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H-Bridge Multi Level STATCOM under Different Loads

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Abstract- Voltage control and fast reactive power compensation are two main application area of Static Synchronous Compensator (STATCOM), which is a shunt connected voltage source converter (VSC) based FACTs controller using power semiconductor devices (particularly IGBT, GTO etc.).However, the total Statcom circuitry has complex and coupled system dynamics which require advanced controllers to achieve well performance. In our paper, we have represented a sixty pulse VSC for producing higher pulse number by combining a twelve pulse converter with a five level VSI in order to obtain the overall performance of the said VSC in a three phase system. As the number of levels increases in the VSI of the Statcom, it will produce a staircase wave with lower value of THD. The simulation results are presented and it is observed that the STATCOM shows excellent response to step change in the reactive current reference & the value of THD is also within the acceptable limit. A new efficient control strategy is proposed, in order to reduce the voltage fluctuations like sag and swell conditions and also to isolate current and voltage harmonics in the transmission system. The multilevel STATCOM which can be used at the point of common coupling (PCC).The static synchronous compensator (STATCOM) is used in power system network for improving the voltage of a particular bus and compensate the reactive power. It can be connected to particular bus as compensating device to improve the voltage profile and reactive power compensation.

Index Terms- FACTS, Multilevel converter, Statcom, Voltage stability, Reactive Power Compensation, THD.

I. INTRODUCTION

A Flexible AC Transmission System (FACTS) is an AC transmission system incorporating power electronic-based or other static controllers which provide better power flow control and enhanced dynamic stability by control of one or more ac transmission system parameters (voltage, phase angle. and impedance) The STATCOM is traditionally modeled for power flow analysis as a PV or PQ bus depending on its primary application. The STATCOM voltage and reactive power compensation are usually related through the magnetic of the STATCOM. This traditional power flow model of the STATCOM neglects the impact of the high frequency effects and the switching characteristics of the power electronics on the characteristics of the power electronics on the active power losses and the reactive power injection (absorption). The STATCOM used to regulate voltage and to improve dynamic stability. There are some variations of the STATCOM. It is composed of inverters with a capacitor in its dc side, coupling transformer, and a control system. The inverters are, in conventional STATCOM's; switched with a single pulse per period and the transformers are connected in order to provide harmonic minimization. The equipment action is made through the continuous and quick control of capacitive or inductive reactive power. Its output voltage is a waveform composed of pulses that approaches a sinusoidal wave.

Several generating stations as well as industrial process have increased their power level needs, driven mainly by economy of scale, triggering the development of new power semiconductors, converter topologies and control methods. Amongst the power switching devices, GTO (rating ≈ 4.7 Kv) was the standard for medium voltage transmission system until the advent of high power IGBTs and gate commutated thyristors (GCTs) in the late 1990s [2]. These switching devices are now extensively used in high power application due to their superior switching characteristics, reduced power losses, ease of gate control and snubberless operation. With the trend of de regulating power industry and installing more distributed generators, the future power system needs to provide sufficient, stable .economic, secure and high quality electric power to various load centers. It is envisaged that FACTS devices or controllers are going to play a critical role in operating the new type of power systems under such a complex operating environment [4].

The STATCOM can be used at this bus to regulate the voltage and reduce the reactive power also [2]. Cascaded Multilevel converter (CMC) is provided to offer bus voltage control and reactive power compensation. The Multifunction controller is provided to offer DC bus voltage control, reactive power compensation and AC voltage control of the bus.

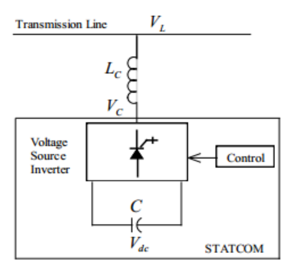

Fig 1 Schematic Configuration of STATCOM

The schematic configuration of STATCOM is shown in Fig.1. A capacitor connected on the DC side of the VSC acts as a dc voltage source.

