Applications of STATCOM for Power Quality Improvement- A Literature Survey

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Abstract— **With the rapid development and improvement of power electronics devices in past decades changing the scenario in the field of controlling and improving the power quality issues and related problems very significantly. FACTS devices are the good examples of these. So in this paper one FACTS device known as STATCOM a powerful shunt controller, for discussing its impact and depth how to improve the power quality by reviewing the past literature published on the various types and configurations of STATCOM using different techniques and configurations in order to reduces harmonics and improved dynamic performance.**

Keywords— **VSC, STATCOM, FACTS, GTO's, SSSC, SVC, Voltage Stabilization, Reactive Compensation, Power Quality**

I. INTRODUCTION

Today's power systems are evolving from a relative static operation scenario to a more dynamic one due to the presence of electricity markets, the deep impact of renewable and distributed generation and other drivers that introduce more variability and uncertainty in the operation of the power system. For example, under the electricity market operation, situations exist where the generation and consumption results coming from the market are limited by power transmission security and loadability constraints.

Fast development of the power electronics sector, a huge number of high power semiconductor devices are available for power system applications. In the past few years, availability of Gate Turn-Off (GTO) thyristor switching devices with high-power handling capacity and the technological improvement of the other power semiconductor devices like IGBTs have led to the development of fast controllable reactive power sources utilizing new electronic switching and converter technology. The GTO thyristor helps in the design of the solid-state shunt reactive compensation and active filtering equipment based upon switching converter technology. These Power Quality Devices (PQ Devices) are power electronic converters connected in parallel or in series with transmission lines. Flexible alternating current transmission systems (FACTS) devices are usually used for fast dynamic control of phase-angle, voltage and impedance of high voltage ac lines. FACTS devices are beneficial for better transmission system power flow through better use of existing transmission assets, increased transmission system security, reliability and availability. It also increase the dynamic and transient grid stability, and increased power quality for sensitive industries. The advancement in FACTS systems are giving rise to a new family of power electronic equipment for controlling and optimizing the dynamic performance of power system, e.g., STATCOM, SSSC, and UPFC. Flexible AC Transmissions Systems (FACTS) were firstly developed in the 1990's [1]. FACTS devices can help to reduce transmission congestions but also other power system problems, which make this technology to be increasingly taken into account. In addition, it can be said that this technology has reached maturity and that the cost of these power electronics based solutions has considerably decreased.

The use of voltage-source inverter (VSI) has been widely used as the next generation of flexible reactive power compensation to replace conventional VAR compensation, such as the Thyristor-Switched Capacitor (TSC) and thyristor controlled reactor (TCR). Now these days Static Synchronous Compensator (STATCOM) has been at the centre of attention and the subject of active research for many years. STATCOM is a shunt-connected compensator and it is used to provide reactive power compensation to a transmission line. Through regulation of the line voltage at the point of connection, STATCOM can increase the power transmission capability and thus improves the steady-state stability limit. The basic Power flow description of three phase 4-wire compensated system is shown in Fig.1.1.

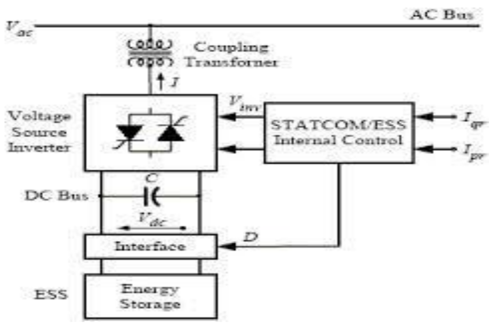

Fig 1.1– Basic interfacing of STATCOM with transmission line

STATCOM is also used for the purpose of damping during power system transients and by this improving the transient stability margin. Theoretically, FACTS controllers can be realized by either a voltage-source converter (VSC) or a current-source converter (CSC) [2]; however, except for the work reported in [3] more than 10 years ago, the focus of most of the research work on STATCOM has been on using VSC topology [4]–[8]. There are various reasons of choosing VSC over CSC, these are as follows: A CSC is more complicated than a VSC in both power and control circuits. Filter capacitors are used at the ac terminals of a CSC to shaping of the output ac current waveforms. This increase cost of the converter.

Furthermore, filter capacitors produces resonant frequencies with the ac-side inductances. This causes some of the harmonic components present in the output current might be amplified, causing high harmonic distortion in the ac-side current. Unless a switch of high reverse voltage withstanding capability such as Gate-Turn-Off Thyristor (GTO) is used, a diode has to be placed in series with each of the switches in CSC. This almost doubles the conduction losses compared with the case of VSC.

