Performance Evolution of Indirect Control Technique for STATCOM

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Abstract— Modern electric power system is very complex network of synchronous generators, transmission lines and loads mainly inductive type loads. The characteristics of the system vary with changes in load and generation schedules. Electric utilities first grew as isolated systems, and then gradually neighboring utilities began to join forming highly interconnected systems. This enabled the utilities to draw on each other‟s generation reserves during the time of need. The overall reliability has improved through interconnection but disturbances in such systems propagate through, leading to system instability and possible black-outs.A good power system should possess the ability to regain its normal operating condition after a disturbance. Since ability to supply uninterrupted electricity determines the quality of electric power supplied to the load, stability is regarded as one of the important topics of power system research. Power system stability can be improved using FACTS controllers by enhancing its steady-state and transient stability or by damping the sub-synchronous resonance oscillations.in this paper an important FACTS devics STATCOM is proposed. For proper controlling of reactive power compensation indirect controlling is proposed.

Key words: Cascaded Multilevel Inverter, Static Synchronous Compensator, Modutaion Index, Newton Raphson Method, Total Harmonic Distortion, Selective Harmonic Elimination

I. INTRODUCTION

Modern electric power system is facing many challenges due to day by day increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instability. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems. Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. The need for the power flow control in electrical power systems is thus evident. With the increased loading of transmission lines, the problem of transient stability after a major fault can become a transmission power limiting factor. To solve the problem of transient stability in the late 1980s, the Electric Power Research Institute (EPRI) introduced a new approach to solve the problem of designing and operating power systems; the proposed concept is known as Flexible AC Transmission Systems (FACTS). An important FACTS device like Static synchronous compensator (STATCOM), which can control all three principle parameters (voltage, impedance and phase angle) and used for dynamic compensation of power system to provide voltage support and stability improvement. When suddenly load changes the voltage also changes according to load. If inductive load increase it requires large amount of reactive power compensation to maintain the load voltage. The reactive power in the system can be compensated using STATCOM. One of the important merits of the STATCOM is that its operation does not depend on power system voltage. For proper reactive power exchange with power system, the STATCOM output voltage needs to be controlled efficiently, and accordingly, two control schemes i.e. direct and indirect control strategies are used. Each of these control strategies has their merits and demerits in sense of response time, harmonic distortion in output voltage etc. In this thesis work indirect control strategy for proper controlling of reactive power to maintain constant voltage is proposed. The main componant of STATCOM is Voltage Source Inverter (VSI) [1].This voltage source inverter may be multi pulse or multilevel. But multilevel inverter has many advantages as compare to multi pulse inverter. As compare to multi pulse inverter, a multilevel inverter produces the desired output voltage by synthesis of several levels of input dc voltages. A nearly sinusoidal fundamental frequency output voltage of high magnitude can be produced by connecting sufficient number of input dc levels.various type of multilevel inverters are reported in the literature. Diode clamped multilevel inverter (DCMLI), flying capacitors multilevel inverter (FCMLI), and cascade multilevel inverter (CMLI).But CMLI is most suitable for power system application.We can use CMLI in power system for reactive power compensation.[2]

II. CASCADED MULTILEVEL INVERTER

Cascaded multilevel inverter (CMLI) consists of a series of H-bridges inverter units .These inverter unit are single ,phase full bridge .The main function of this multilevel inverter is to synthesize a desired voltage from several separate dc sources(SDCSs),which may be obtained from batteries ,fuel cells or solar cells. Each SDCS is connected to an H-bridge inverter. The cascaded multilevel inverter does not require any voltage clamping diodes or voltage balancing capacitors

