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Mitigation of voltage sag/swell using Dynamic voltage restorer (DVR)

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Abstract: *The most noticeable topic for electrical engineering is power quality in recent year. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency. Utility distribution networks, sensitive industrial load and critical commercial operation suffer from various types of outages and service interruption can cost significant financial losses. One of the major problems dealt here is the voltage sag.*

With the fast development in power electronics technology have made it possible to mitigate power quality problems. This work concentrates on the power quality problem such as voltage sag. Many of the devices such as STATCOM, tap changing transformer, UPFC and DVR are available to mitigate voltage sag problems. Among these, dynamic voltage restorer can provide the most commercial solution to mitigate voltage sag by injecting voltage as well as power in to the system.

Dynamic Voltage Restorer is a series connected power electronics based device that can quickly mitigate the voltage sag in the system and restore the load voltage to the pre-fault value.

This thesis first gives an introduction to relevant power quality problems for a DVR and power electronics controllers for voltage sag mitigation. Thereafter the operation and elements in DVR is described. In this thesis proposed utilizes the error signal to control the triggering of the switches of an inverter using Sinusoidal Pulse Width Modulation (SPWM) technique.

Modeling and simulation of proposed DVR is implemented in MATLAB SIMULINK

- ***Dynamic voltage restorer (DVR):***

It is a voltage source converter which is connected in series with supply through injection transformer where voltage sag or swell takes place. The DVR is most technically advanced and economical device for voltage sag mitigation in distribution system. Energy storage in DVR is responsible for supplying active power needed during voltage sag. If this energy is obtained from neighbour feeder than it is called interline dynamic voltage restorer.

I. Introduction:

"Reliability" is a key word for utilities and their customers in general, and it is crucial to companies operating in a highly competitive business environment, because it affects profitability, which definitely is a driving force in the industry. Although electrical transmission and distribution systems have reached a very high level of reliability, disturbances cannot be totally avoided. Any disturbances to voltage waveform can cause problems related with the operation of electrical and electronic devices. Users need constant sine wave shape, constant frequency and symmetrical voltage with a constant rms value to continue the production. This increasing interest to improve efficiency and eliminate variations in the industry has resulted more complex instruments sensitive to voltage disturbances such as voltage sag, voltage swell, interruption, phase shift and harmonic. Voltage sag is considered the most severe since the sensitive loads are very susceptible to temporary changes in the voltage. In some cases, these disturbances can lead to a complete shutdown of an entire production line, in particular at high tech industries like semiconductor plants, with severe economic consequences to the affected enterprise.

The DVR is a power quality device, which can protect these industries against the bulk of these disturbances, i.e. voltage sags and swells related to remote system faults. A DVR compensates for these voltage excursions, provided that the supply grid does not get disconnected entirely through breaker trips. Modern pulse-width modulated (PWM) inverters capable of generating accurate high quality voltage waveforms form the power electronic heart of the new Custom Power devices like DVR. Because the performance of the overall control system largely depends on the quality of the applied control strategy, a high performance controller with fast transient response and good steady state characteristics is required. The main considerations for the control system of a DVR include: sag detection, voltage reference generation and transient and steady-state control of the injected voltage.

The typical power quality disturbances are voltage sags, voltage swells, interruptions, phase shifts, harmonics and transients. Among the disturbances, voltage sag is considered the most severe since the sensitive loads are very susceptible to temporary changes in the voltage.

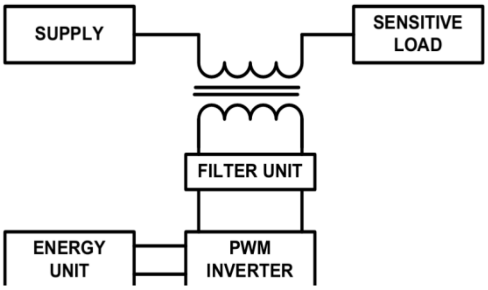

Figure 4.1 Typical applications of DVR and its output.

The wide area solution is required to mitigate voltage sags and improve power quality. One new approach is using a DVR .The basic operation principle is detecting the voltage sag and injecting the missing voltage in series to the bus as shown in Fig.4.1. DVR has become a cost effective solution for the protection of sensitive loads from voltage sags. The DVR is fast, flexible and efficient solution to voltage sag problems. DVR consists of energy storage unit, PWM inverter, and filter and injection transformer as shown in Fig.4.1

1.1 Futures of DVR:

- Lower cost, smaller size, and its fast dynamic response to the disturbance.
- Ability to control activepower flow.
- Higher energy capacity and lower costs compared to the SMES device.
- less maintenance required. UPS is costly; it also requires a high level of maintenance because batteries leak and have to be replaced as often as every five years.

1.2 Location of DVR:

DVR is connected in the utility primary distribution feeder. This location of DVR mitigates the certain group of customer by faults on the adjacent feeder as shown in Fig 4.2.The point of common coupling (PCC) feds the load and the fault. The voltage sag in the system is calculated by using voltage divider rule.

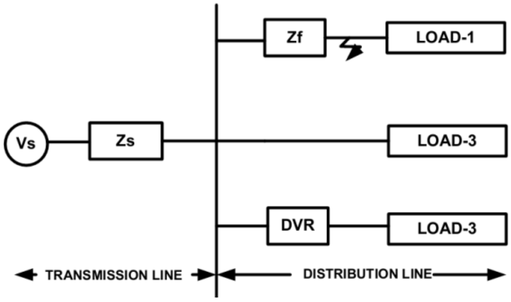

Figure 4.2 Location of DVR

The insertion of a DVR at the low voltage four-wire 440 V level is illustrated in Fig. 4.2. The increase in impedance by insertion of a small rated DVR can be significant for the load to be protected from voltage dips. Thereby, the per cent change in the impedance ($Z_{increase}$, %) in can be increased by several hundred per cent.

Inserting a DVR at LV-level has certain advantages:

- The DVR can be targeted morespecifically at voltage dip sensitive loads.
- a majority of electric customers have only access to the LV-level and the DVR can both be placed by the customer at the customer domain or by the utility at the utility domain.
- The short-circuit level is significantly decreased by the distribution transformer and the DVR is easier to protect.

The disadvantages with a LV solution are:

- The impedance increase after the insertion of the DVR for the protected load can be large, which may influence the site short circuit level and protection. An increased load voltage distortion and load voltage variation can be expected, which may be caused by non-linear and time varying load currents.
- Voltage dips with a zero sequence voltage component can appear and in order to be able to compensate loads connected between phase and neutral adequate, the DVR hardware and control should be able to generate positive, negative and zero sequence voltages.

1.3 Basic Configuration:

Fig.1.1 illustrates some of the basic elements of a DVR, which are:

- Converter

- Line-filter
- Injection transformer DC-link and energy storage
- DC-link and energy storage
- By-pass equipment
- Disconnection equipment

1.3.1 Converter:

The converter is most likely a Voltage Source Converter (VSC), which Pulse Width modulates (PWM) the DC from the DC-link/storage to AC-voltages injected into the system.

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

1.3.2 Line-Filter:

The line-filter is inserted to reduce the switching harmonics generated by the PWM VSC.

1.3.3 Injection Transformer:

In most DVR applications the DVR is equipped with injection transformers to ensure galvanic isolation and to simplify the converter topology and protection equipment. 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:

1) 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.
2) In addition, the Injection / Booster transformer serves the purpose of isolating the
   Load from the system (VSC and control mechanism).

1.3.4 DC-Link and Energy Storage:

A DC-link voltage is used by the VSC to synthesize an AC voltage into the grid and during a majority of voltage dips active power injection is necessary to restore the supply voltages. 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.

1.3.5 By-Pass Equipment:

During faults, overload and service a bypass path for the load current has to be ensured. Illustrated in Fig. 4.1 as a mechanical bypass and a thyristor bypass

1.4 Different Topologies Used For DVR:

- **DVR topology with no energy storage:**

DVR topologies with no energy storage use the fact that a significant

Part of the supply voltage remains present during the sag and this residual supply can be used to provide the boost energy required to maintain full load power at rated voltage. A passive shunt converter is used because only unidirectional power flow is assumed necessary and it is cheap solution for voltage sag.

Two basic topologies can be used, which are categorized here according to the location of shunt converter.

