An Improved Hybrid Dstatcom Topology to Compensate Reactive Power and Nonlinear Loads

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Abstract : *Shunt compensation for medium voltage distribution systems requires higher rating for voltage source converters (VSCs). Ratings of the semiconductor devices in a VSC are always limited; therefore, for higher rated converters it is desirable to distribute the stress among the number of devices using multilevel topology. Cascaded multilevel configuration of the inverter has the advantage of its simplicity and modularity over the configurations of the diode-clamped and flying capacitor multilevel inverters. Application of cascaded multilevel converters for shunt compensation of distribution systems has been described in Literature. This paper presents an investigation of five-Level Cascaded H – bridge (CHB) Inverter as Distribution Static Compensator (DSTATCOM) in Power System (PS) for compensation of reactive power and harmonics. The advantages of CHB inverter are low harmonic distortion, reduced number of switches and suppression of switching losses. A CHB Inverter is considered for shunt compensation of a 11 kV distribution system. Finally a level shift carrier PWM (LSCPWM) and phase shifted PWM (PSPWM) techniques are adopted to investigate the performance of CHB Inverter. The results are obtained through Matlab/Simulink software package. The proposed DSTATCOM is simulated for both linear and nonlinear loads.*

Keywords: *DSTATCOM, Power Quality Level shifted Pulse width modulation (LSPWM), Phase shifted Pulse width modulation (PSPWM), Proportional-Integral (PI) control.*

I.   Introduction

The electric power system has grown in size and complexity with a huge number of interconnections to meet the increase in the electric power demand. Moreover, the role of long distance and large power transmission lines become more important. Now a days the requirement for power quality becomes more and more important to keep safety of the electrical devices and consumer satisfaction. Electric Power quality is a term which has captured increasing attention in power engineering in the recent years. Even though this subject has always been of interest to power engineers; it has assumed considerable interest in the 1990's. Electric power quality means different things for different people. To most electric power engineers, the term refers to a certain sufficiently high grade of electric service but beyond that there is no universal agreement. The measure of power quality depends upon the needs of the equipment that is being supplied. What is good power quality for an electric motor may not be good enough for a personal computer. Usually the term power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency. Electric power quality (EPQ) problems mainly include unbalance voltage and current, flicker, harmonics, voltage sag, dip, swell, and power interruption [1]. These power quality problems may cause abnormal operations of facilities or even trip protection devices. Hence, the maintenance and improvement of electric power quality has become an important scenario today.

Modern power systems are of complex networks, where hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution networks. Even though the power generation is fairly reliable, the quality of power is not always so reliable. Power distribution system should provide with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency to their customers. PS especially distribution systems, have numerous non linear loads, which significantly affect the quality of power. Apart from non linear loads, events like capacitor switching, motor starting and unusual faults could also inflict power quality (PQ) problems. PQ problem is defined as any manifested problem in voltage /current or leading to frequency deviations that result in failure or mal operation of customer equipment. Voltage sags and swells are among the many PQ problems the industrial processes have to face. Voltage sags are more severe. During the past few decades, power industries have proved that the adverse impacts on the PQ can be mitigated or avoided by conventional means, and that techniques using fast controlled force commutated power electronics (PE) are even more effective. PQ compensators can be

categorized into two main types. One is shunt connected compensation device that effectively eliminates harmonics. The other is the series connected device, which has an edge over the shunt type for correcting the distorted system side voltages and voltage sags caused by power transmission system faults.

The STATCOM used in distribution systems is called DSTACOM (Distribution-STACOM) and its configuration is the same, but with small modifications. It can exchange both active and reactive power with the distribution system by varying the amplitude and phase angle of the converter voltage with respect to the line terminal voltage. A multilevel inverter can reduce the device voltage and the output harmonics by increasing the number of output voltage levels. There are several types of multilevel inverters:

cascaded H-bridge (CHB), neutral point clamped, flying capacitor [2-5]. In particular, among these topologies, CHB inverters are being widely used because of their modularity and simplicity. Various modulation methods can be applied to CHB inverters. CHB inverters can also increase the number of output voltage levels easily by increasing the number of H-bridges. This paper presents a DSTATCOM with a proportional integral controller based CHB multilevel inverter for the harmonics and reactive power mitigation of the nonlinear loads. This type of arrangements have been widely used for PQ applications due to increase in the number of voltage levels, low switching losses, low electromagnetic compatibility for hybrid filters and higher order harmonic elimination.