A. *Principle of Operation:*

Fig shows the synthesized phase voltage waveform of a nine level cascaded inverter with four SDCSs.The voltage is synthesized by the sum of four inverter outputs. $van = va1+va2+va3+va4$.Each inverter level can generate three different voltage outputs + Vdc,0,-Vdc,by connecting the dc source, to the ac output side by different combination of four switches S1,S2,S3,S4. By turing on S1 and S4 we get *+Vdc* Turning on S2 and S3 results *-Vdc*. when any two switches of same leg is on then voltage will be 0.In same manner voltage of other level can also be obtained.[3-4]If Ns is the number of DC sources ,the output voltage Level m=2Ns+1 eg. A nine level cascaded inverter needs four SDCs and four full bridges. We can minimize the harmonic distorsion by controlling the conduction angles at different inverter levels.[5] Hence we can say that Cascade multilevel inverter consists of number of H-bridges inverter units having isolated dc source for each unit and are connected in series. Three voltage levels i.e. *+Vdc*, *0*, and *–Vdc* (Vdc is input dc voltage) are produced by proper switching of devices of each H-bridge. The synthesized output voltage waveform is the sum of all of the individual H-bridge's outputs. Nearly sinusoidal output voltage waveforms can be synthesized by using sufficient number of H-bridges in cascade and choosing proper switching angles.[6]

An 9-level cascade multilevel inverter based STATCOM is used in this work. Let the switching angles corresponding to H-bridges H1, H2, H3 and H4 are α1, α2, α3 and α4 respectively. The ac output phase voltage magnitude is given by *van = va1+va2+va3+va4*.

The switching angles α1 … α4, need to be selected properly as the harmonic distortion in the STATCOM output voltage depends very much on these angles. In the present work, these angles have been chosen in such a way that the harmonic distortion upto 49th order given by eqn. (1) is least

$$THD_{49} = \frac{\sqrt{V_5^2 + V_7^2 + \ldots + V_{49}^2}}{V_1} \times 100 \qquad (1)$$

In eqn. (1), Vn, is magnitude of nth harmonic voltage component where n = 1, 5, 7,11,13...49. to find out the angles we use selective harmonic elimination technique.[7]

By using NR method we have solved the equation and we have oblation the various values of m and angles. By using 9 level inverter we can reduce THD upto 9%. And we can define THD as

$$THD = \frac{\sqrt{\sum_{n=x}^{n=49} V_n^2}}{V_1}$$

Using 9 level inverter we can reduce the harmonic distortion upto 9.39%. As waveform is symmetric so even harmonic are zero.and as this is 9 level inverter 5^{th} ,7^{th} and 11^{th} harmonic are eliminated. If we use this inverter in 3 phase circuit we can eliminate tripplen harmonics also.Hence we can get nearly a sine wave. As higher order harmonics can be filtered out.