- **System-I- Supply side connected shunt converter:**

The supply side connected converter has an uncontrollable dc-link voltage and the passive converter will charge the dc-link capacitor to the actual state of the supply voltage. The dc-link voltage is approximately equal to the peak phase-phase value of supply voltage and hence, during voltage sags the dc-link voltage drop proportionally to sag voltage according to,

$$V_{dc} = V_{supply} = \alpha \tag{4.1}$$

The maximum pu voltages for the shunt and series converter can be expressed as

$$V_{shunt} = 1 \; \& V_{series} = 1 - \alpha \tag{4.2}$$

- **System-II- Load side connected shunt converter:**

With the load side connected shunt converter the input voltage to the shunt converter is controlled and the dc-link voltage can be held almost constant by injecting sufficient voltage.

Hence

$$V_{dc} = V_{load} = \alpha + V_{DVR} \tag{4.3}$$

$$V_{shunt} = 1 \; \& V_{series} = 1 - \alpha \tag{4.4}$$

- **Topology with energy storage:**

Storing of electrical energy is expensive but for certain types of voltage sags the performance of the DVR can be improved and the strain on the grid connection is lower. Two methods are considered here and in both the current flow from the grid is unchanged during a voltage sag.

- **System-III- Variable dc-link voltage energy stored in dc link capacitor:**

Storing energy in the dc link capacitor is well suited solution forDVRs. A simple topology can be operated with a variable dc-link voltage. The stored energy$E_{storage}$ is proportional to the square of the rated dc-link voltage.

$$E_{storage} = \frac{1}{2} C_{dc} V_{dc,rated}^2 \tag{4.5}$$

- **System-IV- Constant dc-link voltage:**

Direct energy storage method such as SMES, batteries or super capacitors can be used in a DVR by adding separate high power rating converter to the system. Energy transferred from large energy storage to a similar rated dc-link storage using this converter during sag. Hence the dc-link voltage remains constant.

Experimental test using 10 KVA DVR show that the no energy storage concept is feasible, but an improved performance can be achieved for certain voltage sag using stored energy topology.

1.5 Equation Related To DVR:

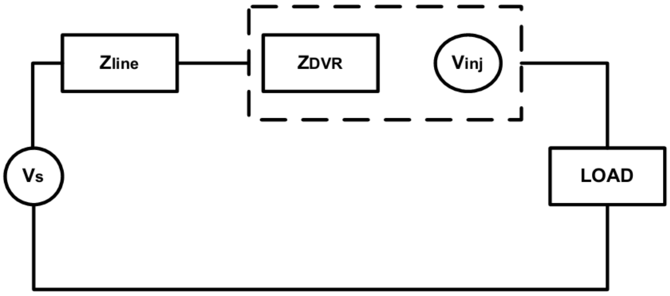

Figure 4.3 Equivalent circuit diagram of DVR

The system impedance (Z_{th}) depends on the fault level of the load bus. 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

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \tag{4.6}$$

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 IL is given by,

$I_L = (\frac{(P_L + j * Q_L)}{V_L})*$ (4.7)

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

$$V_{DVR}\angle\alpha = V_L\angle 0 + Z_{th} I_L \angle(\beta - \theta) - V_{th}\angle\delta \quad (4.8)$$

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

$$\theta = \tan^{-1}\frac{Q_L}{P_L} \quad (4.9)$$

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

$$S_{DVR} = V_{DVR} I_L * \quad (4.10)$$

1.6 Operating Modes:

Generally, the DVR is categorized into three-operation mode: protection mode, standby mode (during steady state) and injection mode (during sag).

4.6.1 Protection Mode:

The DVR will be isolated from the system if the system parameters exceed the predetermined limits primarily current on load side. The main reason for isolation is protecting the DVR from the over current in the load side due to short circuit on the load or large inrush currents. The control system detects faults or abnormal conditions and manages bypass (transfer) switches to remove the DVR from system thus preventing it from damages as shown in Fig. 4.4. During the over current period, *S*1 will be closed; *S*2 and *S*3 will be opened so there will be another path for current to flow. By removing the DVR from system at fault condition, the effects of additional disturbances that can be caused by the DVR are prevented onto the system.

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 as shown in Fig.4.4

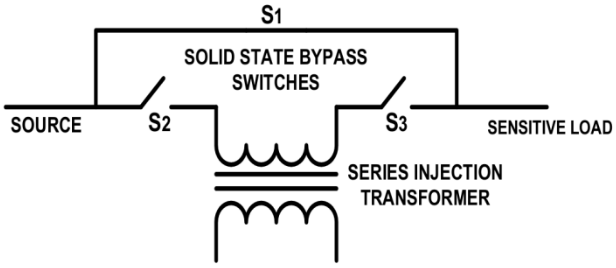

Figure 4.4 the aspect of power switches

1.6.2 Standby Mode:

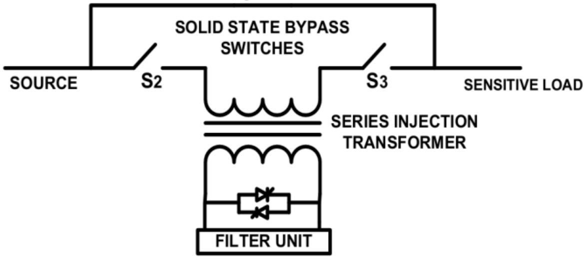

Figure 1.5 the view of standby mode

In standby mode (normal steady state conditions), the DVR may either go into short circuit operation or inject small voltage to compensate the voltage drop on transformer reactance or losses. Short circuit operation of DVR is generally preferred solution in steady state because the small voltage drops do not disturb the load requirements. The solid-state bypass switches are used to perform short circuit operation and they are placed between the inverter and secondary (low side) of series injection transformer as shown in Fig. 4.5. If the distribution circuit is weak there is need to inject small compensation voltage to operate correctly. During short circuit operation, the injected voltages and magnetic fluxes are virtually zero thereby full load current pass through the primary. The DVR will be most of the time in normal mode operation. During standby mode normal operation, the short circuit impedance of the injection transformer determines the voltage drop across the DVR.

1.6.3 Injection Mode:

The primary function of Dynamic Voltage Restorer is compensating voltage disturbances on distribution system. The DVR goes into injection mode as soon as the sag is detected. To achieve compensation, three single- phase ac voltages are injected in series with required magnitude, phase and wave shape. The types of voltage sags, load conditions and power rating ofDVR will determine the possibility of compensating voltage sag. The DVR should ensure the unchanged load voltage with minimum energy dissipation for injection due to the high cost of capacitors. The available voltage injection strategies are pre-sag, phase advance, voltage tolerance and in phase method

1.7 Voltage injection methods:

Compensation of voltage sags/swells is dependent upon a number of factors including DVR power rating, different load conditions and different types of voltage sags/swells. Some loads are very sensitive to phase angle jump while others are tolerant to it. Therefore, the compensation strategy depends upon the type and characteristics of the load connected to DVR. There are three different methods for DVR voltage injection which are presented below.

1.7.1 Pre-Sag Compensation:

In this method DVR injects the difference voltage between during fault and pre-fault voltages to the system. In this method the DVR compensates for both magnitude and Phase angle. The main drawback of this technique is it requires a higher capacity energy storage device. It is the best solution to obtain the same load voltage as the pre-fault voltage but there is no control on injected active power so high capacity energy storage is required. Fig 4a shows the vector diagram for the pre-fault control strategy for a voltage sag event. 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, V pre-fault and V Sag are voltage at the point of common coupling (PCC), respectively before and during the sag. In this case VDVR is the voltage injected by the DVR, which can be obtained as:

$$V_{DVR} = \sqrt{(V_L^2 + V_S^2 - 2V_L V_S \cos\delta)} \qquad (4.11)$$

And the required angle of injection θinj is calculated as:

$$\theta_{inj} = \tan^{-1}\frac{V_S \sin\theta}{V_S \cos\theta - V_L} \qquad (4.12)$$

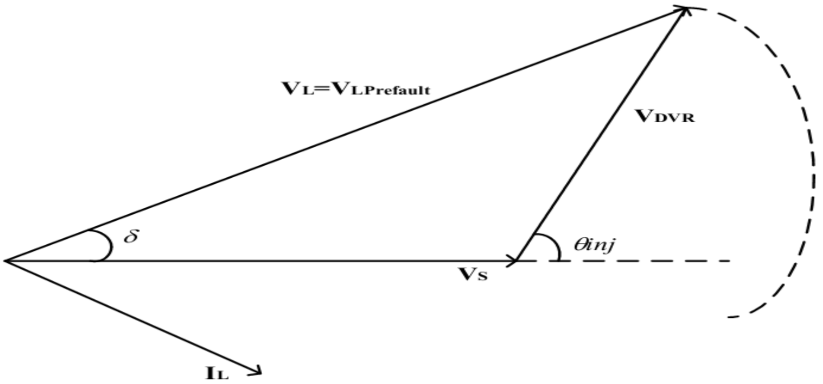

Figure 1.6 Vector diagram for pre-sag compensation

1.7.2 In Phase Compensation:

In Phase compensation technique is designed to compensate for the voltage magnitude only. In this method jumps in the phase angle is not compensated .The injected voltage is in phase with supply voltage. As shown in Fig 3.6 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 is satisfied.

