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Control of Dvr with Battery Energy Storage System Using Srf Theory

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Abstract
One of the best solutions to improve power quality is the dynamic voltage restorer (DVR). DVR is a kind of custom power devices that can inject active/reactive power to the power grids. This can protect loads from disturbances such as sag and swell. Usually DVR installed between sensitive loads feeder and source in distribution system. Its features include lower cost, smaller size, and its fast dynamic response to the disturbance. In this project SRF technique is used for conversion of voltage from rotating vectors to the stationary frame. SRF technique is also referred as park's transformation. In this the reference load voltage is estimated using the unit vectors. The real power exchanged at the DVR output ac terminal is provided by the DVR input dc terminal by an external energy source or energy storage system. In this project three phase parallel or series load may be used along with SRF technique to compensate voltage sag and voltage swell. And also wind generator is also used as a load. This project presents the simulation of DVR system using MATLAB/SIMULINK.
Keywords: DVR (Dynamic voltage restorer), VSC (Voltage source converter), PCC (Point of common coupling), SRF (synchronous reference frame).

I. INTRODUCTION

Power Quality in electric networks is one of today's most concerned area of electric power system. The power quality has serious economic implication for consumer, utilities and electrical equipment manufacturers. The impact of power quality problem is increasingly felt by customers-industrial, commercial even residential. Some of the main power quality problems are sag, swell, transient, harmonic and flickers. Storage technologies have developed significantly in order to meet the challenges of practical power systems applications. Energy storage devices provide valuable benefits to improve stability, power quality and reliability of supply. Energy storage appears to be beneficial to utilities since it can decouple the instantaneous balancing between the demand and the supply. Therefore it allows the increased asset utilization, facilitates the penetration of renewable sources and improves the flexibility, reliability and efficiency of the grid. Also there are several high performance storage technologies available today. Energy storage devices are like Flywheel, Pumped hydro, compressed air, Batteries etc. At present, both hydro pump and compressed air are commercial technologies; several test sites incorporating batteries have been demonstrated.

SOURCES AND EFFECTS OF POWER QUALITY PROBLEMS

In general, the single line diagram of power distribution system is shown below:

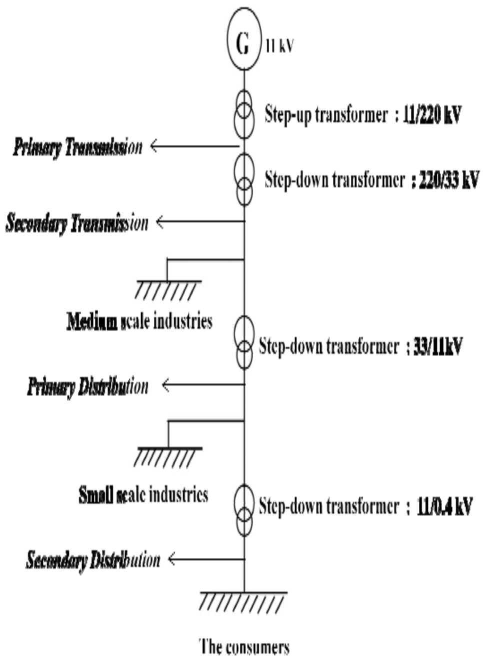


Figure.1 Single line diagram of power supply system

Figure.1 shows the single line diagram of 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 However, in practice, power systems, especially the distribution system 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.

Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions.

- Voltage dip: A voltage dip is used to refer to short-term reduction in voltage of less than half a second.
- Voltage sag: Voltage sags can occur at any instant of time, with amplitudes ranging from 10 – 90% and a duration lasting for half a cycle to one minute.
- Voltage swell: Voltage swell is defined as an increase in rms voltage or current at power frequency for durations from 0.5 cycles to 1 min.
- Voltage 'spikes', 'impulses' or 'surges': These are terms used to describe abrupt, very brief increases in voltage value.
- Voltage transients: They are temporary, undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time.
- Harmonics: The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency.
- Flickers: Visual irritation and introduction of many harmonic components in the supply power and their associated ill effects.

