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Effectiveness of DSTATCOM to Compensate the Load Current Harmonics in Distribution Networks under Various Operating Conditions

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Abstract: ***The Distribution Static Compensator (DSTATCOM) is a compensating device which is used to control the flow of reactive power in the distribution systems. This paper focuses on power quality improvement with DSTATCOM on feeders feeding linear loads, non-linear loads and DTC induction motor drive. In this paper, effectiveness of DSTATCOM in distribution networks to compensate the load current harmonics under various operating and fault conditions is discussed and implemented. Comparison of THD analysis for different types of loads under normal and various faults conditions with or without DSTATCOM is also done in this paper. DSTATCOM is realized using IGBT based PWM-VSI inverter having a DC bus capacitor. A dqo transformation based PWM current controller is used to derive gating pulses for the IGBT switch. The models are developed and simulated in MATLAB using Simulink toolbox. It is observed that DSTATCOM is effective in compensating current, harmonics, reactive power and improving the power quality of the distribution system.***

Keywords: DSTATCOM, power quality, VSC, load compensation, dqo transformation, harmonic distortion.

INTRODUCTION

Utility and customer-side disturbances result in terminal voltage fluctuation, transients, and waveform distortions on the distribution system. In recent years, power quality engineers are becoming increasingly concerned over the quality of electrical power. In modern industries, load equipment uses electronic controller, which are sensitive to poor voltage quality and will shut down if supply voltage is depressed and may mal-operate in other ways, if harmonic distortion of the supply voltage is excessive. Much of these modern load equipments themselves use electronic switching devices which then can contribute to poor network voltage quality.

In recent years, the non-linear loads and complexity of control systems in industrial processes have triggered the power quality problems in distribution network. Power quality issues are gaining significant attention due to the increase in number of sensitive loads [2]. It is expected that a utility will supply a low distortion balanced voltage to its customers, especially those with sensitive loads.

In last two decades, various schemes of load compensation have been proposed. These schemes can cancel the effect of unbalance and distortion in current and can also correct the power factor at the load bus. The FACTS devices offer a fast and reliable control over the transmission parameters, i.e. Voltage, line impedance, and phase angle between the sending end voltage and receiving end voltage [4]. On the other hand the custom power is for low voltage distribution, and improving the poor quality and reliability of supply affecting sensitive loads. 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 [1]. Usually, it is supported by short-term energy stored in a DC capacitor. When a DSTATCOM is associated with a particular load, it can inject compensating current, So that total demand meets the specifications for utility connections. DSTATCOM 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 in various operating and fault conditions.

I. DSTATCOM

A DSTATCOM [3] is a voltage source converter based compensating device which is connected in parallel with the

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distribution system to control the flow of reactive power. In its most basic form, the DSTATCOM configuration consists of a dc capacitor, one or more inverter modules, an ac filter, a transformer to match the inverter output to the line voltage, and a PWM control strategy. Fig.1 shows the schematic representation of DSTATCOM. In this arrangement, the steady-state power exchange between the device and the AC system is mainly reactive [6].

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.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for three distinct purposes [8].

1) Voltage regulation and compensation of reactive power;

2) Correction of power factor;

3) Elimination of current harmonics.

