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Modeling & Simulation of DSTATCOM for Power Quality Improvement of Diesel Generator Stand Alone System

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Abstract:
This paper presents the control of distribution static synchronous compensator (DSTATCOM) for reactive power, harmonics and unbalanced load current compensation of an diesel generator system.The aim of the electric generating system is to generate electrical energy and to deliver this energy to the end user equipment at an acceptable voltage. One of the most common power quality problems is voltage sag. Voltage sag is a reduction in the RMS voltage in the range of 0.1 to 0.9p.u for duration greater less than one minute. There are different ways to mitigate voltage sag, swell and interruptions in distribution system. There are different types of FACTS controllers used for improvement of power quality. These devices are connected either in shunt or in series or in combination of both. The series connected device is DVR(Dynamic voltage restorer) which is used to inject a voltage of desired amplitude, frequency and phase between point of common coupling(PCC) and the load in series with the grid voltage. The shunt-connected device is the DSTATCOM which is used to dynamically inject a current of desired amplitude, frequency and phase into the grid.. Nowadays, there are an increasing number of non-linear loads which inject harmonics into the system. A three-phase insulated gate bipolar transistor (IGBT) based current controlled voltage source converter(VSC) with a DC bus capacitor known as a DSTATCOM is used for power factor correction, harmonic compensation and for providing required reactive power to the load. A model of DSTATCOM connected to diesel generator based isolated generation system feeding linear and non-linear loads (diode bridge rectifier with R and R-C) is developed for predicting the behavior of system under transient conditions. Simulation is carried out in standard MATLAB environment using Simulink and power system blockset toolboxes. Finally the performance of DSTATCOM under various fault conditions is investigated.

Key words: *Diesel generator set, D-STATCOM, Voltage Source Converter (VSC),harmonic elimination, load compensation.*

1.Introduction

Installation of the diesel engine-based electricity generation unit (dg set) is a widely used practice to feed the power to some crucial equipment in remote areas [1], [2]. Dg sets used for these purposes are loaded with unbalanced, reactive and nonlinear loads such as power supplies in some telecommunication equipment and medical equipment. The source impedance of the 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. All of these factors lead to the increased fuel consumption and reduced life of the dg sets. These forces the dg sets to be operated with derating, which results into an increased cost of the system. Nowadays, small generator units are available with full conversion (inverter-converter) units to meet stringent power quality norms [3]. Instead of using these, a dstatcom [2] 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. Moreover, the dsatcom can provide compensation for harmonics which facilitates to load the dg set up to its full kva rating.

The performance of DSTATCOM is very much dependent on the method of deriving reference compensating signals. Instantaneous reactive power theory, modified p-q theory, synchronous reference frame theory, instantaneous id − iq 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 [4]–[7]. 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. In this paper, an indirect current control technique is used to estimate reference source currents for the control of the DSTATCOM. This paper presents a DSTATCOM for the load compensation of a diesel generator set to enhance its performance.. Control algorithm is made flexible so that it can correct supplypower factor, eliminate harmonics and provide load balancing. The control algorithm utilises one closed loop PI controller for regulating the DC linkvoltage of DSTATCOM and second PI controller for regulating the AC voltage at point of common coupling. 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 extraction of reference currents involves an estimation of weights. 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 and PSB Block-set toolboxes.

2.Distribution Static Synchronous Compensator (D-STATCOM)

2.1.Principle of DSTATCOM

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Fig.1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. 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 D-STATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

- Voltage regulation and compensation of reactive power;
- Correction of power factor; and
- Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

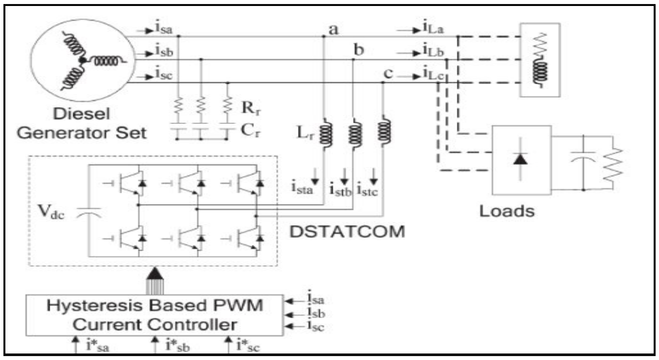

Figure 1: Basic configuration of the DG set with DSTATCOM

In fig. 1 the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the converter. The shunt injected current I_{sh} can be written as,