1.1 CAUSES OF DIPS, SAGS AND SURGES

1. Rural location remote from power source
2. Unbalanced load on a three phase system
3. Switching of heavy loads
4. Long distance from a distribution transformer with interposed loads
5. Unreliable grid systems
6. Equipments not suitable for local supply

1.2 CAUSES OF TRANSIENTS AND SPIKES

1. Lightening
2. Arc welding
3. Switching on heavy or reactive equipments such as motors,
4. Transformers, motor, drives, etc.,
5. Electric grade switching

1.3 VOLTAGE FLUCTUATIONS

Voltage fluctuations can be described as repetitive or random variations of the voltage envelope due to sudden changes in the real and reactive power drawn by a load. The characteristics of voltage fluctuations depend on the load type and size and the power system capacity. Figure.3.2 illustrates an example of a fluctuating voltage waveform. The voltage waveform exhibits variations in magnitude due to the fluctuating nature or intermittent operation of connected loads. The frequency of the voltage envelope is often referred to as the flicker frequency. Thus there are two important parameters to voltage fluctuations, namely the frequency of fluctuation and the magnitude of fluctuation. Both of these components are significant in the adverse effects of voltage fluctuations.

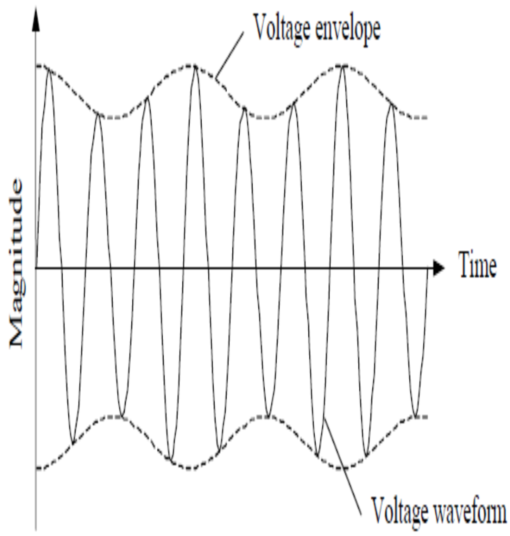


Figure 2: Terminal voltage waveform of fluctuating load

In Figure.2 the voltage changes are illustrated as being modulated in a sinusoidal manner. However, the changes in voltage may also be rectangular or irregular in shape. The profile of the voltage changes will depend on the current drawn by the offending fluctuating load. Typically, voltage changes caused by an offending load will not be isolated to a single customer and will propagate an attenuation form of both upstream and downstream from the offending load throughout the distribution system, possibly affecting many customers.

II. EFFECTS OF VOLTAGE FLUCTUATIONS

The foremost effect of voltage fluctuations is lamp flicker. Lamp flicker occurs when the intensity of the light from a lamp varies due to changes in the magnitude of the supply voltage. This changing intensity can create annoyance to the human eye.

Susceptibility to irritation from lamp flicker will be different for each individual. However, tests have shown that generally the human eye is most sensitive to voltage waveform modulation around a frequency of 6-8Hz. The perceptibility of flicker is quantified using a measure called the short-term flicker index, P_{st}, which is normalized to 1.0 to represent the conventional threshold of irritability. The perceptibility of flicker, a measure of the potential for annoyance, can be plotted on a curve of the change in relative voltage magnitude versus the frequency of the voltage changes. Figure.3.3 illustrates the approximate human eye perceptibility with regard to rectangular modulated flicker noting that around the 6-8Hz region. Fluctuations as small as 0.3% are regarded as perceptible as changes of larger magnitudes at much lower frequencies [1]. Figure.3.3 is often referred to as the flicker curve and represents a P_{st} value of 1.0 for various frequencies of rectangular voltage fluctuations. Although regular rectangular voltage variations are uncommon in practice they provide the basis for the flicker curve, defining the threshold of irritability for the average observer. It is worth noting that the flicker curve is based on measurements completed using a 60W incandescent light bulb. This is used as a benchmark measurement; however the perceptibility of lamp flicker will vary depending on the size and type of lamp used.

