International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 6 (2015) pp. 15059-15070

http://www.ripublication.com

Effective Sag/Swell and Unbalance Supply Voltage Compensation Using DVR

V. Arutselvan[1], A.S. Viswanathan[2], K. Palanisamy[3]
Department of EEE, Sri Chandrasekharendra Saraswathi Viswa Maha Vidyalaya University, Enathur, Kancheepuram[1,2], Associate Professor, SELECT, VIT University, Vellore[3],
arulthen@yahoo.com[1], viswanathan.a.s@kanchiuniv.ac.in[2], kpalanisamy@vit.ac.in[3]

Abstract

Due to the impact on electricity suppliers, equipment manufactures and customers Power quality becomes very important issue. Most of the modern industrial equipments are non linear loads mostly based on electronic devices such as variable speed drives. As a result of non linear loads the AC sine wave purity is lost. Disturbances are produced not only due to non linear loads but also due to fault conditions on distribution grid. Voltage sag is the major power quality issue and is to be addressed in the present grid scenario. Among the various method available for mitigation of voltage sag and swell one of the fast and preferred method is dynamic voltage restorer (DVR). DVR offers most effective solution for power quality issues for sensitive loads than shunt compensators. The shunt compensators require bulky and costly equipment since they are injecting missing potential through reactive power. In this paper the performance of DVR with series compensation of active power using Battery as energy source and dq technique for control VSC is studied using MATLAB Simulink.

Index Terms: Power Quality, DVR, Sag, Swell, Un balance.

Introduction

The present power grid contains large renewable based power generation. The renewable source is not constant by nature and due to this large variation in total power generation. Because of the variation of power generation there is always a difference between demand and generation which cause voltage variation. The grid also facing interconnection problems like power quality issues. Though many types of power quality issues are to be attended by the power suppliers, voltage sags need priority due to its severity. There are many reasons which causes voltage sags such as transmission system fault, LT distribution system fault, due to heavy inrush starting current during Switching of heavy loads Voltage tolerances maintained by grid may not suitable for voltage sensitive equipment, Unbalanced load on a three phase system, [3] capacitor switching.

Many custom power devices are developed recently to overcome Voltage related power quality problems. Dynamic Voltage Restorer (DVR) is most efficient and popular modern device for mitigation of voltage sags and swells. This is widely used in power distribution networks especially supply point of sensitive loads. A DVR is a device connected in series with distribution HT/LT line in all the three phases for compensating voltages into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and a critical load feeder at the so-called point of common coupling (PCC). The DVR was first installed in 1996 [7].The main function of DVR is to compensate missing voltage and to bring back normal load-side voltage in the event of voltage sag. There are various circuit topologies and control schemes that can be used to implement a DVR. Apart from mitigation of voltage sags and swells, DVR can also used for line voltage harmonics compensation, fault current limitations and reduction of transients voltage

General Configuration of DVR

Based on the energy storage the DVR is classified as two types.

1) DVR topology with no energy storage

In this type Grid supply will be utilized in conjunction with AC to DC convertor instead of separate energy storage device. A simple full wave rectifier is connected across the grid to get AC to DC supply for storing energy to DC capacitor. This intern act as DC source for VSC. Here the direction of power flow is unidirectional from grid to VSC. It is cheap solution for voltage sag due to elimination of storage device [5].

a) Supply side connected shunt converter:
b) Load side connected shunt converter

2) Topology With Energy Storage

Even though Storing of electrical energy is expensive the performance of the DVR for certain types of voltage sags can be improved besides lowering the strain on the grid. [5]

a) Variable dc-link voltage energy stored in dc link capacitor
b) Constant dc-link voltage