II. WORKING PRINCIPLE OF ST ATCOM

A. Principle of STATCOM

A STATCOM, which is schematically depicted in Figure-1, consists of a two-level VSC, a dc energy storage device, a

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coupling transformer connected in shunt to the DS. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the STATCOM output voltages allows effective control of active and reactive power exchanges between the STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

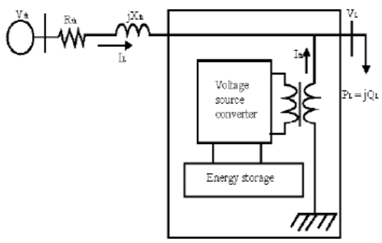

Fig.2. Schematic Diagram of a STATCOM

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter. As shown in Figure-2 the shunt injected current Ish corrects the voltage sag by adjusting the voltage drop across the system impedance Zth. The value of Ish can be controlled by adjusting the output voltage of the converter. The shunt injected current Ish can be written as,

$$I_{sh} = I_L - I_S = I_L - (Vth - V_L) / Z_{th} \qquad (1)$$

STATCOM is a primary shunt device of the FACTS family, which uses power electronics to control power flow and improve transient stability on power grids. The STATCOM regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. For purely reactive power flow the three phase voltages of the STATCOM must be maintained in phase with the system voltages. The variation of reactive power is performed by means of a VSC connected through a coupling transformer. The VSC uses forced commutated power electronics devices (GTO's or IGBT's) to synthesize the voltage from a dc voltage source. It can be seen that if $V_2 > V_1$ then the reactive current I_q flows from the converter to the ac system through the coupling transformer by injecting reactive power to the ac system. On the other hand, if $V_2 < V_1$ then current I_q flows from ac system to the converter by absorbing reactive power from the system. Finally, if $V_2 = V_1$ then there is no exchange of reactive power. The amount of reactive power exchange is given by

$$Q = \frac{V_1(V_1 - V_2)}{X_s} \qquad (2)$$

Where,
V_1: Magnitude of system Voltage.
V_2: Magnitude of STATCOM output voltage.
X_s: Equivalent impedance between STATCOM and the system.

III. REACTIVE POWER COMPENSATION PRINCIPLES

In a linear circuit, the reactive power is defined as the ac component of the instantaneous power, with a frequency equal to 100 / 120 Hz in a 50 or 60 Hz system. The reactive power generated by the ac power source is stored in a capacitor or a reactor during a quarter of a cycle, and in the next quarter cycle is sent back to the power source. In other words, the reactive power oscillates between the ac source and the capacitor or reactor, and also between them, at a frequency equals to two times the rated value (50 or 60 Hz). For this reason it can be compensated using VAR generators, avoiding its circulation between the load (inductive or capacitive) and the source, and therefore improving voltage stability of the power system. Reactive power compensation can be implemented with VAR generators connected in parallel or in series. The principles of both, shunt and series reactive power compensation alternatives, are described below.

A. Shunt Compensation.

Figures 3&4 shows the principles and theoretical effects of shunt reactive power compensation in a basic ac system, which comprises a source V1, a power line and a typical inductive load. Figure 3 shows the system without compensation, and its associated phasor diagram. In the phasor diagram, the phase angle of the current has been related to the load side, which means that the active current IP is in phase with the load voltage V2. Since the load is assumed inductive, it requires reactive power for proper operation and hence, the source must supply it, increasing the current from the generator and through power lines.

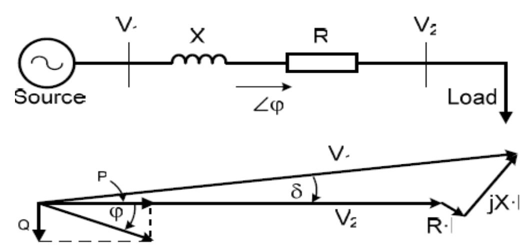

Fig.3. Principles of shunt compensation without reactive compensation

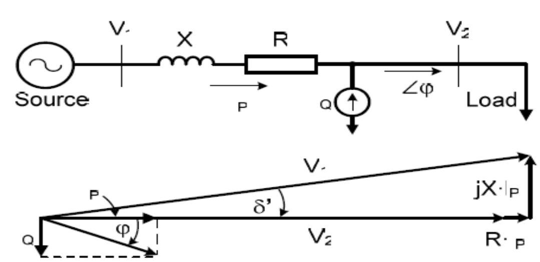

Fig.4. Principles of s hunt compensation with a current source

If reactive power is supplied near the load, the line current can be reduced or minimized, reducing power losses and improving voltage regulation at the load terminals. This can be done in three ways: a) with a capacitor, b) with a voltage source, or c) with a current source. In Fig.4 a current source device is being used to compensate the reactive component of the load current (IQ). As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated. If the load needs leading compensation, then an inductor would be required. Also a current source or a voltage source can be used for inductive shunt compensation. The main advantages of using voltage or current source VAR generators (instead of inductors or capacitors) is that the reactive power generated is independent of the voltage at the point of connection.

