Dynamic performance of the DSTATOM – Diesel Generator system with Linear and Nonlinear loads using Multi Layer Neural Network

Golla jaya Prasad, U Chandra Rao, Ch Rambabu

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 nonlinear 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 hysteresis based Pulse Width Modulation control. This scheme is simulated under MATLAB environment using simulink for feeding linear and nonlinear loads. The modelling 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. The extension part utilizes multi layer neural network for to improve the DC voltage profile (Vdc) and to improve the THD analysis. Compare this with previous results.**

Index Terms—**Adaptive Linear Element (ADALINE), Least Mean Square Algorithm (LMS), Diesel Generator Set (DG set), Voltage-Source Converter (VSC), Distribution Static Synchronous Compensator (DSTATCOM), Pulse Width Modulation (PWM), Proportional-Integral (PI), Load Compensation, Harmonic elimination.**

I. INTRODUCTION

In present day, many electrical power applications require continuous and high quality power. It can be achieved by means of a standby diesel-electric generating set. The diesel generator is a combination of a diesel engine with an electrical generator and is used to produce electrical energy [3]. Diesel Generator (DG) set acts as a source used to produce the power in the places without the connection of power grid. So that it can be termed as a standby or an emergency power supply. DG set is used to feed the power to some crucial equipment in remote areas and are loaded with unbalanced, reactive, nonlinear loads such as power converters, power drives, laser printer, arc lamp, arc welding etc Due to the nonlinear loads, there will high harmonic current at the distribution end. Power quality issues are gaining significant attention due to the increase in nonlinear loads. Since, almost all the power problems originate from disturbances in the distribution network. Due to these distortions, the generator will produce the torque ripples at the generator shaft. Hence, these problems lead to increase in fuel consumption and reduction in life of the DG set. Ultimately, it results in the increase in system cost. The shunt compensator has the ability to solve many power quality problems faced by the distribution system. Conventionally, Static VAR Compensators (SVC) has been installed at the distribution end, to overcome power quality problems. Due to increasing non-linearity in loads, the SVC has drawbacks such as poor dynamic performance and also it will not support the system under low voltage conditions. To overcome these drawbacks, DSTATCOM has been proposed which is a most effective device used at the Point of Common Coupling (PCC). Distribution Static Compensator (DSTATCOM) is basically a converter based Flexible AC Transmission System (FACTS) controller which has a similar concept as that of a STATCOM used at transmission level. STATCOM applied in the distribution system is termed as DSTATCOM. Hence, reactive power control using DSTATCOM is gaining an immense popularity. It is mainly used for load balancing, harmonic elimination and reactive power control. The DSTATCOM performance is very much dependent on the method of deriving reference compensating signals. Synchronous reference frame theory, method for estimation of reference currents by maintaining the voltage of dc link, instantaneous reactive power theory, modified p-q theory and instantaneous id−iq theory 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 [5]–[8]. These techniques 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.

For controlling DSTATCOM, there are number of controllers reported in the literature survey for extracting the reference current such as Linear Matrix Inequalities (LMI) based controller, modified power balance theory, synchronous reference frame theory, instantaneous reactive power p-q theory and modified instantaneous symmetrical component theory [2] .All the above mentioned controllers are complex in calculation and have slow response. In this paper, a fast and simple neural network-based control scheme is used to estimate reference source currents for the control of the DSTATCOM. This paper presents a DSTATCOM for the

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load compensation of a diesel generator set to increase its performance.