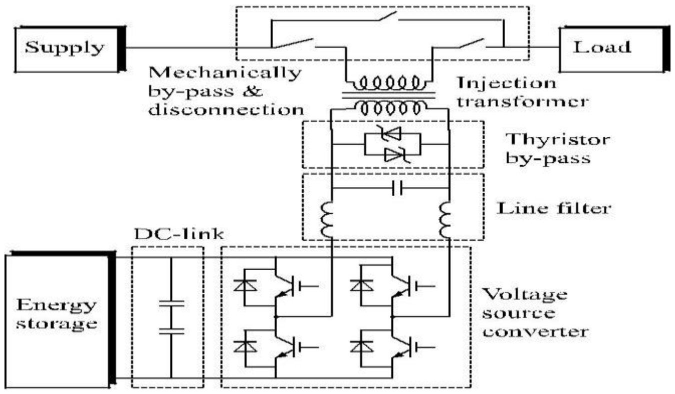

Figure 1: General Configuration of DVR

The important components of the DVR are an injection/ booster transformer, a harmonic filter in between VSC and booster transformer, Energy storage devices, Voltage source Converter (VSC) accompanied with PWM based gate control circuit, DC charging circuit, PWM control and protection system. The configuration of DVR is shown in Fig 1.

i) Injection/ Booster transformer

The Injection/Booster transformer is a specially designed transformer with primary winding forms series connection to load which injects DVR output voltage in to grid without affecting synchronism [7]. Three single-phase injection transformers are used for three phase circuits to inject missing voltage individually to the system. Its main tasks are:

1) The DVR generated compensating voltages is Coupled with incoming supply voltage so that the resultant voltage to load will be in good voltage quality.
2) The Injection Transformer also acts as a Isolating device between load and DVR elements including control mechanism [7].

ii) Harmonic Filter

The filter circuit inserted between VSC and the secondary (LV) side of Booster transformer will be normally passive LC filter. This filter circuit is very essential to minimize the harmonics generated by the PWM which produces high frequency gate pulses to Voltage source converter to the permissible level. The filter converts the pulse modulated voltage of VSC in to sinusoidal voltage [10].

iii) Voltage Source Converter:

Generation of sinusoidal voltage at any required frequency, magnitude, and phase angle is possible by a power electronic system known as VSC which consists of storage device and switching devices. The VSC is used in DVR to compensate the part of missing supply voltage during sag also to control voltage swells.

Out of many switching devices Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT) are most common switching devices employed in VSC. For higher power capacity rating and enhanced performance the IGCT is a recent compact device having good reliability. For obtaining higher power ratings multilevel cascaded H-bridge power converters are used [9],[7].

iv) Energy storage Device

For supplying real power VSC needs additional energy source. The purpose is to supply the necessary energy to the VSC via a dc link for the generation of missing voltages to be injected. The various kinds of energy storage devices are superconductive magnetic energy storage (SMES), batteries, and capacitance [5]. The capacity of the stored energy determines the duration of the sag which can be mitigating by the DVR depends on. The common choice and highly effective storage devices are Batteries. This high voltage string of batteries can be placed across the regulated dc bus with little or no additional circuitry.

Ultra capacitors, which have a wider voltage range than batteries becomes alternative to batteries and can be directly paralleled across the input bus. The specific energy density for Ultra capacitors is less than that of a battery, but has a greater specific power than that of battery. This property is making Ultra capacitors suitable for supplying short pulses of power up to several seconds. Many voltage sag issues can be resolved by DVR active power injection.

The two main tasks of dc charging circuit are

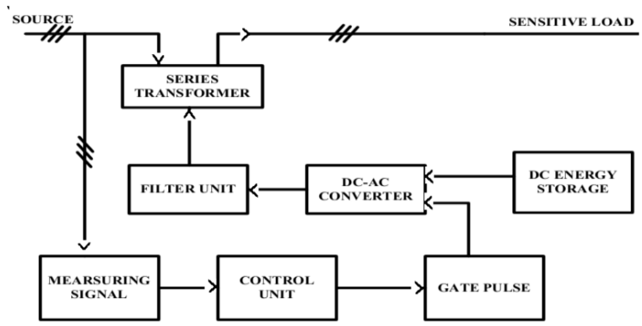

Figure 2: Function blocks of designed DVR

1. To charge the energy source after a sag compensation event.
2. To maintain dc link voltage at the nominal dc link voltage.

v) By-pass equipment

Two types of Bye pass arrangements can be adopted at the primary and secondary side of Injection Transformer,

a) Mechanical Bypass known as circuit breaker connected across the primary side of injection transformer to bypass the entire DVR equipments during short circuit.
b) Thyristor bypass is also a DVR protective device connected across the transformer.

