STATCOM Analysis resolving Power Quality issues in Power Transmission System - A Literature Survey

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Abstract: With the rapid development and advancement of power electronics devices in recent years changing the scenario in the field of controlling and handling the power quality issues or problems very effectively. FACTS devices are the great examples of these. So in this paper we can choose one such FACTS device known as STATCOM a powerful shunt controller, for discussing its impact and depth how to tackle the power quality issues by reviewing the past literature published on the various types and configurations of STATCOM generally current source inverter based or voltage source inverter based, adopting different techniques and configurations in order to reduces harmonics and improved dynamic performance.
Keywords: VSC, CSI, STATCOM, FACTS, GTO's, SSSC, SVC, Voltage Stabilization, Reactive Compensation, Power Quality Issues, PQ Devices.

I. NOMENCLATURE

STATCOM - Static Synchronous Compensator
FACTS- Flexible AC Transmission System
SPWM - Sinusoidal Pulse Width Modulation
VSC- Voltage Source Converter
CSI- Current Source Inverter
GTO- Gate Turn Off Thyristor
SSSC- Static Synchronous Series Compensator
SVC- Static VAR Compensator
PQ Devices - Power Quality Devices

II. INTRODUCTION

Rapid development of the power electronics industry, a large number of high power semiconductor devices are available for power system applications. In the last decade, commercial availability of Gate Turn-Off (GTO) thyristor switching devices with high-power handling capability and the advancement of the other types of power-semiconductor devices such as IGBTs have led to the development of fast controllable reactive power sources utilizing new electronic switching and converter technology. The GTO thyristor enable 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, and the operation is controlled by digital controllers. The interaction between these compensating devices and the grid network is preferably studied by digital simulation. Flexible alternating current transmission systems (FACTS) devices are usually used for fast dynamic control of voltage, impedance, and phase-angle of high-voltage ac lines. FACTS devices provide strategic benefits for improved transmission system power flow management through better utilization of existing transmission assets, increased transmission system security and reliability as well as availability, increased dynamic and transient grid stability, and increased power quality for sensitive industries (e.g., computer chip manufacture). The advent of FACTS systems is 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. The use of voltage-source inverter (VSI) has been widely accepted as the next generation of flexible reactive power compensation to replace other conventional VAR compensation, such as the Thyristor-Switched Capacitor (TSC) and thyristor controlled reactor (TCR). **A**s an important member of the FACTS controllers' family, 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 device that is used to provide reactive power compensation to a transmission line. Through regulation of the line voltage at the point of connection, STATCOM can enhance the power transmission capability and thus extend the steady-state stability limit. The basic Power flow description of three-phase 4-wire compensated system is shown in Fig.1.1.

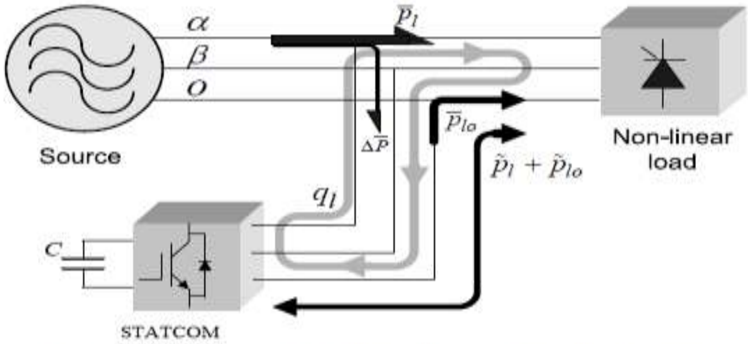

Fig. 1.1 Power flow description of three-phase 4-wire compensated system

STATCOM can also be used to introduce damping during power system transients and thus extend the transient stability margin. Theoretically, FACTS controllers can be realized by either a voltage-source converter (VSC) or a current-source converter (CSC) [10]; however, except for the work reported in [11] more than 10 years ago, the focus of all the published work on STATCOM has been on using VSC topology [12]–[16]. The reasons behind the choice of VSC over CSC are as follows:

- A CSC is more complex than a VSC in both power and control circuits. Filter capacitors are used at the ac terminals of a CSC to improve the quality of the output ac current waveforms. This adds to the overall cost of the converter. Furthermore, filter capacitors resonate with the ac-side inductances. As a result, some of the harmonic components present in the output current might be amplified, causing high harmonic distortion in the ac-side current. Besides, conventional bi-level switching scheme cannot be used in CSC.