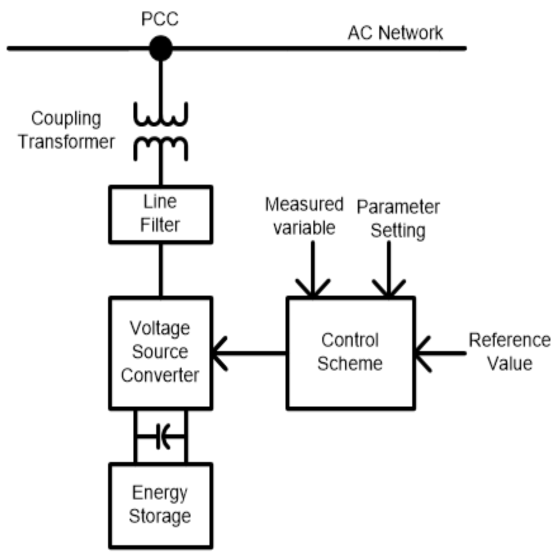

Fig.1: Schematic Representation of DSTATCOM

II. DQO TRANSFORMATION

This transformation is based on the transformation of currents in synchronously rotating d-q frame. The load currents which are in a-b-c frame are first transformed into α-β frame using Clark's transformation as shown in equation (1). Then this αβ frame is converted to dqo frame given by equation (2). This is also called as Park's transformation.

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

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

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

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).

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

III. 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. Fig.2 shows the basic dqo control scheme [16] and parameters that are measured for the control of DSTATCOM. When fault is detected, DSTATCOM should react as fast as possible and inject an ac current to the grid. It can be implemented using a feedback control technique based on the current reference and load current.

This transformation is based on the transformation of currents in synchronously rotating d-q frame. The load currents which are in a-b-c frame are first transformed into α-β frame using Clark's transformation. Output of transformation block is connected to a phase lock loop (PLL) and another transformation block that converts αβ frame to dqo frame which detects fault in supply current. The fault detection block generates the reference supply current whenever fault is generated. The injection current is generated by difference between the reference current and load 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).

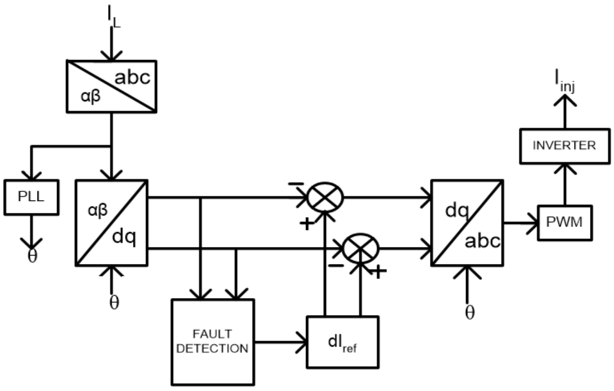

Fig.2: Control Sheme

IV. TEST SYSTEM

Simulation model of the test system for DSTATCOM is shown in Fig.3. Such system is composed by a 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.

In this test system, two similar loads with different feeders are considered. One of the feeders is connected to DSTATCOM and the other is kept as it is. This test system is analyzed under 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).

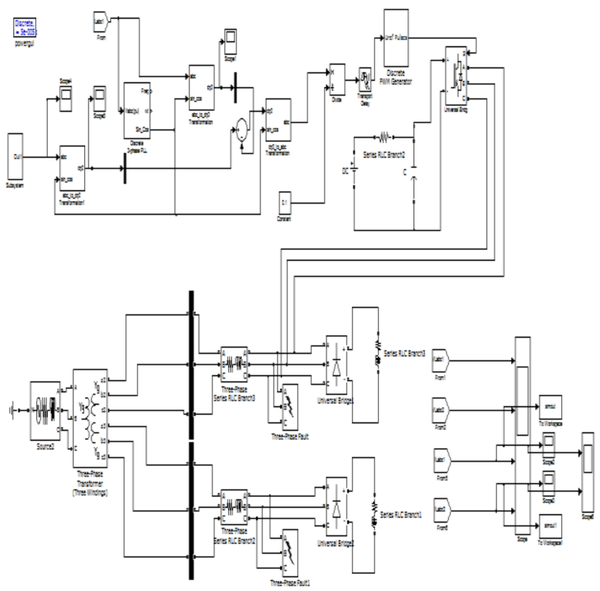

Fig.3: Simulation Diagram of Test System for DSTATCOM

V. PARAMETERS OF DSTATCOM TEST SYSTEM

System test parameters are listed below in table-1:

Table-1: System Parameters

Serial number	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.	Linear Load	400V rms (phase-phase), 50 Hz, 10 kW, 10 kVar.
5.	Non Linear Load	Non-linear Resistance (100ohm), Inductance (50$e^{-3} H$), 400V rms (phase-phase), 50 Hz.
6.	DTC 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.
7.	Transformer	Nominal power 200e3 VA, 50 Hz, 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.

