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# CASCADED MULTILEVEL INVERTER BASED DYNAMIC VOLTAGE RESTORER FOR RESTRUCTURED POWERSYSTEMS

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**Abstract**: In Restructured power systems, Power quality is one of the major concerns in the present era. The problem of voltage sags and swells and its major impact on sensitive loads are well known. To solve this problem, custom power devices are used. One of those devices is the Dynamic Voltage Restorer (DVR), which is one of the most efficient and effective modern custom power devices used in power distribution networks. A new control algorithm for the DVR is proposed in this paper to regulate the load terminal voltage during sag, swell in the voltage at the point of common coupling (PCC).This new control algorithm is based on synchronous reference frame theory (SRF) along with PI controller is used for the generation of reference voltages for a dynamic voltage restorer (DVR). These voltages, when injected in series with a distribution feeder by a voltage source inverter (VSI) with PWM control, can regulate the voltage at the load terminals against any power quality problem in the source side. It first analyzes the power circuit of the system in order to come up with appropriate control limitations and control targets for the compensation voltage control through the DVR. The control of the DVR is implemented through derived reference load terminal voltages. The proposed control scheme is simple to design. Simulation results carried out by MATLAB with its Simulink and SimPower System (SPS) tool boxes to verify the performance of the proposed method.

**Keywords**: Power Quality, DVR, voltage sag/swell, VSI, Controller Design using p-q theory, MATLAB/SIMULINK.

## I. INTRODUCTION

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [1] however, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starting) and unusual (e.g. faults) could also inflict power quality problems [2].Power quality phenomenon or power quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform. Faults at either the transmission or distribution level may cause voltage sag or swell in the entire system or a large part of it. Also, under heavy load conditions, a significant voltage drop may occur in the system. Voltage sag and swell can cause sensitive equipment to fail, shutdown and create a large current unbalance. These effects can incur a lot of expensive from the customer and cause equipment damage [1]. The voltage dip magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min and *swell* is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. Typical magnitudes are between 1.1 and 1.8 p.u[2].
There are many different methods to mitigate voltage sags and swells, but the use of a custom power device is considered to be the most efficient method, e.g. FACTS for transmission systems which improve the power transfer capabilities and stability margins. The term custom power pertains to the use of power electronics controller in a distribution system [10], especially, to deal with various power quality problems. Custom power assures customers to get pre-specified quality and reliability of supply. This pre-specified quality may contain a combination of specifications of the following: low phase unbalance, no power interruptions, low flicker at the load voltage, and low harmonic distortion in load voltage, magnitude and duration of over voltages and under voltages within specified limits, acceptance of fluctuations, and poor factor loads without significant effect on the terminal voltage. There are different types of Custom Power devices used in electrical network to improve power quality problems. Each of the devices has its own benefits and limitations. A few of these reasons are as follows. The SVC pre-dates the DVR, but the DVR is still preferred because the SVC has no ability to control active power flow [3]. Another reason include
that the DVR has a higher energy capacity compared to the SMES and UPS devices. Furthermore, the DVR is smaller in size and cost is less compared to the DSTATCOM and other custom power devices. Based on these reasons, it is no surprise that the DVR is widely considered as an effective custom power device in mitigating voltage sags. In addition to voltage sags and swells compensation, DVR can also add other features such as harmonics and Power Factor

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correction. Compared to the other devices, the DVR is clearly considered to be one of the best economic solutions for its size and capabilities [4].

The organization of the paper is as follows:

In section II, the constructional part of the DVR is briefly described, the operating principle and the voltage injection capabilities of the DVR is discussed. In section III, description of carrier phase shift PWM is discussed. In section IV, the detailed description of MATLAB Simulation models of Voltage Sag/Swell and interruption along with the performance in electrical networks are discussed and in section V, Conclusions are concluded.

## II. DYNAMIC VOLTAGE RESTORER (DVR)

DVR is a Custom Power Device used to eliminate supply side voltage disturbances. DVR also known as Static Series Compensator maintains the load voltage at a desired magnitude and phase by compensating the voltage sags/swells and voltage unbalances presented at the point of common coupling.