The dc-side energy-storage component in CSC topology is an inductor, in case VSC topology it is a capacitor. The power loss of an inductor is larger than that of a capacitor. Thus, the efficiency of a CSC is counted to be low as compared to VSC. As a result of the recent developments in the control of CSC and the technology of semiconductor switches, the above situation is likely to change for the following reasons:

a) Because of the ac- side capacitor, both voltage and current waveforms at the output terminals of a CSC are good sinusoidal shape. Although a 48-pulse VSC STATCOM does not require a filter [9], the cost of the filter is transferred to the cost of multi-converters and multi-winding transformer. Another filter has to be used in a VSC STATCOM if it is used at lower frequency. CSC STATCOM can be used under 900 Hz of switching frequency with a single converter. This reduces the filtering requirements compared with VSC. The problem of the resonance between the capacitances and inductances on the ac-side can be solved by proper selection of the filter capacitors.

b) It features high ratings, high reverse voltage blocking capability, low snubber requirements, lower gate-drive power requirements than GTO, and higher switching speed than GTO, Integrated Gate Commutated Thyristor (IGCT) is the best combination of the characteristics demanded in high-power applications [10]. Also there is no need for the series diode in the CSC topology anymore.

c) The dc-side losses can be minimized by using superconductive materials in the construction of the dc-side reactor. The research on the CSC topology and its applications in power systems has been an on-going process [11], [12].

When STATCOM is operated under SPWM (Sinusoidal Pulse Width Modulation) technique [13], the magnitudes of the harmonic components in the both converters are proportional to the magnitudes of the fundamental components of their direct output quantities. In transmission systems, under normal conditions, the current injected by STATCOM is very small as compared to the line current. So the current harmonics are also small. But, when VSC is used also for the small injected current, the output voltage of VSC is large and very close to the system voltage. This will cause a large voltage harmonics, which can lead to current harmonics that are larger than which are generated by CSC, and thus more costly to filter. The another can be made by using the dc-side energy storage requirement. When the STATCOM is operated as a CSC, the dc-side current is very close to the peak value of the required injected current which is a small percentage of the line current. But when a VSC is used to inject reactive current to the system, the required voltage should be larger than the peak value of the system line-to-line voltage so that the reactive power can be transferred between the transmission line and the STATCOM. This concluded that the CSC requires less energy storage requirement when compared to VSC for the realization of STATCOM.

II WORKING PRINCIPAL OF STATCOM

VSC is the backbone of STATCOM and it is a combination of self-commutating solid-state turn-off devices (viz. GTO, IGBT, IGCT and so on) with a reverse diode connected in parallel to them. The power electronics switches are operated either in square-wave mode or in PWM mode.

High switching frequencies are used for eliminating harmonics. A DC capacitor is used as voltage source on the VSC's input side. The output is multi-stepped AC voltage.

The diode serves the rectification purpose. The main objective of STATCOM is to obtain an almost harmonic neutralized and controlled three-phase AC output voltage waveforms at the point of common coupling (PCC) to regulate reactive current flow by generation and absorption of controllable reactive power by the solid-state switching algorithm. The P-Q relation of STATCOM is found by following relation

$$S = \frac{3VsVc}{X}\sin\alpha - j3\left(\frac{VsVc}{X}\cos\alpha - \frac{Vs^2}{X}\right) = P - jQ$$

where S is the apparent power flow, P the active power flow, Q the reactive power flow, Vs the main AC phase voltage to neutral (rms), Vc the STATCOM fundamental output AC phase voltage (rms), X is the leakage reactance, L the leakage inductance, f the system frequency and α is the phase angle between Vs and Vc.

Active power flow is influenced by the variation of a and reactive power flow is greatly varied with the magnitude of the voltage variation between Vc and Vs. For lagging a, power (P) flows from Vc to Vs, for leading α, power (P) flows from Vs to Vc and for α=0, the P is zero and Q is derived as follows

$$Q = \frac{Vs}{X}(Vc - Vs)$$

III. LITERATURE BACKGROUND

In this paper [14], the dynamic operation of novel control scheme for both Static Synchronous Compensator