B. Circuit Diagram:

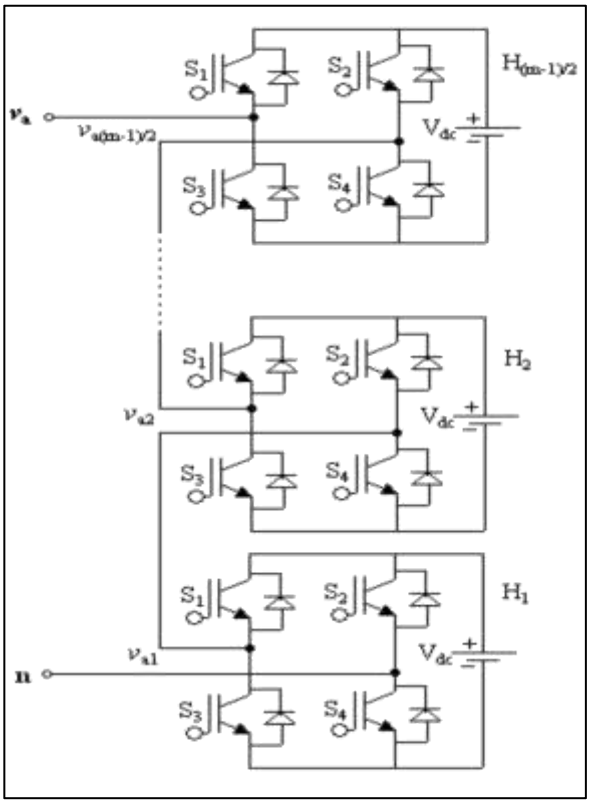


Fig. 1: Circuit Diagram

III. STATCOM

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 solid-state switches are operated either in square-wave mode with switching once per cycle or in PWM mode employing high switching frequencies in a cycle of operation or selective harmonic elimination modulation employing low switching frequencies. A DC voltage source on the input side of VSC, which is generally achieved by a DC capacitor and output, is a multi-stepped AC voltage waveform, almost a sinusoidal waveform. The turn-off device makes the converter action, whereas diode handles rectifier action. STATCOM is essentially consisting of six-pulse VSC units, DC side of which is connected to a DC capacitor to be used as an energy storage device, interfacing magnetic (main coupling transformer and/or inter-mediate/inter-phase transformers) that form the electrical coupling between converter AC output voltage (Vc) and system voltage (Vs) and a controller. The primary objective of STATCOM is to obtain almost harmonic neutralized and controllable 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. As STATCOM has inherent characteristics for real power exchange with a support of proper energy storage system, operation of such controller is possible in all four quadrants of Q–P plane and it is governed by the following power flow

$$.S = 3\frac{V_s V_c}{X_L}\sin\alpha - j3\left(\frac{V_s V_c}{X_L}\cos\alpha - \frac{{V_S}^2}{X_L}\right) = P - jQ \qquad (1)$$

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 the leakage reactance, L the leakage inductance, f the system frequency and α the phase angle between Vs and Vc.

Active power flow is influenced by the variation of α and reactive power flow is greatly varied with the magnitude of the voltage variation between Vc and Vs. Q is derived from (1) as follows

$$S = 3\frac{V_s V_c}{X_L}\sin\alpha - j3\left(\frac{V_s V_c}{X_L}\cos\alpha - \frac{{V_S}^2}{X_L}\right) = P - jQ \qquad (3)$$

Converter fundamental phase terminal voltage(rms)=

$$Q = \frac{V_S}{X_L(V_C - V_S)} \qquad (4)$$

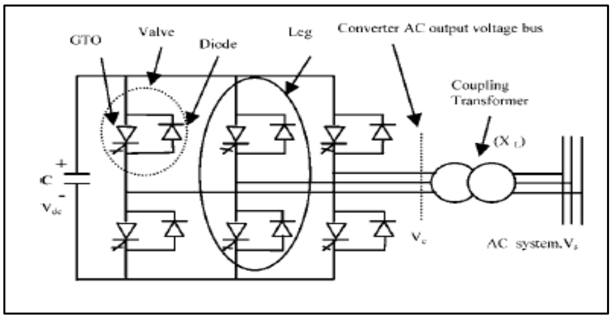
nth harmonic voltage(rms) =

$$V_{c_n} = V_{c_1} = \frac{\sqrt{2}}{\pi}V_{dc} \qquad (5)$$

Converter fundamental reactive current(rms)=

$$I_{q_1} = \frac{V_s - V_c}{jwL} \qquad (6)$$

We can simply understand the working of STATCOM by Fig. 3.The voltage difference between the STATCOM output voltage (V*c*) and the power system bus voltage (V*l*) decides reactive power injection or absorption to the system. This voltage difference can be achieved by two different ways: either by changing the modulation index (*m*) at constant dc link voltage (*vdc*) (direct control) or by varying *vdc* at fixed *m* (indirect control) [11]. In indirect control, variation of *vdc* is achieved by phase shifting *vc* with respect to *vl*. In direct control scheme, reactive power compensation is fast but harmonics level in *vc* may vary according to the switching angles selected. On the other hand, indirect control is slow in operation but harmonic level of *vc* can be kept least by proper selection of switching angles.[5].Many VSC-based topologies and configurations are adopted in the state-of-the-art STATCOM controllers and significantly, multi-pulse and/or multi-level topologies are widely accepted in the design of compensators. An elementary six-pulse VSC which consists of three legs (phases) with two valves per leg and an electrostatic capacitor on the DC bus is illustrated in Fig. 1. Each valve consists of a self-commutating switch with a reverse diode connected in parallel. In square-wave mode, eight possible switching states are possible with respect to the polarity of DC voltage source. A set of three quasi square waveforms at its AC terminals, displaced successively by 120 degree, is obtained using fundamental frequency switching modulation. The phase to neutral and line-to-line voltage of the converter shown in Fig. 1 contain an unacceptable current harmonics causing severe harmonic interference to electrical system. To reduce THD, multi-pulse converter topology derived from the combination of multiple number (N-numbers) of elementary six-pulse converter units to be triggered at specific displacement angle(s), is widely adopted, and output AC voltage waveforms from each unit is electro-magnetically added with an appropriate phase shift by inter-phase transformer(s) to produce a multi- pulse (6* N pulses) waveform close to sinusoidal wave.