VI. SIMULATION RESULTS

Here simulations are performed on the DSTATCOM test system using MATLAB SIMULINK. The system performance is analysed for compensate the load current harmonics in distribution networks under various fault conditions. Three cases of different load conditions are considered to study the impact of DSTATCOM in distribution system. Different cases are listed below:

Case I: Results for Linear load

Three different fault conditions are considered one by one for the test system delivering linear load. These three different fault conditions are single line to ground, double line to ground and three phase fault. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm for all the faults. The fault is created for the duration of 0.05s to 0.1s. The output waves for the load current without compensation are shown in Fig.4a, Fig.4b, and Fig.4c respectively. Here it is clear from the output wave shapes 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.4d.

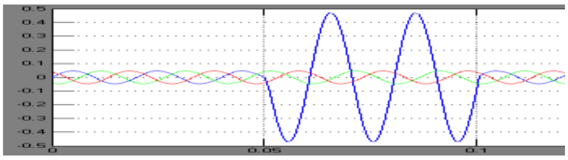

Fig.4a: Load Current for Single Line to Ground Fault(without compensation)

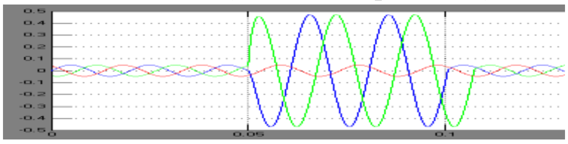

Fig.4b: Load Current for Double Line to Ground Fault (without compensation)

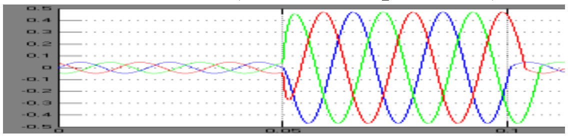

Fig.4c: Load current for Three Fault (without compensation)

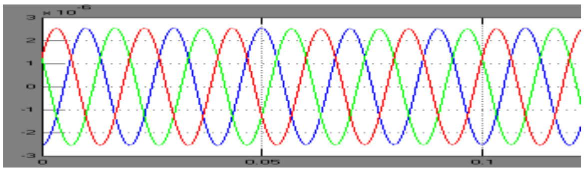

Fig.4d: Load Current (with compensation)

Case II: Results for Non-Linear Load

I. Result for Compensation of Harmonics

Here test system is considered under normal conditions. Due to the non-linear load connected to the system, harmonics are produced in load current waveform as shown in Fig.5a. When DSTATCOM is connected to the system it effectively reduces the harmonics from load current as shown in Fig.5b.

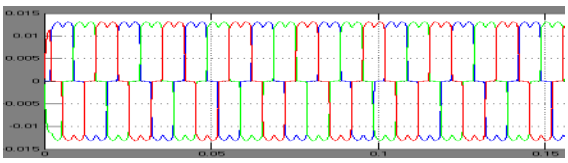

Fig.5a: Load current (without compensation)

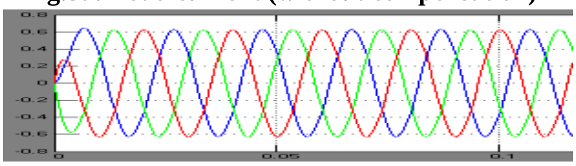

Fig.5b: Load current (with compensation)

II. Results for Fault Conditions

Here three different fault conditions, which are single line to ground, double line to ground and three phase fault, are considered one by one for the test system delivering non-linear load. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm for all the faults. The fault is created for the duration of 0.05s to 0.1s. The output waves for the load current without compensation are shown in Fig.6a, Fig.6b, and Fig.6c respectively. Here it is clear from the output wave shapes 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.6d.

