Load Compensation by Diesel Generator and Three Level Inverter Based DSTATCOM

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***Abstract*- This paper presents the load compensation by diesel generator. In this compensation reactive power, harmonics and unbalanced load current generates because of linear or non-linear loads. The control of Distribution Static Synchronous Compensator (DSTATCOM) is used for reactive power, harmonics and unbalanced load current compensation. Proportional – Integral (PI) controller is used to maintain a constant voltage at the dc – bus of a voltage – source converter (VSC) working as a DSTATCOM. Switching of Three Level VSC is achieved by controlling load current using Sinusoidal Pulse Width Modulation (SPWM) control. This scheme is simulated under MATLAB environment using simulink toolboxes for feeding linear and nonlinear loads. The modeling is performed for a three – phase, three – wire star – connected synchronous generator coupled to a diesel engine, along with the three level inverter based VSC working as a DSTATCOM.**

***Keywords*- Diesel Generator set, DSTATCOM, Harmonic Elemination, load compensation.**

I. INTORDUCTION

Installation of the diesel engine-based electricity generation unit is a widely used practice to feed the power to some crucial equipment in remote areas [1], [2]. The source impedance of the Diesel Generator set (DG set) is quite high, and the unbalanced and distorted currents lead to the unbalanced and distorted three-phase voltages at point of common coupling (PCC), Harmonics and unbalanced currents flowing through the generator result into torque ripples at the generator shaft due to these factors increased fuel consumption and reduced life of the DG sets. DSTATCOM can be used with a three-phase DG set to feed unbalanced loads without derating the DG set and to have the same cost involved.

The performance of DSTATCOM is very much dependent on the method of deriving reference compensating signals [9]. Instantaneous reactive power theory, modified p-q theory, synchronous reference frame theory, instantaneous i_d – i_q theory, and method for estimation of reference currents by maintaining the voltage of dc link are generally reported in the literature for an estimation of reference currents for the DSTATCOM through the extraction of positive-sequence real fundamental current component from the load current [3]–[5]. These techniques are based on complex calculations and generally incorporate a set of low-pass filter which results in a delay in the computation of reference currents and therefore leads to slow dynamic response of the DSTATCOM [10].

This paper presents a DSTATCOM for the load compensation of a diesel generator set to enhance its performance [6]-[8]. The control of DSTATCOM with capabilities of reactive power, harmonics and unbalanced load compensation is achieved by Sinusoidal Pulse Width Modulation technique. The dc-bus voltage of voltage source converter (VSC) is supported by a proportional–integral (PI) controller which computes voltage component to compensate losses in DSTATCOM [10].

These weights are measure of peak of fundamental frequency real current component of the load current. The life of a DG set is enhanced in the absence of unbalanced and harmonic currents. The modeling of the DG set is performed using a synchronous generator, a speed governor, and the excitation control system. This proposed system is simulated under MATLAB environment using Simulink.

II. SYSTEM CONFIGURATION

A three phase three-wire DG set feeding to variety of load is shown in fig. 1. A 30 kVA system is chosen to demonstrate the work of the system with the DSTATCOM. The load voltage is tracked and compared with reference voltage by Sinusoidal PWM current controller that provides switching signals for VSC-based DSTATCOM. It controls load currents to follow a set of three phase reference currents. The parameters of a salient pole synchronous generator are shown in appendix. The other critical parameters are given in Table I.

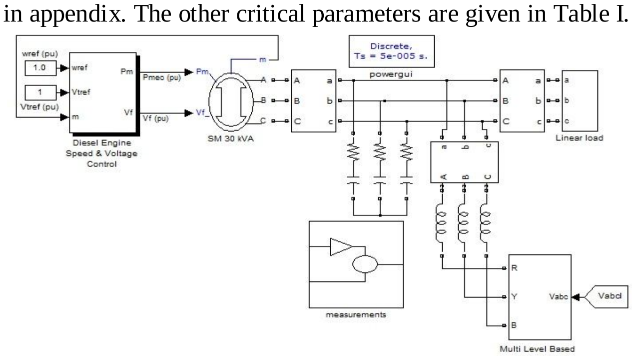


Fig. 1 Circuit Diagram (MATLAB Diagram) of proposed model for Linear Load

TABLE I
SPECIFICATIONS OF PROPOSED SYSTEM

Load	Linear	Star Connected R-L load of 37.5kVA at 0.8pf
	Nonlinear	30kW Diode bridge converter with filter at output with L=2mH and C=500µF

III. CASCADED MULTILEVEL INVERTER

The multilevel inverters have drawn tremendous interest in the power industry. They present a new set of features has are well suited for use in reactive power compensation. It may be easier to produce a high-power, high-voltage inverter with the multilevel structure because of the way in which device stresses are controlled in the structure. Increasing the number of voltage levels in the inverter without requiring higher ratings on individual devices can increase the power rating. The unique structure of multilevel voltage source inverters allows them to reach high voltages with low harmonics without the use of transformers or series-connected synchronized-switching devices. As the number of voltage levels increases, the harmonic content of the output voltage waveform decreases significantly.

