Mitigation of voltage sag and swell in a Grid connected PV system by using Dynamic Voltage Restorer

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Abstract: The development of industries and power electronic devices good electric power quality becomes a major requirement. Every consumer expects a clean and uninterrupted power quality for their sensitive equipment. Due to fast degradation of conventional energy resources, technological advancement is moving towards renewable energy tied grid system such as Photovoltaic energy generation, wind energy generation, Tidal energy generation etc. When there is flow of energy there will be fault and voltage sag voltage swell fluctuations and other problems which are most common in power system. Custom power devices are implemented to power quality problems. . A DVR is a fast acting custom power device provides effective voltage control to the distribution feeder. In this project work DVR is modelled with Grid connected PV system along with battery energy storage system in MATLAB/Simulink environment to mitigate power quality problems and results are discussed.
Index Terms **- Photovoltaic (PV), Dynamic Voltage Restorer (DVR), Voltage Sag, Voltage Swell, MATLAB/Simulink**.

I. INTRODUCTION

Power supply plays an important role in development and advancement of technology in whole world. With the growth of technology and industries, power quality becomes more important. The increasing utilization of power electronics based devices [1, 2] and due to faults occurring in the system sinusoidal nature of waveform lost. Various power quality problems like voltage sag [3], voltage swell [4], flicker [5] etc. affects the whole system and creates problem in achieving reliable and good constant power supply. FACTS controllers [6, 7] are implemented in the distribution feeder to mitigate power quality problems.

In Custom power devices [8, 9], dynamic voltage restorer (DVR) is most reliable and accurate devices to be connected in between the distribution system and consumer. These devices are implemented to compensate voltage and current fluctuations, improve power quality by injecting the reactive power, and by reducing harmonics generated or absorbed by the user. In the PV grid connected system, major problem is the increase in total harmonic distortion (THD) of the current injected in to the grid [10, 11] during low solar radiation period. The current to be injected into the grid system must be low value of THD, less than 5%.

Three control strategies are suggested to compensate for the voltage sags accompanied by phase jump, which is the usual case [4]:

1. Pre-sag compensation: This is one of the most effective anticipatory methods for voltage sag compensation. System voltage at the load end continuously monitored and when there is any possibility of sag in the system DVR acts before sag occurs and system voltage is restored to its nominal value. Pre sag compensation depends upon rating of DVR.
2. In-phase compensation: In this type of compensation, voltage generated by DVR for compensation remains in phase with the system voltage. This generated voltage is independent with the voltage before sag and load current before sag.
3. Energy optimal compensation: In this compensation technique it is mandatory to knowledge about load current so that full utilization of external energy source can be done (battery energy storage) and minimum amount of energy is depleted.

As a result, the aim of the thesis is characterizing voltage sags and inserting the missing voltage by DVR. The simulations are performed by using MATLAB/ Simulink program.

II. POWER QUALITY

Electric power quality is described as maintaining the system voltage that is very close to sinusoidal shape. Today due to increment in power electronic based controllers and other nonlinear loads which are very sensitive to power quality issues it is very difficult to maintain good power supply. Due to interconnect networks, whole system is getting affected if there is any disturbance at any point in the system. In the industries power quality problems are more common due to large loads connected and due to capacitor switching.

1. Problems Regarding Power Quality

Electric power quality is a rising issue in these days. Due to use of various power electronic based controllers [12] and nonlinear loads power quality get affected.

- Voltage Sag (Or Dip) and Voltage Swell [13]
- Interruption [14]
- Transients
- Harmonic Distortion [12]
- Voltage Fluctuation [3]
- Noise [8]
- Voltage Unbalance

2. Effects of Poor Quality on Power System Devices [1]

- Losses in transmission system within transmission lines, induction motors, transformers, increases. Controllers and other protective devices may mal-operate due to harmonics.
- Components working in power system may failure due to excessive harmonics in the system. Total system becomes unstable due to harmonic present in the system.
- Resonance and Ferro resonance also occurs in the system due to harmonics. Parameter failure may occur in the industries due to harmonic components in the feeder. Noise components in the system increases due to harmonics.

