Impacts of Custom Power Device on the Dynamic Performance of Power Network

R. Heera Singh[1], N. Ravi[2], H. O. Gupta[3]

Abstract— **This paper presents the study of transient analysis of custom power device based on voltage source converter. The program investigated is the Power System Blockset for use with Matlab/ Simulink/ SimPowerSystems, which employes state-variable analysis. The objective is to implement a necessary model, to compensate voltage sag and over voltages, to present the superior dynamic performance and accurateness of results. The custom power device analyzed is the DSTATCOM (Distribution Static Synchronous Compensator). In all studies presented, such device is implemented and simulated by using PWM and DC link techniques, i.e, In case of PWM method the switching elements IGBTs/ diodes and the PWM signal generator were explicitly represented, othercase DC link model implemented.**

Index Terms—**Custom power device, Voltage-Sags/Voltage dips, Over-voltage, D-STATCOM, PWM Inverter, DC link model and Matlab/ PSB [4].**

I. Introduction

Power quality is certainly a major concern in the present era; it becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Modern industrial processes are based on a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbances [1] and thus industrial loads become less tolerant to power quality problems such as voltage sags, over voltages, voltage swells and harmonics [9, 10]. Modern equipment is more sensitive to the voltage sag problems, both commercial and industrial facilities are affected by this type of problem [1]. Voltage dips are short-duration reductions in r.m.s.voltage caused by short-duration increases of the current, typically at another location than where the voltage dip is measured. The most common causes of overcurrents leading to voltage dips are motor starting, transformer energising and faults [9]. Also capacitor energizing and switching of electronic load lead to short duration-

[1]R. Heera Singh, Scientist/Engineer-SC (Electrical), Civil Engineering Division, with the Department of Space (ISRO), Govt. of India, NRSA, Hyderabad (phone: +91-9885992795; e-mail: heerasinghrathod@ yahoo.com).

[2]N. Ravi, Asst. Engineer, with the APGENCO, Paloncha, Andhrapradesh State, (phone: +91-9885992795; e-mail: johnraviram@yahoo.co.in).

[3]H. O. Gupta, Prof. & Head, with the Electrical Engineering Department, Indian Institute of Technology Roorkee, Roorkee, (phone: 01332-285231, 285576; fax: 01332 285231; e-mail: harifee@iitr.ernet.in).

overcurrents, but the duration of the overcurrent is too short to cause a significant reduction in the r.m.s. voltage. These events are normally not referred to as voltage dips but as voltage notches or voltage transients. Voltage dips due to short circuit and earth faults are the cause of the vast majority of equipment problems. Moreover, Average US plant has about 66-sags/ year [7]. Cost per sag $6-$40 per KVA/ Event, due to lost production, wasted product, possible equipment damage, restart time and associated labour. Swells and over voltages can cause over heating tripping or even destruction of industrial equipment such as motor drives. Electronic equipments are very sensitive loads against harmonics because their control depends on either the peak value or the zero crossing of the supplied voltage, which are all influenced by the harmonic distortion.

This paper describes the techniques of correcting the supply voltage sag and over voltage in a distribution system by power electronics based device called Distribution Static Synchronous Compensator (DSTATCOM). A DSTATCOM injects a current into the system to correct the voltage sag [1], and it absorbs voltage from the power network to compensate over voltage.

II. Custom Power

Custom power concept has been proposed to ensure high quality of power supply in distribution networks using power electronics devices [1, 2, 7]. Additionally, various custom power devices are based on the voltage source converter technology [3, 11]. Thus, the voltage source converter-based device is investigated in this work. Furthermore, the custom power concept is to use power electronic or static controllers in the medium voltage distribution system aiming to supply reliable and high quality power to sensitive users. Power electronic values are the basis of those custom power devices such as the static transfer switch, active filters and converter-based devices.