The general structure of the multilevel converter is to synthesize a near sinusoidal voltage sources. As the number of level increases, the synthesized output waveform has more steps, which produce a staircase wave that approaches a desired waveform. Also, as more steps are added to the waveform, the harmonic distortion of the output wave decreases, approaching zero as the number of levels increases. As the number of levels increases, the voltage that can be spanned by summing multiple voltage levels also increases. The output voltage during the positive half-cycle can be found from

$$V_{ao} = \sum_{n=1}^{m} E_n SF_n$$

Where *SFn* is the switching or control function of *n*th node and it takes a value of 0 or 1.

The multilevel inverters can be classified into three types.

1. Diode-clamped multilevel inverter;
2. Flying-capacitors multilevel inverter;
3. Cascaded multilevel inverter.

Cascaded Multilevel Inverter:

A cascaded multilevel inverter consists of a series of H-bridge (single-phase, full-bridge) inverter units. A single-phase structure of an *m*-level cascaded inverter is illustrated in Fig.3. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, *0*, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_1, S_2, S_3, and S_4. To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_2 and S_3. By turning on S_1 and S_2 or S_3 and S_4, the output voltage is *0*. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels *m* in a cascade inverter is defined by $m = 2s+1$, where *s* is the number of separate dc sources. An example phase voltage waveform for an 11-level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Fig.2. The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}$. For a stepped waveform such as the one depicted in fig.2 with *s* steps, the Fourier Transform for this waveform follows,

$$V(\omega t) = \frac{4V_{dc}}{\pi} \sum_{\pi} [\cos(n\theta_1) + \cos(n\theta_2) + \ldots + \cos(n\theta_s)] \frac{\sin(n\omega t)}{n},$$

where n = 1,3,5,7,…..

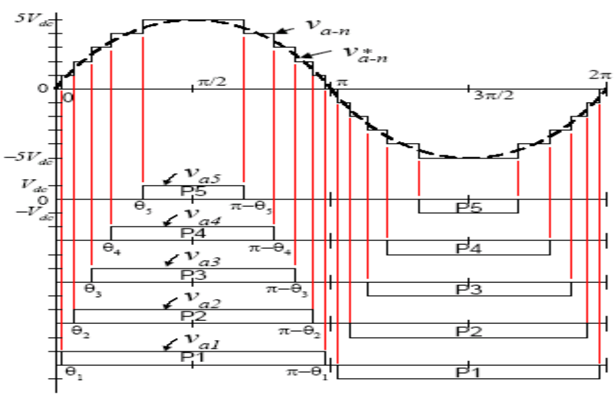


Fig. 2. Output Phase Voltage waveform of an 11-level cascade inverter with 5 separate dc sources.

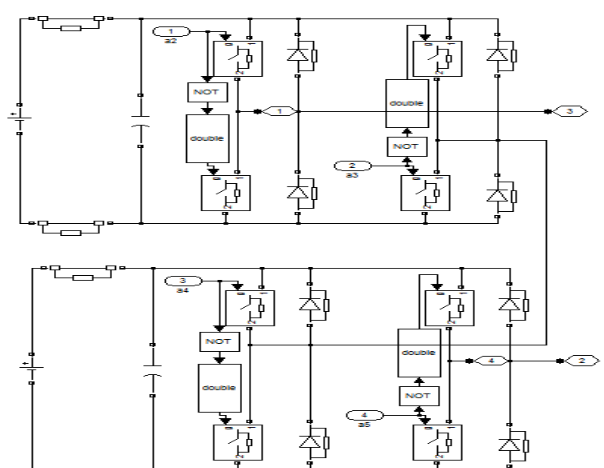


Fig. 3. Three Level cascaded H-Bridge leg

Carrier-based PWM schemes

The carrier-based modulation schemes for multilevel inverters can be generally classified into two categories: *Phase-shifted* and *level-shifted modulations*. Both modulation schemes can be applied to the CHB inverters.