Basic Principle of DVR

The basic function of DVR is to compensate the missing voltage in terms of both magnitude and phase angle at the point of common coupling so that the voltage sensitive load can perform it's normal function. The Voltage source converter (DC-AC Converter) will generate required AC voltage and this will be injected to the system through series Booster Transformer as shown in Fig. 2. As long as the grid voltage is as per requirement of sensitive loads the capacitor across the VSC gets charged from the main supply source. The control unit will continuously track the source voltage through PLL and the difference between the supply voltages with load reference voltage will be the error signals. Using PWM technique these error signals will transform into gate pulses for IGBT based VSC for generating missing voltages. Based on the gate pulses the VSC will generate required compensating voltage, by using the stored DC energy from the capacitor. The converter (VSC) will inject only the missing voltage through the series transformer [8]. A relatively small capacitor is present on dc side of the PWM solid state inverter, and the voltage over this capacitor is kept constant by exchanging energy with the energy storage reservoir. The required output voltage is obtained by using pulse-width modulation switching pattern. As the controller will have to supply active as well as reactive power, some kind of energy storage is needed

Various Methods of Compensation

The voltage sensitivity will vary among various types of loads. Some loads will not tolerate small phase angle jump while others are tolerant to it. Important factors on which the type of Compensation of voltage sags/swells is depend upon are 1) DVR power rating 2) different load conditions 3) Different types of voltage sags/swells. Therefore, the choice of DVR compensation mainly depends upon the type and characteristics of the load and its raid through capability. The three different DVR voltage injection methods are described as below.

i) In-Phase Compensation Method (IPC)

In this method attention is placed on maintaining a constant voltage magnitude on the load regardless of the load current and pre-fault voltage. The injected voltage will be in phase with the sag voltage to bring back the load voltage to constant magnitude. The phase angles of the pre-sag and load voltage are different. The main advantages of this method is that the amplitude of DVR injection voltage is minimum

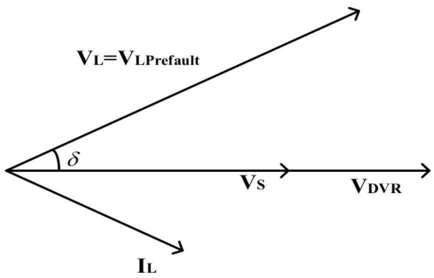

Figure 3: In-phase compensation method

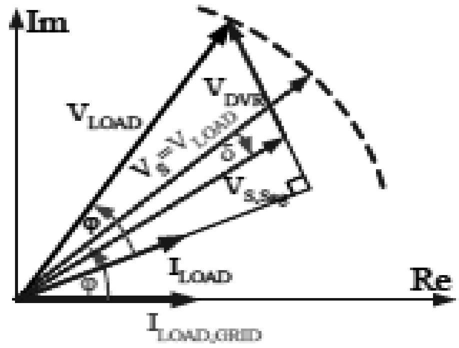

Figure 4: In-Phase Advanced Compensation Method (IPAC)

for a certain voltage sag in comparison with other strategies. The main drawback of this method is that phase-angle jumps could not be resolved hence loads which are sensitive to phase-angle jumps will be affected. Fig. 3 shows the single-phase vector diagram of this method.