B. Series Compensation

VAR compensation can also be of the series type. Typical series compensation systems use capacitors to decrease the equivalent reactance of a power line at rated frequency. The connection of a series capacitor generates reactive power that, in a self regulated manner, balances a fraction of the line's transfer reactance. The result is improved functionality of the power transmission system through:

i) Increased angular stability of the power corridor,
ii) Improved voltage stability of the corridor,
iii) Optimized power sharing between parallel circuits.

Like shunt compensation, series compensation may also be implemented with current or voltage source devices, as shown in Fig.5&6. Figure 5 shows the same power system of figure 5 also with the reference angle in V2, and Fig. 6 the results obtained with the series compensation through a voltage source, which has been adjusted again to have unity power factor operation at V2. However, the compensation strategy is different when compared with shunt compensation. In this case, voltage VCOMP has been added between the line and the load to change the angle of V2'.Which is now the voltage at the load side. With the appropriate magnitude adjustment of VCOMP, unity power factor can again be reached at V2. As can be seen from the phasor diagram of Fig. 6 VCOMP generates a voltage with opposite direction to the voltage drop in the line inductance because it lags the current IP.

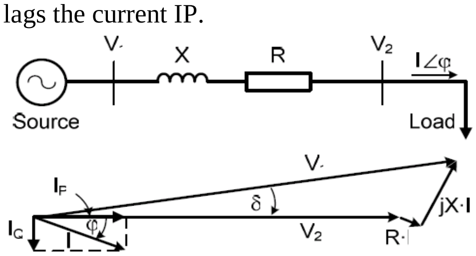

Fig.5. Principles series compensation of without compensation

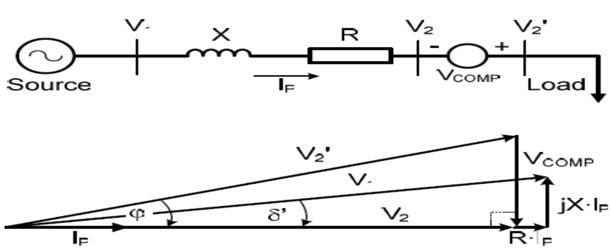

Fig.6. Principles of series compensation with a voltage source

IV. CASCADED MULTILEVEL CIRCUIT

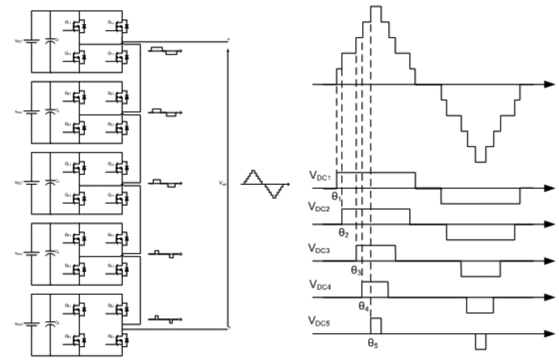

Fig.7. Single phase 9 level H-bridge inverter and switching strategies

A cascaded multi-level converter circuit is shown in Fig. 7. It is a three phase VSC which comprises of three single phases and each phase consists of H-bridges connected in series. The three phases in the converter are star connected. Each single phase H-bridge converter has two arms consisting of two pairs of GTO and diode connected in anti-parallel. Each H-bridge has its own capacitor, acting as a voltage source. Individual capacitors of same capacitance are selected to meet the economic and harmonic criteria.

The peak output voltage of STATCOM is N times to that of the capacitor voltage, where N is the number of H-bridges in each phase. Each H-bridge generates three voltage levels $+V_{dc}$, 0 and $-V_{dc}$ and the total output voltage of each phase is the combination of individual H-bridge voltages. A STATCOM with N converters per phase can synthesize 2N+ 1 voltage levels. The output voltage waveform of the cascaded N-Level STATCOM depends on the switching pattern, which is controlled by the switching angles of the converters. These switching angles can be independently selected, but appropriate switching angles are required to achieve good quality of the output voltage waveform. By employing SHEM, lower order harmonics can be eliminated in the output waveform. The amplitude of the odd harmonic order of the output voltage with 2N+1 level can be represented using Fourier's series method as,

$$V_n = \frac{4V_{dc}}{n\pi}\sum_{k=1}^{N}\cos(n\theta_k) \quad (3)$$

Where,
V_n is the amplitude of voltage harmonic of nth order
V_{dc} is the DC voltage across the capacitor
N is the number of the bridges in each phase
n is the odd harmonic order
θ_k is the switching angle of the single phase bridge.