The chosen device is the DSTATCOM. In distribution voltage level, usually, the employed switching element is the IGBT (Integrated Gate Bipolar Transistor), due to its lower switching losses and reduced size [8]. Moreover, the output voltage control can be executed through PWM (Pulse Width Modulation) switching pattern, reducing the low order harmonic generation. Furthermore, here, the converter is directly controlled, i.e, the angular position and magnitude of output voltage are controllable by appropriate on/off signals [2, 11]. Moreover, output voltage control also executed through Dc link Model and out put voltage execution by both the models for the same network is explicitly represented with necessary results.

III. D-STATCOM

A DSTATCOM (Distribution Static Synchronous Compensator), which is schematically depicted in Fig.1, consists of a voltage source converter shunt connected to the distribution network through a coupling transformer [1, 5, 6]. This configuration allows the device to absorb or generate controllable reactive power. The DSTATCOM has been utilized for voltage regulation, correction of power factor and elimination of current harmonics [2, 5, 7]. In this work, the performance of DSTATCOM device acting as a voltage controller is implemented. Moreover, it is assumed that the converter is directly controlled [3], it is important to mention that a directly controlled converter is more difficult and expensive to implement than an indirectly controlled converter, the former presents a superior dynamic performance [5].

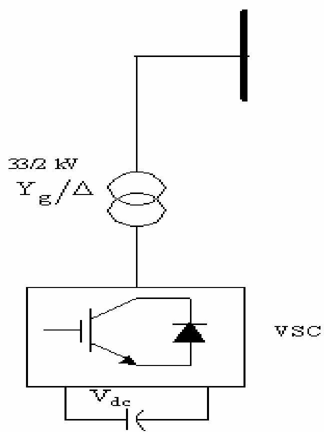


Fig.1. DSTATCOM structure.

IV. DSTATCOM direct Voltage Controller

The voltage controller implemented in this work is exhibited in Fig. 2, which employs the dq0 rotating reference frames because it offers higher accuracy than stationary frame based techniques [2]. In this figure, *Vabc* are the three-phase terminal voltages, *Iabc* are the three-phase currents injected by the DSTATCOM into the network and *Vdc* is the dc voltage measured in the capacitor. Such controller employs a PLL (Phase Locked Loop) to synchronize the three-phase voltages at the converter output with the zero crossings of the fundamental component of the phase-A terminal voltage. Therefore, the PLL provides the angle φ to the abc-to-dq0 (and dq0-to-abc) transformation. There are also four PI regulators. The first one is responsible for controlling the terminal voltage through the reactive power exchange with the ac network

This PI regulator provides the reactive current reference *Iq*, which is limited between +1 pu capacitive and -1 pu inductive. This regulator has one droop characteristic, usually ±5%, which allows the terminal voltage to suffer only small variations. Another PI regulator is responsible for keeping constant the dc voltage through a small active power exchange with the ac network, compensating the active power losses in the transformer and inverter. This PI regulator provides the active current reference *Id*. The other two PI regulators determine voltage reference *Vd* and *Vq*, which are sent to the PWM signal generator of the converter, after a dq0-to-abc transformation. Finally, voltage reference *Vabc* are the three-phase voltages desired at the converter output.

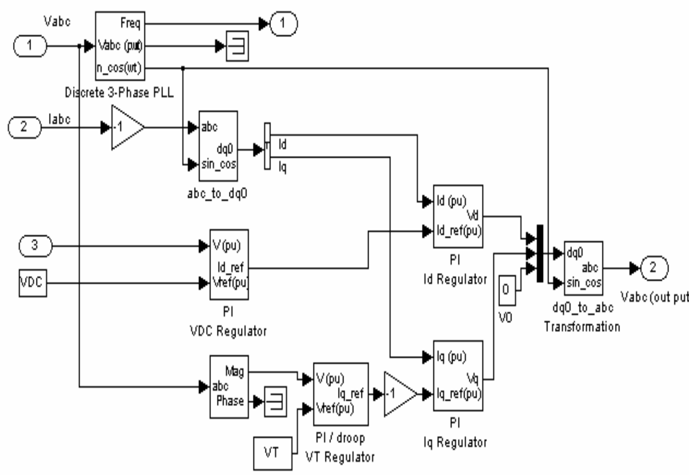


Fig.2. DSTATCOM Direct voltage controller implemented in SimPowerSystems.