ii) In-Phase Advanced Compensation Method (IPAC):
The basic idea of this strategy is to inject DVR voltage perpendicular to Load current vector (Fig. 4) thus to minimization of injected energy is achieved by making the active power component zero. With pure reactive power only shallow sags compensation is possible. If deep sag occurs, a large amount of Active power is also needed. Since energy stored in the DC link is only supplying active power this part of DVR becomes costly. As long as the voltage sag is quite shallow, it is possible to compensate sag with pure reactive power. The two major disadvantages are when a phase jump occurs in the supply voltage and the other is requirement of high DVR voltage amplitude. In this method the values of load current and voltage are fixed in the system. so we can change only the phase of the sag voltage [6].

iii) Pre-dip/sag compensation method
The pre-sag method tracks the supply voltage continuously and if it detects any disturbances in supply voltage it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition VDVR = Vpre fault –Vsag . Hence the load

voltage can be restored back to the pre-fault condition as shown in Fig. 5. Compensation of voltage sags in the both phase angle and amplitude for sensitive loads would be achieved by pre-sag compensation method.

Best solution will be obtained by this method since it produces the load voltage exactly as per the pre-fault voltage. Requirement of higher capacity energy storage device is the main drawback of this technique. In order to get pre-sage voltage condition there is no control over active power injection and hence higher capacity energy storage is required [6][4]. Fig.5. shows the pre-fault control strategy for voltage sag and swell vector diagrams.

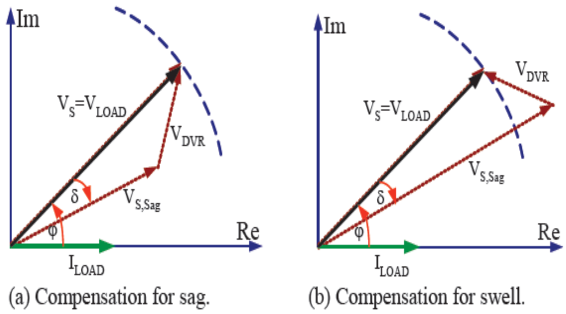

Figure 5: Pre sag Compensation Method

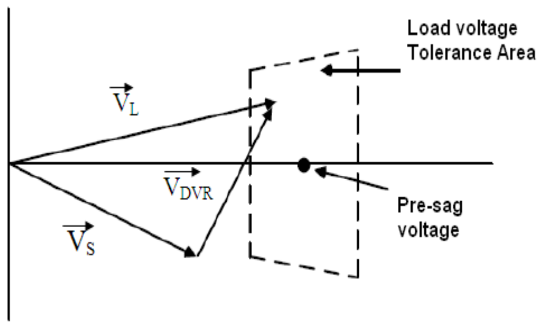

Figure 6: Voltage Tolerance Method With Minimum Energy Injection

events. This method is best suited to loads sensitive to phase angle jumps as it compensates for both the magnitude and phase angle. In this diagram, Vpre-fault condition is Vs=VL and VSag are voltage at the point of common coupling (PCC), before and during the sag respectively. The voltage injected by the DVR is VDVR, which can be obtained as:

$$V_{DVR} = \sqrt{(V_L^2 + V_S^2 - 2V_L V_S \cos\delta)} \tag{1}$$

And the required angle of injection θinj (Angle between Vs,sag and V $_{DVR}$) calculated as:

$$\theta_{inj} = \tan^{-1}\frac{V_S \sin\theta}{V_S \cos\theta - V_L} \quad (2)$$

iv) Voltage Tolerance Method with Minimum Energy Injection

In this method minimum both active and reactive power injection is to bring back the load voltage vector within the tolerance area of sensitive loads [6]. Normally equipments are designed to withstand variation in voltage magnitudes in the range 90%-110% of the nominal voltage and phase angle variations between 5%-10% of the normal state [4]. In this method, the phase angle and magnitude of voltage sag has been compensated to bring the load voltage within the area of tolerance Fig. 6. Loads can also tolerate the small voltage drop and phase angle jump caused by load itself.

