

Power Quality Improvement of Power Distribution System Under Symmetrical and Unsymmetrical Faults Using D-STATCOM



Amit Kumar, Deepak Kumar and Abhay Yadav

Abstract Voltage and current waveform distortion is a most important power quality concern, because a small fluctuation with phase supply, transient condition occurs and unbalanced of phase voltage can create a more derange within phase currents. Three phase balanced system holds only positive sequence constituents of voltage, current, and impedance, whereas both positive and negative sequence constituents of voltages and currents within unbalanced system. The voltages at the generation system side are in sinusoidal wave and have constant equivalent magnitude value within 120° phase difference. However, unbalanced condition arises due to inadequacy in voltage magnitude and in fundamental frequency in load side. This paper proposes the shunt-connected current inserting Distribution Static Synchronous Compensator (D-STATCOM) through appropriate controlling scheme to moderate and compensate the unstable load current. It works as quick reimbursing source for reactive power that is functional on the distribution power system to moderate voltage deviations like voltage sags, swells, and voltage flicker along with unsteadiness produced by quickly changing reactive power demand. This paper presents the scheme and Simulink model of D-STATCOM within PI controller toward improving the superiority of power under dissimilar irregular circumstances like symmetrical and unsymmetrical faults. The controller working efficiency is tested under different fault conditions. The performance of D-STATCOM under different fault conditions in power distribution system is carried out at three phase supply 20 kV, 50 Hz. The controller and D-STATCOM model are designed through Simulink and Power System Blockset toolbox existing in MATLAB program.

Keywords Power quality · D-STATCOM · Voltage source converter flexible alternating current transmission system · Pulse width modulation

A. Kumar (✉) · D. Kumar · A. Yadav
School of Engineering, Gautam Buddha University, Greater Noida, India
e-mail: abes.amit@gmail.com

D. Kumar
e-mail: deepu1796@gmail.com

A. Yadav
e-mail: abhayadav@outlook.com

1 Introduction

Power quality (PQ) is an important and serious issue in power distribution network system. In present day, the industrial equipment is primarily based on electronic components such as rectifier, thyristors together with programmable sensing controllers and power electronic drives [1]. These devices are very sensitive to instabilities and end up less tolerant to PQ issues [3]. In the industrial and commercial equipment, voltage sags, swell, voltage fluctuation are serious and most common problems [1].

D-STATCOM is a reactive power shunt jointed reimbursement device that is capable for generating and absorbing the reactive power and also provides voltage sustenance to a system bus [4]. In a renewable energy system, it is also utilized in improving the constancy of the power system [2]. The reactive power imbalances can be minimized through the compensation device [5]. D-STATCOM is also capable to solve fault problems and compensate harmonics through capability of the system [7].

The first D-STATCOM was introduced by Japan country and it transported to the UK, where it has been installed in southwest England to adjacent a wind farm.

The Flexible Alternating Current Transmission System (FACTS) offers a fast and consistent control mechanism over transmission line constraints, like voltage, phase angle between the sending end and receiving end voltage, line impedance [8]. Custom power devices (CPD) are designed for distribution of voltage supplies at low voltage and encroachment of PQ due to which the system becomes reliable [11]. Solid-state CPD is utilized in electrical power network to offer reimbursement and advance voltage profile [1]. Some CPD are D-STATCOM, unified power quality conditioner (UPQC) as a combination of series and parallel [6], Dynamic Voltage Restorer (DVR) is in series connection [9] among D-STATCOM which is a cost operational solution for reimbursement of reactive power [6]. A FACTS is a power semiconductor device which is utilized to sustain the PQ by preserving superior movement of power and controlling the dynamically stability of system through altering the system constraints like voltage, angle of phase, and impedance [13].

