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# Performance Analysis of DVR and DSTATCOM in Distribution network for Voltage Sag and Swell Conditions

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*Due to the increase in sensitive loads to power disturbances, power quality issues became one of the major concerns in many of the distribution systems and industries. The majority of events causing the power quality issues are because of voltage sag and voltage swell. In a distribution system, it is very important that the fault should be removed immediately so that the whole system is protected and the service is not interrupted. In this paper, the performance of Dynamic Voltage Restorer (DVR) and Distribution Static Compensator (DSTATCOM) is analysed by simulated with PWM control scheme using PSCAD. The simulations were carried out with various test cases associated with voltage sag and swell due to three phase short circuit fault, inductive and capacitive load switching conditions. The analysis of DVR and DSTATCOM was done based on the compensation of each device for various power quality problems. Results are presented for DVR and DSTATCOM showing the compensation of voltage sag/swell for various test conditions.*

***Keywords:*** *Distribution System, DSTATCOM, DVR, Voltage sag, Voltage swell.*

## 1.0 INTRODUCTION

Power quality is described as the variation of voltage, current and frequency in a power system. Voltage sags, swells, harmonics and flickers are the most common power quality issues which relates to the sensitive loads. Voltage sags are reduction in voltages for very short-duration due to short circuits, overloads, and starting of heavy motors. According to IEEE standards [1], voltage sag is a reduction in the voltage in the range of 0.1 to 0.9 p.u with duration from 0.5 cycles to 1 minute. Voltage swells are not common as voltage sags, which causes due to single line-to-ground faults. Generally, the voltage swell lies in the range of 140% to 170% of the rated voltage. Presently, a wide range of controllers emerging for custom power applications which capitalize on new sophisticated power electronic components [2, 3]. Dynamic Voltage Restorer (DVR) and Distribution Static Compensator (DSTATCOM) are the most effective devices operating with VSC principle.

In early days, Static Var Compensators (SVC) is widely used as an effective device for improving the power quality. SVC operates by adjusting its value automatically with the changes in the operating conditions of the distribution network. It regulates the voltage magnitude at the point of connection by controlling its equivalent reactance, enhancing the performance of the system [4]. Precently, a wide range of power electronic devices using newly available electronic components with sophisticated and fast controller techniques are emerging for the applications related to the quality of the customer end receiving power. Among these devices, Dynamic Voltage Restorer (DVR) and Distribution Static Compensator (D-STATCOM) has got better voltage regulation capabilities based on their capacity of the storage system and along with the harmonic reduction in the power system. Both these devices can be operated with Voltage Source Converter (VSC) principle [5]. Hence, in this paper, DVR and DSTATCOM are simulated for compensating various power quality events occurring due fault conditions. The simulation tool PSCAD [6], [7] has been used in this paper to analyze the performance of the compensating devices for different test cases or operating conditions.

## 2.0 DYNAMIC VOLTAGE RESTORER

Dynamic Voltage Restorer (DVR) is the most technically advanced and economical custom power device proposed to protect sensitive loads. The DVR uses a small capacitor to exchange reactive power or supply active power to loads with energy storage. The energy storage can be a capacitor bank, flywheel or battery. The DVR placed between the distribution bus and the sensitive loads has excellent dynamic capability for mitigating voltage sags and swells. The DVR can adjust the magnitude of the load voltage and the phase angle by controlling each phase independently [8].