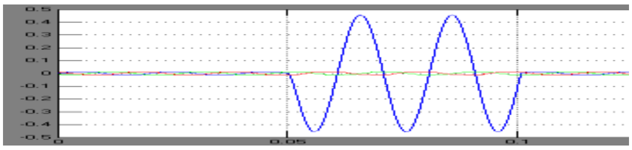

Fig.6a: Load Current for Single Line to Ground Fault (without compensation)

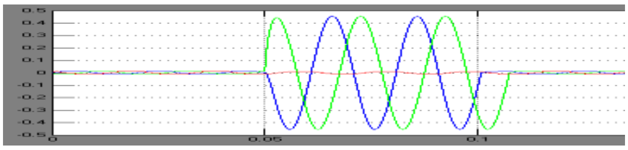

Fig.6b: Load Current for Double Line to Ground Fault (without compensation)

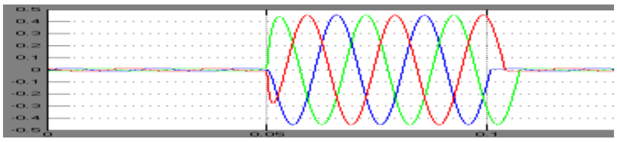

Fig.6c: Load current for Three Fault (without compensation)

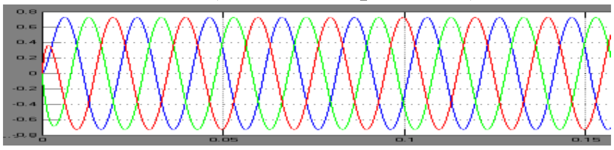

Fig.6d: Load Current (with compensation)

Case III: Results for DTC Induction Motor Drive

I. Result for Compensation of Harmonics

Here test system is considered under normal conditions. Due to DTC Induction Motor Drive connected to the system, harmonics are produced in load current waveform as shown in Fig.7a. When DSTATCOM is connected to the system it effectively reduce the harmonics from load current as shown in Fig.7b.

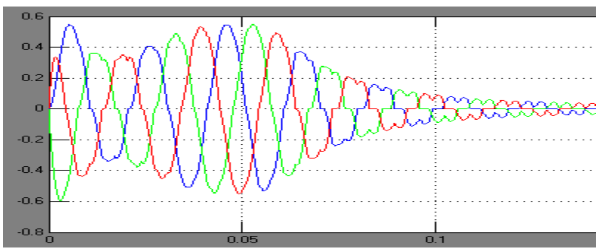

Fig.7a: Load current (without compensation)

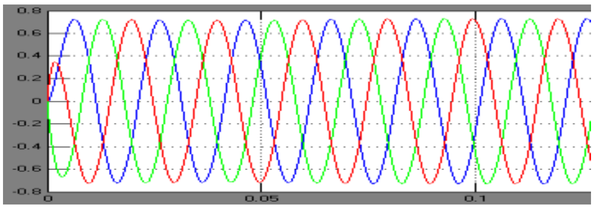

Fig.7b: Load current (with compensation)

II. Results for Fault Conditions

Three different fault conditions are considered one by one for the test system delivering DTC induction motor drive. These three different fault conditions are single line to ground, double line to ground and three phase fault. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm for all the faults. The fault is created for the duration of 0.12s to 0.18s. The output waves for the load current without compensation are shown in Fig.8a, Fig.8b, and Fig.8c respectively. Here it is clear from the output wave shapes 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.8d.

