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RESEARCH ARTICLE

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A Three Phase Three Wire DSTATCOM for Improvement of Power Quality Using Advanced Control Strategy

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ABSTRACT

Variable speed drives (VSD) consists of various motors are widely used in the industrials and process control in the form of varied applications such as fans, compressors, pumps etc. However, they inject high harmonic content into current drawn from the ac system at PCC power can't be maintained as a quality. Power quality problems such as harmonics, reactive power, power factor and so on, have become serious increasingly, passive power filter may not provide better solution and the development of active compensator has been one of the ways to solve these problems. This paper presents a three-phase, 3-level voltage source inverter based DSTATCOM for power line conditioning to improve power quality in the distribution network. Static device compensates both reactive power and harmonic currents drawn by non-linear loads; additionally it facilitates power factor corrections. The compensation process is based on concept of p-q theory as well as unit vector control strategy. This paper deals with the application of a DSTATCOM for compensation of such type of loads. The MATLAB / Simulink based models are developed for variable speed drive loads. The analysis is carried out various control strategies application to proposed DSTATCOM and presented the results.

Keywords- DSTATCOM (Distributed Static Compensator), Unit Vector Control Strategy, Instantaneous P-Q theory, Power quality, DC Link Controller.

INTRODUCTION

The transportation of clean power has been always an important task for utilities. In the past the simplicity of the power systems with almost all the important loads pure linear was an easy job, now days the fastest growth of technology low power and high power semiconductors (e.g. diodes, thyristors, Transistors) and the implementation of this technology in domestic and industrial applications as motor drives and renewable energy sources become the transmission of clean power through the systems a really big deal, especially in distribution systems. In recent years, there has been an increased use of non-linear loads which has resulted in an increased fraction of non-sinusoidal currents and voltages in electric network [1]. Classification of power quality areas may be made according to the source of the problem such as converters, magnetic circuit non linearity, arc furnace or by the wave shape of the signal such as harmonics, flicker or by the frequency spectrum (radio frequency interference). The waveform of electric power at generation stage is purely sinusoidal and free from any distortion. Many of the Power conversion and consumption equipment are also designed to function under pure sinusoidal voltage waveforms. However, there are many devices that distort the waveform. These distortions may propagate all over the electrical network.

Nowadays Active Conditioners (AC) such as APF, DSTATCOM…etc to overcome these problems and are designed for compensating the harmonics and suppressing the reactive power simultaneously [2]. The generalized instantaneous reactive power theory which is valid for sinusoidal or non-sinusoidal and balanced or unbalanced three-phase power systems with or without zero-sequence currents was later proposed [3]. The proposed DSTATCOM can be connected in shunt/parallel with the load. Currently, remarkable progress in the capacity and switching speed of power semiconductor devices such as insulated-gate bipolar transistors (IGBTs) has spurred interest in APF [4]. The DSTATCOM compensation principle is based on the instantaneous real-power theory as well as unit vector control theory it provides good compensation characteristics in steady state as well as transient states [5]. The control instantaneous theory generates the reference currents required to compensate the distorted line current harmonics and reactive power. It also tries to maintain the dc-bus voltage across the capacitor as a constant. Another important characteristic of this control theory is the more calculations that are needs to go unit vector control strategy, which involves only algebraic calculation [6].

This paper presents the operating principals of the D-STATCOM. The D-STATCOM is basically one of the parallel FACTS controllers. The same kind of STATCOM is the so-called distribution static compensator (DSTATCOM), which is applied in distribution networks. The key component of the D-STATCOM is a power VSC, which is based on high-power electronics technologies. Here comparison of instantaneous real-power compensation scheme & UV theory based on 3-level DSTATCOM are used for the minimization of harmonics and reactive power compensation [7]. The compensation process involves calculation of real-power (p) losses only that is derived from sensing phase voltages and distorted source currents. The PI-controller is used to maintain the capacitance voltage of the inverter constant. The proposed DSTATCOM system is validated through extensive simulation and investigated under steady state and transient conditions with various load conditions.