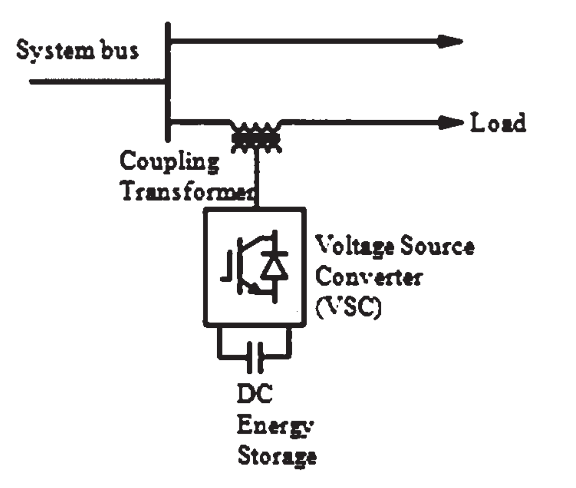


FIG.1. SCHEMATIC REPRESENTATION OF DVR

As shown in Figure 1, the DVR consists of DC energy storage, Voltage Source Converter (VSC), coupling transformer connected in series with the system. The VSC connected to the system provides voltage regulation, reactive power compensation and harmonic elimination. VSC is used to convert the DC voltage into a set of three phase AC voltages, which will be in phase with the system voltage and can be controlled in terms of its phase and magnitude. The three phase voltages are injected into the AC distribution system through coupling transformer to maintain the load voltage at the desired level by improving the voltage profile [9].

The system bus impedance ($Z_S$) = $R_S + jX_S$ depends on the level of fault occurring on the load. When the system bus voltage ($V_S$) drops due to the fault, the DVR injects a voltage (VDVR) in series to the system through the coupling transformer so that the load voltage (VL) can be maintained as desired manner. The voltage injected by the DVR is given by

$$V_{DVR} = V_L + Z_S I_L - V_S \quad ...(1)$$

Where $I_L$ is the load current and is given by

$$I_L = \left( \frac{P_L + jQ_L}{V_L} \right) \quad ...(2)$$

If $V_L$ is considered as a reference, Eqn. (1) can be rewritten as

$$V_{DVR}\angle\alpha = V_L\angle 0 + ZsI_L\angle(\beta - \theta) - V_S\angle\delta \quad ...(3)$$

Where α, β and δ are the angles of $V_{DVR}$, $Z_S$ and $V_S$ respectively. θ is known as load power factor angle, given by,

$$\theta = \tan^{-1}\left( \frac{Q_L}{P_L} \right) \quad ...(4)$$

And finally, the complex power injected by DVR is given by,

$$S_{DVR} = V_{DVR} I_L^{*} \quad ...(5)$$

## 3.0 DISTRIBUTION STATIC COMPENSATOR

Distribution Static Compensator (DSTATCOM) is also one of the compensating devices operating with VSC technology for compensating the power quality issues with sensitive loads [10]. The schematic representation of DSTATCOM is shown in Figure 2. The change in phase and the magnitude of the output voltages of DSTATCOM allows control of active and reactive power exchange between the system and DSTATCOM.

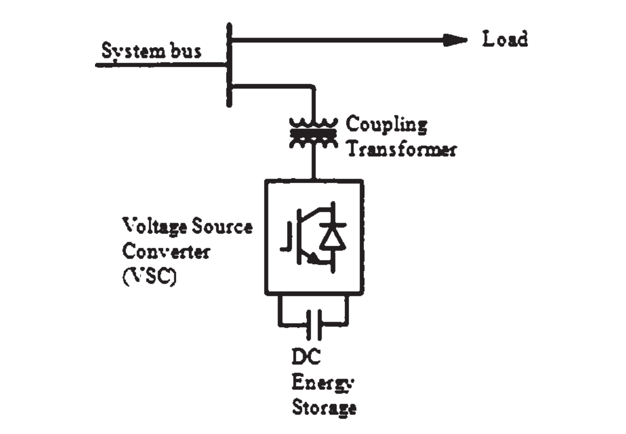


FIG.2. SCHEMATIC REPRESENTATION OF DSTATCOM

The output current ($I_o$) of DSTATCOM compensates the voltage sags by adjusting the voltage drop across the system bus impedance (ZS) = RS + jXS. The capability of DSTATCOM in compensating the voltage sags depends on the bus impedance and the fault level at the load terminals. The output current of the DSTATCOM is given by,

$$I_o = I_L - I_S = I_L - (V_S - V_L)/Z_S \quad ...(6)$$

## 4.0 PWM CONTROL CIRCUIT

Since the distribution network needs relatively low power applications, PWM control method offers more flexibility than other switching methods. The VSC technology used in DVR and DSTATCOM is based on sinusoidal PWM control technique which offers good response [11]. The control scheme maintains the load voltage magnitude constant at the load point under various disturbances causing power quality issues, such as voltage sag, swells and harmonics.

