Role of DSTATCOM to Improve Power Quality of Distribution Network with FOC Induction Motor Drive as Load

Rajan Sharma and Parag Nijhawan

Abstract: This paper focuses on power quality improvement with DSTATCOM on feeders feeding field oriented controlled induction motor drive as load. In this paper, role of DSTATCOM to improve power quality of distribution network under normal operating and fault conditions is investigated. Comparison of THD analysis for FOC induction motor drive load under normal and various faults conditions with or without DSTATCOM is also discussed in this paper. DSTATCOM is realized using IGBT in this paper, and dqo transformation based PWM current controller is used to derive gating pulses for the IGBT switch. The model is developed and simulated in MATLAB using Simulink toolbox. It is observed that DSTATCOM is effective in compensating load current harmonics, reactive power compensation and improving the power quality of the distribution system.

Keywords: DSTATCOM, dqo transformation, FOC induction motor drive, THD, power quality.

I. INTRODUCTION

In present days power distribution systems is suffering from severe power quality problems. Utility and customer side disturbances result in terminal voltage fluctuation, transients, and waveform distortions on the distribution system [1]. Current power distribution systems are experiencing increased installation of distributed generators and application of custom power devices. The most common type of distributed generation employs ac rotating machines. In modern industries FOC induction motor drives are used, which produce distortion in load current and harmonics distortion. It is well known that FOC induction motor drive has some disadvantages [2] that can be summarized in the following points:

1) High current and torque ripple;
2) Variable switching frequency behavior;
3) High noise level at low speed;
4) Lack of direct current control.

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Power quality issues are gaining significant attention due to the increase in number of sensitive loads. Also the widespread use of electronic equipment, such as information technology equipment, adjustable speed drives (ASD), arc furnaces, electronic fluorescent lamp ballasts and programmable logic controllers (PLC) have completely changed the electric loads nature [3]. These loads are the major victims of power quality problems. Due to the non-linearity of these loads, they cause disturbances in the voltage waveform. It is expected that a utility will supply a low distortion balanced voltage to its customers, especially those with sensitive loads.

So to improve the quality of power, we require compensating equipment, which can help to fulfill the standards. In last two decades, various schemes of load compensation have been proposed. In this sense, FACTS based power electronic controllers for distribution systems, namely custom power devices, are able to enhance the reliability and quality of power that is delivered to customers [1][4]. These schemes can cancel the effect of unbalance and distortion in current and can also correct the power factor at the load bus. DVR, DSTATCOM, UPQC are most widely used custom power devices. In this paper, among the different custom power devices, the role of DSTATCOM has been investigated to improve the quality of power under different fault conditions.

A Distribution Static Compensator (DSTATCOM) is a voltage source converter (VSC) based power electronic device which is connected in parallel with the system and injects compensating current into the system when any type of unbalancing occurs. Usually, it is supported by short term energy stored in a DC capacitor. DSTATCOM also generates capacitive and inductive reactive power internally. Its control is very fast and has the capability to provide adequate reactive compensation to the system. DSTATCOM can be effectively utilized to regulate voltage for a series of small Induction motors loads draw large starting currents (5-6 times) of full rated current and may affect working of sensitive loads.

The aim of this paper is to investigate a DSTATCOM that can compensate unbalanced current and harmonic distortion due to FOC induction motor drive, in various operating and fault conditions.

II. DSTATCOM

A DSTATCOM [5] consists of a three phase voltage source inverter shunt connected to the distribution network by means of a coupling transformer, as shown in Fig.1 [11]. In its most basic form, the DSTATCOM configuration consists of a dc capacitor, one or more inverter modules, a transformer to match the inverter output to the line voltage, and a PWM control strategy.

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 DSTATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the AC system.

