Power Quality Improvement of an Interconnected Grid System Using PWM Technique of D-STATCOM

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1 Introduction

In general, power squality (PQ) is the maintenance of a sinusoidal voltage waveform at nominal voltage and frequency. It is the power supply characteristics that allow the equipment to operate properly. Any faults on transmission lines, capacitor switching, switching of large loads, use of power electronic devices cause distortion due to its non-linearity nature. At the generation point, the electric power waveform is strictly sinusoidal and is free from distortion. The same power would be available in the load side if there is no distortion. But, in practical case due to the presence of transmission line reactance, the power to be transmitted gets affected. The current flowing through the system's impedance can cause a number of voltage disruptions. The voltage is often skewed by distorted currents from harmonic production loads as they pass through the impedance of the system. These distortions spread all over the network.

In the early days, the quality of power was mainly concerned with the continuity of the supply of electricity at appropriate voltage and frequency. AC distribution systems are faced with a number of problems in the quality of power. In particular, because of the use of sensitive equipment in the majority of production, residential, industrial, and traction applications. Not only can non-linear loads cause problems with power efficiency, but they are also extremely susceptible to voltage deviations. The ability to monitor both actual and reactive power exchanges can be effectively used to damp power oscillation damping, and for providing uninterrupted power to essential loads.

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Nonlinear loads cause distortions in currents and voltages in the supply mains, leading to deterioration of power quality [1]. Different approaches have been applied for compensating the effect of these non-linear loads [2]. The performance can be improved with different algorithms [3, 4]. A new unified method was proposed for the manipulation of power system waveform parameters such as magnitude, phaseangle, and ffrequency [5]. Though variation of load has effect on PQ, still based on the different environmental conditions PQ disruptions are also classified [6]. The power quality can be improved by using D-STATCOM near the load [7]. In order to produce the reference load voltage for a voltage-controlled DSTATCOM, a control algorithm was proposed [8]. In VSC-based DSTATCOM, an adaptive fuzzy logic controller with IRPT control algorithm has been used [9]. A control algorithm based on SRF theory is implemented to control DSTATCOM efficiently in grid level PQ improvement [10]. A hybrid technique-based icosϕ control algorithm has been used for analyzing the performance [11]. Taking into consideration the costs of DSTATCOM, the optimal location is chosen for loss minimization and enhancement of voltage profile [12]. A DSTATCOM integrated with distribution transformer is used for reactive power compensation [13]. An optimal allocation model of DSTATCOM with multi-objective functions is described [14]. The methods to protect critical loads from voltage-based PQ issues are presented [15]. The PCC voltage and the reactive power are taken care by the DSTATCOM [16]. The mitigation of harmonics and power factor improvement is done by using D-STATCOM [17]. The distorted voltage and hence, the power quality is improved [18].

2 Operation and Control of DSTATCOM

Static compensators connecting at distributed system and operating for mitigating of multiple current power quality problems commonly known as distributed STATCOM (DSTATCOM). It is typically used to boost power quality in low or medium voltage distribution systems. It is often used in three-phase systems to control the terminal vvoltage, dominate the voltage flicker and enhance voltage balance. The basic purpose of DSTATCOM is to alleviate all current power-based problems such as VAR, unbalanced currents, neutral currents, and harmonics. An IGBT dependent current controlled VSC is used as the DSTATCOM with a DC bus capacitor to provide sinusoidal balanced currents in the supply. The VSC uses PWM power, so small ripple filters are needed to minimize switching ripples.

A control algorithm is generally used to control directly the reference currents of the DSTATCOM. By using PWM current ccontrol, which results in an indirect current control, the gating pulses to the DSTATCOM are produced. In all control algorithms, the reactive power and the unbalanced current are being compensated using DSTATCOM.

