Cascaded Seven Levels H-Bridge Inverter Control of DSTATCOM for Compensation of Reactive Power and Harmonics

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Abstract: *The Static Synchronous Compensators (STATCOMs) have been recognized as the most effective solution for dynamic reactive power compensation, voltage stability enhancement and sub synchronous resonance damping purposes in the electric power systems. The STATCOMs in the distribution utilities (DSTATCOMs) are increasingly investigated for dynamic reactive power compensation and power quality improvement in the distribution utilities .This paper presents an investigation of seven-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. The DST ATCOM helps to improve the power factor and eliminate the Total Harmonics Distortion (THD) drawn from a Non-Liner Diode Rectifier Load (NLDRL). Finally a level shifted PWM (LSPWM) and phase shifted PWM (PSPWM) techniques are adopted to investigate the performance of CHB Inverter. The results are obtained through Matlab / Simulink software package.*

Keywords: DSTATCOM, Level shifted Pulse width, Modulation (LSPWM), Phase shifted Pulse width modulation (PSPWM), Proportional-Integral (PI) control, CRB multilevel inverter, D-Q reference frame theory

1. Introduction

An AC power system is a complex network of synchronous generators, transmission lines and loads. The transmission lines can be represented mostly as reactive networks composed of series inductors and shunt capacitors. The total series inductance, which is proportional to the length of the line, determines primarily the maximum transmissible power at a given voltage. The shunt capacitance influences the voltage profile and thereby the power transmission along the line. The transmitted power over a given line is determined by the line impedance, the magnitude of voltage and phase angle between the end voltages, the basic operating requirements of an AC power system are that the synchronous generators must remain in synchronism and the voltage must kept close to their rated values. In the late 1980s, the Electric Power Research Institute (EPRI) in the USA formulated the vision of the Flexible AC transmission System (FACTS) in which various Power electronics based controllers regulate Power flow and transmission voltage through rapid control action, mitigate dynamic disturbances. FACTS devices involve the applications of high power electronics in AC transmission networks enables fast and reliable control of power flows and voltages. Reactive Power compensation can be obtained by Series VAR compensation and Shunt VAR compensation. Series compensation modifies the transmission or distribution system parameters, while shunt compensation changes the equivalent impedance of the load. Traditionally, rotating synchronous condensers and fixed or mechanically switched capacitors or inductors have been used for reactive power compensation. However, in recent years, static VAR compensators employing thyristor switched capacitors and

thyristor controlled reactors to provide or absorb the required reactive power have been developed [1] [3].The FACTS is a concept based on power-electronic controllers, which enhance the value of transmission networks by increasing the use of their capacity As these controllers operate very fast, they enlarge the safe operating limits of a transmission system without risking stability.

2. Design of Multilevel Based DSTATCOM

2.1 Principle of DSTATCOM

AD-STATCOM (Distribution Static Compensator), Which is schematically depicted in Figure- I, 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.
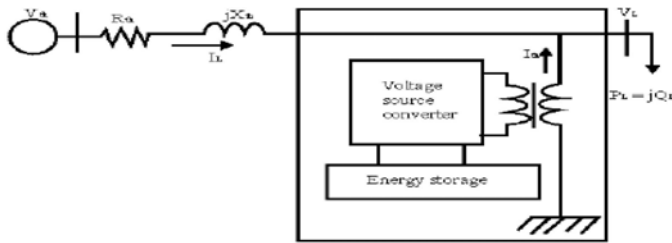
Figure 1: Schematic Diagram of a DST A TCOM

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-l 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.

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 V L, 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.

2.2. 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.
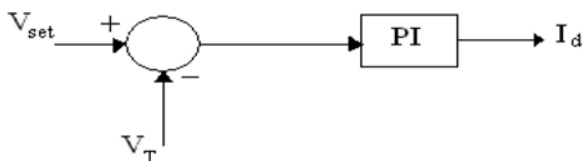

Figure 2: PI control for reactive power compensation

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 0, 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.

