# Power Quality Improvement using Artificial Intelligence (AI) Based Dynamic Voltage Restorer (DVR)

**AmanKumar Sadhu[1] Mayalakshmi Pillai[2] Merolina Christie[3]**
[1]Student [2,3]Assistant Professor
[1,2,3]Department of Electrical Engineering
[1,2,3]Ahmedabad Institute of Technology, India

*Abstract*— Electrical power supply is one of the most important issues to utilities, equipment manufactures and customers. Power quality problem is an event of abnormal voltage, current or frequency. Utility distribution networks experience from various types of disturbances. Now the fast development in power electronics technology have made it possible to mitigate power quality problems. Such as, dynamic voltage restorer can provide the most mercantile solution to compensate voltage sag/swell by injecting voltage in to the sensitive system. The proposed system has less number of switching devices and has good compensating capability in comparison with commonly used compensators. Dynamic voltage restorer is a series connected power electronics based device that can mitigate the power quality issues in the system, by automatically detecting and injecting the voltage components through an injecting transformer. Here comes the importance of soft computing techniques like fuzzy logic. With the help of a newly developed fuzzy rule base, the system will be able to correct repeated occurrences of the power quality problems. The modelling and simulation is done using MATLAB/SIMULINK software.

***Key words:*** Artificial Intelligence (AI), Dynamic Voltage Restorer (DVR)

## I. INTRODUCTION

Electrical energy is the simple and well-regulated form of energy, can be easily transformed to other forms. Along with its quality and continuity has to maintain for good economy. Power quality has become major concern for today's power industries and consumers. Power quality issues are caused by increasingly demand of electronic equipment and non-linear loads. Many disturbances associated with electrical power are voltage sag, voltage swell, voltage flicker and harmonic contents. Due to complexity of power system network voltage sag/swell became the major power quality issue affecting the end consumers and industries. The need for better power quality has prompted the end users to install power conditioning equipment to mitigate voltage sags. One such series custom power device is dynamic voltage restorer (DVR) [1-6-7]. DVR is a custom power device which can be efficiently used for the improvement of power quality in the distribution system for voltage disturbances such as voltage sags, swells, harmonics, and unbalanced voltage. DVR is a protection device whose main function is to protect the precision manufacturing process and sophisticate sensitive electronic equipment from the voltage fluctuation and power outages. The DVR is able to inject a set of three single-phase voltages of an appropriate magnitude and duration in series with the supply voltage in synchronism through injection transformer to restore the power quality. The DVR is a series conditioner based on a pulse width modulated voltage source inverter, which is generating or absorbing real or reactive power independently. Voltage sags caused by unsymmetrical line-to line, line to ground, double-line-to-ground and symmetrical three phase faults is affected to sensitive loads, the DVR injects the independent voltages to restore and maintained sensitive to its nominal value. The injection power of the DVR with zero or minimum power for compensation purposes can be achieved by choosing an appropriate amplitude and phase angle [4-6-7].

## II. DYNAMIC VOLTAGE RESTORER

The Dynamic Voltage Restorer (DVR) is a series device of the Flexible AC Transmission Systems (FACTS) family used to control voltage profile and improve power quality of power grids. The dynamic voltage restorer (DVR) has become popular as a cost-effective solution for the protection of sensitive loads from voltage sags and swells. The DVR is a series connected power electronic device used to inject voltage of required magnitude and frequency. The compensation capability of DVR depends upon the maximum voltage injection ability and real power supplied by it. The main function of DVR is to inject extra voltage to the Transmission system for regulating the voltage across load. The location of dynamic voltage restorer is generally located in distribution side i.e. between distribution feeder and load. The schematic diagram of the DVR is shown in Figure 1[12].

The general configuration of the DVR consists of the following equipment:

1) Voltage Source Inverter (VSI)
2) Voltage Injection/Booster Transformer
3) Passive Filters
4) Energy Storage Unit
5) Control Unit

### A. *Voltage Source Inverter*

Generally, Pulse-Width Modulated Voltage Source Inverter (PWMVSI) is used. The main purpose of Voltage Source Inverter is to convert the DC voltage supplied by the energy storage device into an AC voltage. A step-up voltage injection transformer is employed in DVR power circuit. Hence, a VSI with a low voltage rating is enough [6-12].