$$V_L = V_{Lprefault} \qquad (4.13)$$

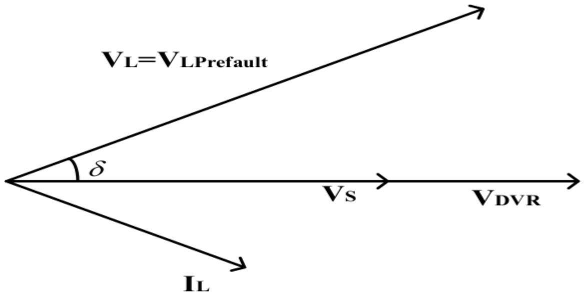

Figure 1.7 Vector diagram for In phase compensation

1.7.3Energy Optimized Compensation:

Another existing strategy is to use as much reactive power aspossible to compensate the sag. Therefore, the DVR voltage iscontrolled in such a way that the needed compensation voltage Of the DVR is controlled perpendicular to the load current. The basic idea of this strategy is to draw as much active power fromthe grid as possible and thus to reduce the amount of active Power needed from the DC-link. As long as the voltage sag isquite shallow, it is possible to compensate sag with pure reactive power and therefore the compensation time is not limited. In Fig.4.8, the voltages for the energy optimized compensationare depicted.Beside the enormous advantage of not requiring active power,this strategy has in most cases two major disadvantages. On theone hand, a phase jump occurs and, on the other hand, the required DVR voltage amplitude can become quite high. Furthermore, the compensation with pure reactive power is only possible for shallow sags. If deep sag occurs, a large amount ofActive power is also needed with this strategy.

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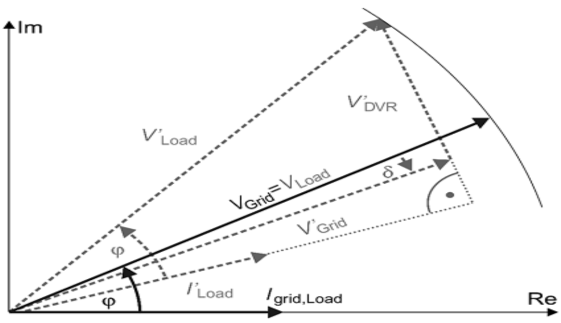

Figure.1.8. Energy optimized compensation

1.8 Working of DVR:

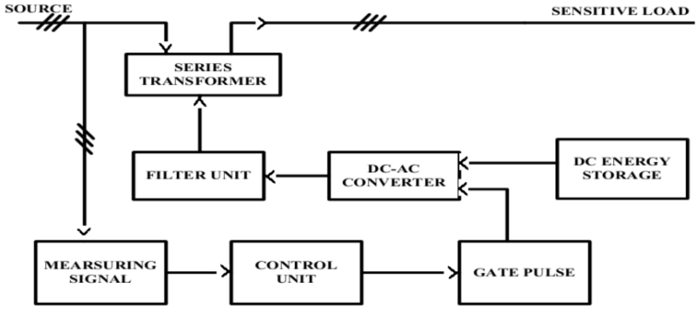

Figure 1.9 Function blocks of designed DVR

Among the voltage transients (sags, swells, harmonics…), the voltage sags are the most severe disturbance. The users may improve end-use devices or use protection devices to reduce the number of voltage sags. But overall solution to mitigate the voltage sags and recovering the load voltage to the pre-fault value is using a Dynamic Voltage Restorer (DVR). It is a solid state DC to AC switching power electronic converter that injects three single-phase AC voltages in series between the feeder and sensitive load. Using a DVR is more reliable and quick solution to maintain with a clean supply of electricity for customers. But standby losses, equipment costs and required large investigation for design are the main drawbacks of DVR. The PWM inverter unit produces required missing voltage by evaluating the control unit signals and this compensating voltage is inserted to the system by injection transformers.

1.8.1 Control strategy of DVR

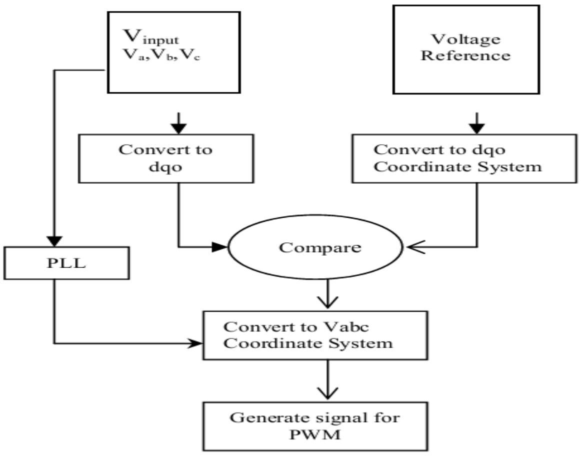

Figure-1.10 Flowchart of feed forward control techniquefor DVR based on dqo transformation.

The basic functions of a controller in a DVR are the detection of voltage sag/swell events in the system; computation of the correcting voltage, generation of trigger pulses to theSinusoidal PWM based DC-AC inverter, correction of any anomalies in the series voltage Injection and terminationofthe trigger pulses when the event has passed. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltagesags/swells. The dqo transformation or Park's transformation is used to control of DVR.The dqomethod gives the sag depth and phase shift information with start and end times. The Quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from abc reference frame to dqoreference. For simplicity zero phase sequence componentsis ignored.
Figure-3.10 illustrates a flow chart of the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases.
The control is based on the comparison of a voltage reference and the measured terminal voltage (V_a,V_b,V_c) .The voltage sags is detected when the supply drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value.
The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches (IGBT's) constituting the voltage sourceconverter. The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM) ; voltages are controlled through the modulation.
The block diagram of the phase locked loop (PLL) is illustrated in Figure-4.10 The PLL circuit is used to generate a unit sinusoidal wave in phase with mains voltage.

$$\begin{bmatrix} Vd \\ Vq \\ Vo \end{bmatrix} = \begin{bmatrix} cos\theta & \cos(\theta - 2\pi/3) & 1 \\ -sin\theta & -\sin(\theta - 2\pi/3) & 1 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \tag{4.14}$$

Equation defines the transformation from three phase system abc to dqo stationary frame. In this transformation, phase A is aligned to the d -axis that is in quadrature with the q-axis. The theta (θ) is defined by the angle between phase A to the d-axis.

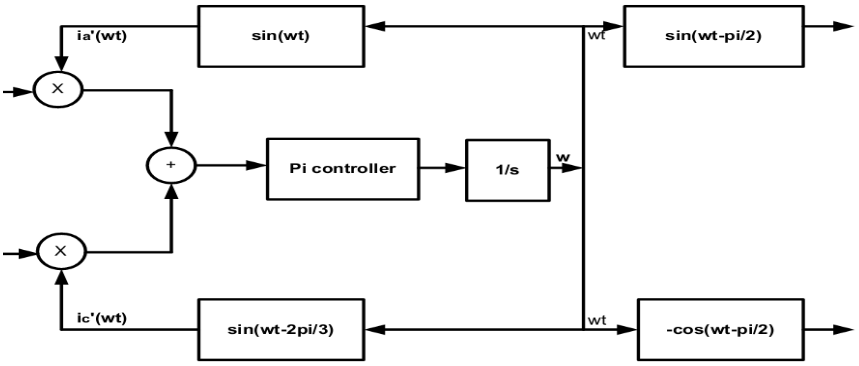

Figure 1.11 Block diagram of PLL

II. Simulation and Results

2.1 Simulation for Sag and Swell without DVR:

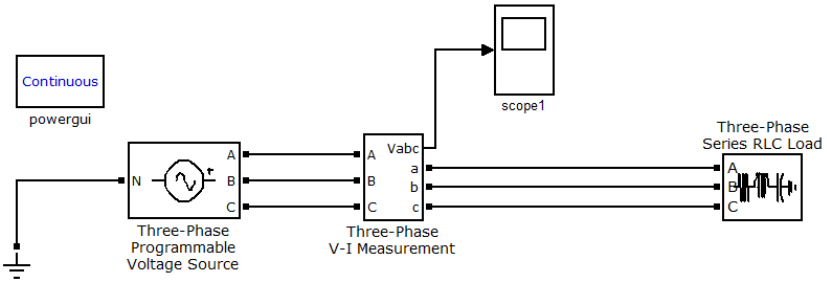

Figure 2.1: simulation circuit for voltage sag and swell without DVR

The system consists of voltage of 1 pu, 50 Hz source with 10kw 3-phase RLC load shown in fig 5.1. voltage sag is occurred at 0.5 sec to 1 sec of .5 pu and voltage swell occurred of 0.5 pu for 0.2 sec to .25 sec. Fig: 5.2 shows three phase voltage waveform under fault condition without DVR. As shown fig 5.1, sag occurs at 0.1 sec to 0.15 sec. Now the function of DVR would be to inject acompensating voltage, which would result in fairly constant voltage across the load terminal. With the use of the fast acting power electronics converters, DVR is capable to inject voltage for such a small duration of few cycles. The simulation parametersare given in following table

