International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 01, January-June 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

POWER QUALITY AND RELIABILITY ENHANCEMENT BY DSTATCOM

Lokpriya Kumawat[1], R.R. Joshi[2]

[1,2]College of Technology and Engineering, Udaipur, Rajasthan (India)

ABSTRACT

Over the recent period of time, power quality (PQ) problems have been considered as a buzzing issue arises with regards to promote the delicate and miniature power electronic devices. Among all the PQ problems, voltage sag problem is the most frequently occurring along with the detrimental power quality issue. In order to maintain the reliability of the system custom power devices are installed to mitigate the PQ issues. The purpose of this study is to assuage voltage sag problem using proposed Distribution Static Synchronous Compensator (D-STATCOM). Utility distribution networks, sensitive industrial loads, domestic loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. In developing countries such as India, Nepal etc. where the power frequency and many such other determinants of power quality are themselves a serious question. This paper deals with the systematic procedure of the modeling and simulation of a DSTATCOM for power quality problems voltage sag based on Sinusoidal Pulse Width Modulation (SPWM) technique. The DSTATCOM is a most effective device which is based on the VSC principle with PI controller. In this paper DSTATCOM, under different faults is analyzed i.e. three phase, two phase and single phase to ground. The modeling and simulation of the proposed shunt compensator was implemented in MATLAB Simulink environment. Simulation results showed that the proposed shunt compensator was effective in mitigating voltage sags power system.

***Keywords*: Distribution Static Synchronous Compensator (DSTATCOM), MATLAB, Power Quality, SPWM, Voltage Source Converter (VSC).**

I. INTRODUCTION

Due to the increasing demand for high quality, reliable electrical power and increasing number of distorting loads may leads tons of increased awareness of power quality both by the customers and utilities. The most common power quality problems today exist in power system are voltage sags, harmonic distortion and low power factor. Among power system disturbance- voltage sags, swells and harmonics are some of the severe problems to the sensitive loads. The role of the compensator is not only to mitigate the effects of voltage sag/swell, but also to reduce the harmonic distortion due to the presence non linear loads in the network. In this paper, a Distribution STATCOM (DSTATCOM) is proposed, for the mitigation voltage sag is investigated. The major problems dealt here is the voltage sag. To solve such problems, custom power devices are used i.e. DSTATCOM, DVR, UPQC. One among those devices is the DSTATCOM (Distribution STATCOM), which is the most efficient and effective modern custom power device used in power distribution networks. The control of the Voltage Source Converter (VSC) is done with the help of SPWM technique. The proposed system is modeled and simulated through MATLAB /SIMULINK.

II. OVERVIEW OF POWER QUALITY PROBLEMS

Power quality as per IEEE standard defined as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment" [2].

The power disturbances eventuate on all electrical systems and electronic devices. In distribution systems and for some of the sensitive devices i.e. personal systems, adjustable speed drives contractors and relays [4]. Power quality problems create a wide range of disturbances such as voltage sags (or dip), swells, flickers, harmonic distortion, impulse transients, long and short interruptions, Voltage spikes and noise [5].

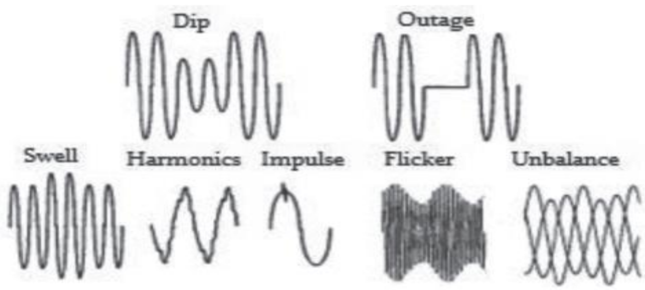

Fig. 1(a): Various Types of power Quality Problem

Fig. 1(a) shows various types of power quality problems being experience by industrial, commercial and residential end user. All the PQ problems are undesirable as the issue arises most commonly is Voltage sag. The event of occurrence of power quality can be seen in fig. 1(b).