### B. *Voltage Injecting Transformers*

The high voltage side of the injection transformer is connected in series to the distribution line, while the low voltage side is connected to the DVR power circuit. Three single-phase or three-phase voltage injection transformers can be connected to the distribution line for a three-phase DVR and for single phase DVR one single-phase transformer is connected. For the three-phase DVR the three single- phase transformers can be connected either in delta/open or star/open configuration [6-12].

### C. Passive Filters

Low pass passive filters are used to convert the PWM inverted pulse waveform into a sinusoidal waveform. This is achieved by removing the unnecessary higher order harmonic components generated from the DC to AC conversion in the VSI, which will distort the compensated output voltage. However, the leakage reactance of the transformer can be used as a part of the filter, which will be helpful in tuning the filter [6-12].

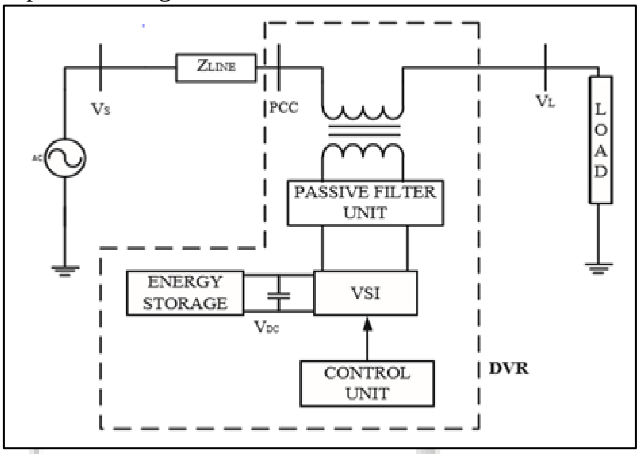



Fig. 1: Dynamic Voltage Restorer (DVR) Schematic Diagram

### D. Energy Storage Unit

Energy storage device is used to supply the real power requirement for the compensation during voltage sag. Energy storage devices generally employed can be a lead acid battery, a superconducting magnetic energy storage (SMES), a flywheel and a super-capacitor. For DC drives such as SMES, batteries and capacitors. For particular voltage sag, the maximum compensation ability of the DVR is dependent on the amount of the active power supplied by the energy storage devices. Lead acid batteries are having high response during charging and discharging hence being popular among the others. But their discharge rate is dependent on the chemical reaction rate of the battery so that the available energy inside the battery is determined by its discharge rate [6-12].

### E. Control Unit

Control circuit steadily observe the system. Its function is to detect any disturbance in the system done by comparing the supply voltage with reference voltage and generate the switching command signals for VSI in order to generate the compensating voltage by DVR [6-12].

## III. Operating Modes of DVR

The basic operation of DVR can be explained in mainly three modes such as: one is protection mode, second one is standby mode, and third one is injection/ boosting mode [4-6-7].

### A. Protection Mode

If the over current on the load side exceeds a permissible limit due to short circuit on the load or large inrush current, the DVR will be isolated from the systems by using the bypass switches (S2 and S3 will open) and supplying another path for current (S1 will be closed) as shown in fig-2[6-7].

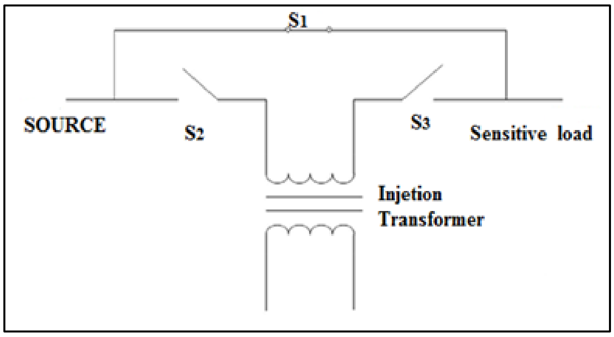



Fig. 2: Protection Mode

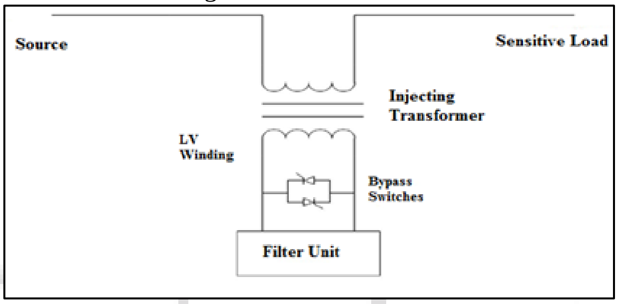



Fig. 3: Standby Mode

### B. Standby Mode($V_{DVR} = 0$ )

In the standby mode, the low voltage winding of the booster transformer is shorted through the converter. There is no switching of semiconductors occurs in this mode of operation and the full load current will pass through the primary as shown in fig-3[6-7].