III. CUSTOM POWER DEVICES

Use of electronic equipment in power system has increased the concern about power quality problems. These devices are the source of power quality issues like, distortions, lower order harmonics, sag, swell, interruption, etc. use of large electronic devices in industries such as cycloconverters, capacitor banks, adjustable speed drives, etc. generate considerably high inrush current and transients. Concept of custom power devices is introduced to overcome all these problems as these devices are capable of handling issues related to all the three quantities, voltage current and active and reactive power. These devices are also having capability to operate in a complex network.

IV. PV CELL MODELING

The one diode model [3] of a solar photovoltaic (PV) cell [12] consists of a current source, a shunt resistance, a series resistance and a semiconductor diode.

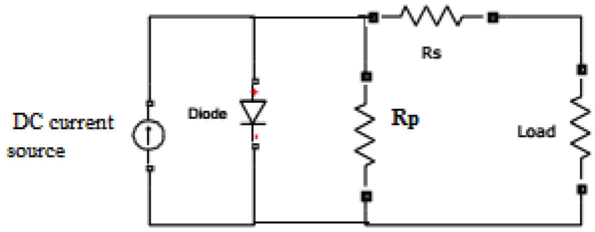

Figure 1: One Diode model of PV cell

The Expression for load current can be derived from the block diagram and is as follows.

$$I_L = I_{PH} - I_o\left[\exp\frac{q(V+IR_s)}{NKT} - 1\right] - \frac{(V+IR_s)}{R_{SH}}$$

Where I_L=Load current, I_{PH}= Photocurrent, Io = Diode reverse saturation current, N= Ideality factor, q = Electron charge (1.6x10-9 c), K=Boltzmann's constant (1.38x10-23 j/k), T = cell temperature, R_s= series resistance, R_{SH}= shunt resistance, I = output cell current, V = output cell voltage.
All this parameters plays important role in solar photo voltaic system.

V.VOLTAGE SAG AND SWELL

Voltage sag is defined as a decrease in the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0.5 cycle to 1 minute.Figure2 shows the decrease in voltage magnitude due to voltage sag. The different types of faults increase the severity of balanced and unbalanced voltage sags. Voltage sags are mostly caused by connection of heavy loads, start-up of large motors and faults in consumer's installation etc.
Voltage swell is defined as very short hike in the system voltage for the duration of one cycle to few milliseconds. Figure3 shows the increase in voltage magnitude due to voltage swell. Various types of faults like three phase short circuit fault, two phase fault, three phase to ground fault, operation of capacitor banks etc. results in short increase in voltage which is termed as voltage swell.

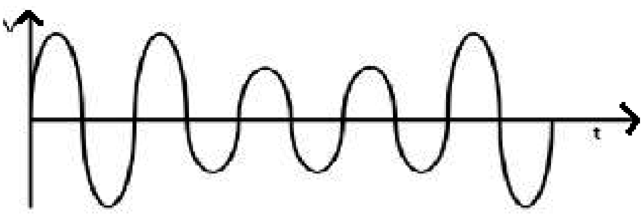

Figure 2: Voltage Sag

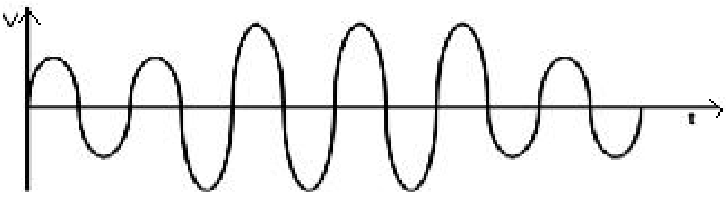

Figure 3: Voltage Swell

VI.CONTROLLER ALGORITHM

The basic objective of the control strategy is to keep voltage amplitude as constant at the point where sensitive equipment is connected, under system disturbances. VSI based control strategy are used in this paper, PWM technique is used mainly because of the low switching losses. The error signal which we obtain from the difference of the desired voltage and the R.M.S. voltage at the load point is the input of the controller.