Figure 3 shows the control scheme implemented in PSCAD. The control scheme consists of mainly three stages: Initially an error signal is generated by comparing the voltage measured at the load point with the reference voltage. This error signal is processed through PI controller, which generates the required angle to make the error to zero, i.e., the load voltage equals to the reference voltage. Then the signal is phase modulated in terms of angle with the help of PWM generators. The modulated signal now compares with carrier signal, generating the switching signals for the valves in Voltage Source Converter (VSC).

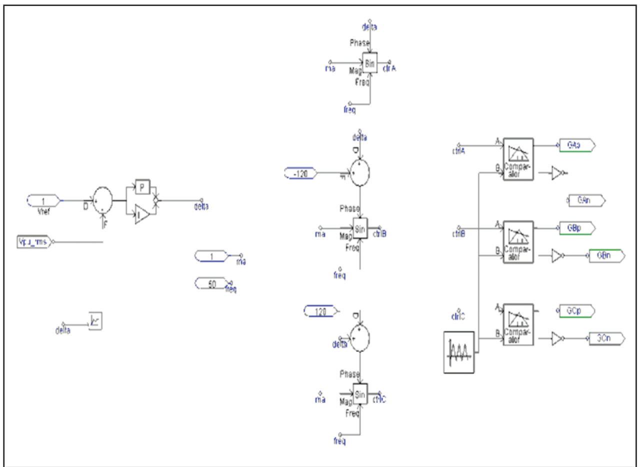

FIG.3. CONTROL SCHEME

## 5.0 TEST CASES AND SIMULATION RESULTS

In this section, the simulations carried out with DVR and DSTATCOM is presented with various test cases such as three phase short circuit fault condition, inductive and capacitive load switching conditions. Simulation results of DVR and DSTATCOM with these operating conditions are presented in this section.

### 5.1 DVR Simulation Results

The system parameters used for DVR simulations is given in Table 1.

**TABLE 1**
**SYSTEM PARAMETERS FOR DVR SIMULATIONS**

| | |
|---|---|
| Supply | 3-Phase100 MVA, 13 kV, 50 Hz AC |
| Injection/ Coupling Transformer | Primary: 11 kV, 100 MVA, 50 Hz Secondary: 11 KV ,100 MVA, 50 Hz |
| L-C Filter | $L_f$ = 0.6366 mH, $C_f$ = 1.5 uF $R_f$ = 9 Ohms |
| Load | 2.3 MVA , 3phase R-L load |
| PI Controller gain | 700 |
| Switching Frequency | 14.4 KHZ |
| Duty cycle | 64% |

Figure 4. shows the test system used for DVR simulations using PSCAD™. The system comprises of a 13 kV, 50 Hz generating system, represented feeding two transmission lines through a three-winding transformer connected in Y/Δ/Δ fashion with ratings of 13/115/115 kV. These transmission lines are connected to two distribution networks through two transformers connected in Δ/Y, of rating 115/11 kV. Initially, a three phase short circuit fault is created at the distribution network with a fault resistance of 0.56 ohms during the time period of 0.3 to 0.6sec. for duration of 300 msec.