Phase-Shifted Multicarrier Modulation

In general, a multilevel inverter with *m* voltage levels requires (*m* – 1) triangular carriers. In the phase-shifted multicarrier modulation, all the triangular carriers have the same frequency and the same peak-to-peak amplitude, but there is a phase shift between any two adjacent carrier waves, given by $\Phi_{cr} = 360°/(m-1)$

The sinusoidal signal $V_{control}$ is phase-modulated by means of the angle α.

$$V_A = \mathrm{Sin}\,(\omega t + \delta);\ V_B = \mathrm{Sin}\,(\omega t + \delta - 2\pi/3);$$
$$V_C = \mathrm{Sin}\,(\omega t + \delta + 2\pi/3)$$

The modulated signal $V_{control}$ is compared against a phase shifted triangular signals in order to generate the switching signals for the VSC valves. The main parameters of the phase shifted PWM scheme are the amplitude modulation index of signal, and the frequency modulation index of the triangular signal. The amplitude index is kept fixed at 1 pu, in order to obtain the highest fundamental voltage component at the controller output.

$$M_a = \frac{V_{control}}{V_{tri}} = 1\text{p.u}$$

Where $V_{control}$ is the peak amplitude of the control signal. V_{tri} is the peak amplitude of the triangular signals.

The switching frequency is set at 2000 Hz. The frequency modulation index is given by

$$M_f = f_s/f_1$$

Where f_1 is the fundamental frequency

The modulating angle is applied to the PWM generators in phase A. The angles for phases B and C are shifted by 240^0 and 120^0, respectively. It can be seen in that the control implementation is kept very simple by using only voltage measurements as the feedback variable in the control scheme. The speed of response and robustness of the control scheme are clearly shown in the simulation results.

The total number of active switches (IGBTs) used in the CHB inverters can be calculated by $N_{sw} = 6(m-1)$

IV. CONTROLLER

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the r.m.s voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favored in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. A PI controller the output is the angle δ, which is provided to the PWM signal generator, processes such error. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller process the error signal generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

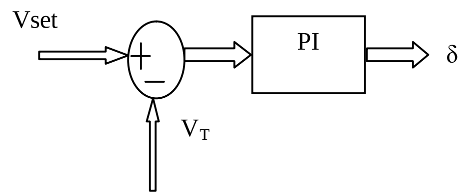


Fig. 4. PI Controller for DSTATCOM

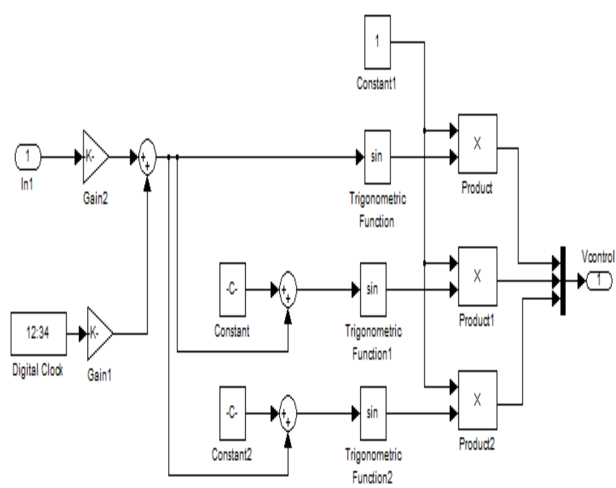


Fig. 5 Generation of reference control signals for PWM controller

V. MATLAB SIMULATION

Fig.6 shows the MATLAB model of the DSTATCOM-DG set isolated system. The modeling of the DG set is carried out using a star connected synchronous generator of 30 kVA, controlled by a speed governor and an excitation system. The linear load applied to the generator is at 0.8 lagging pf which is modeled as a delta connection of the series combination of resistance and inductance (R-L) models. The nonlinear load is modeled using discrete diodes connected in a bridge with a capacitor filter and a resistive load on the dc bus.

The simulation of the DSTATCOM-DG isolated system is carried out with different types of loads i.e., a linear R-L load, a nonlinear load i.e., a diode bridge converter load. The load compensation is demonstrated for these types of loads using DSTATCOM system for an isolated DG set. The following observations are made on the basis of obtained simulation results under different system conditions.