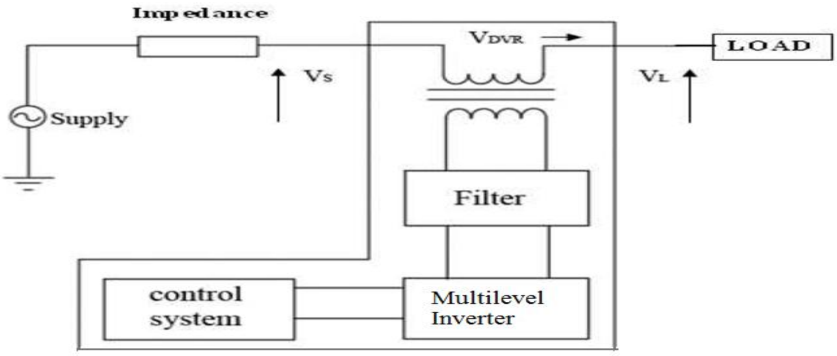


**Fig-1.** Schematic diagram of a Dynamic Voltage Restorer

Basic Configuration of Dynamic Voltage Restorer:

The general configuration of the DVR consists of:

i. An Injection/ Booster transformer
ii. A Harmonic filter
iii. Storage Devices
iv. Voltage Source Converter (VSC)
v. DC charging circuit
vi. Control and Protection system

**i. Injection/ Booster Transformer:**

The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its main tasks are:

- It connects the DVR to the distribution network via the HV-windings and transforms and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage.
- In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

**ii. Harmonic Filter:**

The main task of harmonic filter is to keep the harmonic voltage content generated by the VSC to the permissible level.

**iii. Storage Devices:**

Batteries, flywheels or SMEs can be used to provide real power for compensation. Compensation using real power is essential when large voltage sag occurs.

**iv. Voltage Source Converter:**

A VSC is a power electronic system consists of a storage device and switching devices which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. In the DVR application, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing. There are four main types of switching devices: Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT). Each type has its own benefits and drawbacks. The IGCT is a recent compact device with enhanced performance and reliability that allows building VSC with very large power ratings. Because of the highly sophisticated converter design with IGCTs, the DVR can compensate dips which are beyond the capability of the past DVRs using conventional devices. The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. The different kinds of energy storage devices are Superconductive magnetic energy storage (SMES), batteries and capacitance.

**v. DC Charging Circuit:**

The DC Charging Circuit has two main tasks.

1. The first task is to charge the energy source after a sag compensation event.
2. The second task is to maintain dc link voltage at the nominal dc link voltage

**vi. Control and Protection:**

The control mechanism of the general configuration typically consists of hardware with programmable logic. All protective functions of the DVR should be implemented in the software. Differential current protection of the transformer, or short circuit current on the customer load side are only two examples of many protection functions possibility.

## III. CARRIER PHASE SHIFTING PULSE WIDTH MODULATION

Carrier phase-shift sinusoidal pulse width modulation (PS-SPWM) switching scheme is proposed to operate the switches in the system. Optimum harmonic cancellation is achieved by phase shifting each carrier by (k-1) $\pi$/n.
Where k is the $k^{Th}$ inverter, n is the number of series-connected single phase inverters.

$$n = (L-1)/2$$

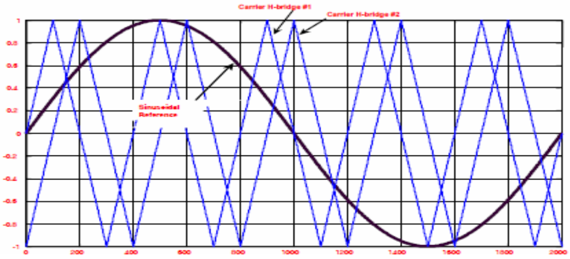


Fig-2**.** Phase shifted carrier PWM

Fig-2 shows the PSCPWM. In general, a multilevel inverter with *m* voltage levels requires (*m*–1) triangular carriers. In the PSCPWM, all the triangular carriers have the same frequency and the same peak-to-peak amplitude, but there is a phase shift between any two adjacent carrier waves, given by $\varphi_{cr}=360^0/(m-1)$. The modulating signal is usually a three-phase sinusoidal wave with adjustable amplitude and frequency. The gate signals are generated by comparing the modulating wave with the carrier waves. It means for five-level inverter, four triangular carriers are needed with a 90° phase displacement between any two adjacent carriers. In this case the phase displacement of $V_{cr1}$ = 0°, $V_{cr2}$ = 90°, $V_{cr1-}$ = 180° *and* $V_{cr2-}$ = 270°.