STRUCTURE & OPERATING PRINCIPLE OF DSTATCOM

The D-STATCOM is the solid-state-based power converter version of the SVC. The concept of the D-STATCOM was proposed by Gyugyi in 1976. Operating as a shunt-connected SVC, its capacitive or inductive output currents can be controlled independently from its connected AC bus voltage. Because of the fast-switching characteristic of power converters, the D-STATCOM provides much faster response as compared to the SVC. Therefore the shunt compensator can measure the PCC voltages and use them in the reference current generation algorithms without any problem as these voltages are pure sinusoids. This however may not be possible in actual systems where the loads are connected at the end of the feeder [8]-[10]. The PCC voltage in this case will be balanced condition. In addition, the PCC voltage will be distorted by both the harmonics generated by a non-linearity in the load and by the switching frequency harmonics generated by the D-STATCOM. Furthermore there will be switching and resistive losses in the D-STATCOM circuit. These losses must be supplied by the source. We must therefore suitably modify the reference current generation algorithm to accommodate all these factors. Finally, to provide a path for the harmonic current generated by the VSI realizing the D-STATCOM to flow, we must place additional filters in the circuit.

In addition, in the event of a rapid change in system voltage, the capacitor voltage does not change instantaneously; therefore, the D-STATCOM effectively reacts for the desired responses. For example, if the system voltage drops for any reason, there is a tendency for the D-STATCOM to inject capacitive power to support the dipped voltages. Theoretically, the power converter employed in the D-STATCOM can be either a VSC or a current-source converter (CSC). In practice, however, the VSC is preferred because of the bidirectional voltage-blocking capability required by the power semiconductor devices used in CSCs. To achieve this kind switch characteristic, an additional diode must be connected in series with a conventional semiconductor switch, or else the physical structure of the semiconductor must be modified [11]. Both of these alternatives increase the conduction losses and total system cost. In general, a CSC derives its terminal power from a current source, i.e., a reactor. In comparison, a charged reactor is much lousier than a charged capacitor. Moreover, the VSC requires a current-source filter at its AC terminals, which is naturally provided by the coupling transformer leakage inductance, while additional capacitor banks are needed at the AC terminals of the CSC. In conclusion, the VSCs can operate with higher efficiency than the CSCs do in high-power applications.

A suitable VSC is selected based on the following considerations: the voltage rating of the power network, the current harmonic requirement, the control system complexity, etc. Basically, the D-STATCOM system is comprised of three main parts: a VSC, a set of coupling reactors or a step-up transformer, and a controller. In a very-high-voltage system, the leakage inductances of the step-up power transformers can function as coupling reactors. The main purpose of the coupling inductors is to filter out the current harmonic components that are generated mainly by the pulsating output voltage of the power converters. The D-STATCOM 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.

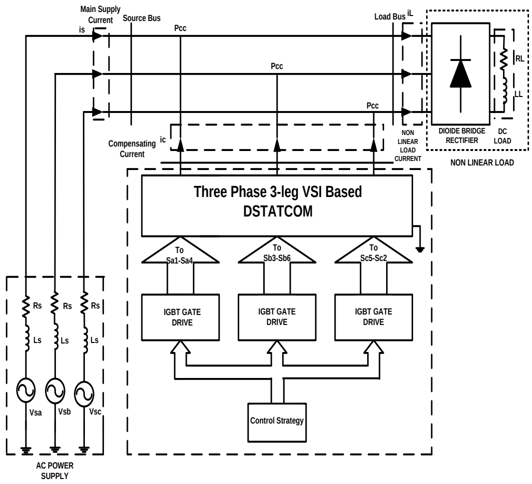

Fig. 1 Basic Block Diagram of CMC Based DSTATCOM with Non-Linear Load

The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches of the power converter accordingly. The block diagram representation of the D-STATCOM system with non-linear load is illustrated in Fig.1. In general, the VSC is represented by an ideal voltage source associated with internal loss connected to the AC power via coupling reactors [12]. In principal, the exchange of real power and reactive power between the D-STATCOM and the power system can be controlled by adjusting the amplitude and phase of the converter output voltage. In the case of an ideal lossless power converter, the output voltage of the converter is controlled to be in phase with that of the power system.

ROPOSED COMPENSATION CONROL STRATEGIES

A. Instantaneous P-Q Theory:

Control strategy plays a vital role in overall performance of the compensating device. The control of a compensating device is realized in three stages. In the first stage, the essential voltage and current signals are sensed using power transformers (PT's), CT's, Hall-effect sensors, and isolation amplifiers to gather accurate system information. In the second stage, compensating commands in terms of current or voltage levels are derived based on different control methods and device configurations. In the third stage of control, the gating signals for the solid-state devices of the compensating devices are generated either in open loop or closed loop [13]. There are many control approaches available for the generation of reference source currents for the control of VSC of DSTATCOM for three-phase, three-wire system in the literature viz.

