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CASCADED H-BRIDGE MULTILEVEL INVERTER BASED DSTATCOM

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ABSTRACT

The Power Quality (PQ) in distribution system is affected by the pollution introduced by the customers. Voltage Sag is one of the Power Quality problem created by the nonlinear loads. When nonlinear load is connected to a source, there is a dip in the voltage which could be critical for the entire system. The power electronics based equipment known as Custom Power Devices (CPD) is used in distribution system to solve PQ problems. DSTATCOM (Distribution Static Compensator) which is connected in shunt at point of common coupling is one effective solution for system facing such problems. This work proposes a Cascaded H-bridge (CHB) Inverter based DSTATCOM to compensate voltage sag in power distribution network. CHB converters are being considered for the increasing number of applications due to their high power capability associated with low output harmonics and low commutation losses. The proposed design uses a standard three-leg inverter (one leg for each phase) and an H-bridge in series with each inverter leg which uses a capacitor as the dc power source. The performance of the proposed DSTATCOM is validated through simulation using MATLAB software with its Simulink and Power system block set tools and also the performance of the system without DSTATCOM and with DSTATCOM is evaluated.

Keywords: D-STATCOM, multilevel, CHB, MATLAB, voltage sags

I.INTRODUCTION

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 nonlinear loads, which significantly affect the quality of power. Voltage sags are one of the most dominating power quality assets, which dragged the attention of many researchers as the sensitivity of loads are increasing due extensive usage of power electronic devices. Fault at distribution level, sudden increase of loads, motor starting are some of the causes of the voltage sags. Such sudden variations of voltage are undesirable for sensitive loads. These undesirable voltage sags can be mitigated by connecting controlled devices either in series or shunt to the load. A few of such devices are dynamic voltage restorer (DVR) and DSTATCOM (Distribution Static Compensator). Both these devices require voltage source converters to satisfactory operation. Many topologies have been proposed in recent past for voltage source converters. Multilevel inverter has drawn attention of many researchers. The proposed cascaded H-bridge multilevel inverter based DSTATCOM uses a standard three-leg inverter (one leg for each phase) and an H-bridge in series with each inverter leg which uses a capacitor as the dc power source.

Voltage sags and swells are among the many PQ problems the industrial processes have to face. Voltage sags are more severe. 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. 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 voltage sag 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

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compatibility for hybrid filters and higher order harmonic elimination.

The paper is divided as per the following sections. Section-I gives the overview of the total project. Section-II presents the description of DSTATCOM. Modulation strategy is described in Section-III. Section-IV & V depicts the description of the Simulink modeling and simulation results. Finally conclusions are presented in section-VI.

II. DSTATCOM

Distribution Static Synchronous Compensator (DSTATCOM) is a shunt connected device. This can perform load compensation, i.e. power factor correction, harmonic filtering, load balancing etc. when connected at the load terminals. It can also perform voltage regulation when connected to a distribution bus. In this mode it can hold the bus voltage constant against any unbalance or distortion in the distribution system. The DSTATCOM must be able to inject an unbalanced and harmonically distorted current to eliminate unbalance or distortions in the load current or the supply voltage. The structure of DSTATCOM is similar to STATCOM but its control is different from that of a STATCOM.

Basically, the DSTATCOM system is comprised of three main parts: a VSC, a set of coupling reactors and a controller. The basic principle of a DSTATCOM installed in a power system is the generation of a controllable ac voltage source by a voltage source inverter (VSI) connected to a dc capacitor (energy storage device). The ac voltage source, in general, appears behind a transformer leakage reactance. The active and reactive power transfer between the power system and the DSTATCOM is caused by the voltage difference across this reactance. The DSTATCOM is connected to the power networks at a PCC, where the voltage-quality problem is a concern. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches (IGBT's, which are used at the distribution level) of the power converter accordingly.

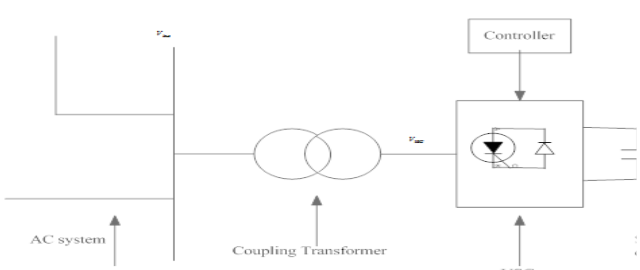

Fig.1 Basic block diagram of DSTATCOM

The proposed cascaded H-bridge multilevel inverter based DSTATCOM uses a standard three-leg inverter (one leg for each phase) and an H-bridge in series with each inverter leg which uses a capacitor as the dc power source.