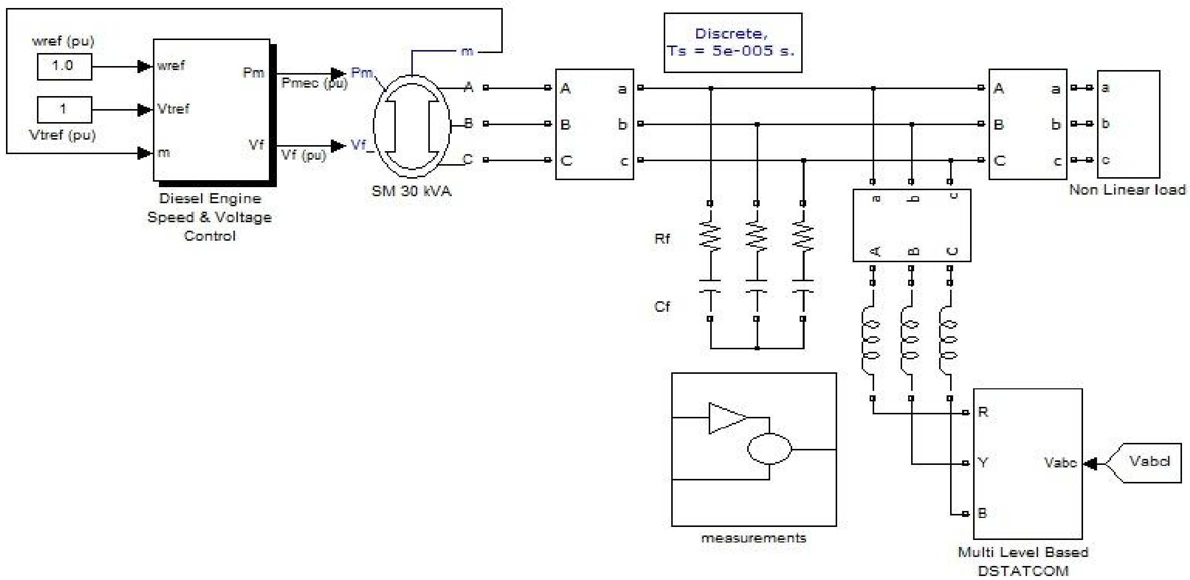
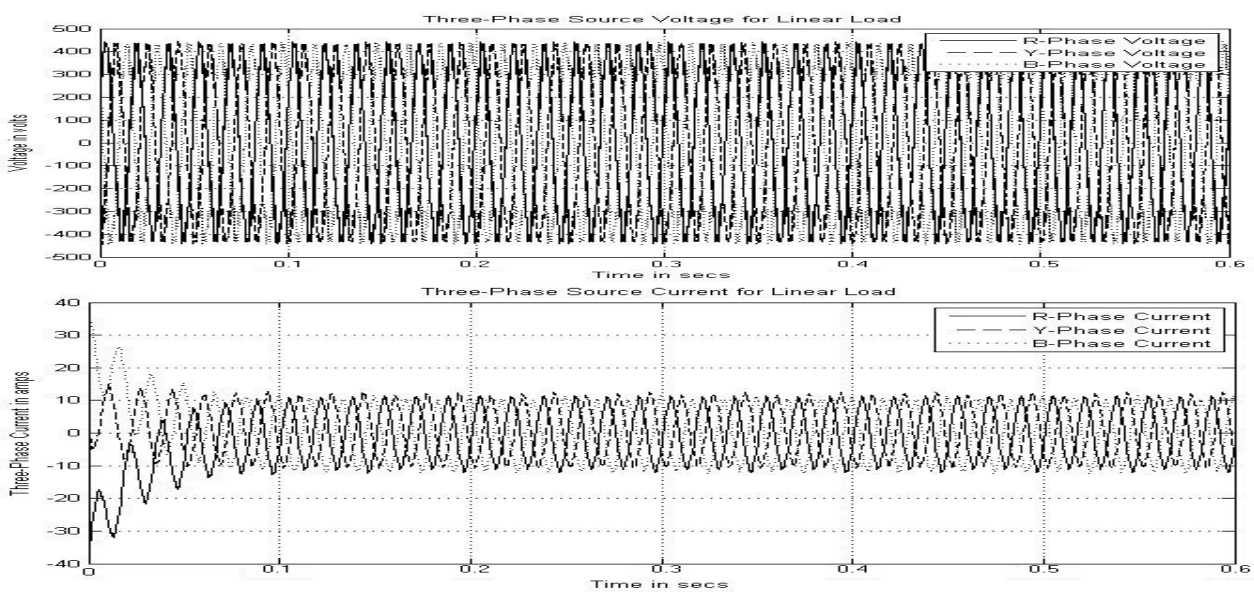


