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Contemporary Control of DG Integrated DVR for Sag, Swell and Harmonic Mitigation

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ABSTRACT

This paper presents a novel control strategy to control DG integrated DVR (dynamic voltage restorer) for mitigation voltage quality problems. Power quality is the most concerning areas in power engineering and voltage quality is of prime focus. Voltage sag, voltage swell and harmonics in voltage causes deterioration in quality of voltage delivered to load. A minor disturbance in voltage profile can degrade the performance of load. Dynamic voltage restorer is a quick responsive custom power device for voltage quality improvement. Photovoltaic (PV) system is considered as DG and output voltage of PV system is boosted with a boost converter to support voltage source converter of DVR. DG integrated DVR with novel control strategy for mitigation of voltage sag, swell and voltage harmonic is presented in this paper. The power system model with DG integrated DVR is developed and results are obtained using MATLAB/SIMULINK. Results are discussed during pre and post sag/swell condition with compensation and THD in voltage is maintained within nominal values.

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1. INTRODUCTION

Power quality is utmost concern for power engineers in these modern days scenario of loads mostly being very sensitive. Advancements in power electronic segment gave greater flexibility in power system but the usage of power electronic based loads can cause power quality issue like harmonics to be induced in to the power system. Power system is subjected to faults very often due to local conditions, environmental conditions, and natural conditions or due to power system conditions [1-2]. Faults can introduce sag or swell in voltage profile of power system and presence of sag or swell in voltage profile seriously affects the power system performance especially in load segment. The phenomenon of sag, swell or harmonics in voltage waveform affects the voltage quality delivered and can seriously harm the devices connected at load centers.

Sag or swell phenomenon can be occurred with fault in either distribution system or in transmission system and can occur at any instant of time and lasts for few seconds or milliseconds [3-4]. Sag is generally observed in power system with the presence of short faults. Sag can also be observed in power system with sudden switching ON of heavy loads. Sag is reduction in voltage profile in power system below 90% to 10% of nominal RMS voltage. A small reduction in voltage level reduces the performance of load and even reduces the efficiency. Sag in voltage profile can reduced the life period of the load devices.

Swell is increase in voltage level above 110% of the nominal RMS voltage. Unlike sag, swell is very dangerous as it can damage the load devices [5-6]. Swell is observed due to sudden switching ON of capacitor banks, sudden release of heavy loads. Swell in voltage profile is very rare in occurrence. Harmonics in voltage profile are caused due to current harmonics [7-8]. Current harmonics are present due to non-linear loads and this non-linear current induces harmonics in voltage profile. Source impedance can cause voltage harmonics and for this source impedance is kept low in value to limit voltage harmonics.

Compensation schemes like the use of passive filters and other equipment for sag, swell and harmonics are conventional but contemporary compensation scheme using power electronic converters are used. N. G. Hingorani in the year 1995 developed the concept of FACTS and custom power devices for smart control and flow of power in transmission system and distribution system respectively. Custom power devices are power electronic based compensators used to address power quality problems.