Supply Source	3-Φ, 1 puV, 50 Hz
Load	10kW, 100Var
Filter	L=20mH, C=30μF
DC Voltage Source	600V

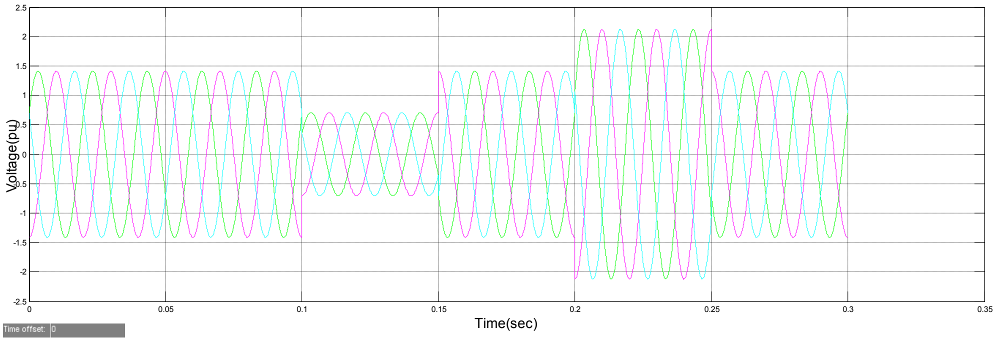

Figure 2.2: simulation result for voltage sag and swell without DVR

2.2 Simulation of system with PLL circuit:

Fig 5.3 shows the simulation of system with PLL circuit which gives the output of frequency wt, and sin_cos function which is as shown in fig. 2.4, fig,2.5 and fig 2.6 respectively,

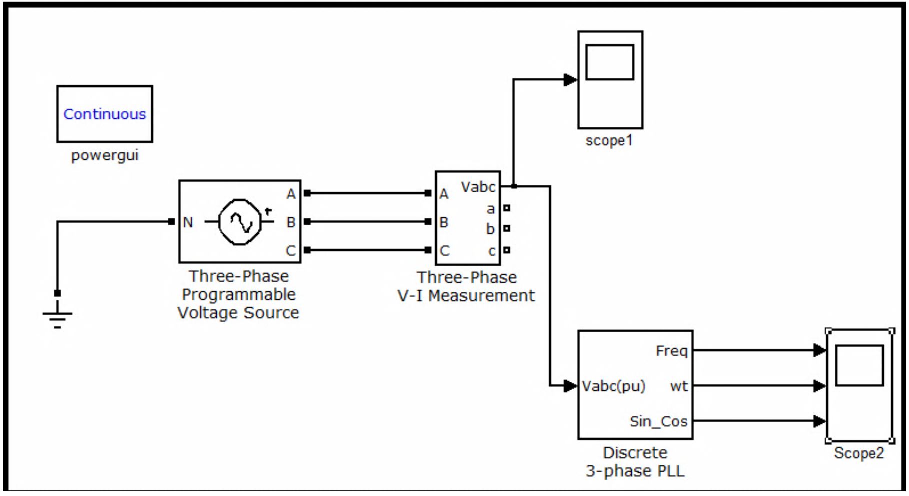

Figure 2.3: Simulation of system with PLL circuit

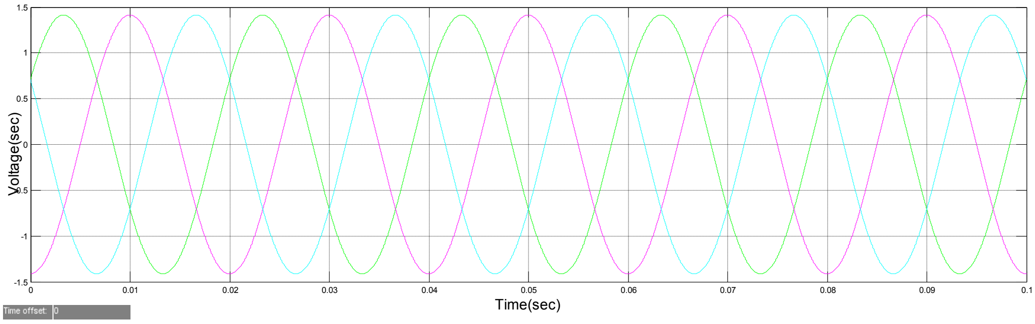

Figure 2.4: Simulation result of voltage for system with PLL circuit

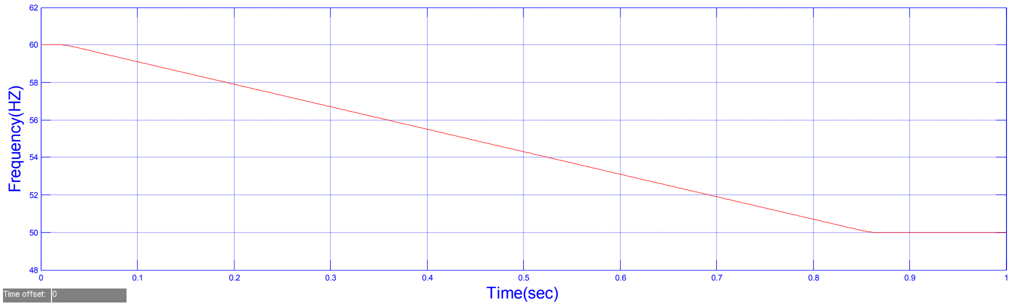

Figure 2.5: Simulation result of Frequency for system with PLL circuit

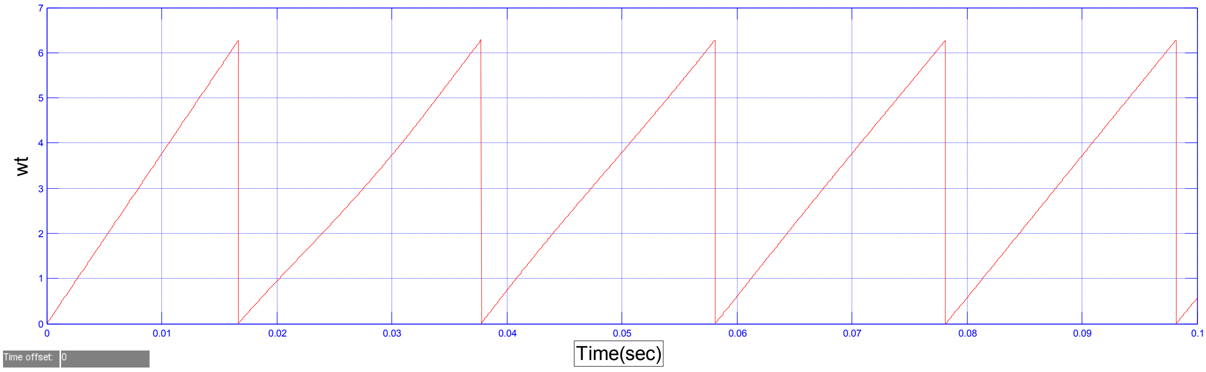

Figure 2.6: Simulation result of angle (wt) for system with PLL circuit

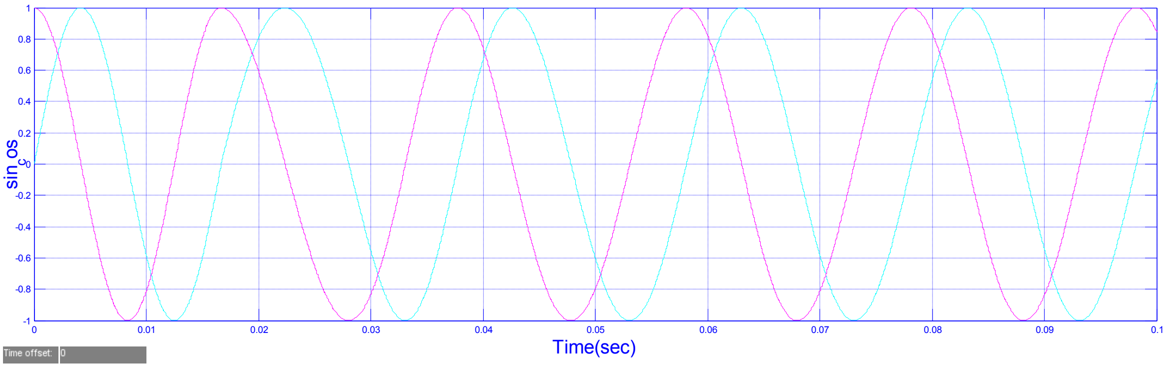

Figure 2.7: Simulation result of function sin_cos for system with PLL circuit

2.3 Simulation for system with PLL circuit and abc to dq0 Block

Fig 2.8 shows the simulation of system with abc to dq0 transformation block which convert voltage waveform into dq0 form as shown in fig 5.9