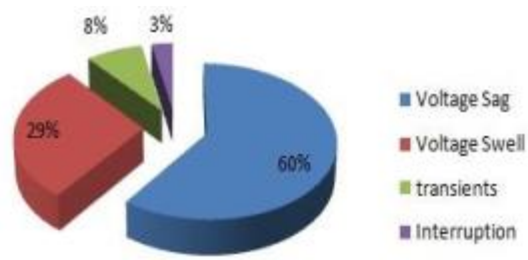

Fig. 1(b): Classification of power quality problems

III. MATRIALS AND METHODS

D-STATCOM is the most important power electronic device for distribution networks. It has been widely used to regulate system voltage along with improve voltage profile, reduce voltage harmonics, reduce transient voltage disturbances and load compensation [5]. The DSTATCOM uses a power electronics converter is controlled using pulse width modulation. It consists of a two level self-commutated Voltage source converter (VSC), a dc energy storage device, a coupling transformer connected in shunt (parallel) with the distribution network through a coupling transformer [6]. Such configuration allows the device to absorb or generate controllable active and reactive power.

The DSTATCOM has been utilized mainly for the regulation of voltage, power factor correction and elimination of current harmonics [8]. Such a device is employed to provide the continuous voltage regulation using an indirectly controlled converter. The D-STATCOM is used to regulate the voltage at the point of connection. The control is based on sinusoidal PWM control and requires the measurement of the value of RMS voltage at the load point. The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator that is used for the correction of bus voltage sags. It may be mention that the effectiveness of D-STATCOM in correcting voltage sags depends upon the following:

a) The value of Impedance of the line and,

b) The fault level of the load bus

The major components of a D-STATCOM are shown in Fig.2. It consists of a source, DC link capacitor, one or more inverter modules, an ac filter, a transformer to match the inverter output to the line voltage [8].

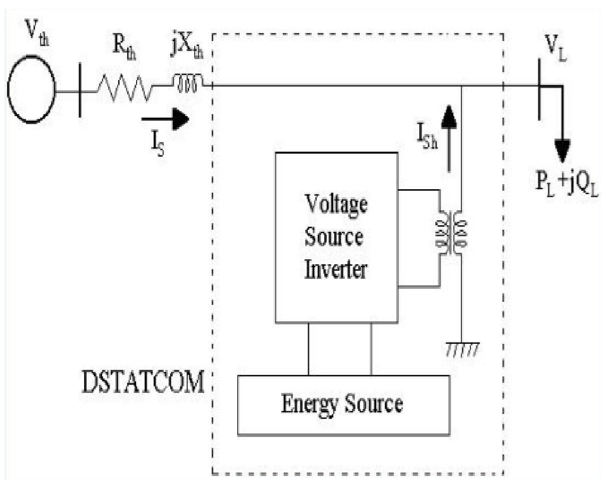

Fig. 2: Structure of DSTATCOM

IV. MATHMATICAL MODELLING OF DSTATCOM

By making the voltage connection $V_{sh} = V_{sh}\angle\delta_{sh}$ as point reference phase and the fundamental component of the Voltage Source Converter (VSC) is $V_S = V_S{}^{\angle 0}$. The active and the reactive power exchanged with network are given by the equations:

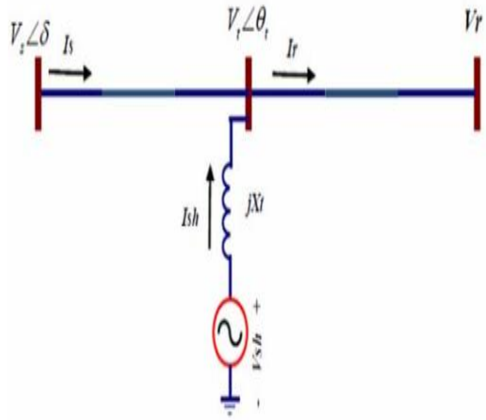

Fig 3. Equivalent circuit diagram of DSTATCOM

$$P = \frac{V_S\ V_{sh}}{X_t} \sin \delta_{sh} \tag{1}$$

$$Q = \frac{V_S^2}{X_t} - \frac{V_S\ V_{sh}}{X_t} \cos \delta_{sh} \tag{2}$$

The DSTATCOM, as it was already described in Figure 3.2, can be represented by the equivalent circuit taking into account only bus bar where this device is connected. The current injected by the DSTATCOM is given by:

$$I_{sh} = \frac{V_{sh} - V_t}{jX_t} \tag{3}$$

where quantities are in three phase:

$$\bar{V} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}; \bar{V}sh = \begin{bmatrix} V_{a\ sh} \\ V_{b\ sh} \\ V_{c\ sh} \end{bmatrix}; \bar{V} = \begin{bmatrix} I_{sh\ a} \\ I_{sh\ b} \\ I_{sh\ c} \end{bmatrix}; \tag{4}$$

The power injected to the bus bar is given by the following equation:

$$\bar{S} = \bar{V}_t\ .\bar{I}_{sh} = \frac{\bar{V}_t(\bar{V}_{sh} - \bar{V}_t^{\ *})}{-jX_t} = \frac{\bar{V}_t.\bar{V}_{sh} - \bar{V}_t^2}{-jX_t} \tag{5}$$

Where it led to active and reactive power injected by the DSTATCOM to the bus bar expressed by:

$$\begin{cases} P_{sh} = -V_t V_{sh}\ .\ \sin(\theta_t - \theta_{sh}) /\ X_t \\ Q_{sh} = V_t (V_{sh}\ .\ \cos(\theta_t - \theta_{sh}) - V_t)/X_t \end{cases} \tag{6}$$

To study the relationship between the grid and the STATCOM we will adopt it for the mathematical model of Figure 4, he current of the STATCOM depends on the difference between the system voltage *Vt* (voltage at node) and adjustable voltage STATCOM. We applying Ohm's law we have:

$$\bar{V} - \bar{V}_{sh} = R_{sh}.\bar{I}_{sh} + L_{sh}\frac{dI_{sh}}{dt} \tag{7}$$

We turns rotating frame *(d,q)*, the repository synchronization, multiplying all quantities by phasor $e^{-j\gamma}$ with $d\gamma/dt = \omega$ the pulse of the quantities concerned.

$\therefore \bar{U}_{(d,q)} = \bar{U}_{(\alpha,\beta)}.e^{-j\gamma}$ and conversely $\bar{U}_{(\alpha,\beta)} = \bar{U}_{(d,q)}.e^{j\gamma}$

Applying this writing on the equation (7) we have:

$$\overline{V}^{(d,q)}.e^{j\gamma} - \overline{V}_{sh}^{(d,q)}.e^{j\gamma} = R_{sh}.\overline{I}_{sh}^{(d,q)}.e^{j\gamma} + L_{sh}.\frac{d}{dt}(\overline{I}_{sh}^{(d,q)}.e^{j\gamma}) \quad (8)$$

After simplification of calculation leads to dynamic equations of DSTATCOM in the frame (*d*,*q*) as follows:

$$V_d - V_{sh\ d} = R_{sh}.I_{sh\ d} + L_{sh}\frac{dI_{sh\ d}}{dt} - L_{sh}.\omega.I_{sh\ q} \quad (9.a)$$

$$V_q - V_{sh\ q} = R_{sh}.I_{sh\ q} + L_{sh}\frac{dI_{sh\ q}}{dt} - L_{sh}.\omega.I_{sh\ d} \quad (9.b)$$

In matrix form, we write the system state of the DSTATCOM as follows:

$$\frac{d}{dt}\begin{pmatrix} I_{sh\ d} \\ I_{sh\ q} \end{pmatrix} = \begin{bmatrix} \frac{-R_{sh}}{L_{sh}} & \omega \\ -\omega & \frac{-R_{sh}}{L_{sh}} \end{bmatrix} . \begin{bmatrix} I_{sh\ d} \\ I_{sh\ q} \end{bmatrix} + \frac{1}{L_{sh}}\begin{bmatrix} V_d & -V_{sh\ d} \\ V_q & -V_{sh\ q} \end{bmatrix} \quad (10)$$

