Modeling analysis and solution of Power Quality Problems

Mahesh Singh (Lecturer) SSCET BHILAI INDIA
Vaibhav Tiwari CSIT BHILAI INDIA

***Abstract*-- A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end use equipments. Utility distribution networks, sensitive industrial loads, and critical commercial operations all suffer from various types of outages and service interruptions which can cost significant financial 1oss per incident based on process down-time, lost production, idle work forces, and other factors. With the restructuring of Power Systems and with shifting trend towards Distributed and Dispersed Generation, the issue of Power Quality is going to take newer dimensions. The aim therefore, in this work, is to identify the prominent concerns in the area and thereby to recommend measures that can enhance the quality of the power, keeping in mind their economic viability and technical repercussions. In this paper electromagnetic transient studies are presented for the following two custom power controllers: the distribution static compensator (D-STATCOM), and the dynamic voltage restorer (DVR). Comprehensive results are presented to assess the performance of each device as a potential custom power solution.**

***Index Terms*-- Power Quality Problems, Power System Restructuring, Voltage Sag, DSTATCOM, DVR, MATLAB.**

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 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 dips, voltage swells, and harmonics.

Voltage dips are considered one of the most severe disturbances to the industrial equipment. A paper machine can be affected by disturbances of 10% voltage drop lasting for 100ms. A voltage dip of 75% (of the nominal voltage) with duration shorter than 100ms can result in material loss in the range of thousands of US dollars for the semiconductors industry [2]. 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 analyzes the key issues in the Power Quality problems, specially keeping in mind the present trend towards more localized generations (also termed as distributed and dispersed generation) and consequent restructuring of power transmission and distribution networks. As one of the prominent power quality problems, the origin, consequences and mitigation techniques of voltage sag problem has been discussed in detail. The study describes the techniques of correcting the supply voltage sag in a distribution system by two power electronics based devices called Dynamic Voltage Restorer (DVR) and Distribution STATCOM (D-STATCOM).A DVR voltage in series with the system voltage and a D-STATCOM injects a current into the system to correct the voltage sag [1]. The steady state performance of both DVR and D-STATCOM is studied for various levels of voltage sag levels.

II. SOURCES AND EFFECTS OF POWER QUALITY PROBLEMS

The distortion in the quality of supply power can be introduced /enhanced at various stages; however, some of the primary sources of distortion [3] can be identified as below:

A. Power Electronic Devices
B. IT and Office Equipments
C. Arcing Devices
D. Load Switching
E. Large Motor Starting
F. Embedded Generation
G. Electromagnetic Radiations and Cables
H. Storm and Environment Related Causes etc.

While power disturbances occur on all electrical systems, the sensitivity of today's sophisticated electronic devices makes them more susceptible to the quality of power supply. For some sensitive devices, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc. A power voltage spike can damage valuable components. Some of the common power quality issues and their prominent impact are summarized in the table below:

Problem	Effects
Voltage sags	Devices/process downtime, effect on product quality, failure/malfunction of customer equipments (such as tripping of large industrial drives) and associated scrap cost, clean up costs, maintenance and repair costs etc
Transients	Tripping, component failures, flashover of instrument insulation, hardware rebooting, software 'glitches', poor product quality etc
Harmonics	Excessive losses and heating in motors, capacitors and transformers connected to the system, insulation failure due to overheating and over voltages, loss of conductor life and possible risk of fire due to overheating, malfunctioning of sophisticated electronic equipments, higher dielectric stress and harmonic resonance, saturation in transformer cores, interference with adjacent communication networks, audio hum, video 'flutter', power supply failure etc.
Flicker	Visual irritation, introduction of many harmonic components in the supply power and their associated ill effects

Table1: Various power quality problems and their effects

III. SOLUTIONS TO POWER QUALITY PROBLEMS

There are two approaches to the mitigation of power quality problems. The solution to the power quality can be done from customer side or from utility side [4]. First approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. A flexible and versatile solution to voltage quality problems is offered by active power filters. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Both schemes are implemented preferable with voltage source PWM inverters [5], with a dc bus having a reactive element such as a capacitor. Active power filters can perform one or more of the functions required to compensate power systems and improving power quality. Their performance also depends on the power rating and the speed of response.

