

Harmonic Mitigation using D STATCOM through a Current Control Technique

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Abstract

The harmonic mitigation using shunt active filters are most widely used in industrial and commercial applications. In this paper a Multi-Level Inverter is considered as DSTATCOM to compensate harmonics. The mathematical modeling of the system and design of the controller using synchronous reference frame theory is also presented. The nonlinear load generally known as diode rectifier load and an unbalanced load is simulated with the system using MATLAB/SIMULINK.

Keywords: Shunt Active Power Filter, Voltage Source Converter, D STATCOM, Harmonics

I. INTRODUCTION

In the midst of the recent developments, power electronic devices playing a vital role in controlling and compensating the harmonics. With the help of Power Quality concepts and semiconductor technology, the utility and customers are finding various solutions to mitigate or compensate the harmonics in nonlinear loads. As the nonlinear loads draw nonlinear currents from the sources, this is a main concern to the generation of harmonic currents in the lines. The other causes of harmonics are, impedances resulting distorted voltages which can disturb the operation of users connected to the same supply, malfunctioning and insulation breakdown of equipment due to overheating, false tripping of protection equipment, wrong measurements, poor power factor etc., [1].

In order to provide stable, reliable and high quality power, a voltage source inverter with series inductances, automatic voltage regulators or controller and a shunt capacitor C_{dc} shown in Fig.1, is combined in Distributed Static Compensator (D-STATCOM)[2].

D-STATCOM also contributes in an unbalanced voltage sag mitigation, drives the source current to be fundamental frequency sinusoidal and balanced, also capable in achieving reactive power compensation. In addition to this, several topologies like series shunt and hybrid power filters [3] are designed and implemented to meet IEEE 519-1992 guidelines of harmonic standards. The multilevel inverter topologies are provided highest importance in reducing the harmonic components. These multilevel structures are best suited in obtaining high powers and with a simple conversion process using semiconductor switches. This multilevel approach synthesizes the voltage levels of the bridge circuit and attains the waveforms to be sinusoidal and balanced with reduced harmonic content.

In this paper, a Shunt Active Power Filter (SAPF) as Cascaded H Bridge Multilevel Inverter D-STATCOM is proposed to mitigate harmonic component in the source currents. In order to generate the reference current to the D-STATCOM, the three phase line currents are converted to single phase currents using d-q transformation theory. The compensating currents from D-STATCOM are then added with source currents, to make the source currents sinusoidal and balanced, which are free from harmonic components.

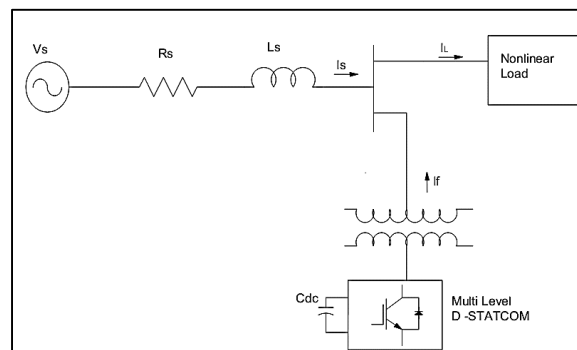


Fig. 1: Block diagram of D-STATCOM

This paper is formulated as follows: Modeling of D-STATCOM in section II, D-STATCOM control strategy in section III, Simulation and Results in section IV and Conclusion in V.

II. MODELING OF D-STATCOM

As many authors were stated that SAPF as D-STATCOM is more popular due to its performance and flexibility [4]. The source, V_s is assumed to be balanced, sinusoidal with frequency ' ω ', the SAPF operates as a controlled voltage source, V_f through the inductance X_f at PCC. In this paper, a multilevel converter topology called Cascaded H- Bridge (CHB) Multilevel Inverter as D-STATCOM is considered, as CHB inverter has the potential for utility interface applications because of its capabilities for applying modulation and soft switching techniques.

A simplified equivalent circuit of the D-STATCOM is shown in Fig2.