V. Compact Analysis

In this section, the paper deals with the implementations of DSTATCOM Devices in MATLAB/ Simulink/ SimPowerSystems. consequently, the implementation of DSTATCOM with DC-link model is compared to implementation of DSTATCOM with PWM technique by using electromagnetic transient simulations, the well-developed graphic facilities available in an industry standard power system package, namely, MATLAB (/Simulink) [4], is used to conduct all aspects of model implementation and to carry out extensive simulation studies. The test system is shown in Fig. 3. Such system comprises a 33 kV, 100 MVA, 60 Hz, substation, represented by a Thévenin equivalent, feeding a distribution network where there is a DSTATCOM connected at bus 2 through a 33/2 kV, Yg/Δ, transformer.

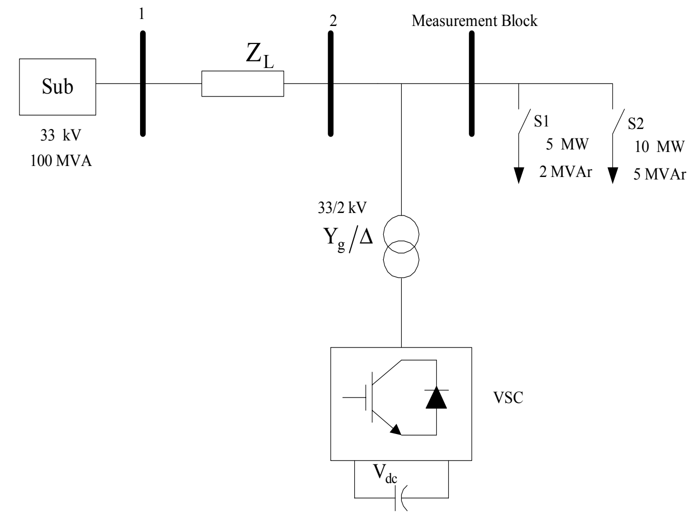


Fig.3. Single-line diagram of test system.

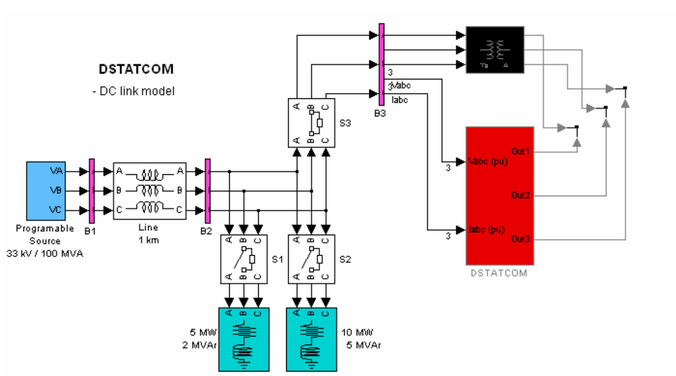


Fig.4. Mat lab Simulation model of Test System

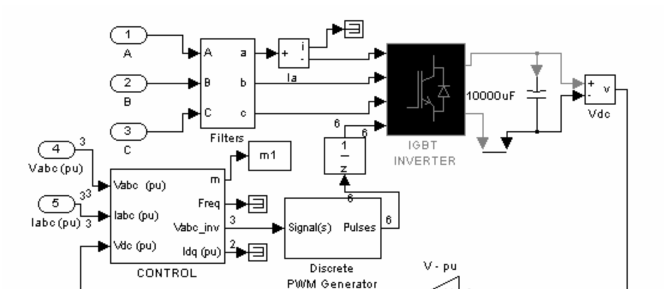


Fig.5. DSTATCOM with detailed model implemented in Simulink/ SimPowerSystems.