$I_{sh} = I_L – I_S = I_L – (V_{th} – V_L) / Z_{th}$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{sh} = V_L I_{sh}^*$$

It may be mentioned that the effectiveness of the DSTATCOM in correcting voltage sag depends on the value of Zth or fault level of the load bus. When the shunt injected current Ish is kept in quadrature with V_L, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of Ish is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

2.2.Voltage Source Converter (VSC)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9]. In addition, D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of interfacing inductor. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage [10].

3.**Controller For DSTATCOM**

The three-phase reference source currents are computed using three-phase AC voltages (*v*ta, *v*tb and *v*tc) and DC bus voltage (*V*dc) of DSTATCOM. These reference supply currents consist of two components, one in-phase (*I*spdr) and another in quadrature (*I*spqr) with the supply voltages. The control scheme is represented in Fig. 2. The basic equations of control algorithm of DSTATCOM are as follows

3.1.*Computation of in-phase components of reference supply current*

The instantaneous values of in-phase component of reference supply currents (*I*spdr) is computed using one PI controller over the average value of DC bus voltage of the DSTATCOM (*v*dc) and reference DC voltage (*v*dcr) as

$$I_{spdr(n)} = I_{spdr_{(n-1)}} + K_{pd}\{v_{de(n)} - v_{de(n-1)}\} + K_{id}\, v_{de(n)}$$

where Vde(*n*) Vdcc-Vdc*n*) denotes the error in Vdcc and average value of Vdc *Kpd* and *Kid* are proportional and integral gains of the DC bus voltage PI controller. The output of this PI controller (*I*spdr) is taken as amplitude of in-phase component of the reference supply currents. Three-phase in-phase components of the reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed using the in-phase unit current vectors (*u*a, *u*b and *u*c) derived from the AC terminal voltages (*v*tan, *v*tbn and *v*tcn), respectively.

$$u_a = v_{ta}/V_{tm}, \quad u_b = v_{tb}/V_{tm}, \quad u_c = v_{tc}/V_{tm}$$

where *V*tm is amplitude of the supply voltage and it is computed as

$$V_{tm} = \left[(2/3)\left(v_{tan}^{\ 2} + v_{tbn}^{\ 2} + v_{tcn}^{\ 2}\right)\right]^{1/2}$$

The instantaneous values of in-phase component of reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed as

$$i_{sadr} = I_{spdr}\ u_a,\quad i_{sbdr} = I_{spdr}\ u_b,\quad i_{scdr} = I_{spdr}\ u_c$$

3.2.*Computation of quadrature components of reference supply current*

The amplitude of quadrature component of reference supply currents is computed using a second PI controller over the amplitude of supply voltage (*v*tm) and its reference value (*v*tmr)

$$I_{spqr(n)} = I_{spqr(n-1)} + K_{pq}\left\{v_{ae(n)} - v_{ae(n-1)}\right\} + K_{iq}\ v_{ae(n)}$$

whereVac= Vtmc-Vmc(n) denotes the error in Vtmc and computed value *Vtmn* from Equation (3) and Kpqand Kiq are the proportional and integral gains of the second PI controller.

$$w_a = \left\{-u_b + u_c\right\}/\left\{(3)^{1/2}\right\}$$
$$w_b = \left\{u_a(3)^{1/2} + u_b - u_c\right\}/\left\{2(3)^{1/2}\right\}$$
$$w_c = \left\{-u_a(3)^{1/2} + u_b - u_c\right\}/\left\{2(3)^{1/2}\right\}$$

Three-phase quadrature components of the reference supply currents (*i*saqr, *i*sbqr and *i*scqr) are computed using the output of second PI controller (*I*spqr) and quadrature unit current vectors (*w*a, *w*b and *w*c) as

$$i_{saqr} = I_{spqr}\ w_a,\quad i_{sbqr} = I_{spqr}\ w_b,\quad i_{scqr} = I_{spqr}\ w_c$$