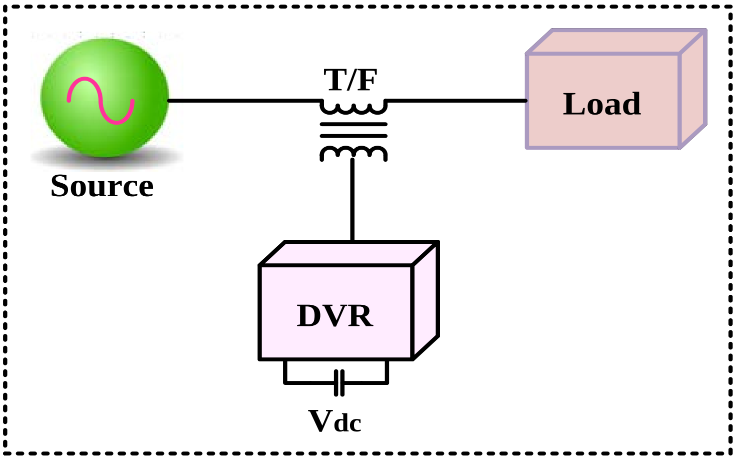

Figure 1. General block diagram of DVR in power system

Dynamic voltage restorer (DVR) [9-10] is a compensation type custom power device primarily used for compensation of voltage quality issues. Voltage profile problems like voltage sag, voltage swell. Voltage harmonics in distribution system can be affectively addressed by using DVR. DVR is a series compensator circuit placed in series with the power system line. A typical block diagram of DVR connected in power system is shown in Figure 1. General DVR configuration consists of capacitor as DC source to provide stiff voltage. To deliver heavy compensating voltages from voltage source converter of DVR and capacitor might not be sufficient enough to deliver required compensating voltages. A simple photovoltaic (PV) system as distributed generation (DG) is placed to support the voltage source converter of DVR to provide strength to deliver required compensating voltages from voltage source converter of DVR.

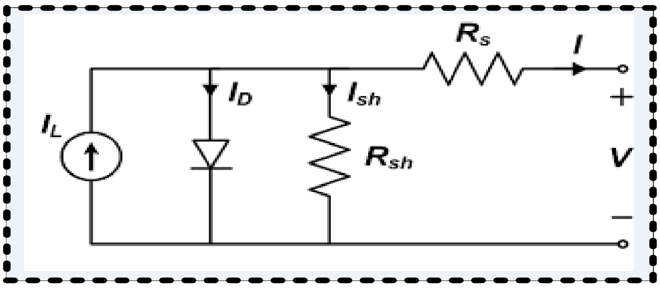

Figure 2. PV equivalent circuit

This paper presents a novel control strategy to control DG integrated DVR (dynamic voltage restorer) for mitigation voltage quality problems. Voltage sag, voltage swell and harmonics in voltage causes deterioration in quality of voltage delivered to load. A minor disturbance in voltage profile can degrade the performance of load. Photovoltaic (PV) system is considered as DG and output voltage of PV system is boosted with a boost converter to support voltage source converter of DVR. PV equivalent circuit is shown in Figure 2. DG integrated DVR with novel control strategy for mitigation of voltage sag, swell and voltage harmonic is presented in this paper. The power system model with DG integrated DVR is developed and results are obtained using MATLAB/SIMULINK. Results are discussed during pre and post sag/swell condition with compensation and THD in voltage is maintained within nominal values.

2. DG INTEGRATED DVR FOR VOLTAGE QUALITY ISSUES

Dynamic voltage restorer is a series compensating type custom power device placed in series to power system line to compensate voltage quality problems. A DVR is typically a voltage source converter consisting of solid-state switches. DVR induces voltage in to power system line for voltage problem compensation. Generally, voltage source converter is driven with a small DC voltage source typically a capacitor. If the voltage quality problem is weighted, capacitor perhaps cannot drive voltage source converter of DVR for compensating voltages. A simple photovoltaic (PV) system as distributed generation (DG) is placed to support the voltage source converter of DVR. The output of PV system is boosted with the help of simple boost converter. PV system with boost converter provides strength to deliver required compensating voltages from voltage source converter of DVR during weighted voltage profile issues. DG with PV system and boost converter integrated DVR connected in power system line is shown in Figure 3. The solid-state switches of DVR are triggered by the pulses obtained from control circuit. DVR is sourced from PV fed boost converter as shown in Figure 3.