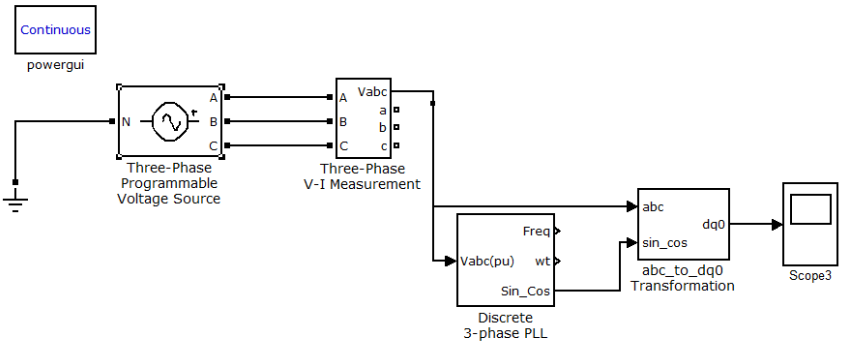

Figure 2.8: Simulation for system with PLL circuitand abc to dq0 Block

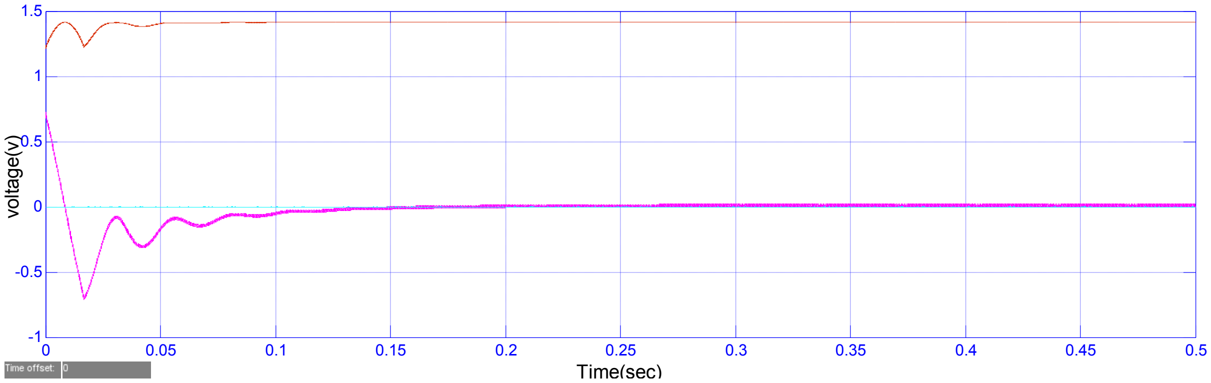

Figure 2.9: Simulation result of voltage in dq0 for system with PLL circuit and abc to dq0 block

2.4 Simulation for system with error signal generated

Fig 2.9 shows the simulation of comparison of reference voltage and supply voltage fig 5.10 shows the supply voltage and reference voltage in steady state condition.

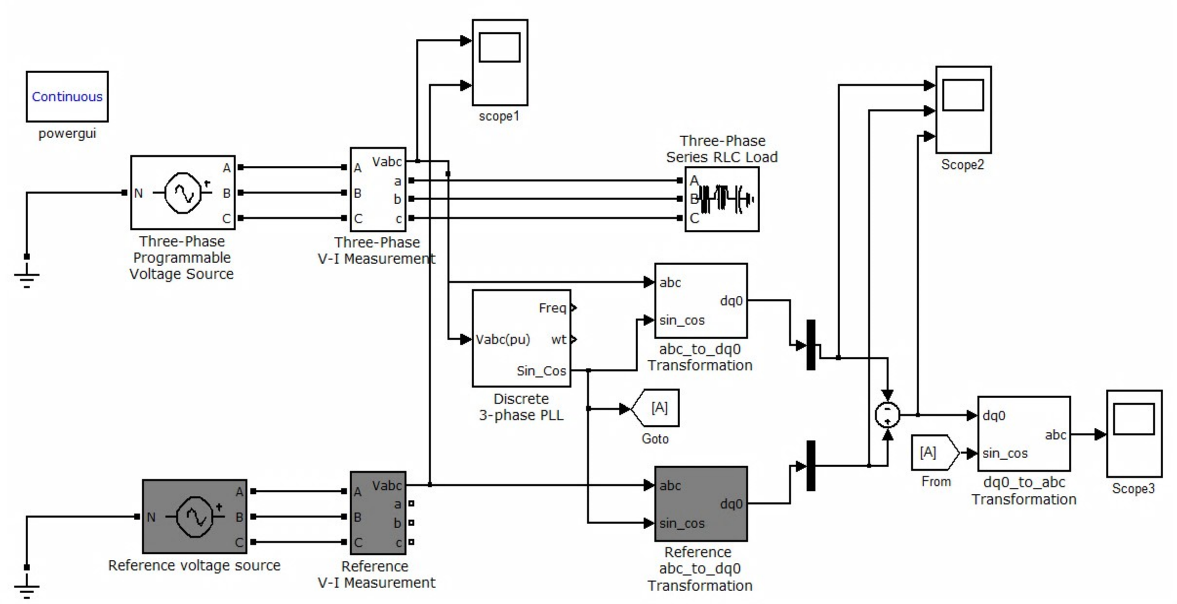

Figure 2.10: Simulation for system with error signal generated

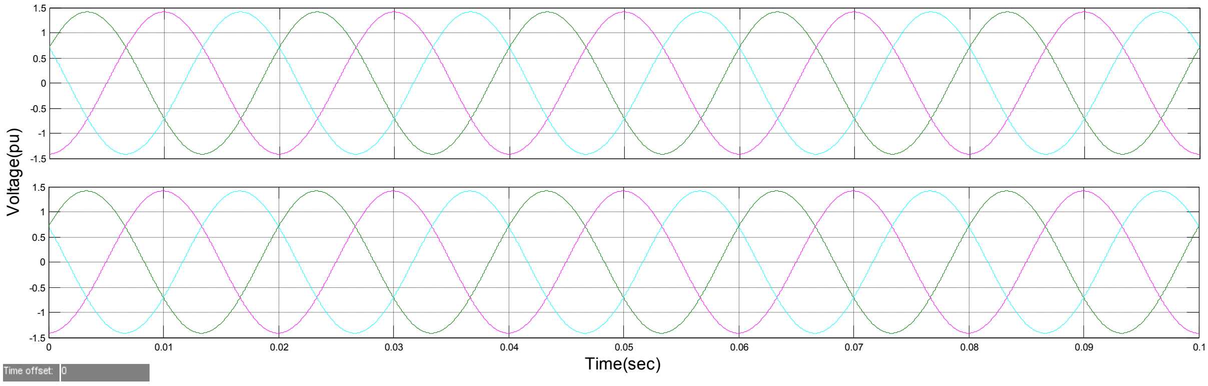

Figure 2.11: Simulation result of supply voltage and reference voltage

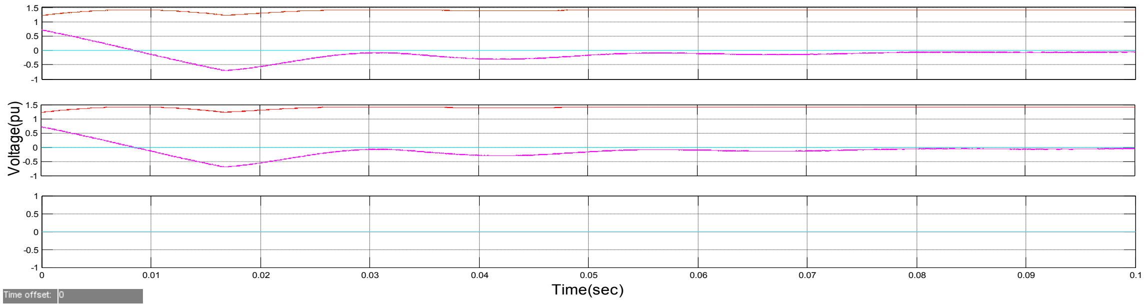

Figure 2.12: Simulation result of supply voltage and reference voltage and error signal in dq0