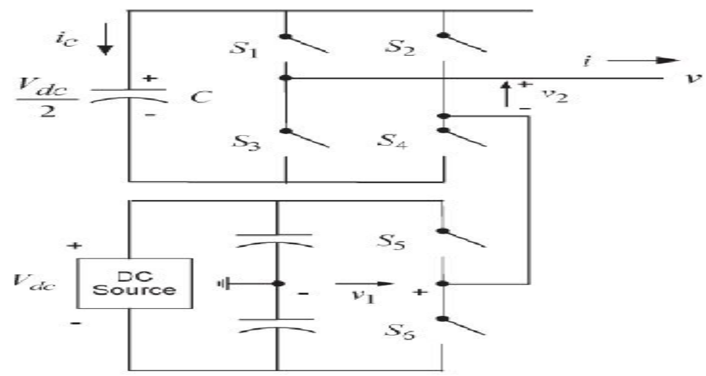

Fig.2 Single phase topology of proposed DSTATCOM

To see how the system works, a simplified single phase topology is shown in Fig. 2. The output voltage $v1$ of this leg of the bottom inverter (with respect to the ground) is either $+Vdc/2$ ($S5$ closed) or $-Vdc/2$ ($S6$ closed). This leg is connected in series with a full H-bridge, which, in turn, is supplied by a capacitor voltage. If the capacitor is kept charged to $Vdc/2$, then the output voltage of the H-bridge can take on the values $+Vdc/2$ ($S1$ and $S4$ closed), 0 ($S1$ and $S2$ closed or $S3$ and $S4$ closed), or $-Vdc/2$ ($S2$ and $S3$ closed). When the output voltage $v = v1 + v2$ is required to be zero, one can either set $v1 = +Vdc/2$ and $v2 = -Vdc/2$ or $v1 = -Vdc/2$ and $v2 = +Vdc/2$. If $S1$ and $S4$ are closed (so that$v2 = +Vdc/2$) and $S6$ is closed (so that $v1 = -Vdc/2$), then the capacitor is discharging and$v = v1 + v2 = 0$. On the other hand, if $S2$ and $S3$ are closed (so that $v2 = -Vdc/2$) and $S5$ is also closed (so that $v1 = +Vdc/2$), then the capacitor is charging and$v = v1 + v2 = 0$.

III. MODULATION STRATEGY

The modulation methods used in multilevel inverters can be classified according to switching frequency. Methods that work with high switching frequencies have many commutations for the power semiconductors in one period of the fundamental output voltage. A very popular method in industrial applications is the classic carrier-based sinusoidal PWM (SPWM) that uses the phase-shifting technique to reduce the harmonics in the load voltage. Another interesting alternative is the SVM strategy, which has been used to reduce the harmonics. There are several kinds of modulation control methods such as traditional sinusoidal pulse width modulation (SPWM), space vector PWM, harmonic optimization or selective

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harmonic elimination and active harmonic elimination and they all can be used for inverter modulation control. Space-vector PWM methods generally have the following features: good utilization of dc-link voltage, low current ripple, and relatively easy hardware implementation by a digital signal processor (DSP). These features make it suitable for high-voltage high-power applications. As the number of levels increases, redundant switching states and the complexity of selecting switching states increase dramatically.

