Journal of Applied Sciences Research, 8(7): 3619-3625, 2012
ISSN 1819-544X
This is a refereed journal and all articles are professionally screened and reviewed

ORIGINAL ARTICLES

Statcom for Voltage Sag Mitigation: A detail Modeling and Analysis

Abdus Salam

Department of Electrical and Electronic Engineering Faculty of Engineering Institute Technology Brunei JalanTungku Link, Gadong, BE1410, Negara Brunei Darussalam

ABSTRACT

One of the important aspects in improving power quality in distribution networks is the mitigation of voltage sags. The effects of voltage sags can be very expensive for the customer because it may lead to production downtime and equipment damage. Voltage sags can be mitigated by voltage and power injections into the distribution system using power electronics based devices, which are also known as custom power devices. This paper presents the operational principle of the 24-pulse static compensator, which is usually known as STATCOM. The effectiveness of the STATCOM in mitigating voltage sags are examined through analytical simulations using the PSCAD/EMTDC simulation software. The performance of the STATCOM as capacitive and inductive compensators is also analyzed. The simulations results show that the 24-pulse STATCOM gives good performance in mitigating voltage sag by generating or absorbing reactive power in the system.

Key words: STATCOM, power quality, voltage sag mitigation.

Introduction

In recent years, there has been an increasing amount of focus on power quality in distribution systems. The widespread use of computers and microprocessors demands a much better power quality than passive loads like electric machines or lighting systems (Carlos *et al*. 1999.; Daehler and Affolter, 2000; Haque, 2001; Fang *et al*., 1998; Taylor,1995; Hannan *et al*., 2012). A high power quality is essential for the proper operation of many industrial processes such as automation plants and process control systems which rely on computers for data acquisition, data processing and control. Power disturbances such as voltage sags, swells, transient and harmonics can cause the process to stop or malfunction (Taylor,1995; Hannan and Azah, 2005). Among the most common disturbance encountered at an industrial or commercial facility are voltage sags. Voltage sags which last for only few tenths of a second may result in disruptions with considerable costs due to loss of production. This effect is very expensive for customers since a long time interval is needed to restart industrial processes. In order to maintain customer satisfaction, the utilities are continuously seeking for cost-effective voltage sag mitigation techniques.

The importance of maintaining a good load voltage profile mainly for computer based and variable speed drive loads has resulted in the development of a new generation of power electronic controllers with sag mitigation capability. One class of such controllers arenamed as Custom Power Devices(Douglas, 1996; Stump,1998; Middlekauff *et al*., 1998;Pilotto *et al*., 2000; Nielsen, 2000; Subiyanto *et al*., 2011). The custom power device presently in use for the elimination of voltage sags are the distribution static compensators (STATCOM) (Sutanto,1999; Hannan *et al*., 2009).Presently in use for the elimination of voltage sags are the distribution static compensators (STATCOM). This device can provide voltage sag ride-through capability to critical loads by either absorbing or injecting reactive power on an electricity system at distribution voltages.

This paper is focusing on the operational principle of custom power device namely the STATCOM. The objective of study is to develop simulation models of this device in the PSCAD/EMTDC electromagnetic transient simulation program(PSCAD,1994; Hannan *et al*. 2011) for voltage sag studies. Issues involved in the operation of the device topologies and the design of control strategies are addressed in this paper.

The STATCOM is a solid-state, three phase device, which is connected in shunt between a distribution feeder and a load (Hannan and Chan, 2006; Salam *et al*., 2010). It can provide both capacitive and reactive compensation to the full MVA rating of the device's power electronics. The basic configuration of a STATCOM as shown in Fig.1 is made up of a coupling transformer, a voltage-sourced inverter and a dc capacitor. The voltage-sourced inverter, which is the main component of the STATCOM, converts an input dc voltage into a three-phase output voltage at fundamental frequency.

