International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Research Article

Load Compensation for Diesel Generator-Based Isolated Generation System Employing DSTATCOM using PI and Neuro Fuzzy Controllers

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Accepted 05 November 2013, Available online 01 December 2013, **Vol.3, No.5 (December 2013)**

Abstract

This paper aims to compensate harmonics, reactive power and unbalanced load current of diesel generator set for an isolated system by controlling Distribution static synchronous compensator (DSTATCOM). DSTATCOM control is achieved by using least mean square based adaptive linear element (ADALINE).To extract balanced positive sequence real fundamental frequency component of the load current an ADALINE is used. To maintain a constant voltage at the dc- bus of voltage- source converter (VSC) and to obtain a fast dynamic response a proportional-integral (PI) controller is used. Switching signals to voltage source converter are obtained from hysteresis-based Pulse Width Modulation controller. The simulation is carried out in matlab environment by using simulink and PSB tool boxes, for to demonstrate the load compensation of DG set for an isolated system feeding to both linear and nonlinear loads. Results are given to verify the optimal operation of the DG set and to verify the effectiveness of the control of DSTATCOM. The extension part utilizes Neuro Fuzzy controller instead of PI controller to reduce steady state error, and to improve THD, compare this with previous results.

Keywords: *ADALINE, Diesel Generator Set, Distribution Static Synchronous Compensator (DSTATCOM), Voltage Source Converter(VSC), Load Compensation ,Harmonic elimination.*

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1. Introduction

Diesel engine based electricity generation unit (DG) set is a widely used practice to feed power to some crucial equipment in remote areas. Normally Distributed Generation sets used are loaded with unbalanced, reactive and nonlinear loads. By using these loads some power quality problems like voltage sag, swell, flickers are occurred. The DG set is having high source impedance. The unbalanced and distorted currents lead to the unbalanced and distorted three phase voltages at the point of common coupling(PCC).Unbalanced and harmonic currents flowing through the generator results into torque ripples at the generator shaft. All these factors leading to reduce the life of the dg sets. These forces the DG sets to be operated with derating, which results into an increased cost of the system. Now a days in distribution systems, major power consumption has been in reactive loads, such as fans, pumps, etc. These loads draw lagging power-factor currents and therefore give rise to reactive power burden in the distribution system. Moreover, this situation worsens in the presence of unbalanced loads. Excess reactive power demand results into increase of feeder losses and reduces active power flow capability in the distribution system, whereas unbalancing affects the operation of transformers and generators (Bhim Singh et al, 2009). Non linear loads may create problems of high input current harmonics and excessive neutral current. Now a days, small generator units are available with full conversion(inverter-converter) units to meet stringent power quality norms. Instead of using these, a DSTSTCOM with a three phase DG set can be used to feed unbalanced loads without derating the DG set and to have the same cost involved. Moreover, the dstatcom can provide compensation for harmonics which facilitates to load the dg set up to its full KVA rating.

The DSTATCOM performance is very much dependent on the method of deriving reference compensating signals. Instantaneous reactive power theory, instantaneous id-iq theory, modified p-q theory, synchronous reference frame 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 (E. Acha, 2002;IEEE Std 387- 1995, 1996.). These techniques are based on complex calculations and these generally incorporate a set of low-pass filter which results in a delay in computation of reference currents and therefore leads to slow dynamic response of the DSTATCOM.

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In this paper a DSTATCOM is used for load compensation of a diesel generator. The Control algorithm is prepared flexibly so that it can provide load balancing, eliminate harmonics and maintain supply power factor to unity. The control algorithm is achieved Least Mean Square (LMS) algorithm (B. Mazari, 2005) based adaptive linear element (Adaline). The control algorithm utilizes PI controller for regulating the DC link voltage of DSTATCOM and this PI controller computes current component to compensate losses in DSTATCOM. The Adaline is used to extract positive-sequence fundamental frequency real component ofthe load current. The modeling of the DG set is performed using a synchronous generator, a speed governor, and the excitation control system. In this paper, a fast and simple neural network based control scheme is used for the control of the DSTATCOM.In this paper control of DSTATCOM is used foe load compensation of DG set to increase its performance. This proposed system is simulated by MATLAB/SIMULINK. 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.