### C. Injection Mode ($V_{DVR} > 0$)

In this case of injection mode, the Transformer is called injection Transformer and the DVR has the capability of injecting voltage for compensating the power quality problems [6-7].

## IV. Different Compensation Techniques

Voltage injection or compensation methods by means of a DVR depend upon the limiting factors such as; DVR power ratings, various conditions of load, and different types of voltage sags. Some loads are sensitive towards phase angle jump and some are sensitive towards change in magnitude and others are tolerant to these [6-7].

### A. Pre-Sag Compensation Technique

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, so that the load voltage can be restored back to the pre-fault condition. Voltage sag compensation in sensitive loads for both phase angle and amplitude would be achieved by pre-sag compensation method as shown in fig.4. In this compensation technique, the injected active power cannot be controlled and it is determined by external conditions such as the type of faults and load conditions [6-7].

$$\boldsymbol{V}\text{DVR} = \text{Vprefault} - \text{Vsag}$$

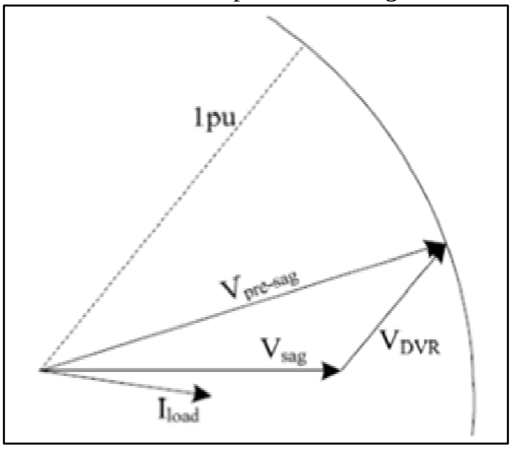



Fig. 4: Pre-Sag Compensation Technique

### B. *In-Phase Compensation Technique*

This is the most straight forward method. In this method, the injected voltage is in phase with the supply side voltage irrespective of the load current and pre-fault voltage as shown in fig.5. The phase angles of the pre-sag and load voltage are different but the most important criteria for power quality that is the constant magnitude of load voltage are satisfied. The load voltage is given below**:** One of the advantages of this method is that the amplitude of DVR injection voltage is minimum for certain voltage sag in comparison with other strategies. Practical application of this method is in non-sensitive loads to phase angle jump [6-7]

$$|VL|=|Vprefault|$$

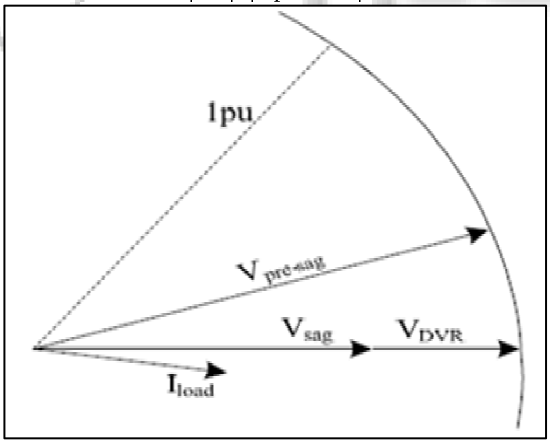



Fig. 5: In-Phase Compensation Technique

### C. *In-Phase Advanced Compensation Technique*

In this technique, by the minimization of power angle between sag voltage and load current, the real power spent by the DVR is decreased. In case of pre-sag and in phase compensation method the active power is injected into the system during disturbances. And the source of active power is limited stored energy in the DC links and this part is being one of the most expensive parts of DVR. The minimization of injected energy is achieved by making the active power component zero by having the injection voltage phasor perpendicular to the load current phasor. In this technique, the values of load current and voltage are fixed in the system so that we can change only the phase of the sag voltage. IPAC method uses only reactive power and unfortunately, not al1 the sags can be mitigated without real power, as a consequence, this method is only suitable for a limited range of sags [6-7].