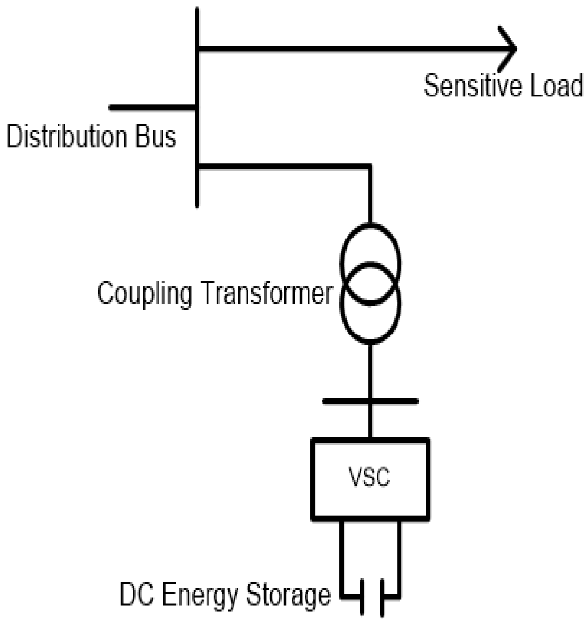

Fig.1: Schematic Representation of DSTATCOM

III. DQO TRANSFORMATION

The dqo transformation or Park's transformation is used to control of DSTATCOM [6]. The advantage of using dqo method is that it gives information about current unbalance, phase faults and phase shift with start and end times. The quantities are expressed as the instantaneous space vectors. The load currents which are in a-b-c frame are first transformed into α-β frame using Clark's transformation as given in equation (1). Then this α-β frame is converted to dqo frame given by equation (2). This is also called as Park's transformation.

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (1)$$

If θ is the transformation angle, then the currents transformation from α-β to d-q is defined as:

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \\ i_0 \end{pmatrix} \qquad (2)$$

Inverse Park's transformation can now be made to obtain three phase reference currents in a-b-c coordinates from the i_d, i_q dc components given by equation (3).

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos\theta & -\sin\theta & \frac{1}{\sqrt{2}} \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & \frac{1}{\sqrt{2}} \\ \cos(\theta - \frac{4\pi}{3}) & -\sin(\theta - \frac{4\pi}{3}) & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} (3)$$

The flow chart of the feed forward dqo transformation is shown in Fig.2.

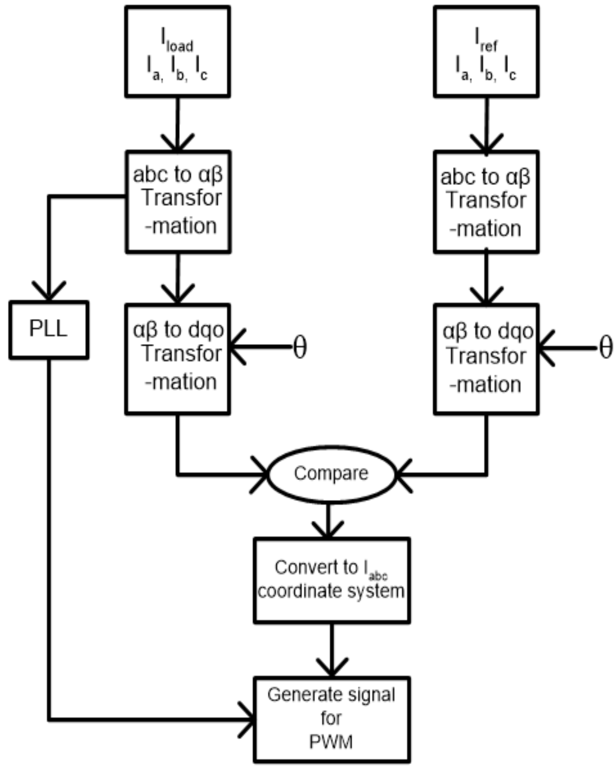

Fig.2: Flow Chart of DQO Transformation

IV. CONTROL SCHEME

The basic function of a controller in a DSTATCOM is the detection of faults in the system, computation of correcting voltage, generation of trigger pulses to sinusoidal PWM based DC-AC inverter and termination of the trigger pulses when the event has passed. When fault is detected, DSTATCOM should react as fast as possible and inject an ac current to the grid [6][11]. It can be implemented using a feedback control technique based on the current reference and load current. The basic control scheme is shown in Fig.3.

The load current is connected to a transformer block that converts stationary abc frame to rotating αβ frame. Output of transformation block is connected to a phase lock loop(PLL) and another transformation block that converts αβ frame to dqo, which detects fault in load current.

The fault detection block generates the reference supply current whenever fault is generated. The injection current is also generated by difference between the reference current and load current. Now i_d, i_q dc components are converted into three phase reference currents in a-b-c coordinates using Inverse Park's transformation and applied to converter to produce required current, with the help of pulse width modulation(PWM).