Corresponding Author: Abdus Salam, Department of Electrical and Electronic Engineering Faculty of Engineering Institute Technology Brunei JalanTungku Link, Gadong, BE1410, Negara Brunei Darussalam

J. Appl. Sci. Res., 8(7): 3619-3625, 2012

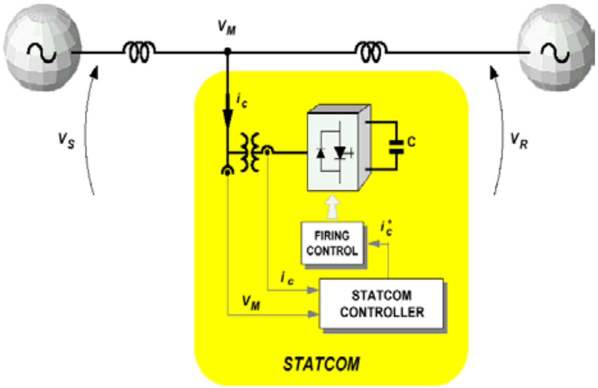

Fig. 1: Basic Configuration of STATCOM

To describe the operation of the STATCOM, the active and reactive power flow between the system ac voltage (V_s) and the STATCOM ac voltage (V_M)are considered (Hannan *et al*., 2005) as,

$$P_s = \frac{V_s V_M}{X_L} \sin\delta \quad (1)$$

$$Q_s = \frac{V_s}{X_L}(V_s - V_M \cos\delta) \quad (2)$$

where, X_L is the line reactance and δ is the line phase angle.

When operating, the STATCOM continuously monitors the line voltage at the primary terminal and compares it with a reference signal. From equations (1) and (2), it is observed that in normal operation the phase angle $\delta = 0$, in which voltages V_s and V_M are in the same phase. If the amplitude of the ac system voltage is lower than the amplitude of the STATCOM output voltage, the current flows through the transformer from the inverter to the ac system, and the device generates reactive power. However, if the amplitude of the ac system voltage is greater than the amplitude of the inverter output voltage, the current flows from the ac system to the inverter, resulting in the device absorbing reactive power. A capacitor is used to maintain dc voltage to the inverter. By controlling the inverter output voltage with respect to the ac system voltage, the capacitor voltage can be decreased or increased, respectively, to control the reactive power output of the device. In this way, the STATCOM is capable of mitigating voltage sags by injecting the necessary voltage into the system.

Modeling of the 24-pulse STATCOM and Control System:

Fig. 2 shows the topology of a two level, 24-pulse voltage source convertertype STATCOM, connected in shunt between a generator and a load in a distribution system. The STATCOM consists of twenty four self-commutated GTO switches with anti-parallel diodes. The firing of each switch is controlled to generate a set of three alternating voltages at terminals A, B and C with controllable amplitude, phases and frequencies. The capacitor is kept charged to provide the dc stored energy when necessary. The sinusoidal pulse width modulation (PWM) technique is used to control the magnitude and phase of the ac voltage by synchronizing the GTOs switching to the ac system voltages (Hannan *et al*.,2009;Hannan *et al*., 2012; Ghani *et al*., 2012). The PWM switching pattern is determined by comparing a sine wave with a synchronized high frequency triangular wave. In the PWM process, the value of the fundamental voltage obtained is,

$$V_{an}\underline{|0^\circ} = \frac{1}{2} m_a V_d = \frac{1}{2}\frac{V_{Sin}\underline{|0^\circ}}{V_T} V_d \quad (3)$$

Where,

m_a = Modulation Index $= \frac{V_{Sin}}{V_T}$

V_{Sin} = Peak of modulation signal ,

V_T = Peak of carrier signal ,

V_d = dc capacitor voltage .

Fig. 3 illustrates the relationship between the PWM and the control loops of STATCOM in terms of a block diagram in which it is used as a basis in the controller design developed in PSCAD. The measured phase voltages and reactive power at the transformer primary winding side are represented by sinusoidal signal. The phase voltages are fed to the phase locked loop (PLL) in order to detect the phase angles and to generate synchronizing signals. The measured voltage in per unit is multiplied by a constant which is obtained by comparing the measured reactive power with the rated reactive power and it is then compared with a reference voltage. An error is observed and is fed to the voltage lag-lead function block, in which the output $Y(t)$ is fed to the proportional integral (PI) control block. The $Y(t)$ can be expressed as,

$$Y(t) = \Im^{-1}\left[\frac{GX_s(1+T_1 s)}{(1+T_2 s)}\right] \tag{4}$$

where G is the gain, T_1 is lead time constant, T_2 is lag time constant, s is Laplace variable, X_s is input in the Laplace domain and $\Im^{-1}$ is the inverse Laplace transform.

The output of the PI controller is the angle order δ, which gives leading or lagging phase angle, which is necessary to adjust the voltage of the capacitor. Angle order represents the required shift between the system voltage and the voltage generated by STATCOM. In this way the power flowing in or out of STATCOM can be controlled. The angle order or the displacement angle δ can be expressed as

$$\delta = \beta - \cos^{-1}\left[\frac{V_L}{V_S}\cos\beta + \frac{ZP_L}{V_S V_L}\right] \tag{5}$$

where Z is the impedance depending on the fault level, V_S is the system voltage, V_L is the load voltage, β is the angle of the system impedance and P_L is the power flow into the system.