The control of DSTATCOM with capabilities of reactive power, harmonics and unbalanced load compensation is achieved by Least Mean Square (LMS) algorithm [9]-[10] based adaptive linear element (Adaline). The Adaline is generally used to extract positive-sequence fundamental frequency real component of the load current. The dc-bus voltage of voltage source converter (VSC) is supported by a proportional–integral (PI) controller which computes current component to compensate losses in DSTATCOM. 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 by MATLAB/Simulink [11]. The results for a 30-kVA DG set with the linear load at 0.8 lagging pf and a nonlinear load with different load dynamics and unbalance load conditions are presented to demonstrate the effectiveness of DSTATCOM-DG set system

II. CONFIGURATION OF THE SYSTEM AND SPECIFICATIONS

The configuration of the system shown in fig.1, for a three phase three-wire DG set feeding to variety of loads such as linear and nonlinear loads. A 30 kVA system is chosen to demonstrate the work of the system with the (VSC) system. AC inductor is used to interface the VSC to the line at PCC. If any distortions occur in the distribution system, then the load currents and the source voltages are sensed by using the controlling algorithm. The purpose of control algorithm is used to generate the reference currents. Then the hysteresis based Pulse Width Modulation (PWM) current controller compares the reference and source currents and generate the switching pulses to the VSC. According to the pulses given, the VSC based DSTATCOM will be turned on and it in jects the current to the line through the AC inductor at the PCC point and the distortion will be compensated.

The parameters of a salient pole synchronous generator are 415 V, 30 kVA, 4 pole, 1500 rpm, 50 Hz, Xd = 1.56 pu, Xd' = 0.15 pu Xd'' = 0.11 pu, Xq =0.78, Xq' = 0.17, Xq'' = 0.6, Hs = 0.08. The other critical parameters are given in Table

TABLE I: SYSTEM SPECIFICATIONS

Load	***Linear***	Delta connected R-L load of 37.5KVA at 0.8 pf
	Non linear load	30 KW Diode bridge converter with LC filter at output with L=2mH and C=500µF
Voltage Source Converter	DC link capacitor Cdc=10000 µF, AC inductor=3mH, Ripple Filter: Cr=10µF and Rr=8Ω,fs=20kHz	

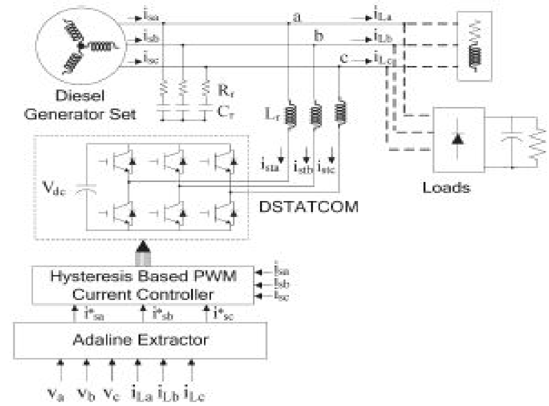


Fig.1. Basic configuration of DG set with DSTATCOM

III. PROPOSED METHOD FOR CONTROLLER

The system operation requires a DG set to supply real power needed to the load and some losses (switching losses of devices used in VSC, losses in the reactor, and dielectric losses of the dc capacitor) in DSTATCOM. Therefore, the reference source current used to decide the switching of the DSTATCOM has two parts. One is real fundamental frequency component of the load current, which is being extracted using Adaline and another component, which corresponds to the losses in the DSTATCOM, are estimated using a PI controller over dc voltage of DSTATCOM. Fig. 2(a) shows the control scheme for the implementation of reactive, unbalanced and harmonic currents compensation.

The output of the PI controller is added to the weight calculated by the Adaline to maintain the dc-bus voltage of the DSTATCOM.

