it is a very important FACTS Controller. A variable reactor such as a Thyristor-Controlled Reactor (TCR) is connected across a series capacitor. When the TCR firing angle is 180 degrees, the reactor becomes nonconducting and the series capacitor has its normal impedance. As the firing angle is advanced from 180 degrees to less than 180 degrees, the capacitive impedance increases. At the other end, when the TCR firing angle is 90 degrees, the reactor becomes fully conducting, and the total impedance becomes inductive, because the reactor impedance is designed to be much lower than the series capacitor impedance. With 90 degrees firing angle, the TCSC helps in limiting fault current. The TCSC may be a single, large unit, or may consist of several equal or different-sized smaller capacitors in order to achieve a superior performance.

TCSC configurations comprise controlled reactors in parallel with sections of a capacitor bank. 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 enable full insulation to ground. The thyristor valve contains a string of series connected high power thyristors. The inductor is of air-core design. A metaloxidevaristor (MOV) is connected across the capacitor to prevent overvoltage.

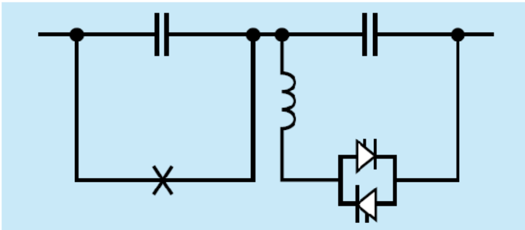

Figure 1: Thyristor controlled series capacitor.

TCSC introduce a number of important benefits in the application of series compensation:

- Elimination of subsynchronous resonance risks
- Damping of active power oscillations
- Post-contingency stability improvement
- Dynamic power flow control
- Increased transfer capacity: The overall result typically appears as increased transfer capacity.
- Applicable in new as well as existing systems

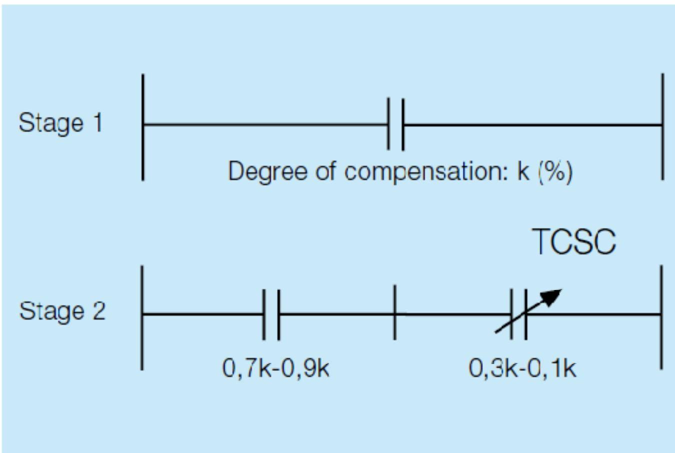

Figure2 Upgrading of series capacitor into TCSC (typical values).

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

2.1 Power flow Control

In interconnected power systems, the actual transfer of power from one region to another might take unintended routes depending on impedances of transmission lines connecting the areas. TCSC is a useful means for optimizing power flow between regions for varying loading and network configurations. It becomes possible to control power flows in order to achieve a number of goals:

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

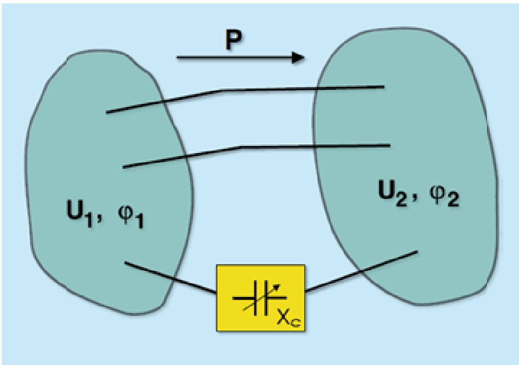

Figure 3 Control of power flow between regions.

2.2 Damping of power oscillations

Oscillations of active power in power transmission systems may arise in corridors between generating areas as a result of poor damping of the interconnection, particularly during heavy power transfer. Such oscillations can be excited by a number of reasons such as line faults, switching of lines or a sudden change of generator output. The presence of active power oscillations acts to limit the power transmission capacity of interconnections between areas or transmission regions. It is often possible to find remedy by building additional lines or upgrading existing lines, but this costs a lot of money and takes a lot of time, if not rendered impossible altogether by lack of the necessary permits. In some cases, it may also be possible to introduce Power System Stabilizers (PSS) on generators, but this will not always work, particularly not for inter-area power oscillations which tend to be of a low frequency (typically 0.2 Hz to 0.7 Hz). In either case, TCSC will be an attractive alternative to consider. It offers a cost-effective, robust power oscillation damper, insensitive to its location in the system and noninteracting with local oscillation modes. In a number of cases,it will turn out to be the best practicable solution.