DQ Technique

Normally we are dealing with three phase supply from power grid or source (R, S, T). These voltages are sensed and converted into equivalent two phase system α & β vector in the stationary reference frame. This will be the input to PLL.

The PLL locks to the supply angle [10] with a preferable low phase delay from the input to the output, damp the background harmonics, non-symmetrical voltages etc

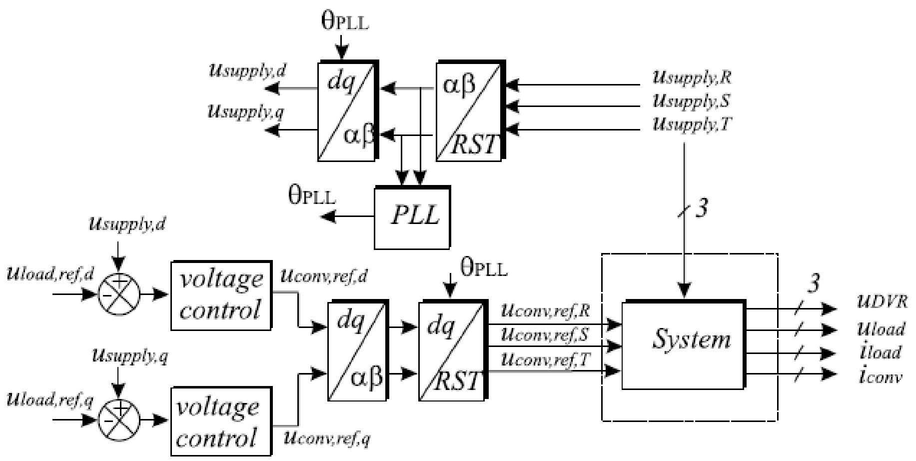

Figure 7: Feed forward control in the rotating reference (DQ) frame

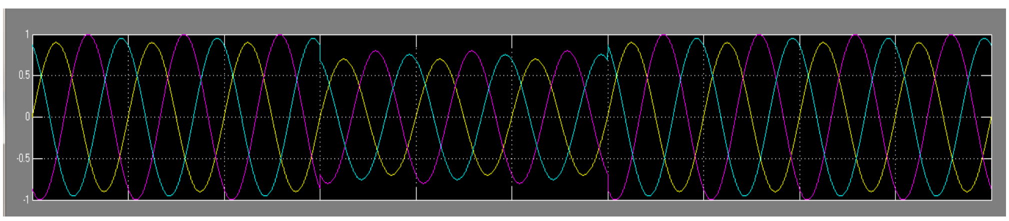

Figure 8: Three Phase Unbalance system with 0.2 PU sag simulation in the Grid voltage

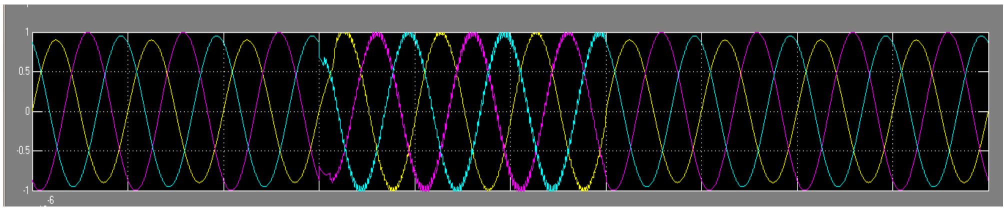

Figure 9: Three Phase Unbalance system with compensated Load Voltage after DVR mitigation

The phase detector in PLL continuously monitors phase and frequency of fundamental components of supply. In steady state the magnitude $U_{supply,d}$ is equal to the peak value of supply voltage. $U_{supply,d}$ is a DC value and equal to the peak value of the phase voltages. For synchronization the angle between the supply and PLL output, should be minimized and can be described as, $\Delta\theta = \theta_{supply} - \theta_{PLL}$. [1]

A control loop like PLL force $\Delta\theta$ to zero.The low pass filter in PLL tracks supply frequency and phase angle by proper gain control dynamically. By Setting a DC-value to 'd' Component of the reference load voltage $U_{load,ref,d}$ the DVR after comparing with $U_{supply,d}$ will generate corresponding magnitude of DVR voltage which is in-phase with the supply voltage. The q-reference component of $U_{load,ref,q}$ indicates a reference voltage perpendicular to the supply voltage [1]. The detailed procedure is shown in Fig. 7.