The main purpose of DSTATCOM's control algorithm is to use feedback signals to calculate the reference currents. In PWM current controllers, these reference currents are used, along with corresponding sensed currents, to generate PWM gating signals

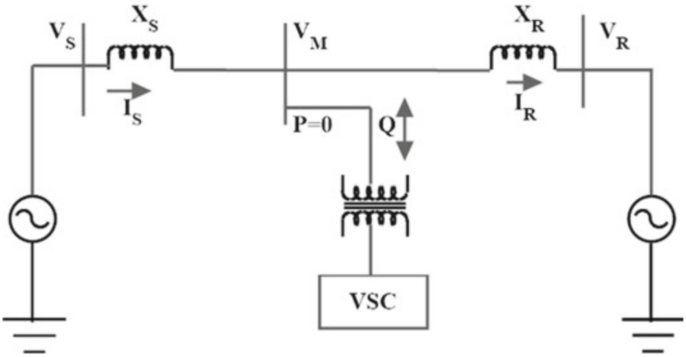

Fig. 1 Schematic diagram of the DSTATCOM

for VSC switching devices used as DSTATCOM. Figure 1 shows the reactive power generation using the basic VSC scheme.

A coupling transformer is installed to match the voltage level because the device rating may not match with system rating. The DC storage capacitor is used to keep the instantaneous output and input powers equal. Semiconductor switches having some losses in a practical converter. These losses are being compensated by the stored energy in the dc capacitor. Thus, to replenish the internal losses, the converter consumes a small amount of active power from the system, maintaining the desired capacitor voltage.

The schematic diagram of the DSTATCOM is shown in Fig. 1. If the voltage magnitude of the VSC is more than the system AC voltage V_M, the reactive current starts flowing from the converter to the ac system through the tie line reactance, and the VSC produces reactive power for the ac system which is capacitive in nature. If the output voltage amplitude is less than that of the ac system, then the current flows from the AC system to the converter and the reactive power is absorbed by the converter which is inductive in nature. If the amplitude of both is equal, then there is no exchange of reactive power.

3 Modeling

The basic diagram of the DSTATCOM based on VSC is shown in Fig. 2.

The three-phase AC system voltage V_s lags the STATCOM output voltage by an angle and is given by Eq. (1).

$$V_{s,abc} = \begin{bmatrix} V_{sa}(t) \\ V_{sb}(t) \\ V_{sc}(t) \end{bmatrix} = \sqrt{\frac{2}{3}} V_s \begin{bmatrix} \sin \omega t \\ \sin(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \tag{1}$$

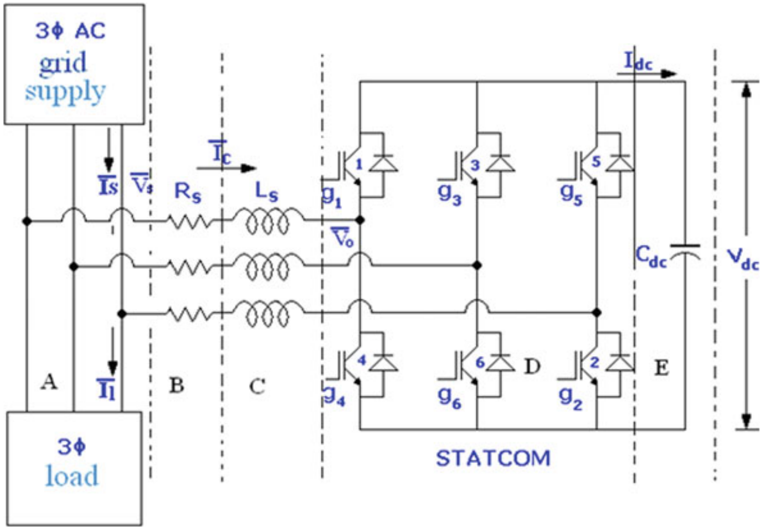

Fig. 2 Block diagram of the VSC-based DSTATCOM

The STATCOM currents are given by Eq. (2).

$$L_s \frac{d}{dt}\begin{bmatrix} i_{ca}(t) \\ i_{cb}(t) \\ i_{cc}(t) \end{bmatrix} = R_s \begin{bmatrix} i_{ca}(t) \\ i_{cb}(t) \\ i_{cc}(t) \end{bmatrix} + \begin{bmatrix} V_{sa}(t) \\ V_{sb}(t) \\ V_{sc}(t) \end{bmatrix} - \begin{bmatrix} V_{oa}(t) \\ V_{ob}(t) \\ V_{oc}(t) \end{bmatrix} \tag{2}$$

The above voltage and currents are transformed into α-β axis as below:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{3.1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{3.2}$$

where α and β are the orthogonal coordinates.