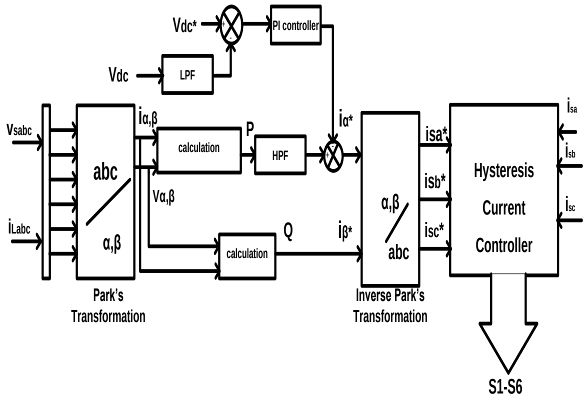

Fig. 2 Block Diagram of Proposed Control Strategy-Instantaneous Real & Reactive Power Theory

Instantaneous Reactive Power theory was initially proposed by Akagi. This theory is based on the transformation of three phase quantities to two phase quantities in α-β frame and the calculation of instantaneous active and reactive power in this frame. A basic block diagram of this theory is shown in Fig. 4. Sensed inputs $Vsa, Vsb, Vsc\ and\ iLa, iLb, iLc$ are fed to the controller, and these quantities are processed to generate reference current commands $(i^*_{Sa}, i^*_{Sb}, i^*_{Sc})$, which are fed to a pulse width modulation (PWM) signal generator to generate final switching signals fed to the D-STATCOM; therefore this block works as controller for D-STATCOM [14].

The system terminal voltages are given as

$$va = Vm \sin(\omega t)$$
$$vb = Vm \sin(\omega t - 2\pi/3)$$
$$vc = Vm \sin(\omega t - 4\pi/3) \quad (5)$$

And the respective load currents are given as

$$i_{La} = \sum I_{Lan} sin\{n(\omega t) - \theta_{an}\}$$
$$i_{Lb} = \sum I_{Lbn} sin\{n(\omega t - 2\pi/3) - \theta_{bn}\}$$
$$i_{Lc} = \sum I_{Lcn} sin\{n(\omega t - 2\pi/3) - \theta_{cn}\} \quad (6)$$

In a-b-c coordinates, a, b, and c axes are fixed on the same plane, apart from each other by 2π/3. The instantaneous space vectors *va* and *iLa* are set on the "*a*" axis, and their amplitude varies in positive and negative directions with time. This is true for the other two phases also. These phases can be transformed into *α–β* coordinates using Park's transformation as follows:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (8)$$

Where α and β axes are the orthogonal coordinates. Conventional instantaneous power for three-phase circuit can be defined as

$$p = v_\alpha i_\alpha + v_\beta v_\beta \quad (9)$$

Where p is equal to conventional equation

$$p = v_a i_a + v_b i_b + v_c i_c \quad (10)$$

Similarly, the IRP is defined as

$$q = -v_\beta i_\alpha + v_\alpha i_\beta \quad (11)$$

Therefore, in matrix form, instantaneous real and reactive power are given as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (12)$$

The α-β currents can be obtained as

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (13)$$

Where

$$\Delta = v_\alpha^2 + v_\beta^2 \quad (14)$$

Instantaneous active and reactive powers p and q can be decomposed into an average (dc) and an oscillatory component.

$$p = \bar{p} + \tilde{p}$$
$$q = \bar{q} + \tilde{q} \quad (15)$$

Where $\bar{p}$ and $\bar{q}$ are the average (dc) part and $\tilde{p}$ and $\tilde{q}$ are the oscillatory (ac) part of these real and reactive instantaneous powers. Reference source currents are calculated to compensate the IRP and the oscillatory component of the instantaneous active power. Therefore, the reference source currents $i^*_{s\alpha}$ and $i^*_{s\beta}$ in α-β coordinate are expressed as

$$\begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix} \quad (16)$$

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Theses currents can be transformed in a-b-c quantities to find the reference currents in a-b-c coordinates using inverse transformation.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0^* \\ i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} \quad (17)$$

Where i_0^* is the zero sequence components, which is zero in three- phase three wire system.