II. Design Of Multilevel Based D-Statcom

A: Principle of DSTATCOM : A D-STATCOM(Distribution Static Compensator), which is schematically depicted in Figure-1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. 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 D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.
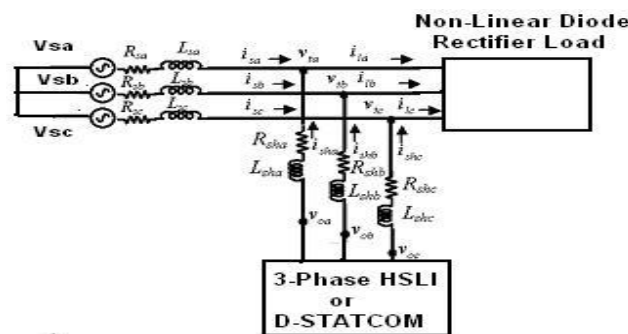

Figure – 1 Schematic Diagram of a D-STATCOM

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:
1. Voltage regulation and compensation of reactive power;
2. Correction of power factor
3. Elimination of current harmonics.

B. Control for Reactive Power Compensation : The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load under system disturbances is connected. The control system only measures the rms voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the fundamental frequency switching methods favored in FACTS applications. Apart from this, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.
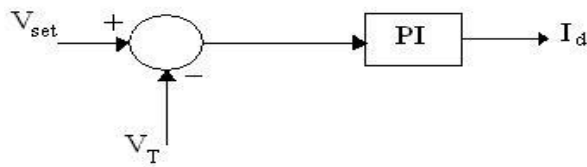
Figure-2 PI control for reactive power compensation

The controller input is an error signal obtained from the reference voltage and the rms terminal voltage measured. Such error is processed by a PI controller; the output is the angle δ, which is provided to the PWM signal generator. It is important to note that in this case, of indirectly controlled converter, there is active and reactive power exchange with the network simultaneously. The PI controller processes the error signal and generates the required angle to drive the error to zero, i.e. the load rms voltage is brought back to the reference voltage.

Control for Harmonics Compensation : The Modified Synchronous Frame method is presented in [7]. It is called the instantaneous current component (id-iq) method. This is similar to the Synchronous Reference Frame theory (SRF) method. The transformation angle is now obtained with the voltages of the ac network. The major difference is that, due to voltage harmonics and imbalance, the speed of the reference frame is no longer constant. It varies instantaneously depending of the

waveform of the 3-phase voltage system. In this method the compensating currents are obtained from the instantaneous active and reactive current components of the nonlinear load. In the same way, the mains voltages V(a,b,c) and the available currents i_l

(a,b,c) in α-β components must be calculated as given by (4), where C is Clarke Transformation Matrix. However, the load current components are derived from a SRF based on the Park transformation, where „θ" represents the instantaneous voltage vector angle (5).

Table-1 Switching table of single CHB inverter

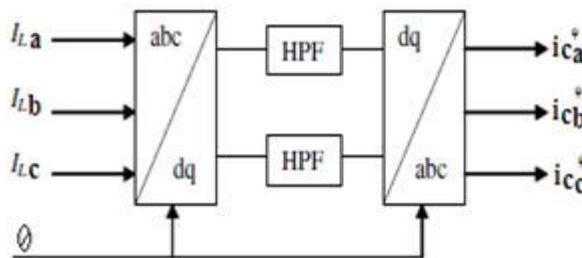| Switches Turn ON	Voltage Level
S1,S2	Vdc
S3,S4	-Vdc
S4,D2	0

Figure-3 Block diagram of SRF method

C.   Cascaded H-Bridge Multilevel Inverter

Fig.4 shows the circuit model of a single CHB inverter configuration. By using single H-Bridge we can get 3 voltage levels.
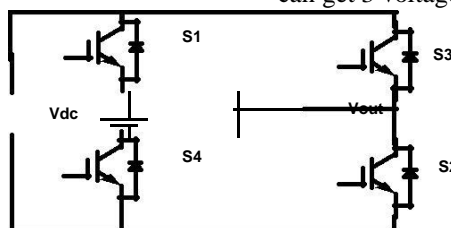

Figure-4 Circuit of the single cascaded H-Bridge Inverter

The number of output voltage levels of CHB is given by 2n+1 and voltage step of each level is given by Vdc/2n, where n is number of H-bridges connected in cascaded. The switching table is given in Table 1.
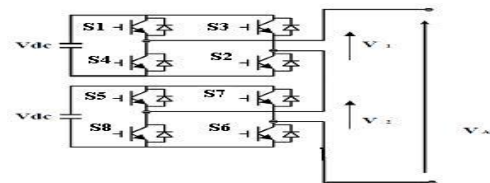

Figure-5 Block diagram of 5-level CHB inverter model

The switching mechanism for 5-level CHB inverter is shown in table-2.