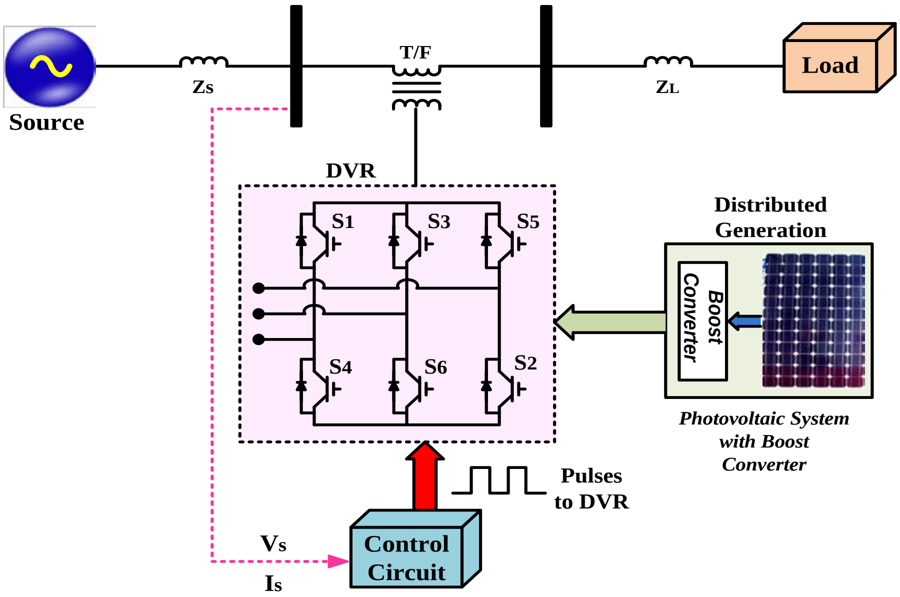

Figure 3. DG integrated DVR connected in power system line

3. NOVEL CONTROL STRATEGY FOR DVR

The novel control strategy of DG integrated DVR for suppression of sag, swell and voltage harmonics in distribution system is shown in Figure 4. Source voltage is sensed from input source bus and information regarding Va, Vb and Vc are obtained from source voltage Vs. From phase-A, ie., from Va, signal Vα is obtained. By delaying Vα signal by 90^0 yields Vβ signal. From the obtained Vα and Vβ signals, $V^2\alpha$ and $V^2\beta$ are obtained and both are added. Applying square-root to obtained signal ($V^2\alpha+V^2\beta$) yields actual maximum value of voltage. This actual value is compared with reference signal and is multiplied with signal shape obtained from phase locked loop. Similar process is carried out for remaining two phases Vb and Vc. The shape of the waveform is delayed by 120^0 and 240^0 respectively for phase-B and phase-C. The final signals of three phases are sent to PWM generator to produce pulses to switches in DVR. Figure 5 shows the overall schematic arrangement of DG integrated DVR with proposed novel control strategy.

