TCSC based filtering and improvement of power quality

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Abstract: Thyristor Controlled Series Capacitor (TCSC) as a dynamic system, also its competence in growing power allocation in transmission lines, can be used to improve different power system problems. TCSC’s dissimilar advantages can be categorised as steady-state and transient ones. During a fault, TCSC can increase power quality by reducing the current and benefit to keep the voltage as high as conceivable. In this paper, the application of TCSC to enrich one of the vital power quality issues, i.e., voltage sag is investigated. Different operating modes of TCSC have dissimilar influences on the voltage of the bus that the line armed with TCSC is connected to. Relocating to bypass mode upon manifestation of a fault is a significant feature of TCSC to advance voltage sag. The simulations on a trial network disclose these facts.

1. Introduction
The usage of power electronics devices to advance the power transfer proficiency of long transmission lines customs the basis of the concept of FACTS. Thyristor Controlled Series Capacitor (TCSC) is one of the most widespread devices of the FACTS [1]. Series capacitor compensation is an approach to increase stability limits and increase transfer capabilities. The transmitted power through a line is inversely proportional to the transfer impedance. TCSC may also be used for controlling fault current by modifying its impedance value to a large inductive value that depends upon the TCSC design.

Power quality is an issue that is currently gaining major attention to both electric utilities and end users. The word power quality comprises a multitude of features, which is not new in spirit, but has a developing concern owing to the dissemination of sensitive loads (e.g. industrial plants) that use power electronics as a means of modernizing their manufacturing processes. Most of power quality complaints are fretful with voltage sags, which are chiefly caused by short circuits on transmission and distribution systems. These sags be able to moderated by different resources that include reserves on the power systems over aids; the usage of power conditioners to defend the load against these sags. Until a few years ago, the voltage sags due to faults were of little consequence. Use of adjustable speed drives and programmable logic-based process control in mining, pulp and paper, and electronic chip manufacturing plants has escalated over the last decade. It has made power quality problems associated with voltage sags an important design issue. Voltage sags of as little as 10% of the nominal voltage and of duration as short as 2 or 3 cycles can affect critical equipment and adversely impact the production processes. As an example, ac voltage is rectified and converted to pulsed dc when it is applied to an adjustable speed drive. This pulsing dc is stored in a capacitor, which in turn supplies smooth dc.
capacitor stores energy, it allows the system to ride through some sag. But if voltage sag is of sufficient depth and duration, the capacitor voltage will drop below a critical level (typically several cycles after the sag begins), at which point the drive may misoperate or simply shut down, resulting in process disruptions. Outages due to poor power quality can have detrimental impact as sustained power interruptions [2].

There are a few papers investigating the effect of TCSC on the voltage sag [3], but they have mainly considered the TCSC in its steady-state operating conditions. Neglecting the dynamics of TCSC in disturbances prevent observing the transients and accurate system behaviour. The main objective of this paper is to demonstrate in detail how the dynamics of a TCSC influence the voltage of the bus that the transmission line equipped with TCSC is connected to. It is shown if TCSC’s control system is well designed, it will help to mitigate the voltage sag consequences during emergencies. Another point is the oscillations created during and after TCSC’s transfer from one mode to the other. These oscillations could only be observed if TCSC is introduced by sophisticated models. TCSC’s operation as a fault current limiter to mitigate voltage sags is also investigated.

2. Structure of a TCSC
The basic structure of TCSC is shown in Fig.1. The degree of TCSC basic compensation is precise by the size of capacitor. The main function of bypass inductance is to decrease the short circuit current and the energy absorbed by MOV. Bi-direction thyristor SCR is used to transform the equivalent impedance of TCSC which satisfy the needs in all types of power system condition, such as improving the stability, increasing the transmission ability, preventive hypo synchronization resonance and so on [4].

By controlling the trigger pulse, TCSC can transform the trigger angle of thyristor. Subsequently, the current value of inductance sub-circuit which controlled by TCSC can be transformed, and then the total equivalent impedance will be changed continuously. Generally, when the trigger angle is 55°~90°, measuring from the peak of capacitor voltage, the corresponding impedance of TCSC is appeared as capacitance. When the trigger angle is 0°~50°, the equivalent impedance of TCSC is performed as inductance as which characteristic can limit short circuit current in system failure.

3. TCSC’S different modes of operation
The thyristor valve is not triggered and they are preserved in non-conducting mode, the TCSC is functioning in blocking mode. In this mode, the TCSC achieves like a fixed series capacitor.