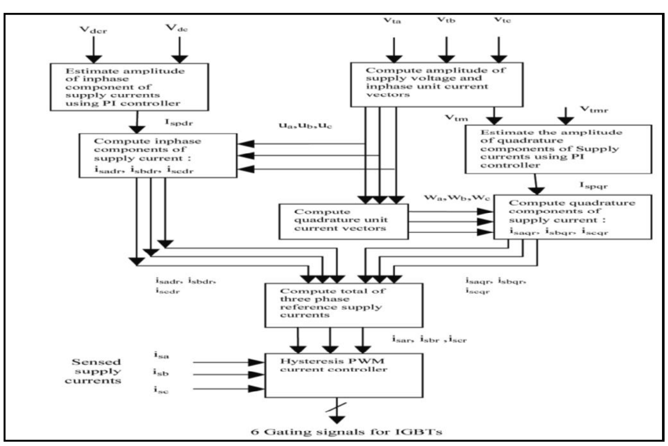

Figure 2: Control method for DTSATCOM

3.3.Computation of total reference supply currents

Three-phase instantaneous reference supply currents (*i*sar, *i*sbr and *i*scr) are computed by adding in-phase (*i*sadr, *i*sbdr and *i*scdr) and quadrature components of supply currents (*i*saqr, *i*sbqr and *i*scqr) as

$$i_{sar} = i_{sadr} + i_{saqr}, \quad i_{sbr} = i_{sbdr} + i_{sbqr}, \quad i_{scr} = i_{scdr} + i_{scqr}$$

A hysteresis pulse width modulated (PWM) current controller is employed over the reference (*i*sar, *i*sbr and *i*scr) and sensed supply currents (*i*sa, *i*sb and *i*sc) to generate gating pulses for IGBTs of DSTATCOM.

4.Matab/Simulink Modeling of DSTATCOM

4.1.Modeling of Power Circuit

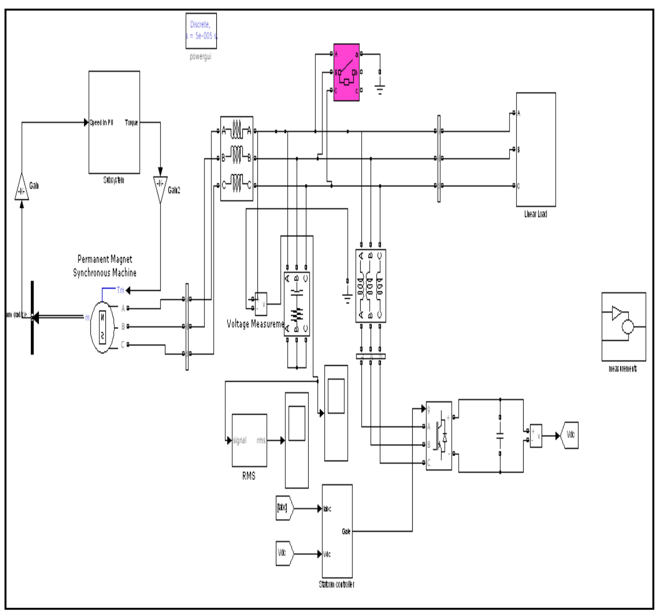

Figure 3:Matlab/Simulink Model of DSTATCOM Power Circuit

Fig.3 shows the complete MATLAB model of DSTATCOM along with control circuit. The power circuit as well as control system are modelled using Power System Block set and Simulink. The grid source is represented by synchronous generator. Three-phase AC loads are connected at the load end. DSTATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. Snubber circuits are connected in parallel with each IGBT for protection. Simulation of DSTATCOM system is carried out for linear and non-linear loads. The linear load on the system is modeled using the block three-phase parallel R-L load connected in delta configuration. The non-linear load on the system is modeled using R and R-C circuits connected at output of the diode rectifier. Provision is made to connect loads in parallel so that the effect of sudden load addition and removal is studied. The feeder connected from the synchronous generator to load is modelled using appropriate values of resistive and inductive components.

4.2 Modeling of Control Circuit

Figure.4 shows the control algorithm of DSTATCOM with two PI controllers. One PI controller regulates the DC link voltage while the second PI controller regulates the terminal voltage at PCC. The in-phase components of DSTATCOM reference currents are responsible for power factor correction of load and the quadrature components of supply reference currents are to regulate the AC system voltage at PCC.