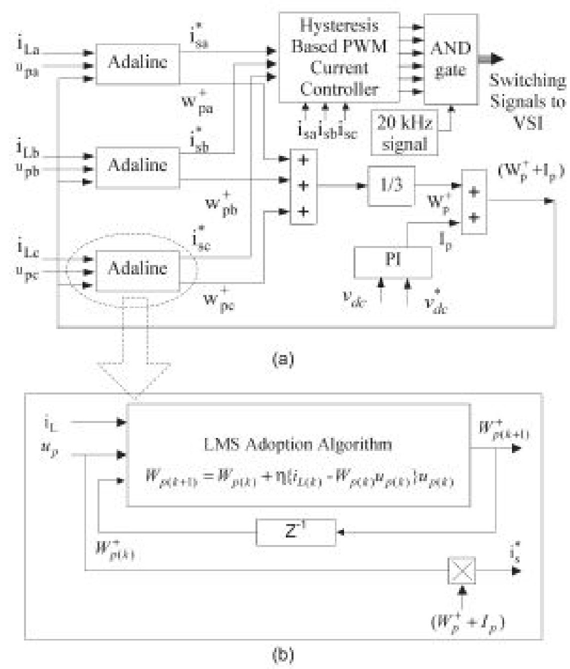


Fig. 2. (a), (b). Control block diagram of the reference current extraction scheme

3.1. Real positive-sequence fundamental frequency current Extraction from load current

The proposed decomposer's basic theory is based on LMS

Algorithm and its training through Adaline, which tracks unit voltage vector templates to maintain minimum error. The basic concept of theory used here can be understood by considering the analysis in single-phase system which is given. For an ac system, the supply voltage may be expressed as

$$vs = V \sin \omega t \qquad (1)$$

Where vs is the instantaneous ac terminal voltage, V is an Amplitude and ω is the angular frequency of the voltage. The load current (iL) consists of active current ($ip+$), reactive Current ($iq+$) for the positive sequence, negative-sequence current ($i-$), and harmonic frequency current (ih) can be written as summation of different parts as

$$iL = ip+ + iq+ + i- + ih. \qquad (2)$$

The control algorithm is based on the extraction of the current component in phase with unit voltage template. To estimate the fundamental frequency positive-sequence real component of load current, the unit voltage template should be in phase with the system voltage and should have unit amplitude. The unit voltage template (up) derived from the system phase voltage can be represented as:

$$up = vs/V. \qquad (3)$$

For proper estimation of the current components of the load current, the unit voltage templates must be undistorted. In case of the voltage being distorted, the zero crossing of phase voltage is detected to generate sinusoid(sinwt) vector template, synchronized with system terminal voltage. An initial estimate of the active part of load current for single-phase can be chosen as

$$ip+ = Wpup \qquad (4)$$

where weight (Wp) is estimated using an Adaline. This weight is variable and changes as per the load current. The scheme for estimating weights corresponding to fundamental frequency real component of load current (for three-phase system), based on LMS algorithm-tuned Adaline tracks the unit vector templates to maintain minimum error. The estimation of the weight is given as per the following iterations:

$$Wp(k+1)=Wp(k)+\eta(iL(k)-Wp(k)up(k))up(k) \qquad (5)$$

Where subscript k and k + 1 represent sample instant and η is the convergence coefficient. The value of convergence coefficient decides the rate of convergence and the accuracy of the estimation. The practical range of convergence coefficient lies in between 0.1 to 1.0. Three-phase reference currents corresponding to positive-sequence real component of the load current may be computed as

$$ipa+=Wp+upa;:ipb+=Wp+upb;ipc+=Wp+upc \qquad (6)$$

$$Wp+ = (Wpa+ +Wpb+ +Wpc+)/3 \qquad (7)$$

where $Wp+$ is averaged weight. Weights of phase a, b and c are averaged to compute the equivalent weight for positive sequence current component in the decomposed form. The averaging of weights helps in removing the unbalance in load current components.

3.2. PI controller for maintaining constant dc-bus voltage of DSTATCOM

To compute the second component of reference active power current, a reference dc-bus voltage is compared with sensed dc bus voltage of DSTATCOM. This comparison of sensed dc-bus voltage (vdc) to the reference dc-bus voltage (vdc^*) of VSC, results in a voltage error ($vdcl$), which in the nth sampling instant is expressed as

$$vdcl(n) = vdc^*(n) - vdc(n). \qquad (8)$$

This error signal is processed in a PI controller and output $\{Ip(n)\}$ at the nth sampling instant is expressed as:

$$Ip(n)=Ip(n-1) + Kpdc\,(vdcl(n) - vdcl(n-1)) + Kidc\,vdcl(n)$$

where $Kpdc$ and $Kidc$ are proportional and integral gains of the PI controller. The output of the PI controller accounts for the losses in DSTATCOM and it is considered as the loss component of the current, which is added with the weight estimated by the Adaline corresponding to fundamental frequency positive sequence reference active current component. Therefore, the total real reference current has component corresponding to the load and component corresponding to feed the losses of DSTATCOM, is expressed
as

$$isa^* = (Wp+ + Ip)\,upa;\ isb^* = (Wp+ + Ip)\,upb;$$
$$isc^* = (W+p + Ip)\,upc. \qquad (10)$$

These three-phase currents are considered reference source currents $iref$ (isa^*, isb^* and isc^*) and along with sensed source currents $iact$ (isa, isb and isc), these are fed to the hysteresis based PWM current controller to control the source currents to follow these reference currents. The switching signals generated by the PWM current controller force actual source currents to acquire shape close to the reference source currents. This indirect current control results in the control of the slow varying source current (as compared to DSTATCOM currents) and therefore requires less computational efforts. Switching signals are generated on the following logic:

if ($iact$) < ($iref - hb/2$) upper switch of the leg is ON and lower switch is OFF

if ($iact$) > ($iref + hb/2$) upper switch of the leg is OFF and lower switch is ON

where hb is hysteresis band around the reference current $i$ref .

The weights are computed online by LMS algorithm. The update equation of weights based on LMS algorithm is described in (5) for each phase. The structure of such Adaline is depicted in Fig. 2(b). Weights are averaged not only for averaging at fundamental frequency but to cancel out sinusoidal oscillating components in weights present due to harmonics in the source current. The averaging of weights in different phases is shown in Fig. 2(a). Thus Adaline is trained at fundamental frequency of a particular sequence in-phase with voltage. Fig. 2(a) and (b) show the detailed scheme implemented for control of DSTATCOM. Because of the unbalance in the load currents, a second harmonic ripple is produced in the dc-bus voltage. Similarly, harmonics in the load currents also produce ripple at dc-bus voltage. However, this ripple is at higher frequency as compared to the second harmonic ripple. These ripples have to be filtered out before feeding the signal of the PI controller; otherwise this may introduce the harmonics component in source currents (predominantly because of harmonic ripple at dc bus). For this purpose the dc-bus voltage is filtered using a low-pass filter (LPF). Since major amount of reference current (load real current component) is computed using Adaline-based extractor, effect of the delay caused by the LPF is negligible in practical cases.