2 Configuration and Operation of D-STATCOM

A D-STATCOM is voltage source inverter (VSI)-fed semiconductor-based power electronic expedient [2] that is associated with shunt to the system to moderating harmonics and PQ problems [9]. Its performance depends upon different control algorithms, for taking out reference current to deliver pulses to gate-terminals of VSI [10]. The D-STATCOM is extremely effective to providing regulation at load voltage. It keeps rated voltage value at load point that has numerous undesirable things from customer point of view. Within voltage value of 1 per unit at load point, D-STATCOM force to load to drive continuously at rated value [3]. It can easily convert both active and reactive power within electrical power

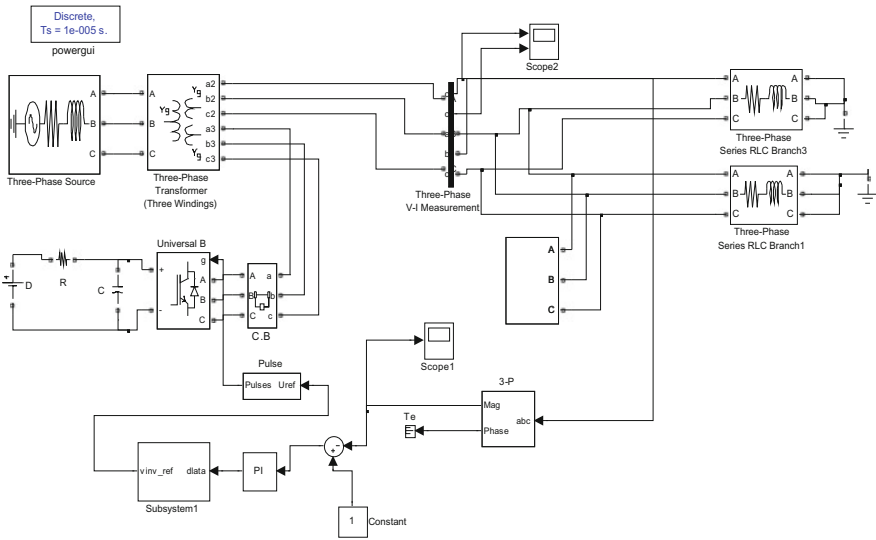


Fig. 1 MATLAB simulink model of D-STATCOM

distribution network through flexible amplitude and phase angle of the voltage converter device [4].

2.1 MATLAB Simulink Model of D-STATCOM

In Fig. 1, three phase supply 20 kV is utilized in power distribution system and nonlinear load is connected as a load in power system network. Three phase distribution transformer is connected with the three phase supply voltage. D-STATCOM is a shunt-connected device which is in between the power supply and nonlinear load. A fault occurs in distribution line near a load in a transmission line network. Circuit breaker is used to isolate the faulty network in power system network which can observe the difference at the time of fault and after the compensation by D-STATCOM. The symmetrical and unsymmetrical fault study and performance is done by the given D-STATCOM Simulink model.

2.2 Controlling Scheme of D-STATCOM

A controller is utilized to sustain a continuous voltage magnitude at the value of point where a sensitive load is associated under system disturbances [11]. The VSC switching stratagem is based on a sinusoidal pulse width modulation (SPWM). This

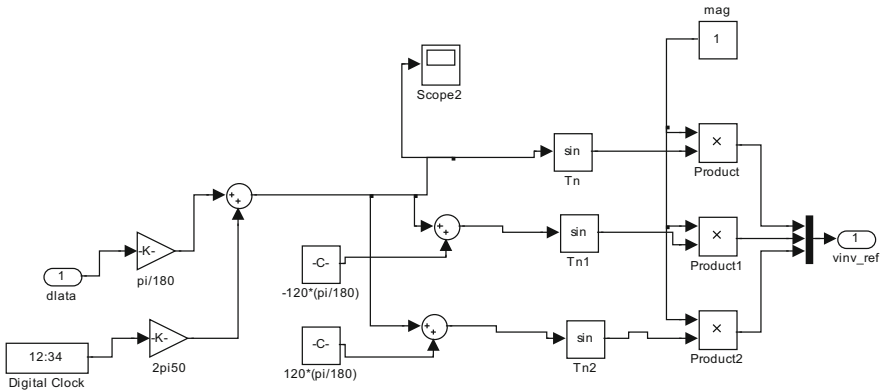


Fig. 2 Mathematical model of pulse width modulation (PWM) generator

technique compromises a more efficient flexible and reliable preference than the fundamental frequency switching (FFS) techniques preferred within FACTS applications [8]. High switching frequencies (HSF) are utilized to improve the effectiveness of the voltage converter without acquiring substantial switching losses [12]. The error signal is the input for controller which is acquired from the reference value and rms value of the voltage measured at the terminal point [16]. This error is processed through a PI controller that output is the angle ϕ which is delivered to the PWM signal generator [13]. In case of indirectly controlled converter, power exchanges with the network simultaneously of the active and reactive power. Error signal is achieved through relating the reference voltage within rms measured value near the load point [15]. The PI controller develops the error signal and produces requisite and suitable angle to determine the error to zero; i.e., the load rms voltage is taken back to the reference voltage [14] (Fig. 2).