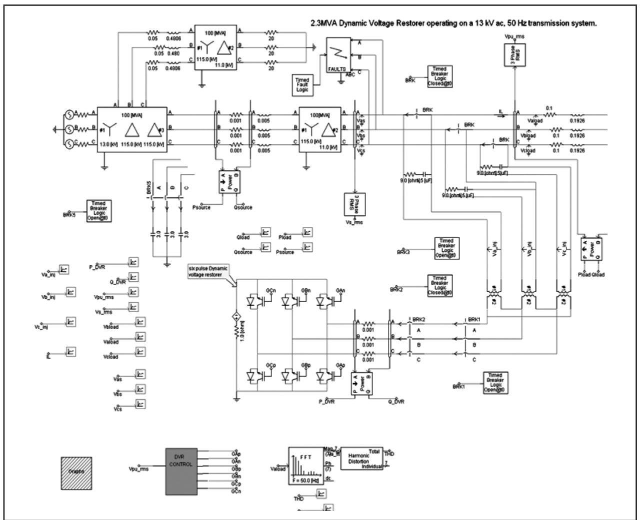


FIG.4. TEST SYSTEM IMPLEMENTED IN PSCAD™ FOR DVR SIMULATIONS

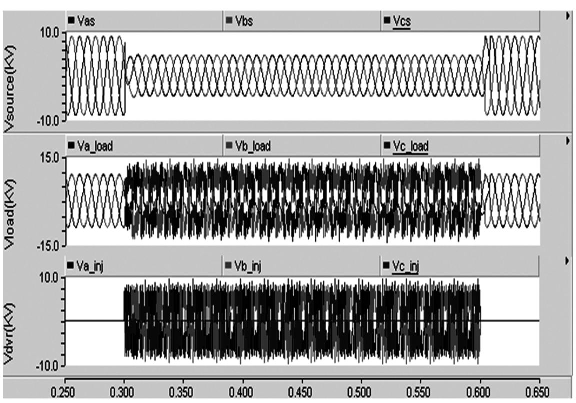


FIG.5 (A) SOURCE VOLTAGE (B) LOAD VOLTAGE (C) VOLTAGE INJECTED BY DVR

The simulation results without DVR and with DVR in operation are shown in Figure 5. Due to three phase short circuit fault, voltage sag of 50% is created as shown in Figure 5(a). The DVR comes into operation when the fault occurs in the system by injecting the voltage into the system shown in Figure 5(c) to make the load voltage shown in Figure 5(b) to its nominal value.

The Figure 5(d) represents the source and load rms voltage in p.u. The load current is shown in Figure 5(e) and the active & reactive powers at source and load is shown in Figure 5(f) and (g).

