Power Quality Improvement using FUZZY Logic Based Dynamic Voltage Restorer (DVR)

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Abstract— Power quality is one of the most important issues to utilities and customers. Power quality problem is abnormal voltage, current or frequency. Distribution networks experience from various types of disturbances like, voltage sag, voltage sewll transients etc., Now the fast developments in power electronics technology have made it possible to mitigate power quality problems. Such as, dynamic voltage restorer can provide the most popular solution to compensate voltage sag/swell by injecting voltage in to the sensitive system. Dynamic voltage restorer is a series connected power electronics based device that can mitigate the power quality problem in the system, by automatically detecting and calculating of injecting power then the inject through an injecting transformer. The proposed system has less number of switching devices and has good compensating capability in comparison with commonly used compensators. 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: DVR, FACTS, VSI, PWM

I. Introduction

Electrical energy is the well-regulated form of energy, can be easily converted to other forms. Electrical power quality and continuity has to maintain for good economy. The electrical power is major concern for today's power industries and consumers. Power quality problems caused by increasingly demand of electronic equipment like ASD etc., and using non-linear loads. Some disturbances associated with electrical power are voltage dip(Sag), voltage swell, voltage flicker and harmonic. This overcome the efficiency and reduces the life time of end-user equipment. It also affected the data and memory loss of electronic equipment like computer and other electronics devices.

Power system network voltage sag/swell became the major power quality problem affecting the end user consumers and industries. The voltage sag and swell occurs frequently and result is high electrical power losses. Voltage sag is due to sudden disconnection of load, fault in the system and voltage swell is due to single line to ground fault results in voltage rise of un-faulted phases. The power supply can be maintained by clearing the faults at faster rate of time. Other power quality issues i.e. voltage sag, voltage swell, voltage flickering, harmonics, transients etc. are to compensated to enhance the power quality.

Now the recent advancements in power electronic devices, there are many possibilities to reduce these problems in the power system. The power electronic devices use for reduces power quality. The Flexible AC Transmission System (FACTS) devices are one of the power electronics devices. This devices use for the electrical power improving the quality and reliability. In this project the mitigation of voltage sag problems using Dynamic voltage restorer (DVR) And Artificial intelligence of studied and analysed. The DVR was installed first in North America in 1996, In Anderson place at 12.47 KV substations. Then, it is being used to protect the sensitive loads and enhance the power quality.

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 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 Modulalation (PWM) Voltage Source Inverter (VSI) 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].

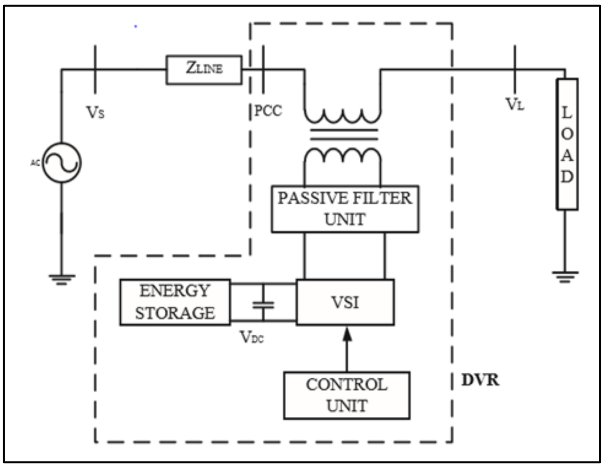

Fig. 1: Dynamic Voltage Restorer (DVR) schematic diagram

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, 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].

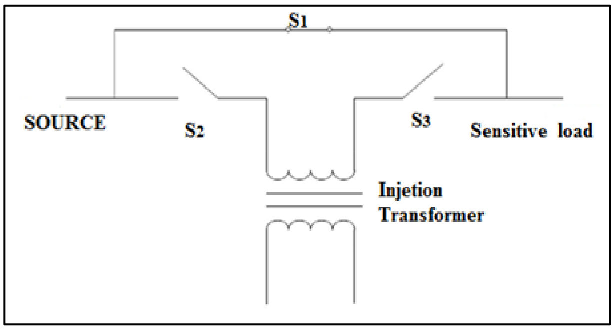

Fig. 2: Protection mode

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].