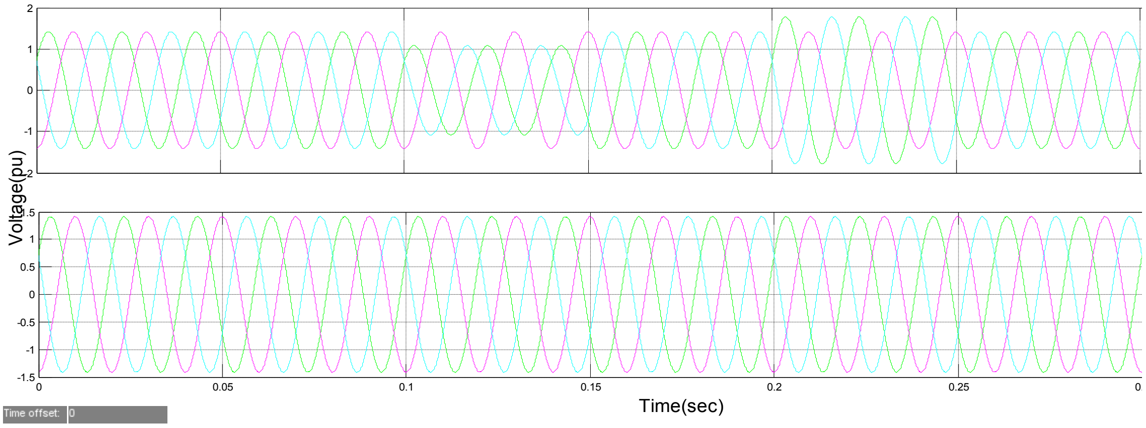

Figure 2.13: Simulation result of supply voltage and reference voltage in the event of sag and swell in one phase

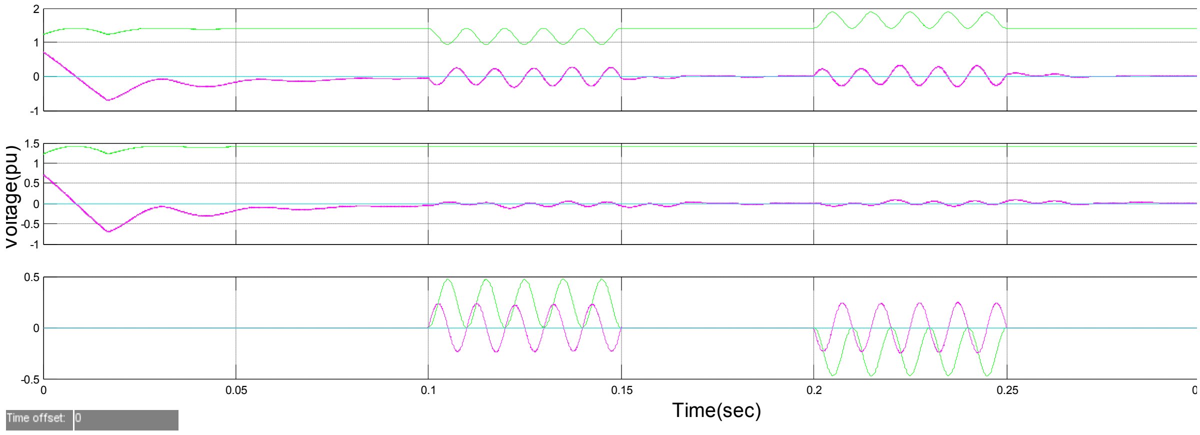

Figure 2.14: Simulation result of supply voltage and reference voltage and error signal in dq0 in the event of sag and swell in one phase

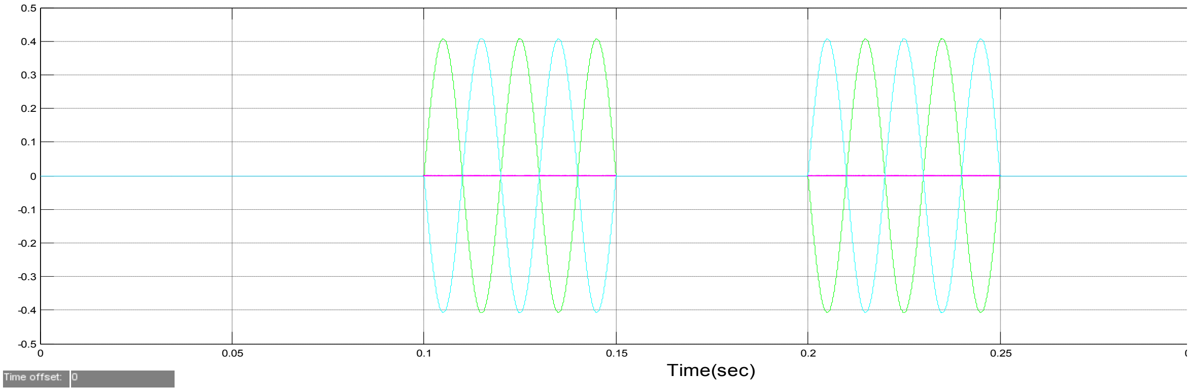

Figure 2.15: Simulation result of error signal in abc in the event of sag and swell in one phase

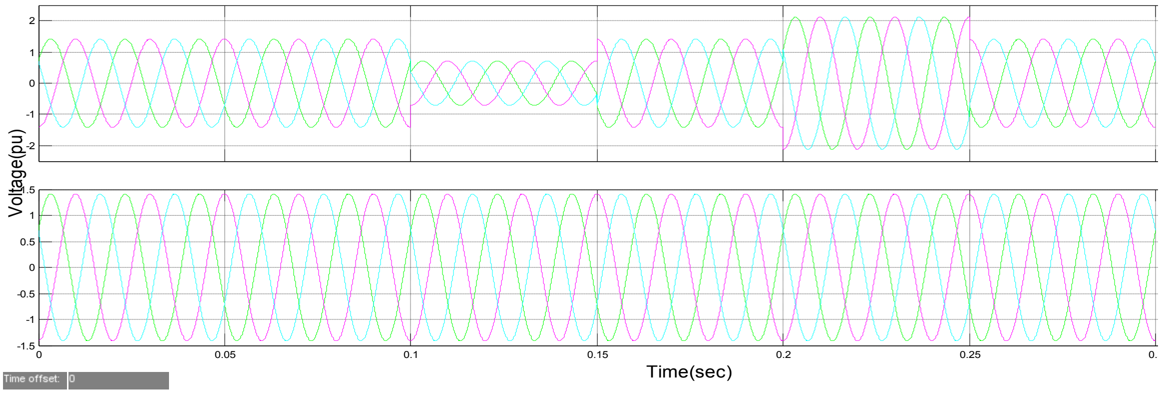

Figure 2.16: Simulation result of supply voltage and reference voltage in the event of sag and swell in all phases

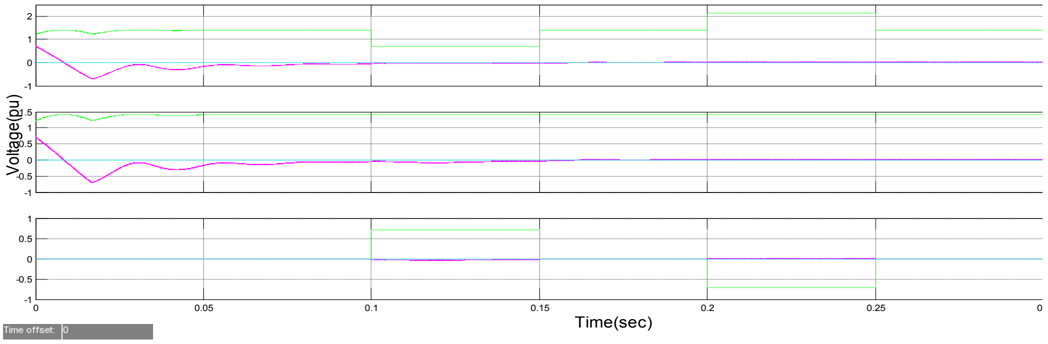

Figure 2.17: Simulation result of supply voltage and reference voltage and error signal in dq0 in the event of symmetrical sag and swell