V. MATLAB MODELING AND SIMULATION RESULTS

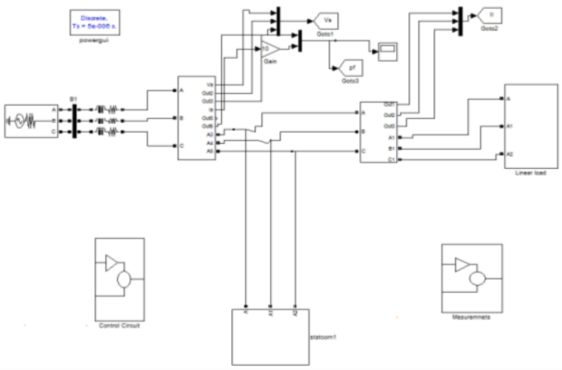

Fig 5.1:-Matlab/Simulink model of Nine level Inverter controlled Statcom.

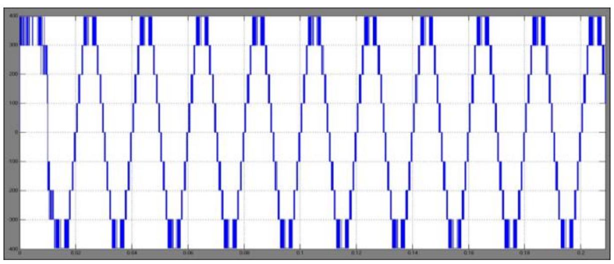

Fig 5.2:Output voltage wave form of Nine level Nine level Inverter controlled Statcom.

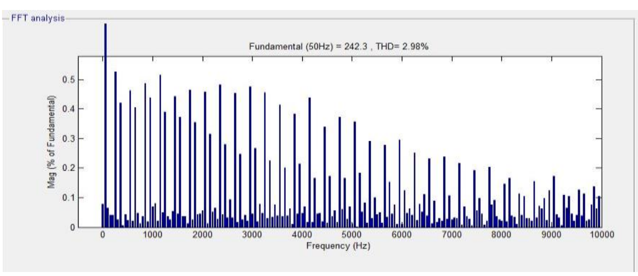

Fig 5.3: Total Harmonic Distortion of Source currents

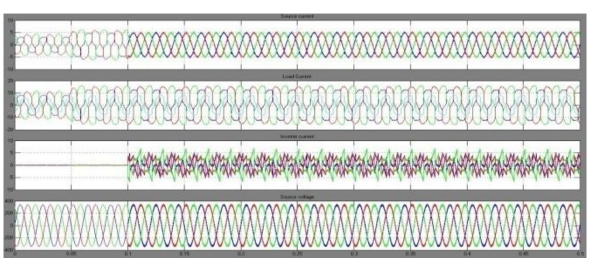

Fig 5.4:Output wave forms of Source currents, Load current, Inverter currents, Source voltage of Nine level Inverter controlled Statcom.

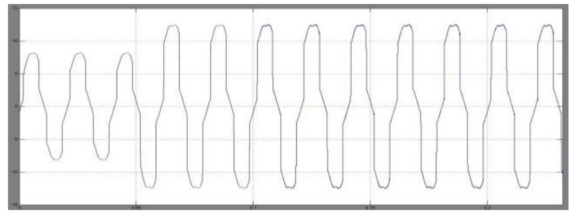

Fig 5.5: Harmonics in the Load Current

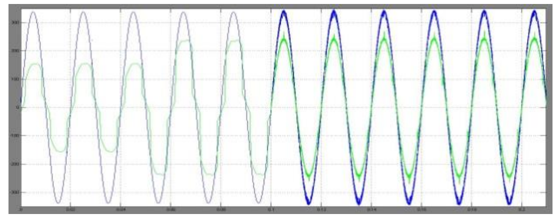

Fig 5.6: Power Factor

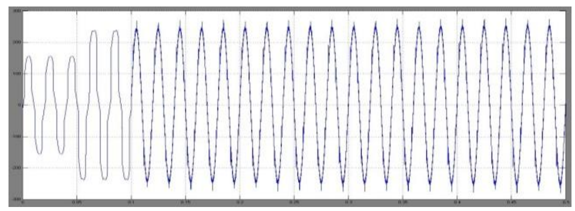

Fig 5.7: Source Currents

VI. CONCLUSION

Cascade H-bridge multilevel inverter has the advantages of simple structure and little harmonic content. The application of Nine level output can improve equivalent frequency and reduce output harmonic, which can solve the problems in high-power converters. Simulation results verify the compensation function and dynamic response of STATCOM based on the control strategy introduced in this paper, which indicates a fine prospect of the device in high-power

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