Switches Turn On	Voltage Level
S1, S2	Vdc
S1,S2,S5,S6	2Vdc
S4,D2,S8,D6	0
S3,S4	-Vdc
S3,S4,S7,S8	-2Vdc

Table 2. Switching table for 5-level CHB Inverter

D. PWM Techniques for CHB Inverter : The most popular PWM techniques for CHB inverter are 1. Phase Shifted Carrier PWM (PSCPWM), 2. Level Shifted Carrier PWM (LSCPWM).

Phase Shifted Carrier PWM (PSCPWM)
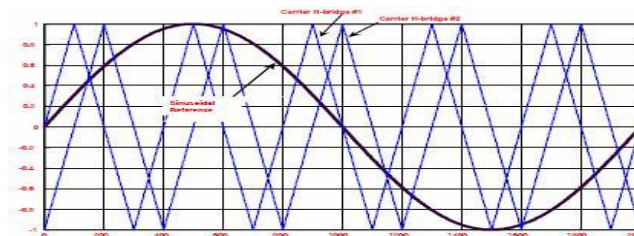
Fig. 6 phase shifted carrier PWM

Fig.6 shows the Phase shifted carrier pulse width modulation. Each cell is modulated independently using sinusoidal unipolar pulse width modulation and bipolar pulse width modulation respectively, providing an even power distribution among the cells. A carrier phase shift of 180°/m (No. of levels) for cascaded inverter is introduced across the cells to generate the stepped multilevel output waveform with lower distortion.
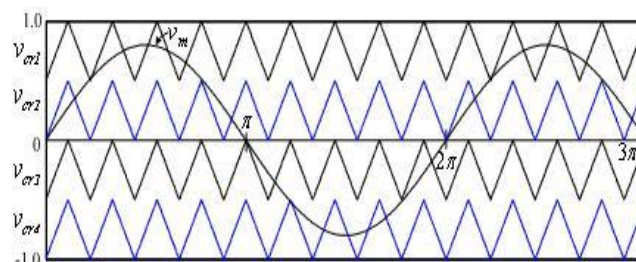
Level Shifted Carrier PWM (LSCPWM)

Fig. 7 Level shifted carrier PWM

Fig.7 shows the Level shifted carrier pulse width modulation. Each cell is modulated independently using sinusoidal unipolar pulse width modulation and bipolar pulse width modulation respectively, providing an even power distribution among the cells. A carrier Level shift by 1/m (No. of levels) for cascaded inverter is introduced across the cells to generate the stepped multilevel output waveform with lower distortion.

III. MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

Here Matlab/Simulink model is developed for two cases. In case one DSATCOM with Linear load and in case two D-STATCOM with nonlinear load are simulated.

A. Case one

Fig. 9 shows the Matab/Simulink power circuit model of DSTATCOM. It consists of five blocks named as source block, non linear load block, control block, APF block and measurements block.
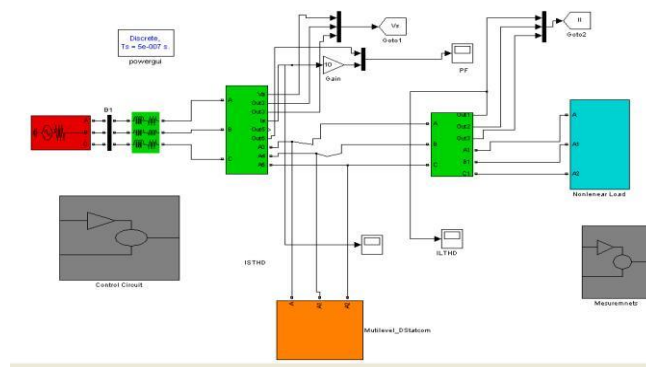
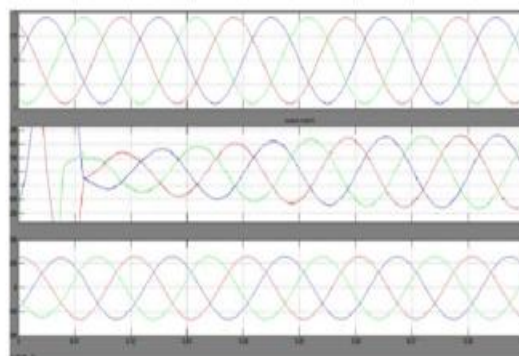**Fig. 8** Matlab/Simulink power circuit model of DSTATCOM