2.3. Control for Harmonics Compensation

The Modified Synchronous Frame method is presented in [7]. It is called the instantaneous current component (idiq) method. This is similar to the Synchrous 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 compo nents of the nonlinear load. In the same way, the mains voltages V(a,b,c) and the available currents ij (a,b,c) in a-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 '8' represents the instantaneous voltage vector angle (5).
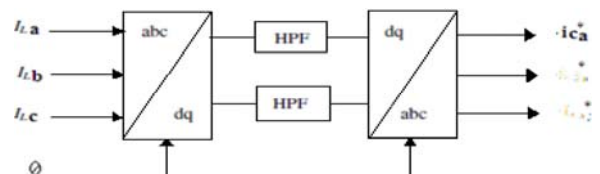

Figure 3: Block diagram of SRF method

Fig. 3 shows the block diagram SRF method. Under balanced and sinusoidal voltage conditions angle fI is a uniformly increasing function of time. This transformation angle is sensitive to voltage harmonics and un balance; therefore d fI /d t may not be constant over a mains period. With transformation given below the direct voltage component
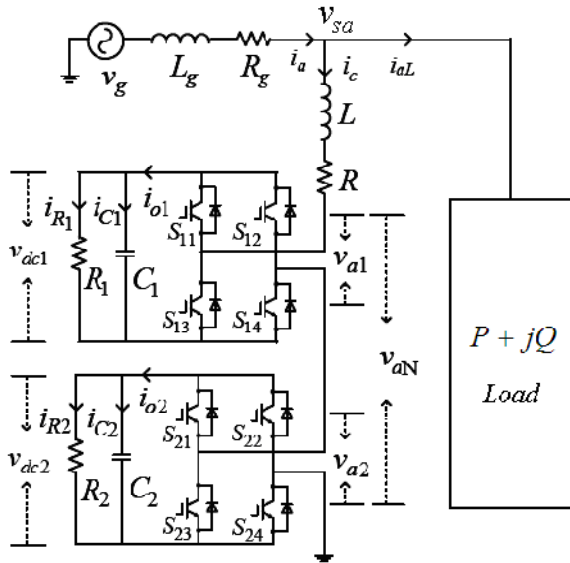
2.4 Cascaded H-Bridge Multilevel Inverter

Fig 4 shows the circuit model of a single eRB inverter configuration. By using single R-Bridge we can get 3 voltage levels. The number of output voltage levels of eRB is given by 2n+l and voltage step of each level is given by Vdcl2n, where n is number of R-bridges connected in cascaded. The switching table is given in Table l.

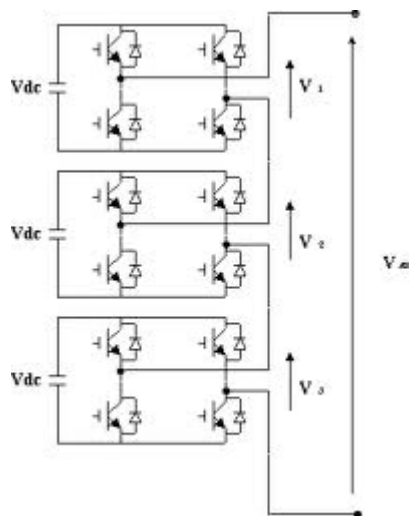**Figure 5:** Block diagram of 7-level CHB inverter model

2.5 Design of Single H-Bridge Cell

Device Current Voltage Level: The IGBT and DIODE currents can be obtained from the load current by multiplying with the corresponding duty cycles. Duty cycle, d = Yz(l +KmsinCDt), Where, m = modulation index K = + 1 for IGBT, -1 for Diode. For a load current given by

Iph = .v2 I sin (wt - ¢) (9)

Then the device current can be written as follows Col18ctar current vs_ Collector-Emitter voltage