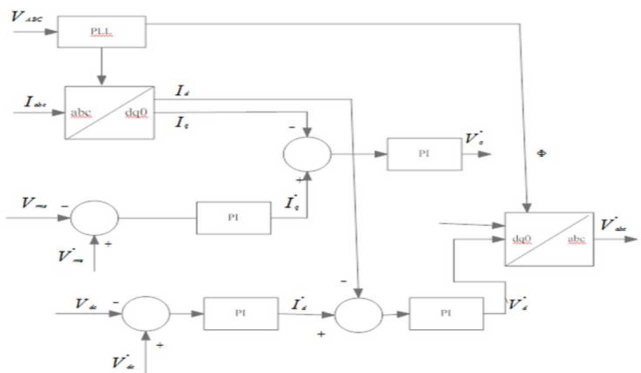

Fig.3 Block diagram of controller

The voltage controller technique (also called as decouple technique) is used as the control technique for DSTATCOM. This control strategy uses the dq0 rotating reference frame because it offers higher accuracy than stationary frame-based techniques. In this V_{abc} are the three-phase terminal voltages, Iabc are the three-phase currents injected by the DSTATCOM into the network, Vrms is the root-mean-square (rms) terminal voltage, Vdc is the dc voltage measured in the capacitor, and the superscripts indicate reference values. Such a controller employs a phase-locked loop (PLL) to synchronize the three phase voltages at the converter output with the zero crossings of the fundamental component of the phase-A terminal voltage. The block diagram of a proposed control technique is shown in Fig 3. Therefore, the PLL provides the angle φ to the abc-to-dq0 (and dq0-to-abc) transformation. There are also four proportional-integral (PI) regulators. The first one is responsible for controlling the terminal voltage through the reactive power exchange with the ac network. Another PI regulator is responsible for keeping the dc voltage constant through a small active power exchange with the ac network, compensating the active power losses in the transformer and inverter. This PI regulator provides the active current reference Id*. The other two PI regulators determine voltage reference Vd*, and Vq*, which are sent to the PWM signal generator of the converter, after a dq0-to-abc transformation. Finally, Vabc* are the three-phase voltages desired at the converter output.

IV SIMULINK MODELLING

Figure-4.1 and 4.2 shows the Matab/Simulink power circuit model of DSTATCOM. It consists of four blocks named as source block, nonlinear load block, control block, measurements block. The system parameters for simulation study are source voltage of 3.3 kV, 50 Hz ACsupply, Inverter series inductance 10 mH, Source resistance of 0.001 ohm and inductance of 30mH Load resistance and inductance are chosen as 100ohm and 500mH respectively.

4.1) without compensation

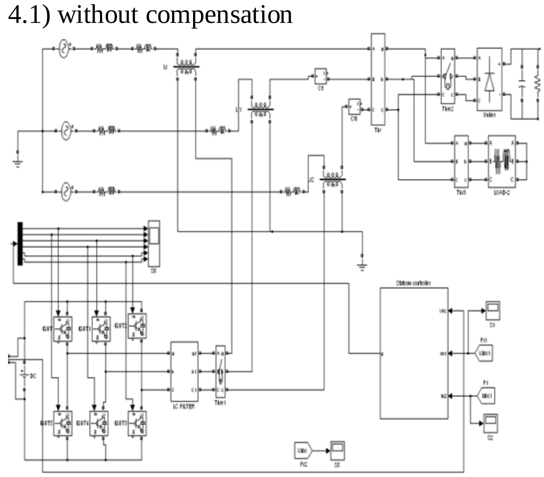

Fig.4.1 Simulink model without DSTATCOM

In this model a three phase source of 3.3KV is connected to load 1 and load 2. Load 1 is a nonlinear load. When this is connected to the source a dip in voltage called sag occurs. Due to the sag the voltage will get reduced and current will get increased. Without compensation means no compensating device is connected to compensate the voltage sag. This dip in voltage is the pollution caused by the nonlinear loads.