- Unless a switch of sufficient 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 element in CSC topology is an inductor, whereas that in VSC topology is a capacitor. The power loss of an inductor is expected to be larger than that of a capacitor. Thus, the efficiency of a CSC is expected to be lower than that of a 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) Due to the presence of the ac-side capacitors, both voltage and current waveforms at the output terminals of a CSC are good sinusoids. The capacitors are the inherent filter for the CSC. Although a 48-pulse VSC STATCOM does not require a filter [16], the cost of the filter is transferred to the cost of multi-converters and multi-winding transformer. Additional filter has to be used in a VSC STATCOM if operating at a lower frequency. It is possible to operate a CSC STATCOM under 900 Hz of switching frequency with a single converter. This reduces the filtering requirements compared with the case of a VSC. The problem of the resonance between the capacitances and inductances on the ac-side can be overcome by careful design of the filter capacitors and introduction of sufficient damping using proper control methods. Furthermore, all the switching problems faced in the early stages of CSC development can be overcome by employing tri-level switching scheme [18], which has become a standard technique in the control of CSC.

b) Featuring 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 optimum combination of the characteristics demanded in high-power applications [19]. Using the state-of-the-art technology of the semiconductor switches, there will be no need for the series diode in the CSC topology anymore.

c) The dc-side losses are expected to be minimized 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 [20], [21]. When applied to STATCOM, CSC topology offers a distinct advantage over VSC topology. The direct output of a CSC is a controllable ac current, whereas that of a VSC is a controllable ac voltage.

When operated under SPWM (Sinusoidal Pulse Width Modulation) technique [22], the magnitudes of the harmonic components in both converters are directly proportional to the magnitudes of the fundamental components of their direct output quantities. In most transmission systems, under normal operating conditions, the current injected by STATCOM is a small percentage of the line current. Thus, when CSC is used, the current harmonics are also small. But, when VSC is used, for a small injected current, the output voltage of VSC is large and very close to the system voltage. This results in large voltage harmonics, leading to current harmonics that are larger than those generated by CSC, and thus more costly to filter. The other aspect of comparison is the dc-side energy storage requirement. When the STATCOM is realized by a CSC, the dc-side current is just larger than the peak value of the required injected current which is a small percentage of the line current. However, when a VSC is used to inject reactive power to the system, the dc-side voltage must be larger than the peak value of the system line-to-line voltage so that the reactive power can be transferred between the STATCOM and the transmission line. This means that the dc energy storage requirement of CSC is lower than that of VSC when used to realize a STATCOM.

III. LITERATURE BACKGROUND

In this paper [1], 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 behaviour, 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 [2], 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 are 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, synchronised 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 D-STATCOM 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.

This paper [3] presented a novel dual loop current decoupled controller scheme for the 48- pulse GTO based voltage source converter used as a STATCOM for providing the voltage regulation and reactive compensation of the power system. The decoupled controller scheme is based on a decoupled current strategy using direct and quadrature component of STATCOM current. The performance of this controller is evaluated by ±100 MVAR STATCOM scheme connected to the 230-kV grid. Reactive power compensation and voltage regulation is validated for load and system excursions in both the capacitive and inductive modes of operation. The controller is modelled using simulink and the STATCOM or power grid is simulated using MATLAB/SIMULINK by using power system block-set. The dynamic simulation results have demonstrated the high quality of the 48 pulse STATCOM for reactive power compensation and voltage regulation while the system subjected to disturbances such as switching different types of loads. The full 48 pulse model can be utilized in other Facts device studies such as Active Power Filters and new hybrid stabilization topologies.

In this paper [4], 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 [5], a generalized per-phase DC-bus voltage balancing scheme of a CMC-based STATCOM is proposed. The cascade multilevel converter (CMC), comprising a number of modular H-bridge voltage source converter (VSC) in each phase, is considered as one of the most promising topologies for STATCOM application now days because of its modularity, scalability and good power quality. However, how to maintain a balanced DC-bus voltage is not well known so for this the author has reviewed the STATCOM small signal model and existing control scheme first. The basis of proposed per-phase DC-bus voltage balancing scheme is based on the loop-gain shaping control design method and an "imaginary" dq/abc park transformation. The features of the proposed scheme are listed below:

- Small-signal model-based design without any tuning;
- Control bandwidth is flexible through the design;
- Stability margin is guaranteed through the design;
- Easy to implement into DSP;

The verification of proposed per-phase DC voltage control strategy is done by extensive switching simulations as well as by TNA experiments. To inject unbalanced reactive power for each phase, which is important for STATCOM application for unbalanced system the proposed control scheme can even be extended.

In this paper [6], 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 [7], an analytical state-space model of an indirect voltage-controlled cascaded-type multilevel static synchronous compensator (STATCOM) with square wave control is proposed. The model is divided into a dynamic and static part for accurately represent all internal feedback connections. Each voltage component is analyzed in detail and described mathematically by an averaged expression with an equivalent capacitance. The model is linearized and linked with a D-Q frame ac system model and the controller model, and they implemented in MATLAB. The controller gains are selected by analyzing the root locus of the analytical model to give optimum responses. The proposed model are verified and validated against non-linear digital simulation PSCAD/EMTDC in the time and frequency domain. The author also attempts to establish generic modeling principles that are applicable for a range of multilevel-cascaded converters, even those which exchange real power.. The dynamic, analytical state-space model is built of subsystems to enable model application to a wide range of system configurations and various dynamic studies. Eigen-value studies are conducted for each particular test system in order to select optimum open-loop controller gains. When the proposed model is tested in the frequency domain and it is observed that the presented model can be used for dynamic studies below 100 Hz.

In this paper [8], 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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