(STATCOM) and Static Synchronous Series Compensator(SSSC) based on a new full model comprising a 48-pulse Gate Turn-Off thyristor voltage source converter for combined reactive power compensation and voltage stabilization of the electric grid network is investigated.
The digital simulation of the STATCOM and SSSC within the power system is performed in the MATLAB/Simulink environment using the Power System Blockset (PSB). Two novel controllers for the STATCOM and SSSC are proposed in this paper based on a decoupled current control strategy. The proposed decoupled controllers for the 48-pulse voltage source converter STATCOM demonstrated high efficiency for reactive power compensation and voltage regulation with the system subjected to load disturbances such as switching different types of loads. The performance of the Auxiliary Tracking control with PWM switching technique in suppressing any oscillation and damping the transients that may appear during the transition from capacitive to inductive mode of operation compared with the decoupled current control strategy are described in this paper. A complete digital simulation study using the full 48-pulse GTO-SSSC device model for a sample test power system is also presented in this paper. The digital simulation is performed in the MATLAB/Simulink software environment using the PSB.
The basic building block of the SSSC device is the same cascade of converters forming the 48-pulse GTO converter whose complete digital simulation model was implemented using MATLAB/Simulink. The control strategies implement decoupled current control and auxiliary tracking control based on a pulse width modulation switching technique to ensure fast controllability, minimum oscillatory behavior, and minimum inherent phase locked loop time delay as well as system instability reduced impact due to a weak interconnected ac system.
In the paper [15], a multi-level D-STATCOM configuration consisting of a three level voltage source converter, a DC energy storage device, a coupling transformer and associated control circuits is introduced. The control is based on sinusoidal PWM and only requires the measurement of the RMS voltage at the load point. The validity and effectiveness of the proposed power conditioner has been demonstrated through PSCAD/EMTDC simulation tool used for its modelling and simulation. Extensive simulation is also carried out to verify the superiority of multi-level D-STATCOM with two level D-STATCOM. By this unique structure of the multi-level Voltage Source Converter (VSC) allows it to reach high voltages with low harmonics without the use of transformers or series connected, synchronized switching devices. It is observed that for increased number of levels of VSC the output voltage and current waveforms approaches a sinusoidal nature with minimum harmonics.
With the help of this Comparison of multi-level DSTATCOM with two-level DSTATCOM finds that the multi-level VSC is preferred over the commonly used two level VSC for high power applications from the standpoint of harmonic components, %THD in voltage and current, efficiency, DC link voltage and inverter switching frequency. The efficiency, % THD in voltage and current for various levels of D-STATCOM are evaluated and finds as the number of level increases, the THD of the output voltage and current decreases. The three-level VSC shows max efficiency, with decreased values of %THD in voltage and current. This custom power controller may find application in automated industries with critical loads.
In this paper [16], a novel double loop control strategy of current feed-forward plus double PI loop for adjusting transmission line real power is proposed. Bus-bar voltage outer loop control system adopts voltage droop control which consists of PI regulation and scaling factors of droop characteristic. A current feed-forward control is introduced into double loop de-coupled control system of dc capacitor voltage regulation. Designing process of control system is discussed briefly in this paper. The experimental results on a15-KVA laboratory-scale equipment and also simulation results for a case study indicate that dc capacitor voltage and bus-bar voltage can be controlled efficiently, and proved that the control scheme and controller design are viable and effective. Basically we know that the Static Synchronous Compensator (STATCOM) based on voltage source converter is one of the most used FACTS device..
The proposed novel double loop control system, including current controller, dc-link capacitor voltage controller, feed-forward controller and bus-bar voltage controller are designed independently and briefly presented in this paper. The experimental and simulated results indicates that the dc-link capacitor voltage and bus-bar voltage is controlled efficiently, and the system has good dynamic and stable performances and also verify that current feed-forward plus double PI loop is a viable control scheme and controller design is accurate and effective.
In this paper [17], a flatness-based tracking control for the VSC is proposed where the nonlinear model is directly compensated without a linear approximation. Flatness leads to straightforward open-loop control design. A full experimental validation is given as well as a comparison with the industry-standard decoupled vector control. Robustness of the flatness-based control is investigated and set-point regulation for unbalanced three-phase voltage is considered. Traditional approaches to this problem are often based on a linearized model of the VSC and proportional-integral (PI) feedback. This proposed control commonly used cascade controller structure for the real current and dc voltage where the PI control for the real current is contained inside the PI control for dc voltage. The reactive current is independently controlled by a separate PI controller. This control is based on a linearized averaged model of a VSC which accounts for the fundamental components of the switching voltages. As the averaged model of the VSC is nonlinear, it is natural to apply model-based nonlinear control strategies which directly compensate for system nonlinearity without requiring a linear approximation. Experimental results illustrates that the nonlinear control provides improved transient tracking performance relative to a traditional vector control method.
In this paper [18], a two-level 48-pulse ±100MVAR STATCOM is proposed where eight, six-pulse GTO-VSC are employed and magnetics is simplified to single-stage using four transformers of which three are PSTs and the other is a normal transformer. Simple PI-controllers is

adopted so that, the model is simulated in a MATLAB environment by SimPower Systems toolbox for voltage regulation in the transmission Under single stage configuration of magnetics, the overall capacity requirement (MVA) of the magnetics has been optimized to half of that needed in the commercially available compensator and thus, becomes cost effective. The number of transformers in the magnetic circuit has been reduced from nine to four. With the standard PI-control algorithm adopted in the inner current control and outer voltage control loops, the compensator has enabled smooth control of load voltage in the system under various operating conditions and it has provided the damping to rapidly settle to steady state condition. The simulation results show that the THD levels in line voltage and current are well below the limiting values specified in the IEEE Std. for harmonic control in electrical power systems. The controller performance is observed reasonably well during capacitive and inductive modes of operation. The presence of lower and higher order harmonics in both line voltage and current has also been found to be appreciably low.

IV. CONCLUSION

In this paper, a revision of past literature published on the various control strategies of STATCOM is presented. By doing so we have found that with the advancement of power electronics converters, the power engineers find various opportunities to develop the control strategy so that harmonics are reduced as possible. We can also see that a multilevel cascaded multi-pulse STATCOM have found great applications in today power system .There is a great scope for power quality researchers for developing fast adaptive controllers for STATCOM.

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