From this circuit, the differential equations of the D-STATCOM currents are:

$$\frac{di_{fa}}{dt} = \frac{1}{L_f} (-R_f i_{fa} + V_{sa} - V_{fa}) \quad (1)$$

$$\frac{di_{fb}}{dt} = \frac{1}{L_f} (-R_f i_{fb} + V_{sb} - V_{fb}) \quad (2)$$

$$\frac{di_{fc}}{dt} = \frac{1}{L_f} (-R_f i_{fc} + V_{sc} - V_{fc}) \quad (3)$$

Where V_{sk} is the converter output phase voltage with respect to neutral and V_{fk} are the PCC bus phase voltage with respect to neutral, where $k = a, b, c$ lines

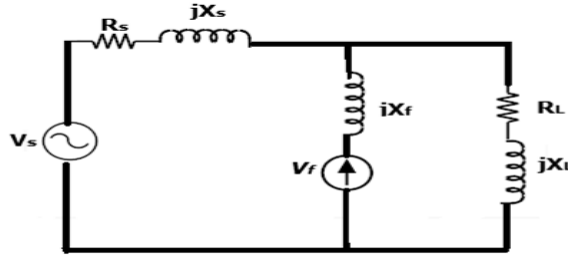


Fig. 2: Equivalent circuit of D-STATCOM

III. D-STATCOM CONTROL STRATEGY

A. Fundamental Frequency Extraction:

The Fig.3 shows the control scheme is used to generate the reference currents $i_f^*(a,b,c)$ for the D-STATCOM. These references are injected at PCC with the source currents having balanced sinusoidal and in phase with the supply voltages [5].

In order to improve the performance of D-STATCOM, a filtering algorithm is required to extract the fundamental positive sequence components of load voltages and designated as terminal voltages. The instantaneous PQ theory is then applied to detect the fundamental positive sequence. The load currents are transformed into α - β axis to determine the auxiliary currents i_α and i_β as shown in the equations given below:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (4)$$

The fundamental frequency (ω) can be evaluated accurately by the Phased Locked Loop (PLL). The auxiliary currents are as follows:

$$i_\alpha = \sin \omega t \quad (5)$$

$$i_\beta = -\cos \omega t \quad (6)$$

b. Reference currents generation

Due to various nonlinear loads, the analysis of power flow is required in time domain rather than in frequency domain. The time domain approach is more popular, easy to implement and faster response. The Instantaneous Active and Reactive Power theory (IPQ) and Synchronous reference Frame (SRF) are most commonly used for evaluating the reference currents. In this paper the SRF approach is used to for reference currents calculation with load currents as follows:

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \begin{bmatrix} \cos \omega t & -\sin \omega t \\ \sin \omega t & \cos \omega t \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (7)$$

Where i_{ld} is active component of load current and i_{lq} is reactive component of load current in DQ Frame reference. As the i_{ld} and i_{lq} DC components that have oscillating quantities, in order to filter out, an II order low pass Butterworth filter $G(S)$ is included in the feedback path.

$$i_{sd}^* = \bar{i}_{ld} + i_{cd} \quad (9)$$

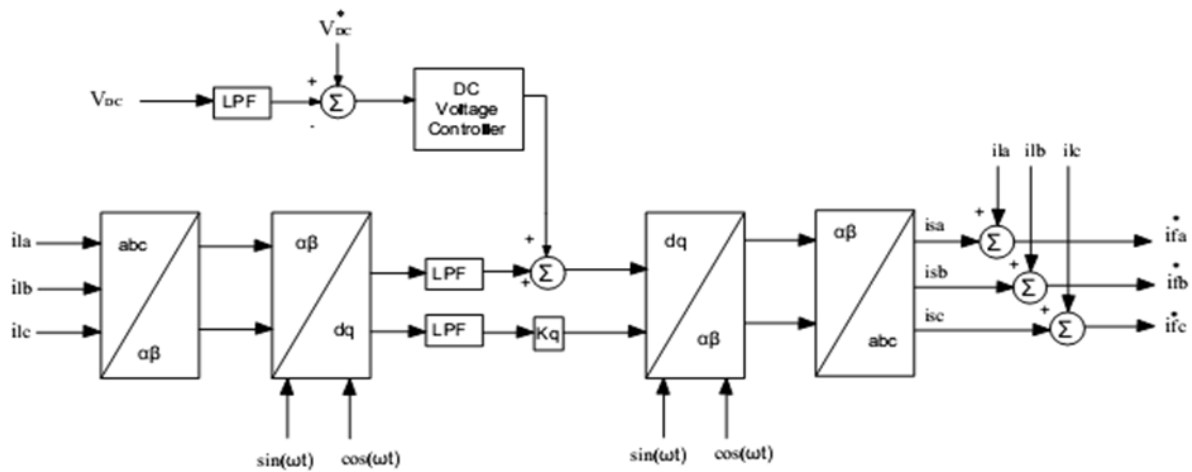


Fig. 3: Control circuit for reference current generation

The desired active component of source current is given by

$$\begin{bmatrix} \bar{i}_{ld} \\ \bar{i}_{lq} \end{bmatrix} = G(s) \begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} \quad (8)$$

Where i_{cd} is the current from DC component of C_{dc} .