Injection of voltage in-phase with the supply by DVR can be achieved by setting the 'q' Component of the reference load voltage $U_{load,ref,q}$ to zero. In this paper we deal with this type of In-Phase compensation method. This method is practiced to get effective control over the magnitude of load voltage but always in-phase with supply voltage. Transformation angle Θ_{PLL} from PLL is used to transform the dq-reference values for the converter back to the rotating reference frame. The rotating reference values are then converted as the reference phase values $U_{conv,ref,R}$, $U_{conv,ref,S}$ and $U_{conv,ref,T}$ [1]. These ref signals are used to PWM which offers gate pulses to DVR's VSC.

When grid voltage is normal or run through capacity of load is with in the tolerance, gating will not take place in other words DVR will not produce any voltage.

Short circuit protection:

In case of any short circuit at the load side will affect the operation of DVR and may cause severe damages to the DVR components. We can protect the series connected DVR from very high short circuit currents in the following two methods.

Passive control of the DVR:

In this method fast acting circuit breaker is connected in shunt with primary side of injection transformer. This will bypass the fault current and protect the DVR during Earth /Short circuit fault. In this type of protection the VSC can be designed for low current rating and hence cost is less.

Active control of the DVR:
In this type of protection the VSC are rated for the short circuit currents, and can be operated actively to clear the fault.

Operating Modes of DVR
Generally, the DVR is categorized into three-operation mode: protection mode, standby mode (during steady state No injection) and injection mode (during sag).

1. Protection Mode: The DVR is protected from the over current in the load side due to short circuit on the load or large inrush currents. The bypass switches remove the DVR from system by supplying another path for current [6].
2. Standby Mode:This is normal operating mode in which grid voltage is free from sag and swell. In standby mode (normal steady state conditions), the DVR may go into short circuit operation. The solid-state by-pass thyristors connected in anti parallel are used to perform short circuit operation. They are placed between the inverter and secondary (low side) of series injection transformer. During normal steady state operation DVR can inject small voltage to compensate the voltage drop on transformer reactance or losses. However short circuit operation (zero injection)of DVR is generally preferred [6] during steady state grid condition. The small voltage drops due to do transformer reactance or losses will not disturb the load requirements. If the distribution circuit is weak there is need to inject small compensation voltage to operate correctly. During short circuit operation, the DVR injected voltages and injection Transformer winding magnetic fluxes are zero hence full load current pass through the primary winding [6]. Most of the time the DVR will be in normal operating mode. During standby mode normal operation the voltage drop across the DVR is determined by the short circuit impedance of the injection transformer. The Anti parallel thyristors can react fast by taking the current limiting capability of the series booster transformer as advantage. Due to very fast reaction of Thyristers they are serving to protect the DVR elements temporarily by short circuiting until a more robust and slower mechanically bypass is ensured.
3. Injection Mode: The DVR goes into injection mode as soon as the sag is detected. Three single-phase ac voltages are injected in series with required magnitude, phase and wave shape for compensation [6]. The types of voltage sags, load conditions and power rating of DVR.

Simulation Results
Simulation of the DVR is performed in MATLAB SIMULINK using the above DQ control technique for 415 V 50 Hz distribution supply. The type of sag mitigation is “In phase voltage compensation technique” is adopted to control the load voltage RMS value. The condition of unbalance is simulated by introducing additional single phase AC sine wave sources 33.89V each at R and B phases. By adopting DQ method gate pulses to CVS converter is synthesized to control the DVR output voltage for active and reactive

power control individually. By setting q component to zero the voltage injection in quadrature with the load current will be zero.