VGE""15V I chip
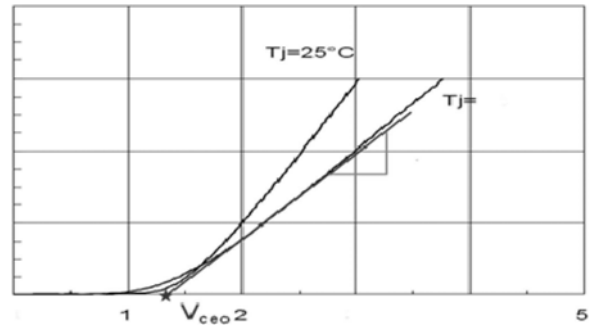
Thermal Calculations: The junction temperatures of the IGBT and DIODE are calculated based on the device power losses and thermal resistances. The thermal resistance equivalent circuit for a module is shown in Fig 5. In this design the thermal calculations are started with heat sink temperature as the reference temperature. So, the case temperature from the model can be written as follows.
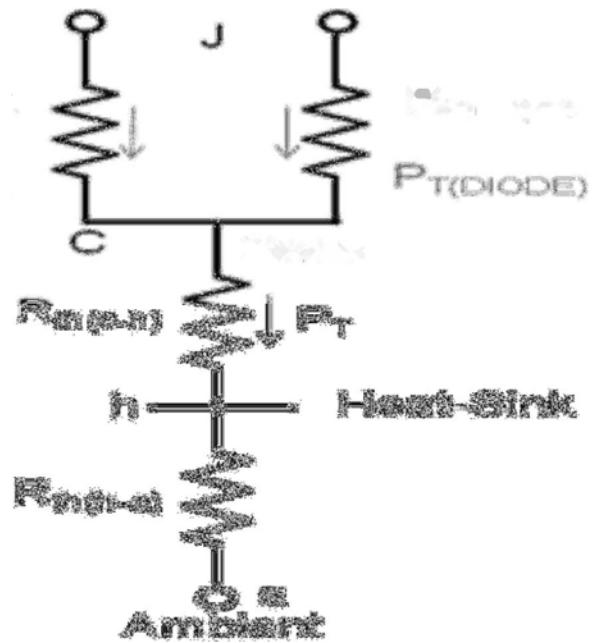

Figure 7: Thermal resistance equivalent circuit

2.6. DC-Capacitor Selection

The required capacitance for each cell depends on the allowable ripple voltage and the load current. The rms ripple current flowing into the capacitor can be written as follows and the ripple current frequency is double the load current frequency.
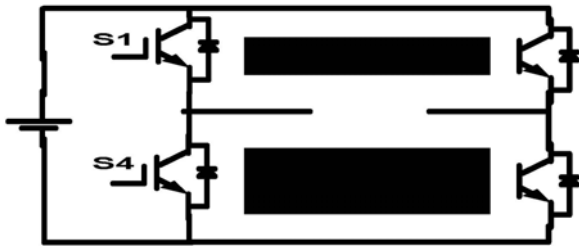
Figure 8: H-Bridge converter

2.7. 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).
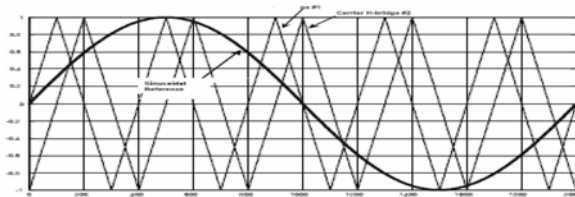
1. Phase Shifted Carrier PWM (PSCPWM)

Figure 9: phase shifted carrier PWM

Figure-9 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 1800 1m (No. of levels) for cascaded inverter 1S introduced across the cells to generate the stepped multi level output waveform with lower distortion.
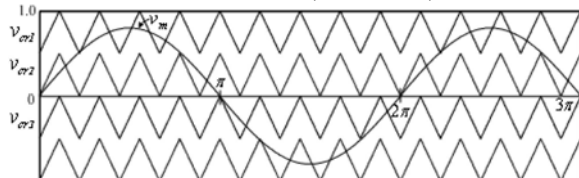
2. Level Shifted Carrier PWM (LSCPWM)

Figure 10: Level shifted carrier PWM

Figure 10 shows the Level shifted carrier pulse width modulation. Each cell is modulated independently using sinusoidal unipolar width modulation and bipolar pulse width modulation respectively, providing an even power distri bution among the cells. A carrier Level shift by 11m (No. of levels) for cascaded inverter 1S introduced across the cells to generate the stepped multilevel output waveform with lower distortion.