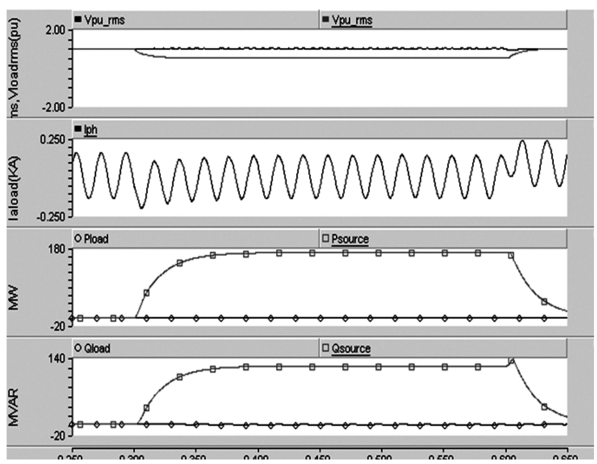


FIG.5 (D) SOURCE AND LOAD RMS VOLTAGE (E) LOAD CURRENT (F) ACTIVE POWERS (G) REACTIVE POWERS

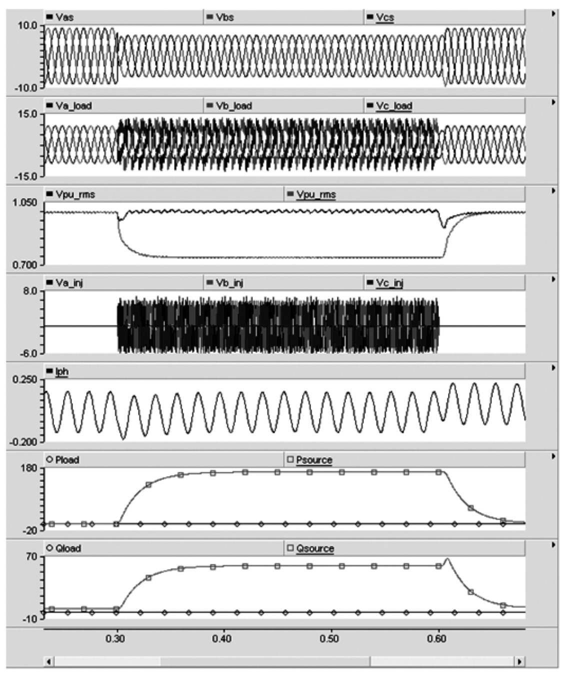


FIG.6. DVR SIMULATIONS FOR A VOLTAGE SAG OF 26%

In the next case, during the same time period (0.3 – 0.6 sec.) the fault resistance is increased to 1.2 ohms so that the voltage sag of around 26 % is created. The simulations results are shown in Figure 6. Various parameters such as laod and rms voltages in p.u, load current, active and reactive powers have been shown in figure.

In the next simulation, by connecting a capacitor of 300 uF/phase and by this capacitive load switching a voltage swell of around 26% is created. Figure 7 shows the simulation results consisting of the source voltage with swell effect, compensation by DVR and the load voltage after compensating the voltage swell. Also the load current, active and reactive powers are shown in the figure.

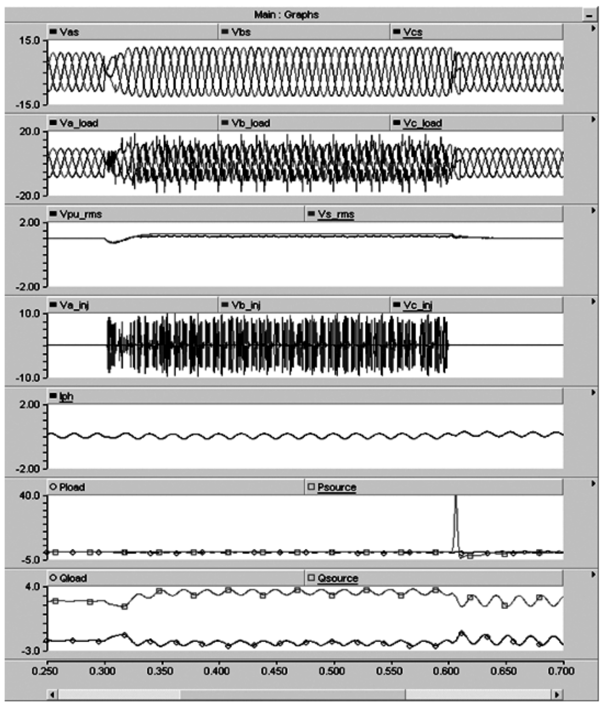


FIG.7. DVR SIMULATIONS FOR A VOLTAGE SWELL OF 26%

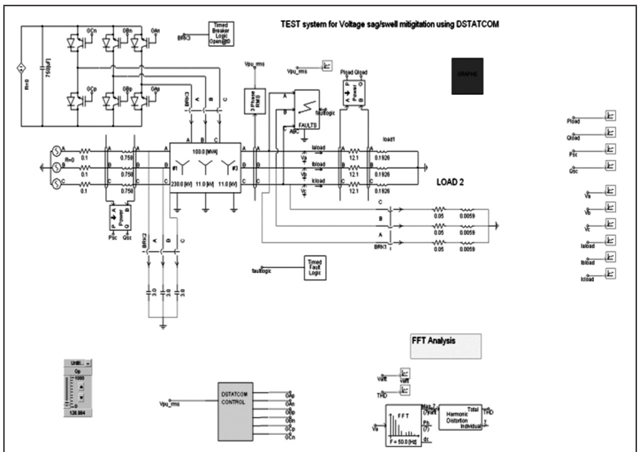


FIG.8. TEST SYSTEM IMPLEMENTED IN PSCAD FOR DSTATCOM SIMULATIONS

## 5.2 DSTATCOM Simulation Results:

The system parameters used for DSTATCOM simulations is given in Table II.