From equation (10), the block diagram of the STATCOM main system in *d-q* frame is established and depicted in Figure. Real and Reactive power can also be computed by using the equation:

$$P = V_d I_d + V_q I_q \quad (11)$$

$$Q = V_q I_d - V_d I_q \quad (12)$$

Three Phase Voltage Source Converter (VSC) & Controller

VSC is the heart of most new FACTS power equipments used in power electronics. Voltage source converters (VSC) are commonly used to transfer the power between a dc and an ac system or in back to back connection for ac systems with different frequencies. VSC is a power electronic device, which can generate a three-phase ac output voltage, which is controllable in phase and magnitude [1]. These voltages are injected into ac distribution network in order to keep the load voltage at the desired voltage reference. VSCs are widely used in not only for adjustable speed drives, but can also be used to mitigate the voltage sags/swells in the system. VSC is used either to completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' can be defined as the difference between the nominal voltage and the actual voltage. The converter is generally based on some kind of energy storage, which will supply the converter with a dc voltage. A basic VSC structure is shown in Fig. 3 where Rs and Ls represents the resistance and inductance between the converter ac voltages V and the ac system voltage Vs and I_s is the current injected into the grid. A dc capacitor is connected on the dc side in parallel with the energy storage device to produce a smooth dc voltage. IGBTs are connected in antiparallel with diodes for commutation purposes in the system and for charging of the DC capacitor [9].

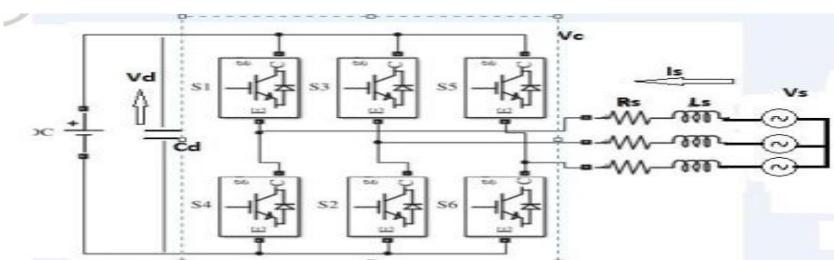

Fig.4 Voltage source converter

The main aim of the control scheme is to provide constant voltage at the point where a sensitive load is connected, under system disturbance. The control system measures only the RMS voltage at the load point i.e., no reactive power measurements are required in the system [10]. The VSC switching [4][5] strategy is based on the sinusoidal PWM technique which offers simplicity and a good response. The PI controller identifies the error signal and generates the required angle (α) to drive the error to 0, i.e., the load RMS voltage is brought back to reference voltage. As in the PWM generator, the sinusoidal signal $V_{control}$ is compared with a triangular signal (carrier) in order to generate the switching signals for the VSC valves [11].The main parameters of the sinusoidal PWM scheme are the amplitude modulation index M_a of signal $V_{control}$ and the frequency modulation index M_f of the triangular signal and the amplitude index

$$M_a = V_{control}/V_{in}$$

where,

$V_{control}$ - Peak amplitude of the signal.

V_{in} -peak amplitude of the Triangular signal.

V. SIMULINK MODEL FOR THE DSTATCOM

In order to enhance the performance of the distribution network, DSTATCOM is connected in shunt with the distribution system. The performance of the distribution system in terms of power quality problems is analyzed by the DSTATCOM. DSTATCOM was designed using MATLAB Simulink software.