B. ***Unit Vector Template***

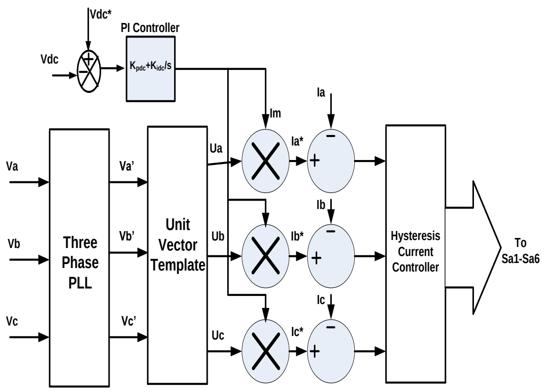

Fig. 3. Block diagram representation of grid-interfacing inverter control.

The control diagram for a 3-phase 3-wire system is shown in Fig. 3. The main aim of proposed approach is to regulate the power quality features at PCC during the output of dc-link voltage regulator results in an active current component (Im). The multiplication of active current component (Im). With unity voltage vector templates (U_a,U_b, and U_c) generates the reference currents(I_a^*, I_b^*, and I_c^*). The source synchronizing angle (θ) obtained from phase locked loop (PLL) is used to generate unity vector template as [9]–[15]. The actual dc-link voltage (V_{dc}) is sensed and passed through a first-order *low pass filter* (LPF) to eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage (V^*_{dc}) is given to a discrete- PI regulator to maintain a constant dc-link voltage under varying generation and load conditions.

The switching pattern of each IGBT inside inverter can be formulated on the basis of error between actual and reference current of inverter, which can be explained as: If $I_{Inva} < (I^*_{Inva}-h_b)$, then upper switch S_1will be OFF (P_1 =0) and lower switch S_4 will be ON (P_4=1) in the phase "a" leg of inverter. If $I_{Inva} > (I^*_{Inva}-h_b)$, then upper switch S_1 will be ON (P_1 =1) and lower switch S_4 will be OFF (P_4=0) in the phase "a" leg of inverter Where hb is the width of hysteresis band. On the same principle, the switching pulses for the three legs can be derived [16].

MATLAB/SIMULINK MODELLING AND SIMULATION RESULTS

Here the simulation is carried out by two cases with different control strategies 1. Proposed DSTATCOM Operated Under Instantaneous P-Q Theory, 2. Proposed DSTATCOM Operated Under Unit Vector Control Theory

Case 1: Proposed DSTATCOM Operated Under Instantaneous P-Q Theory

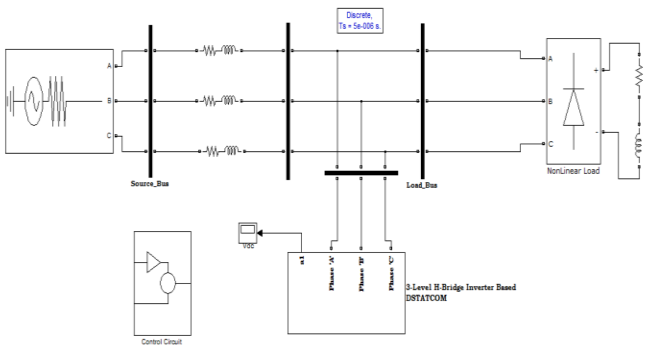

Fig. 4 Matlab/Simulink Model of Proposed DSTATCOM with Instantaneous P-Q Theory

Fig. 4 shows the Matlab/Simulink Model of Proposed DSTATCOM with Instantaneous P-Q Theory. With this Active compensator compensate the harmonics from Non-Linear Load. The performance of the proposed instantaneous real-power compensator 3 level inverter based DSTATCOM is evaluated through Matlab/Simulink tools. The non-linear diode rectifier R-L load is connected with ac mains and DSTATCOM is connected in parallel at the PCC for injecting the anti-harmonics and eliminating the harmonics and improving the Reactive power.

