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Analysis of Control Technique for STATCOM

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Abstract: ***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. 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).STATCOM is new FACTS devices used to solve voltage instability. This paper proposes the use of 9 levels Cascaded Multilevel Inverter (CMLI) as a STATCOM to improve the performance of transmission line. In this paper we have taken only single machine connected to a bus. In order to reduce the THD selective harmonic elimination technique is proposed.***

Keywords: cascaded multilevel inverter, static synchronous compensator, modulation index, Newton raphson method, total harmonic distortion, selective harmonic elimination

1. Introduction

Power is being transmitted through transmission line and they are interconnected due to economical reasons .There are mainly three type of transmission line 1)short transmission line 2)medium transmission line 3) long transmission line. There are various limits on these transmission line, these are thermal limit, voltage limit, stability limit. Thermal limit is mainly for short transmission line. Voltage and stability limit is for long transmission line. Voltage profile of a line depend upon the SIL (surge impedance loading) of the line .Voltage will sag if loading is more than SIL. So to improve the voltage profile we have supply additional reactive power. So we can use capacitor bank near the load end but this is not good. So we use FACTS (flexible alternating current transmission system) devices to improve the transmission line voltage profile. STATCOM is one of the important FACTS device. The main component 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]

2. Cascaded Multilevel Inverter

Cascaded multilevel inverter (CMLI) consists of a series of H-bridges inverter units. This inverter unit is 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. [2]

2.1 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 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. Controlling the conducting angles at different inverter levels can minimize the harmonic distortion of the output voltage.[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]

2.2 Circuit Diagram

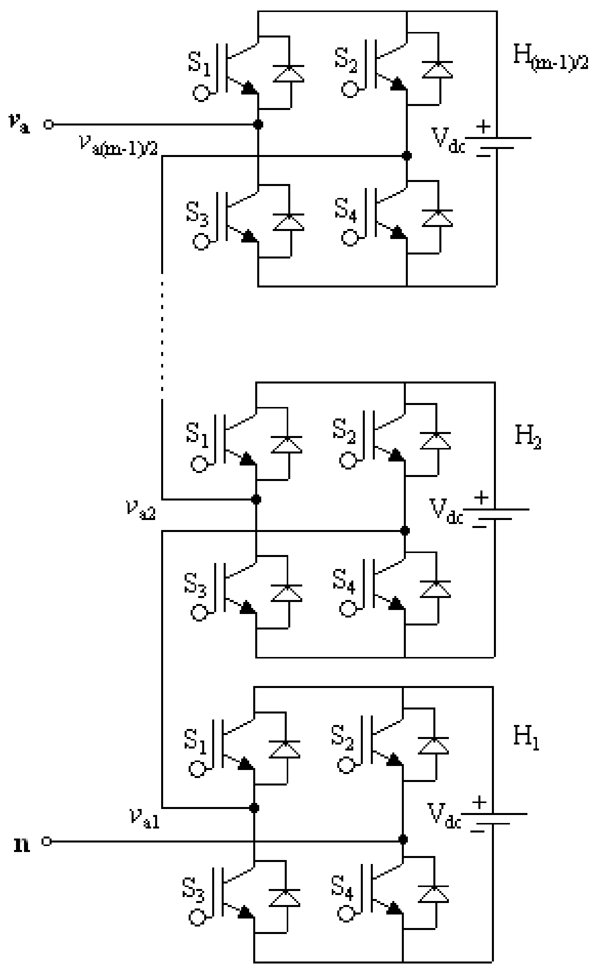

Figure 1: Single-phase cascade multilevel inverter topology.

The magnitude of the ac output phase voltage is the sum of the voltages produced by H-bridges. In the Fig. 2, α1, α2 and α3 are the switching angles for three H-bridges in each phase, and β1, β2 and β3 are corresponding supplementary angles for α1, α2 and α3. The magnitude and THD content of output voltage depends very much on these switching angles, therefore, these angles need to be selected properly. [8]