Fig. 6 MATLAB model for the proposed system (with Non-Linear load)



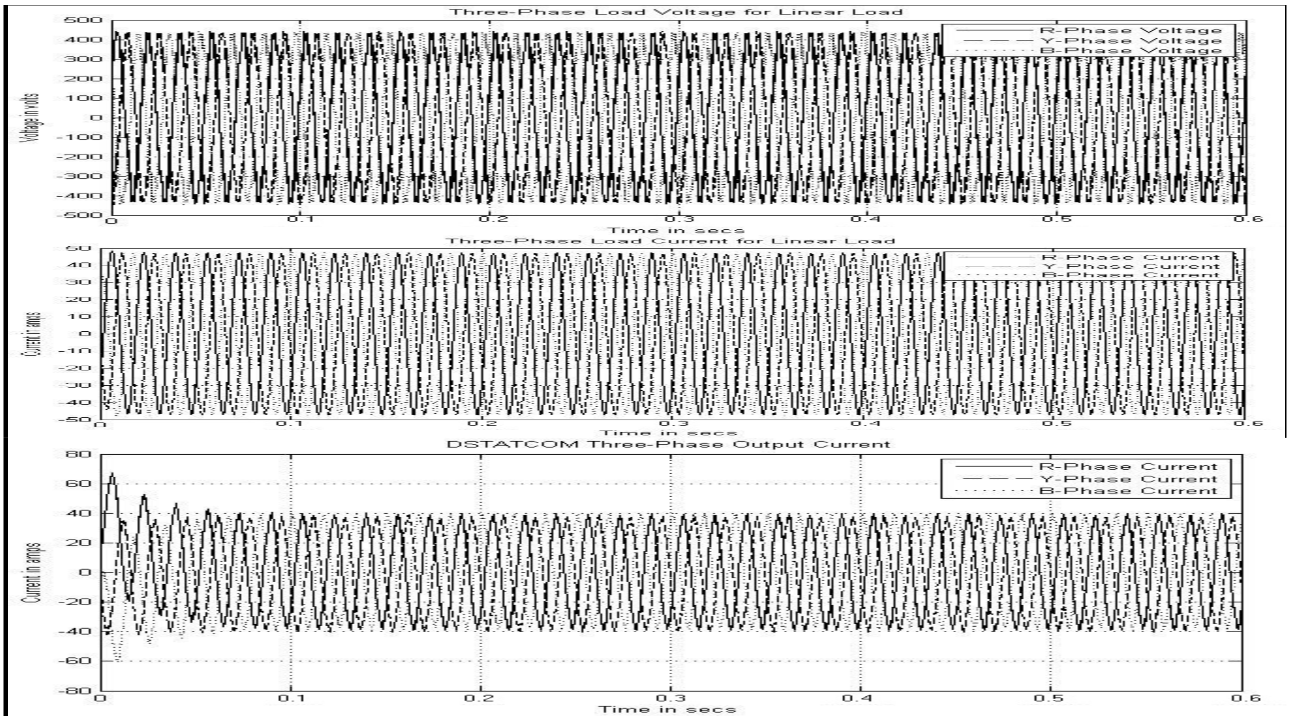


Fig. 7 Three Phase Input Voltage, Current and Output Voltage, Current Waveforms for Linear load and DSTATCOM Output Current (all are MATLAB outputs from scope)