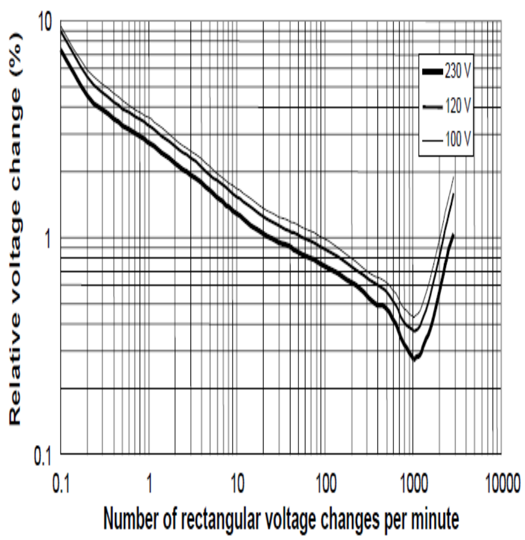


Figure3: Flicker curve for rectangular modulation frequencies

Voltage fluctuations on the public low voltage power system are required to be within accepted tolerances specified in the standards. In general the acceptable region of voltage fluctuations falls below the flicker curve illustrated in Fig.3. Voltage fluctuations may also cause spurious tripping of relays; interfere with communication equipment; and trip out electronic equipment. Severe fluctuations in some cases may not allow other loads to be started due to the reduction in the supply voltage. Additionally, induction motors that operate at maximum torque may stall if voltage fluctuations are of significant magnitude.

III. Improvement Of Voltage Profile Using DVR

One of the major problems dealt here is the power sag. To improve the power quality, custom power devices are used. The device considered in this work is DVR. In this project, different voltage injection schemes for Dynamic Voltage Restorers (DVRs) are analysed with particular focus on a new method used to minimize the rating of the voltage source converter (VSC) used in DVR. This project presents simulation of DVR system using MATLAB/SIMILINK.

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the DVR, which is the most efficient and effective modern custom power device used in power distribution networks. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also add other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations and the location of DVR.

Note that the DVR is capable of generating or absorbing reactive power but the active power injection of the device must be provided by an external energy source or energy storage system. The response time of DVR is very short and is limited by the power electronic devices and the voltage sag detection time. The prediction response time is about 25millisecond, and which is much less than some of the traditional methods of voltage correction such as tap-changing transformer.

3.2 BASIC CONFIGURE RATION OF DVR

The schematic diagram of DVR is shown in Figure.4.1 and the general configure ration of the DVR consists of

1. An Injection/ Booster transformer
2. A Harmonic filter
3. Storage Devices
4. A Voltage Source Converter (VSC)
5. DC charging circuit
6. A Control and Protection system

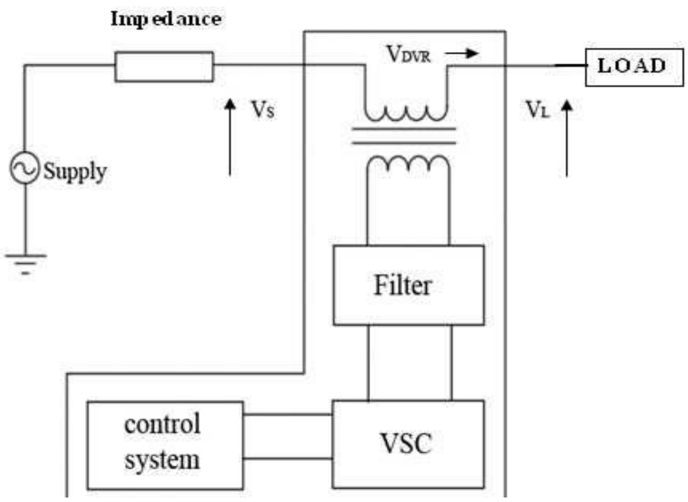


Figure.4: Schematic diagram of DVR

3.2.1 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).

3.2.2 Harmonic Filter

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

3.2.3 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.

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.

3.2.4 DC Charging Circuit

The dc charging circuit has two main tasks

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

3.2.5 Control and protection

The control mechanism of the general configure ration 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.

IV. EQUATIONS RELATED TO DVR

Equivalent circuit diagram of DVR is shown in Figure.5. The system impedance Z_{th} depends on the fault level of the load bus.