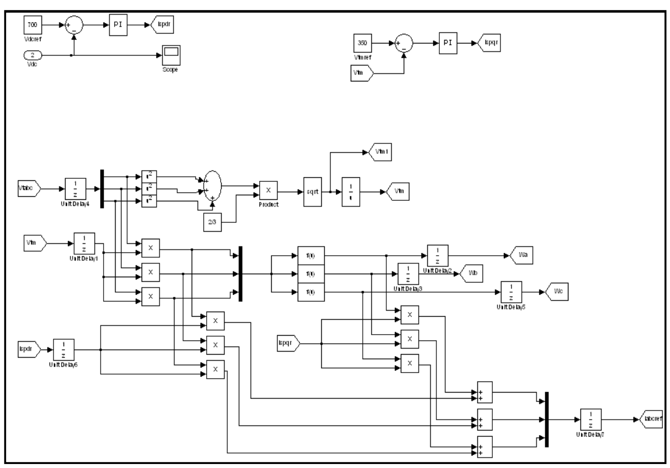

Figure 4: Control circuit of the STATCOM

The output of PI controller over the DC bus voltage (*I*spdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of PI controller over AC terminal voltage (*I*spqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents (*i*sar, *i*sbr and *i*scr) are obtained by adding the in-phase supply reference currents (*i*sadr, *i*sbdr and *i*scdr) and quadrature supply reference currents (*i*saqr, *i*sbqr and *i*scqr). Once the reference supply currents are generated, a carrierless hysteresis PWM controller is employed over the sensed supply currents (*i*sa, *i*sb and *i*sc) and instantaneous reference currents (*i*sar, *i*sbr and *i*scr) to generate gating pulses to the IGBTs of DSTATCOM. The controller controls the DSTATCOM currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses for six IGBTs of the VSI working as DSTATCOM.

5.Simulation Results

Here Simulation results are presented for four cases. In case one load is linear RL load, in case two non linear R load, in case three non linear RC load, and in case four we have considered line disturbance like single line to ground fault (SLG), without DSTATCOM and with DSTATCOM.

5.1.Case one

Performance of DSTATCOM connected to a weak supply system is shown in Fig.6 for power factor correction and load balancing. This figure shows variation of performance variables such as supply voltages (*v*sa, *v*sb and *v*sc), terminal voltages at PCC (*v*ta, *v*tb and *v*tc), supply currents (*i*sa, *i*sb and *i*sc), load currents (*i*la, *i*lb and *i*lc), DSTATCOM currents (*i*ca, *i*cb and *i*cc) and DC link voltage (*V*dc) for load changes from 36 kW (three-phase) to two-phase (24 kW) to single-phase (12 kW) to two-phase (24 kW) to three-phase (36 kW). The response shows that DSTATCOM balances unbalanced loads either of single-phase or two-phase type and improves the power factor of AC source to unity under varying load. Supply currents (*i*sa, *i*sb and *i*sc), compensator currents (*i*ca, *i*cb and *i*cc) and DC bus voltage (*v*dc) settle to steady-state values within a cycle for any type of change in load.