## IV. MAT LAB/SIMULINK MODEL

### A. Voltage Sag-Open loop system

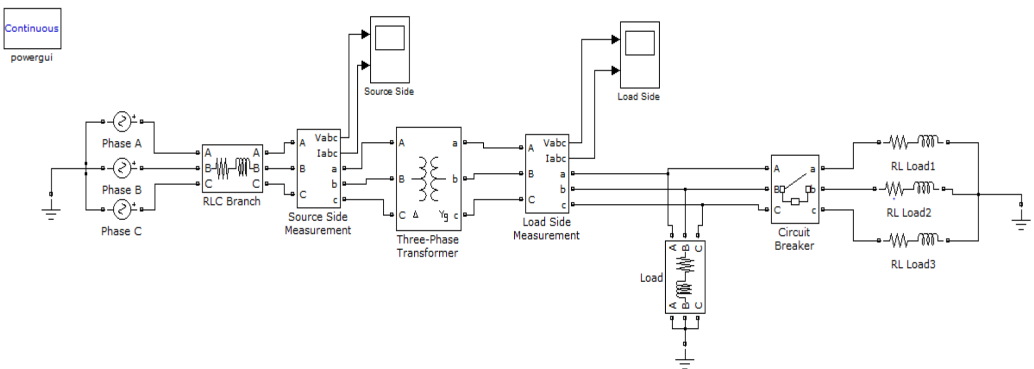


Fig. 4.1 Simulink diagram of open loop system for voltage sag

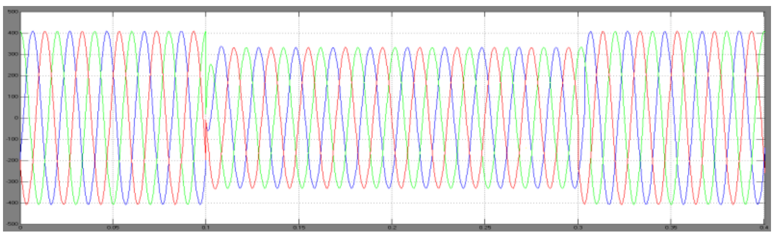

Fig. 4.2 Load Voltage Waveform

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B. **Voltage Sag-Closed loop system**