These currents can be transformed from α-β to d-q by using Park's transformation defined as

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{4}$$

The STATCOM model in d-q frame is given in Eq. (5).

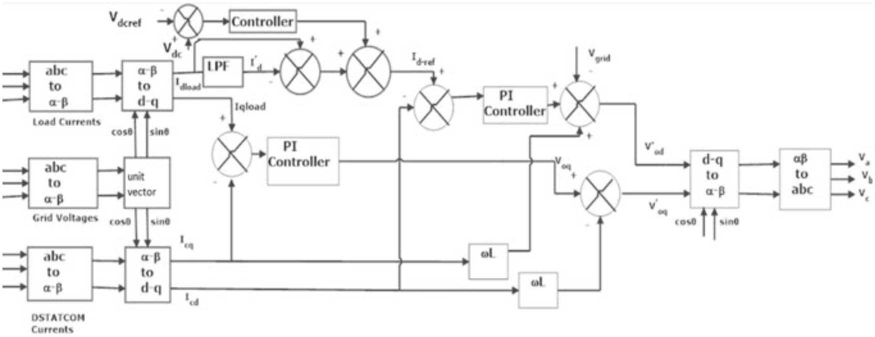

Fig. 3 Transformation block diagram

$$\frac{d}{dt}\begin{bmatrix} i_{cd}(t) \\ i_{cq}(t) \\ v_{dc}(t) \end{bmatrix} = \begin{bmatrix} -R_s/L_s & \omega & -m/L_s \\ -\omega & -R_s/L_s & 0 \\ m/C & 0 & 0 \end{bmatrix}\begin{bmatrix} i_{cd}(t) \\ i_{cq}(t) \\ v_{dc}(t) \end{bmatrix} + \frac{V_s}{L_s}\begin{bmatrix} \cos\alpha \\ -\sin\alpha \\ 0 \end{bmatrix} \tag{5}$$

The transformation block diagram is shown in Fig. 3.

4 Controller Design

Two controllers namely voltage and current controller are used to analyze the performance.

Equation (5) can be rewritten as

$$\frac{d}{dt}\begin{bmatrix} i_{cq} \\ i_{cd} \end{bmatrix} = \begin{bmatrix} -R_s/L_s & -\omega \\ \omega & -R_s/L_s \end{bmatrix}\begin{bmatrix} i_{cq} \\ i_{cd} \end{bmatrix} + \frac{1}{L_s}\left[\begin{bmatrix} V_{sq} \\ V_{sd} \end{bmatrix} - \begin{bmatrix} V_{oq} \\ V_{od} \end{bmatrix}\right] \tag{6}$$

4.1 Current Controller Design

The harmonic current is supplied by the d-axis controller and a small amount of active current is drawn to meet the switching losses where as both harmonic and reactive current are supplied by the q-axis controller.

$$v_{oq} = -v_{oq}^{*} - \omega L_s i_{cd} + v_{sq} \tag{7.1}$$

$$v_{od} = -v_{od}^{*} - \omega L_s i_{cq} + v_{sd} \tag{7.2}$$

Applying the Laplace transformation and then rearranging, the transfer function can be obtained as follows

$$G_i(s) = \frac{I_{cq}(s)}{v_{oq}^*(s)} = \frac{I_{cd}(s)}{v_{od}^*(s)} = \frac{1}{R_s + L_s} \tag{8}$$