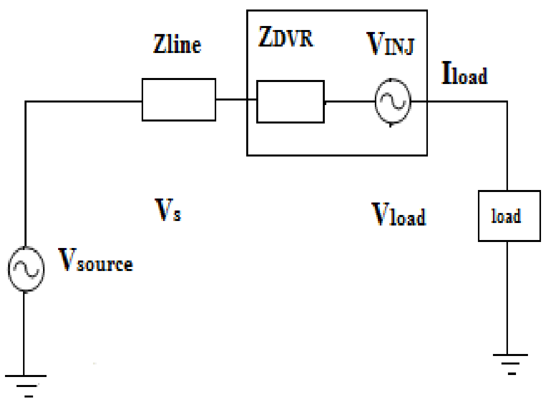


Figure.5: Equivalent circuit diagram of DVR

When the system voltage (V_{th}) drops, the DVR injects a series voltage V_{DVR} through the injection transformer so that the desired load voltage magnitude

V_L can be maintained. The series injected voltage of the DVR can be written as

$$\mathbf{V_{DVR}=V_L+Z_{TH}I_L-V_{TH}} \quad (3.1)$$

Where
V_L: The desired load voltage magnitude
Z_{TH}: The load impedance
I_L: The load current
V_{TH}: The system voltage during fault condition

The load current I_L is given by,

$$\mathbf{I_{L}} = \frac{P_L + jQ_L}{V} \quad (3.2)$$

When V_L is considered as a reference equation can be rewritten as,

$$V_{DVR}<0=V_L<0+Z_{TH} \quad (3.3)$$

α, β, δ are angles of V_{DVR} Z_{TH} V_{TH} respectively and θ is Load power angle

$$\tan^{-1}\frac{\theta_L}{P_L} \quad (3.4)$$

The complex power injection of the DVR can be written as,

$$S_{DVR}=V_{DVR}I_L^* \quad (3.5)$$

It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power.

V. DVR WITH PI CONTROLLER

A DVR is a custom power device used to correct the voltage sag by injecting voltage as well power into the system. The mitigation capacity of DVR is generally influenced by the maximum load; power factor and maximum voltage dip to be compensated. The DVR is to transfer the voltage which is required for the compensation capacity of a particular DVR depends on the maximum voltage injection capability and the active power that can be supplied by the DVR. When DVR'S voltage distribution system occurs, active power or energy should be injected from DVR to the distribution system.

Figure.6 shows a Controller is required to control or to operate DVR during the fault conditions only. Load voltage is sensed and passed through a sequence analysers. The magnitude of the actual voltage is computed with reference voltage (V_{ref}). Pulse Width Modulated (PWM) control system is applied for inverter switching so as to generate a three phase 50 HZ sinusoidal voltages at the load terminals. Chopping frequency is in the range of a few KHz.

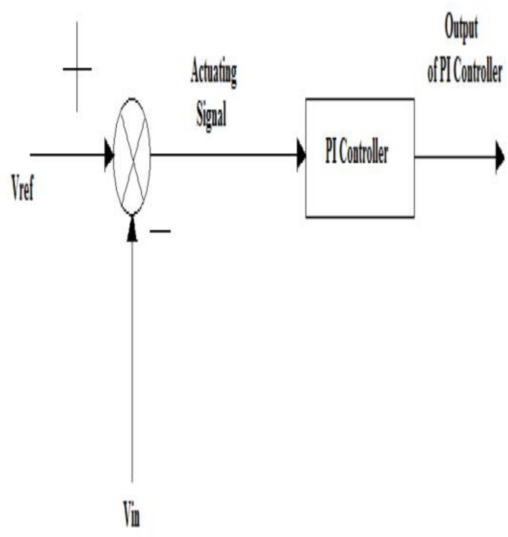


Figure.6: Schematic of a typical PI controller.

VI. SYNCHRONOUS REFERENCE FRAME THEORY

The synchronous reference frame strategy uses co-ordinate transformations to generate the current reference [11]. The abc quantities can be converted into d-q quantities using the Equations (1) to (4).

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_o \end{bmatrix} = Q \begin{bmatrix} V_{La} \\ V_{Lb} \\ V_{Lc} \end{bmatrix} \quad (1)$$

Where,

$$\mathbf{Q = 2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = 2/3 \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = 2/3 \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -1/2 & \sqrt{3}/2 & 1 \\ -1/2 & \sqrt{3}/2 & 1 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} \quad (4)$$

A study on the issues in power grid and its compensation system has been discussed. DVR is a suitable compensation device for the system.

VII. CONTROL ALGORITHM

The flow chart of the control algorithm for inverter is shown in Fig. 4.1. If a three phase voltage of the grid is balanced, a transformation into d-q frame will result in dc quantities. The dq0 transformation technique is used to give the information of the depth (d) and phase shift (q) of voltage sag with start and end time. The V0, Vd and Vq are obtained as V0 =1/a (Va+ Vb+ Vc) = 0, Vd =2/3 [Va sin ωt + Vb sin (ωt - 2π/3) + Vc sin (ωt +2π/3)], Vq =2/3 [Va cos ωt + Vb cos (ωt -2π/3) + Vc cos (ωt +2π/3)].