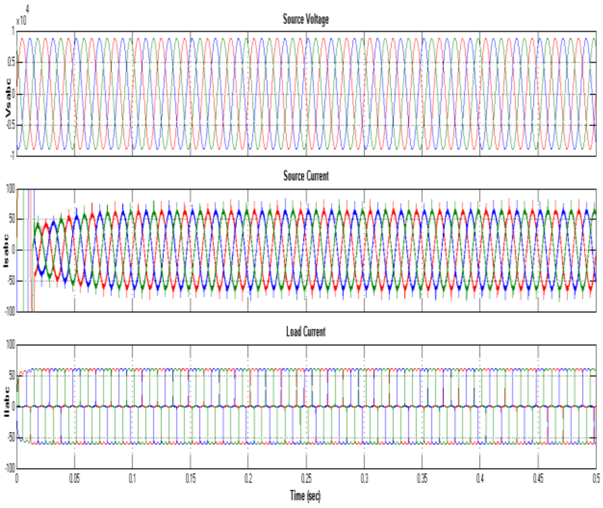

Fig. 5 Source Voltage, Source Current, Load Current

Fig. 5 shows the three phase source voltages, three phase source currents and load currents, respectively with DSTATCOM operated by Instantaneous P-Q Control Theory.

Fig. 6 shows the three phase Compensation Currents, DC Link Voltage respectively with DSTATCOM operated by Instantaneous P-Q Control Theory.

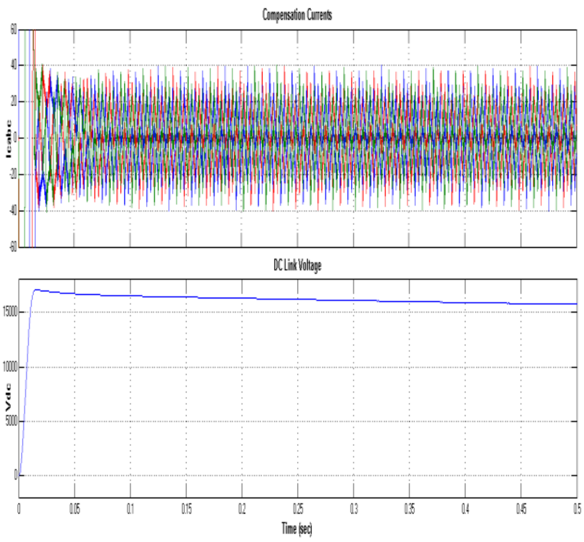

Fig. 6 Compensation Currents, DC Link Voltage

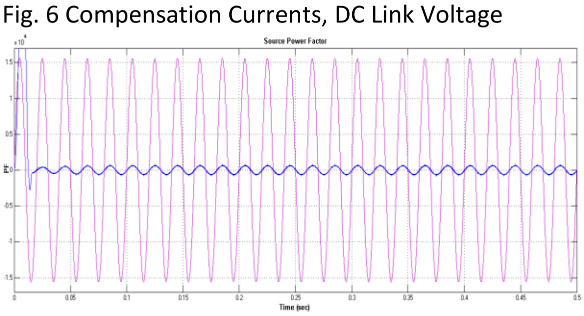

Fig. 7 Source Side Power Factor

Fig. 7 shows the Source Side Power Factor of the Proposed DSTATCOM operated by Instantaneous P-Q Theory

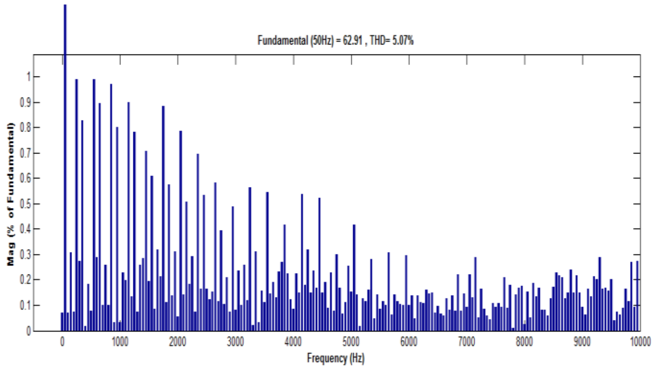

Fig. 8 Harmonic spectrum of Phase-A Source current with 3 level DSTATCOM

Fig. 8 shows the harmonic spectrum of Phase –A Source current with 3 level DSTATCOM. The THD of source current is 5.07%.