The PLL is responsible for voltage synchronization of the STATCOM with the ac network. The output signals of the voltage control combined with the error voltage signal becomes the voltage modulating signal in which its magnitude and phase are controlled. The PWM control circuit generates the firing signal of the GTO by comparing the triangular wave carrier signals with the voltage modulating signal. The zero crossings of the voltage ramps fire/block the GTOs depending on the displacement angle δ. If $\delta = 0$, the resulting output voltage is said to be in phase with the ac system voltage. However, if there is an error between the reference voltage and the system voltage in per unit i.e. $V_{pu} < V_{ref}$, then the displacement angle $\delta > 0$ and the STATCOM voltage lags the ac voltage thus causing a real power flow into the devices. Consequently, the dc bus voltage will increase, causing an increase of the ac output voltage of the devices. The increasing output voltages causes the capacitive reactive current to increase and reduces the error voltage until $V_{pu} = V_{ref}$. The inverse occurs, if $V_{pu} > V_{ref}$.

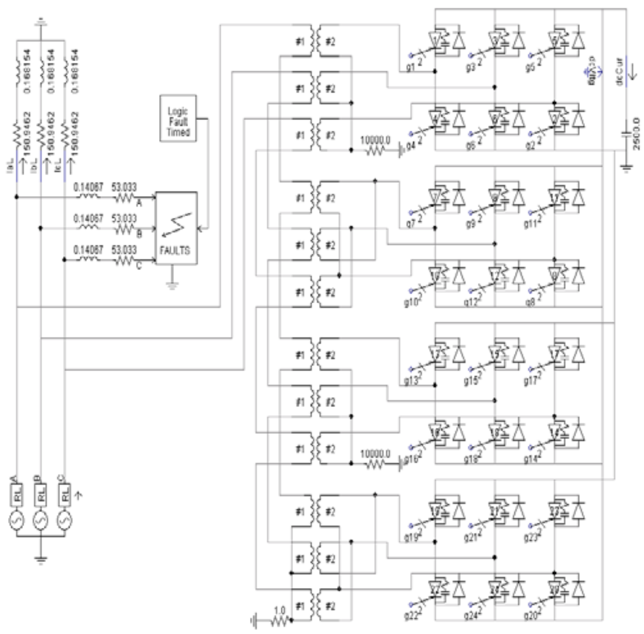

Fig. 2: The STATCOM in a Distribution System

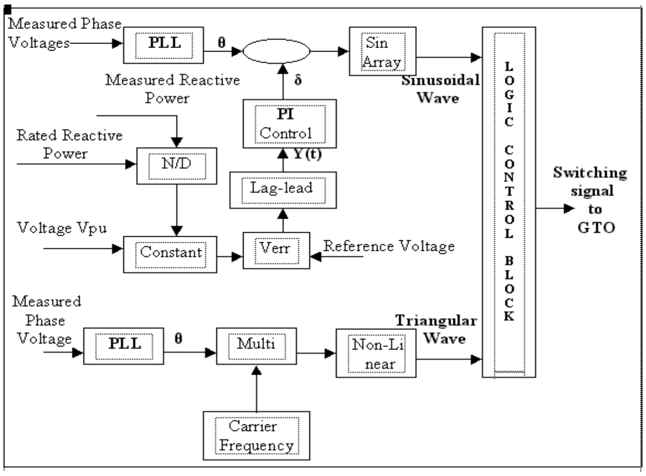

Fig. 3: Block Diagram of the PWM STATCOM controls

Results and Discussions

To analyze the performance of the STATCOM in mitigating voltage sags, this device is modeled using the PSCAD/EMTDC simulation package (Ghani *et al*., 2012; Subiyanto *et al*., 2012). Simulations were performed on a distribution system rated at 100 kV with a load of 88 MVA, .96 power factor (Fig. 2). Each single phase transformer is rated for 100 MVA, 100/6.75 kV with a leakage reactance of 0.1 p.u.