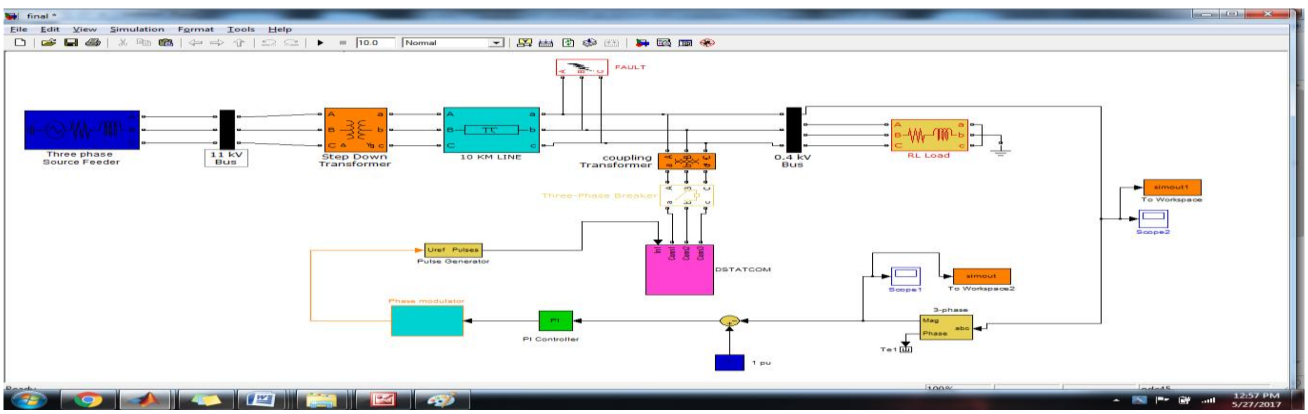

Fig.6: simulation with DSTATCOM

VI. RESULT AND DISCUSSION

The simulated model has been analysed for various conditions like three phase fault, two phase fault and single phase to ground (SLG) fault. A distribution line of 10 km is considered for the proposed model and DSTATCOM is designed based on PI model. But the results of SLG faults are not displayed.

THREE PHASE FAULT CONDITION:

Condition 1. R_f = 0.70 Ω, t_f = 0.55s-0.65s

A 3-Φ fault is created at point A via a resistance of 0.70 Ω for the transition time of 0.55s to 0.65s and system is operated without DSTATCOM, which causes voltage sag of 31%. During fault there is sudden drop in voltage as magnitude drops from 1pu to 0.684 pu shown in figure 7(a) below. When system is operated under the above

International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 01, January-June 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

specified conditions with DSTATCOM compensation then value of voltage magnitude is reduced from 31% to 6%, due to injection of reactive current by DSTATCOM in the system (Fig 7(f)) and improvement in the voltage profile can be observed from fig 7(d). The voltage magnitude (in pu), 3-Φ waveform of the line and reactive current injection with. DSTATCOM compensation and without DSTATCOM compensation is shown in Fig. 7.