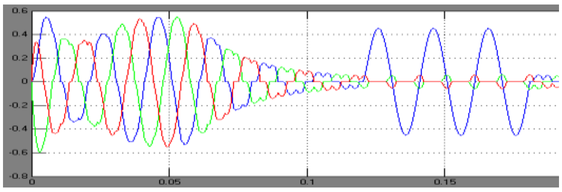

Fig.8a: Load Current for Single Line to Ground Fault (without compensation)

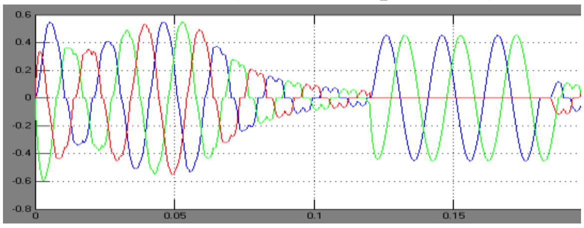

Fig.8b: Load Current for Double Line to Ground Fault (without compensation)

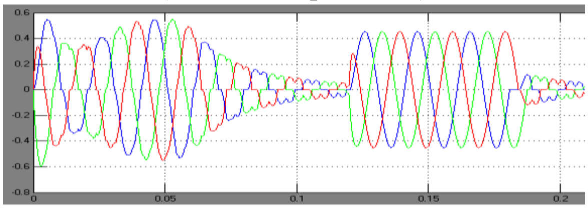

Fig.8c: Load current for Three Fault (without compensation)

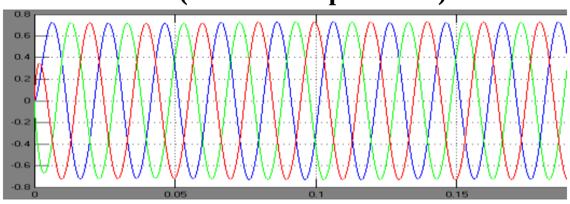

Fig.8d: Load Current (with compensation)

The Comparison of THD levels for different types of loads under normal and various faults conditions with or without DSTATCOM is shown in table-2. It is clear from the THD analysis that DSTATCOM effectively removes harmonics from load current and makes it smooth.

VII. Conclusions

In this paper DSTATCOM has been modeled and simulated in MATLAB environment. The performance of DSTATCOM has been analyzed for varying linear loads, non-linear loads and DTC induction motor drive, using dqo transformation technique. DSTATCOM has been found to regulate PCC current under varying load condition and load unbalancing. It is clear from comparison of THD analysis for different types of loads under normal and various faults conditions that DSTATCOM reduces harmonics from load current very effectively and makes it smooth. According to IEEE standards the THD level must remain below 5% and DSTATCOM effectively reduces THD level below 5%. It is concluded that DSTATCOM has a huge scope in improving power quality in distribution systems.

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Sr. No.	**System Conditions**	**Without DSTATCOM**		**With DSTATCOM**	
		Load Current (Fundamental) In P.U.	**THD**	**Load Current (Fundamental) In P.U.**	**THD**
1.	Linear Load				
	a) Single Line to Ground fault	0.04698	4.47 %	2.545e-6	0%
	b) Double Line to Ground fault	0.04698	4.46 %	2.545e-6	0%
	c) Three Phase fault	0.04698	4.48 %	2.545e-6	0%
2.	Non Linear Load				
	a) Normal Condition	0.01395	28.09%	0.7284	0.07%
	b) Single Line to Ground fault	0.01397	29.13%	0.7284	0.07%
	c) Double Line to Ground fault	0.01392	29.07%	0.7285	0.08%
	d) Three Phase fault	0.01392	28.90%	0.7284	0.08%
3.	DTC Induction Motor Drive				
	a) Normal Condition	0.01395	44.49%	0.7284	0.29%
	b) Single Line to Ground fault	0.1015	13.93%	0.7271	0.26%
	c) Double Line to Ground fault	0.1046	14.03%	0.7272	0.26%
	d) Three Phase fault	0.1047	14.02%	0.7266	0.27%

Table-2: THD Levels of Test Systems