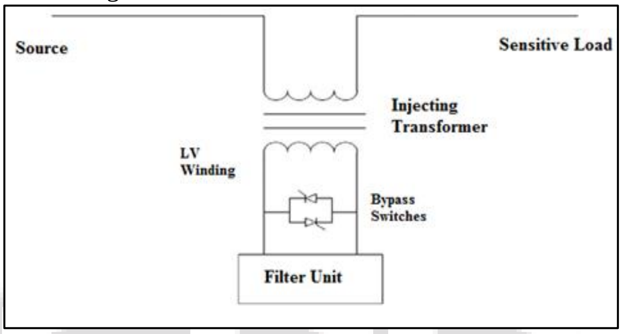

Fig. 3: Standby mode

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. METHODOLOGY

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

Vinj = VLoad + Vs

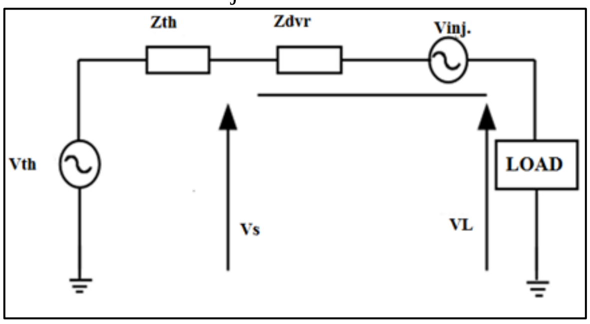

Fig. 4: Equivalent Circuit Diagram of DVR

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

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

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

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

DVR control algorithm

The principle contemplations for the control of a DVR are- identification of the begin and completion of the hang, voltage reference era, transient and unfaltering state control of the infused voltage and security of the system. Any control technique implemented to control the DVR should fulfil all the above aspects.

The basic idea behind the control strategy is to find the amount by which the supply voltage is dropped. For this the three-phase supply voltage is compared with the reference voltage V_{ref}. If there is voltage sag (or any other voltage imbalance) then an error occurs. This error voltage is then sent to the PWM generator, which generates the firing, pulses to the switches of the VSI such that required voltage is generated. The whole control strategy can be implemented in 2-ϕ rotating (d-q) coordinate system. The flow chart of the control technique based on dq0 transformation is shown in Fig.5