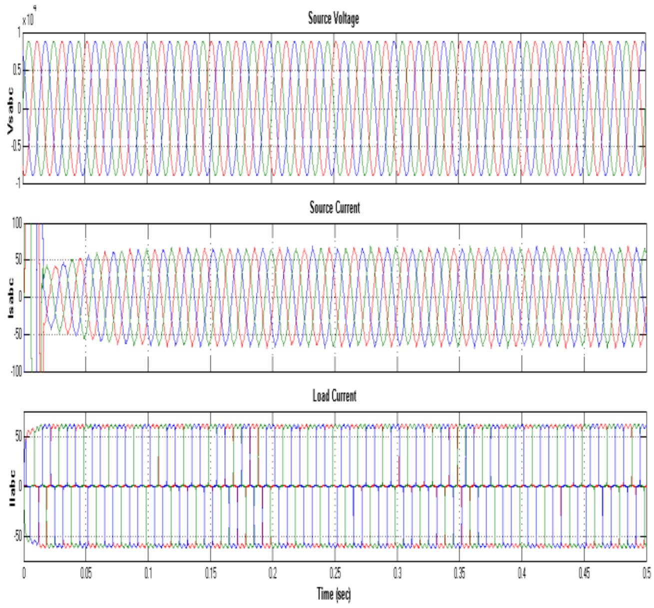

Fig. 9 Source Voltage, Source Current, Load Current

Fig. 9 shows the three phase source voltages, three phase source currents and load currents, respectively with DSTATCOM operated by Unit Vector Control Theory.

Fig. 10 shows the three phase compensation currents and DC link voltage respectively with DSTATCOM operated by using Unit Vector Theory

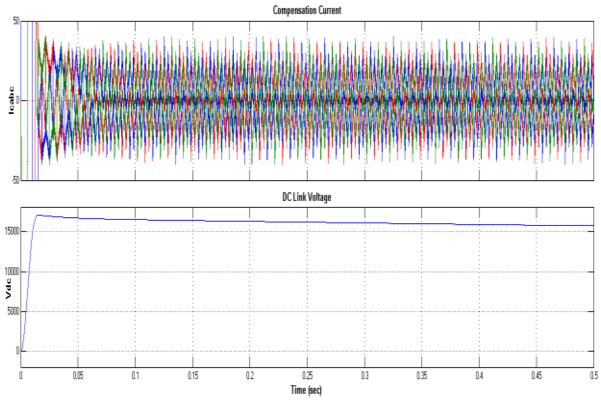

Fig. 10 Compensation Current, Dc Link Voltage

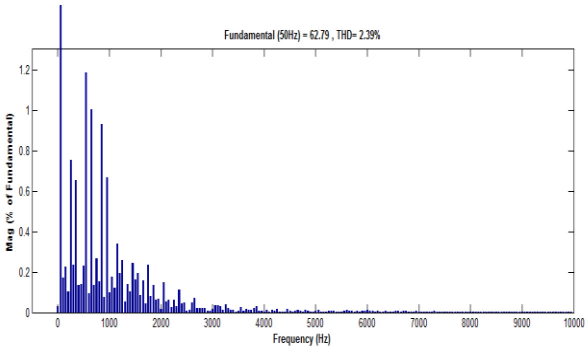

Fig. 11 Harmonic spectrum of Phase-A Source current with 3 level DSATATCOM

Fig. 11 shows the harmonic spectrum of Phase –A Source current with 3 level DSATATCOM operated with Unit Vector Control Theory. The THD of source current is 2.39%.

CONCLUSION

A new control algorithm of Proposed DSTATCOM has been implemented for compensation of three phase nonlinear loads. The performance of DSTATCOM and its control algorithm has been demonstrated for reactive power compensation, harmonics elimination, and load balancing in under any type of load such as linear, nonlinear, and mixed loads. In all operating conditions, the THD of source current has been observed within limit of 5%. The performance of DSTATCOM and its control has been found satisfactory under different control schemes. The dc bus voltage of the DSTATCOM has also been regulated without any overshoot to the desired value under varying load conditions. The proposed unit vector control strategy uses reduced computation for reference current calculations compared to conventional instantaneous approach. As evident from the simulation studies, dc bus capacitor voltage settles early and has minimal ripple because of the presence of PI-controller & maintains constant DC Link Voltage and get low THD in comparison of both the control schemes. The THD of the source current when 3-Level DSTATCOM is well within harmonic limit imposed by the IEEE-519 standard.

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