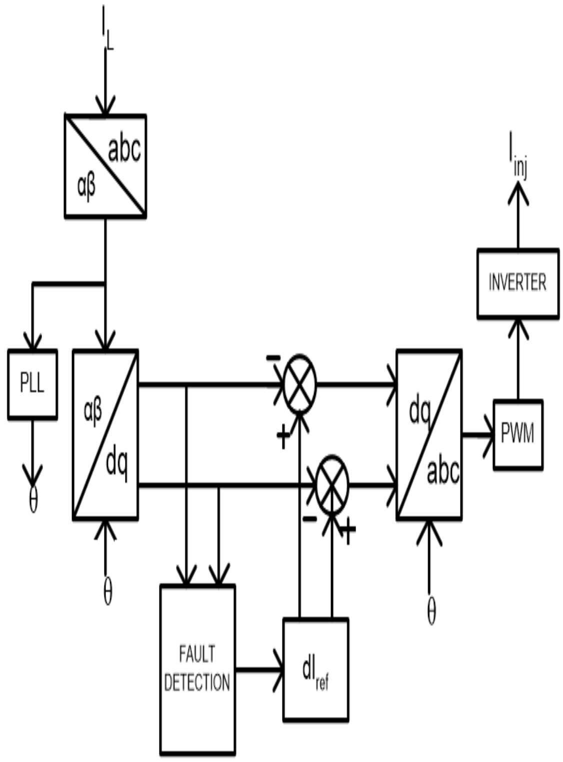

Fig.3: Control Scheme

V. TEST SYSTEM

Simulation model of the test system for DSTATCOM is shown in Fig.4. Such system is composed by an 11 kV, 50 Hz generation system, which is connected to a three phase three winding transformer connected in Δ/Y/Y, 11000/400/400V. This three winding transformer feeds two distribution networks. These distribution feeders feed two similar FOC induction motor drive load . One of the feeders is connected to DSTATCOM and the other is kept as it is. This test system is analyzed under various operating and different fault conditions. The control technique implements a dqo transformation which starts from the difference between the load current and reference current (identified current) that determines the reference current of the inverter (modulating reference signal).

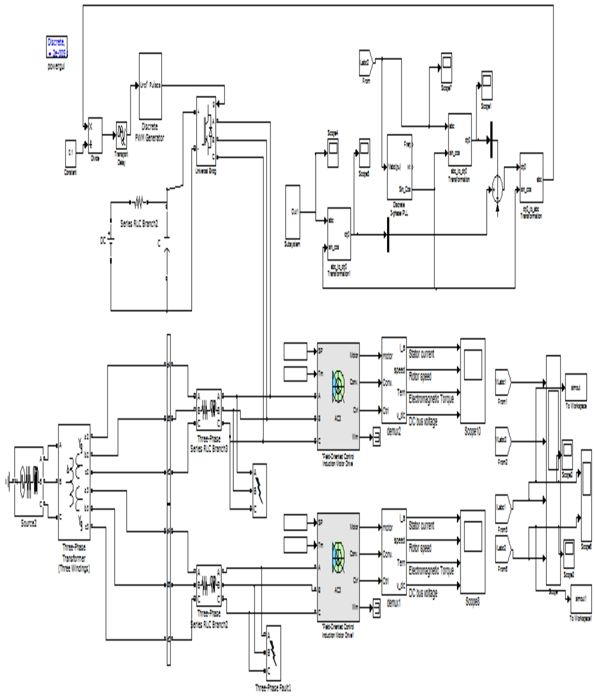

Fig.4: Simulation Diagram of Test System for DSTATCOM

VI. PARAMETERS OF DSTATCOM TEST SYSTEM

System test parameters are listed below in table-1:

Table-1: System Parameters

Sr. no.	System Quantities	Parameters
1.	Source	3 phase, 11kv rms (phase-phase), 50Hz, 500e6 Short circuit level(VA), 11kV Base voltage, $\frac{X}{R}$= 0.5.
2.	Convertor	IGBT based, 3 arms, 6 pulse, $R_{on} = 1e^{-3} ohms$
3.	Discrete 3-phase PLL	$K_p = 20, K_i = 50$, sampling time 50μs
4.	FOC Induction Motor Drive	Stator Resistance (14.85e-3), Rotor Resistance (9.295e-3), Leakage Inductance (0.3027e-3), Mutual Inductance (10.46e-3), Nominal power 200e3 VA, 400V rms (phase-phase), 50 Hz.
5.	Transformer	Nominal power 200e3 VA, 50Hz, Δ/Y/Y(grounded)11000/400/400V, $(R_1/R_2/R_3, L_1/L_2/L_3)$ = (0.002/0.002/0.002,0.08/0.08/0.08) p.u.