2. Configuration of the System and Specifications

Fig.1 shows the configuration of the system for a three phase three wire DG set feeding to both linear and non linear loads. A 30KVA system with the DSTATCOM is used to demonstrate the work. The DSTATCOM consists of an insulated gate bipolar transistors-based three-phase three-leg VSC system and a capacitor $v_{dc}$to support dc bus.ADALINE based reference current generator,which in conjunction with the hysteresis-based PWM current controller that provides switching signals for VSC-based DSTATCOM. The parameters of salient pole synchronous generator are 415V, 4POLE, 30KVA, 1500RPM, 50HZ, X_d=1.56 pu, x'_d=0.15 pu, x_d=0.11 pu, x_q=0.78, x'_q=0.17, x_q=0.6, H_s=0.08.The other parameters are given in TableI.

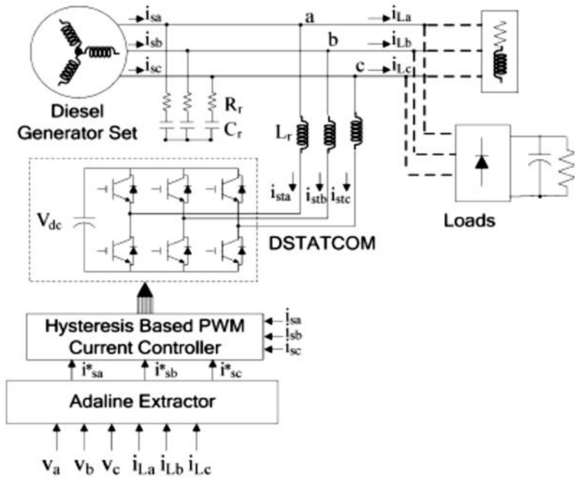


Fig.1 Basic configuration of the diesel generator set with DSTATCOM

Table1 System specifications

Load-1	Linear Load	Star connected R-L load of 37.5KVA at 0.8pf
Load-2	Non Linear Load	30KW Diode bridge converter with LC filter at output with L=2mH and C=500µF
Voltage Source Converter		DC link capacitor C_{dc}=10000 µF, ACinductor=3mH,Ripplefactor: C_r=10µF and R_r=8Ω, f_s=20kHz

3. Proposed Control Algorithm

For proper operation, the system requires a DG set to supply the real power needed to the load and some losses in DSTATCOM. Losses include switching losses of devices used in VSC, losses in reactor, and dielectric losses of the capacitor. Therefore, the reference source current, which is used 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.

3.1 Real Positive-Sequence Fundamental Frequency Current Extraction from Load Current

The basic theory is based on LMS algorithm and its training through Adaline.T o maintain minimum error Adaline tracks unit voltage vector templates. For a single phase ac system, the supply voltage may be expressed as

$$v_s = V\sin\omega t \tag{1}$$

Where v_s is the instantaneous ac terminal voltage, V is an amplitude and ω is the angular frequency of the voltage. The load current (i_L) can be written as summation of active current (i_p^+), reactive current (i_q^+) for the positive sequence, negative sequence current (i^-)and harmonic frequency current (i_h)

$$i_L = i_p^+ + i_q^+ + i^- + i_h \tag{2}$$

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

$$u_p = v_s / V \tag{3}$$

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 the phase voltage is detected to generate sinusoid ($\sin\omega t$) vector template, synchronized with system terminal voltage.

An initial estimate of the active part of load current for single-phase can be chosen as

$$i_p^+ = W_p u_p \tag{4}$$

where weight (W_p) is estimated using an Adaline.

