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Analysis of STATCOM for Voltage Stability under Different Configuration: 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. A review is done on the past literature published on the various types and configurations of STATCOM generally current source inverter based or voltage source inverter based.

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. Flexible AC Transmissions Systems (FACTS) were firstly developed in the 1990's [1]. FACTS devices can help to alleviate transmission congestions but also other power system problems, which make this technology to be increasingly taken into account by TSOs. 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. However, as the investment cost of FACTS is still high, their optimal location in the Power System is a crucial factor. Therefore, several FACTS location methods considering power system optimization techniques have been developed in the last years.

Developing countries especially can apply versatile voltage regulation and system Stabilization measures, in order to utilize more effectively the latent capacity in existing transmission networks, in preference to committing larger resources to new overhead lines and stations. The use of power electronics in the form of Thyristor Controlled Reactors (TCR) and Thyristor Switched Capacitors (TSC) in a Static Var Compensator (SVC) is well established. The application of power electronics in new configurations of FACTS offers the possibility of meeting such demands. FACTS devices are routinely employed in order to enhance the power transfer capability of the otherwise under-utilized parts of the interconnected network. The Static Synchronous Compensator (STATCOM) using GTOs (Gate-Turn-off Thyristors) is a principal state-of the- art FACTS equipment and is now a commercially available additional tool for use by system planners and designers [2,3] for shunt reactive power compensation in transmission and distribution systems. As with all static FACTS devices the STATCOM has the potential to be exceptionally reliable but with the added capability to: sustain reactive current at low voltage (constant current not constant impedance), reduce land use and increase relocatability (footprint 40% of SVC) and, be developed as a voltage and frequency support (by

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replacing capacitors with batteries as energy storage). Although currently being applied to regulate transmission voltage to allow greater power flow in a voltage limited transmission network in the same manner as a static var

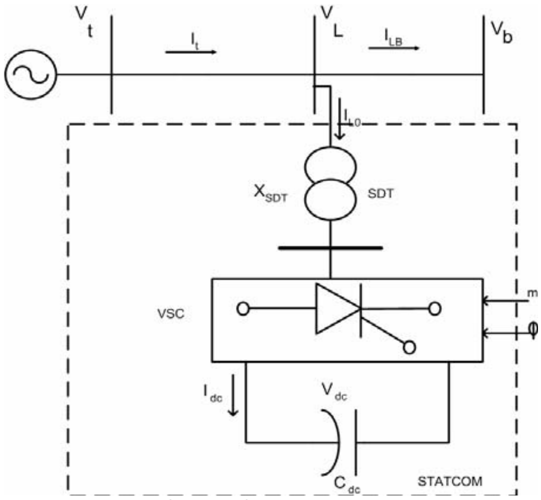

Fig 1– Basic interfacing of STATCOM with transmission line

compensator (SVC), the STATCOM has further potential. By giving an inherently faster response and greater output to a system with a depressed voltage, the STATCOM offers improved quality of supply.

II.THEORY OF STATCOM

The STATCOM is basically a DC-AC voltage source converter with an energy storage unit, usually a DC capacitor. It operates as a controlled Synchronous Voltage Source (SVS) connected to the line through a coupling transformer. Fig. 1 shows the schematic configuration of STATCOM. The controlled output voltage is maintained in phase with the line voltage, and can be controlled to draw either capacitive or inductive current from the line in a similar manner of a synchronous condenser, but much more rapidly. Compared to SVC and other conventional reactive power compensators, STATCOM has several advantages listed below. STATCOM has a dynamic performance far exceeding the other var compensators. The overall system response time of STATCOM can reach 10 ms or less.
STATCOM has the ability to maintain full capacitive output current at low system voltage, which also makes it more effective than SVC in improving the transient stability. Simulations indicate that 1.3Mvar SVC and 1 Mvar STATCOM have similar effects in maintaining dynamic voltage stability. STATCOM has much larger operating range as compared with that of SVC. Compared with SVC, STATCOM can easily realize redundancy design, which brings a higher reliability. IGCT, IGBT, used in STATCOM, require simpler gate drives and snubber circuits, and also make STATCOM more reliable. STATCOM has a smaller installation space, about 50% of that for SVC. The STATCOM of Alstom and Mitsubishi are made relocatable, with a power density of 1Mvar/m3.
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 equation

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

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.