VII. SIMULATION RESULTS

Here simulations are performed on the DSTATCOM test system using MATLAB SIMULINK. The system performance is analyzed for compensate the load current harmonics due FOC induction motor drive as load in distribution networks under normal operating and various fault conditions. Four cases of different operating and fault conditions are considered to study the impact of DSTATCOM in distribution system. Different cases are listed below:

Case I: Results for Normal Operating Conditions

Here test system is considered under normal conditions. Due to FOC induction motor drive connected to the system, harmonics are produced in load current waveform as shown in Fig.5a. The frequency spectrum graph of load current for uncompensated feeder is shown in Fig.5b. When DSTATCOM is connected to the system it effectively reduces the harmonics from load current as shown in Fig.5c. Also frequency spectrum graph of load current for compensated feeder is shown in Fig.5d. It is clear from the frequency spectrum graphs that THD level reduced from 26.99% to 0.23% when DSTATCOM is connected to the system.

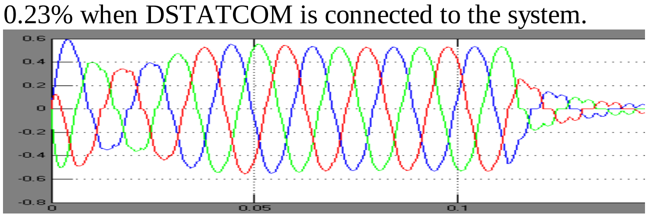

Fig.5a: Load Current vs Time waveform (without compensation)

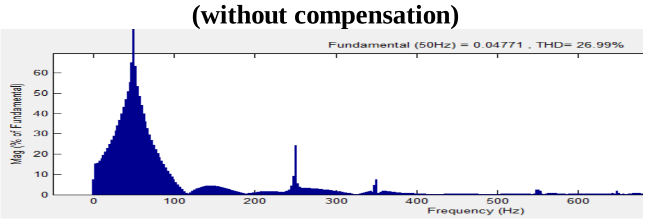

Fig.5b: Frequency Spectrum of Load Current (without compensation)

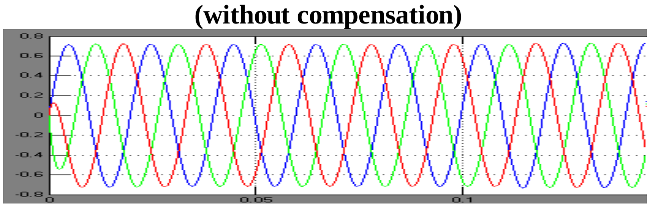

Fig.5c: Load Current vs Time waveform (with compensation)

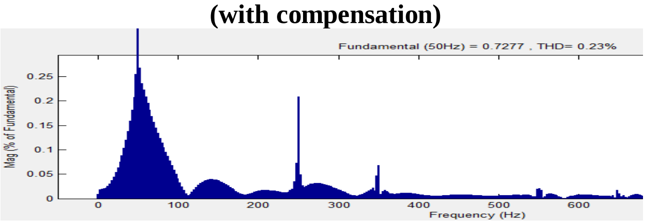

Fig.5d: Frequency Spectrum of Load Current (with compensation)

Case II: Results for Single Line to Ground Fault

In this case, a single line to ground fault is considered for both the feeders feeding FOC induction motor drive load. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm. The fault is created for the duration of 0.12s to 0.18s. The output wave for the load current without compensation is shown in Fig.6a. It is clear from the output wave shape that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder, When DSTATCOM is connected in the system the unbalancing is reduced clearly as shown in Fig.6c. These results become clear from the frequency spectrum graphs, which are taken one by one for non-compensated and compensated feeders with FOC induction motor drive load as shown in Fig.6b and Fig.6d. It is clear from the frequency spectrum graphs that THD level reduced from 11.07% to 0.22% when DSTATCOM is connected to the system.

