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Utilizing Cascaded Multilevel Inverter in DSTATCOM for Reactive Power Compensation in Restructured Power Grids

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Abstract

The power quality (PQ) within distribution systems can be compromised by customer-induced pollution, leading to issues like voltage sag, particularly exacerbated by nonlinear loads. Voltage dips stemming from these loads can pose critical challenges to system stability. To address such concerns, this study introduces a novel solution: a DSTATCOM (Distribution Static Compensator) employing a Cascaded H-bridge (CHB) Inverter. CHB converters are gaining popularity due to their capacity for high power, minimal output harmonics, and reduced commutation losses. The proposed design incorporates a standard three-leg inverter, with each phase augmented by an H-bridge utilizing a capacitor as the DC power source. Verification of the DSTATCOM's efficacy is achieved through MATLAB simulation, leveraging its Simulink and Power System Blockset tools. Comparative analysis of system performance, both with and without the DSTATCOM, underscores its effectiveness in mitigating voltage sag within the power distribution network.

Keywords: *Power Quality; DSTATCOM; Restructured Power Systems; Reactive Power Compensation*

INTRODUCTION

Power Quality (PQ) is the key to successful delivery of quality product and operation of an industry. The increased application of electronic loads and electronic controllers which are

sensitive to the quality of power makes serious economic consequences and of revenues loss each year. Poor PQ can cause malfunctioning of equipment performance, harmonics, voltage imbalance, sag and flicker problems, standing waves and resonance – are some of the issues that adversely affect production and its quality leading to huge loss in terms of product, energy and damage to equipment. Thus, it becomes imperative to be aware of quality of power grid and the deviation of the quality parameters from the norms / standard such as IEEE-519 standard [1] to avoid breakdown or equipment damage. In present day distribution systems (DS), major power consumption has been in reactive loads.

The typical loads may be computer loads, lighting ballasts, small rating adjustable speeds drives (ASD) in air conditioners, fans, refrigerators, pumps and other domestic and commercial appliances are generally behaved as nonlinear loads. These loads draw lagging power-factor currents and therefore give rise to reactive power burden in the DS. Moreover, situation worsens in the presence of unbalanced and non-linear loads, affect the quality of source currents to a large extent. It affects the voltage at point of common coupling (PCC) where the facility is connected. This has adverse effects on the sensitive equipments connected to PCC and may damage the equipment appliances. Excessive reactive power demand increases feeder losses and reduces active power flow capability of the DS, whereas unbalancing affects the operation of transformers and generators [2-3]. Many techniques have been proposed to improve the supply side power factor to cancel out the harmonics generated by power electronic loads. The remedies to PQ problems are reported in the literature and are known by the generic name of custom power devices (CPD) [4].

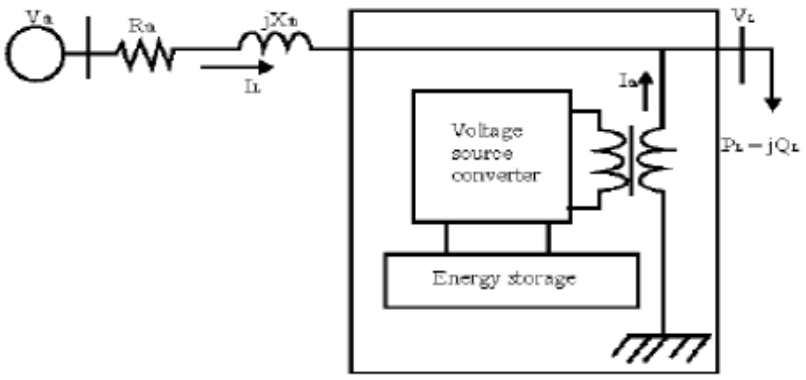
The DSTATCOM (Distribution static compensator) is a shunt-connected CPD, with the load which takes care of the compensation of reactive power and unbalance loading in the DS (i.e PQ problems). Similarly, the application of Cascaded H-Bridge (CHB) Multilevel Voltage source converter with split capacitors for three-phase three-wire system is found to be satisfactory [6]. Among the different control techniques applied to three-phase three-wire compensators, the SRFT (synchronous reference frame theory) based technique is found to be suitable for the control of DSTATCOM. This paper presents various issues in design of Proportional Integral (PI) and comparison between the level shifted carrier (LSCPWM) and phase shifted carrier pulse width modulation (PSCPWM) techniques are used to obtain

switching logic for DSTATCOM. The performance of these controllers is demonstrated with linear resistive-inductive (R-L) loads through simulation results using Power System toolboxes (PST) of Simulink / MATLAB.

DESIGN OF MULTILEVEL BASED DSTATCOM

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 DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power



Fig–1 Schematic Diagram of a DSTATCOM

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.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter. As shown in Figure-1 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, It may be mentioned that the effectiveness of the DSTATCOM in correcting voltage sag depends on the value of Zth or fault level of the load bus. When the shunt injected current Ish is kept in quadrature with VL, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of Ish is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

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 root mean square (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.