The estimating of weights is 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:

$$W_{p(k+1)} = W_{p(k)} + \eta\{i_{L(k)} - W_{p(k)} u_{p(k)}\} u_{p(k)} \tag{5}$$

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

$$i_{pa}^+ = W_p^+ u_{pa}\,;\; i_{pb}^+ = W_p^+ u_{pb}\,;\; i_{pc}^+ = W_p^+ u_{pc} \tag{6}$$

$$W_p^+ = (W_{pa}^+ + W_{pb}^+ + W_{pc}^+)/3 \tag{7}$$

Where W_p^+ is averaged weight. 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

In order to compute the second component of reference active power current, the voltage of the reference dc-bus is compared with the sensed dc-bus voltage of the DSTATCOM.This comparison of voltage of sensed dc-bus (v_{dc}) to the voltage of reference dc-bus (v_{dc}^*) of VSC, results in a voltage error (v_{dcl}), which expressed in the nth sampling instant as:

$$v_{dcl(n)} = v_{dc(n)}^* - v_{dc(n)} \tag{8}$$

This error signal is processed in a PI controller and outputat the nth sampling instant is expressed as:

$$I_{p(n)} = I_{p(n-1)} + K_{pdc}\{v_{dcl(n)} - v_{dcl(n-1)}\} + K_{idc} v_{dcl(n)} \tag{9}$$

Where K_{pdc} and K_{idc} are proportional and integral gains of the PI controller.

The PI controller output accounts for the losses in DATATCOM and it is considered as the loss component of the current, which is added with the weight estimated he Adaline . Therefore, the total real reference current has two parts. one is load component of current and another one is loss component of current.

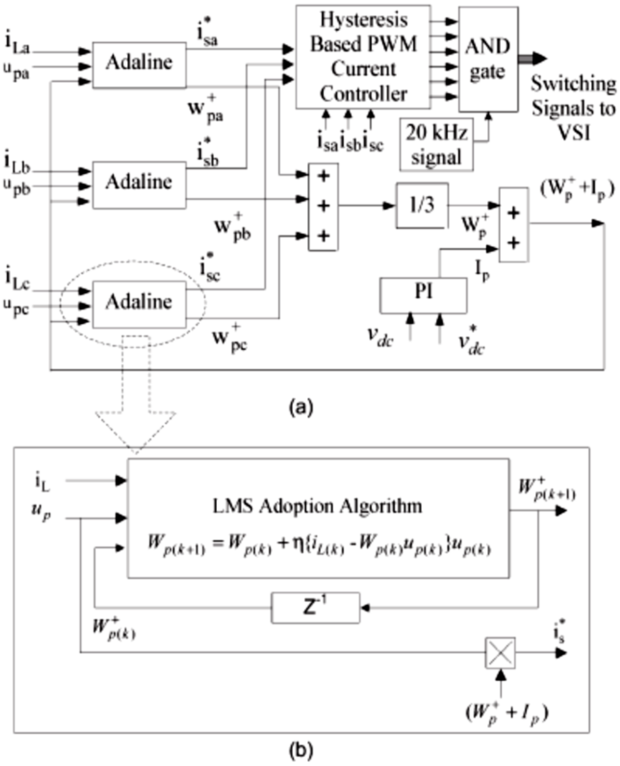


Fig. 2(a),(b) Control block diagram of the reference current extraction scheme

$$i_{sa}^* = (W_p^+ + I_p) u_{pa}\,;\; i_{sb}^* = (W_p^+ + I_p) u_{pb}\,;\; i_{sc}^* = (W_p^+ + I_p) u_{pc}\,. \tag{10}$$

Now these three-phase currents are considered as reference sourcecurrents $i_{ref}(i_{sa}^*, i_{sb}^*, i_{sc}^*)$ and along with sensed sourcecurrents $i_{act}(i_{sa}, i_{sb}, i_{sc})$,all these are fed to the hysteresis –based PWM controller and it provide switching signals to force actual source currents to acquire shape close to the reference source currents. This scheme of indirect current control, which 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 $(i_{act}) < (i_{ref} - hb/2)$ upper switch of the leg is ON and lower switch is OFF

If $(i_{act}) < (i_{ref} + hb/2)$ upper switch of the leg is OFF and lower switch is ON

where*hb*is hysteresis band around the reference current *i*ref .Fig. 2(a) and (b) show the detailed scheme for control of DSTATCOM.