However, with the restructuring of power sector and with shifting trend towards distributed and dispersed generation, the line conditioning systems or utility side solutions will play a major role in improving the inherent supply quality; some of the effective and economic measures can be identified as following:

A. *Lightening and Surge Arresters:*

Arresters are designed for lightening protection of transformers, but are not sufficiently voltage limiting for protecting sensitive electronic control circuits from voltage surges.

B. *Thyristor Based Static Switches:*

The static switch is a versatile device for switching a new element into the circuit when the voltage support is needed. It has a dynamic response time of about one cycle. To correct quickly for voltage spikes, sags or interruptions, the static switch can used to switch one or more of devices such as capacitor, filter, alternate power line, energy storage systems etc. The static switch can be used in the alternate power line applications. This scheme requires two independent power lines from the utility or could be from utility and localized power generation like those in case of distributed generating systems [4]. Such a scheme can protect up to about 85 % of interruptions and voltage sags.

C. *Energy Storage Systems:*

Storage systems can be used to protect sensitive production equipments from shutdowns caused by voltage sags or momentary interruptions. These are usually DC storage systems such as UPS, batteries, superconducting magnet energy storage (SMES), storage capacitors or even fly wheels driving DC generators [6]. The output of these devices can be supplied to the system through an inverter on a momentary basis by a fast acting electronic switch. Enough energy is fed to the system to compensate for the energy that would be lost by the voltage sag or interruption. In case of utility supply backed by a localized generation this can be even better accomplished.

D. *Electronic tap changing transformer:*

A voltage-regulating transformer with an electronic load tap changer can be used with a single line from the utility. It can regulate the voltage drops up to 50% and requires a stiff system (short circuit power to load ratio of 10:1 or better). It can have the provision of coarse or smooth steps intended for occasional voltage variations.

E. *Harmonic Filters*

Filters are used in some instances to effectively reduce or eliminate certain harmonics [7]. If possible, it is always preferable to use a 12-pluse or higher transformer connection, rather than a filter. Tuned harmonic filters should be used with caution and avoided when possible. Usually, multiple filters are needed, each tuned to a separate harmonic. Each filter causes a parallel resonance as well as a series resonance, and each filter slightly changes the resonances of other filters.

F. *Constant-Voltage Transformers:*

For many power quality studies, it is possible to greatly improve the sag and momentary interruption tolerance of a facility by protecting control circuits. Constant voltage transformer (CVTs) can be used [6] on control circuits to provide constant voltage with three cycle ride through, or relays and ac contactors can be provided with electronic coil hold-in devices to prevent mis-operation from either low or interrupted voltage.

G. *Digital-Electronic and Intelligent Controllers for Load-Frequency Control:*

Frequency of the supply power is one of the major determinants of power quality, which affects the equipment performance very drastically. Even the major system components such as Turbine life and interconnected-grid control are directly affected by power frequency. Load frequency controller used specifically for governing power frequency under varying loads must be fast enough to make adjustments against any deviation. In countries like India and other countries of developing world, still use the controllers which are based either or mechanical or electrical devices with inherent dead time and delays and at times also suffer from ageing and associated effects. In future perspective, such controllers can be replaced by their Digital-electronic counterparts.

IV. USE OF CUSTOM POWER DEVICES TO IMPROVE POWER QUALITY

In order to overcome the problems such as the ones mentioned above, the concept of custom power devices is introduced recently; custom power is a strategy, which is designed primarily to meet the requirements of industrial and commercial customer. The concept of custom power 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 [1]. Power electronic valves are the basis of those custom power devices such as the static transfer switch, active filters and converter-based devices. Converter based power electronics devices can be divided into two groups: shunt-connected and series-connected devices. The shunt connected devices is known as the DSTATCOM and the series device is known as the Static Series Compensator (SSC), commercially known as DVR. It has also been reported in literature that both the SSC and DSTATCOM have been used to mitigate the majority the power system disturbances such as voltage dips, sags, flicker unbalance and harmonics.

For lower voltage sags, the load voltage magnitude can be corrected by injecting only reactive power into the system. However, for higher voltage sags, injection of active power, in addition to reactive power, is essential to correct the voltage magnitude [8]. Both DVR and D-STATCOM are capable of generating or absorbing reactive power but the active power injection of the device must be provided by an external energy source or energy storage system. The response time of both DVR and D-STATCOM is very short and is limited by the power electronics devices. The expected response time is about 25 ms, and which is much less than some of the traditional methods of voltage correction such as tap-changing transformers.