The sinusoidal signal $V_{Control}$ is phase modulated by means of the angle

$$V_A = \sin \omega t + \phi \tag{1}$$

$$V_B = \sin \omega t + \phi - \frac{2\pi}{3} \tag{2}$$

$$V_C = \sin \omega t + \phi + \frac{2\pi}{3} \tag{3}$$

The foremost constraints of SPWM technique are modulation of amplitude indeed of signal and (FMI) frequency modulation index (M_f) of the triangular signal. The amplitude index (AI) is reserved stable at 1 per unit in directive to achieve the component of maximum fundamental voltage at controller output. The switching frequency (F_S) is set at the point 1080 Hz. The frequency modulation index is specified by

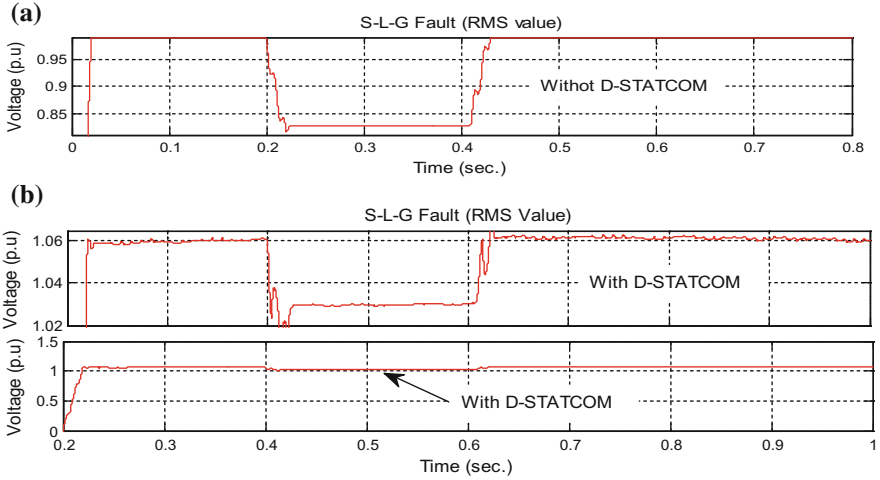


Fig. 3 a SLG fault waveform without D-STATCOM. b SLG fault waveform without D-STATCOM

$$M_f = \frac{F_S}{F_f} = 1080/50$$

$$M_f = 21.6 \tag{4}$$

where M_f is modulation index, F_S is switching frequency, and F_f is fundamental frequency

3 Performance of D-STATCOM Simulink Model Under Different Fault Conditions

3.1 Single Line-to-Ground Fault (SLG Fault)

In case of SLG fault, phase A is faulty and connected to the ground and phase B and phase C are unfaulty phases. The fault has impedance which is known as fault impedance denoted by Z_F . Phase B and phase C are like an open circuit, and there is no current flow through these phases.

In Fig. 3a, single line-to-ground (SLG) fault shows the result when D-STATCOM is not connected along with transmission line, and the rms voltage value is 0.80 per unit duration of 0.2–0.4 s.

Figure 3b shows the rms value is 0.99 per unit when D-STATCOM is coupled within transmission line and regulates the voltage near about to 1 per unit for time period of fault and attains the sinusoidal waveform at the load terminal in power distribution system.

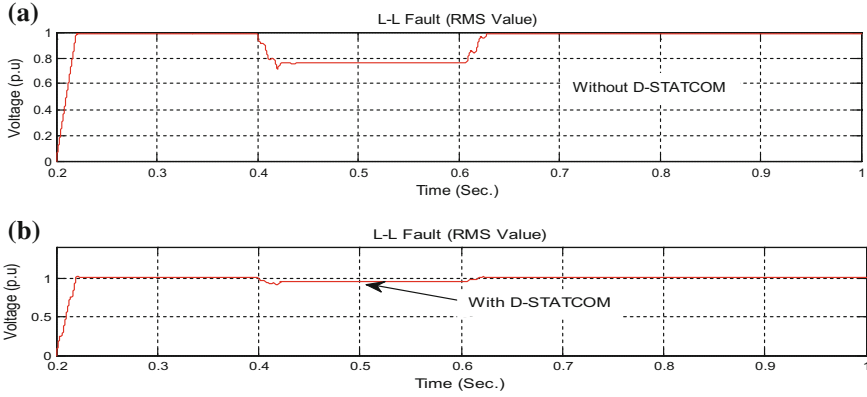


Fig. 4 **a** LL fault waveform without D-STATCOM. **b** LL fault waveform with D-STATCOM