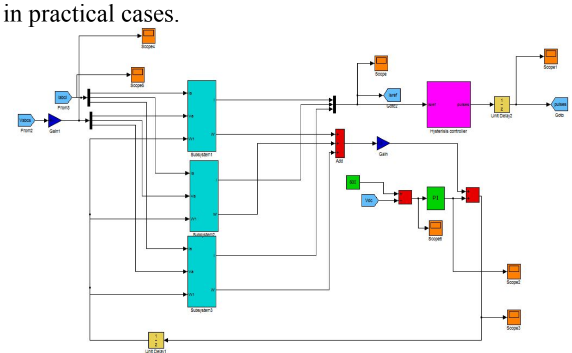


Fig-3 simulink model of the control scheme for the ADALINE neural network

IV. MULTI LAYER NEURAL NETWORK

The extension part utilizes Multi layer neural network to improve the voltage profile (Vdc) and observe an improvement of THD analysis. Multilayer feed forward network is a particular type of neural networks. It consists of a set of source nodes which forms the input layer, one or more hidden layers, and one output layer. The input signal is applied in a forward direction through the network, on a layer-by-layer basis. A multilayer perceptron network contains one input layer one or more hidden layers and one output layer. The input layer consists of input data of the network. The hidden layer consists of computational nodes known as hidden neurons. The hidden neurons perform function of the interaction between the external input and network output in an efficient manner and extraction of higher order statistics. The function of the source nodes, in input layer of network, is to supply the input signal to neurons in the second layer (first hidden layer). The second layer's output signals are applied as inputs to the third layer and so on. The set of output signals constitutes the overall response of network to the activation pattern supplied by source nodes in the input first layer. The back-propagation learning algorithm is applied for training Multi Layer Perceptron (MLP) networks which is based on supervised learning. The algorithm is applied for adapting weights and biases of the neural network and reducing the error in its predictions on the training set. Training of the weight is carried out by Generalized Delta Rule also known as Back Propagation algorithm (BPA). The neural network consist three layers. These are input, hidden, and output Layers. During the training lagging pf which is modeled as a delta connection of the phase, the training data is fed into to the input layer. The data is propagated to the hidden layer and then to the output layer. This is called the forward pass of the back propagation algorithm. In forward pass**,** each node in hidden layer gets input from all the nodes from input layer, which are multiplied with appropriate weights and then summed. The output of the hidden node is the nonlinear transformation of the resulting sum. Similarly each node in output layer gets input from all the nodes from hidden layer, which are multiplied with appropriate weights and then summed. The output values of the output layer are compared with the target output values**.** The target output values are those that we attempt to teach our network. The error between actual output values and target output values is calculated and propagated back toward hidden layer. This is called the backward pass of the back propagation algorithm. The error is used to update the connection strengths between nodes. That is weight matrices between input-hidden layers and hidden-output layers are updated. During the testing phase, no learning takes place the weight matrices are not changed. Each test vector is fed into the input layer. The feed forward of the testing data is similar to the feed forward of the training data. From fig.7,8 we can observe the dynamic performance of the DSTATCOM-DG isolated system feeding linear and non-linear loads. By using multi layer neural network the voltage profile (Vdc) maintain at constant. The harmonic spectra of the phase-a voltage at PCC, load current and source currents are showing fig.10. we improve the THD analysis.

V. MATLAB BASED SIMULATION MODEL

Fig.5. 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

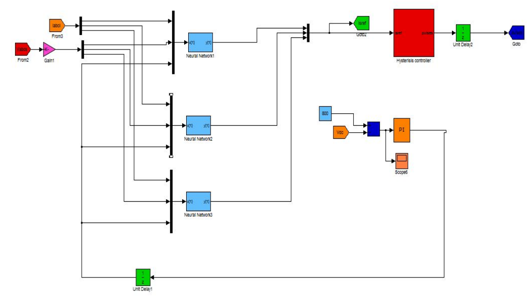


Fig.4.simulink model of the control scheme using multi layer neural network

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 unbalanced was created by disconnecting phase-a from the diode bridge organization

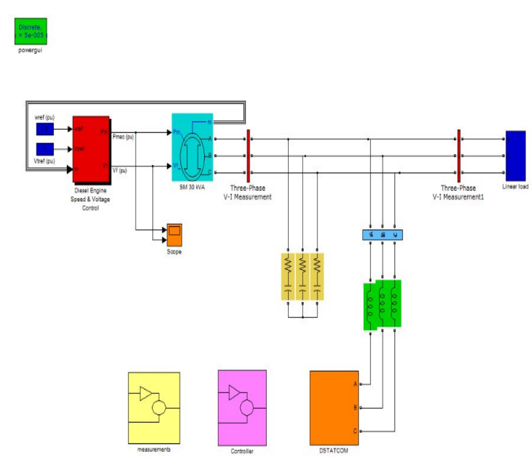


Fig.5.simulink model of basic DG set with DSTATCOM

VI. RESULTS AND DISCUSSION

The simulation is carried out for to demonstrate the load compensation of DG set for an isolated system by using

DSTATCOM, feeding both linear and nonlinear loads. The following observations are observed in simulation results under different system conditions.