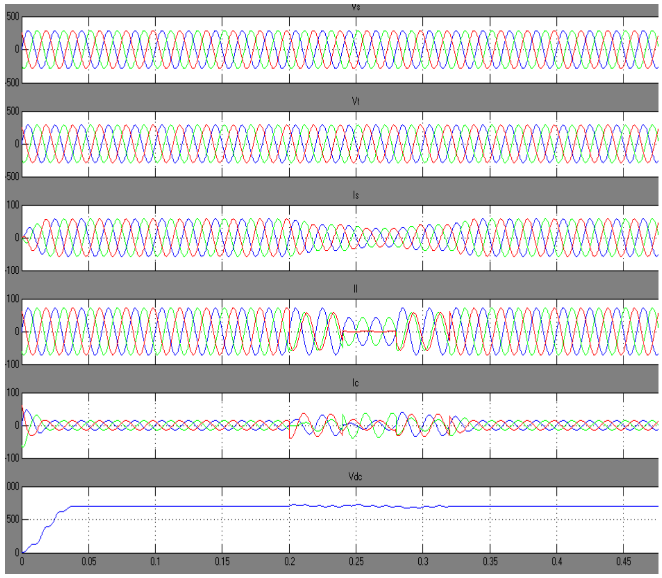

Figure 5: Simulation results for Linear RL Load

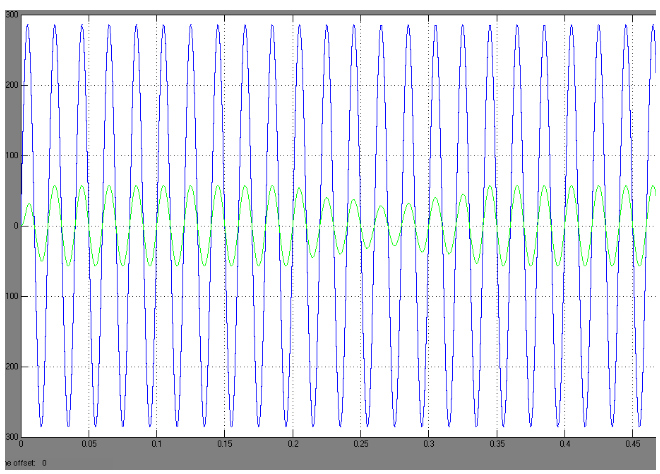

Figure 6: Simulation results power factor for Linear RL Load

5.2.Case two

Balanced three-phase non-linear load is represented by three-phase uncontrolled diode bridge rectifier with pure resistive load at its DC bus. Fig. 7 shows the transient responses of distribution system with DSTATCOM for supply voltages (*v*sabc), supply currents (*i*sabc), load currents (*i*la, *i*lb and *i*lc), DSTATCOM currents (*i*ca, *i*cb and *i*cc) along with DC link voltage (*V*dc) and its reference value (*V*dcr) at rectifier nonlinear load.

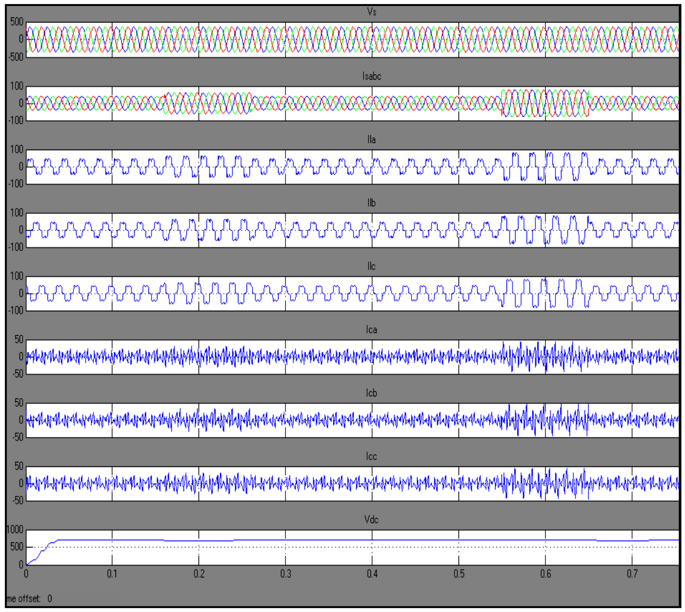

Figure 7:Simulation results Non- Linear R Load

At *t* =0.16 sec, the DC load resistance is changed from 15 to 10 ohm to increase the loading thereby the power absorbed changes from 21 to 30 kW. Consequently, load, supply and DSTATCOM currents increase to provide demanded active and reactive power to the load. The increased load on the rectifier reflects in the form of undershoot in DC link voltage. At *t*=0.26 sec, the load resistance is changed back to 15ohm and an overshoot is observed now, which settles down within a few cycles due to action of PI controller. Results show that the supply currents are balanced, sinusoidal and in-phase with the supply voltages.

5.3.Case three

Fig. 8 shows, the transient waveforms of all performance variables of distribution system with DSTATCOM supplying R-C load at the terminal of diode bridge rectifier. At *t* =0.55 sec, DC link resistance of load is changed from 15 to 7.5ohm . The load has increased from 20 kW to 40 kW. It is observed that the DC bus voltage of DSTATCOM regulates itself at its reference value and thus a self-supporting DC bus is obtained. The supply currents are sinusoidal even though the load currents are non-linear in nature.