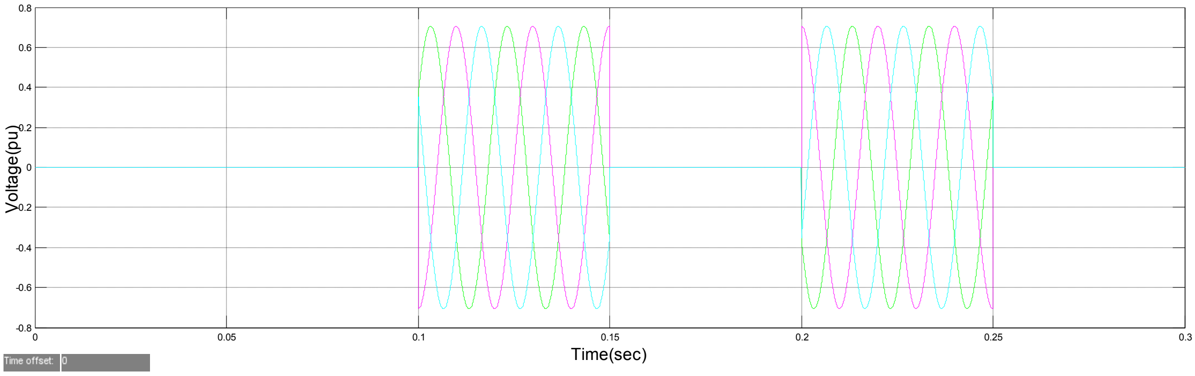

Figure 2.18: Simulation result of error signal in abc in the event of symmetrical sag and swell

Fig 2.16,fig.2.17 and fig.2.18 shows the output of voltage,Simulation result of supply voltage and reference voltage and error signal in dq0 in the event of symmetrical sag and swell,Simulation result of error signal in abc in the event of symmetrical sag and swell respectively.

2.5 simulation of SPWM based inverter

2.5.1 Generation of Gate pulse:

Fig. 2.19 shows the pulse generation circuit in which reference wave is compared with carrier wave.

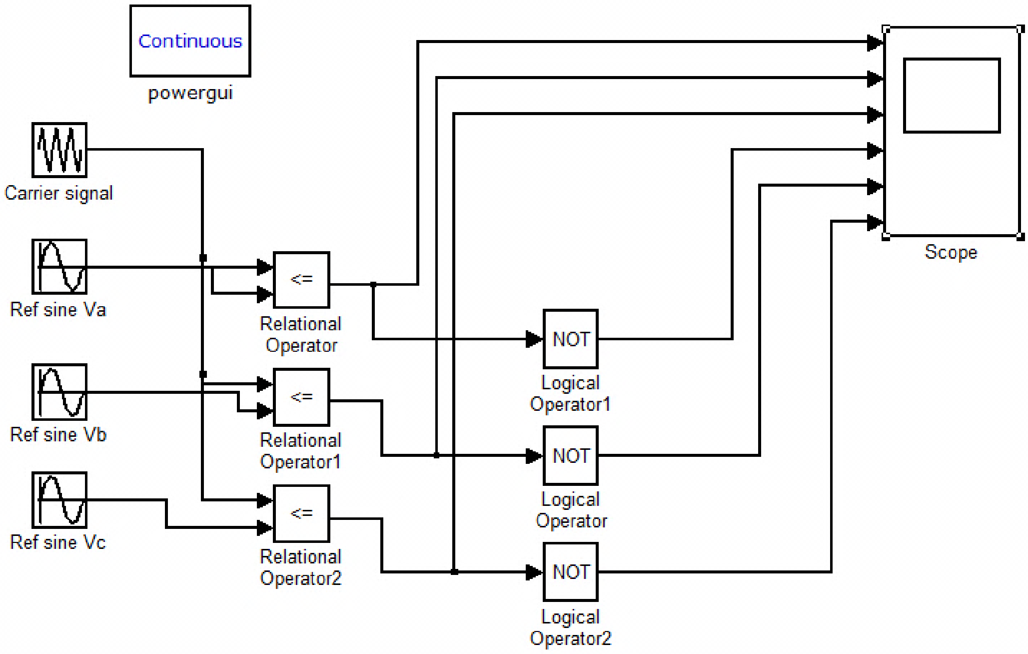

Figure 2.19: Generation of Gate Pulse

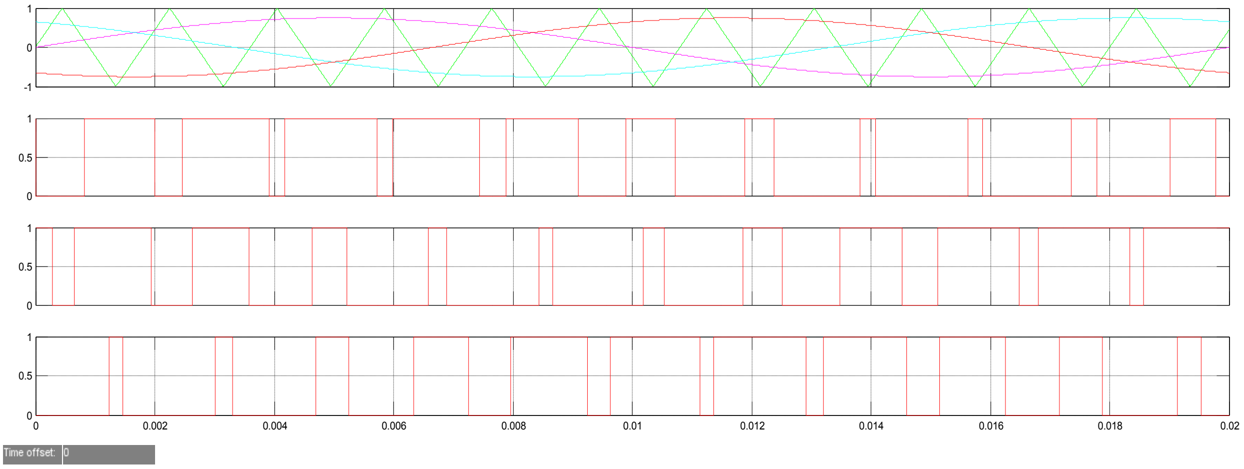

Figure 2.20: waveforms of Gate Pulse Generation

Fig 5.20 shows the phenomenon of pulse generation, when the reference wave magnitude is more than carrier wave the pulse is generated.