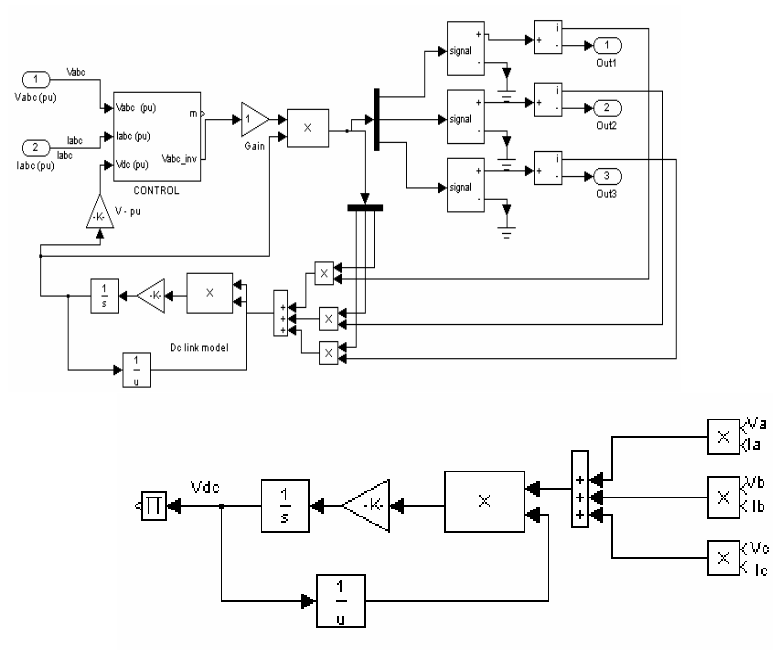


Fig.6. DSTATCOM with DC-link model implemented in Simulink/ SimPowerSystems.

The compensation capacity of the DSTATCOM is ±5 MVAr and the voltage level of the dc capacitor is 4 kV. To verify the performance of the DSTATCOM, a variable load is connected at bus 2 and the substation voltage is also changed during the simulation. The sequence of events simulated is explained as follows. Initially, there is no load connected at bus 2; at t = 200 ms the switch S1 is closed and at t = 400 ms the switch S2 is closed too; both switches remain closed until the end of the simulation. During these events, the terminal voltage of bus 2 decreases. At t = 700 ms the substation voltage is increased about 40 kV, consequently, the terminal voltage of bus 2 also rises. It is important to mention that the sub-station voltage increased about 40kV by means of programmable voltage source, purposely to see the dynamic behavior of DSTATCOM during over voltage period also. It is also mentioned that the former has presented well dynamic behavior of DSTATCOM during voltage sag and over voltage conditions.

Implementation of DSTATCOM Methods in MATLAB Simulink

A. DSTATCOM with PWM Method

In the PWM method, the switching elements–IGBTs/diodes, the PWM signal generator and the dc capacitor are explicitly represented. Here, a DSTATCOM model was implemented using SimPowerSystems. Considering the DSTATCOM as a voltage controller, the implemented model is shown in Fig. 5. Such a model consists of a six-pulse voltage-source converter using IGBTs/diodes, a 10000µF dc capacitor, a PWM signal generator with switching frequency equal to 3 kHz, a passive filter to eliminate harmonic components, and a voltage controller as that shown in Fig. 2. The dc voltage (V_{dc}) is measured and sent to the controller as well as the three-phase terminal voltages (V_{ABC}) and the injected three-phase currents (I_{abc}). V_a, V_b and V_c are voltages at the converter output.

B. DSTATCOM with DC-link Method

In the DC-link method, the converter, the PWM signal generator, and the filter are replaced by a set of three controllable ac voltage sources. Such sources are controlled by the reference signal V_{abc} obtained from the controller, which is a voltage controller. However, the three-phase voltages at the converter output, in volts, are dependent on the dc link voltage [3] (i.e., Va= $KV_{dc}V_b$ reference, and V_c = $KV_{dc}V_c$ reference, where K depends on the kind of converter). This can be carried out by applying the energy conservation principle, which resides in the physical fact that, neglecting the converter losses, the instantaneous power at the ac output terminals must always be equal to the instantaneous power at the dc input terminal [3]. Such principles can be expressed by

$$V_{dc}I_{dc} = V_aI_a+V_bI_b+V_cI_c \qquad (1)$$

Where I_{dc} is the current in the dc link. Moreover, the relationship between V_{dc} and I_{dc} is given by (2), where C is the dc capacitance value. Equations (1) and (2) can be iteratively solved by means of an algebraic-differential loop, as schematically depicted in Fig.7.