V. MODELING OF CUSTOM POWER DEVICES AND SIMULATION RESULTS

As mentioned in the previous section that custom power devices could be the effective means to overcome some of the major power quality problems by the way of injecting active and/or reactive power(s) into the system [9]-[11]. This section of the paper deals with the modeling of DSTATCOM and DVR. Consequently some case studies will be taken up for analysis and performance comparison of these devices. The modeling approach adopted in the paper is graphical in nature, as opposed to mathematical models embedded in code using a high-level computer language. The well-developed graphic facilities available in an industry standard power system package, namely, MATLAB (/Simulink) [12], is used to conduct all aspects of model implementation and to carry out extensive simulation studies.

The control scheme for these devices is shown in Fig.1. The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller and the output is the angle δ, which is provided to the PWM signal generator. The PWM generator then generates the pulse signals to the IGBT gates of voltage source converter [10].

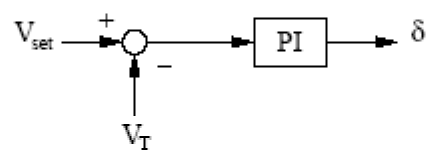

Fig.1. The PI Controller

(A) D-STATCOM

The test system employed to carry out the simulations concerning the DSTATCOM actuation for voltage sag compensation is shown in Fig.2. Such system is composed by a 230 kV, 50 Hz transmission system, represented by a Thevenin equivalent, feeding a distribution network through a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. To verify the working of a DSTATCOM, a variable load is connected at bus 2. During the simulation, in the period from 500 to 900 ms, the switch S1 is closed .The above test system is simulated under the environment of Matlab-Simulink and power system block set (PSB) the model used for this purpose is shown in the fig.3.

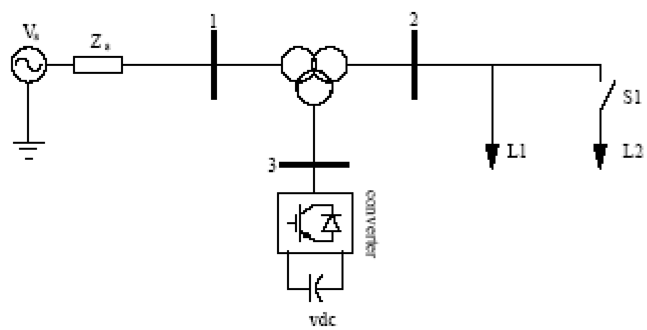

Fig.2. Test system for DSTATCOM

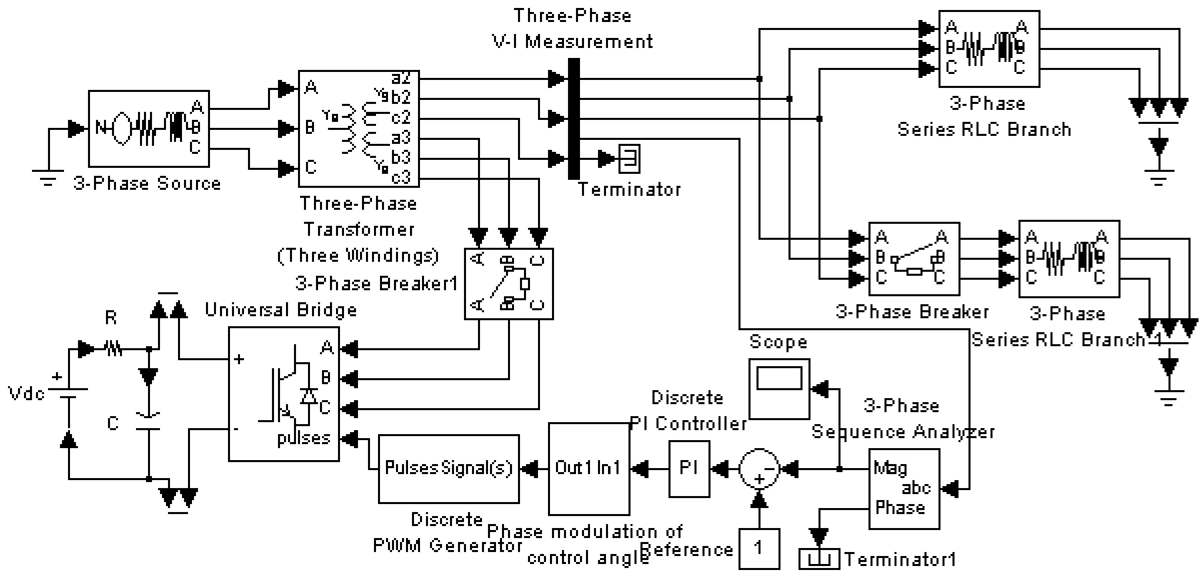

Fig.3. MATLAB Simulation model of DSTATCOM

A set of simulations was carried out for the test system shown in Fig.2. The simulations relate to three main operating conditions.