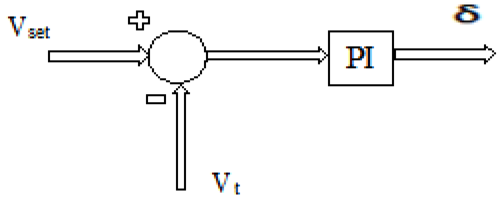

Figure 4: Block Diagram of PI Controller

PI (Proportional Integral) controller [6, 7] is used to process this error signal and then generate the phase angle, δ as the output, which is then given to the PWM generator. The PI controller is used to make the error signal to zero. The schematic diagram of PI controller is shown in Figure4 and Simulink model of PI controller are shown.

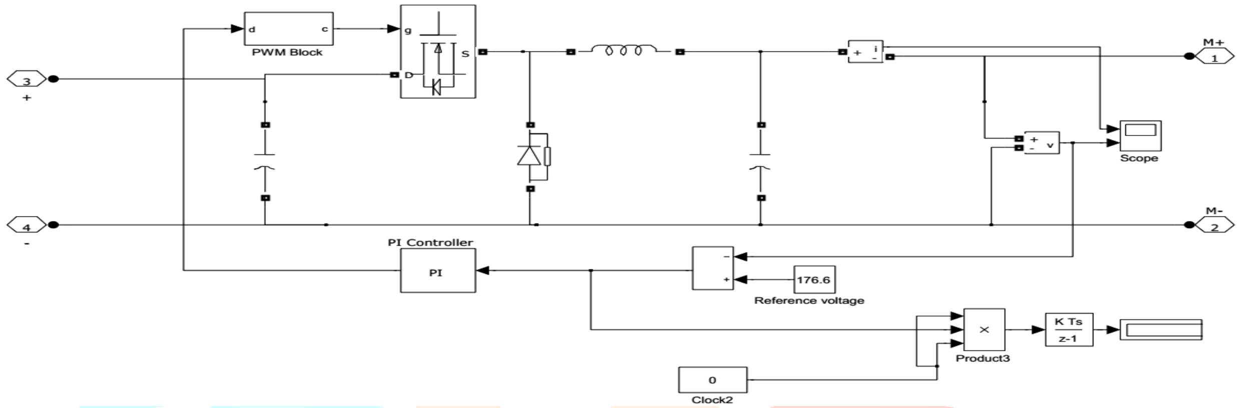

Figure 5: Simulink model of Controller

VII.DYNAMIC VOLTAGE RESTORER

1. Basic Operating Principle

Dynamic Voltage Restorer is one of the most accurate and efficient custom power devices in power systems. These devices are utilized to protect the sensitive loads in the industry from trip and these also protects from Voltage sag, Voltage swell, and other system faults. DVR provides compensation for voltage sag and swell both; condition is that the supply to the grid must not be entirely shut. The basic block diagram is shown in Fifure6 as below.