4. Simulation Model

Fig.9 shows the MATLAB model of the DSTATCOM-DG set isolated system for linear and nonlinear loads. The modeling of the DG set is carried with a star connected salient pole synchronous generator of 30 kVA, controlled by a speed governor and an excitation system. The linear load applied to the generator is modeled as a delta connection of the series combination of resistance and inductance (R-L) models and is at 0.8 pf lagging. 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.

5. Results

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.

5.1 DG Set System Operation Under Linear Load

From Fig 10. We can observe the dynamic performance of the DG set system feeding with linear load. From $t = 2.10$ s to 2.12 s, a three-phase 18.75-kVA load at 0.8 pf is being connected .The load is increased upto 37.5 kVA at 0.8 pf. The real power supplied by the DG set is 30 kWand reactive power is suppliedby 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 (i_L) are unbalanced, the source currents (i_S) are still balanced. The load is taken out from phase b at t=2.24s, 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 voltage of VSC is 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.

5.2 DG Set System Operation Under Non- Linear Load

From fig.11.we can observe the dynamic performance of the DG set feeding with nonlinear load. The load on the system is kept 15.0 kW initially for time $t = 2.1$ s to 2.12 s, during this condition the dstatcom provides the load compensation in terms of harmonic mitigation .The load is increased to 30 kW at $t = 2.12$ s. An unbalanced

- is introduced in load at t=2.18s 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 (15.6 kW) and at $t = 2.42$ s, to demonstrate the dynamics in reverse sequence of events.

6. Neuro-Fuzzy Control

Instead of using PI controller for reduction of steady state error, by using a neuro-fuzzy controller we can get better performance in reduction of steady state error and observe an improvement in THD.

Here the fuzzy controller, controls the dc side capacitor voltage(V_{dc}) based on processing of the dc voltage error e(t) and its variation or change in error in order to improve the dynamic performance of dstatcom (E. Acha et al,2002).In fuzzy controller optimization process requires more time since the system must be tuned by 'trial-and-error' methods.

To simplify the design and optimization process learning techniques derived from neural networks (neuro-fuzzy approaches) are used.

Normally fuzzy control consists of four steps namely fuzzification, knowledge base, fuzzy inference mechanism, defuzzification.

Fuzzification: in this process the crisp sets are converted in to fuzzy sets. It performs the following functions(B. Mazari et al,2005)

- Initially it measure the values of variables
- Performs a scale of transformation which maps the range of values of input variables in to corresponding universe of discourse.
- Performs the so called fuzzification which converts input variables in to suitable linguistic variables.

Here the inputs are error in voltage of dc bus (V_{dc}), change in error of V_{dc}.

Knowledge base: it consists of linguistic control rule base and data base. Data base consists of input and output membership functions which represents the meaning of the linguistic values of the process and the control output variables.

Here the triangular membership function is used because of its advantages of simplicity and easy implementation.

Fuzzy-inference mechanism: it performs a collection of linguistic rules to convert the input conditions or values in to fuzzy output.

Normally, while designing a fuzzy control system, the formulation of rule set plays an important key role in improvement of the performance of the system. Here for this system rule table is prepared which is composed of 49 rules as shown in table.2 , here the linguistic codes are LP(large positive), MP(medium positive), SP(small positive), ZE(zero), LN(large negative), MN(medium negative), SN(small negative).