STATCOM used for voltage sag mitigation:

To simulate a voltage sag condition, a balanced three-phase fault is created using the three-phase fault generator. The simulation results of the STATCOM response in terms of the terminal voltages in per unit are shown in fig. 4. For the system without the STATCOM, the terminal voltage of the system drops from 0.91p.u to 0.70 p.u as shown in Fig. 4 (a). This is a voltage sag condition which is due to a three-phase fault created at time $t = 1.5$s for a duration of 0.75 sec. Fig. 4 (b) shows the system voltage response for the system with the STATCOM, in which the terminal voltage is increased from 0.70 p.u to 1.003 p.u. Thus the system voltage returns to near its rated voltage due to the voltage sag mitigation capability of the STATCOM with a capacitance value of 2500 microfarads.The results shown here are for the phase A voltage but however the responses are similar for the phase B and C voltages. The effect of the STATCOM on the load terminal voltage shows that the voltage sag is eliminated and it proves that the STATCOM is capable of mitigating voltage sag.

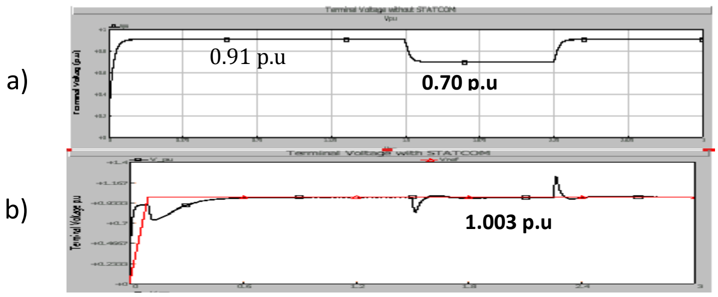

Fig. 4: Terminal Voltages a) system without STATCOM b) system with STATCOM

STATCOM as an Inductive Compensator:

In this simulation a capacitive load rated at 88 MVA and the system voltage of 100 kV has been considered. The simulation result shown in Fig.5 indicates that without the STATCOM connected the capacitor switching results in a high voltage of 1.10 p.u. With the STATCOM connected and switched at time $t = 0.45$s, the system voltage returns to its rated voltage within a very short time. Fig. 6 shows the STATCOM current lagging the system voltage by 90 degrees. To illustrate further the operation of the STATCOM as an inductive compensator, the dc voltage and the reactive power responses are shown as in Fig.7. It can be seen that the excess MVAr generated by the capacitive load is absorbed by the STATCOM and the dc voltage is reduced. Thus reducing the overall system voltage to 0.996 p.u from 1.10 p.u.

a)
b)

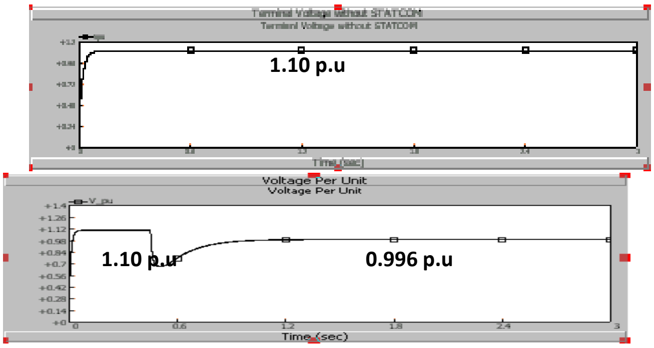

Fig. 5: System Voltage a) without STATCOM and b) with STATCOM

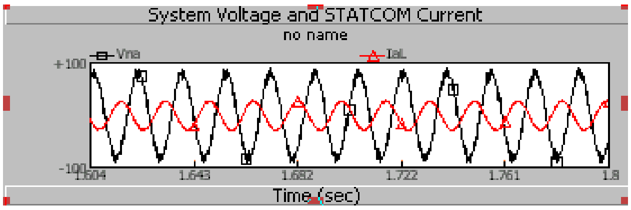

Fig. 6: System Voltage and STATCOM Output Current

a)
b)

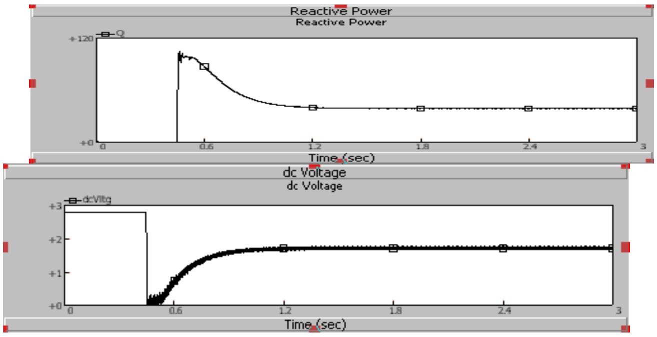

Fig. 7: Reactive Power and dc Voltage of the System

STATCOM as a Capacitive Compensator:

In this simulation, the system load is purely inductive rated at 88 MVA and the system voltage is 100 kV. Fig.8 (a) shows the system voltage response without the STATCOM connected in which the voltage reach a low steady-state value of 0.85 p.u. As for the system with the STATCOM connected, the system returns to its rated voltage of 1.004 p.u within a very short time. Fig. 9 shows that the STATCOM current leads the system voltage by 90 degrees so as to illustrate the capacitive compensation effect of the STATCOM. Fig.10 shows that the reactive power is generated by the STATCOM and that the dc voltage is increased so as to increase the system voltage from 0.85 p.u. to 1.004 p.u.

a)
b)

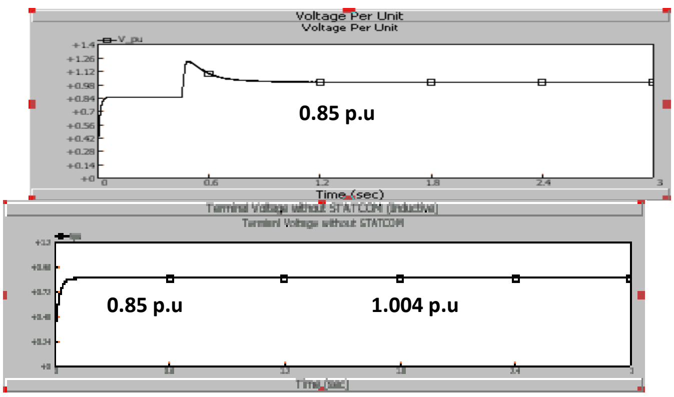

Fig. 8: System Voltage a) without STATCOM and b) with STATCOM

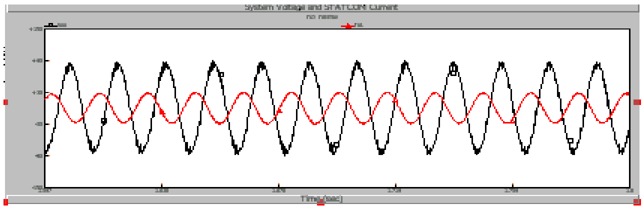

Fig. 9: System Voltage and STATCOM Current

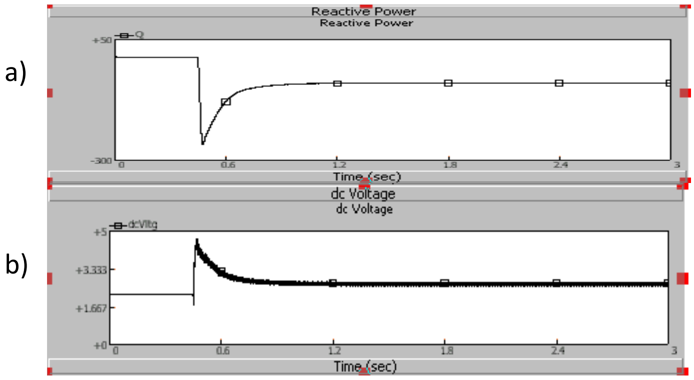

Fig. 10: Reactive Power and dc Voltage of the System

Conclusion:

A detailed modeling and analysis of the two levels, 24-pulse STATCOM has been developed using the PSCAD/EMTDC software package. The control system of the STATCOM is based on the sinusoidal pulse width modulation technique in which it is the most popular method used for inverter control in the power electronic switching system. Simulations have been carried out to evaluate the performance of the STATCOM in mitigating voltage sag and its operation as inductive and capacitive compensators. The effect of the dc capacitance is also investigated. Simulation results prove that the STATCOM is capable of mitigating voltage sag by injecting voltages into the distribution system and there is no doubt about the voltage sag mitigation capability of this device. The simulation results also indicate that it is important to determine the optimum size of the dc capacitance required to mitigate voltage sag in the distribution system. The developed STATCOM model can be used for detail simulation studies in the distribution system.

References

Carlos, A.C., Cavaliere, Edson H. Watanabe, A. Mauricio, 1999. “Comparison Between the Conventional STATCOM and the PWM STATCOM”, Brazilian Congress of Power Electronics, COBEP 99, Foz do Iguacu, Brazil,

Daehler, P., R. Affolter, 2000. “Requirements And Solutions For Dynamic Voltage Restorer, A Case Study” ABB Review Proceedings, IEEE Power Engineering Society Meeting,

Douglas, J., 1996. Custom Power: Optimizing Distribution Services, EPRI Journal, pp 7-15.