3.2 Line-to-Line Fault (LL Fault)

In case of LL fault, fault takes place between two conductors, phase B and phase C, and both are short circuit; current flows through both phases. Fault impedance is Z_F .

Figure 4a presents the result without connected D-STATCOM along with distribution line, and rms voltage value is 0.75 per unit which is less than 1 per unit, and the sinusoidal waveform of system is not perfectly sinusoidal.

Figure 4b shows the voltage rms value is 0.95 per unit when D-STATCOM is utilized along with distribution line and regulates the voltage near to 1 per unit for duration of fault and achieves the sinusoidal waveform at the load terminal.

3.3 Double Line-to-Ground Fault (LLG Fault)

In case of LLG fault, phase B and phase C are short circuit and have their fault impedance value Z_F , and both conductors are connected to the ground after a fault through a common line and have the value of ground impedance Z_g .

Figure 5a presents the result when D-STATCOM is not used in distribution system and shows the rms voltage value is 0.70 per unit and waveform is not sinusoidal.

Figure 5b shows the rms value is 0.93 per unit when D-STATCOM is utilized along with system. D-STATCOM regulates the voltage 0.70–0.95 per unit Regulated voltage is 0.25 per unit duration of fault, and achieved waveform is sinusoidal at the load terminal.

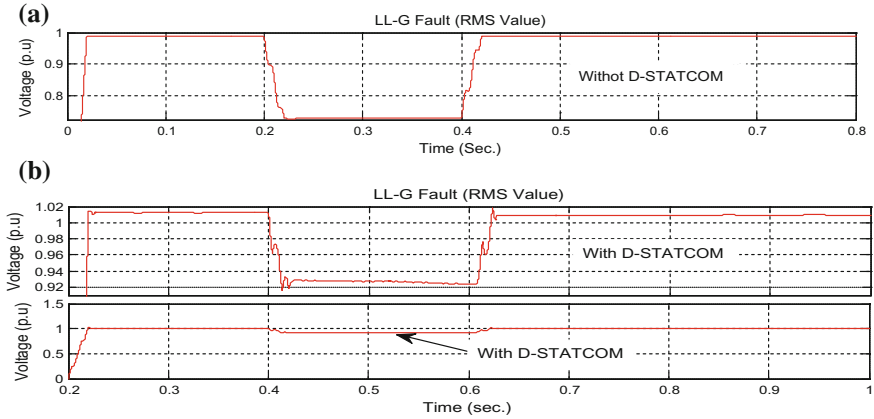


Fig. 5 a LLG fault waveform without D-STATCOM. b LLG fault waveform with D-STATCOM

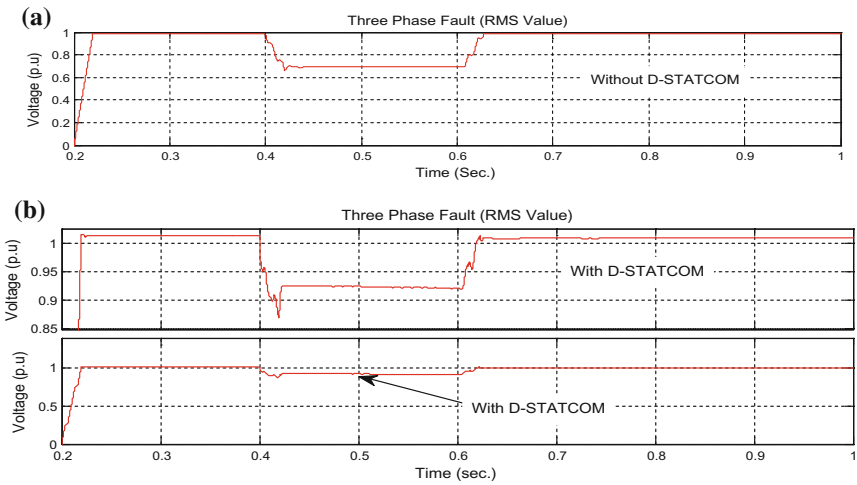


Fig. 6 a Three phase fault without D-STATCOM. b Three phase fault with D-STATCOM

3.4 Three Phase Fault

Three phase fault is known as symmetrical fault which involves all the three phases A, B, and C.