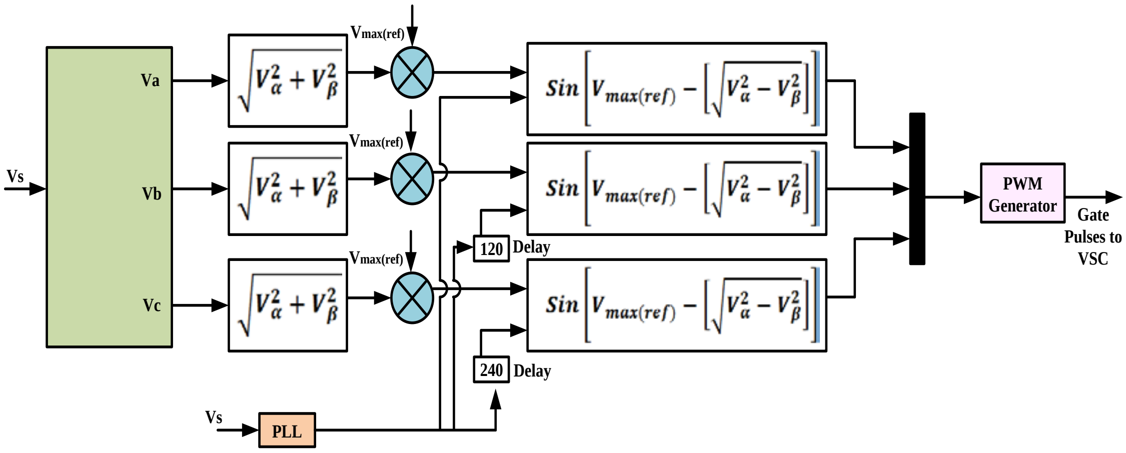

Figure 4. Proposed control strategy for DG integrated DVR

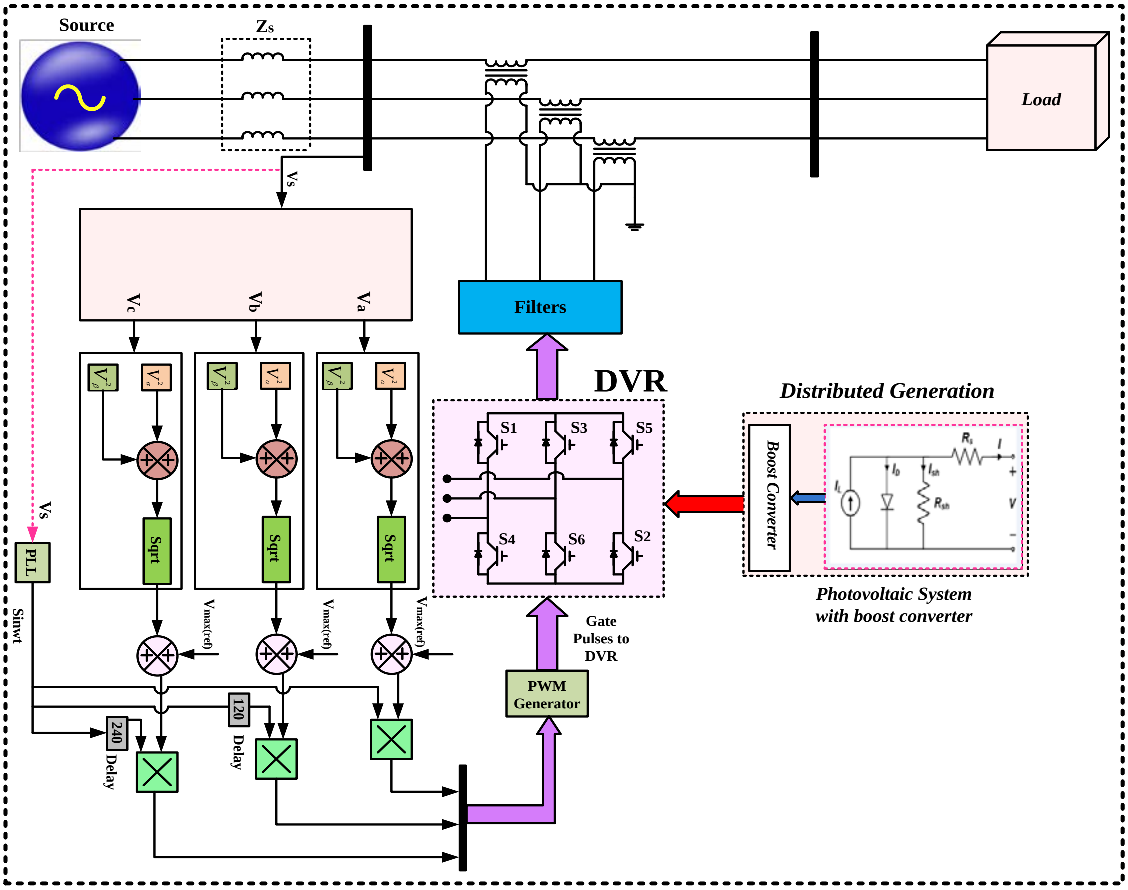

Figure 5. Overall schematic arrangement of DG integrated DVR with proposed control strategy

4. RESULTS AND ANALYSIS

System parameters used to develop the model is tabulated in Table 1. Three-phase source voltage with sag, DVR injected voltage and load voltage is shown in Figure 6. Sag is present in source voltage from duration 0.1 sec to 0.2 sec. During the sag period in source voltage, DG integrated DVR injects compensating voltages and thus load voltage is maintained with constant amplitude as shown in Figure 6.

Table 1. System Parameters

Parameter	Value
Frequency	50 Hz
Load Power	10 KW
DC-Link Voltage (Boost Output)	550 V
PV Output Voltage	200 V

4.1. DG Integrated DVR for SAG Compensation

The boost converter output and the PV system output voltage are shown in Figure 7 and Figure 8 respectively. The PV output of 200 V is boosted to 550 V by using boost converter as shown in their respective Figures.

