Design and Simulation of Cascaded H-Bridge Multilevel Inverter Based DSTATCOM for Compensation of Reactive Power and Harmonics

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Abstract— This Paper presents the orientation procedure for diagnosing the power quality problems in different fault occurring conditions by using Distribution STATCOM (D-STATCOM) with non-linear loads. This modelling and simulation of D-STATCOM is achieved by using voltage regulation block. The major problem is that, during fault conditions there is a probable disturbance in the load side and this problem is diagnosing by utilizing the D-STATCOM at load side, as well as in between source and load. D-STATCOM is developed using MATLAB simulation program. The model is simulated, first without DSTATCOM and then with it. The results obtained in both the cases are analyzed and which shows the effectiveness of tracking the voltage sag and its correction.

Key words: DSTATCOM, Voltage Source Converter (VSI), Total harmonic distortion (THD, cascaded H-bridge (CHB)

I. INTRODUCTION

As the demand for sensitive load increases in the distribution side, power quality issues emerge as a serious issue. Present distribution system faces variety of power quality and among them voltage sag is found to be the most challenging issue faced by industrial consumers according to the power quality surveys. Voltage sag is a momentary dip in RMS voltage magnitude for a duration varying between half a cycle up to some cycles. Voltage dip problems are mainly due to the use of voltage-sensitive loads such as adjustable speed drives (ASD), induction motors, computers, process control equipment etc. Based on inverter systems, there are many voltage sag mitigation schemes. The DSTATCOM is a device to provide a set of power quality solutions such as voltage stabilization, flicker suppression, power factor correction and harmonic control along with the voltage sag mitigation Different control strategies and different converter topologies are used in DSTATCOM. Here the DSTATCOM consists of a two level voltage source inverter that allow fast inductive and capacitive compensation. PI control strategies are adopted as the control system. SIMULINK/MATLAB is used for simulation of the compensator and the performance is analysed. The VSI converts the dc link voltage into a three phase ac voltages and are coupled through the coupling transformer reactance to the ac system. The DSTATCOM inject or absorbs current at the point of common coupling (PCC) as per the requirement.

II. WORKING OF DSTATCOM

The D-STATCOM is a voltage source inverter based device is connected shunt to the ac system. It is connected at the distribution system near the load end. Here voltage-source inverter, which compensate the active and reactive power demanded by the system by converting a DC input voltage into AC output voltage. The connection and schematic view of DSTATCOM is shown in Fig.1.The DSTATCOM consists of DC voltage source, DC capacitor and a coupling transformer. It provides a topology that performs different functions such as;

- Voltage correction and compensation of reactive power.
- Power factor improvement
- Current harmonics reduction

The capacitor in the D-STATCOM is used to maintain dc voltage to the inverter. The amplitude of the inverter voltage Vi is proportional to the dc voltage of the capacitor, which is also proportional to the amount of energy stored in capacitor. If there is any difference in phase shift, active power flows through the inverter, charging or discharging the capacitor. The charging or discharging of the capacitor affects the dc voltage level and alters the amplitude of the inverter ac voltage. DSTATCOM controller makes the voltage stable and thus to improves the power quality. If the magnitudes of AC system voltage and DSTATCOM output voltage are equal, there will be no reactive power absorption or generation and the reactive current supplied is zero. If the voltage amplitude at the output of DSTATCOM is greater than the ac system voltage, the current flow will be from the DSTATCOM to the AC system, and the device generates reactive power (capacitive). If the voltage amplitude at the output of the DSTATCOM is below that of the AC system, then the current flows from the AC system to the DSTATCOM, and the device will absorb reactive power (inductive). The current lags behind voltage by an angle of 90° in inductive mode.

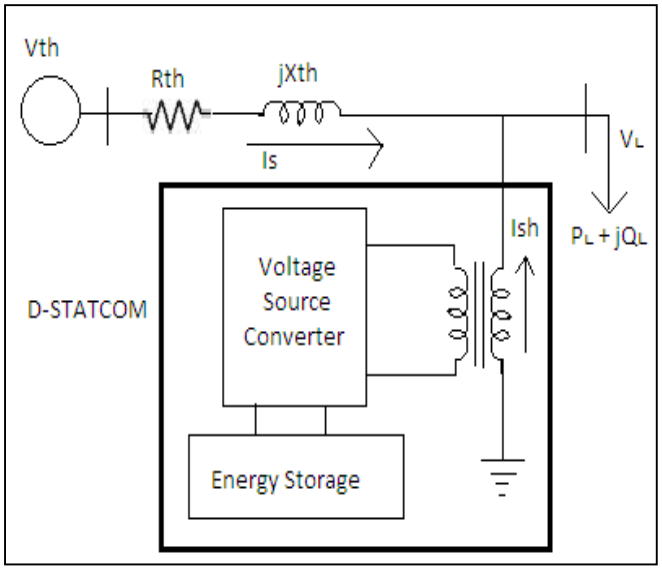

Fig. 1: Schematic Diagram of a DSTATCOM

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,

$$I_{sh} = I_L - I_S = I_L - \left(\frac{V_{Th} - V_L}{Z_{Th}}\right)$$

$$I_{Sh}\angle\eta = I_L \angle -\theta - \frac{V_{th}}{Z_{th}}\angle(\delta - \beta) + \frac{V_L}{Z_{th}}\angle -\beta$$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{sh} = V_L I^*_{sh}$$