1) In the simulation period 500–900 ms, the load is increased by closing switch S1. In this case, the voltage drops by almost 27% with respect to the reference value.

2) At 900 ms, the switch S1 is opened and remains so throughout the rest of the simulation. The load voltage is very close to the reference value, i.e., 1 pu.

3) In order to gain insight into the influence that capacitor size has on D-STATCOM performance, simulations were carried out with different size of capacitors. The total simulation period is 1.4 s.

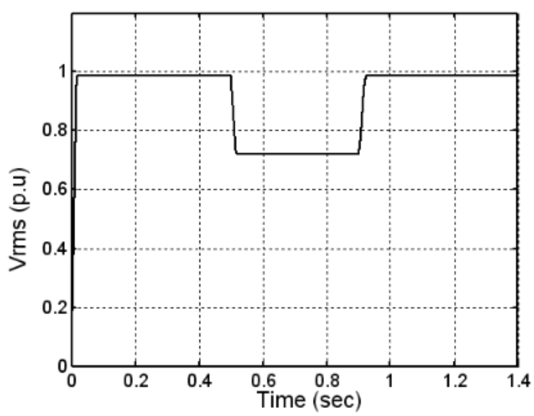

Fig.4. Voltage response of the test system without DSTATCOM

Fig.4. shows the rms voltage at the load point for the case when the system operates with no D-STATCOM. Similarly, a new set of simulations was carried out but now with the D-STATCOM connected to the system. The results are shown in Fig.5(a). Where the very effective voltage regulation provided by the D-STATCOM can be clearly appreciated.

When the Switch S1 closes, the D-STATCOM supplies reactive power to the system. By way of example, Fig.5(a). shows the regulated rms voltage corresponding to a 750 F capacitor, where a rapid regulation response is obtained and transient overshoots are almost nonexistent.

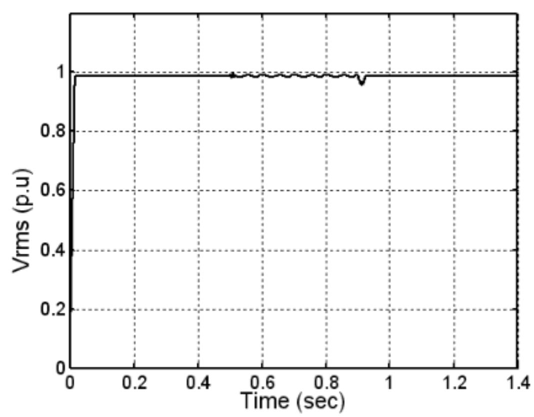

Fig 5(a) Voltage response of the test system 1 with DSTATCOM; With 750µF Capacitor

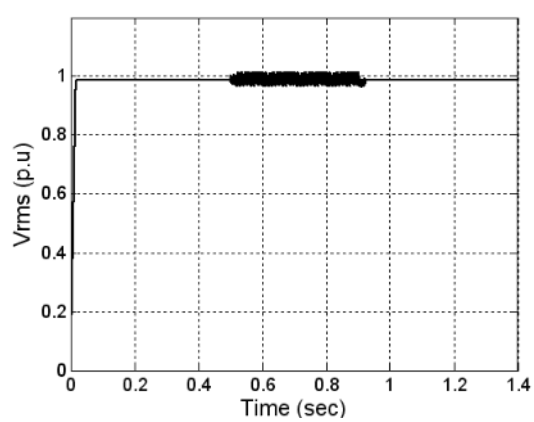

Fig 5(b) Voltage response of the test system 1 with DSTATCOM; With 75µF Capacitor

This contrasts with cases where the capacitor is undersized. For instance, Fig. 5(b) shows the rms voltage for the case when a 75 F capacitor is employed.