Fang, M., A.I. Gardiner, A. MacDougall and G.A. Mathieson, 1998. “A Novel Series Dynamic Voltage Restorer For Distribution Systems” POWERCON'98, 1: 38- 42.

Ghani, Z.A., M.A. Hannan, A. Mohamed, 2012. “Investigation of Three-Phase Grid-Connected Inverter for Photovoltaic Application.” Electrical Review, 88(7a): 8-13.

Ghani, Z.A., M.A. Hannan, A. Mohamed, 2012. “Simulation Model of Three-Phase Inverter using dSPACE Platform for PV Application.” International Review of Modeling and Simulations, 5(1): 137-145.

Hannan, M.A. and A. Mohamed, 2005. “PSCAD/EMTDC Simulation of Unified Series-Shunt Compensator for Power Quality Improvement”, IEEE Transaction on Power Delivery, 20(2): 1650-1656.

Hannan, M.A. and A. Mohamed, 2012. “Study of Basic Properties of an Enhanced Controller for DVR Compensation Capabilities.” Electrical Review, 88(4a): 293-299.

Hannan, M.A. and K.W. Chan, 2006. “Transient Analysis of FACTS and Custom Power Devices Using Phasor Dynamics”, Journal of Applied Science, 6(5): 1074-1081.

Hannan, M.A., A. Mohamed, A. Hussain and A. Majid, 2009. “Development of the USSC Model for Power Quality Mitigation.”American Journal of Applied Sciences, 6(5): 978-986.

Hannan, M.A., A. Mohamed, A. Hussain and M. AI-Dabbagh, 2009. “Power Quality Analysis of STATCOM using Dynamic Phasor Modeling, International Journal of Electric Power System Research, 79(6): 993-999.

Hannan, M.A., F.A. Azidin, A. Mohamed, 2012. “Multi-sources model and control algorithm of an energy management system for light electric Vehicles”. Energy Conversion and Management, 62(2012): 123-130,

Hannan, M.A., Z.A. Ghani and A. Mohamed, 2011. “An Enhanced Inverter Controller for PV Applications Using the dSPACE Platform”, International Journal of Photoenergy, 2011, doi:10.1155/2010/457562.

Haque, M.H., 2001.“Compensation of Distribution System Voltage Sag by DVR and D-STATCOM”, IEEE Porto Power Tech Conference, 10^{th}-13^{th}, Porto, Portugal.

Middlekauff, S.W. and E.R. Collins Jr, 1998. “System and Customer Impact: Considerations For Series Custom Power Devices” IEEE Trans. on Power Delivery, 13(1): 278-282.

Nielsen, J.D., 2000. “Analysis of Topologies For Dynamic Voltage Restorer” Nordic Distribution Automation Conference, NORDAC, 22-23 May 2000, Trondheim, Norway.

Pilotto, L.A., *et al*, 2000. “Back-To-Back VSC Devices: A New Solution For The Interconnection of Asynchronous AC Systems”Proceedings of CIGRE Session, paper no.14-203.

PSCAD/EMTDC, 1994. User’s Manual Version 3.0, Manitoba HVDC Research Centre,

Salam, A., A. Mohamed, M.A. Hannan, H. Shareef, 2010. “An improved inverter control scheme for managing the distributed generation units in a microgrid.” International Review of Electrical Engineering, 5(3): 891-899.

Stump, M.D., G.J. Keane, F.K.S. Leong, 1998. “The Role of Custom Power Products in Enhancing Power Quality at Industrial Facilities” IEEE catalogue No: 98EX137,.

Subiyanto, A. Mohamed and M.A. Hannan, 2011. “Photovoltaic Maximum Power Point Tracking Controller Using a New High Performance Boost Converter.”International Review of Electrical Engineering, 5(6): 2535-2545.

Subiyanto, A. Mohamed and M.A. Hannan, 2012. Intelligent Maximum Power Point Tracking For PV System Using Hopfield Neural Network Optimized Fuzzy Logic Controller. Energy and Buildings, 51: 29-38.

Sutanto, D., L.A. Snider, K.L. Mok, 1999. “EMTP simulation of a STATCOM using Hysteresis Current Control”, IEEE International Conference on Power Electronics and Drive Sustems, PEDS’99, Hong Kong.

Taylor, G.A., 1995. “Power Quality Hardware Solutions for Distribution Systems: Custom Power” IEEE North Eastern Centre Power System Symposium,.