4.2 Voltage Controller Design

The DC link voltage is maintained constant using voltage controller

$$V_{dc} = \frac{1}{C} \int i_{dc}(t) \tag{9}$$

$$G_v(s) = \frac{V_{dc}}{I_{dc}} = \frac{1}{sC} \tag{10}$$

5 Simulation Results

The performance of the 3-ϕ grid-connected system with nonlinear load has been studied with MATLAB/SIMULINK and the results have been presented. The 3-ϕ source voltage waveform is given in Fig. 4. Due to the non-linearity nature of the load, the current waveform gets distorted and is shown in Fig. 5. When the DSTATCOM is enabled at t = 0.1 s, it injects the harmonic current and thus maintains sinusoidal source current by compensating the distortion. The injected current waveform with enabled DSTATCOM at t = 0.1 s is shown in Fig. 6. The power factor is found to be unity after the DSTATCOM is enabled thus improves the power quality of the system which is shown in Fig. 7. The THD of the grid current is found to be 31.08% and 2.67% without and with compensation which is given in Fig. 8 and Fig. 9 respectively.

6 Conclusion

The analysis of DSTATCOM and design of controllers are presented in this paper. A DSTATCOM based on VSI is used to provide the load with both VAR and harmonic current so that the source current becomes sinusoidal and has a unit power factor. The controllers are designed on the basis of parameters of the STATCOM and time constant. THD is reduced from 31.08 to 2.67% after connecting DSTATCOM. Thus, the effectiveness of DSTATCOM with PI controller to improve the power factor