(B) DVR

The test system employed to carry out the simulations concerning the DVR actuation is shown in Fig. 6. Such network is composed by a 13 kV, 50 Hz generation system, represented by a Thevenin equivalent, feeding two transmission lines through an 3-winding transformer connected in Y/Δ/Δ 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ/Y, 115/11 kV. To verify the working of a DVR employed to avoid voltage sags during short-circuit, a fault is applied at point X via a resistance of 0.4 Ω. Such fault is applied from 500 to 900 ms.

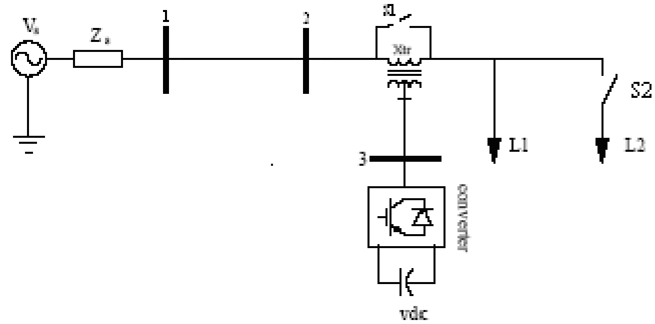

Fig.6. Test system for DVR

The above test system is simulated under the environment of Matlab-Simulink and power system block set (PSB) the model used for this purpose is shown in the fig.7.

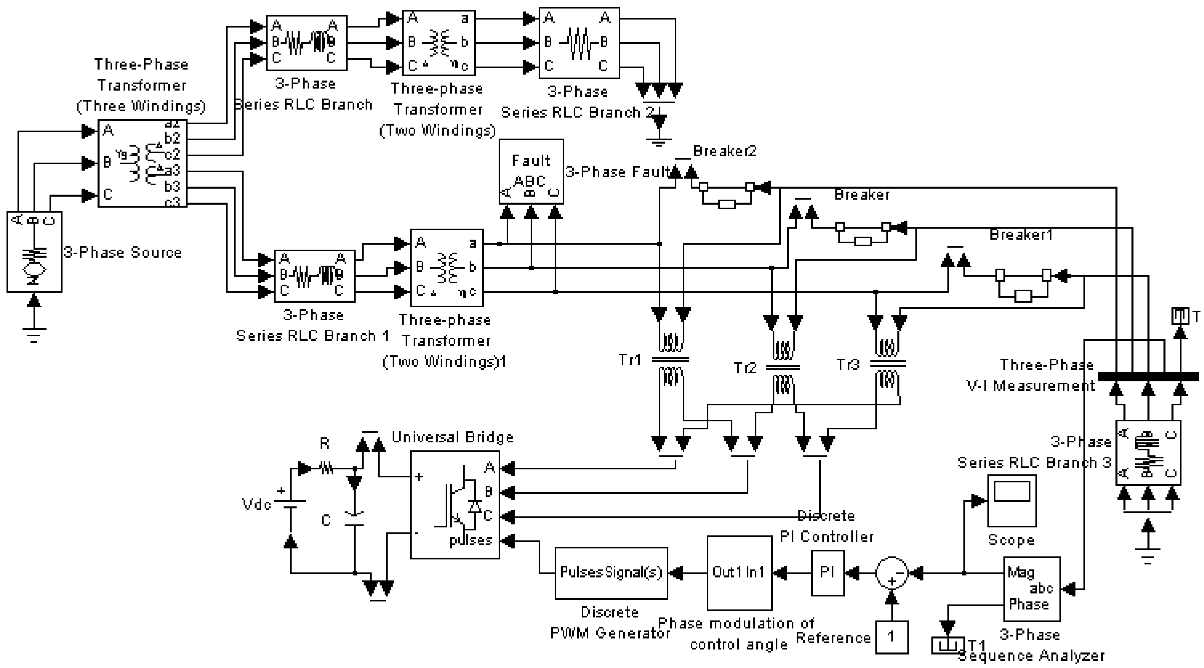

Fig.7 MATLAB Simulation model of DVR

Two simulations studies are carried out as follows:

1) The first simulation contains no DVR and a three-phase short-circuit fault is applied at point A, via a fault resistance of 0.4 , during the period 500–900 ms. The voltage sag at the load point is almost 60% with respect to the reference voltage.

2) The second simulation is carried out using the same scenario as above but now with the DVR in operation. The total simulation period is 1.4 s.