It may be mentioned that the effectiveness of the D-STATCOM 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. The exchange of reactive power between the converter and the AC system can be controlled by varying the amplitude of the 3-phase output voltage, Vc, of the converter. Therefore, if the amplitude of the output voltage is increased above that of the utility bus voltage, Vs, then the current flows through the reactance from the converter to the AC system and the converter generates capacitive-reactive power and is said to operate in CAPACITIVE MODE as shown in below Figure.

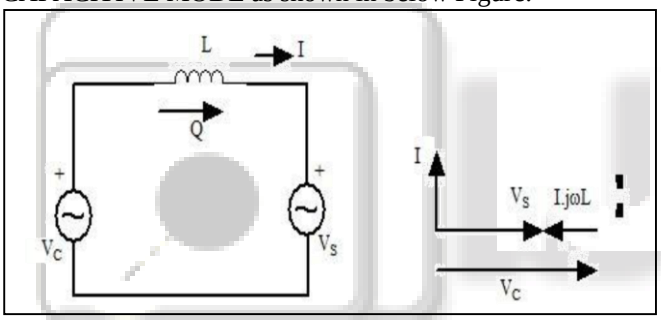

Fig. 2: Capacitive Mode

If the amplitude of the output voltage, Vc, is decreased below the utility voltage Vs, then the current flows from the AC system to the converter and the converter absorbs inductive reactive power from the AC system and it is said to operate in INDUCTIVE MODE as shown in Figure 2(b).

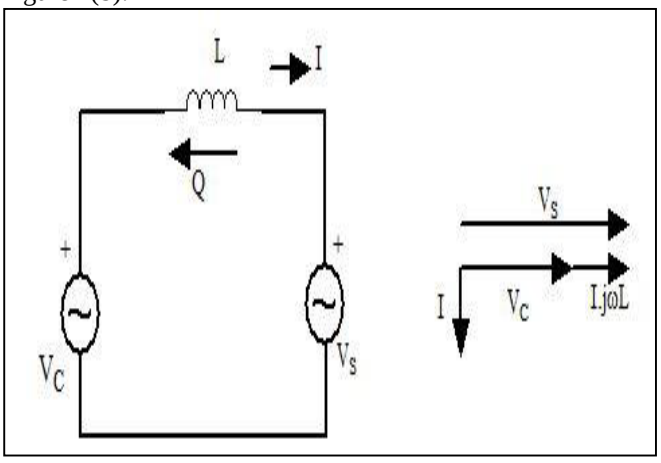

Fig. 3: Inductive Mode

If the amplitude of the output voltage, Vc, equals the AC system voltage, the reactive power flow is zero, and the STATCOM is said to be FLOATING MODE as shown in Figure 2(c)

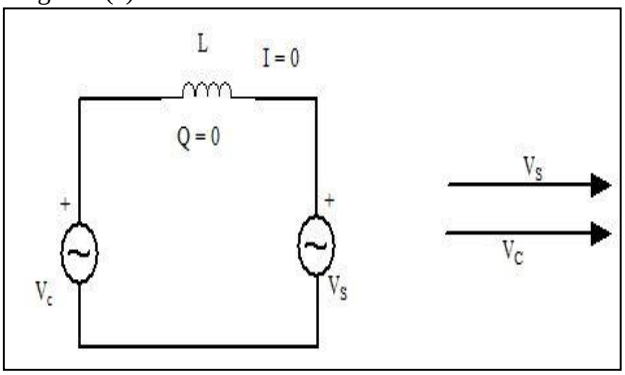

Fig. 4: Floating Mode

III. VOLTAGE SOURCE CONVERTER (VSC)

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the missing voltage. The missing voltage is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics. Here cascaded H-bridge inverter is used.