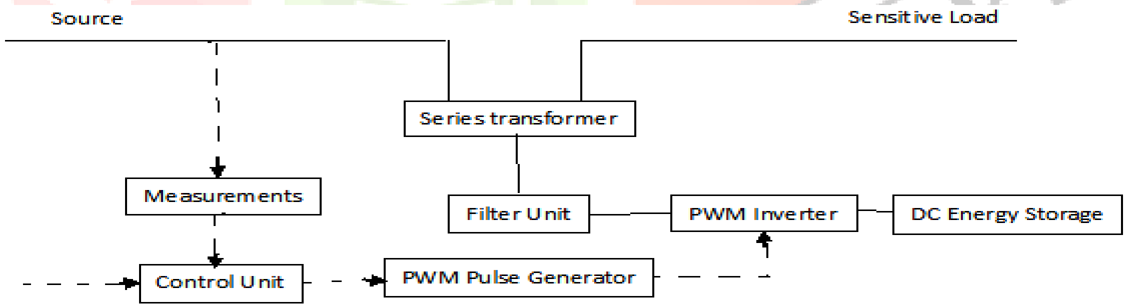

Figure 6: Basic block diagram of DVR

2. Configuration

In the basic configuration of the DVR majorly consists of following components.

A) Voltage Source Inverter: Voltage source inverters are widely used in low and high power applications such as motor drives, traction, UPS and bi-directional AC-DC converters.

B) Injection Transformer: Injection transformer is utilized in DVR connected system to isolate the system and also to provide support for converter and other protection equipment like fuses and circuit breakers.

C) Energy Source: Operating with energy storage gives limitations in the performance to compensate for long duration sags and large energy storage is still costly, therefore most of the proposed DVR solutions have been realized with a shunt converter fed from the line itself or an auxiliary supply.

D) Filtering Schemes: Filters are utilized in the distribution system to mitigate harmonics and noise from the resulting waveform**.**

E) DC link, Control and Protection System: The capacitor is used as DC link in system as high rating. The control unit controls the total operation of DVR. The protection system is backup of whole technique.

3. Emplacement of DVR

Dynamic voltage restorer is placed in between the source feeder and the distribution feeder. Location of DVR is chosen as to compensate the voltage sag or voltage swell being observed by the consumer. The position of the DVR in the system is represented in below Figure7.

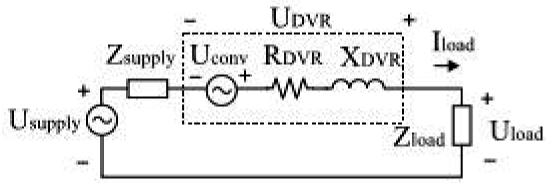

Figure 7: Schematic representation of Position of DVR in System

4. Operating modes of DVR

Basic operation of DVR is to provide a solution for power quality related problems with minimum requirement of energy source. DVR mainly operates in three modes, which are given below.

4. A.Protection Mode: In this mode DVR is bypassed to avoid injection of voltage. This is the case when there is short circuit occurs in the system and load current has increased drastically and has crossed the limit.

4. B.Standby Mode: In this mode there is no injection through booster transformer so injected voltage magnitude is zero. The secondary winding of injection transformer gets short circuited and the load current passes through only primary winding of injection transformer.

4. C.Injection Mode: In this injection mode voltage is injected is series with the system. When the sag or swell is detected in the system, the injection phenomenon starts.

5. Basic Key Advantages of DVR

There are number of advantages of DVR, in those some basic advantages are as follows. In battery energy storage integrated Dynamic Voltage Restorer, have capability to compensate and control active power flow in the distribution system.

- Cost relatively very low as we consider other compensation techniques.
- Total controller size is compact.
- Its transient response is very accurate.
- Its energy capacity is comparably higher than other devices in the market.
- Maintenance cost is quite low as and it's easy to maintain.
- Its response to power quality problem is very quick and response time is short as compare to other devices.

VIII.PROPOSED INTEGRATED PV-DVR SYSTEM

The Figure8 shows the grid connected PV system with integrated DVR topology. The PV system is connected in series with the system and the output voltage given to the transformer. Here the three phase programmable voltage source is taken as grid which is connected with transformer. The DVR is connected in series with system by transformer. The fault is created at the grid side as shown.