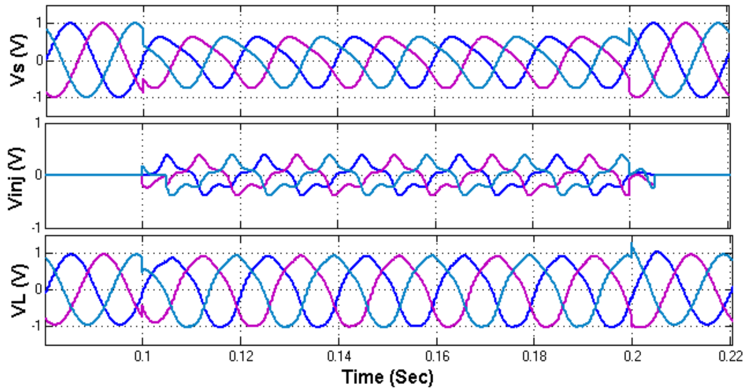

Figure 6. Three-phase source voltage, DVR injected voltage and load voltage

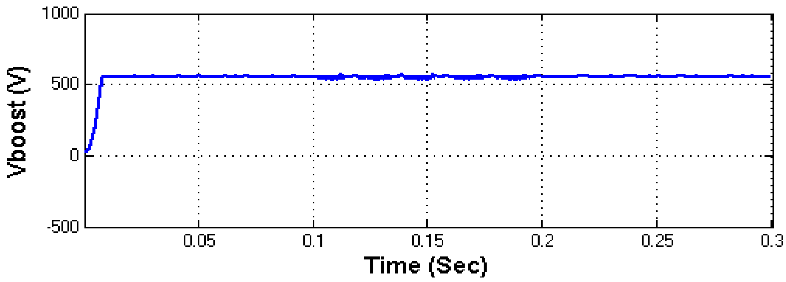

Figure 7. Boost converter output voltage

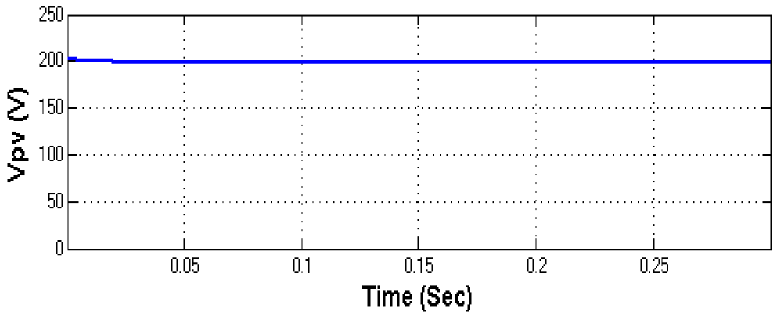

Figure 8. PV output voltage

4.2. DG Integrated DVR for Sag and Harmonic Compensation

Figure 9 shows the source voltage containing sag and harmonics, DVR injected voltage and load voltage after compensation. Sag is present in source voltage from 0.2 sec to 0.4 sec also containing harmonics. DG integrated DVR injected voltage and compensates the sag so that sag is not appeared in load voltage thus maintaining load voltage profile constant peak amplitude. Harmonic THD of 23.09% is present in source voltage during sag condition as shown in Figure 10. DVR compensates harmonics with THD of 4.44% in load voltage profile and is well maintained within nominal limit as shown in Figure 11.