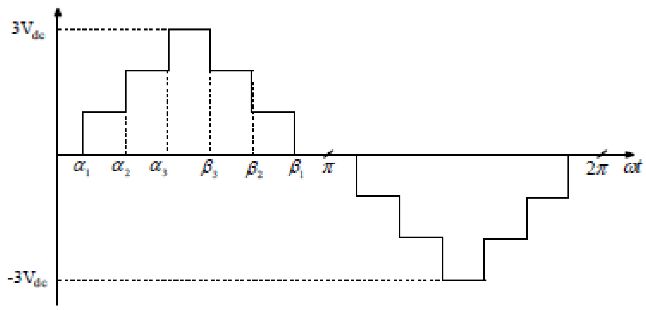

Figure 2: Output Phase Voltage Waveform for 7-Level CMLI

2.3 Selective Harmonic Elimination Technique

There are various PWM technique to control the voltage profile of VSI

1. Sinusoidal PWM 2.Third Harmonic injected PWM 3.Harmonic elimination PWM technique 4.Space vector Modulation. But in this work we have used Selective harmonic elimination technique.[8-9]

In general, the Fourier series expansion of the staircase output voltage waveform as shown in Fig. 2 is given by

$$v_{an}(wt) = \sum_{k=1,3,5,...}^{\infty} \frac{4V_{dc}}{k\pi}(\cos(k\alpha_1) + \cos(k\alpha_2) + ... + \cos(k\alpha_s))\sin(k\omega t) \quad (2)$$

Where s is the number of H-bridges connected in cascade per phase and k is order of harmonic components. For a given desired fundamental peak voltage V1, it is required to determine the switching angles such that 0 ≤ α1 < α2 … < αs ≤ π/2 and some predominant lower order harmonics of phase voltage are zero. Among s number of switching angles, generally one switching angle is used for fundamental voltage selection and the remaining (s-1) switching angles are used to eliminate certain predominating lower order harmonics. In three-phase power system, triplen harmonic components are absent in line-to-line voltage, as a result, only non-triplen odd harmonic components are present in line-to-line voltages the expression for the fundamental voltage in terms of switching angles is given by

$$\frac{4V_{dc}}{\pi}(\cos(\alpha_1) + \cos(\alpha_2) + ... + \cos(\alpha_s)) = V_1$$

Moreover, the relation between the fundamental voltage and the maximum obtainable voltage is given by modulation index. The modulation index, m, is defined as the ratio of the fundamental output voltage (V1) to the maximum obtainable fundamental voltage. The maximum fundamental voltage is obtained when all the switching angles are zero i.e. V1max = 4sVdc/π, therefore, m = πV1/4sVd .[10]

3. STATCOM Operation

3.1 Basic Operating Principle

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) =

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

Converter fundamental reactive current(rms)=

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

STATCOMs are typically applied in long distance transmission systems, power substations and heavy industries where voltage stability is the primary concern.

In addition, static synchronous compensators are installed in select points in the power system to perform the following:

i. Voltage support and control
ii. Voltage fluctuation and flicker mitigation
iii. Unsymmetrical load balancing
iv. Power factor correction
v. Active harmonics cancellation
vi. Improve transient stability of the power system

We can simply understand the working of STATCOM by Fig. 3.The voltage difference between the STATCOM output voltage (Vc) and the power system bus voltage (Vl) 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.

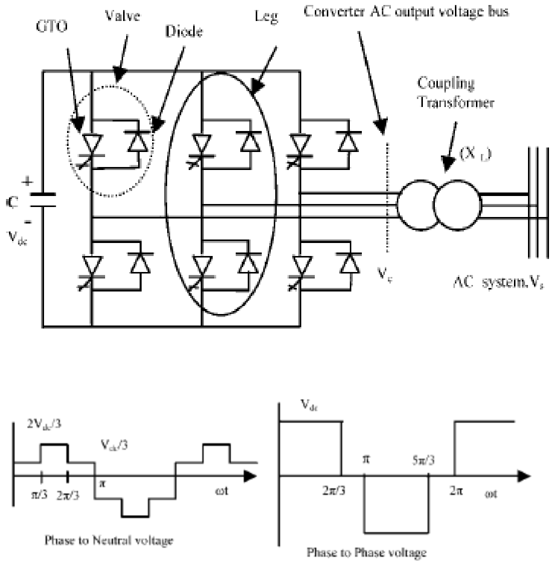

Figure 2: Basic two level six pulse VSC bridge and its output voltage waveform in square wave mode of operation