| TABLE 2 | |
|---|---|
| SYSTEM PARAMETERS FOR DVR SIMULATIONS | |
| Supply | 3-Phase100 MVA, 230 kV, 50 Hz AC |
| Injection transformer | Primary: 230 kV, 100 MVA, 50 Hz<br>Secondary: 11 KV , 100 MVA, 50 Hz |
| Load1(sensitive load)<br>Load 2<br>Load3 | R=12.1 L=0.1926/phase<br>R=0.05 L=0.0059/phase<br>C=3uF/phase |
| PI controller gain | 126 |
| Switching frequency | 5 KHZ |
| Duty cycle | 50% |

The analysis with DSTATCOM has been done by considering two test cases. Firstly, a three phase short circuit fault is created, due to which voltage sag occurs. In second case, he inductive and capacitive load switching causes voltage sag and swell at various instants. The performance of the DSTATCOM is analysed for compensating in both the cases effectively.

**Case (i) :** A three phase short circuit fault is created during the time period of 0.3 - 0.6 sec.via a fault resistance of 0.45 Ohms creating a voltage sag of around 81% for a duration of 0.3sec. The results in Figure 9.(a) show that DSTATCOM mitigates the sag in very short time and the r.ms voltage is increased to 0.98 p.u. The three phase load voltages with and without DSTATCOM is shown in Figure 9 (b). And also, it maintains the load current, load active power, load reactive powers constant.