## V. METHODOLOGY

The main operation of the DVR is to inject voltage of required magnitude and frequency when desired by the power system network [9].

$$\text{Vinj} = \text{VLoad} + \text{Vs}$$

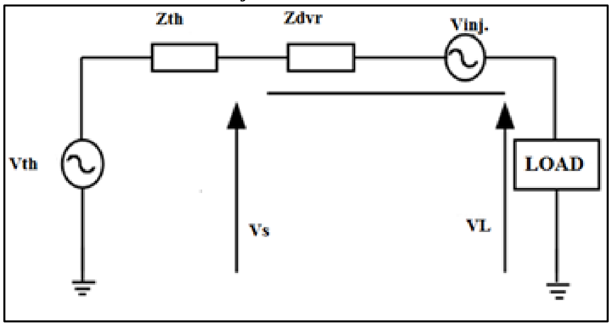



Fig. 6: Equivalent Circuit Diagram of DVR

As per the diagram shown in fig.6

Applying KVL,

$$V_{th} - Z_{th}I_L + V_{DVR} = V_L \quad (1)$$

$$V_{DVR} + V_{th} = V_L + Z_{th}I_L \quad (2)$$

The series voltage injected by DVR can be given as

$$V_{DVR} = V_L + Z_{th}I_L - V_{th} \quad (3)$$

Where,

Vth = equivalent Thevenin voltage of the system

VL= load voltage

Zth = equivalent Thevenin impedance of the system

IL= Load current and

$$\mathbf{I_L} = \left[\frac{P_L + jQ_L}{V_L}\right]^* \quad (4)$$

Taking VL as reference, equation (3) can be rephrase as

$$V_{DVR}\angle\alpha = V_L\angle 0^\circ + Z_{th}I_L\angle(\beta - \theta) - V_t\angle\delta \quad (5)$$

Where, α = angle of VDVR

β = angle of system impedance Zth

δ = angle of system impedance Vth

Φ = Load pf angle and

$$\theta = \tan^{-1}\left(\frac{Q_L}{P_L}\right) \quad (6)$$

The complex power injected by DVR is

$$S_{DVR} = V_{DVR}I_L \quad (7)$$

## VI. FUZZY LOGIC CONTROLLER

Fuzzy logic is developed by Dr. Lotfi Zadeh in 1964.The control strategy based on PI controller it has high settling time and has large steady state error. In order to rectify this problem, the application of a Fuzzy Logic Controller (FLC) shown in Figure 7. Generally, the FLC is one of the most important software based technique in adaptive methods. Fuzzy Logic is based on rules of the form IF-THEN that converts an input fuzzy sets into output fuzzy set. A fuzzy logic system is unique in that it is able to simultaneously handle numerical data and linguistic knowledge. In the proposed method, Mamdani type fuzzy logic controller is selected for the computation purpose [11].

As compared with previous controllers, the FLC has low settling time, low steady state errors. In this is the process which maps the given input into the output using fuzzy logic. The operation of fuzzy controller can be explained in four steps [11].

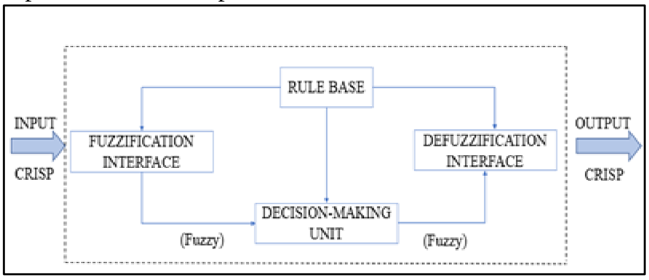



Fig. 7: Block Diagram of Fuzzy

- A fuzzification interface which convert input data into suitable linguistic values.
- The rule base is formed by the set of linguistic rules related to the particular controller.
- The decision-making logic is used to collect all the linguistic rules and to convert the input conditions to fuzzified output.
- The defuzzification unit is used to convert the fuzzy values into crisp values by Centroid based defuzzification method.
- The FLC is designed to control the inverter action based on the designed rule base.
- The crisp output generated by the FLC is used to control the PWM generator circuit.

## VII. Simulation Results and Discussions

The three phase systems with a critical load is considered. The simple sag generation MATLAB modelled done with different types of Fault analysis. The system is modelled using MATLAB/Simulink environment along with Simpowersystem tools. The load considered here is 10KVA, 0.8pf lag linear load. And also modelled in MATLAB for IGBTs of the VSC of DVR.