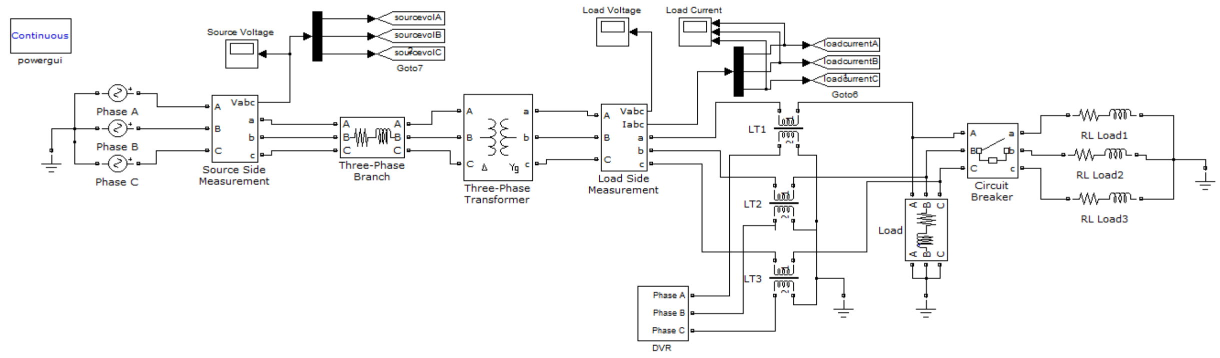


FIG. 4.3 SIMULINK DIAGRAM OF CLOSED LOOP SYSTEM FOR VOLTAGE SAG

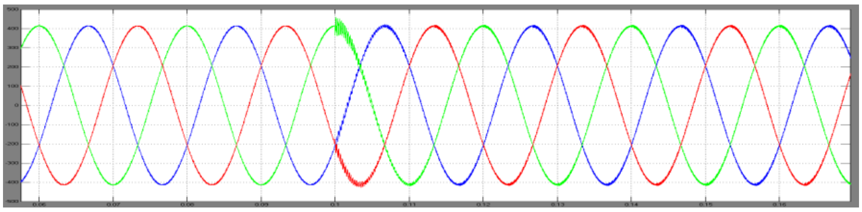

Fig. 4.4 Load Voltage waveform

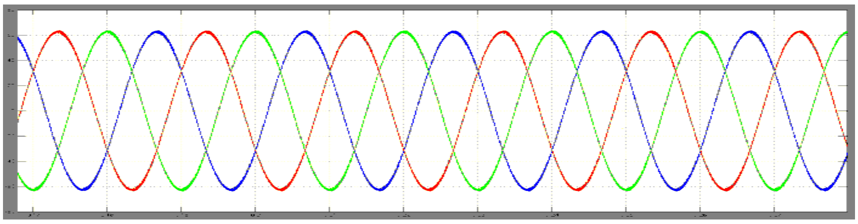

Fig. 4.5 Compensator Voltage Waveform

Fig 4.1 shows the simulink diagram of open loop system for voltage sag. Fig 5.2 shows the load voltage waveform in which voltage sag is created from 0.1 to 0.3 seconds by adding an extra RL Load i.e. voltage level is below 90% of the rated voltage and above 10% of the rated voltage according to IEEE std l159-1995. Fig 4.3 shows the simulink diagram of closed loop system using Dynamic Voltage Restorer where the reference voltages are generated by using PQ theory. By observing Fig 4.4 we can say that voltage sag is eliminated by using Dynamic Voltage Restorer so as to maintain load voltage constant. Fig 4.5 shows the voltage waveforms generated by the compensator during voltage sag so as to maintain load voltage constant.

**C.Voltage Swell-Open loop system**

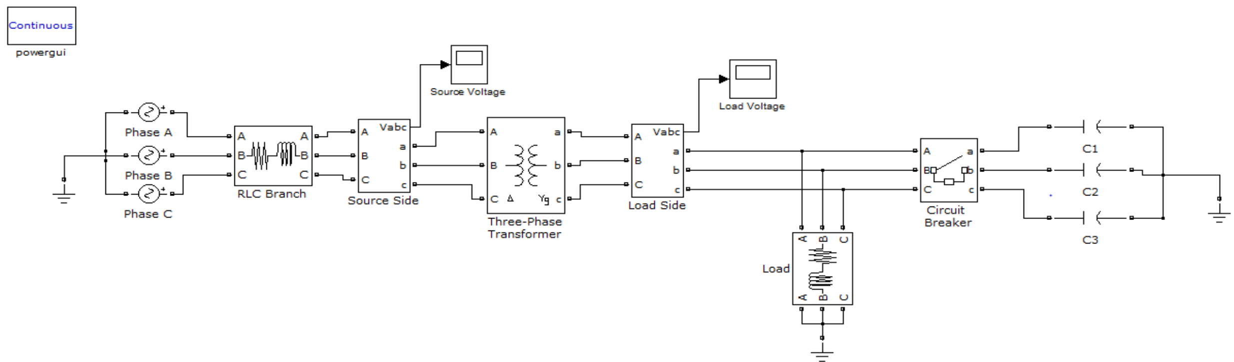


Fig. 4.6 Simulink Diagram of Open Loop System for voltage swell

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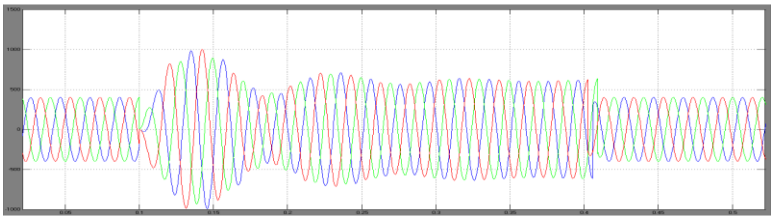