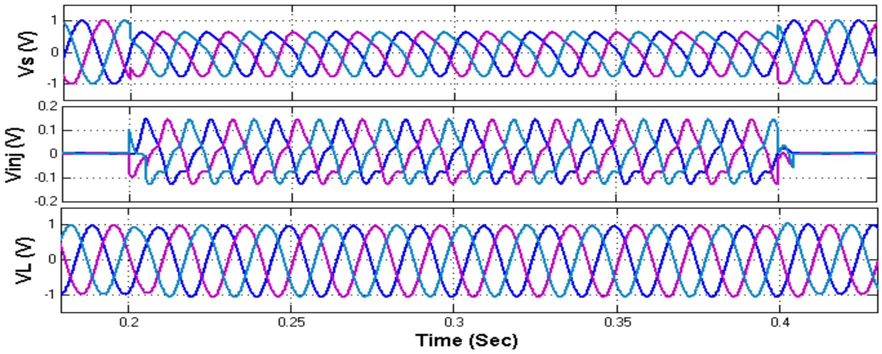

Figure 9. Source voltage, DVR injected voltage and Load voltage

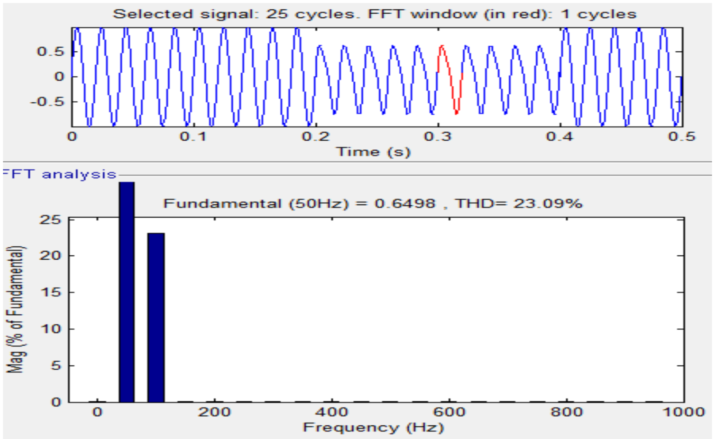

Figure 10. Source voltage THD during sag

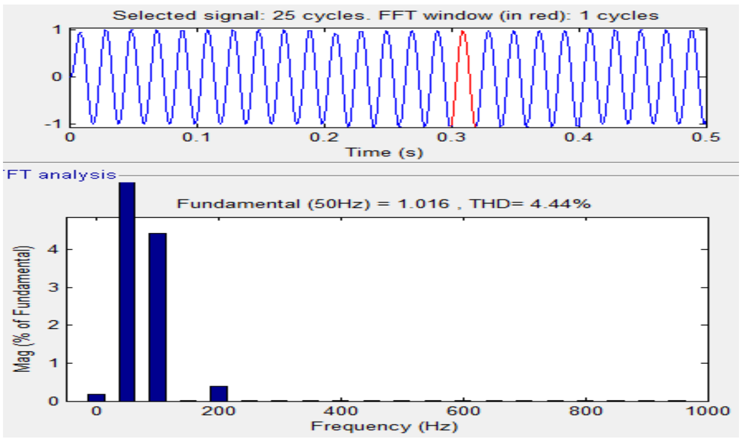

Figure 11. Load voltage THD after compensation

4.3. DG Integrated DVR for Swell Compensation

Three-phase source voltage with swell, DVR injected voltage and load voltage is shown in figure 12. Swell is present in source voltage from duration 0.1 sec to 0.2 sec. During the swell period in source voltage, DG integrated DVR injects compensating voltages and thus load voltage is maintained with constant amplitude of 1 P.U as shown in Figure 12.

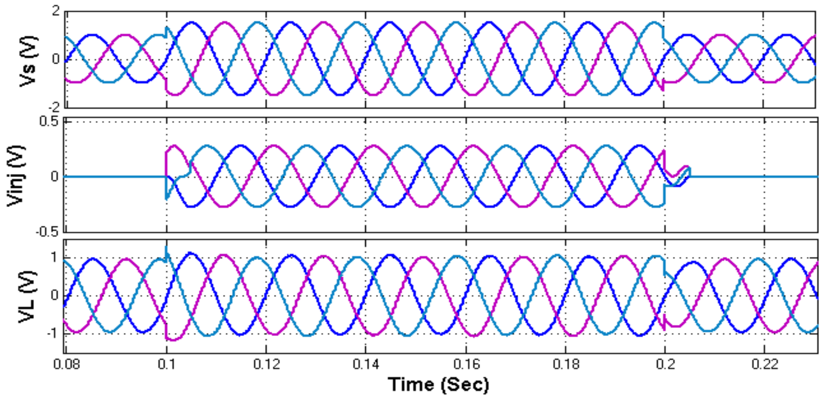

Figure 12. Source voltage, DVR injected voltage and Load voltage during swell compensation