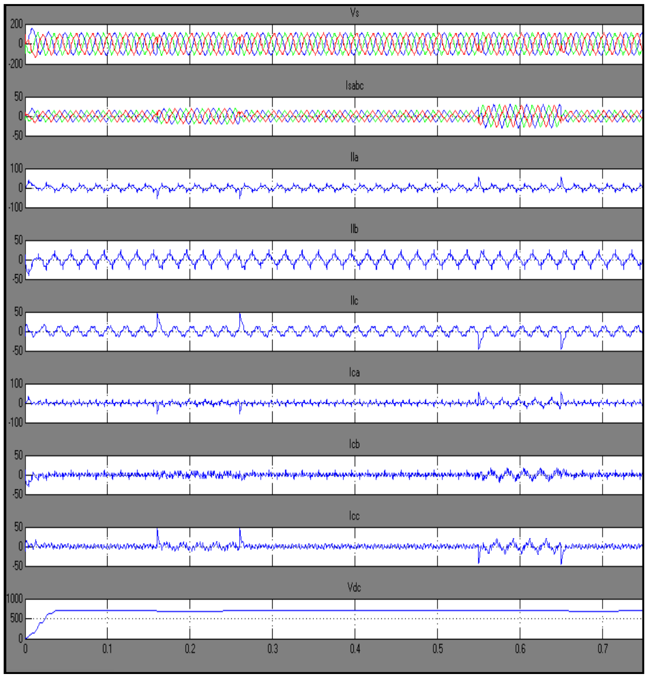

Figure 8: Simulation results Non- Linear RC Load

5.4.Case four

Fig. 9 shows RMS value of line voltage. Here at t=0.2 sec a SLG fault is created the line voltage fall from1 P.U to 0.78 P.U. Fig. 10 shows the RMS value of line voltage with DSTATCOM. Here at t=0.2 sec a SLG fault is created the line voltage fall from1 P.U to 0.98 P.U.