Fig. 4.7 Load Voltage Waveform

**C.Voltage Swell-Closed loop system**

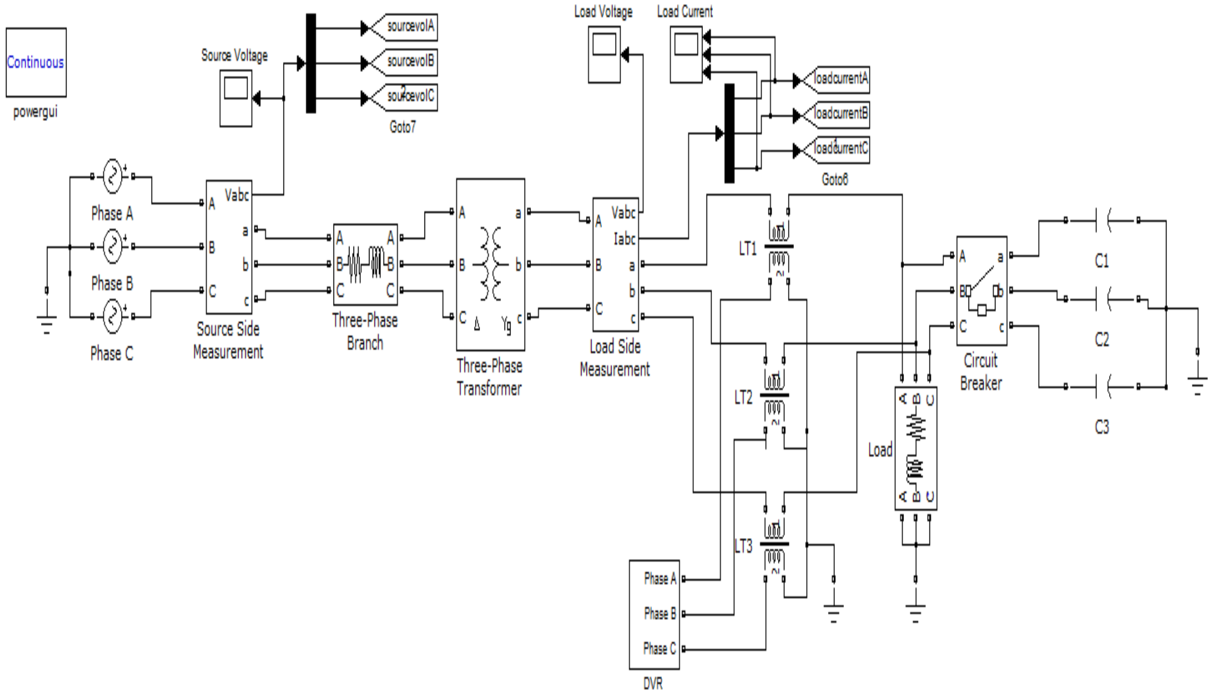


Fig. 4.8 Simulink diagram of closed loop system for voltage swell

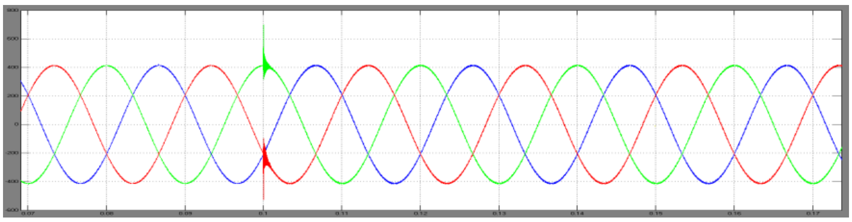

Fig. 4.9 Load Voltage waveform

Fig 4.6 shows open loop simulink diagram for voltage swell. Fig 4.7 shows the load voltage wave form for voltage swell which is created by adding an extra capacitor bank from 0.1 sec to 0.4 seconds i,e voltage level is above 110% of the rated voltage according to IEEE std l159-1995. Fig 4.8 shows the simulink diagram of closed loop system using dynamic voltage Restorer for elimination of voltage swell where the reference voltages are generated using PQ theory. Fig 4.9 shows the load voltage wave form where voltage swells is mitigated to maintain constant voltage at load side. Fig 4.10 shows the Compensator Voltage with DVR.