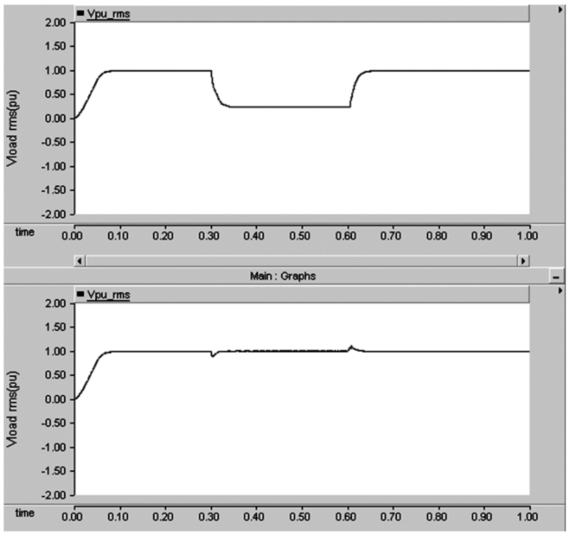


FIG.9. (A) RMS VOLTAGE AT LOAD: WITHOUT AND WITH DSTATCOM

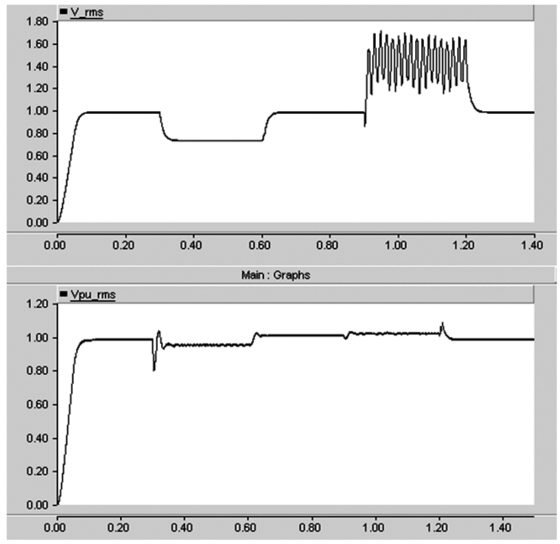


FIG.10. (A) RMS VOLTAGE AT LOAD: WITHOUT AND WITH DSTATCOM

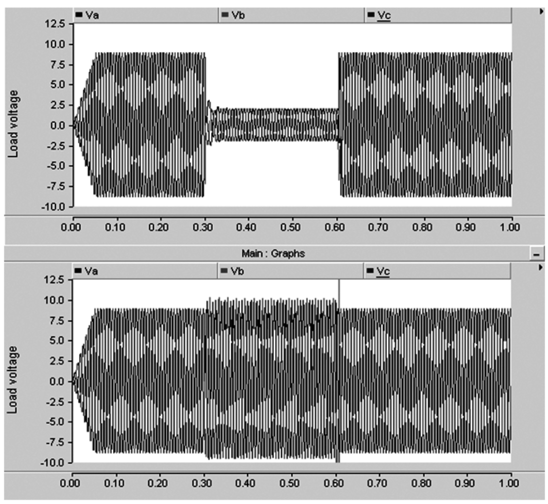


FIG.9. (B) THREE PHASE LOAD VOLTAGE: WITHOUT AND WITH DSTATCOM

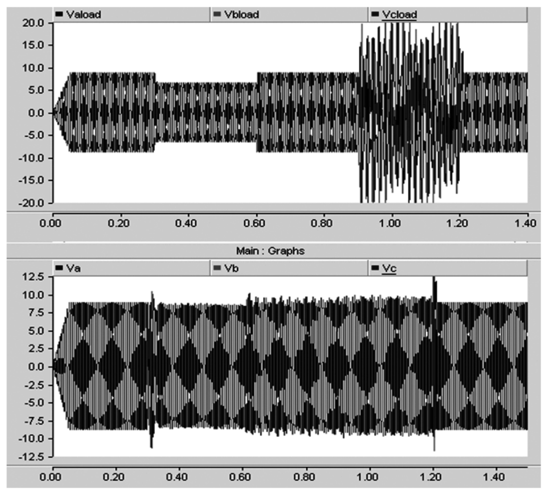


FIG.10. (B) THREE PHASE LOAD VOLTAGE: WITHOUT AND WITH DSTATCOM

**Case (ii):** In this case, the simulation was done with inductive and capacitive load switching causing voltage sag and swell respectively. Initially, an inductive load is added so that the load is increased at 0.3 sec. during the simulation period 0.3–0.6sec., resulting in the voltage drop by almost 27% with respect to the reference value. At 0.6 sec. the inductive load is removed by opening the switch so that the load voltage becomes close to 1 p.u. and this phase continues from 0.6 to 0.9 sec., for duration of 0.3 sec. At 0.9 sec., a capacitor bank is connected to the network on HV side during the period 0.9 to 1.2 sec. This results in the increase in the rms voltage by 27% with respect to the reference voltage.

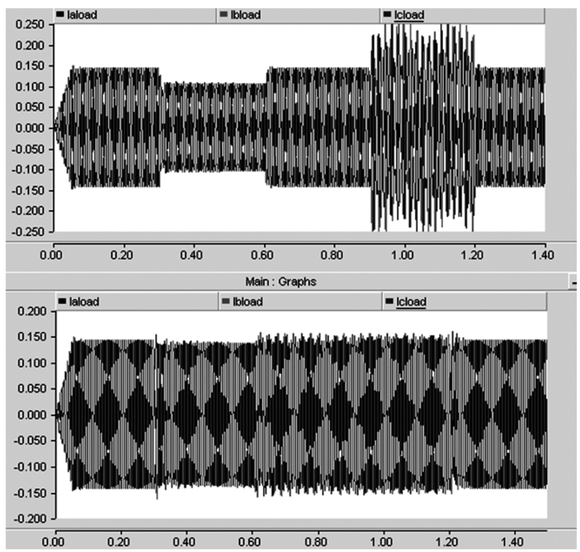


FIG.10. (C) THREE PHASE LOAD CURRENT: WITHOUT AND WITH DSTATCOM

The test case results in Figure 10 shows that the DSTATCOM is an effective mitigating device, maintaining the load voltage and current to its rated value even during sudden switching on inductive and capacitive loads at various instants.