In bypass mode the thyristor valve is activated continuously and the valve stays conducting all the time; so the TCSC performs like a parallel connection of the series capacitor with the inductor. In this mode, the subsequent voltage in the steady state across the TCSC is inductive and the valve current is slightly superior than the line current owing
to the current generation in the capacitor bank. For practical TCSCs with $X_L/X_C$ ratio between 0.1 to 0.4 range, the capacitor voltage at a specified line current is much lesser in bypass than in blocking mode. Consequently, the bypass mode is developed as a means to reduce the capacitor strain during faults. In capacitive boost mode a trigger pulse is provided to the thyristor consuming forward voltage just before the capacitor voltage crosses the zero line, the capacitor discharge current pulse will flow through the parallel inductive branch. The capacitor peak voltage thus will be improved in proportion to the charge that passes over the thyristor branch. The vital voltage also rises nearly proportionally to the charge. From the system view, this mode supplements capacitors to the line up to closely three times the fixed capacitor. This is the normal operating mode of TCSC. In inductive boost mode the circulating current in the TCSC is greater than the line current. In this mode, huge thyristor currents effect and advance the capacitor voltage waveform is unfair from its sinusoidal shape. The peak voltage seems close to the turn on. The unfair waveform and the high valve stress make the inductive boost mode less attractive for steady state operation. This mode rises the inductance of the line, so it is in contrast to the advantages associated with the application of TCSC.

4. Simulation Results

In order to show the effect of TCSC on the voltage of the buses with sensitive loads, a sample network as Figure 2 is used. The transmission line A1-B1 is compensated by a TCSC. Sensitive load is connected to bus B1. The nominal compensation is 76%.

![Figure 2 Sample network used for simulation](image)

The normal oscillatory frequency of the TCSC is 170Hz, which is 2.8 times the fundamental frequency. The impedance of line A1-B1 is 6.0852+j163Ω. The left source voltage is 549 kV and the right is 488.8kV. System frequency is 60Hz. The ratio of TCSC, i.e., $X_L/X_C$ is 0.1243; $C=23.977\mu F$ and $L=0.033H$. This sample system is described in [10]. Without the TCSC the power transfer is around 110MW, as seen throughout the first 0.6s of the simulation when the TCSC is out of service by the bypass C.B. operation, as seen in Figure 3. The resonance for this TCSC is around 57° firing angle, the operation is forbidden in firing angle range 47° - 63°. Note that the resonance for the total system is around 64°. The capacitive mode is achieved with firing angles 64°-90°. The impedance is lowermost at 90°, and hence power transfer increases as the firing angle is reduced. In capacitive type the collection of impedance values is approximately 120-133Ω. This range corresponds to approximately 480-860MW power transfer range. Matching with the power transfer of 110 MW with an uncompensated line, TCSC permits major development in power transfer level. The inductive mode corresponds to the firing angles 0°-53°, and the least impedance is at 0°. In the inductive operating mode, the range of impedances is 17-75Ω, which agrees to 82-100 MW choice of power transfer level. As can be seen from figure, the voltage of bus B1 is constant and during the first second of simulation time.
As Figure 4 shows, at t=1.0 Sec. a three phase fault occurs on line A1-B1 at 76% from the beginning of the line. TCSC transfers to bypass mode to save the capacitor from overvoltage. As can be seen from the figure, the voltage of bus B1 with sensitive loads does not drop considerably; voltage sag is at a permissible level. At t=1.3 Sec., TCSC transfers to C.B. bypass operation in order to save itself from heavy current flow for long time. Voltage sag is higher than the TCSC bypass mode. This transfer is only for demonstration, because in real cases, the fault is cleared much faster, and rarely it is necessary to operate bypass C.B. Between t=0 to t=1.0, the firing angle $\alpha$ is zero, and after t=1.3 Sec. firing angle will remain 90° for easy transfer of TCSC to capacitive boost mode. Figure 5 shows the operation of TCSC for the same fault, but without C.B. bypass operation. Voltage sag of bus B1 is at its lowest value, but the same figure shows oscillations before reaching to a stable situation. Figure 6 shows the voltage sag of B1 without the presence of TCSC on line A1-B1. As can be deduced from this figure, voltage sag is significant and would disturb the sensitive loads connected to bus B1. TCSC can transfer to fault current limiting at t=1.0 Sec. instead of bypass operation. This case can be seen in Figure 7 for $\alpha=49°$. As can be deduced from this figure, voltage sag is the smallest and this mode can be considered for conservative conditions. Figure 8 shows the instantaneous values of voltage and current of bus B1. This figure indicates the necessity of considering the dynamics of TCSC during transition from a mode to another. If TCSC dynamics is neglected, the resulting phasor model uses the equivalent impedances at the fundamental frequency, and therefore it is not as accurate as the thyristor transient model. Nevertheless, the phasor model is much simpler and the speed of simulation is increased.
5. Conclusions
This paper examines the TCSC's consequence on the voltage sag of the buses with penetrating loads. The simulation results demonstrate one of the noticeable features of TCSC, i.e., enhancement of voltage sag during disturbances, as one of the important issues of power quality. This is attained by transferring of TCSC to suitable modes during instabilities. For examining the voltage condition of the desired buses during system instabilities, a detailed dynamic model of the TCSC is essential. Else, the examination does not show the transients occurring during TCSC's mode transfer.

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