4.4. DG Integrated DVR for Swell and Harmonic Compensation

Figure 13 shows the source voltage containing swell and harmonics, DVR injected voltage and load voltage after compensation. Swell is present in source voltage from 0.2 sec to 0.4 sec also containing harmonics. DG integrated DVR injected voltage and compensates the swell so that swell is not appeared in load voltage thus maintaining load voltage profile constant peak amplitude. Harmonic THD of 11.11% is present in source voltage during swell condition as shown in Figure 14. DVR compensates harmonics with THD of 4.65% in load voltage profile and is well maintained within nominal limit as shown in Figure 15.

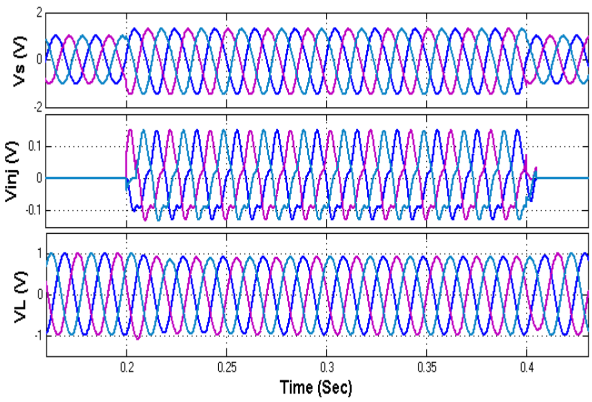

Figure 13. Source voltage, DVR injected voltage and load voltage during swell and harmonic compensation

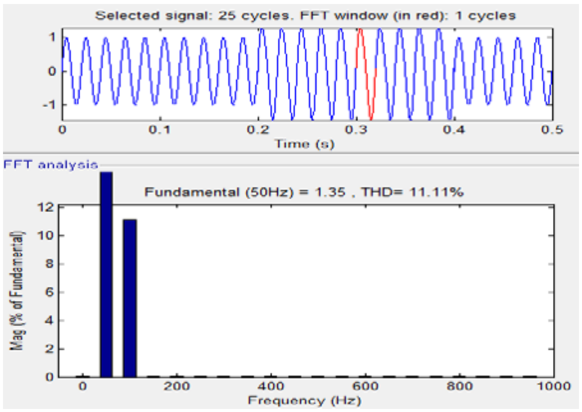

Figure 14. Source voltage THD

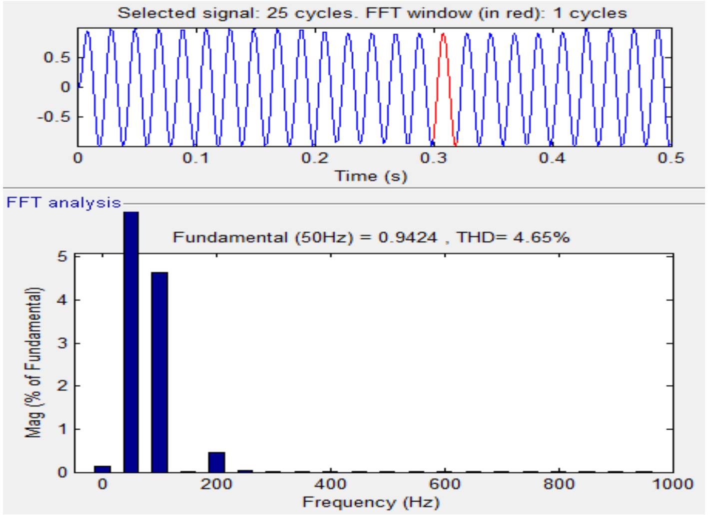

Figure 15. Load voltage THD

4.5. DG Integrated DVR for Sag and Swell Compensation

Figure 16 shows the Source voltage, DVR injected voltage and Load voltage during sag and swell compensation. Source voltage contains sag from duration 0.1 sec to 0.2 sec. After 0.2 sec, source voltage restores to normal value. From 0.2 to 0.4 sec, source voltage contains voltage swell. DVR injects compensation signals from 0.1 to 0.2 sec to compensate for voltage sag and injects compensation signals from 0.2 to 0.4 sec to compensate for voltage swell. Load voltage is maintained at constant voltage profile with no sag and swell.