3. MATLAB / SIMULINK Modeling and Simulation Results

Figure 11 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. The system parameters for simulation study are source voltage of llkv, SO hz AC supply, DC bus capacitance ISSOe-6 F, Inverter series inductance 10 mH, Source resistance of 0.1 ohm and inductance of 0.9 mHo Load resistance and inductance are chosen as 30mH and 60 ohms respectively.
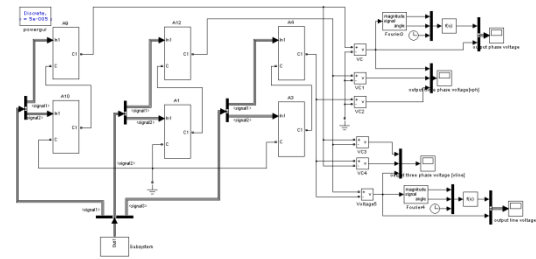

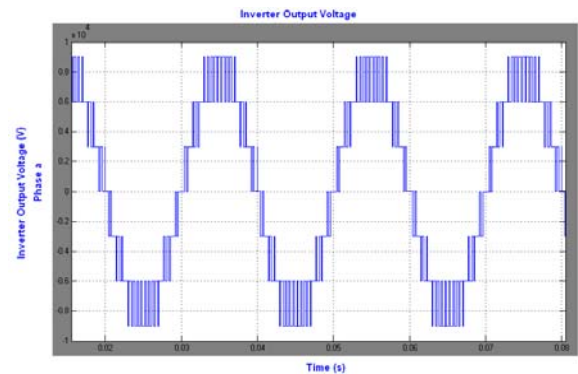**Figure 11:** Matlab/Simulink power circuit model of seven levels CHB

Figure 12: seven levels PSCPWM output

4. Conclusion

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, and load current, power factor simulation results under nonlinear loads are presented. Finally Matlab / Simulink based model is developed and simulation results are presented.

References

[1] K.A Corzine and Y.L Familiant, "A New Cascaded Multi-level HBridge Drive:' IEEE Trans. Power Electron, vol. I 7. No. I.pp. I 25-I 3 I, Jan 2002.
[2] J.S.Lai. and F.Z.Peng "Multilevel converters - A new bread of converters, "IEEE Trans. Ind. Appli, vo1.32. No.3. pp.S09-S17. May/Jun. 1996.
[3] T.A.Maynard. M.Fadel and N.Aouda. "Modelling of multilevel converter:' IEEE Trans. Ind. Electron, vol.44. pp.3S6-364. Jun. 1997
[4] P.Bhagwat. and V.R.Stefanovic, "generalized structure of a multilevel PWM Inverter:' IEEE Trans. Ind. Appln, VoI.IA-19.no.6, pp. I OS7-1069, Nov.!Dec, 1983.
[5] J.Rodriguez. Jih-sheng Lai, and F Zheng peng, "Multilevel Inverters; A Survey of Topologies, Controls, and Applications," IEEE Trans. Ind. Electron., vol.49, n04. pp.724-738. Aug.2002

[6] Roozbeh Naderi, and Abdolreza rahmati, "Phase-shifted carrier PWM technique for general cascaded inverters," IEEE Trans, Power Electron., vo1.23, no.3, pp. I 257-I 269. May.2008

[7] Bhim Singh, Kamal AlHaddad & Ambrish Chandra, 1999, A Review of Active Filter for Power Quality Improvements, IEEE Trans on Industrial Electronics, 46(S), pp.960970

[8] Mauricio Angulo, Pablo Lezana, Samir Kouro, Jos'e Rodr'lguez and Bin Wu, "Level-shifted PWM for Cascaded Multilevel Inverters with Even Power Distribution" IEEE Power Electronics specialist conference, 17-21 june 2007, pp.2373-2378.

[9] B. P. McGrath and D. G. Holmes, "Multicarrier PWM strategies for multilevel inverters," IEEE Trans. Ind. Electron., vol. 49, no. 4, pp. 858- 867, August 2002