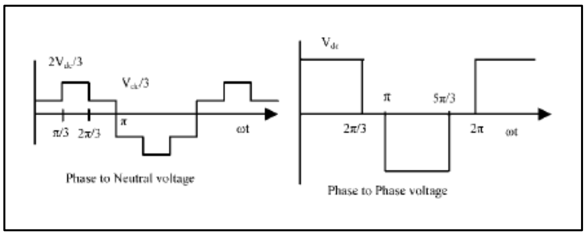


Fig. 2: Basic Two Level Six Pulse VSC Bridge and Its Output Voltage Waveform in Square Wave Mode of Operation

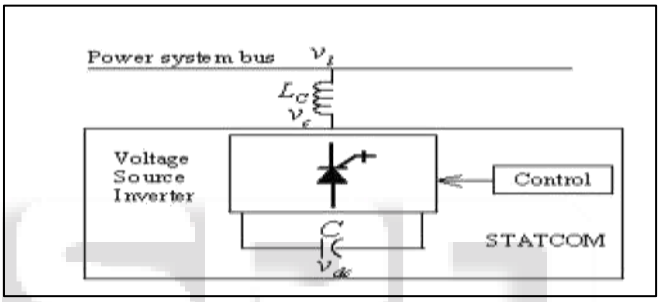


Fig. 3: Basic Building Block for STATCOM

If For proper working of statcom, proper voltge regulation we have to use proper control scheme for STATCOM.In this paper we are using cascaded multilevel inverter as a STATCOM.The output voltage generated by the cascade multilevel inverter needs to be varied smoothly and continuously so that the right amount of the reactive power can be exchanged with the ac system at all instants, therefore, an efficient control system is required.There are two type of controlling of STATCOM namely direct control and indirect control.In this paper we have carried out indirect controlling of STATCOM.

A. *Indirect Control Scheme:*

Indirect control scheme the output voltage is controlled by varying the dc capacitor voltages at constant modulation index (i.e. at fixed switching angles). The indirect control scheme employed in this work is shown schematically in Fig. 4 for a CMLI having s number of H-bridges. As in direct control scheme, the switching angles for each H-bridge are calculated off-line and are stored in a look-up table. However, in this case, we can have fixed switching angles for a given value of m or if it is required to change m in that case we may have the look-up table.