The reactive component of load current \bar{i}_{lq} is required to achieve reactive compensation [6].

The desired reference currents are calculated along with fundamental frequency is as follows:

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \end{bmatrix} = \begin{bmatrix} \cos \omega t & \sin \omega t \\ -\sin \omega t & \cos \omega t \end{bmatrix} \begin{bmatrix} i_{sd}^* \\ i_{sq}^* \end{bmatrix} \quad (10)$$

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{sa}^* \\ i_{sb}^* \end{bmatrix} \quad (11)$$

The reference currents for the D-STATCOM are

$$i_{fa}^* = i_{la} - i_{sa}^* \quad (12)$$

$$i_{fb}^* = i_{lb} - i_{sb}^* \quad (13)$$

$$i_{fc}^* = i_{lc} - i_{sc}^* \quad (14)$$

B. Cascaded H Bridge Multi level Inverter

In general, the primary features of multilevel inverter structure gives high power demands, low Total Harmonics Distortion (THD) and low dv/dt stress [7-10]. In this paper, a Cascaded H Bridge (CHB) multi-level Inverter of 5 level is considered as D-STATCOM. The structure is shown in Fig.4. This CHB multi-level inverter eliminates the excessive use of bulky transformers, clamping diodes and flying capacitors.

The carrier based schemes for multilevel inverter are classified into two categories: Phase shifted modulation and Level shifted modulation. In phase shifted modulation, the triangular carriers have the same frequency with same amplitude, but the phase shift between any two adjacent carrier waves are given by the equation:

$$\phi_{cr} = \frac{360}{m-1} \quad (15)$$

Where m is the number of levels of the inverter. For a five level inverter, four triangular carriers are needed. With a 90° phase displacement between any two adjacent carriers. In this case the following phase displacement of carriers are required $cr_1=0^\circ$, $cr_2=90^\circ$, $cr_3=180^\circ$, $cr_4=270^\circ$. The Fig.5 shows the triangular carrier waves with 90° with phase displacement each other.

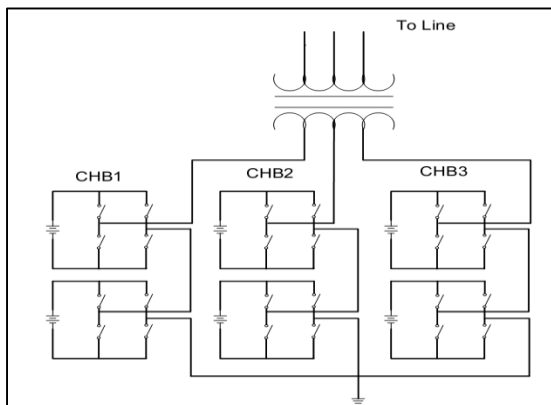


Fig. 4: Modelling of Cascaded H Bridge Multilevel Inverter

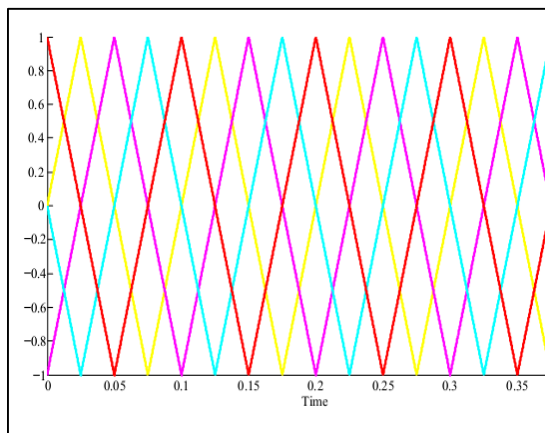


Fig. 5: Carrier Waveforms for CHB Multilevel Inverter

IV. SIMULATION RESULTS

To validate the proposed D-STATCOM system, the computer simulation using MATLAB/SIMULINK package is used, which is shown in Fig.6. The specifications of the system as follows: source voltage of 415v with fundamental frequency of $f=50\text{Hz}$, source inductance $L_s=40\text{mH}$. The Unbalanced load $R_{La}=10$, $R_{Lb}=25$, $R_{Lc}=5$, $L_{La}=120\text{mH}$, $L_{Lb}=205\text{mH}$, $L_{Lc}=135\text{mH}$. The three phase nonlinear load is a Rectifier with $R_d=125$ and $L_d=30\text{mH}$.