Using the facilities available in MATLAB the DVR is simulated to be in operation only for the duration of the fault, as it is expected to be the case in a practical situation. The results for both simulations are shown in Fig.8 and Fig.9 Voltage response without DVR is shown in Fig.8

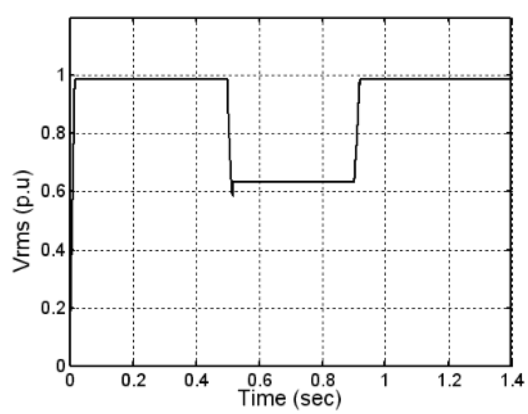

Fig.8 Voltage Response of the test system without DVR.

When the DVR is in operation the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 98%, as shown in Fig. 9.

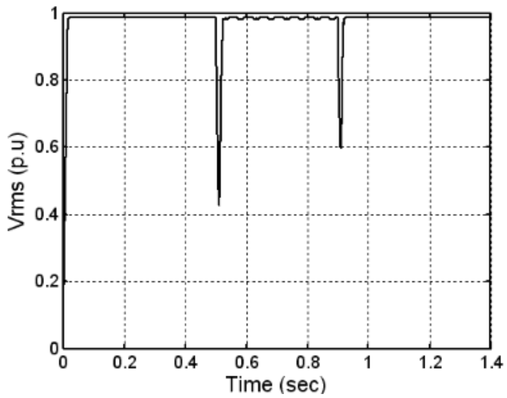

Fig 9 Voltage Response of the test system2 with DVR.

The PWM control scheme controls the magnitude and the phase of the injected voltages, restoring the rms voltage very effectively [13]-[14]. The sag mitigation is performed with a smooth, stable, and rapid DVR response;

VI. 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 models of custom power equipment, namely D-STATCOM, DVR, and applied them to mitigate voltage dip which is 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 systems. A new PWM-based control scheme has been implemented to control the electronic valves in the two-level VSC used in the D-STATCOM and DVR. As opposed to fundamental frequency switching schemes already available in the MATLAB SIMULINK. This characteristic makes it ideally suitable for low-voltage custom power applications. It was observed that in case of 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.

VII. REFERENCES

[1] H. Hingorani "Introducing custom power" IEEE spectrum, vol.32 no.6 June 1995 p 41-48.

[2] Ray Arnold "Solutions to Power Quality Problems" power engineering journal 2001 pages: 65-73.

[3] John Stones and Alan Collinsion "Introduction to Power Quality" power engineering journal 2001 pages: 58-64.

[4] Gregory F. Reed, Masatoshi Takeda, "Improved power quality solutions using advanced solid-state switching and static compensation technologies," Power Engineering Society 1999 Winter Meeting, IEEE

[5] 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.

[6] 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.

[7] F. Z. Peng, H. Akagi, and A. Nabae, "Compensation characteristics of the combined system of shunt passive and series active filters," IEEE Trans. Ind. Applicat., vol. 29, pp. 144–151, Jan./Feb. 1993.

[8] M.H.Haque "Compensation of distribution system voltage sag by DVR and DSTATCOM" Power Tech Proceedings, 2001 IEEE Porto , Volume: 1 , 10-13 Sept. 2001 Pages:5 pp. vol.1

[9] S. S. Choi, B. H. Li, and D. D.Vilathgamuwa, "Dynamic voltage restoration with minimum energy injection," IEEE Trans. Power Syst., vol. 15,pp. 51–57, Feb. 2000

[10] O. Anaya-Lara, E. Acha, "Modeling and Analysis of Custom Power Systems by PSCAD/EMTDC," IEEE Trans., Power Delivery, PWDR vol-17 (1), pp. 266-272, 2002.

[11] P.W. Lehn and MR. Iravani, "Experimental Evaluation of STATCOM Closed Loop Dynamics," IEEE Trans. Power Delivery, vol. 13, no.4, October 1998, pp.1378-1384.

[12] TEQSIM International Inc., "Power System Blockset User'sGuide", 2001.

[13] M. H. J. Bollen, "Understanding Power Quality Problems—Voltage Sags and Interruptions" Piscataway, New York: IEEE Press, 2000.

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