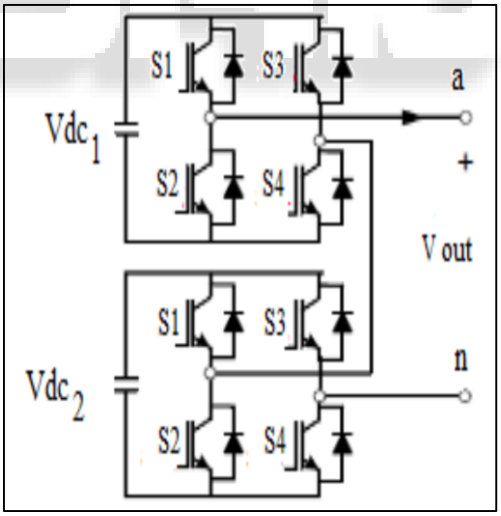

Fig. 5: one phase single diagram of 5-level CHB inverter

Operation of Cascaded H-Bridge Multilevel Inverter is based on the switching of different combination of IGBT switches. switching scheme is given in table.

Switches Turn On (Upper Bridge)	Switches Turn On (Lower Bridge)	Voltage Level
S1, S4	--	Vdc
S1,S4	S1,S4	2Vdc
S2, S4	S2, S4	0
S3,S2	--	-Vdc
S3,S2	S3,S2	-2Vdc

Table 1: Switching table for 5-level CHB Inverter

IV. DESIGN OF SINGLE H-BRIDGE CELL

A. Device Current

The IGBT and DIODE currents can be obtained from the load current by multiplying with the corresponding duty cycles. Duty cycle, d = 1/2(l +KmsinCDt), Where, m = modulation index K = + 1 for IGBT, -1 for Diode. For a load current given by

$$I_{ph} = \sqrt{2}\, I \sin(wt - \phi)$$

Then the device current can be written as follows.

$$\therefore i_{device} = \frac{\sqrt{2}}{2} I \sin(wt - \phi) x\,(1 + km \sin wt)$$

The average value of the device current over a cycle is calculated as

$$i_{avg} = \frac{1}{2\pi} \int_{\varphi}^{\pi+\varphi} \frac{\sqrt{2}}{2} I \sin(wt - \phi) x\,(1 + km \sin wt)\, dwt$$

$$-\sqrt{2}I\left[\frac{1}{2\pi} + \frac{km}{g}\cos\varphi\right]$$

The device RMS current can be written as

$$i_{rms} = \sqrt{\int_{\varphi}^{\pi+\varphi} \frac{1}{2\pi}(\sqrt{2}I \sin(wt - \phi))^2 x\, \frac{1}{2} x\,((1 + km \sin wt)\, dwt)}$$

$$= \sqrt{2}I \sqrt{\frac{1}{g} + \frac{km}{3\pi}\cos\varphi}$$

B. Igbt Loss Calculation

IGBT loss can be calculated by the sum of switching loss and conduction loss. The conduction loss can be calculated by,

$$P_{on\,(IGBT)} = V_{ceo} * I_{avg\,(igbt)} + I^2_{rms\,(igbt)} * r_{ceo}$$

$$P_{on\,(IGBT)} = V_{ceo} * I_{avg\,(igbt)} + I^2_{rms\,(igbt)} * r_{ceo}$$

$$I_{avg\,(igbt)} = \sqrt{2}I\left[\frac{1}{2\pi} + \frac{m}{g}\cos\varphi\right]$$

$$I_{rms\,(igbt)} = \sqrt{2}I\sqrt{\left[\frac{1}{g} + \frac{m}{3\pi}\cos\varphi\right]}$$

Values of Vceo and fceo at any junction temperature can be obtained from the output characteristics (Ic vs. Vce) of the IGBT as shown in Figure

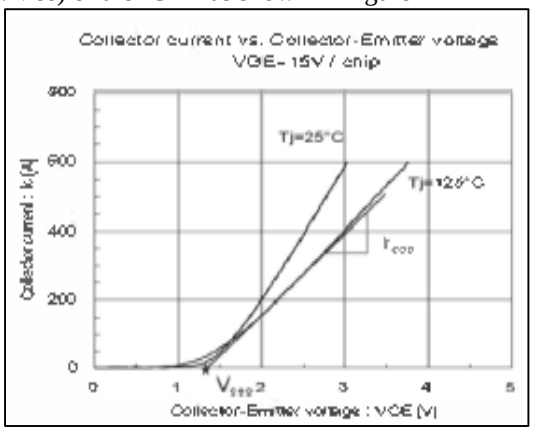

Fig. 4: IGBT output characteristics

The switching losses are the sum of all tum-on and tum-off energies at the switching events

$$E_{sw} = E_{on} + E_{off} = a + bI + cI^2$$

Assuming the linear dependence, switching energy

$$E_{sw} = (a + bI + cI^2) *$$

Here VDC is the actual DC-Link voltage and VnoIn is the DCLink Voltage at which Esw is given. Switching losses are calculated by summing up the switching energies.

$$P_{sw} = \frac{1}{T_0}\Sigma_n E_{sw}(i)$$

Here 'n' depends on the switching frequency

$$P_{sw} = \frac{1}{T_0}\Sigma_n(a + bI + cI^2) = \frac{1}{T_0}\left[\frac{a}{2} + \frac{bI}{\pi} + \frac{cI^2}{4}\right]$$