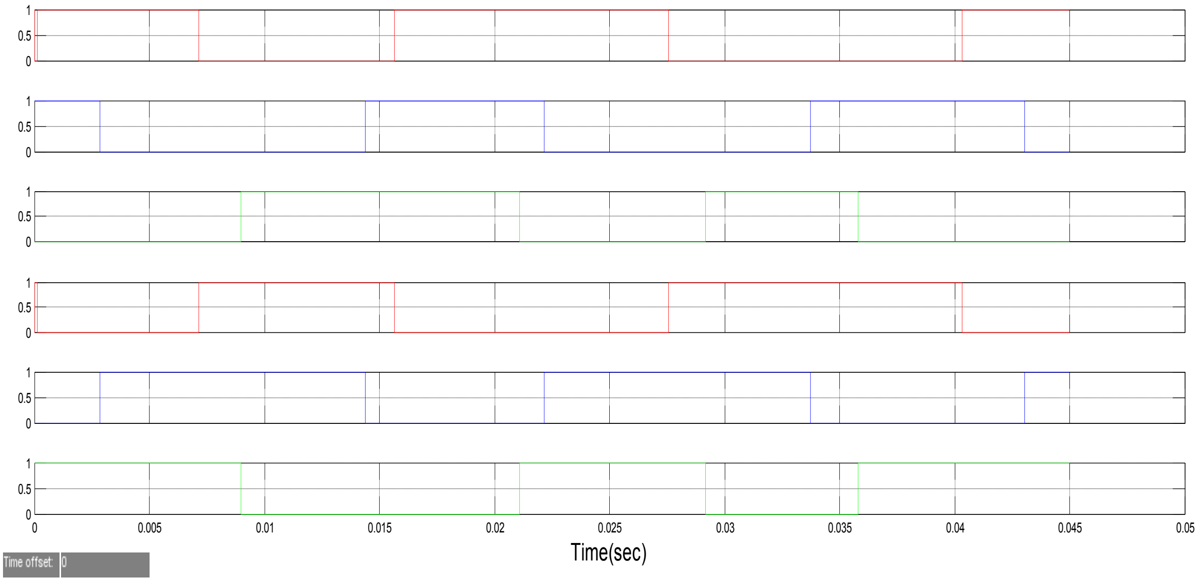

Figure 2.21: Gate Pulses

5.5.2 Generation of Gate pulse

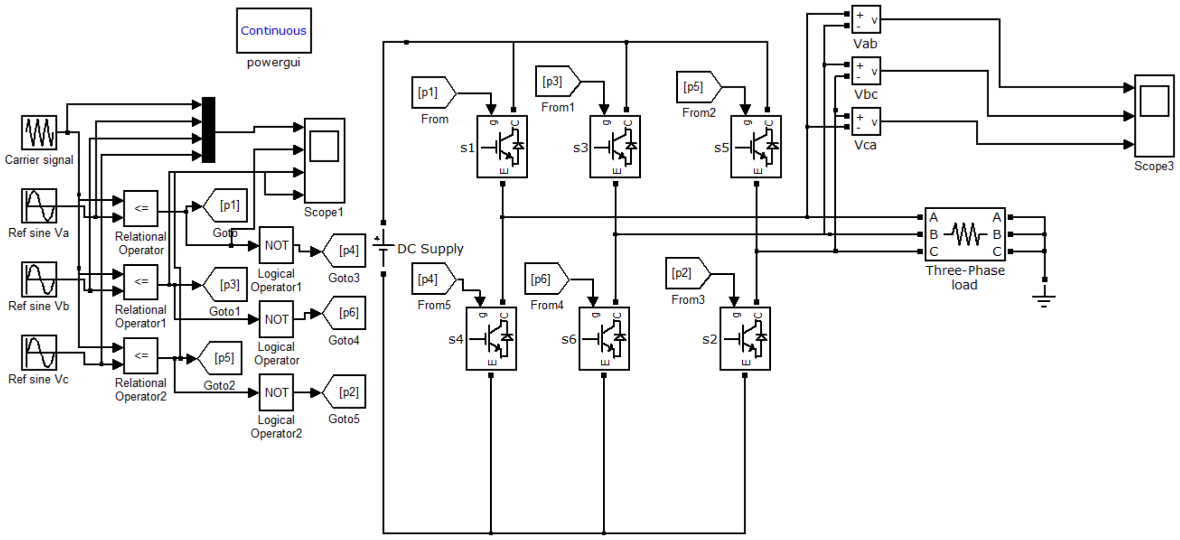

Figure 2.22: SPWM based inverter Without Filter Circuit

Fig 2.22 shows the SPWM without Filter circuit the output waves contains harmonics as shown in fig.5.23

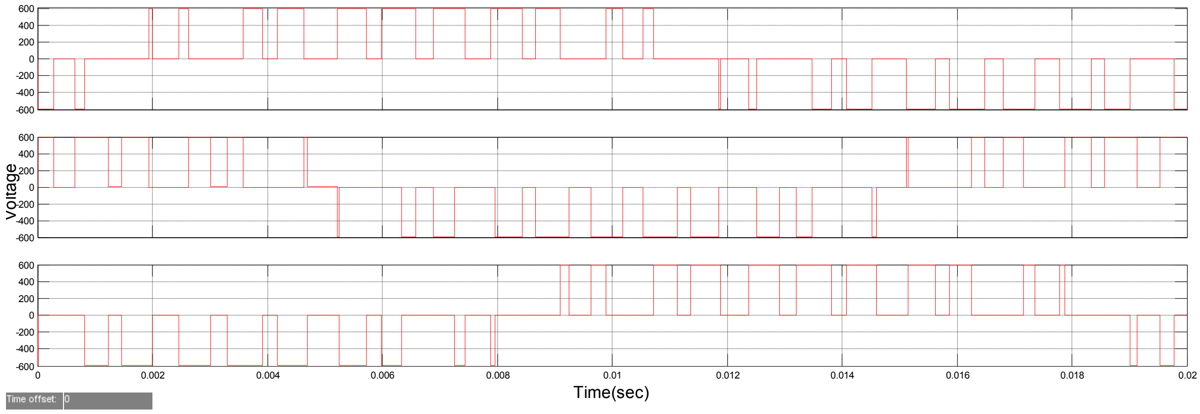

Figure 2.23: SPWM based inverter Voltage waveforms Without Filter Circuit

2.5.3 Simulation of SPWM inverter with filter circuit

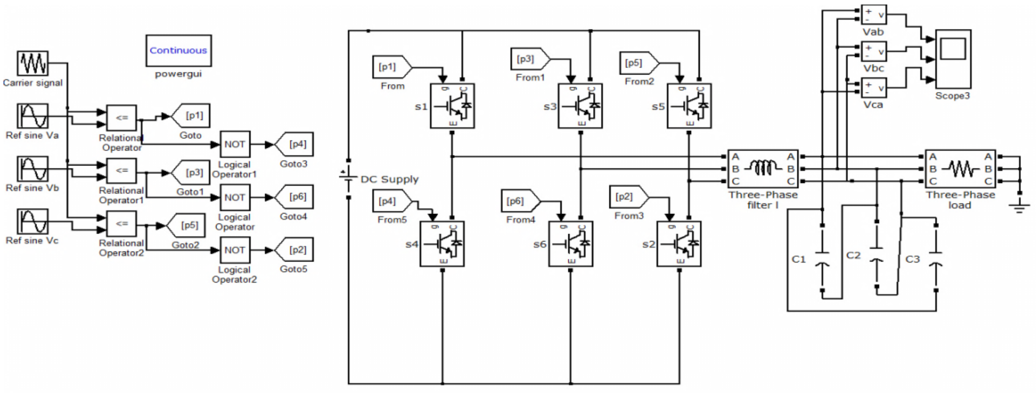

Figure 2.24: SPWM based inverter With Filter Circuit

Fig 2.24 shows the simulation of SPWM inverter with Filter circuit so that the output voltage is purely sinusoidal as shown in fig, 2.25

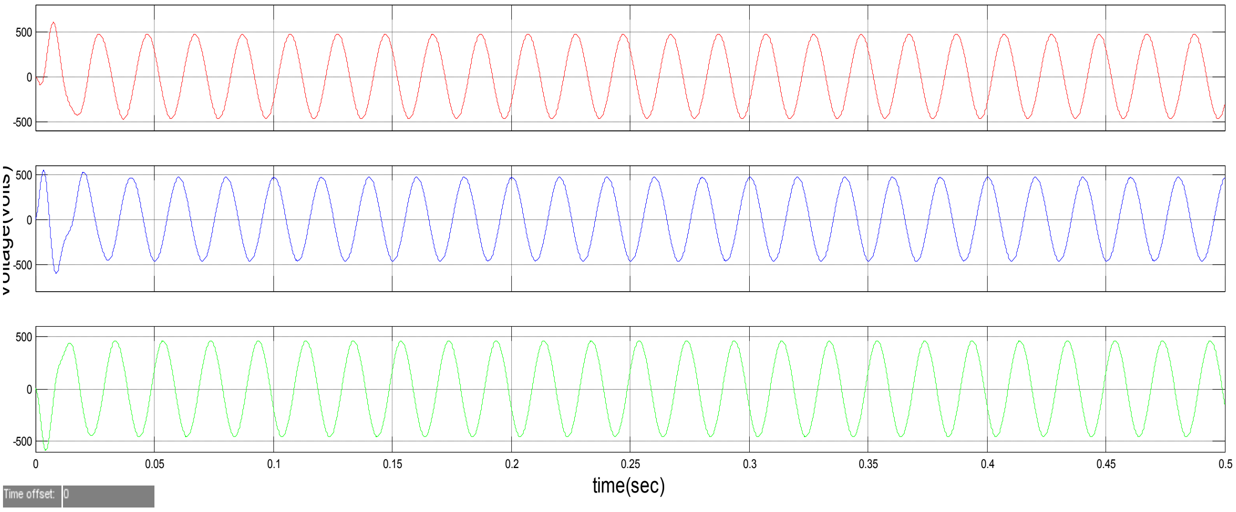

Figure 2.25: SPWM **based inverter Voltage waveforms With Filter Circuit**

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III. Conclusion and future work

3.1 Conclusion:

In this thesis the main objectives for the utilization of the studied equipment to mitigate the voltage sag and voltage swell. In order to protect critical loads from more sever fault in distribution network. The facility available in MATLAB/SIMULINK is used to carry out extensive simulation study.

Supply voltage is compared with reference voltage to get error signal which is given to the gate pulse generation circuit as a reference sine wave which is compared with carrier signal to get pulses for inverter.
PLL circuit is used to extract angle from supply voltage so that this circuit can be used at supply of any frequency so the error signal will be synchronisedsupply frequency.

3.2Future Work:

- Use error signal as a reference signal for pulse generation.
- Connect DVR with main supply through Boosting Transformer.
- Test the performance under various values of voltage sag and swell.

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