Figure 6a presents the rms voltage value that is 0.70 per unit duration of 0.4–0.6 s; this result is achieved when D-STATCOM is not connected along with distribution line. In this case, voltage sag takes place.

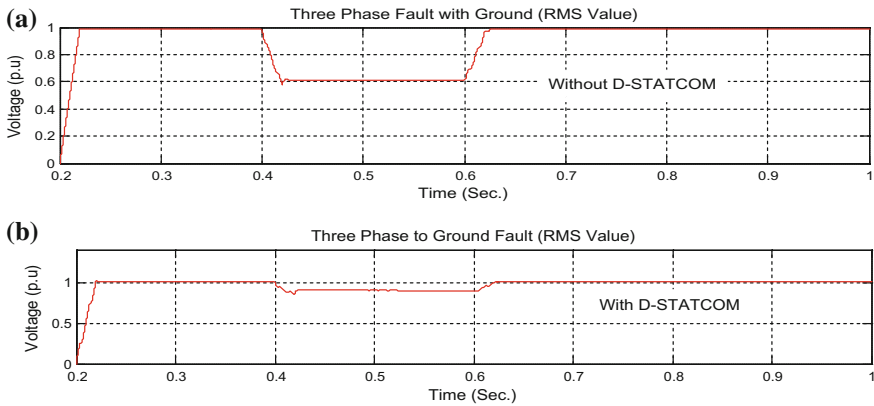


Fig. 7 **a** Three phase to ground fault without D-STATCOM. **b** Three phase to ground fault with D-STATCOM

Figure 6b shows the rms value is 0.94 per unit when D-STATCOM is connected with system. It regulates the voltage 0.7–0.94 per unit during fault occurring time (0.4–0.6 s). D-STATCOM is used to get sinusoidal balanced waveform at the load terminal in power distribution system.

3.5 Three Phase-to-Ground Fault

In three phase-to-ground fault, all the phases are involved with fault and connected with ground. This fault destroys the sinusoidal wave and causes to the unbalanced condition at the near nonlinear load.

Figure 7a presents the three phase-to-ground fault, and the result shows the rms voltage value is 0.60 per unit during the time 0.4–0.6 s; this duration is fault occurring time, and D-STATCOM is not linked within distribution line; the waveform is not sinusoidal at the load terminal.

Figure 7b shows the rms value is 0.90 per unit when D-STATCOM is attached along with system; it regulates the voltage 0.60–0.90 per unit D-STATCOM regulate value is 0.30 per unit during fault condition, and achieved waveform is sinusoidal at the load terminal in power distribution system.

4 Results and Discussion

Fault condition	Without D-STATCOM voltage (RMS value) (per unit)	With D-STATCOM voltage (RMS value) (per unit)	Power quality improvement (per unit)
SLG fault	0.80	0.99	0.19
LL fault	0.75	0.95	0.20
LLG fault	0.70	0.93	0.23
Three phase fault	0.70	0.94	0.24
Three phase-to-ground fault	0.60	0.90	0.30

5 Conclusion

The PWM voltage control scheme of D-STATCOM is utilized to regulate the load voltage under the symmetrical and unsymmetrical fault, and the D-STATCOM can regulate the load voltage to the desired level which is described in this paper. The performance of D-STATCOM has been evaluated for linear loads and static nonlinear loads. In this paper, the problems associated with faults determination and proper D-STATCOM injected reactive power rating which causes improvement in profile of voltage, current and reduction of power-losses in electrical power system network has been presented. Pulse width modulation control scheme is appropriate for both unbalanced load compensation and balanced RC or RL load. In this paper, the exploration of the D-STATCOM is carried out to improve the power quality in power distribution networks within static linear and nonlinear loads. Proportional integral (PI) controller is utilized within device to improve system performance. The results show the satisfactory performance of D-STATCOM in the distribution system under different fault conditions, and it can be concluded that D-STATCOM effectively improves the power quality and voltage profile in power distribution system.