Normally many inference mechanisms have been developed to defuzzify the fuzzy rules, here we use max-min inference method for to obtain an implified fuzzy set of turning rules.Defuzzification: if for any system whose output is represented as single scalar quantity, then it is easier to take a crisp decision rather than to a fuzzy. So the process of conversion of fuzzy set to crisp set is called defuzzification.

Normally so many defuzzification methods are there among all the centroid method or center of gravity method is used here. The centre of gravity method gives a crisp output Z_0 of Z variables by taking the geometric centre of the output fuzzy value μ (Z) area (IEEE Std 387- 1995, 1996). It is given by the expression below

$$X^* = (\int\mu(z).zdz)/(\int\mu(z)dz)$$

Neuro fuzzy model is able to learn and optimize the rule base of a fuzzy controller by a learning algorithm that uses a fuzzy error measure.

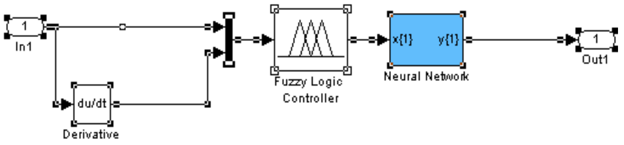


Fig.3 Neuro fuzzy control

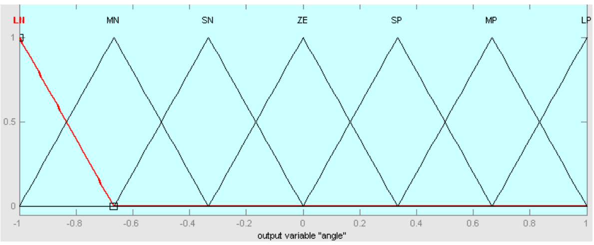


Fig.4 Membership function plot of output of Fuzzy logic controller

Table2 Rule table

e/Δe	LN	MN	SN	ZE	SP	MP	LP
LN	LN	LN	LN	LN	MN	SN	ZE
MN	LN	LN	LN	MN	SN	ZE	SP
SN	LN	LN	MN	SN	ZE	SP	MP
ZE	LN	MN	SN	ZE	SP	MP	LP
SP	MN	SN	ZE	SP	MP	LP	LP
MP	SN	ZE	SP	MP	LP	LP	LP
LP	ZE	SP	MP	LP	LP	LP	LP

By using neural network, fuzzy membership functions are tuned and output is obtained by following neural network equations.

$$a^1 = \tan sig\left(IW^{1,1}P^1(k-1)+b^1\right) \qquad (11)$$

$$a^2 = purelin\left(LW^{2,1}a^1(k-1)+b^2 \qquad (12)$$

X^1 is the input vector

p^1 is the input layer input vector

$IW^{1,1}$ is the input layer weight vector

b^1 is the bias of input layer

a^1 is the output of input layer

$LW^{2,1}$ is hidden layer weight vector

b^2 is the bias of hidden layer

a^2 is the hidden layer output vector

Y^1 is the output vector

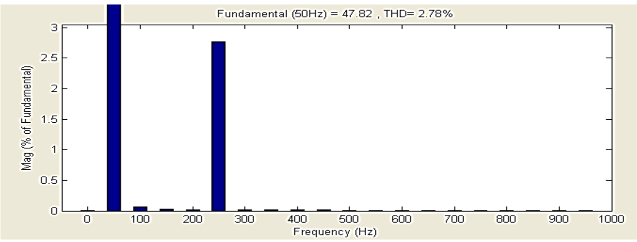


Fig.5 THD of i_{sa} with PI controller at nonlinear condition

The harmonic spectra of source and load currents of phase a by using PI controller are shown in below figures 5,6, and compare this with harmonic spectra of currents by using Neuro-fuzzy controller