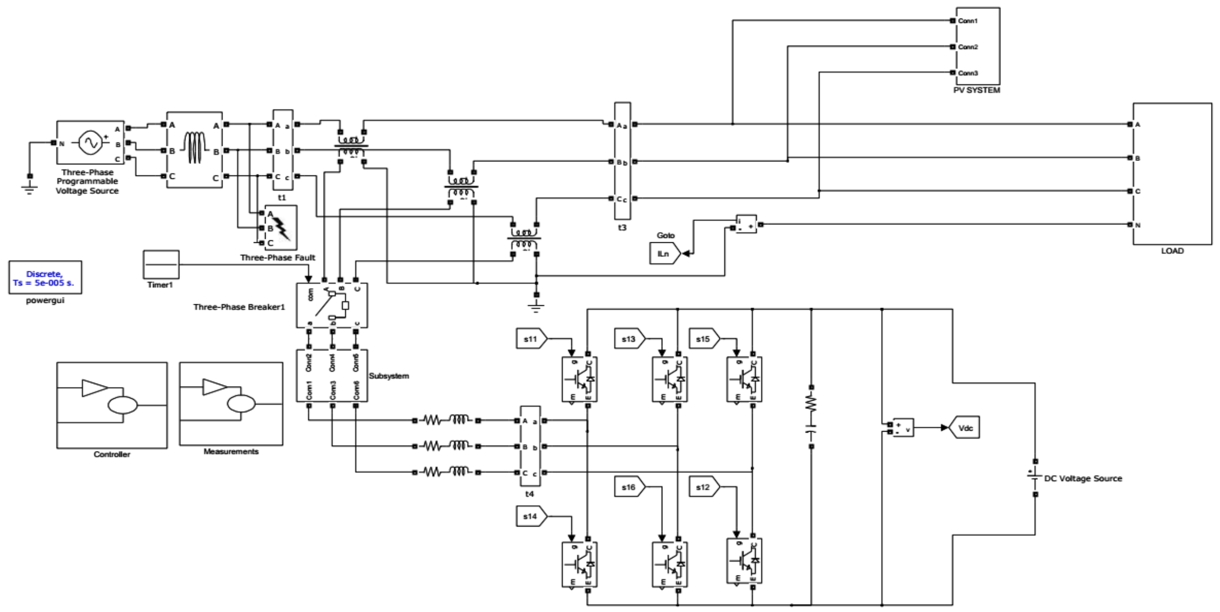

Figure **8**: Simulation Diagram of DVR integrated PV System

A three level inverter technique is utilized to obtain the harmonic free stable AC. In the grid connected system, it is necessary to provide a clean AC to the grid. In case of three phase fault in the system, grid voltage collapses and the grid current increases sharply and the whole system will be affected. To compensate voltage sag, custom power devices are implemented in which DVR is more efficient and accurate. When sag or swell comes the DVR injects voltage according to requirement.

IX.SIMULATION RESULTS

The Simulation results were run at 0.35seconds and the results were recorded. Without DVR topology for sag and swell, the results are shown in Fgure9 and Figure10.When the DVR is connected, the results as shown in Figure11 as for Sag condition.

Similarly, the results for Swell condition is shown in Figure12 below. The capacitor voltage (DC) and neutral current waveforms are shown in Figure13.