$$Vdc = -(1/C)\int I_{dc}\, dt. \qquad (2)$$

Fig.7. Dc link Model

The implementation of the DSTATCOM with Dc-link model using Simulink/ SimPowerSystems is shown in Fig. 6, a set of three controllable ac voltage sources, and a dc link model as exhibited in Fig. 7. Note that the three-phase currents injected by the DSTATCOM into the network are measured and sent to the dc link model. Moreover, the reference voltage of the controller is multiplied by a constant K to take into account the relationship among the rms voltage, modulation index, and dc voltage of a six-pulse voltage-source converter.

VI. Simulation Results

The three-phase rms value of the terminal voltage of bus 2 for the events previously described is shown in Fig. 8. In the absence of the DSTATCOM, the terminal voltage varies considerably, but such variations are minimized in the presence of the DSTATCOM, which is as shown in Fig.9 and Fig.12, DSTATCOM with PWM technique and DSTATCOM with Dc-link model, respectively. Thus when the DSTATCOM is in operation the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 98% and 99% as shown in Fig.9 and Fig.12, DSTATCOM with PWM technique and DSTATCOM with Dc-link model, respectively. However, it is indispensable to mention here is to show that the results obtained using the DSTATCOM is very similar with actual results [5]. The dynamic behavior of the dc voltage and inverter output voltage using PWM technique can be seen in Fig. 10. Furthermore, the reactive and active power injected by the DSTATCOM into the network is shown in Fig. 11 and Fig.14, where the consumption of active or reactive power by the DSTATCOM is represented by positive values and the generation by negative values. These consumptions and compensations of DSTATCOM are accordingly the variations in voltage/currents with the PWM technique, which is as shown in Fig.10. Practically, there is no difference among the results obtained from the DSTATCOM with DC-link or PWM Models and, therefore, the DSTATCOM with DC-link model can represent very well the dynamic behavior of the DSTATCOM.

The switching rate utilized for the PWM was 3000 Hz, considering a 60 Hz system, the settling time of the system may be 5.555 microseconds. Furthermore, the PWM control scheme controls the magnitude and the phase of the injected voltages, restoring the rms voltage very effectively [10]. The sag mitigation is performed with a smooth, stable, and rapid DSTATCOM response; only switching transients are observed when the DSTATCOM comes in and out of operation.

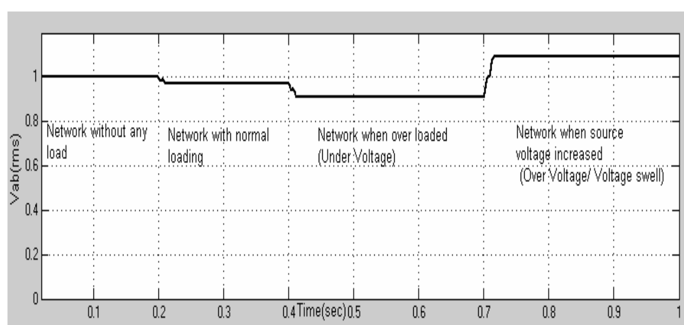
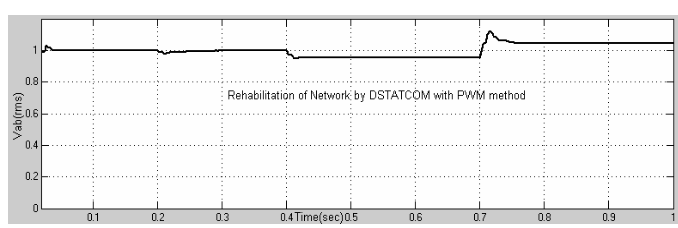


Fig.8. Terminal voltage of bus 2: without DSTATCOM;