4.2) with compensation

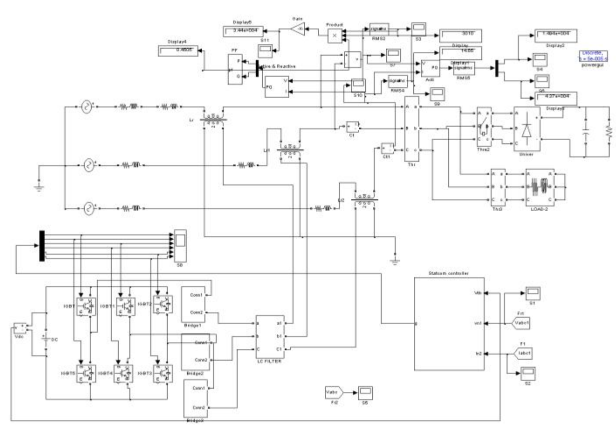

Fig.4.2 Simulink model with DSTATCOM

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When the dip in voltage occurs due to nonlinear load, the DSTATCOM which is connected in shunt at the point of common coupling inject the required compensating voltage to the PCC.The inverter uses a standard three-leg inverter (one leg for each phase) and an H-bridge with a capacitor as its dc source in series with each phase leg. The output of five level boost inverter is given to the LC filter. The LC filter filters the harmonics in the voltage to be injected. The filtered voltage is injected to the line through the coupling transformer. The output voltage, output current and DC voltage are given as the input to the controller. There is four PI controllers used. The output voltage is compared with the reference. The error voltage is given to the PI controller. Similarly the output current and DC voltage is compared with its reference and error output is given to the PI controller. The vector control is used here. Modulation index lies between 0 and 1. The three phase voltages abc variables are converted to dq variables using park's transformation. Then dq variables are converted to abc variables using Inverse Clarke transformation. The m-shaped signals are then compared with reference square signal to produce the gating for the converter.

V. SIMULATION RESULTS

5.1 Without compensation

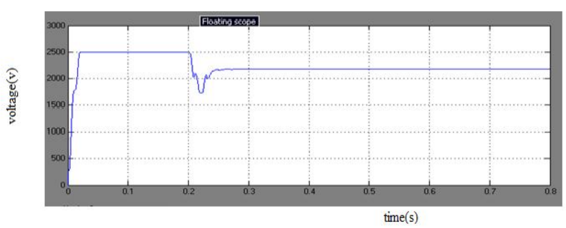

Fig.5.1 RMS Load voltage

The fig.5.1 shows the rms value of the voltage. It is approximately 2184 v without compensation.

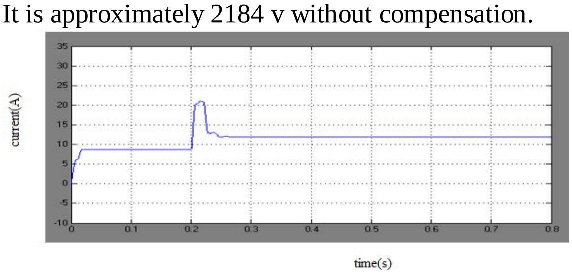

Fig.5.2 RMS Load current

Fig.5.2 shows the RMS value of the current. It is approximately 11A without compensation. As there is a dip in voltage, the current increases.

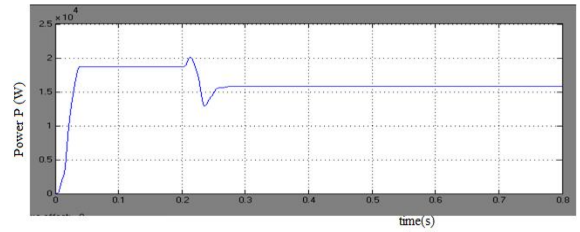

Fig. 5.3 Real Power

From the fig.5.3 the real power without compensation is approximately 0.015MW. As the voltage decreases the real power will also get reduced.

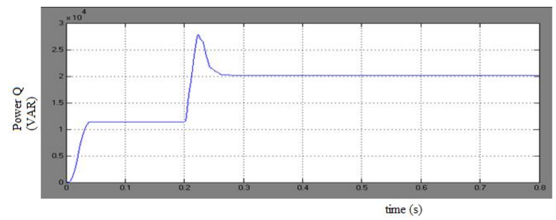

Fig.5.4 Reactive power

From the fig.5.4 the reactive power without compensation is approximately 0.0201 MVAR. Reactive power will increase as the dip in voltage occurs.

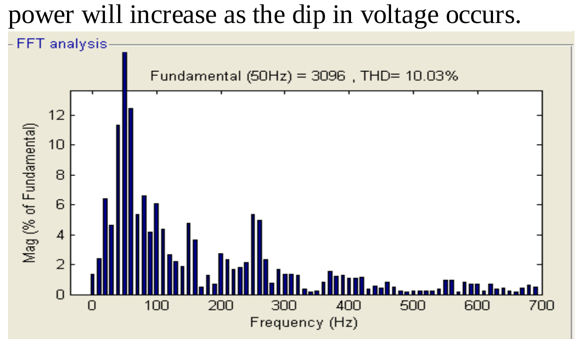

Fig.5.5 FFT analysis

From the FFT analysis, the Total Harmonic Distortion without compensation is approximately 10.03%. From the voltage and current we can calculate the power factor. It is approximately 0.76 for the system without compensation.