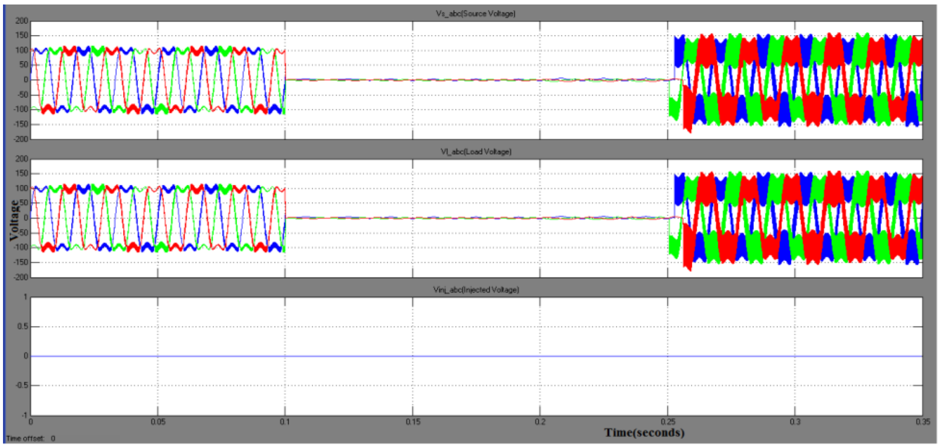

Figure 9: Without DVR topology for Sag Case

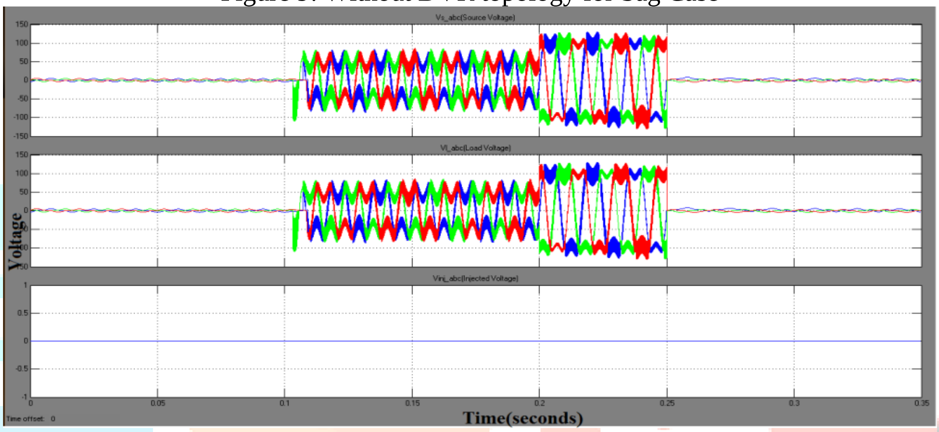

Figure 10: Without DVR topology for Sag Case

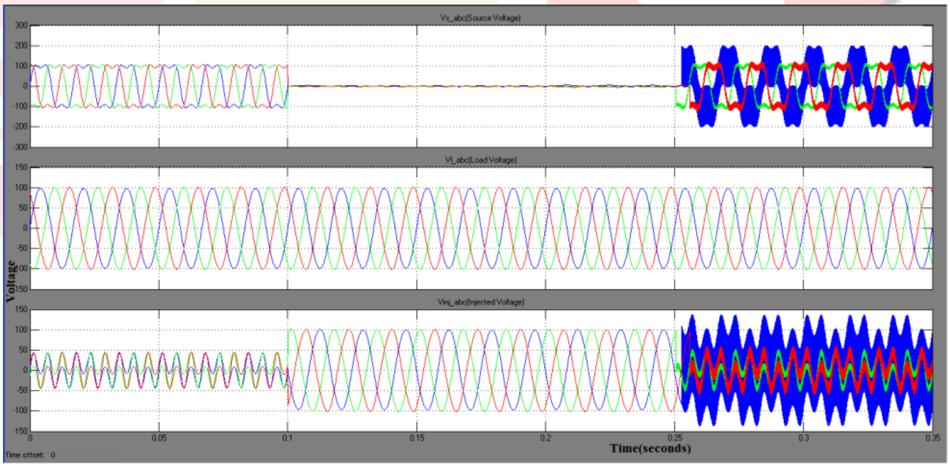

Figure 11: With DVR topology For Sag Condition

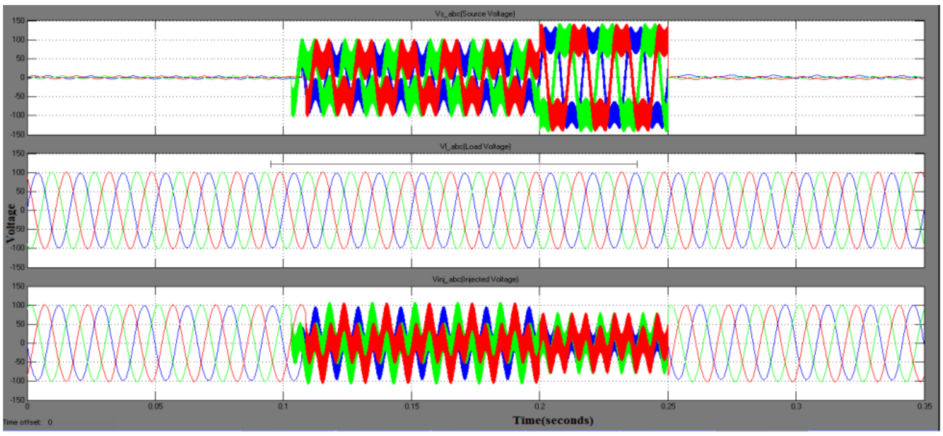

Figure 12: With DVR topology For Swell Condition

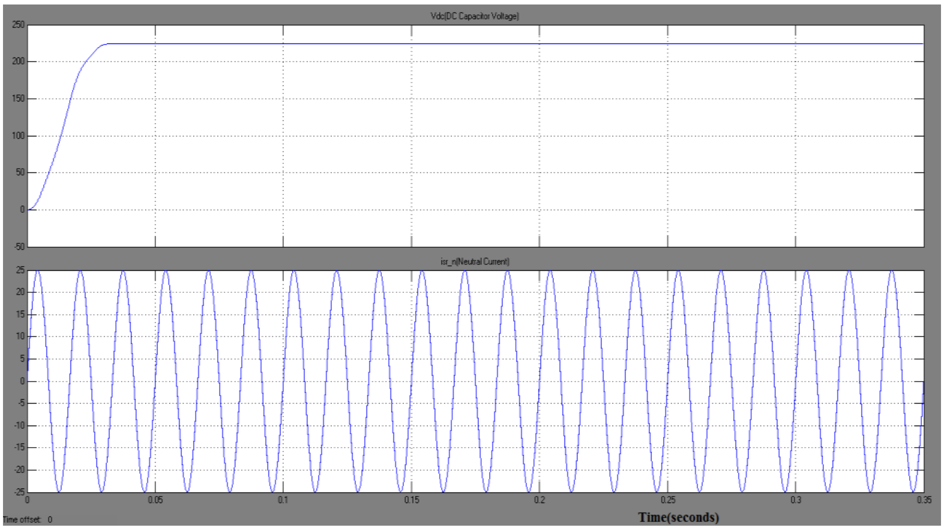

Figure 13: Capacitor Voltage and Neutral Current

IX.CONCLUSION

In this project a PV grid integrated system is used in which voltage sag and swell compensation were done with the DVR technique. A three level inverter converts the DC into AC and grid is connected to line and the PV system is connected in series with the system. The fault analysis is done. Voltage sag and swell compensation are mitigated with DVR technique as efficiently. Voltage compensated by DVR is up to 0.95 p.u. By seeing the simulation results we can conclude that, the proposed system works efficiently and voltage compensation technique of DVR for Sag and Swell is accurate and precise.

X.FUTURE SCOPE

In this thesis work it is clearly shown that DVR can effectively mitigate voltage sag and it is one of the most effective FACTS controllers used for voltage sag mitigation. Some other points are given below which suggests the future extension of this work.

- Controllers used in the DVR can be replaced with fuzzy controllers, artificial intelligence techniques or state space vector techniques to improve response of DVR and also to increase effectiveness.
- Other liner or nonlinear loads can also be used to check the performance of DVR.
- Filters used in the system can be replaced by advance synchronous filters to improve resulting waveforms.
- Materials used for fabrication of PV cell can be replaced with other new more efficient semiconductor materials to improve performance of PV module so as to improve overall system response.

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