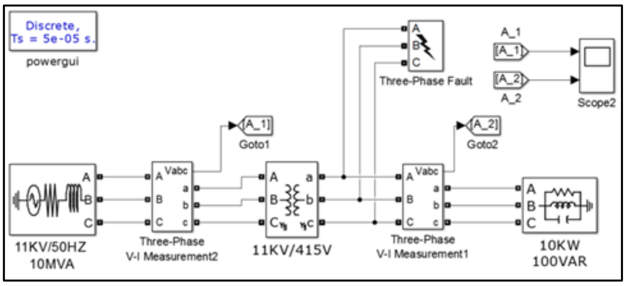



Fig. 8: Simulink model of Voltage Sag Analysis

### A. Fault Analysis

Simulation of voltage sag disturbance on the industrial electricity system is done by generating fault using 3-phase fault generator at load is affected too by sag phenomenon. Two types of faults generated at load to produce sag phenomenon which is Double-line-to-ground fault and three phase balance fault. Every fault created in duration of 0.02 to 0.07 seconds duration.

*1) Double-Line-to-Ground Fault with 50% Sagging:*

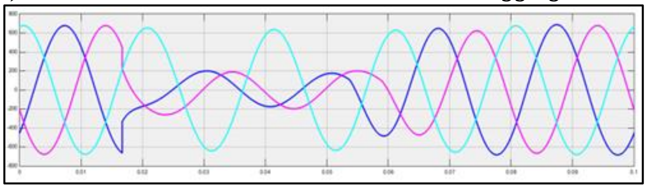


Fig. 9: Double-Line-To-Ground Fault with 50% Sagging

*2) Balanced Three Phase Fault with 50% Sagging:*

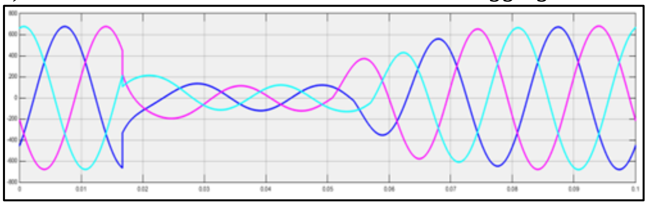


Fig. 10: Balanced Three Phase Fault with 50% Sagging

Fig. 9 shows that, the moment where fault occurred at load, resultant in sag happened at load as dip as 50% voltage drop. Fig.10 shown that, Even for worst case, balanced three phase fault with 0.1 p.u voltage sag.

### B. Three-Phase Two-Level Single Bridge VSC

The DVR is connected in series between PCC and the nonlinear load with the help of an injection transformer. The primary side of injecting transformer is connected in order to see the voltage sag. The DVR uses self-commutating IGBT solid-state power electronic switches to mitigate voltage sags in the system. The voltage controlled three-phase single bridges PWM inverters are used to produce compensating voltage. These inverters are connected to the common DC voltage source. The DC voltage source is an external source of supplying DC voltage to the inverter for AC voltage generation.

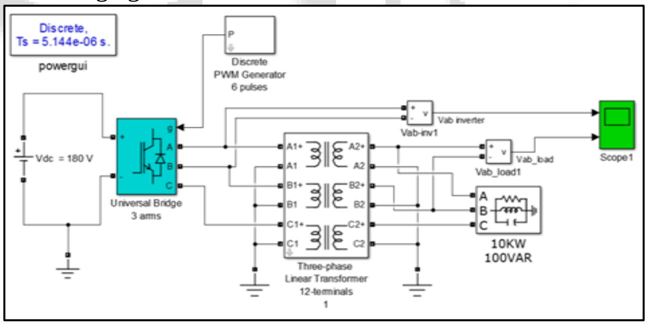



Fig. 11: MATLAB model of Three-Phase Two-Level Single Bridge VSC

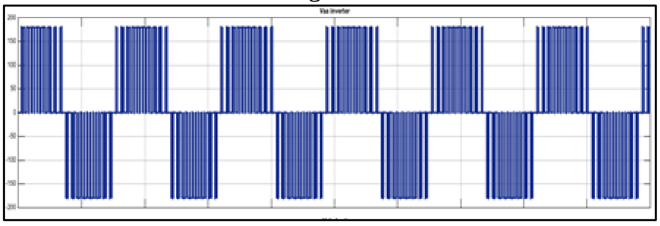
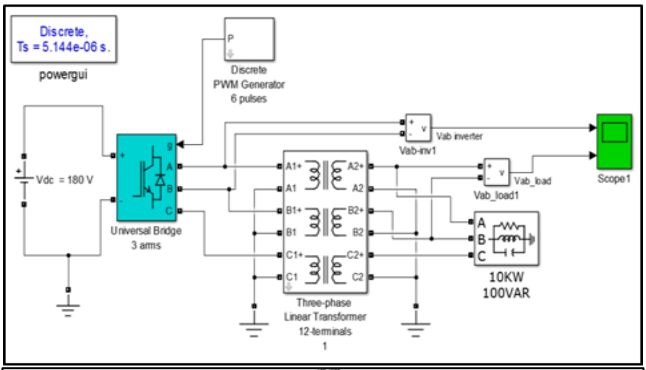