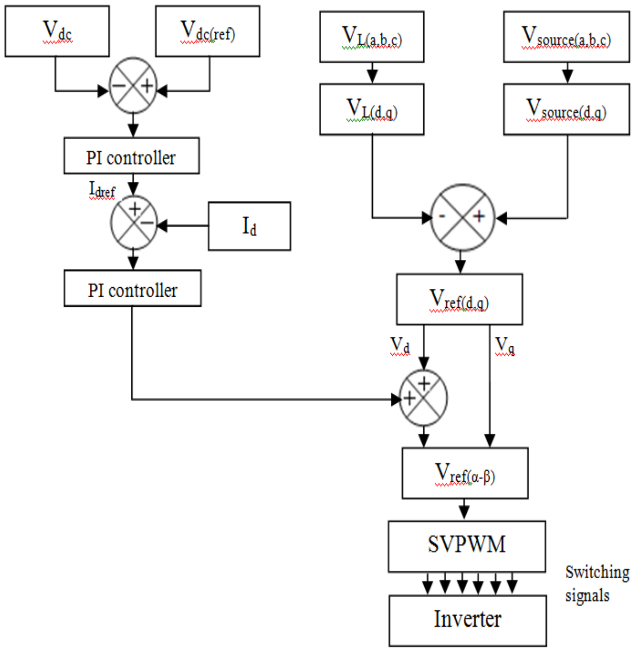


Figure 7: Flowchart of control algorithm for inverter

After conversion of the three phase voltage Va, Vb and Vc into two constant voltages Vd and Vq the three phase system is simplified for voltage calculations and the system can be easily controlled. Actual values of wind generator voltage (VLa, VLb, VLc) in d–q coordinates are calculated (VLd and VLq) using the above equations. θ is calculated using three phase Phase Locked Loop. The synchronous reference frame variables, Vd and Vq are compared with the d and q components of the reference voltage which is the nominal grid voltage and the error voltages in Vd and Vq are obtained. The supercapacitor dc voltage is compared with the reference dc voltage and the error voltage is given to a PI controller. The output of the PI controller is compared with the reference current and again given to another PI controller. The output of this PI controller is then added with the error Vd component. These d-q quantities are then converted to α-β quantities. These signals are used as reference voltage for the SVPWM generator, which provides firing signals for the inverter switches.

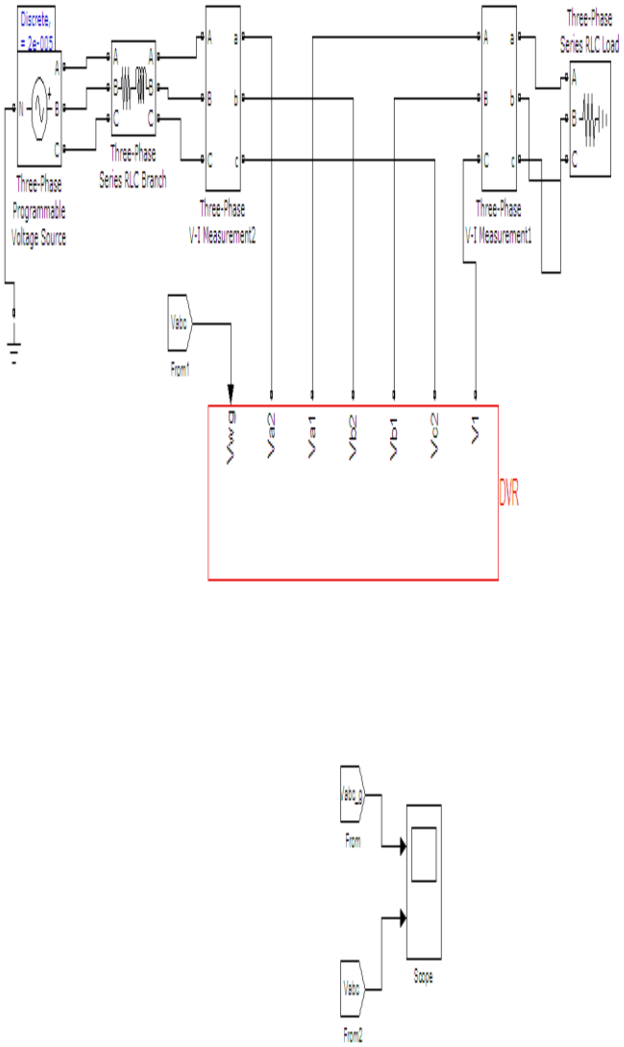
Thus the injection voltage is generated according to the difference between the wind generator voltage and the reference supply voltage and is applied to the VSI. The output of the inverter is filtered using an LC filter and is then given to the grid through a series transformer. A super capacitor is used as energy storage device for the inverter. This gives a faster response than a battery and also has a longer life. The proposed system compensates the voltage sag in the grid system during the fault.