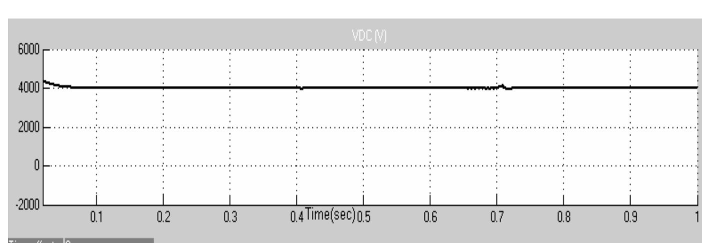
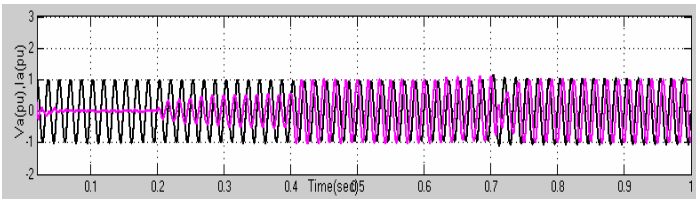
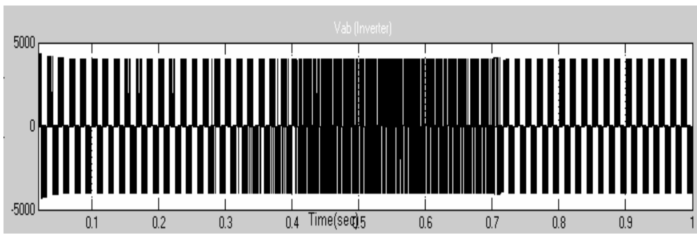


Fig.9. Terminal voltage of bus 2; with DSTATCOM PWM model;

(a)



(b)



(c)

Fig.10. (a)DC voltage,(b)Voltage & Current variations and (c) Inverter output voltage: with DSTATCOM PWM Technique;

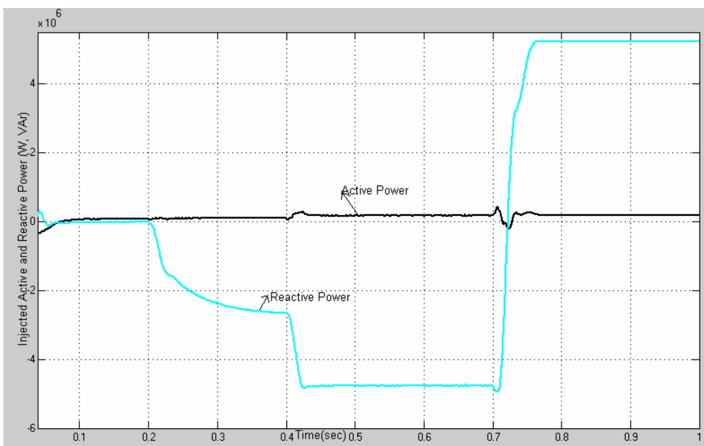


Fig.11. Active (P) and Reactive (Q) power injected by DSTATCOM represented with PWM Technique.

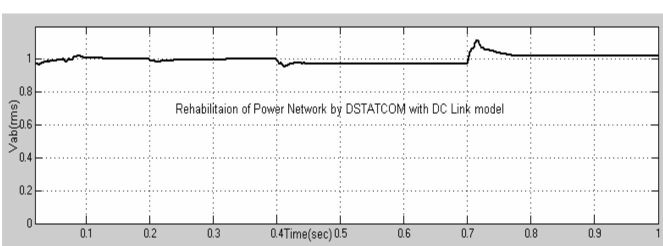


Fig. 12. Terminal voltage of bus 2; DSTATCOM with DC-link model.