After considering the DC-Link voltage variations, switching losses of the IGBT can be written as follows.

$$P_{sw\,(IGBT)} = f_{sw}\left[\frac{a}{2} + \frac{bI}{\pi} + \frac{cI^2}{4}\right] * \frac{V_{DC}}{V_{nor}}$$

So, the sum of conduction and switching losses is the total losses given by

$$P_{T\,(IGBT)} = P_{on\,(IGBT)} + P_{sw\,(IGBT)}$$

C. Diode Loss Calculation

The DIODE switching losses consist of its reverse recovery losses; the tum-on losses are negligible.

$$E_{rec} = a + bI + cI^2$$

$$P_{sw\,(DIODE)} = f_{sw}\left[\frac{a}{2} + \frac{bI}{\pi} + \frac{cI^2}{4}\right] * \frac{V_{DC}}{V_{nor}}$$

So, the sum of conduction and switching losses gives the total DIODE looses.

$$P_{T\,(DIODE)} = P_{on\,(DIODE)} + P_{sw\,(DIODE)}$$

The total loss per one switch (IGBT +DIODE) is the sum of one IGBT and DIODE loss

$$P_T = P_{T\,(IGBT)} + P_{sw\,(DIODE)}$$

D. 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.

$$T_c = P_T R_{th\,(c\,h)} + T_h$$

Here Rth(c-h) = Thermal resistance between case and heat sink

PT = Total Power Loss (IGBT + DIODE)

IGBT junction temperature is the sum of the case temperature and temperature raise due to the power losses in the IGBT.

$$T_{j\,(DIODE)} = P_{T\,(DIODE)} R_{th\,(j\,c)\,DIODE} + T_c$$

The DIODE junction temperature is the sum of the case temperature and temperature raise due to the power losses in the DIODE.

The above calculations are done based on the average power losses computed over a cycle. So, the corresponding thermal calculation gives the average junction temperature. In order to make the calculated values close to the actual values, transient temperature values are to be added to the average
junction temperatures.

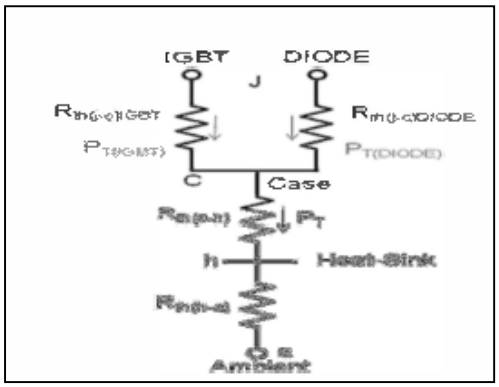

Fig. 5: Thermal resistance equivalent circuit

V.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).

E. Phase Shifted Carrier PWM (PSCPWM)

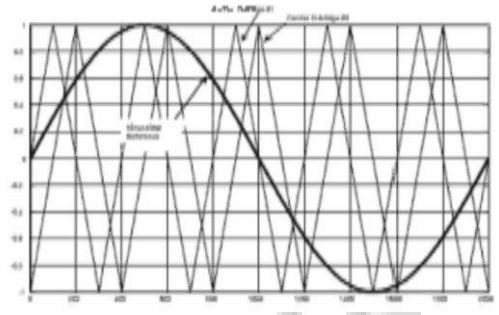

Fig. 6: phase shifted carrier PWM

Figure- 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 distri bution 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.

F. Level Shifted Carrier PWM (LSCPWM)

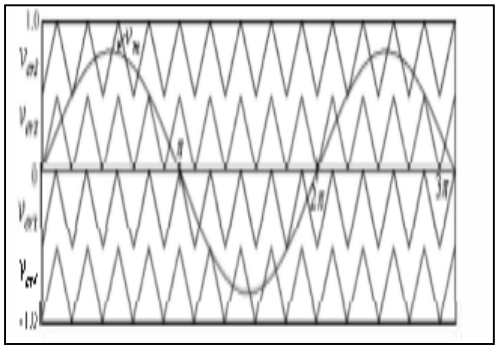

Fig. 7: Level shifted carrier PWM

Figure- shows the Level shifted carrier pulse width modulation. Each cell is modulated independently using sinusoidal unipolar width modulation and bipolar pulse 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.

V. CONCLUSIONS

Level shift Pulse width modulation(LSPWM) constructed and assess its execution DSTATCOM with five level CHB inverter is displayed in this thesis. The source current, source voltage, load current, load voltage, active power, reactive power, power factor comes under nonlinear load with STATCOM and without STATCOM are displayed. Utilizing multilevel converters to minimize the total harmonics distortion and improve the power factor. The Total harmonics distortion of source current& load current measured after connecting DSTATCOM is within the acceptable limit given by IEEE 519

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