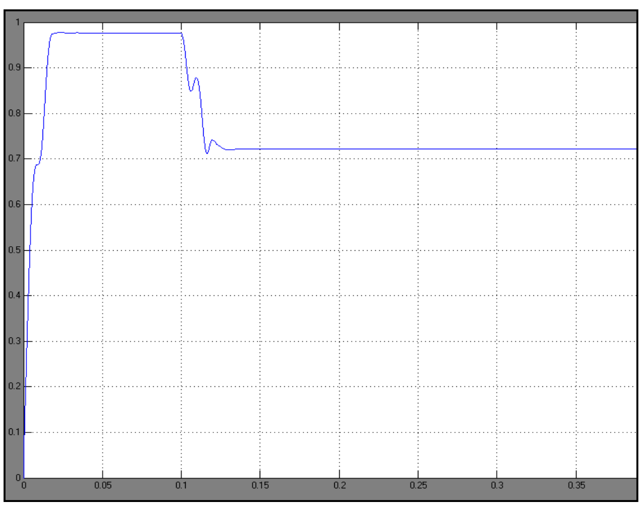

Figure 9: PCC Voltage without DSTATCOM during LG fault

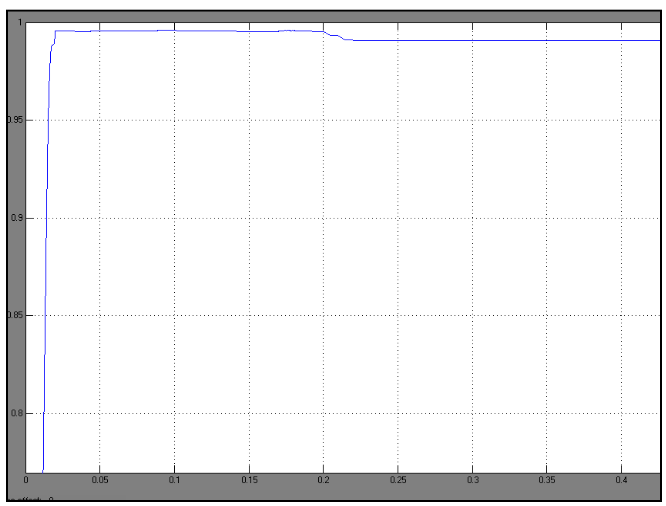

Figure 10: PCC Voltage with DSTATCOM during LG fault

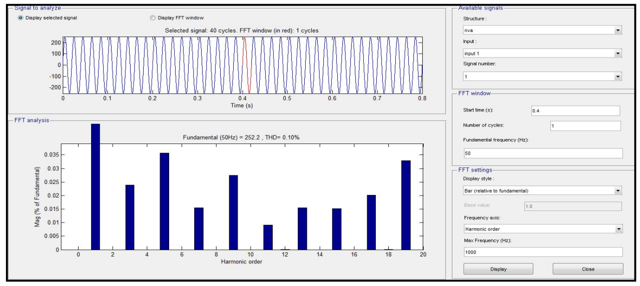

Figure 11: Harmonic spectra of V_{pcc}

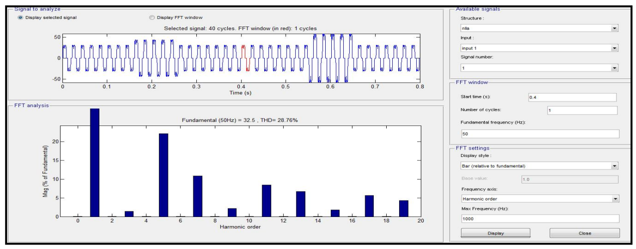

Figure 12: Harmonic spectra of load current of phase a, Ila

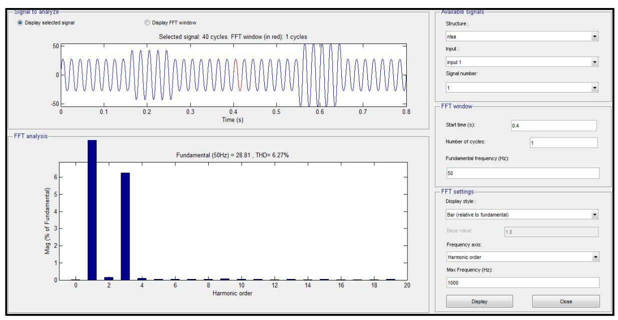

Figure 13: Harmonic spectra of source current of phase a, Isa

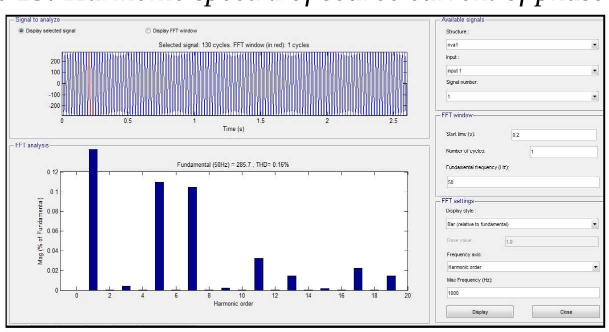

Figure 14:Harmonic spectra of Vpcc at phase a

Figure 11 to 14 shows the harmonic spectrum of voltage and current wave forms at PCC, load and source.

Table .1 shows the spectrum analysis of individual peak to peak and RMS voltage at PCC, source and load currents.

	%THD			RMS VOLTAGE(Volts) RMS CURRENTS(Amps)		
	Ph_a	Ph_b	Ph_c	Ph_a	Ph_b	Ph_c
V_{pcc}	0.16	0.16	0.16	202	202	202
I_l	84.88	85.87	85.47	49.85	50.33	50.56
I_s	0.19	0.18	0.16	20.2	20.22	23.89

Table1: Spectra analysis

6. Conclusion

DSTATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. DSTATCOM compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of DSTATCOM system has been found to be satisfactory for improving the power quality at the consumer premises. DSTATCOM control algorithm is flexible and it has been observed to be capable of correcting power factor to unity, eliminate harmonics in supply currents and provide load balancing. It is also able to regulate voltage at PCC. The control algorithm of DSTATCOM has an inherent property to provide a self-supporting DC bus of DSTATCOM. It has been found that the DSTATCOM system reduces THD in the supply currents for non-linear loads. Rectifier-based non-linear loads generated harmonics are eliminated by DSTATCOM. When single-phase rectifier loads are connected, DSTATCOM currents balance these unbalanced load currents. The simulation results show that the voltage sags can be mitigate by inserting D-STATCOM to the distribution system. The same analysis can be carried out for Double Line to Ground (DLG) fault and Three Line to Ground (TLG) fault also.

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