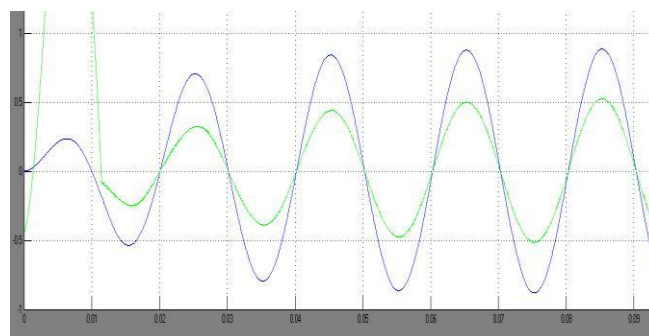**Fig. 9** Source voltage, current and load current with DSTATCOM

Fig. 10 Phase-A source voltage and current

Fig. 10 shows the phase-A source voltage and current, even though the load is non linear RL load the source power factor is unity
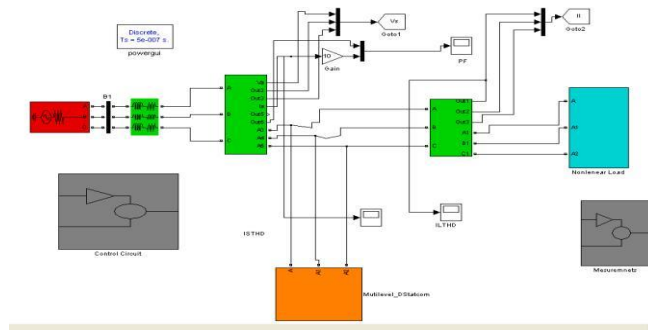
B.   Case two

Fig. 11 Matlab/Simulink power circuit model of DSTATCOM

Fig. 11 shows the phase-A voltage of five level output of phase shifted carrier PWM inverter.
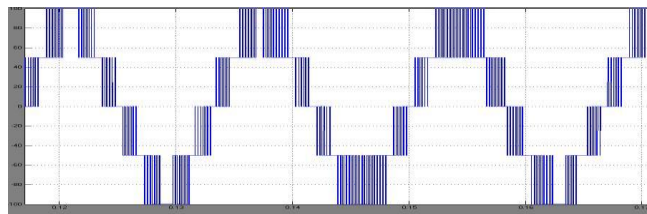

Fig. 11 five level PSCPWM output

Fig. 12 shows the three phase source voltages, three phase source currents and load currents respectively without DSTATCOM. It is clear that without DSTATCOM load current and source currents are same.
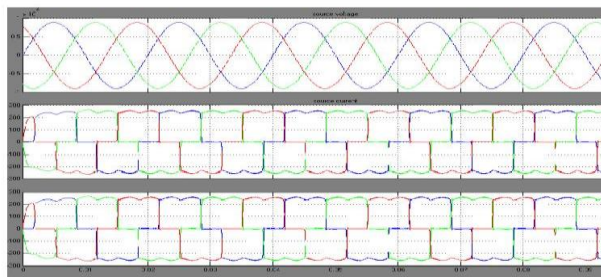