6.1. DG Set System Operation Under Linear Load

Fig.6. shows the dynamic performance of the DG set with DSTATCOM system. From t = 2.10 s to 2.12 s, a three-phase 18.75-kVA load at 0.8 pf is being connected. At t = 2.12 s, the load is increased upto 37.5 kVA at 0.8 pf. The real power supplied by the DG set is 30 kW and reactive power is supplied by the DSTATCOM. At t = 2.18 s, an unbalanced is introduced in the load by taking off load from phase a. It can be easily observed that even if load currents (iL) are unbalanced, the source currents (Is) are still balanced.
At t = 2.24 s, the load is taken out from phase b also, even in this condition the DSTATCOM system is able to balance DG set currents. For time t = 2.3 s to t = 2.48 s these dynamics are shown in the reverse sequence of events. The dc-bus voltages of VSC are well maintained at 800 V during the complete range of operation and the small sag and swell in the voltage at the load change are compensated by the PI controller action.

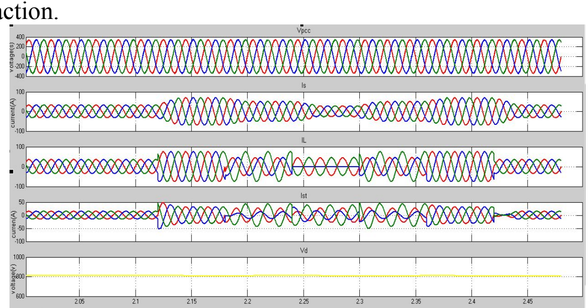


Fig.6. Dynamic performance of the DSTATCOM-DG isolated system with linear load.

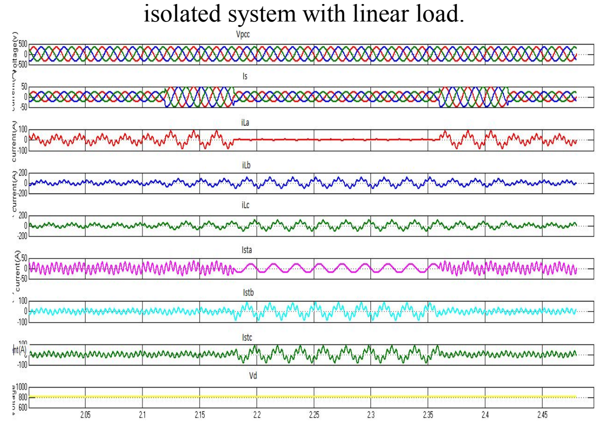


Fig.7.Dynamic performance of the DSTATCOM-DG isolated system with non linear load

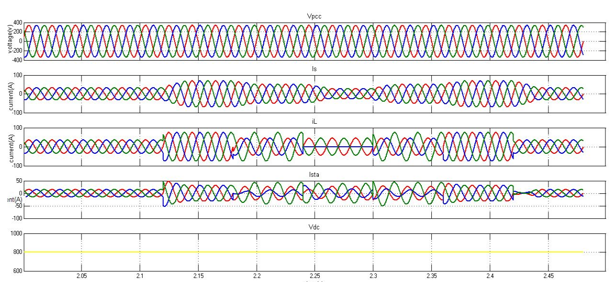


Fig.8.Dynamic performance of the DSTATCOM-DG isolated system with linear load using multi layer neural network