**D.Interruption**

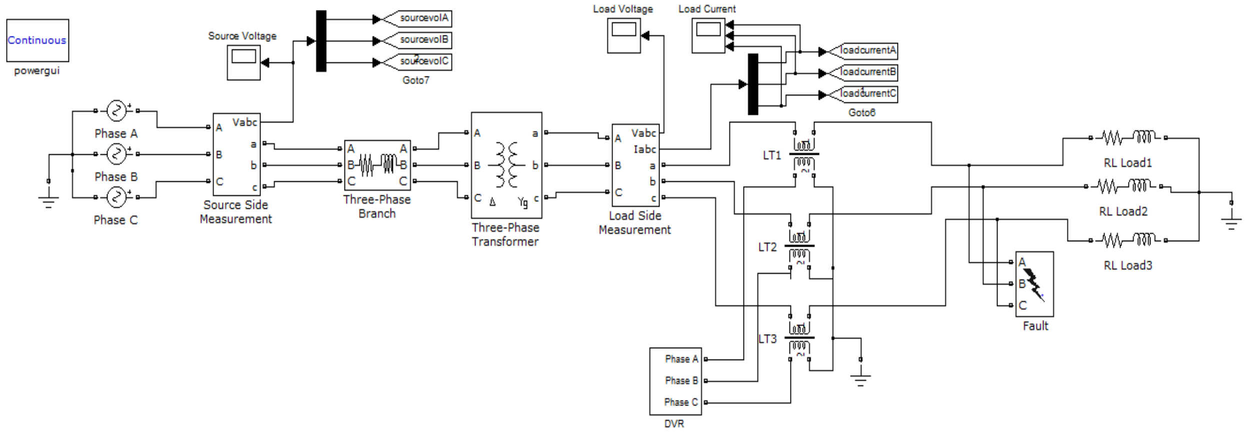


Fig 4.10 Simulink diagram of closed Loop System for voltage Interruption

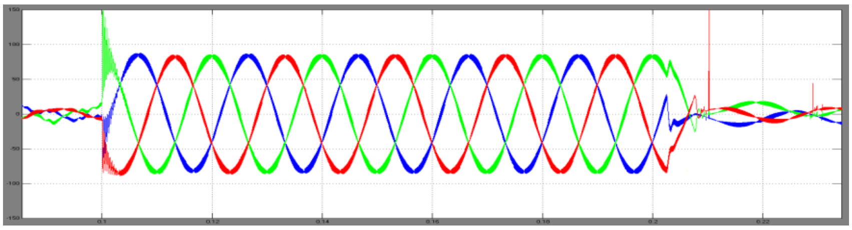

Fig 4.11 Compensator Voltage with DVR

## IV. CONCLUSION

In this paper cascaded H-Bridge Seven level multilevel inverter is implemented as Dynamic Voltage Restorer to compensate voltage sag, voltage swell and interruption. Closed loop control of Dynamic Voltage Restorer is designed for better regulation of the load voltage. Reference signal is generated using PQ theory for closed loop control with voltage Sag, voltage Swell and interruption are compensated using Dynamic Voltage Restorer and MATLAB simulations are carried for the above to maintain load voltage constant.

## REFERENCES

[1] G. Yaleinkaya, M.H.J. Bollen, P.A. Crossley, "Characterization of voltage sags in industrial distribution systems", IEEE transactions on industry applications, vol.34, no. 4, July/August, pp. 682-688, 1999.
[2] Haque, M.H., "Compensation of distribution system voltage sag by DVR and D-STATCOM", Power Tech Proceedings, 2001 IEEE Porto, vol.1, pp.10-13, Sept. 2001.
[3] Anaya-Lara O, Acha E., "Modeling and analysis of custom power systems by PSCAD/EMTDC", IEEE Transactions on Power Delivery, Vol.17, Issue: 1, Pages:266 – 272, Jan. 2002.
[4] Bollen, M.H.J.," Voltage sags in three-phase systems" Power Engineering Review, IEEE, Vol. 21, Issue: 9, pp: 8 - 11, 15, Sept. 2001.
[5] M.Madrigal, E.Acha., "Modelling of Custom Power Equipment Using Harmonic Domain Techniques", IEEE 2000.
[6] R.Mienski,R.Pawelek and I.Wasiak., "Shunt Compensation for Power Quality Improvement Using a STATCOM controller: Modelling and Simulation", IEEE Proceedings., Vol.151, No.2. Jan. 2006.
[7] Sasitharan S., Mahesh K. Mishra, *Member, IEEE*, B.Kalyan Kumar, and Jayashankar V., m*ember, IEEE*, " Rating and Design Issues of DVR Injection Transformer", *IEEE Press.*, New York, 2008.
[8] Math H.J. Bollen, "Understanding power quality problems: voltage sags and interruptions", IEEE Press, New York, 2000.
[9] A.Ghosh and G. Ledwich. " Power Quality Enhancement Using Custom Power Devices", 2002. Kluwer Academic Publishers.
[10] S. Chen, G. Joos, L. Lopes, and W. Guo." A nonlinear control method of dynamic voltage restorer" , IEEE 33rd Annual Power Electronics Specialists Conference. pp. 88- 93.Sept2002.

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**BIOGRAPHY**

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