The source currents are analyzed before connecting to D-STATCOM, with a maximum THD of 24.5% and the waveforms are shown in Fig.7. It is worth noting that the source current after connecting to D-STATCOM, is sinusoidal and balanced, shown Fig.8

The fig.9 shows THD of the source current, which is 2.15%.

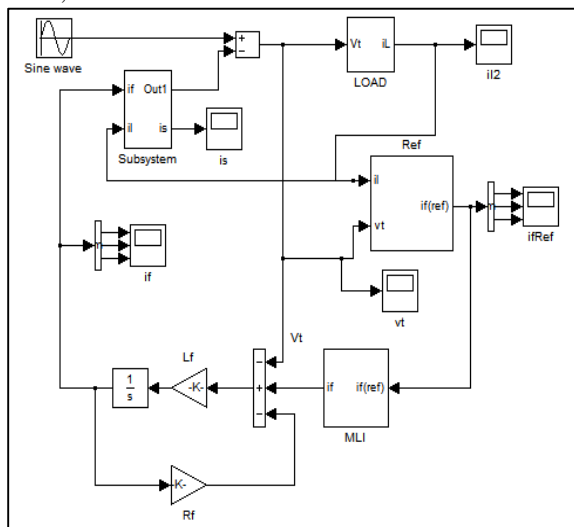


Fig. 6: MATLAB Model of D-STATCOM

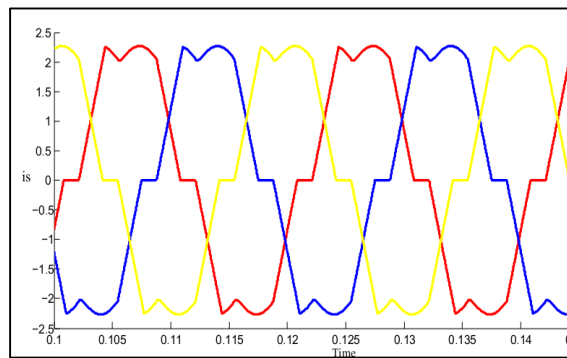


Fig. 7: Source Current before connecting to D-STATCOM

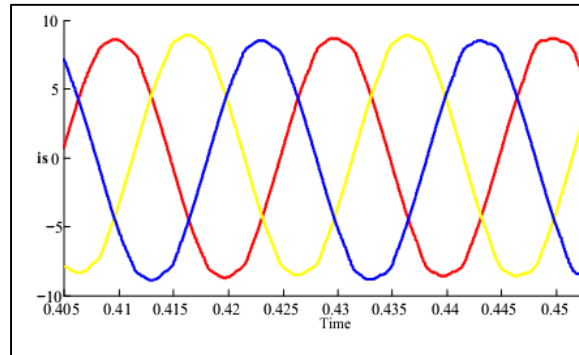


Fig. 8: Source Current after connecting to D-STATCOM

V. CONCLUSION

The mathematical modelling of the control structure to the D-STATCOM, Nonlinear load and the modelling of 5 level Cascaded H Bridge Inverter with Phase shifted PWM technique is presented. It is proved that the CHB based multilevel inverter mitigates the harmonics in the source current at distribution system. The results from the simulation demonstrates the effectiveness of the D-STATCOM in providing balanced sinusoidal source currents, though the load currents are distorted. It is noted that the THD is 2.15% which is well within IEEE 519-1992 standards.

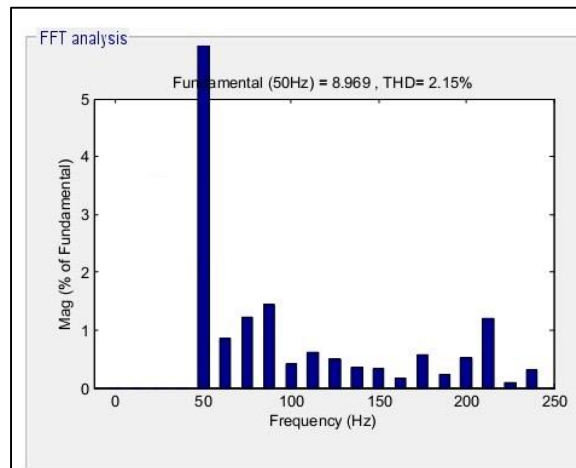


Fig 9: THD of Source current after connecting to D-STATCOM

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