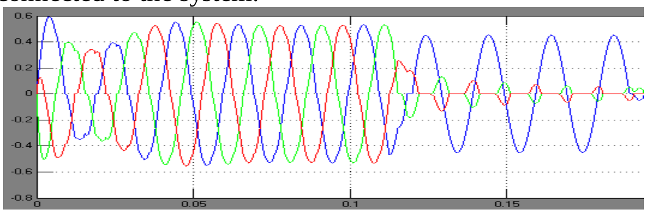

Fig.6a: Load Current vs Time waveform (without compensation)

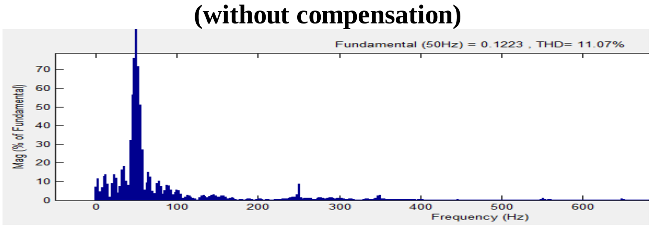

Fig.6b: Frequency Spectrum of Load Current (without compensation)

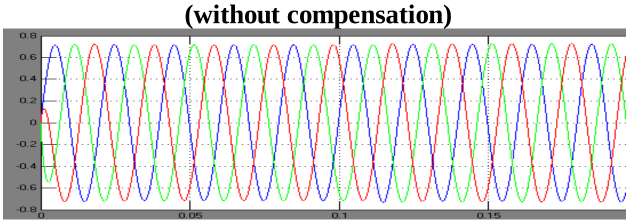

Fig.6c: Load Current vs Time waveform (with compensation)

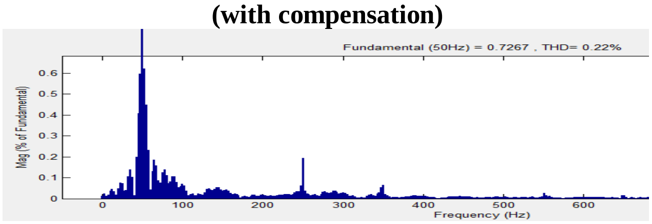

Fig.6d: Frequency Spectrum of Load Current (with compensation)

Case III: Results for Double Line to Ground Fault

In this case, a double line to ground fault is considered for both the feeders feeding FOC induction motor drive load. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm. The fault is created for the duration of 0.12s to 0.18s. The output wave for the load current without compensation is shown in Fig.7a. It is clear from the output wave shape that the current in the phases where fault is created is increasing during the fault duration in the uncompensated feeder, When DSTATCOM is connected in the system the unbalancing is reduced clearly as shown in

Fig.7c. These results become clear from the frequency spectrum graphs, which are taken one by one for non-compensated and compensated feeders with FOC induction motor drive load as shown in Fig.7b and Fig.7d. It is clear from the frequency spectrum graphs that THD level reduced from 11.20% to 0.24% when DSTATCOM is connected to the system.

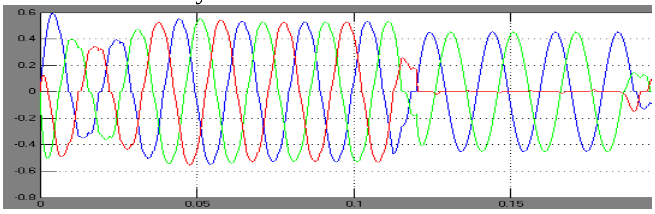

Fig.7a: Load Current vs Time waveform (without compensation)

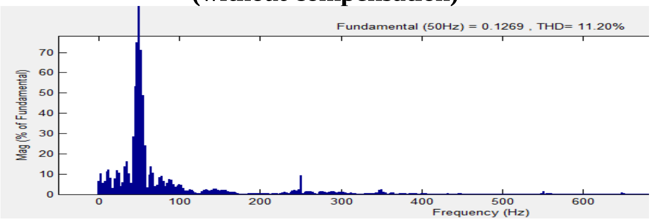

Fig.7b: Frequency Spectrum of Load Current (without compensation)

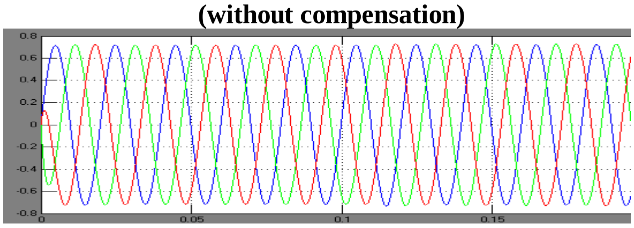

Fig.7c: Load Current vs Time waveform (with compensation)