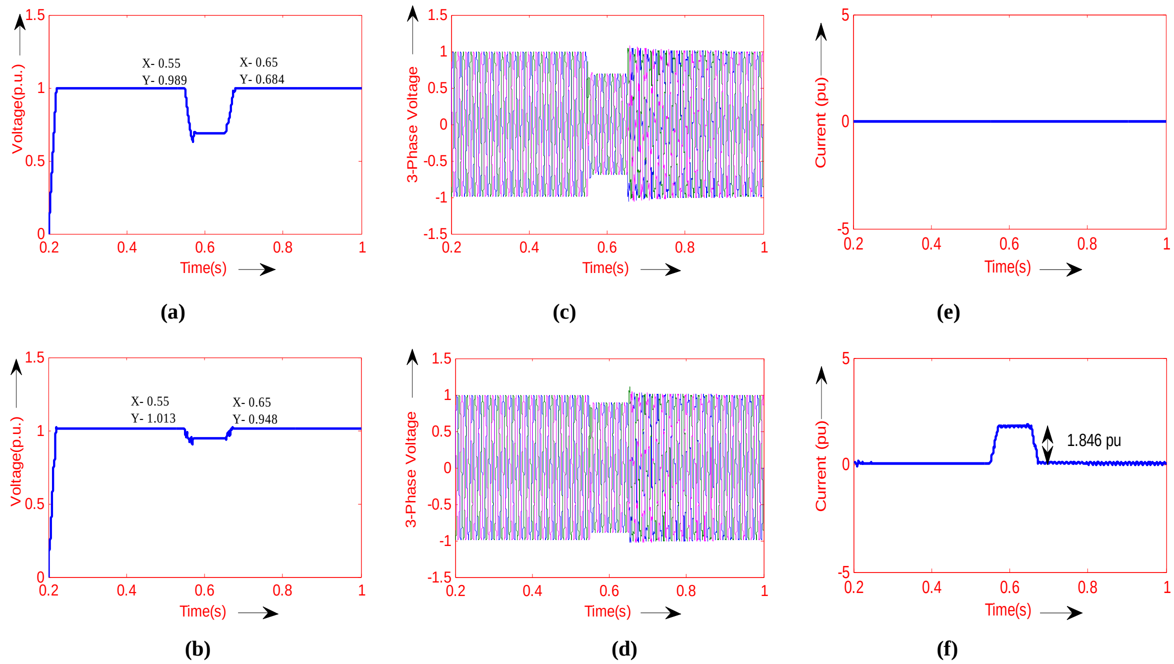

Fig. 7: (a), (b) Line voltage magnitude without and with DSTATCOM compensation respectively; (c), (d) 3-Φ line voltage without and with DSTATCOM compensation respectively; (e), (f) Reactive current without and with DSTATCOM compensation respectively.

VII. TWO PHASE FAULT CONDIDTION:

Condition 2. $R_f = 0.70\ \Omega$, $t_f = 0.55s\text{-}0.65s$

A 2-Φ fault is created at point A via a resistance of 0.70 Ω for the transition time of 0.55s to 0.65s. When system is operated without DSTATCOM, sag of about 23% is observed as the voltage drops from 0.989pu to 0.7715pu. This drop compensates with the injection of reactive power in the system. When operated under the above specified conditions with DSTATCOM compensation then sag value of voltage is reduced from 23% to 1.7%. The voltage magnitude (in pu) of the line, 2-phase voltage and reactive current injection with DSTATCOM compensation and without DSTATCOM compensation is shown in Fig. 8.

International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 01, January-June 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