VIII. SIMULATIONS AND RESULTS

The simulation has been done using MATLAB/ SIMULINK and the results obtained have been discussed in this chapter. The control algorithm has been tested for voltage sag and swell condition. Figure no:8 which represents the simulink model with three phase RLC series load.

Figure :9 represents the subsystem for DVR which is used to inject voltage.

Figure: 10 represents the subsystem for Synchronous reference frame theory used for the control process.



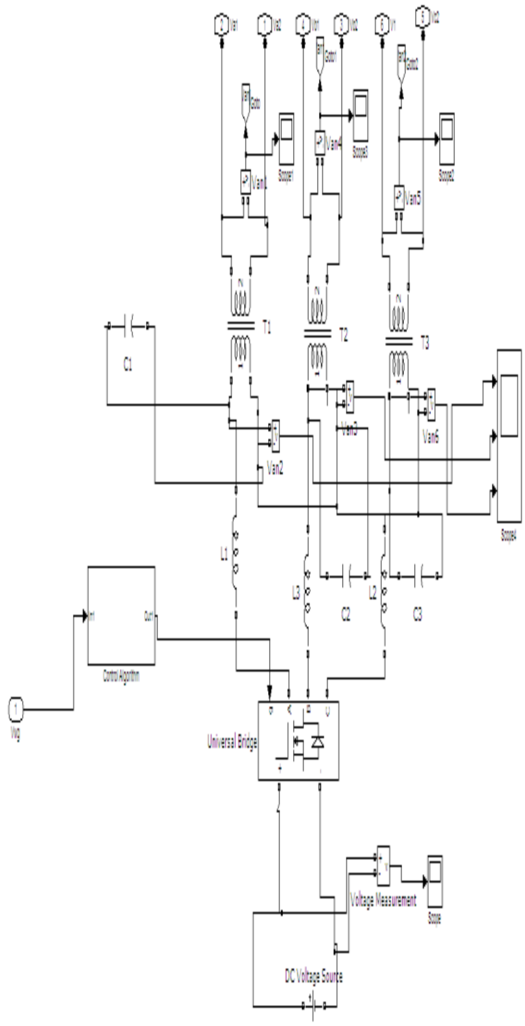


Figure.9: subsystem for DVR

Figure.8 : simulink model with series load

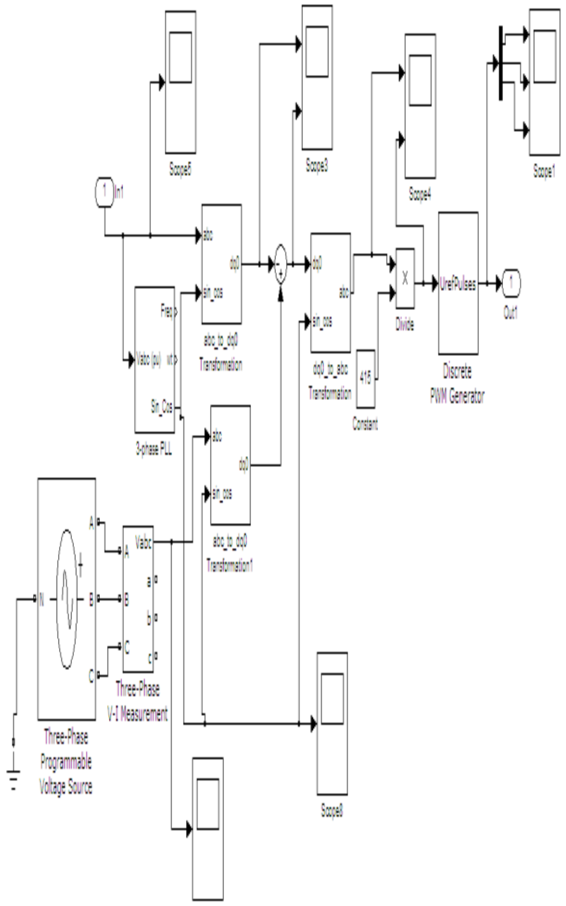