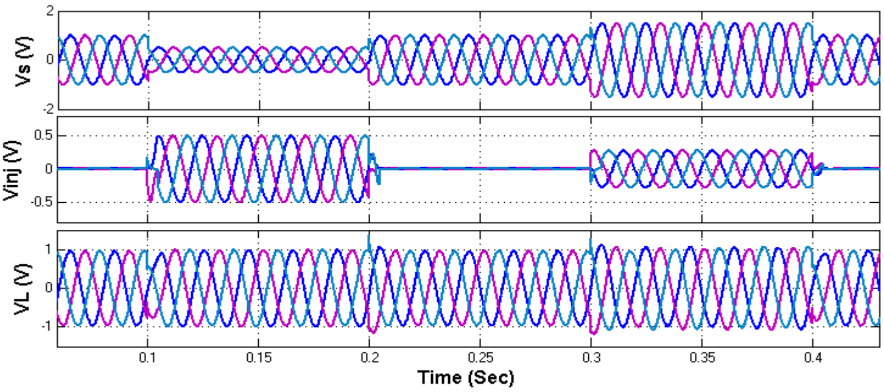

Figure 16. Source voltage, DVR injected voltage and load voltage during sag and swell compensation

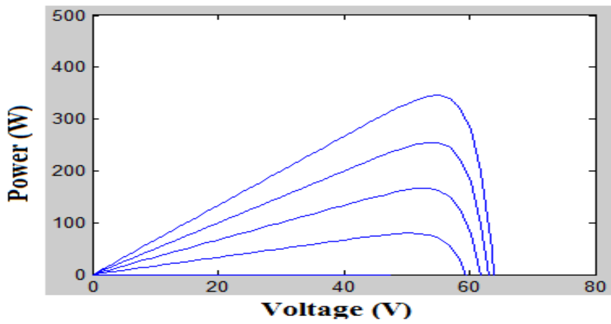

Figure 17. PV power

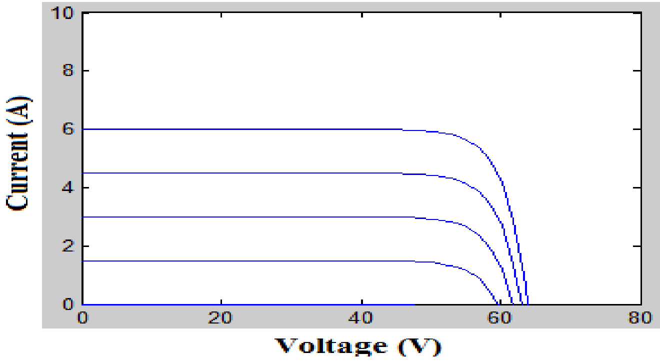

Figure 18. I-V characteristics

Power-Voltage (P-V) characteristics of photovoltaic system are shown in Figure 17 and current-voltage (I-V) characteristics of photovoltaic system are shown in Figure 18. Table 2 represents the THD analysis of voltage harmonic compensation with DG integrated DVR.

Table 2. THD analysis

THD	Source voltage	Load Voltage
Sag Compensation	23.09 %	4.44 %
Swell Compensation	11.11 %	4.65 %

5. CONCLUSION

Distributed generation (DG) integrated DVR for voltage quality improvement is presented in this paper with voltage sag, swell and harmonic compensation. PV system is considered as DG and output of PV system is boosted to required level using boost converter. 200V output from PV system is boosted to 550V using boost converter. DG integrated DVR is tested for cases like presence of only sag in source voltage and its compensation in load voltage. Similarly DG integrated DVR is tested for only swell condition and its compensation, sag and harmonics, swell and harmonic conditions. THD is well maintained within nominal limits during harmonic compensation and load voltage is maintained with constant peak in all the conditions. PV characteristics were also shown.

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