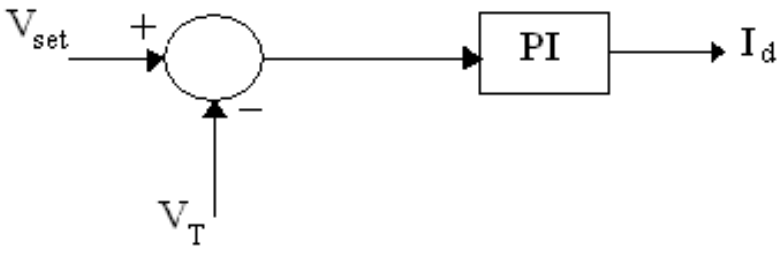


Fig-2 PI control for reactive power compensation

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.

C. 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 Synchrous Reference Frame theory (SRFT) 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 il (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).

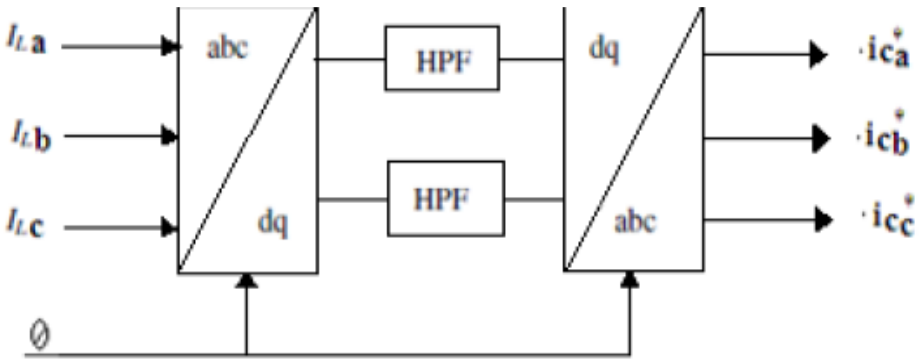


Fig-3 Block diagram of SRF method

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 *v*1 of this leg of the bottom inverter (with respect to the ground) is either +*V*dc/2 (*S*5 closed) or −*V*dc/2 (*S*6 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 *V*dc/2, then the output voltage of the H-bridge can take on the values +*V*dc/2 (*S*1 and *S*4 closed), 0 (*S*1 and *S*2 closed or *S*3 and *S*4

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$v = v1 + v2 = 0$.

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 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. 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 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.