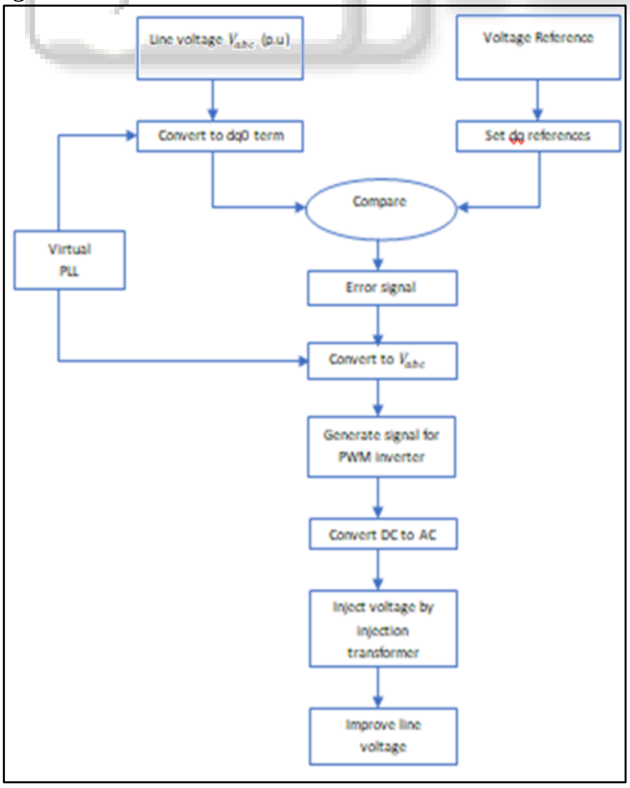

Fig. 5: Control Algorithm

V. 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 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].

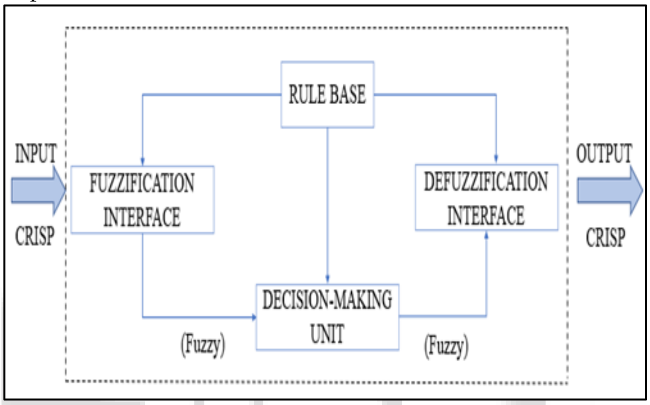

Fig. 6: Block diagram of Fuzzy

- 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 logicis 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.

VI. SIMULATION RESULTS AND DISCUSSIONS

The three phase system 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 Simpower system tools. The load considered here is 10KVA, 0.8pf lag linear load then modelled in MATLAB for IGBTs of the VSC of DVR.

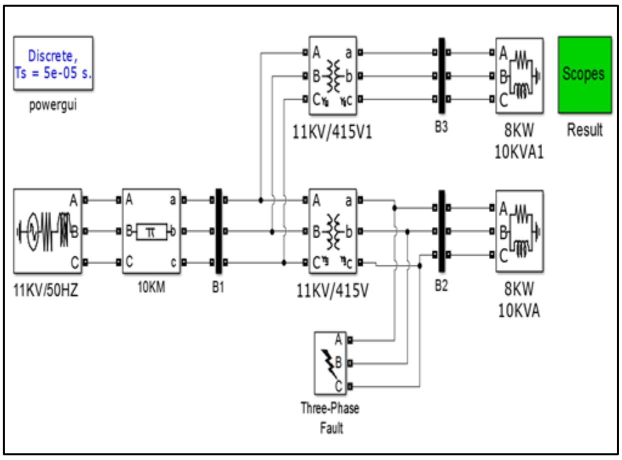

Fig. 7: Simulink model of voltage sag analysis

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. Four types of faults generated at load to produce sag phenomenon which are L-G, L-L-G, L-L and (L-L-L-G) three phase balance fault. Every fault created in duration of 0.02 to 0.05 seconds duration.