5.2 with compensation

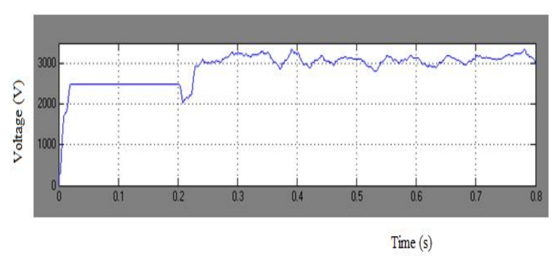

Fig.5.6 RMS Load voltage

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The Fig 5.6 shows that the rms value of load voltage is around 3250V when compensating device, CHB based DSTATCOM is used.

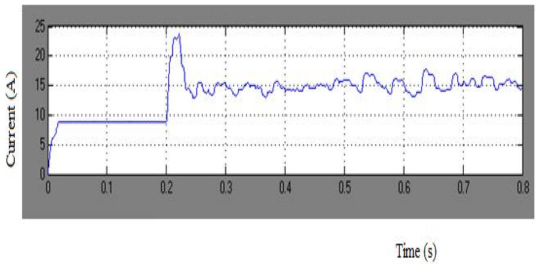

Fig.5.7 RMS Load current

From the fig 5.7 the RMS value of load current with compensation is approximately 15A.

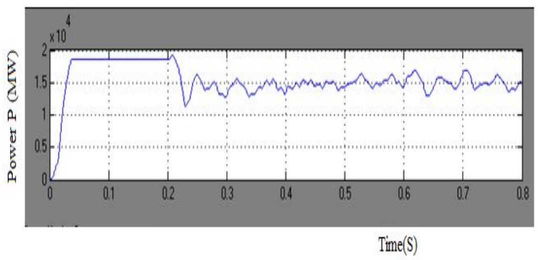

Fig.5.8 Real power

From the fig 5.8 the real power with compensation is approximately 0.0179 MW. The real power is increased when compensation is done.

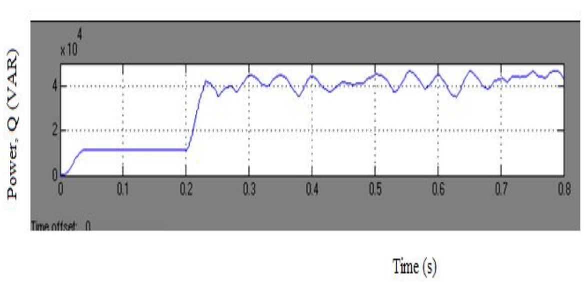

Fig.5.9 Reactive power

The reactive power with compensation is approximately 0.0412 MVAR from fig 5.9.

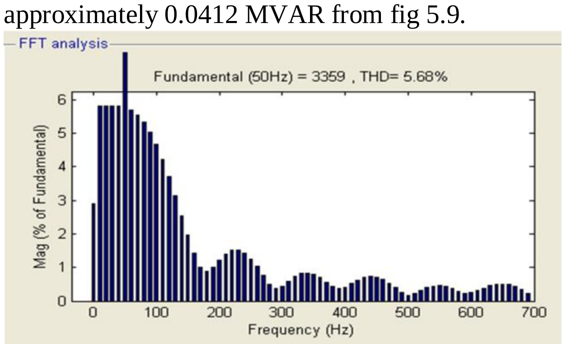

Fig.5.10 FFT analysis

From the fig.5.10 FFT analysis the THD is 5.68% with compensation. Due to the use of CHB based DSTATCOM the THD is 5.68% only. The harmonic order is also reduced.

VI.CONCLUSION

A model of system feeding nonlinear loads has been developed using MATLAB Simulink. DSTATCOM with Cascaded H-bridge Inverter is investigated. The cascaded H-bridge multilevel boost inverter without inductors uses a standard three-leg inverter (one leg for each phase) and an H-bridge in series with each inverter leg. The load voltage, RMS voltage, current, real power, reactive power under nonlinear loads is simulated. From the results we can see that there is an improvement in power factor. Finally, the performance of the system without DSTATCOM and with DSTATCOM using CHB is evaluated.

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