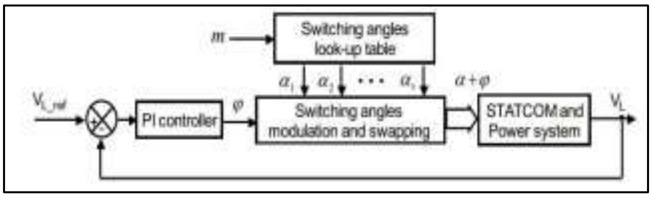


Fig. 4: Schematic Diagram of Indirect Control Scheme for STATCOM

B. Matlab Modelling and Simulation Result:

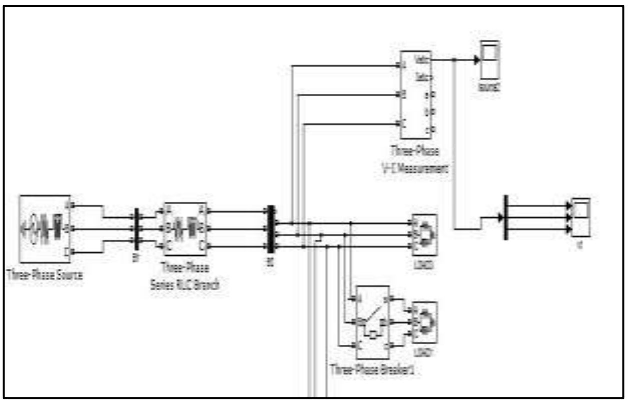


Fig. 5: Transmission Line Model without STATCOM

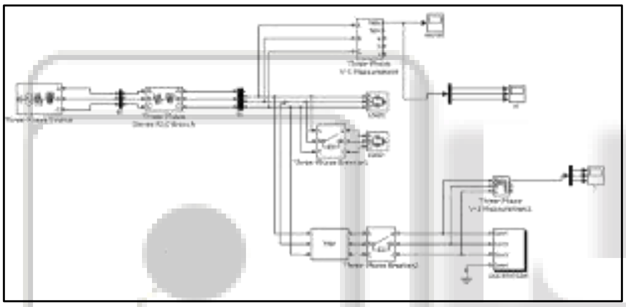


Fig. 6: Transmission Line Model with STATCOM

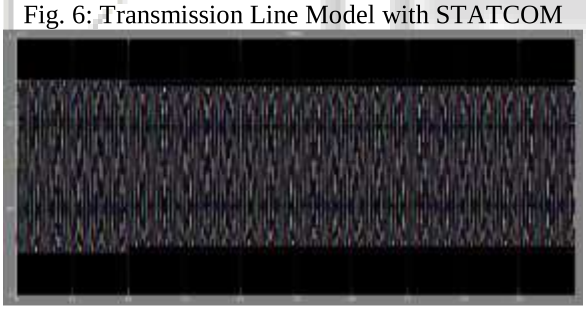


Fig. 7: Load Voltage without STATCOM

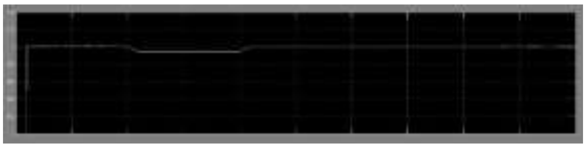


Fig. 8: Load Voltage In Per Unit

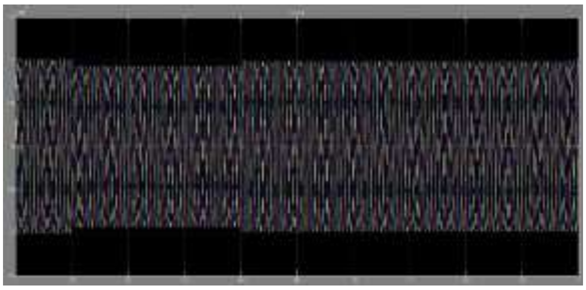


Fig. 9: Load Volatge with STATCOM for Inductive Load

Fig. 10: CMLI Inverter Output Voltage

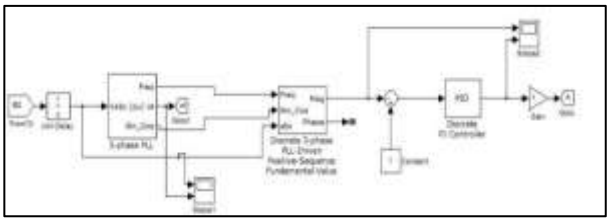


Fig. 11: Indirect Controlling Model for STATCOM

IV. CONCLUSIONS

As STATCOM is basically a voltage source inverter so we can use CMLI with capacitor with initial voltage Vdc as a STATCOM. To control the reactive power generation and absorption we use different control techniques reported in literature. Using cmli we can get nearly a sine wave and can minimize distortion.as we increase in level different harmonics can be eliminated

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