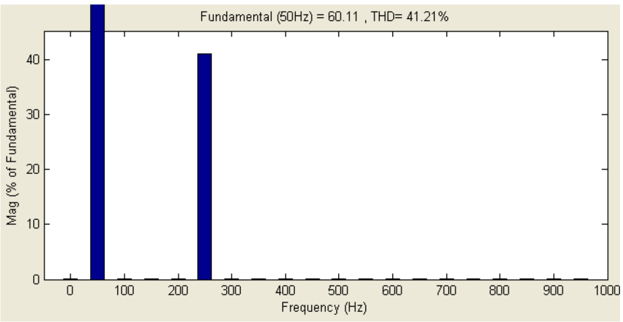


Fig.6 THD of i_{La} with PI controller at nonlinear condition

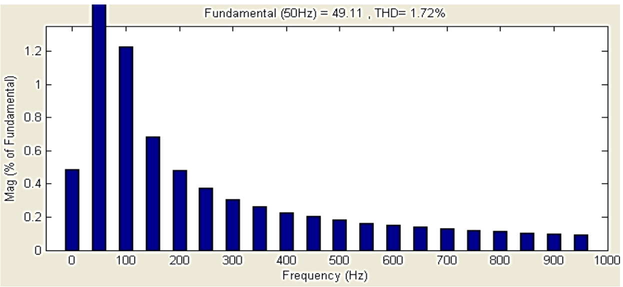


Fig.7 THD of i_{sa} with Neuro-fuzzy controller at nonlinear condition

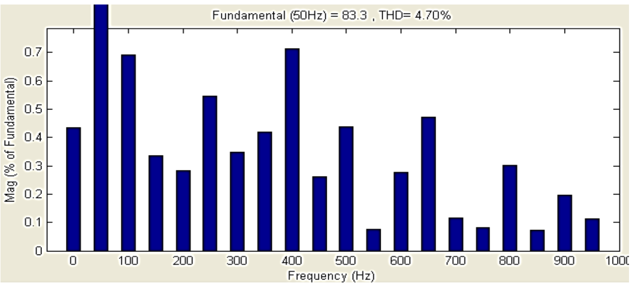


Fig.8 THD of i_{La} with Neuro-fuzzy controller at nonlinear condition

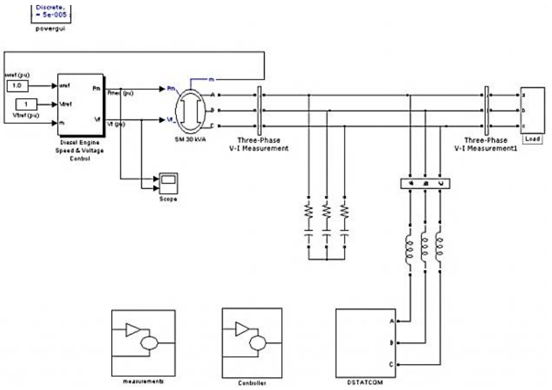


Fig.9 MATLAB based simulation model

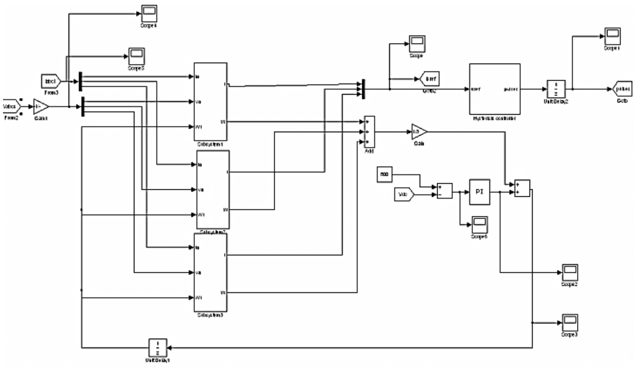


Fig.10 Control scheme using PI controller

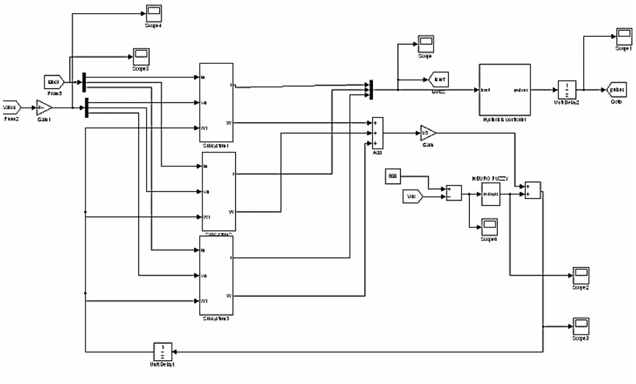
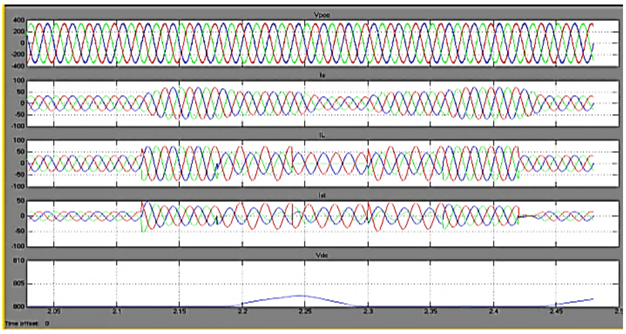
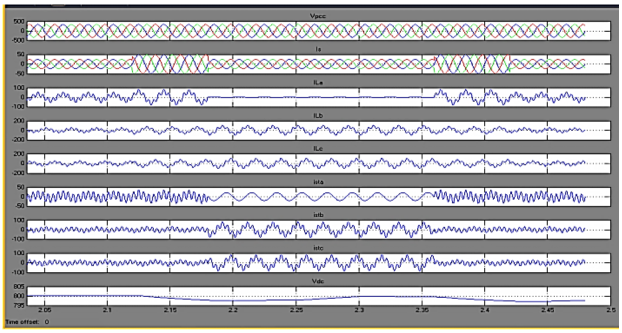


Fig.11 Control scheme using Neuro-fuzzy controller



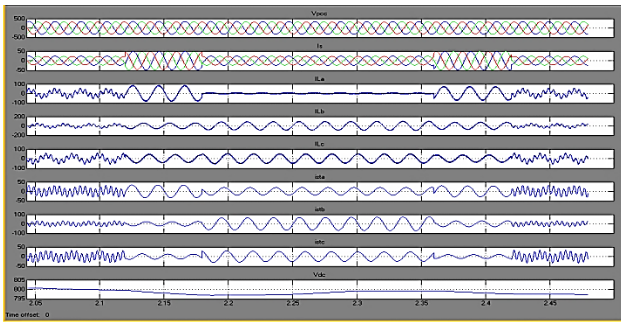
Time(sec)

Fig.12 Dynamic performance of DSTATCOM-DG isolated system with linear load using PI controller



Time(sec)

Fig.13 Dynamic performance of DSTATCOM-DG isolated system with nonlinear load using PI controller



Time(sec)

Fig.14 Dynamic performance of DSTATCOM-DG isolated system with nonlinear load using Neuro-fuzzy controller

Table 3 Comparison of THD

Currents	PI controller	Neuro-fuzzy controller
i_{sa}	2.78%	1.72%
i_{sb}	2.45%	1.71%
i_{sc}	2.62%	0.78%
I_{La}	41.21%	4.70%
I_{Lb}	38.79%	6.53%
I_{Lc}	38.88%	9.41%

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, unbalanced load currents of DG set, so it has been found to improve the performance of isolated DG system. Dstatcom has an inherent property to provide self-supporting DC bus and requires less number current sensors resulting in cost reduction. By using neuro-fuzzy control a better performance is observed in reduction of steady state error, improvement in THD analysis.

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