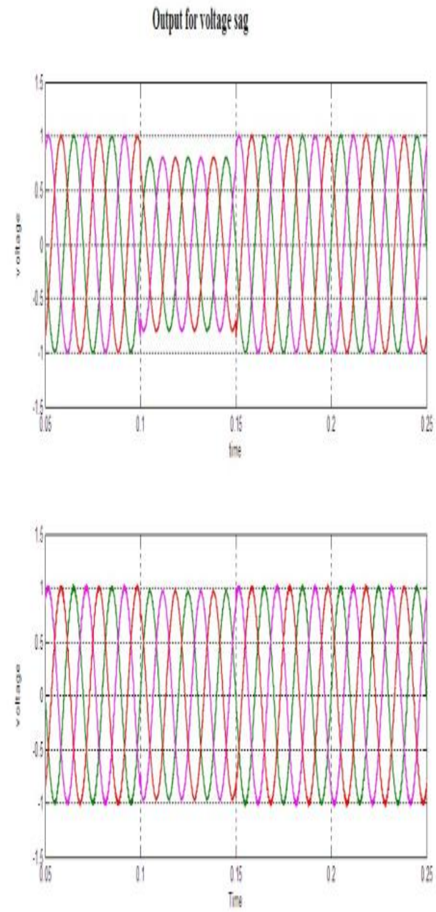


Figure.10: Subsystem for SRF



.Figure.11: Output for voltage sag

From this the figure 11,12 which represents the output for voltage sag and voltage swell.

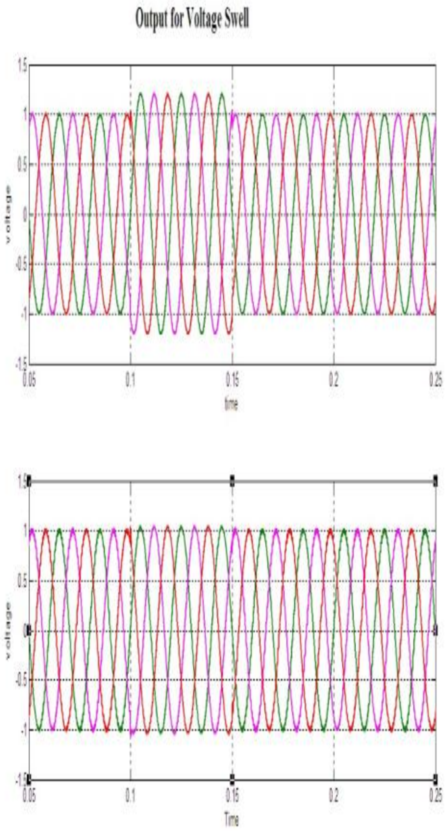


Figure. 12: Output for voltage swell

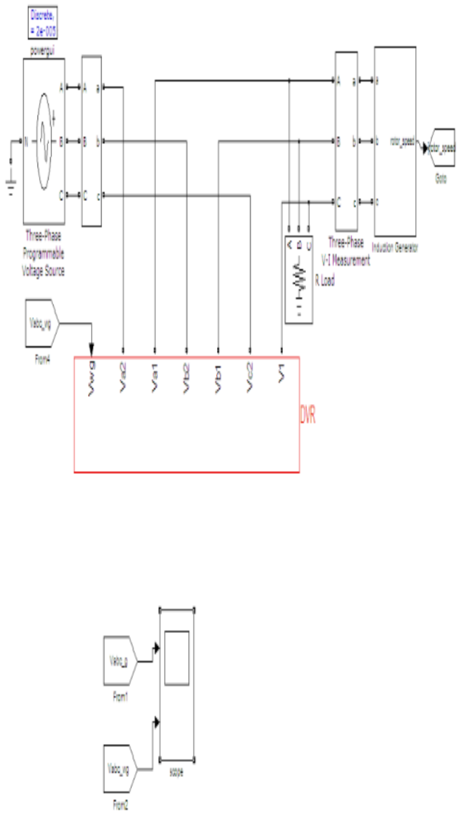


Figure.13: Simulink model with wind generator

In this figure .13 which shows the simulink model which consists of wind generator as a load. Figure .14 represents the subsystem for wind generator used to measure the speed of the generator. Figure .15,16 which shows the Output for voltage sag and voltage swell.