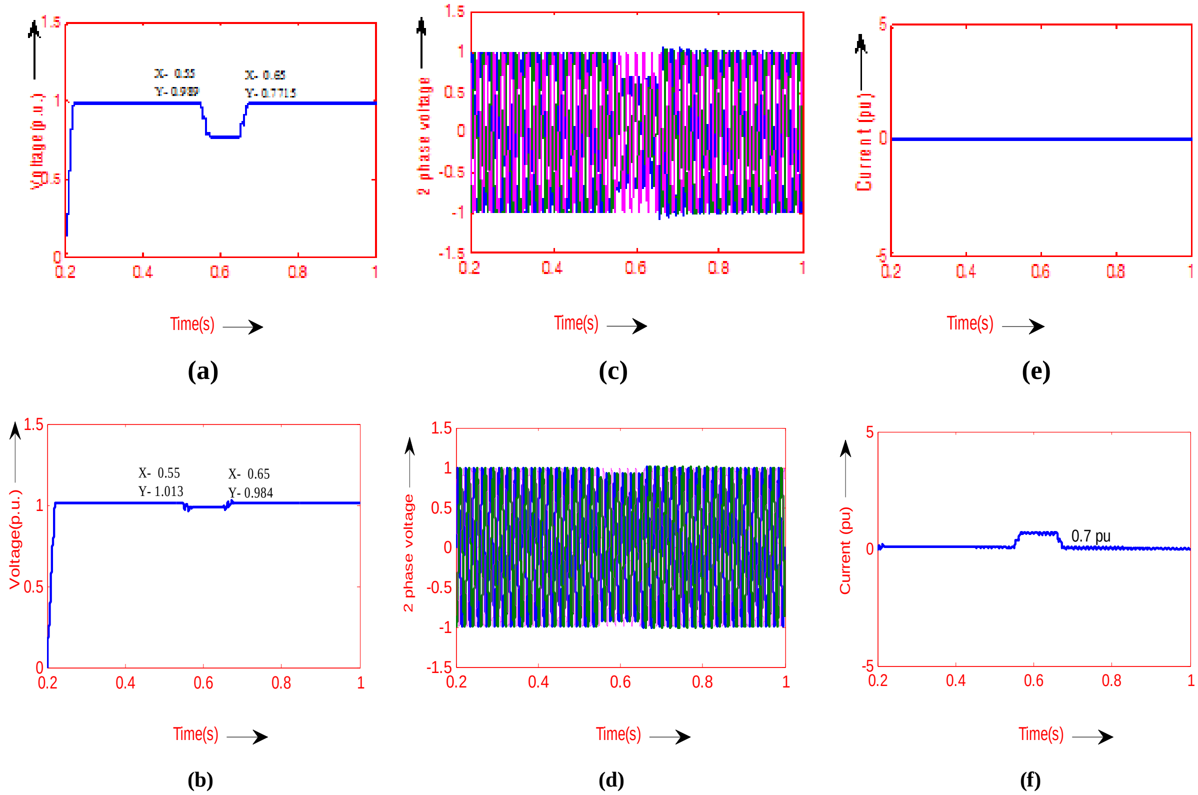

Fig. 8: (a), (d) Line voltage magnitude without and with DSTATCOM compensation respectively; (b), (e) 2-Φ line voltage without and with DSTATCOM compensation respectively; (c), (f) Reactive current without and with DSTATCOM compensation respectively.

SINLE PHASE TO GROUND FAULT:

Condition 3. R_f = 0.70 Ω, t_f = 0.55s-0.65s

A SLG fault is created at point A via a resistance of 0.70 Ω for the transition time of 0.55s to 0.65s and system is operated without DSTATCOM, the voltage value drops from 0.989 p.u. to 0.838 p.u., which causes voltage sag of 16% shown in fig.4.17 (a). When system is operated under the above specified conditions with DSTATCOM compensation, injection of reactive power causes sag value of voltage is reduced from 16% to 1% as shown in fig. 4.17(d) and the amount of reactive power injected is 0.31 p.u. in the system which shows rise in the voltage magnitude. The voltage magnitude (in pu), SLG waveform of the line and reactive current injection with DSTATCOM compensation and without DSTATCOM compensation is shown in Fig. 4.17.

International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 01, January-June 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