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III.MAIN CIRCUIT TOPOLOGY

There are mainly two types of STATCOM main circuit configurations: multipulse converter, multilevel converter [4-5] In the multipulse converter, the 3-phase bridges are connected in parallel on the DC side, as shown in Fig. 2. The bridges are magnetically coupled through a zigzag transformer, and the transformer is usually arranged to make the bridges appear in series viewed from the AC sides. Each winding of the transformer is phase-shifted to eliminate selected harmonics and produce a multipulse output voltage. Pulse Width Modulation (PWM) can be applied to improve the harmonics content, at the expense of higher switching and snubber loss, plus reduced fundamental var rating. The disadvantages of multipulse converter configuration are: the phase-shift transformer makes the system complex and bulky; there will be a unique transformer design for each STATCOM installation. Compared to the multipulse converter based STATCOM multilevel converters are more flexible and have a wide application. They can be used as active power filters and to handle unbalanced loads. No phase shift transformer is required in this configuration, so a lower investment cost, plus a lower power loss, can be expected. The multilevel converter configuration can be further classified into three different configurations: 1) Diode-clamped converter, [6] 2) Flying capacitor converter, 3) Cascade converter. The concept of the cascade multilevel converter is put forward by Fang Zheng Peng in 1996 [7-8]. A cascade converter is constructed by standard H-bridges in series. Each H-bridge converter unit provides three voltage levels (-U+ 0, U-). A single phase STATCOM based on this configuration is shows in Fig.3 and in Fig. 3. is a typical output waveform of a three level cascade converter.

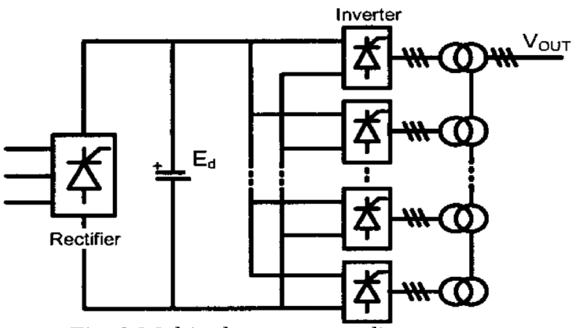

Fig. 2 Multipulse converter diagram

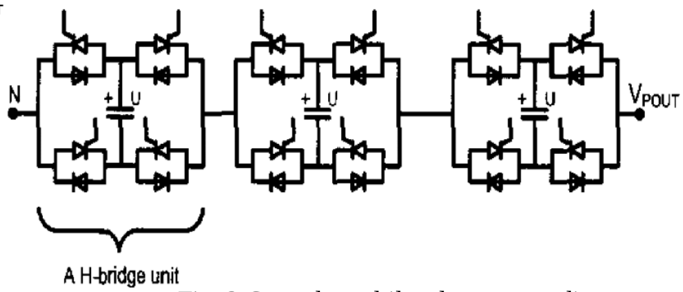

Fig. 3 Cascade multilevel converter diagram

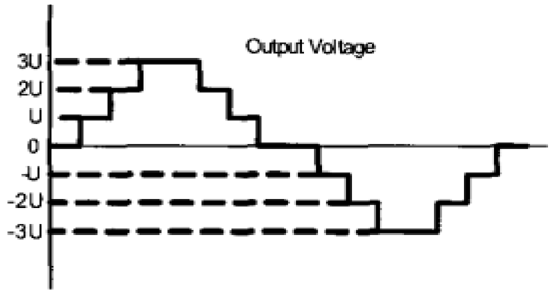

Fig. 4 Typical output voltage waveform of a three level cascaded converter.

Compared with the other two multilevel configurations and the multipulse converter, the cascade converter eliminates clamping diodes, flying capacitors, or the bulky zigzag transformer, and so requires least component mounts, and the modularity of this configuration makes it much easier to implement converters with a large number of levels. Larger dc-side capacitors are required compared to the diode clamped and flying capacitor converter under balanced condition but it provides separate phase control to support significant voltage unbalance.

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IV.CONTROL STRATEGIES AND APPROCHES

The control system is the heart of state-of-the-art STATCOM controller for dynamic control of reactive power in electrical system. Based on the operational requirements, type of applications, system configuration and loss optimization, essential control parameters are controlled to obtain desired performance and many control methodologies in STATCOM power circuits have been presented in [9-11]. In a square-wave mode of operation, phase angle control (α) across the leakage reactance (L) is the main controlling parameter. This control is employed in a two-level converter structure, where DC voltage (Vdc) is dynamically adjusted to above or equal to or below the system voltage for reactive power control. In a three-level configuration, the dead-angle or zero-swell period (β) is controlled to vary the converter AC output voltage by maintaining Vdc constant. The control system for STATCOM operated with PWM mode employs control of α and m (modulation index) to change the converter AC voltages keeping Vdc constant. For voltage regulation, two control-loop circuits namely inner current control loop and external/outer voltage control loop are employed in STATCOM power circuit. For voltage regulation, two control-loop circuits namely inner current control loop and external/outer voltage control loop are employed in STATCOM power circuit. The current control loop produces the desired phase angle difference of the converter voltage relative to the system voltage and in turn, generates the gating pulses, whereas the voltage control loop generates the reference reactive current for the current controller of the inner control loop. This control philosophy is implemented with proportional and integral control (PI control) algorithm or with a combination of proportional (P), integral (I) and derivative (D) control algorithm in d–q synchronous rotating frame.