Fig. 12 Source voltage, current and load current without DSTATCOM

Fig. 13 shows the three phase source voltages, three phase source currents and load currents respectively with DSTATCOM. It is clear that with DSTATCOM even though load current is non sinusoidal source currents are sinusoidal.
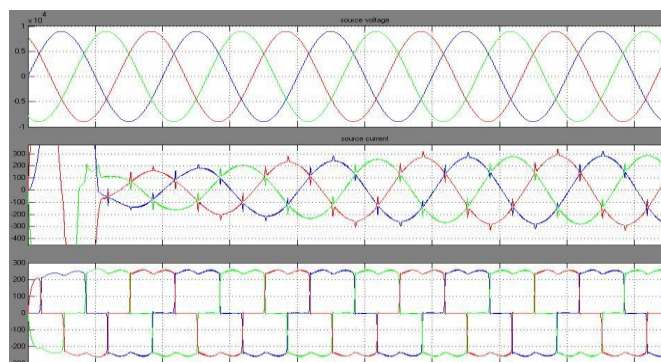

Fig. 13 Source voltage, current and load current with D-STATCOM

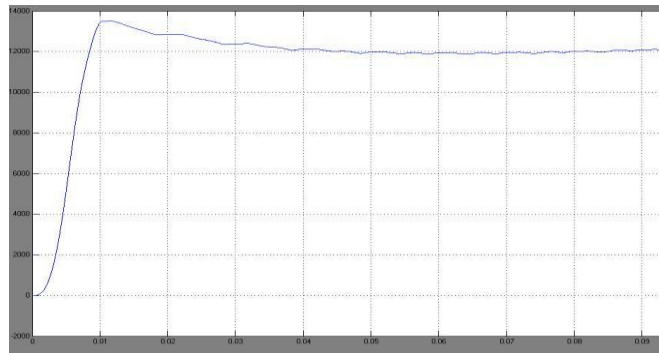Fig. 14 shows the DC bus voltage. The DC bus voltage is regulated to 11kv by using PI regulator.

Fig. 14 DC Bus Vooltage

Fig. 15 shows the phase-A source voltage and current, even though the load is non linear RL load the source power factor is unity.
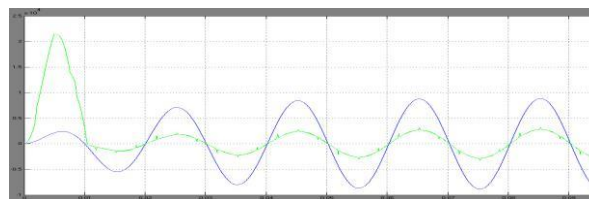

Fig. 15 Phase-A source voltage and current

Fig. 16 shows the harmonic spectrum of Phase –A Source current without DSTATCOM. The THD of source current without DSTACOM is 36.89%.
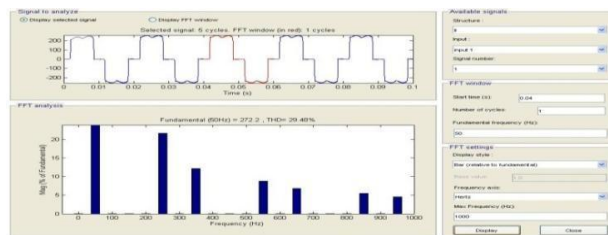

Fig. 16 Harmonic spectrum of Phase-A Source current without DSTATCOM

Fig. 17 shows the harmonic spectrum of Phase –A Source current with DSTATCOM. The THD of source current without DSTACOM is 5.05%
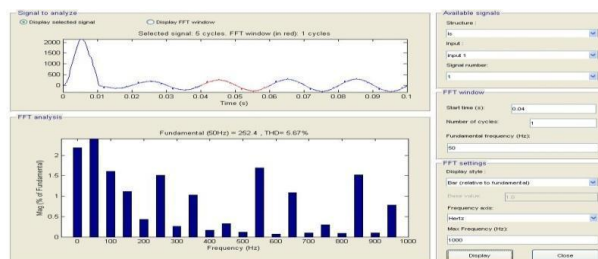

Fig. 17 Harmonic spectrum of Phase-A Source current with DSTATCOM

IV. CONCLUSION

This paper studied a five level inverter used in a D-STATCOM in PS and has been successfully demonstrated in MatLab/Simulink. The benefits of five level inverter has low harmonics distortion, reduced number of switches

to achieve the seven- level inverter output over the cascaded seven level inverter and reduced switching losses. A D-STATCOM with five level CHB inverter is investigated. Mathematical model for single H-Bridge inverter is developed which can be extended to multi H-Bridge. The source voltage , load voltage , source current, load current, power factor simulation results under non-linear loads are presented. Finally Matlab/Simulink based model is developed and simulation results are presented for both linear and non linear loads.

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