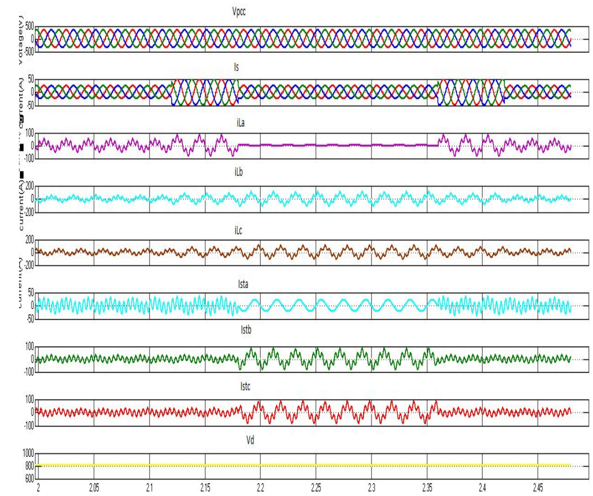
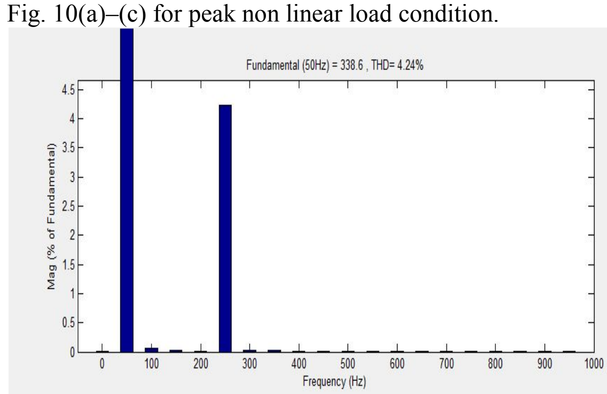


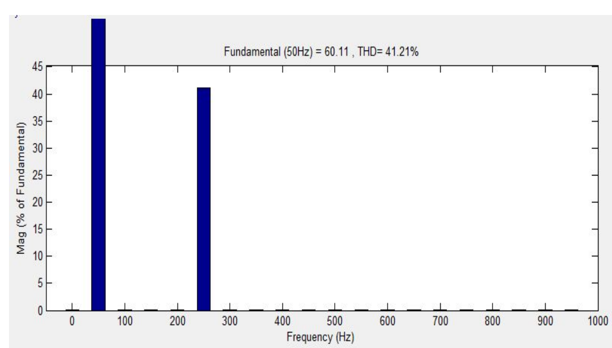
Fig.9. Dynamic performance of the DSTATCOM-DG isolated system with non-linear load using multi layer neural network

6.2. DG Set System Operation under Non-Linear Load

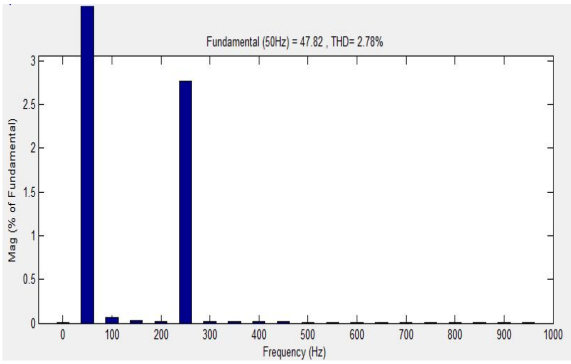
Fig.7. shows the performance of the DG set with DSTATCOM under nonlinear loading conditions. The load on the system is kept 15.0 kW initially for time t = 2.1 s to 2.12 s. The load compensation in terms of harmonic mitigation is also being provided by the DSTATCOM during this condition. The load is increased to 30 kW at t = 2.12 s. At t = 2.18 s, an unbalanced is introduced in load and therefore the load is reduced to 16.4 kW. At t = 2.36 s, phase-a load is reconnected again to the diode bridge and the load is reduced to its initial value and at t = 2.42 s, to demonstrate the dynamics in reverse sequence of events. The harmonic spectra of the phase- a voltage, load and source currents are shown in Fig. 10(a)–(c) for peak non linear load condition.