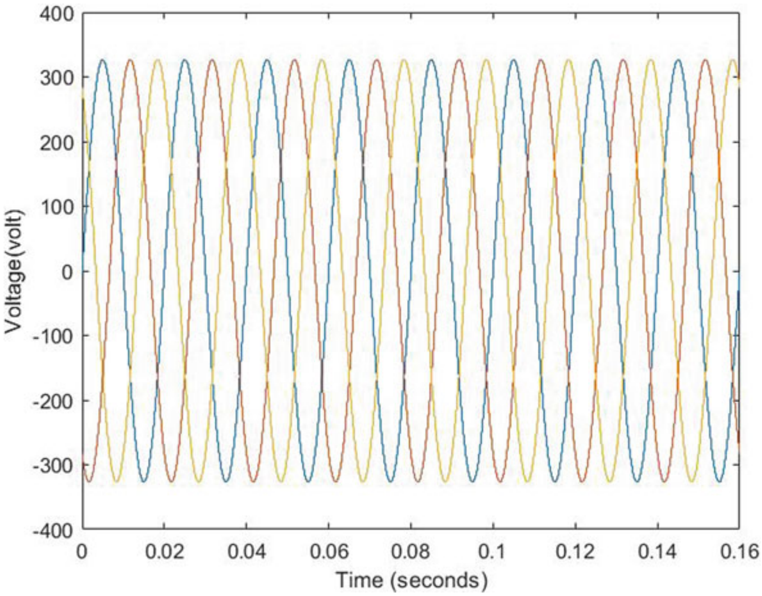

Fig. 4 Three-phase source voltage waveforms

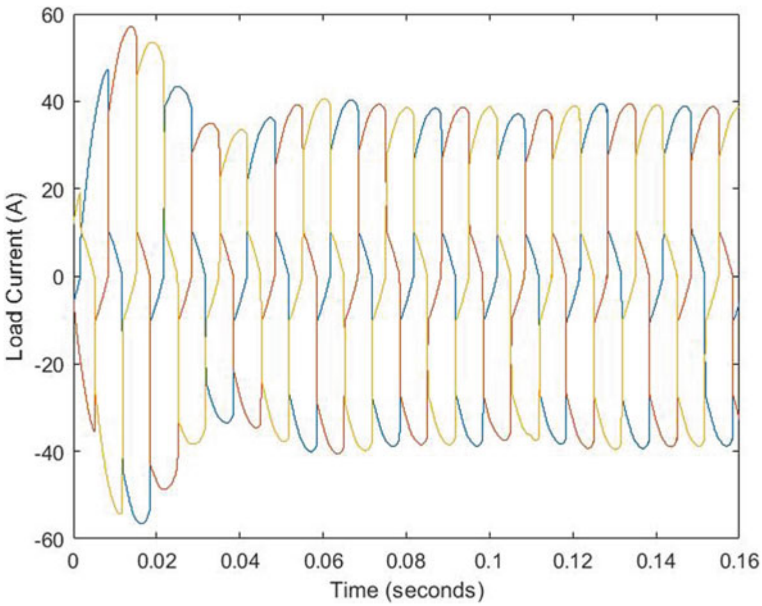

Fig. 5 Load current waveform

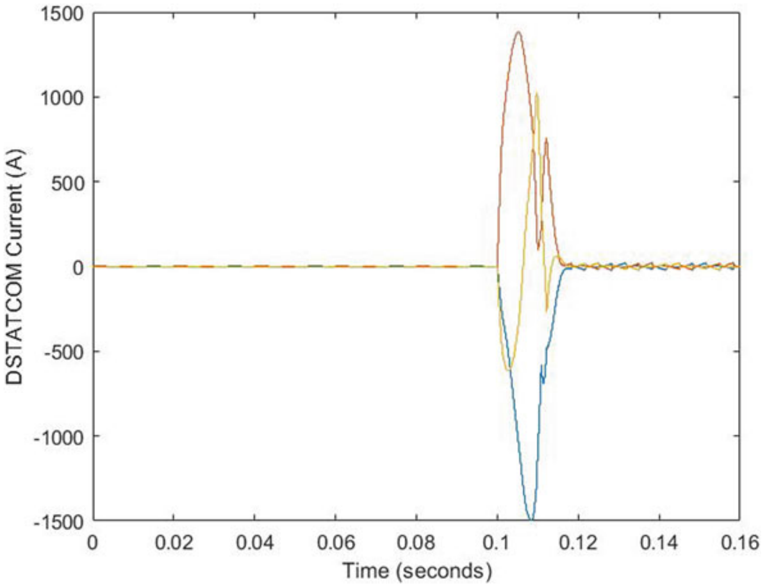

Fig. 6 Current injected by DSTATCOM

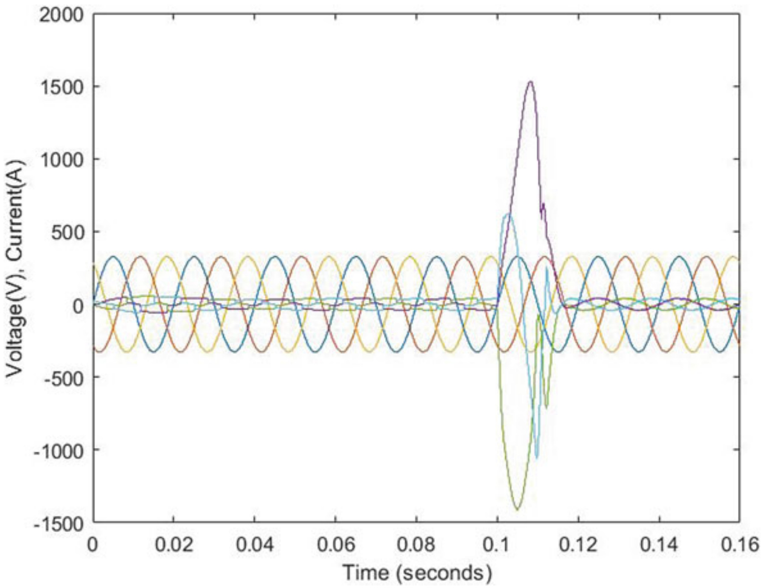

Fig. 7 UPF operation after using DSTATCOM

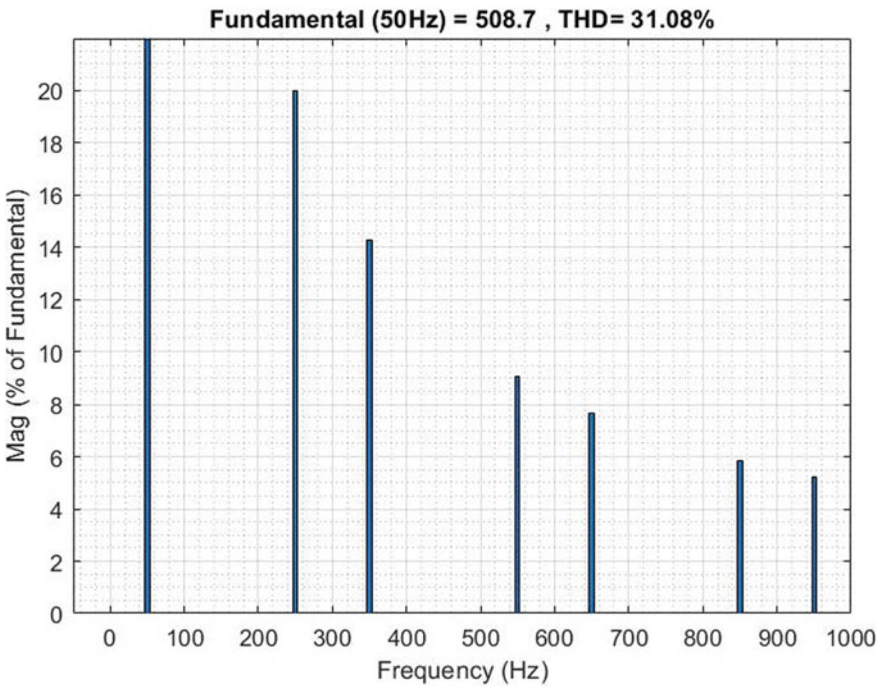

Fig. 8 THD before using DSTATCOM