The general mathematical approach, modelling and design of control systems for compensator circuits are proposed in [13-15]. In the process of designing and implementation of control system, acquisition of many signals is involved. Initially, the essential AC and DC voltages and current signals (instantaneous values/vectors) are sensed using sensors. In the next step, these signals are synthesised by techniques such as d–q synchronous rotating axis transformation, α-β stationery reference frame of transformation and so on.

V. EFFECTS ON NO. OF PULSES IN STATCOM PERFORMANCE

Self-commutating GTO devices in VSC technology are widely used as main controllable switching element for high power rating compensators, and operated either in square wave or quasi square wave mode by means of GTO triggering once per cycle of fundamental power frequency. In the state of the art dynamic reactive power compensator, use of multipulse topology along with fundamental frequency switching control of GTO-VSC is a mature technique employed to achieve a close to sinusoidal AC output voltage from GTOVSCs. In this topology, a number (P) of elementary six-pulse converters waveforms are electro-magnetically added to produce a multi-pulse waveform which contains harmonics in the order of 6NP + 1 ,where N=1, 2, 3, 4,...and P=1, 2, 3, 4.. .number of six pulse VSC. For example, in a 4x6-pulse STATCOM, AC voltage output waveform will contain harmonics of the order of23rd, 25th 47th 49th .etc.

In [16] is focused on design and modeling of a new fundamental frequency switching based 24-pulse 2-level + 100MVAR STATCOM in MATLAB platform for high power applications. Only four 6-pulse elementary Gate Turn off voltage source converters (GTO-VSC) along with single stage magnetics meeting dual objectives of magnetic summing circuit and coupling transformer at PCC, and PI-controllers employing principle of phase angle control, are modeled to achieve an improved performance to regulate load voltage in an ac network with THD values within limits.

Multi-pulse GTO based voltage source converter (VSC) topology together with a fundamental frequency switching mode of gate control is a mature technology being widely used in static synchronous compensators (STATCOMs) is presented in [17]. High number of pulses in the STATCOM, preferably a 48-pulse along with matching components of magnetics for dynamic reactive power compensation, voltage regulation, etc. in electrical networks is proposed. With an increase in the pulse order, need of power electronic devices and inter-facing magnetic apparatus increases multi-fold to achieve a desired operating performance. In [17], a competitive topology with a fewer number of devices and reduced magnetics is evolved to develop an 18-pulse, 2-level 100MVAR STATCOM in which a GTO-VSC device is operated at fundamental frequency switching gate control. The inter-facing magnetics topology is conceptualized in two stages and with this harmonics distortion in the network is minimized to permissible IEEE-519 standard limits. This compensator is modeled, designed and simulated by a SimPowerSystems tool box in MATLAB platform and is tested for voltage regulation and power factor correction in power systems. The operating characteristics corresponding to steady state and dynamic operating conditions show an acceptable performance.

In [18] 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 STATCOM scheme and the electric grid network are modeled by specific electric blocks from the power system blockset, while the control system is modeled using Simulink. Two novel controllers for the STATCOM and SSSC are presented in this paper based on a decoupled current control strategy. The performance

of both STATCOM and SSSC schemes connected to the 230-kV grid are evaluated. The proposed novel control schemes for the STATCOM and SSSC are fully validated by digital simulation.
If the no. of pulses are increased then the output voltage of the STATCOM becomes more and more sinusoidal and harmonics contents in the voltage waveforms decreases.

VI. SIMULATION TOOLS

STATCOM controllers have been reported in research publications. Simulation of various configurations/topologies, control strategies, magnetics, filter requirements, component level designing and so on, have been presented by various researchers with the help of many standard software simulation tools. MATLAB/SIMULINK/PSB, EMTP, PSCAD/EMTDC, SPICE, EUROSTAG and so on, are some of the software tools being extensively used by researchers and engineers to simulate various power electronics devices in power system circuits, electrical machines and so on. Detailed modelling of STATCOM controllers and performance analysis and sensitivities of various passive components under varying system-operating conditions ensure the researchers and engineers to firm up the design parameters in pre-fabrication stage.

VII.CONCLUSION

In this research, a review of past literature published on the various control strategies of STATCOM is presented. In this work, we have found that with the advancement of power electronics converters, the power engineers find various occasions 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. Different configuration of STATCOM has been discussed. Different types of software tools which can be used for simulation of STATCOM are also been discussed.

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