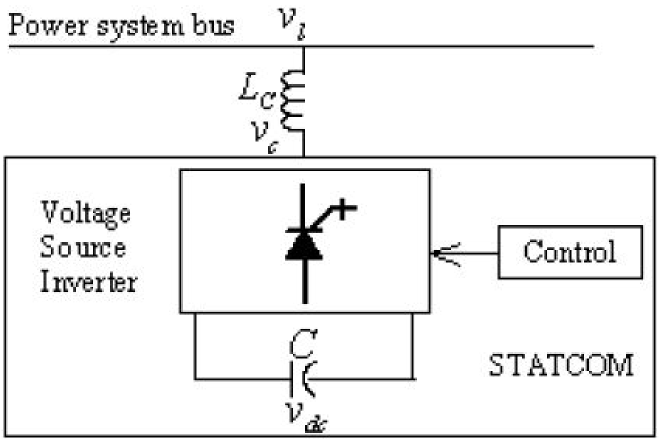

Figure 3: Basic Building Block for STATCOM

4. Controlling of STATCOM

If For proper working of statcom, proper voltage 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.

4.1 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.

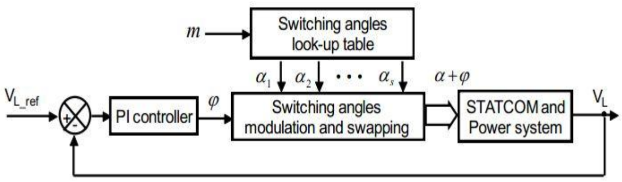

Figure 4: Schematic diagram of indirect control scheme for STATCOM

5. Simulation Results

Output load voltage waveform is as shown in fig 4. Here we can see that when at 0.1 sec load is increased voltage came down, and at 0.2 sec STATCOM is on and STATCOM improve the output voltage. STATCOM provide the necessary reactive power to system hence improve the load voltage.

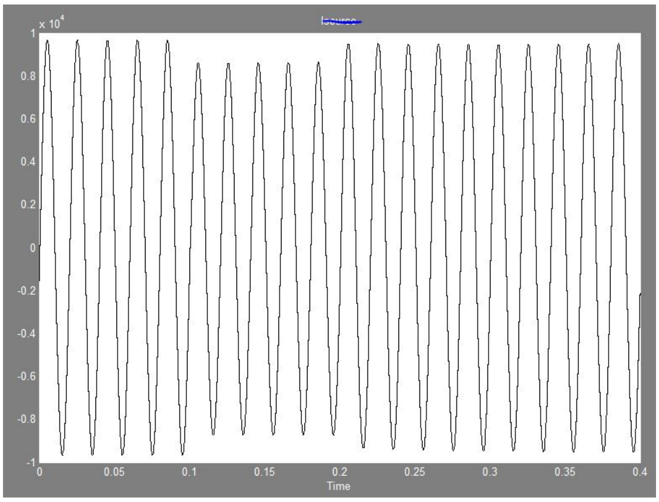

Figure 4: Output voltage at load bus

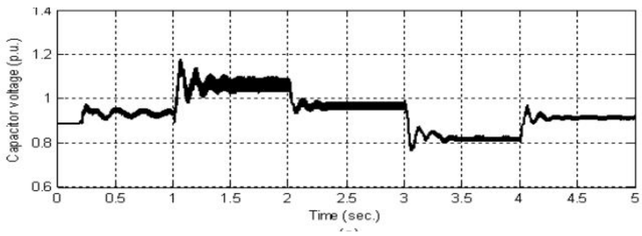

Figure 5: Capacitor Voltage (PU)

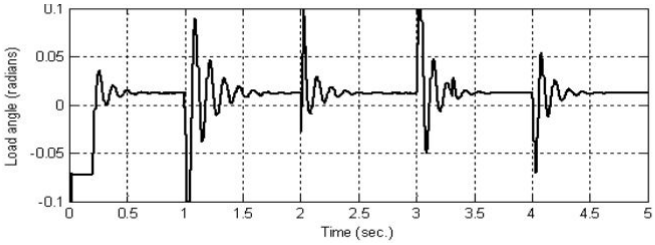

Figure 6: Load angle variation

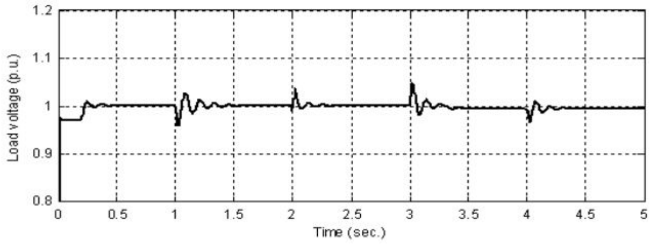

Figure 6: Output Load voltage variation in per-unit

6. Conclusion

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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