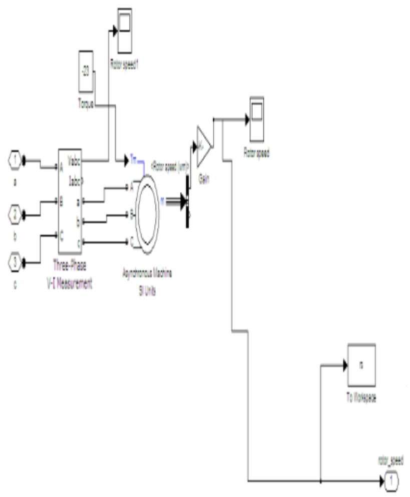


Figure.14: Subsystem for wind generator

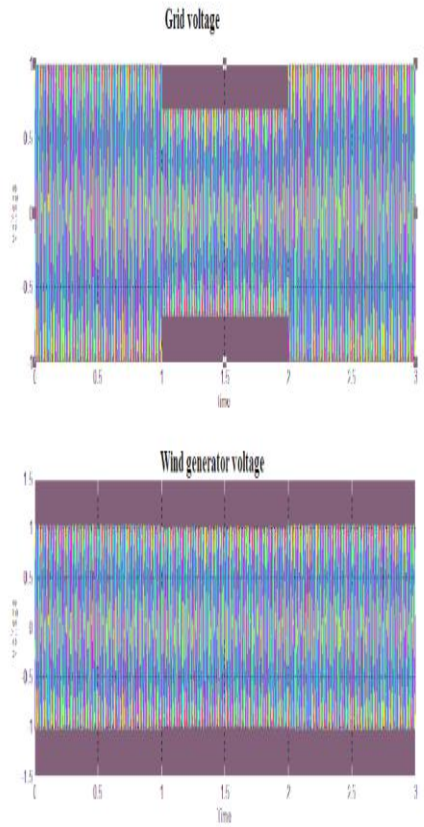


Figure.15: Output for voltage sag

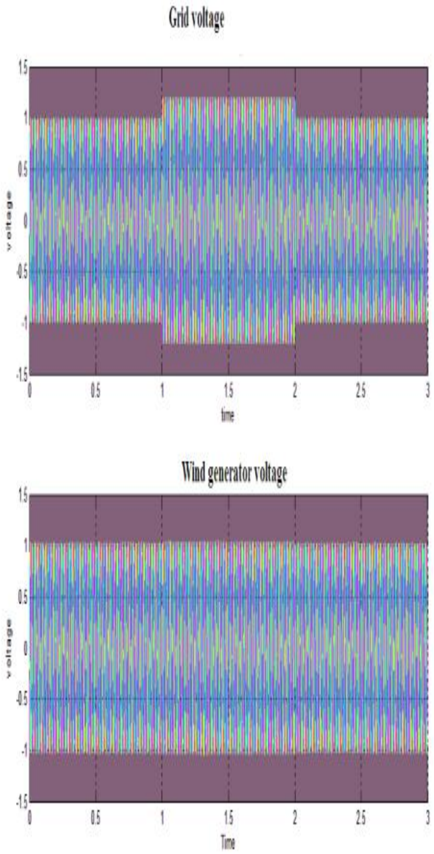


Figure.16: Output for voltage swell

IX. CONCLUSION

In this project, a fast and cost efficient Dynamic Voltage Restorer (DVR) comprising of a discrete PI controller is an emerging device used for power quality improvement. This new technique incorporates a module as a DC voltage source to mitigate voltage variations and enhances power quality of a distribution system.

Simulations are carried out by using MATLAB/SIMULINK. Simulation results demonstrated good performance. The simulation result shows the fault clearing using DVR. It is clear from the result that, the increase in unbalance load voltage is decreased by using DVR. Thus the proposed system eliminates the problem of voltage dip, swell and other voltage disturbances problem in industrial distribution system.

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