is also investigated. Unity power factor operation is observed after 0.1 s when the DSTATCOM is enabled. The proposed DSTATCOM model effectively reduces the current harmonics injected by the load into the distribution network and hence enhances the power quality of the system.

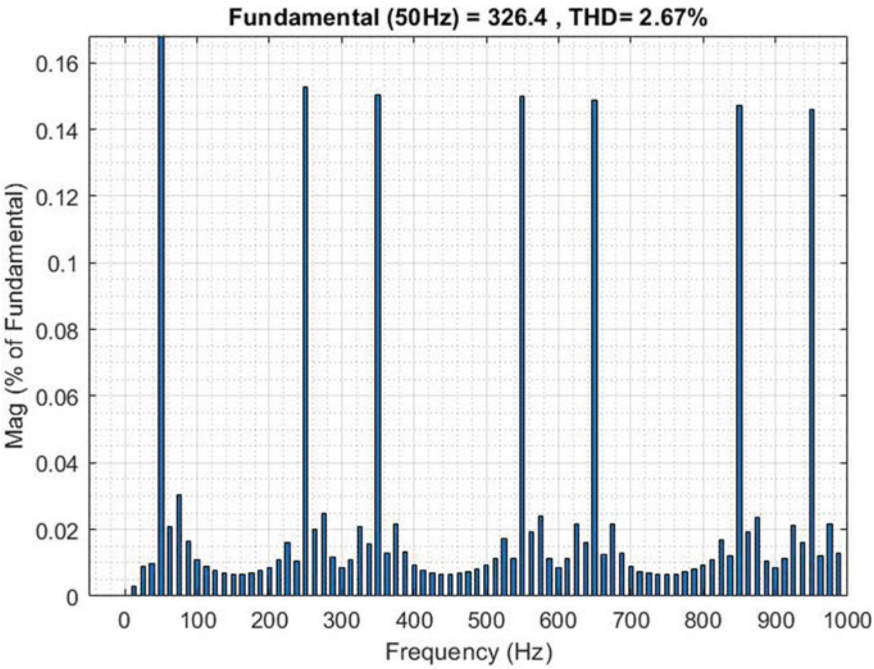

Fig. 9 THD after using DSTATCOM

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