Three single phase two winding transformers with all the terminals accessible with phase voltage for each winding is 239.6V is adopted. Three arm bridge IGBT voltage source converters are used for best result. LC filter circuit is consist of 0.43 MH series inductance and 10µF three phase shunt capacitors are used to minimize the DVR voltage harmonics. Simulation is performed under balanced load condition. PLL block 50Hz is adopted with suitable regulator gain KP=180, KI=3200, KD=1 for synchronizing the injected DVR voltage with grid voltage. The grid and load voltage are shown in Fig. 8 and Fig. 9. The DVR is switched to compensate from 4^{th} cycle (from 0.06 sec to 0.12ecs) to 6^{th} cycle. The load voltage shown in Fig. 9 is clearly indicating that the DVR compensates both unbalance and sag.

Conclusion

The simulation of the DVR system for mitigation of balanced and unbalanced voltage sag is done in Matlab Simulink and tested the performance for sag mitigation for 0.5PU sag in series compensation technique. From the simulations we can conclude that the series compensation technique is most reliable compared to shunt.

References

[1] Nielsen, John Godsk Aalborg “Design and Control of a Dynamic Voltage Restorer” Universitet Publication date: 2002 - Denmark.

[2] Omar, R.; Rahim, N.A., "Modeling and simulation for voltage sags/swells mitigation using dynamic voltage restorer (DVR)," Power Engineering Conference, 2008. AUPEC '08. Australasian Universities, vol., no., pp.1,5, 14-17 Dec. 2008

[3] Norbert Edomah “Effects of voltage sags, swell and other disturbances on Electrical Equipment and their economic implications”20th International Conference on Electricity Distribution Prague, 8-11 June 2009

[4] Syed Shahnawaz Husain , Dr. Jyoti Srivastava “Enhancing Power Quality with improved Dynamic Voltage Restorer” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 3, Issue 6, June 2014

[5] Sanjay Haribhai Chaudhary, Mr. Gaurav gangil, “Mitigation of voltage sag/swell using Dynamic voltage restorer (DVR)” IOSR Journal of Electrical and Electronics Engineering, Volume 8, Issue 4 (Nov. - Dec. 2013), PP 21-38.

[6] Mehmet Tümay Ahmet Teke K. Çağatay Bayındır M. Uğraş Cuma “Simulation and Modeling of a Dynamic Voltage Restorer” EMO chambers of electrical Engineers.

[7] Chellali Benachaiba, Brahim Ferdi “Voltage Quality Improvement Using DVR” - Electrical Power Quality and Utilisation -, Journal Vol. XIV, No. 1, 2008,

[8] Vijayakumar.R, Thangaraj.R “Distribution Systems Voltage Regulation using Multifunctional DVR Implementation for Emergency Control and Protect Consumers System” IJAREEE, Volume 2 Issue 2, 2014

[9] Bingsen Wang, Giri Venkataramanan, and Mahesh Illindala, ”Operation and Control of a Dynamic Voltage Restorer Using Transformer Coupled H-Bridge Converters” IEEE Transactions on power electronics, vol 21, No. 4, July 2006

[10] Krischonme BHUM kittipich and Nadarajah Mithulananthan “Performance enhancement of DVR for mitigating voltage sag / Sweel using vector control strategy” - 9Th Eco- Energy and Material Science and Engineering Symposium, The University of Queensland Brisbane.

[11] Praveen. J', Bishnu, P. Muni S.V&Wdu 'and H.V. Maktba “Review of Dynamic Voltage Restorer for Power Quality Improvement” - The 30th Annual Conference of the IEEE Industrial Electronics Society, November 2 - 6, 2004, Busan, Korea.