1) line-to-ground fault with 50% sagging

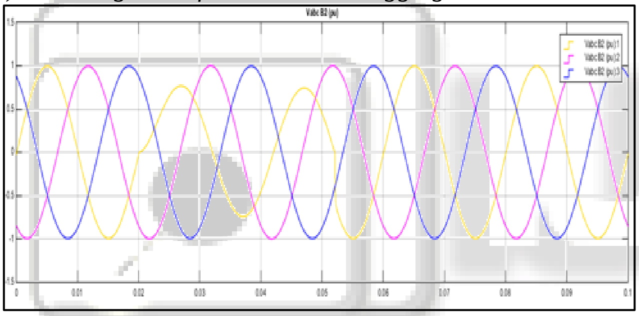

Fig. 8: line-to-ground fault with 50% sagging

2) Double line-to-ground fault with 50% sagging

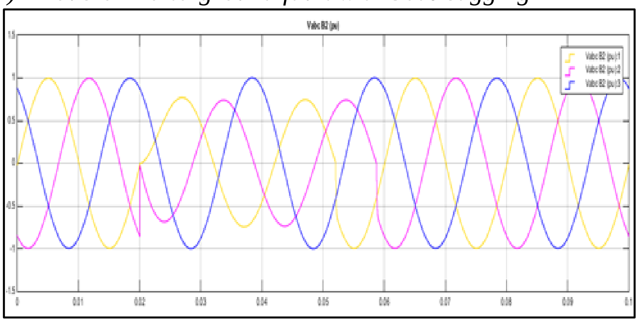

Fig. 9: Double line-to-ground fault with 50% sagging

3) Line-to-line fault with 50% sagging

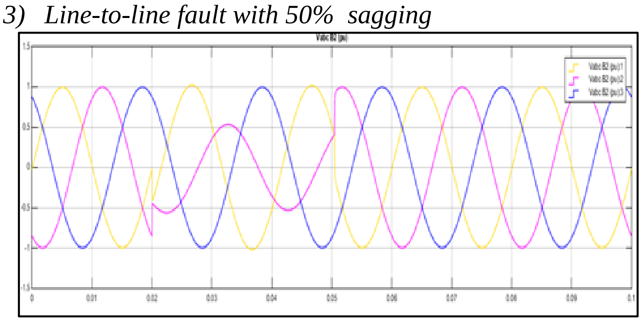

Fig. 10: line-to-line fault with 50% sagging

4) Three phase balance Fault with 50% sagging

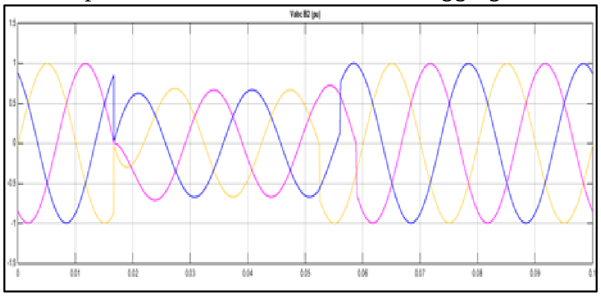

Fig. 11: three phase balance fault with 50% sagging

Fig. 10 shows that, the moment where fault occurred at load, resultant in sag happened at load as dip as 50% voltage drop. Fig.12 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.