(a)

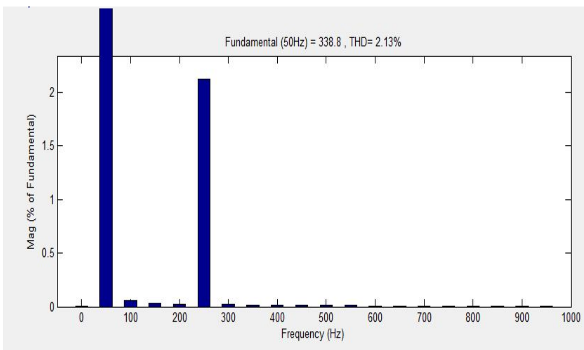


(b)

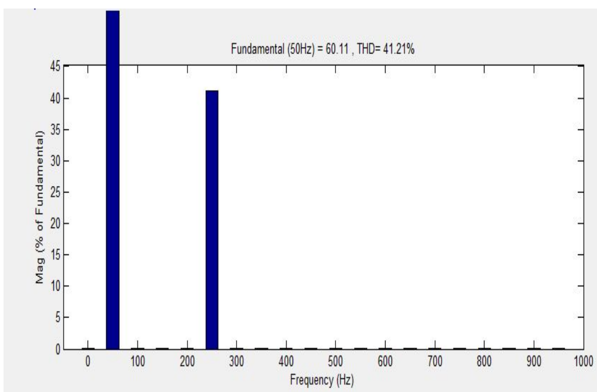


(c)

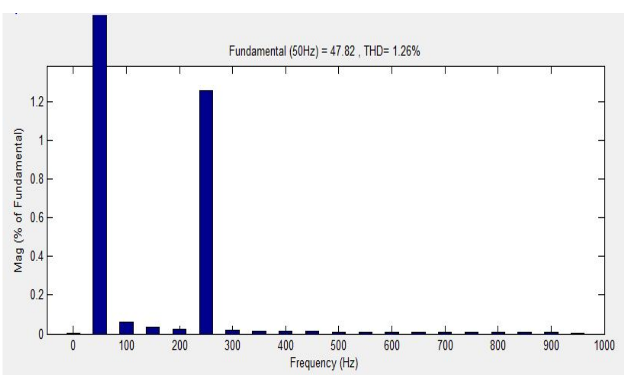
Fig. 10.Harmonic spectra of phase-a (a) voltage at PCC (b) load current (c) source current at peak nonlinear load condition.



(a)



(b)



(c)

Fig. 11. Harmonic spectra of phase-a (a) voltage at PCC (b) load current And (c) source current at peak nonlinear load condition using multilayer neural network

TABLE I

%THD OF THREE-PHASE VOLTAGES AT PCC , LOAD CURRENTS AND SOURSE CURRENTS WITH NON-LINEAR LOADS AND COMPARE BY USING MULTI LAYER NEURAL NETWORK

% THD analysis

condition		**Single Layer Neural Network(ADALINE)**			**Multi Layer Neural Network**		
		Ph.a	***ph.b***	***Ph.c***	***Ph.a***	***Ph.b***	***Ph.c***
Light load	***Vpcc***	3.51	3.72	4.10	1.77	1.36	2.11
	iL	69.97	68.77	70.69	69.97	68.7	70.69
	Is	2.77	2.45	2.62	1.27	1.25	1.32
Peak load	***Vpcc***	4.24	4.19	4.35	2.13	2.05	2.17
	Il	41.19	39.29	39.39	41.19	39.29	39.39
	Is	2.78	4.53	4.66	1.26	3.96	4.04

CONCLUSION

Thus from the simulation results we observe the performance of DSTATCOM has been found to satisfactory for improving Power quality problems at consumers. The DSTATCOM has Compensated the variety of loads (both linear, nonlinear), which are feed by DG set. It maintains sinusoidal voltages and balanced currents at PCC, even if the load currents are unbalanced. The DSTATCOM can be able to compensate Reactive power, harmonics, and unbalanced load currents of DG set, so it has been found to improve the performance of isolated DG system. The cost of the installation of DSTATCOM system with the DG set can be compensated as it leads to less initial an running cost of DG set as its ideal operation while feeding variety of loads. By using multi layer neural network observe the improvement of voltage profile (Vdc) and improvement in THD analysis.

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