Fig. 12: Output of Inverter Side



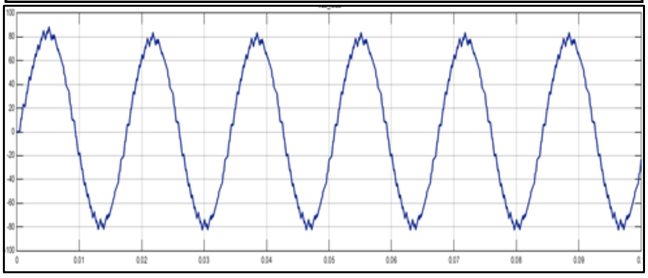



Fig. 13: Output at Load Side

### C. Appendix

| Description | Rating |
|---|---|
| Supply Voltage | 11 KV,50 HZ |
| Load transformer rating | 11 KV/ 415 V |
| Series transformation turns ratio | 1:1 |
| DC Bus battery voltage | 180 V |
| Load resistance | 40Ω |
| Load inductance | 100mH |
| PWM generator, switching frequency | 6 pulses, 1080 HZ |

## VIII. CONCLUSION

This paper has proposed the modelling and simulation of DVR using Simulink MATLAB to mitigate power quality problems such as voltage sag and swell. The major operation principles of DVR include, the compensation techniques, the transformer voltage injection methods, operating modes, PWM inverter, are also discussed. Finally, a Fuzzy system is developed to increase the reliability of the compensation system. Simulation results show the DVR at different fault analysis and three phase two-level bridge inverter. This study also gives useful knowledge for the researchers to develop a design of DVR for voltage disturbances in electrical system.

## REFERENCES

[1] Sankaran “Power Quality”, CRC Press 2002.
[2] N.G. Hingorani, Flexible AC Transmission", IEEE Spectrum, vol. 30, pp. 40-44, 1993.
[3] N.G. Hingorani and L. Gyugyi, Understanding FACTS – Concepts and Technology of Flexible AC Transmission Systems, IEEE Press, New York, 2000.
[4] Moreno-Munoz, Power Quality: Mitigation Technologies in a Distributed Environment. London, U.K.: Springer-Verlag, 2007.
[5] N. G. Hingorani, "FACTS-flexible AC transmission system," in AC and DC Power Transmission, 1991., International Conference on, 1991, pp. 1-7.
[6] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, Electric Power Systems Quality, 2nd ed. New York, NY, USA: McGraw-Hill, 2006.
[7] M. H. J. Bollen, Understanding Power Quality Problems—Voltage Sags and Interruptions. New York, NY, USA: IEEE Press, 2000.
[8] Archana T.C.Dr. Reji P “Power Quality Improvement Using Self-supported DYNAMIC VOLTAGE RESTORER (DVR) In Distribution System" International Conference on Power, Instrumentation, Control and Computing (PICC) IEEE 2015.
[9] R.H. Salim, M.S.A Rahim “Simulation Analysis of DYNAMIC VOLTAGE RESTORER (DVR) Performance for Voltage Sag Mitigation” The $5^{th}$ International Power Engineering and Optimization Conference PEOCO 2011.
[10] Khirod Kumar Senapati, Mousumi Bala Panda, Rafiya Sultana Syed “A Novel Algorithm for Power Quality Improvement Using Dynamic Voltage Restorer with Fuzzy Logic” International conference on Signal Processing, Communication, Power and Embedded System (SCOPES)-2016.
[11] Abhijith Augustine, Ruban Deva Prakash, Rajy Xavier “Investigation of Voltage Sag and Swell Problems using DVR and Fuzzy Logic” International Journal of Computer Applications Volume 117 No. 3, May 2015
[12] Shakti Prasad Mishra, BishnuPriya Biswal, J. Preetha Roselyn, D. Devaraj, “Simulation and Analysis of DYNAMIC VOLTAGE RESTORER(DVR) For Mitigation Voltage Sags and Swells” International Conference on Design and Mitigating, IConDM 2013.