CASCADED H-BRIDGE MULTILEVEL INVERTER

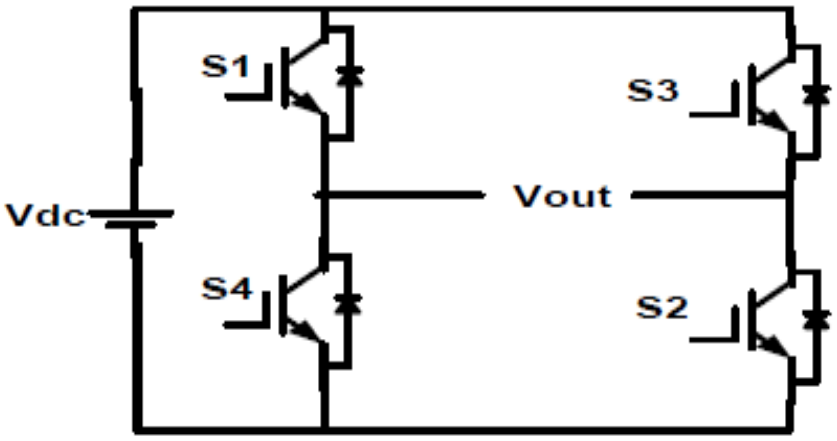


Fig-4 Circuit of the single cascaded H-Bridge Inverter

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

Table-1 Switching table of single CHB inverter

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

SIMULINK MODELLING

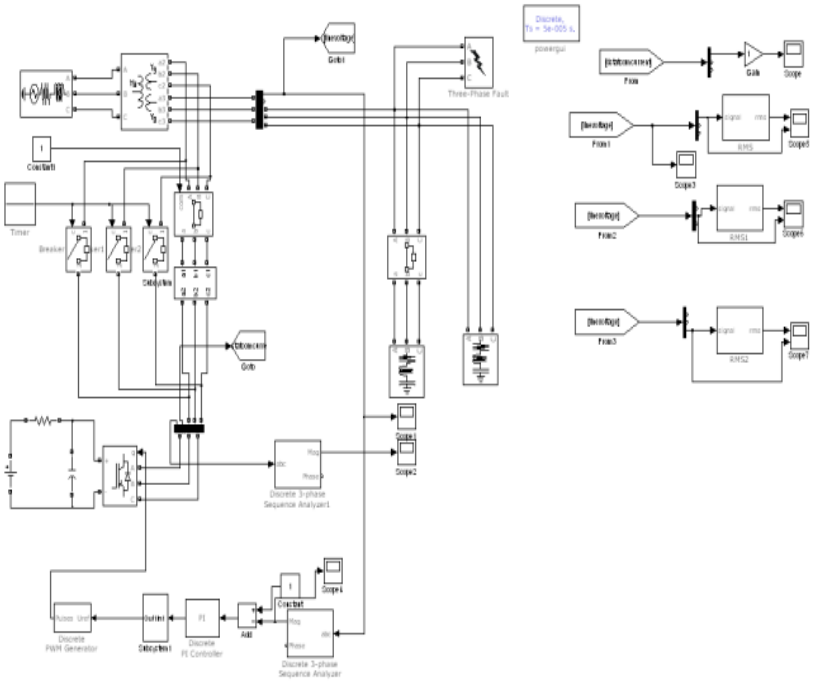


Fig 5. Conventional circuit

Matlab/Simulink power circuit model of DSTATCOM without multilevel inverter

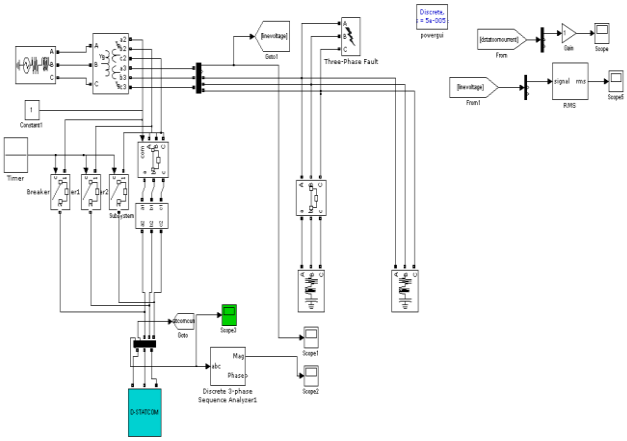


Fig.6. Proposed circuit Matlab/Simulink power circuit model of DSTATCOM with multilevel inverter

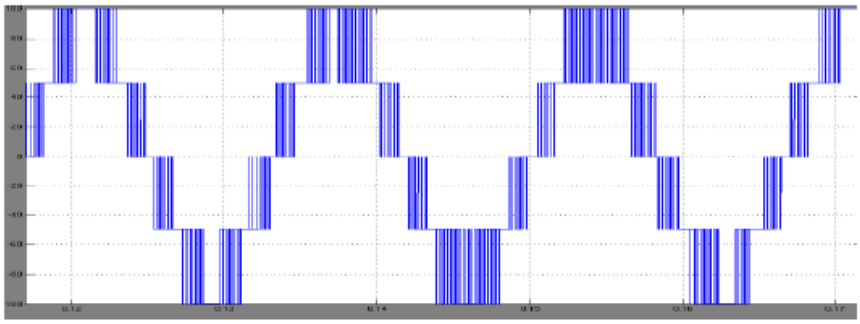


Fig. 7 Fve levels PSCPWM output

Figure-7 shows the phase-A voltage of five level output of phase shifted carrier PWM inverter

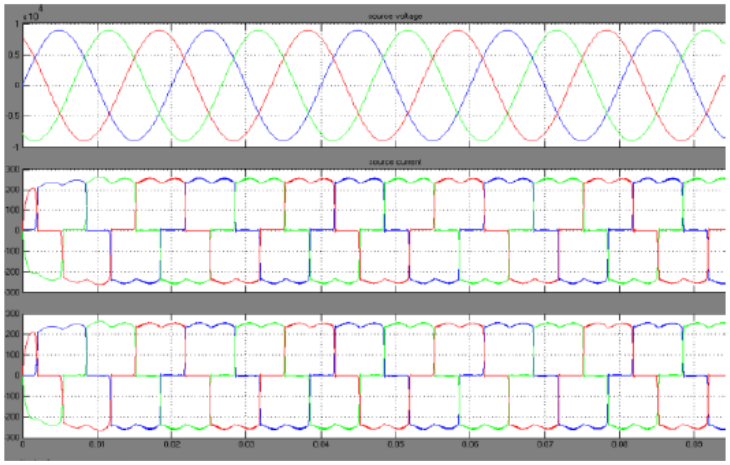


Fig-8 Source voltage, current and load current without DSTATCOM

Figure-8 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.

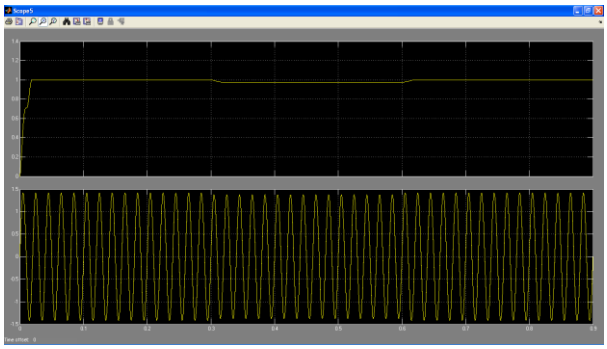


Figure-9 Voltage v RMS at load point with three phases – ground fault

CONCLUSION

A DSTATCOM with five levels 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 investigated for both PSCPWM and LSCPWM and are tabulated. Finally with the help of Matlab/Simulink based model simulation we conclude that PSCPWM is better than LSCPWM techniques and the results are presented.

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