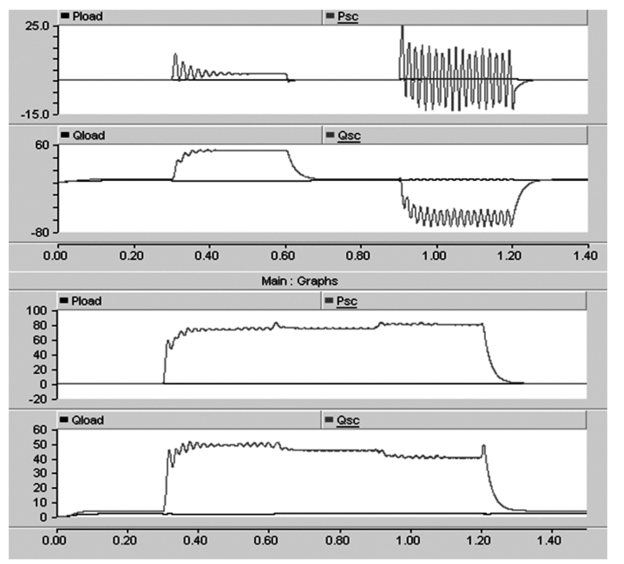


FIG.10. (D) ACTIVE & REACTIVE POWER AT SOURCE AND LOAD: WITHOUT AND WITH DSTATCOM

## 6.0 CONCLUSION

This paper has presented the analysis of two important custom power devices namely DVR and DSTATCOM applied for power quality improvement in distribution networks. A PWM based control scheme has been implemented to control the VSC switches in DVR and DSTATCOM. The simulation of these devices was done using a tool PSCAD. Comprehensive results were presented for different operating conditions of the distribution network. Test conditions are formed by creating various types of faults in the system. Simulations were done with DVR and DSTATCOM for mitigating the voltage sag and swell in the distribution system. Each device performance is assessed with the simulation results, which has shown excellent voltage regulation capabilities of both the devices at different operating conditions such as three phase faults, inductive and capacitive switching of loads.

## REFERENCES

[1] Roger C. Dugan, Surya Santoso, Mark F. McGranaghan, and H.Wayne Beaty, “Electric Power Systems Quality”, *McGraw-Hill*, 2nd Edition, 2002.

[2] Anaya-Lara O, Acha E., “Modeling and analysis of custom power systems by PSCAD/EMTDC”, IEEE Transactions on Power Delivery, Vol.17, No. 1, Pages:266 – 272, Jan. 2002

[3] Bollen, M.H.J.,” Voltage sags in three-phase systems” Power Engineering Review, IEEE, Vol. 21, No. 9, pp: 8 - 11, 15, Sept. 2001.

[4] N. Hingorani, “FACTS-Flexible AC transmission systems”, Proc.IEE 5th Intl. Conf. AC/DC Transmission, London, U.K., Conf.Pub.345, pp 1-7, 1991.

[5] L. Gyugyi, “Dynamic compensation of ac transmission lines by solidstate synchronous voltage sources,” IEEE Trans. Power Delivery, Vol. 9, pp. 904–911, Apr. 1994.

[6] Manitoba HVDC Research Centre, “PSCAD/EMTDC™: Electromagnetic transients program including DC systems,”, 1994.

[7] A. M. Gole, O. B. Nayak, T. S. Sidhu, and M. S. Sachdev, “A graphical electromagnetic simulation laboratory for power systems engineering programs,” *IEEE Trans. Power Syst.*, Vol. 11, pp. 599–606, May 1996.

[8] Omar R and Rahim, N.A. “New Control Technique Applied in Dynamic Voltage Restorer for Voltage Sag Mitigation” Industrial Electronics and Applications, 2009. ICIEA 2009. 4th IEEE Conference, pp.848 - 852, 2009.

[9] M. Sharanya, B. Basavaraja, and M. Sasikala, “An Overview of Dynamic Voltage Restorer for Voltage Profile Improvement”, International Journal of Engineering and Advanced Technology (IJEAT), Vol. 2, No. 2, pp. 26-29, Dec. 2012.

[10] Masand, Deepika, Shailendra Jain, and Gayatri Agnihotri. "Control strategies for distribution static compensator for power quality improvement", IETE Journal of Research, Vol. 54, No. 6, 421-428, 2008.

[11] Olimpo Anaya-Lara and E. Acha, “Modeling and Analysis of Custom Power Systems by PSCAD/EMTDC”, IEEE Trans.on Power Delivery, Vol.17, No.1, pp.266-272, January 2002.