2.3 Post-contingency stability improvement and loadability control

An important benefit of TCSC is its ability for quick boosting of its degree of compensation, making it very useful as a tool for improving the post-contingency behaviour of networks. By means of this quality of the TCSC, the degree of compensation of a series capacitor can be increased temporarily following upon a network contingency, thereby adding to the dynamic stability of the network (voltage and angular) precisely when it is needed. By this feature, the series capacitor can be lower rated for steady-state conditions, thereby keeping transmission losses smaller. For instance, in many applications it is desirable to enable an underlying transmission system to carry a higher amount of power under contingency conditions where a circuit is tripped in higher voltage transmission paths. Series compensation is not needed during normal operation as it would only influence overall system losses in an unfavourable way. In order to meet both objectives, i.e. safeguarding power transmission capability during contingencies and at the same time keeping transmission losses as low as possible during normal operating conditions, TCSC can be advantageously utilized.

3. Conventional TCSC Control

TCSC can be used for power flow control in steady states and for improving stability at dynamic conditions. The structure of the TCSC controller is designed upon pre-defined control aims. In engineering applications, conventional TCSC controls consist of, in general, three control loops:

- Power flow control loop
- Damping loop to suppress the subsequent power oscillation
- Transient control loop for improving the first swing stability.

Two strategies for the power flow control loop can be adopted. One strategy keeps the power flow in transmission line at a pre-selected value and will here be referred to as “constant line power” strategy. The second strategy keeps the power flow in the transmission line, which is connected in parallel to the TCSC installation, at a constant level and is known as “constant-angle” strategy. Since the line power scheduling is meant to be done over a period of 30 s, the power low control loop with PI acts quite slowly in practice. A schematic power flow control loop is shown in Fig. 1, where P_{Ref} and X_{Ref} are preselected reference value of the line active power and an initial value of the line reactance, respectively.

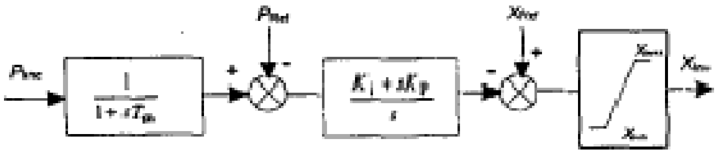

Figure 1: Power flow loop with PI.

The transient control loop is a preprogrammed open-loop control which is used to improve transient (or first swing) stability. When a fault is detected in a power system, it acts initially, leading to the maximum compensation level during a pre-set time *(T_a)*. The control is then transferred to the damping loop to suppress the subsequence power oscillations. Damping control is a supplementary control with a transfer function consisting of a measurement-amplification link, wash-out link and two lead-lag links. In Fig. 2, both of the transient and damping control loops are illustrated.

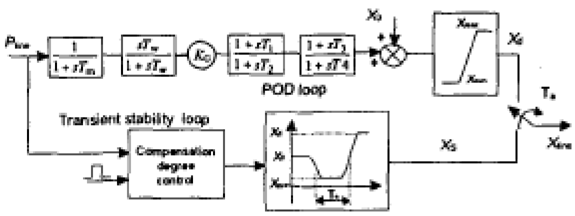

Figure 2: Transient and damping control loop.

In practice, it is difficult to measure the rotor angle of the generator directly. Thus, the line active power is usually adopted as the input signal for the both control loops.

4. Conclusion

Deregulation has resulted in more competition in the power market so that it is becoming necessary to allow the operating points of generators to vary quickly to meet the needs according to the power purchase agreement between the seller and buyer. Conventional control strategies based on approximate linearized models have proven to be very valuable to the design condition However, they are usually tuned at one particular operating point and may be required to be tuned again at another operating point to ensure a satisfactory transient performance due to the inherent nonlinear nature of power systems In fact, the nature of a power system is not only highly nonlinear, it exhibits also somewhat uncertainty: their operation conditions may also happen. Especially, in the event of several disturbances on the power system, the topology of the power system can be drastically changed due to tripping of faulted circuits. Thus control strategies to be adopted should reflect the nonlinearity, and be adaptive to the uncertainty of power systems to ensure the improvement of dynamic performance in different operating conditions.

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