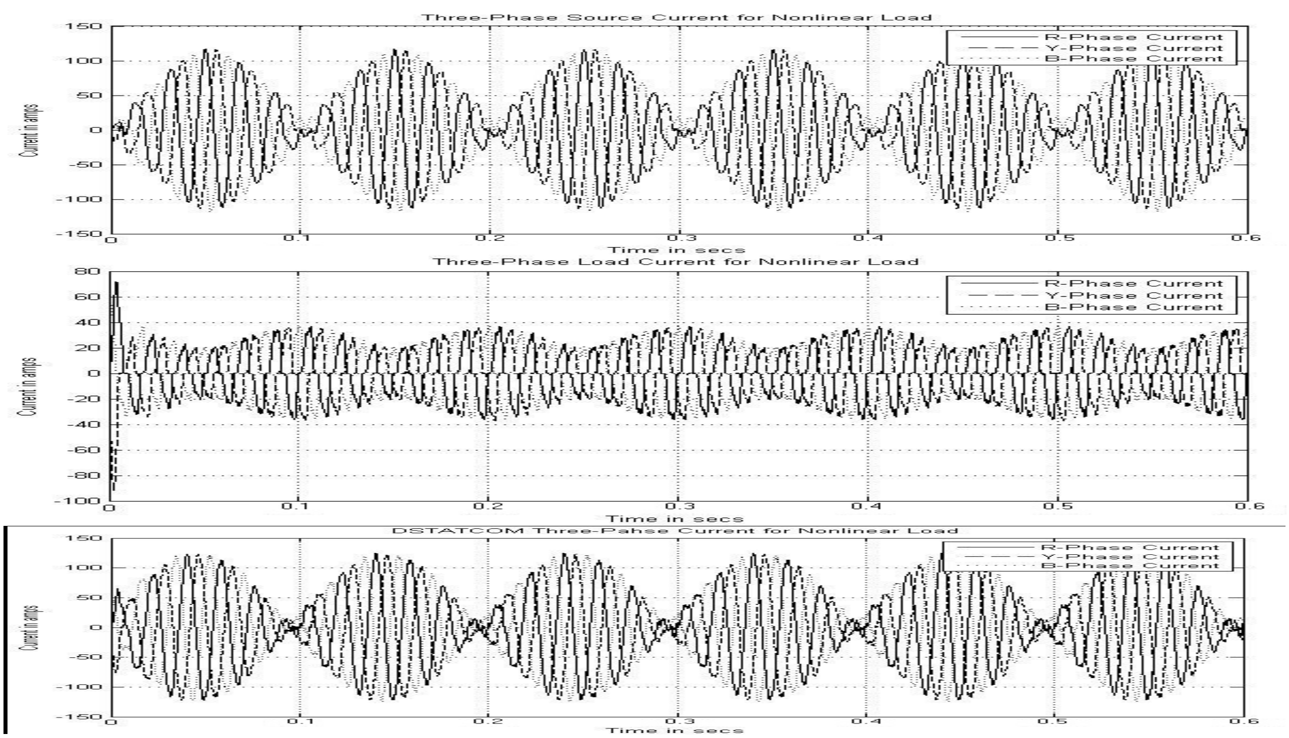


Fig. 8 Three Phase Input Current and Output Current Waveforms for Non-Linear load and DSTATCOM Output Current (all are MATLAB outputs from scope)

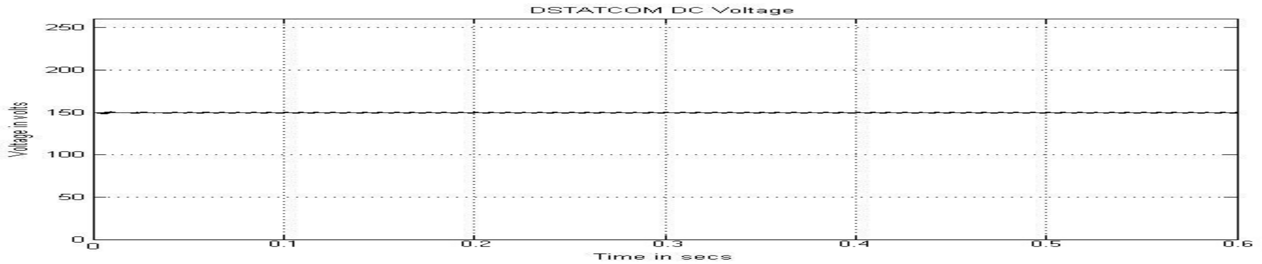


Fig. 9 Five Level Inverter DC Voltage (all are MATLAB outputs from scope)

VI. CONCLUSION

The proposed control algorithm of the DSTATCOM has been found to improve the performance of the isolated DG system. The DSTATOM has compensated the variety of loads on the DG set and it has sinusoidal voltages at PCC and currents with compensated and equivalent linear balanced unity power factor loads. The cost of the installation of DSTATCOM system with the DG set can be compensated as it leads to less initial and running cost of DG set as its ideal operation while feeding variety of loads.

APPENDIX

Generator Voltage = 415 V,
Generator kVA = 30 kVA,
Pole = 4,
Speed = 1500 rpm,
Frequency = 50 Hz,
X_d = 1.56 pu,
X_d' = 0.15 pu,
X_d'' = 0.11 pu,
Xq =0.78,
X_q' = 0.17,
X_q'' = 0.6,
H_s = 0.08.

ACKNOWLEDGMENT

It is our sincere obligation to thank our well-wishers Mr. K. Murali, M.Tech in stream of power system engineering, has been Completed at NIT Warangal.

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