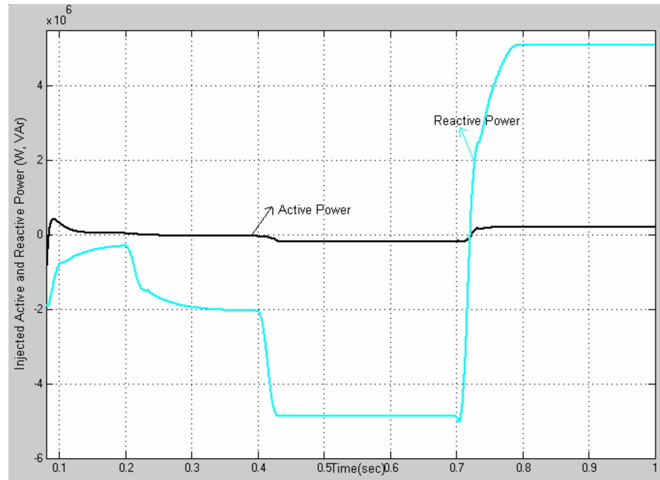


Fig.14. *Active (P) and Reactive (Q) power injected by DSTATCOM with Dc-link model;*

VII. Conclusions

Power quality measures can be applied both at the user end and also at the utility level. The work identifies some important measures that can be applied at the utility level without much system upset (or design changes). This paper has presented model of custom power equipment, i.e. DSTATCOM, and applied to mitigate voltage sag and over voltage, which are very prominent as per utilities are concerned. The highly developed graphic facilities available in MATLAB SIMULINK were used to conduct all aspects of model implementation and to carry out extensive simulation studies on test system. A new PWM-based control scheme has been implemented, and direct controller (dq0 rotating reference frame) is used as a controller to the test system DSTATCOM, because it offers higher accuracy than stationary frame based techniques. This characteristic makes it ideally suitable for low-voltage custom power applications. It was observed that the DSTATCOM capacity for power compensation and voltage regulation depends mainly on the rating of the dc storage device. The simulation results presented shows good accuracy with results reported in index journals. It is also found that a DSTATCOM can correct much higher voltage sags without injecting any active power into the system Furthermore, we can use the DSTATCOM for both downstream as well as upstream sides. Furthermore, there is no difference between DSTATCOM with PWM technique and DSTATCOM with DC-link model. Hence, DSTATCOM with DC-link model can represent well dynamic behavior of power network.

References

[1] N.G. Hingorani, “Introducing Custom Power”, IEEE Spectrum, Vol.31, pp. 41-48, 1995.

[2] E Acha, V.G. Agelidis, O. Anaya-Lara, T.J. Miller, “Power Electronic Control in Electrical Systems”. 1st edition, Newnes, 2002.

[3] N.G. Hingorani and L.Gyugyi, “Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems”, 1st edition. The Institute of Electrical and Electronics Engineers, 2000.

[4] TEQSIM International Inc., “Power System Blockset User’s guide”, 2001.

[5] Olimpo Anaya-Lara and E. Acha "Modeling and Analysis of Custom Power Systems by PSCAD/EMTDC" IEEE Transaction on power delivery, Vol. 17, No.1, January 2002.

[6] M.H.Haque "Compensation of distribution system voltage sag by DVR and D-STATCOM." 2001 IEEE Porto power tech conference. 10th-13th September, Porto, Portugal.

[7] Dan Sabin, Ambra Sannino "A summary of Draft IEEE1409 Custom power application guide", IEEE T&D Conference& Expo 2003. Web: http://grouper.ieee.org/groups/1409.

[8] G. Venkataramanan and B. Johnson, "A pulse width modulated power line conditioner for sensitive load centers," IEEE Trans. Power Delivery, vol. 12, pp. 844–849, Apr. 1997.

[9] M. H. J. Bollen, "Understanding Power Quality Problems—Voltage Sags and Interruptions" Park Avenue, New York: IEEE Press, 2001.

[10] Sannio, M.G. Miller, M. J. H. Bollen, "Overview of voltage sag mitigation," power engineering society winter meeting, 2002. IEEE, Volume: 4, PP. 2872-2878, 2002.

[11] Mohan, T. M. Undeland, andW. P. Robbins, *Power Electronics: Converters, Applications and Design*. New York: Wiley, 1995.