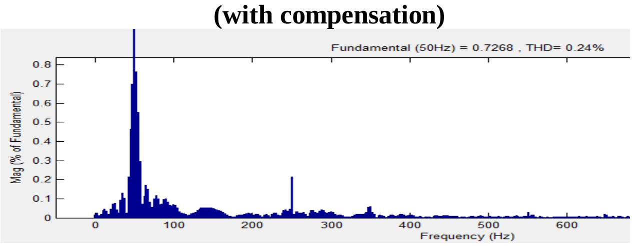

Fig.7d: Frequency Spectrum of Load Current (with compensation)

Case IV: Results for Three Phase Fault

In this case, three phase fault is considered for both the feeders feeding FOC induction motor drive load. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm. The fault is created for the duration of 0.12s to 0.18s. The output wave for the load current without compensation is shown in Fig.8a. It is clear from the output wave shape of load current that the current in the phases where fault is created is increasing during the fault duration in the uncompensated feeder, When DSTATCOM is connected in the system the unbalancing is reduced clearly as shown in Fig.8c. These results become clear from the frequency spectrum graphs, which are taken one by one for non-compensated and compensated feeders with FOC induction motor drive load as shown in Fig.8b and Fig.8d. It is clear from the frequency spectrum graphs that THD level reduced from 11.23% to 0.25% when DSTATCOM is connected to the system.

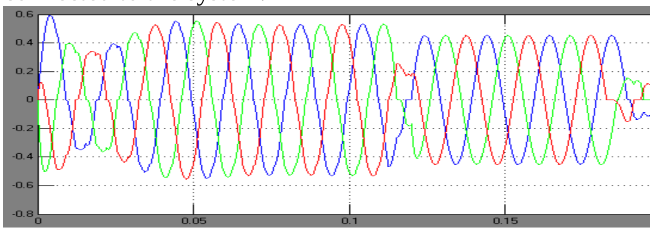

Fig.8a: Load Current vs Time waveform (without compensation)

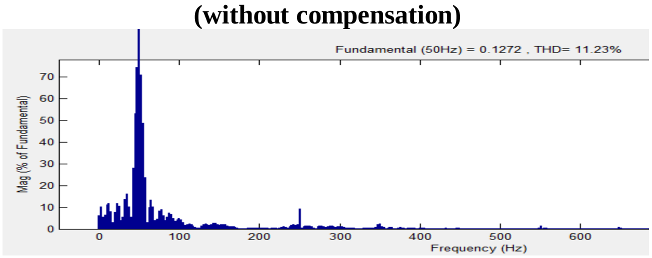

Fig.8b: Frequency Spectrum of Load Current (without compensation)

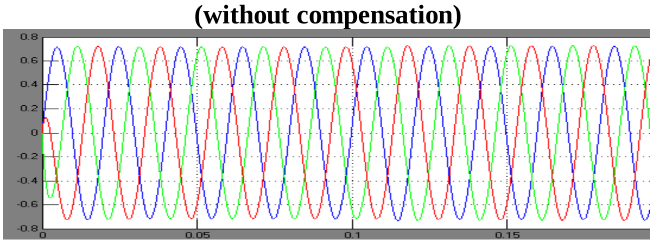

Fig.8c: Load Current vs Time waveform (with compensation)

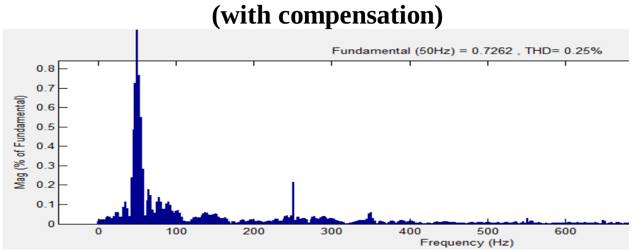

Fig.8d: Frequency Spectrum of Load Current (with compensation)

VIII. CONCLUSION

In this paper, the performance of DSTATCOM has been analyzed for FOC induction motor drive as load, using dqo transformation technique. The FOC induction motor drive introduces appreciable amount of current harmonics into the distribution system network, which can even affect the performance of other equipments connected in the network. Also, the effectiveness of DSTATCOM with dqo transformation to reduce the current harmonics introduced by the FOC induction motor drive load is also investigated. It is clear from frequemcy spectrum analysis of load current under normal and various faults conditions that the proposed DSTATCOM reduces harmonics from load current very effectively and makes it smooth.

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