Appendix

The constraints of the system considered in table:

Constraints	Parameters
Three phase source	20 kV
Three phase transformer	Nominal power = 100 MVA, frequency = 50 Hz
PI controller	$K_p = 0.5$, $K_i = 500$
Converter	3Arm-bridge, 6 pulse, carrier frequency = 50 Hz.
Load	RL load (non-linear load)
Switching frequency	1080 Hz

References

1. Kumar, A., Pal, N.S., Ansari, M.A.: Mitigation voltage sag/swell and harmonics using self-supported DVR. In Ist IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES-2016), pp 393–399 (2016)
2. Woo, S.M., Kang, D.W., Lee, W.C., Hyum, D.S.: The distribution STATCOM for reducing the effect of voltage sag and swell, IECON'01, vol. 2, pp. 1132–1137 (2001)
3. Park, S.Y., Park, J.K.: The modeling and analysis of shunt type custom power device. IEEE Power Eng. Soc. Winter Meet. **1**, 186–191 (2001)
4. Chiang, H.K., Lin, B.R., Yang, K.T., Yang, C.C.: Analysis and implementation of a NPC-based DSTATCOM under the abnormal voltage condition. In International Conference on Industrial Technology 2005, pp. 665–670, Dec 2005
5. Muni, B., Rao, S., Vithal, J.: SVPWM switched DSTATCOM for power factor and voltage sag compensation. In 2006 International Conference on Power Electronics, Drives and Energy Systems, PEDES'06, pp. 1–6, New Delhi, India (2006)
6. Kumar, C., Mishra, M.K.: A voltage-controlled DSTATCOM for power-quality improvement. IEEE Trans. Power Delivery **29**(3), 1499–1507 (2014)
7. Geddada, N., Karanki, S.B., Mishra, M.K.: Synchronous reference frame based current controller with SPWM switching strategy for DSTATCOM Applications. In Proceedings of IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES). Bengaluru, India, 16–19 Dec 2012
8. Singh, B., Jayaprakash, P., Dp, Kothari: A T-connected transformer and three-leg VSC based DSTATCOM for power quality improvement. Proc. IEEE Trans. Power Electron. **23**, 2710–2718 (2008)
9. Bilgin, H.F., Ermis, M.: Design and implementation of a current source converter for use in industry applications of D-STATCOM. Proc. IEEE Trans. Power Electron. **25**, 1943–1957 (2010)
10. Deben Singh, M., Khumanleima, Chanu L.: Power electronics technology for power quality improvement. Int. J. Adv. Res. Electr. Electron. Instrum. Eng. **4**, 2073–2080 (2015). <https://doi.org/10.15662/ijareeie.2015.0404031>
11. Ghosh, A., Jindal, A.K., Joshi, A.: Inverter control using output feedback for power compensating devices. In Conference on Convergent Technologies for Asia Pacific Region, pp. 48–52 (2003)

12. Singh, B., Jayaprakash, P., Kothari, D.P.: Three-phase four-wire DSTATCOM with H-bridge VSC and star/delta transformer for power quality improvement. In Proceedings of INDICON 2008, vol. 2, pp. 412–417, Dec 2008
13. Singh, B., Jayaprakash, P., Kothari, D.P.: Three-phase 4-wire DSTATCOM based on H-Bridge VSC with a star/hexagon transformer for power quality improvement. In: Proceedings of ICIS 2008, pp. 1–6, Dec 2008
14. Tavakoli Bina, M., Eskandari, M.D., Panahlou, M.: Design and installation of a ± 250 kVAR D-STATCOM for a distribution substation, Elsevier, Electric Power Systems Research, vol. 73, pp. 383–391, 2005. <https://doi.org/10.1016/j.epsr.2004.09.005>
15. Tavakoli Bina, M., Eskandari, M.D.: Consequence of unbalance supplying condition on a distribution static compensator. In: IEEE Power Electronics Specialists (PESC'04), vol. 8, pp. 3900–3904, June 2004
16. Singh, B., Adya, A., Mittal, A.P., Gupta, J.R.P.: Power quality enhancement with DSTATCOM for small isolated alternator feeding distribution system. In: Conference on Power Electronics and Drive Systems, vol. 1, pp. 274–27 (2005)