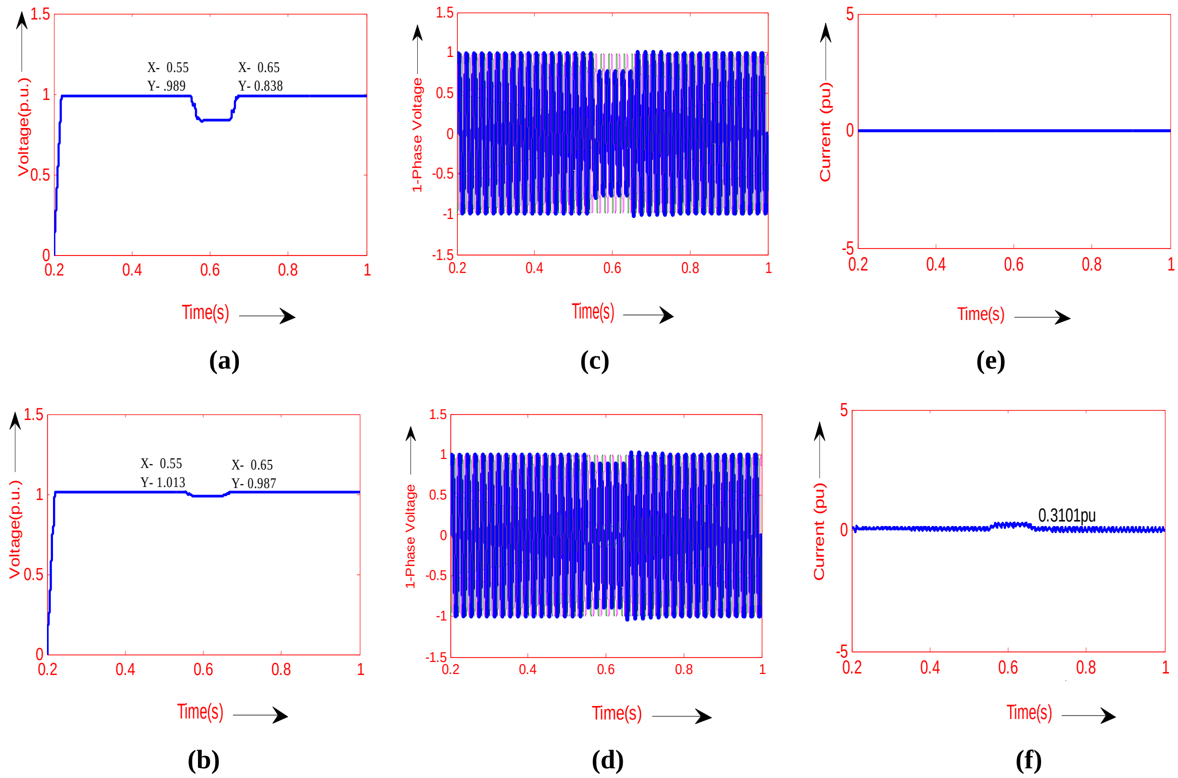

Fig. 4.17: (a), (d) Line voltage magnitude without and with DSTATCOM compensation respectively (b), (e) SLG (1-Φ)line voltage without and with DSTATCOM compensation respectively; (c), (f) Reactive current without and with DSTATCOM compensation respectively.

VIII. CONCLUSION

This paper presents the problem of voltage sags and its severe impact on nonlinear loads and on sensitive loads. The design procedure for the various components of DSTATCOM is presented. The control of the Voltage Source Converter (VSC) is done with the help of SPWM. Analyzing the above conditions i.e. three phase fault , two phase fault and single phase to ground fault in the distribution system, it can be concluded that the DSTATCOM is capable to mitigate the voltage sag up to an appreciable level. Other ancillary benefits include reduction in losses, improved stability and reliability, better voltage profile and better performance of load side equipments. The proposed DSTATCOM is modeled and simulated using MATLAB/SIMULINK software. The simulation results show clearly the performance of a DSTATCOM in mitigating voltage sags and also it has a fast dynamic response. The further work focuses on the study of DSTATCOM by using multilevel inverter instead of VSC.

REFERENCES

[1] H. Hingorani, Introducing custom power, IEEE Spectrum, 32(6), 1995, 41 48.

[2] M. F. Faisal, Power quality management program: TNB's experience Distribution Engineering Department, TNB, 8(2), 2005, 789-795.

[3] IEEE Std. 1159-1995. Recommended Practice for Monitoring Electric Power Quality.

[4] P. Boonchiam, and N. Mithulananthan, Understanding of Dynamic Voltage Restorers through MATLAB Simulation. Thammasat Int.J.Sc.Tech, 11(3), 2006, 85-89.

[5] A. Ghosh, and G. Ledwich, Power Quality enhancement Power Devices, Kluwer Academic Publishers, 23(5), 2002, 989-992.

[6] O. Anaya-Lara, and E. Acha, Modeling and analysis of custom power systems by PSCAD/EMTDC, IEEE Transaction on Power Delivery, 17 (1), 2002, 266-272.

[7] A.Visser, J.Enslin, and H. Mouton, Transformer-less Series Sag Compensation with a Cascaded Multilevel Inverter, IEEE Transaction Industrial Electronics, 49(4), 2002, 824-831.

[8] P. Loh, M. Vilathgamuwa, S. Tang, and H. Long, Multilevel Dynamic Voltage Restorer, IEEE Power Electronics Letters, 2(4), 2004, 125-130.

[9] E. Acha, V. G. Agelidis, O. Anaya-Lara, and T.J.E. Miller, Power Electronic Control in Electrical Systems, Newnes Power Engineering series, 5(1), 2002, 526-529.

[10] P. Kumar, N. Kumar and A.K.Akella, Review of D-STATCOM for Stability Analysis, IOSR Journal of Electrical and Electronics Engineering, 1(2), 2012, 01-09.

[11] David and Cholleti, Implementation of SPWM Technique in DSTATCOM for Voltage Sag and Swell, International Electrical Engineering Journal, 5(12), 2014, 1649-1654.

[12] H.A. Mohammad, and M. N. Reddy, Mitigation of Voltage SAG and Voltage Swells By Controlling the DSTATCOM, International Journal of Ethics in Engineering & Management Education. 2(1), 2015, 20-24.