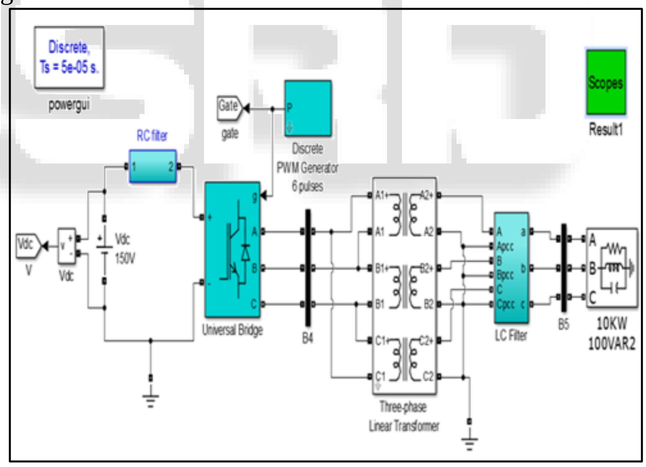

Fig. 12: MATLAB model of Three-Phase Two-Level Single Bridge VSC

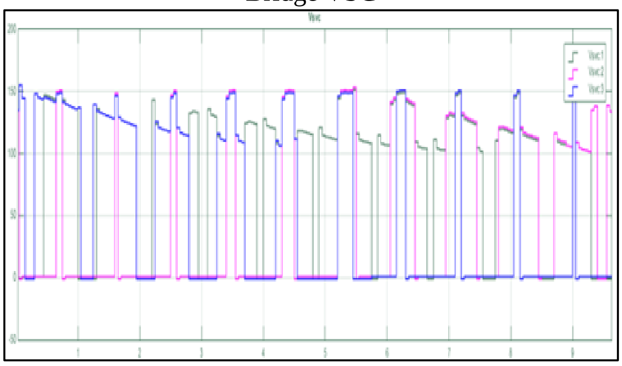

Fig. 13: Output of VSC side without filter

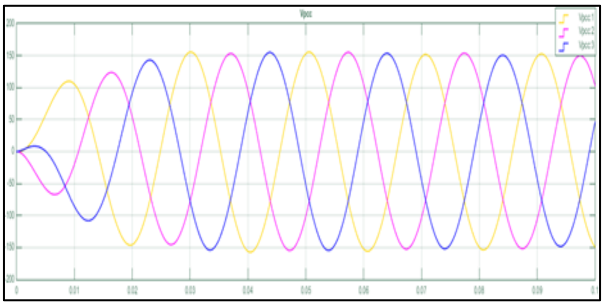

Fig. 14: Output at load side with filter

C. DVR Control Model

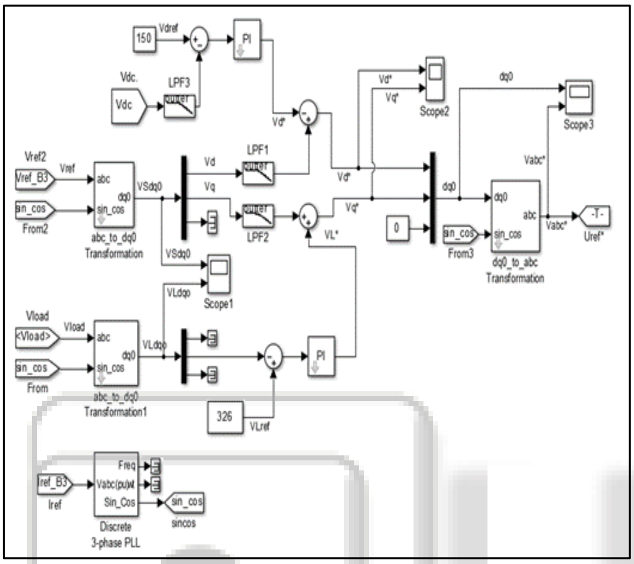

Fig. 15: DVR control model

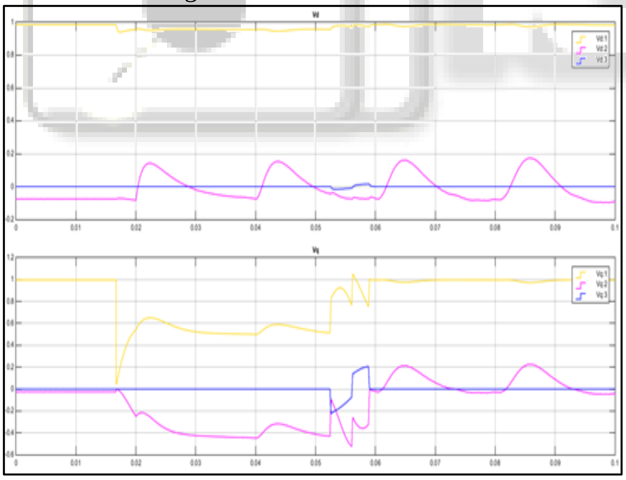

Fig. 16: Input abc-dqo at given to control model

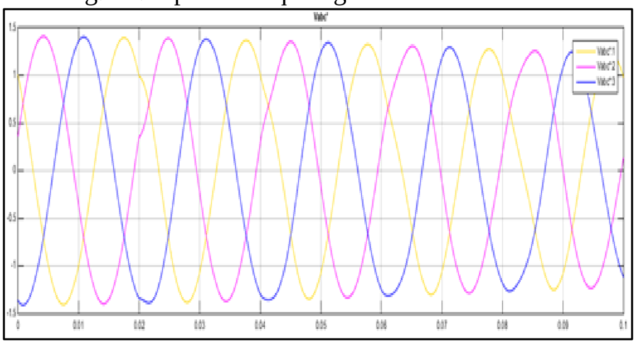

Fig. 17: Final output of control model

VII. 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

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] C. 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] A.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.

