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A Novel Control Strategy Based Dynamic Voltage Restorer for Compensation of Voltage Harmonics in Distribution System

Syed Suraya*, P Sujatha, P Bharat Kumar
Department of EEE, JNTUA, Ananthpur, AP, India
*Corresponding author, e-mail: syedsuraya143@gmail.com

Abstract

Power quality is one of the areas that the power sector is worried about. Power quality is the measure of practical system resemblance to ideal system. Voltage quality can be defined as the maintenance of voltage waveform shape close to ideal shape with proper magnitude and frequency. Even a slight change in voltage of the system can cause serious damage to the power system. Sensitive loads cannot adjust for small change in voltage. This paper presents Dynamic Voltage Restorer (DVR) for voltage harmonic suppression along with sag/swell compensation in distribution system. DVR is a voltage source converter which sends compensating signals when operated through switches of voltage source converter. This paper presents a novel control strategy to control DVR to block out the voltage harmonics in distribution system. The models and results are developed using MATLAB/SIMULINK software and comparative analysis of source voltage harmonics and load voltage harmonics during sag/swell compensation was tabulated.

Keywords*: novel control, DVR, Voltage harmonics, sag, swell*

1. Introduction

Voltage quality issues are the main concern for power engineers in these modern days. Voltage quality is the measure of maintaining voltage profile in the power system as close to ideal system with fitting magnitude and frequency. Quality issues in voltage profile might be due to sag, swell or harmonics problem. Sag can be defined as reduction in voltage level from 90 % to 10% of its final value for less than one minute and swell can be defined as raise in voltage level more than 110 % of its final value for one less than one minute. Harmonics are the waveforms with frequency which is integral multiples of fundamental component. Voltage quality issues mainly occur due to sudden switching ON or switching OFF the heavy loads, motor starting, change in impedance [1]. Sensitive loads connected to power system are very sensitive to voltage quality issues [2]. Even a slight change in voltage level can create serious damage to the equipment connected at load points. Sag can decrease the efficiency of the system and reduces the life time of the equipment. Swell can damage the equipment. Type of loads can also cause voltage quality issues like non-linear loads in power system can induce harmonics in to source components. Presence of harmonics in source components can cause excessive heating of coils and might lead to damage of equipment.

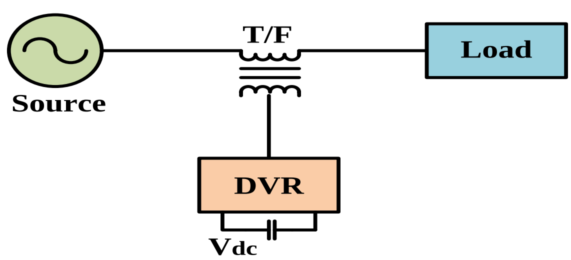

Figure 1. Basic diagram of DVR in power system

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Some of the voltage quality issues can be addressed using tap changers or by transformers [3] as conventional solutions. But this solution involves bulky equipment and increases the cost of the system [4]. The other method is to use uninterrupted power supplies (UPS), but use of battery banks in UPS makes system costlier. Use of FACTS devices based compensators for voltage quality problems is a viable solution. DVR (Dynamic voltage restorer) is one among FACTS devices used to improve voltage profile in power distribution system.

Figure 1 shows the basic schematic arrangement of how DVR is connected to power distribution system. DVR is a series compensator and is connected in series to distribution system through transformer. DVR is a voltage source converter consisting of power electronic switches triggered from pulses obtained from gate drive circuit of control strategy. DVR is supported with a stiff DC voltage source [5] at the input. DVR compensates for the voltage quality issues inducing suitable voltage [6] in to distribution system through transformer. Compensating signals from DVR depends on control technique we are selecting for particular issue [7]. Different control strategies are presented in [8-9] for obtaining gate pulses to DVR.

This paper presents Dynamic Voltage Restorer (DVR) for voltage harmonic suppression along with sag/swell compensation in distribution system. DVR [10-13] is a voltage source converter which sends compensating signals when operated through switches of voltage source converter. This paper presents a novel control strategy to control DVR to block out the voltage harmonics in distribution system. The models and results are developed using MATLAB/SIMULINK software and comparative analysis of source voltage harmonics and load voltage harmonics during sag/swell compensation was tabulated.

2. Dynamic Voltage Restorer for Voltage Harmonic Compensation

Dynamic voltage restorer (DVR) [10-12] is also called as series voltage booster or static series compensator (SSC). DVR consists of solid state switches forming a voltage source converter with stiff input DC source provided either by small DC source or by capacitor. DVR is a series compensating FACTS device connected in series to distrinution system with transformer. Transformerless DVR configuration is also reviewed in literature. DVR induces vector voltage which adds to source voltage and thus maintaining load voltage profile constant. Figure 2 shows the schematic arrangement of DVR with gate drive circuit giving triggering pulses to switches in DVR through control circuit.

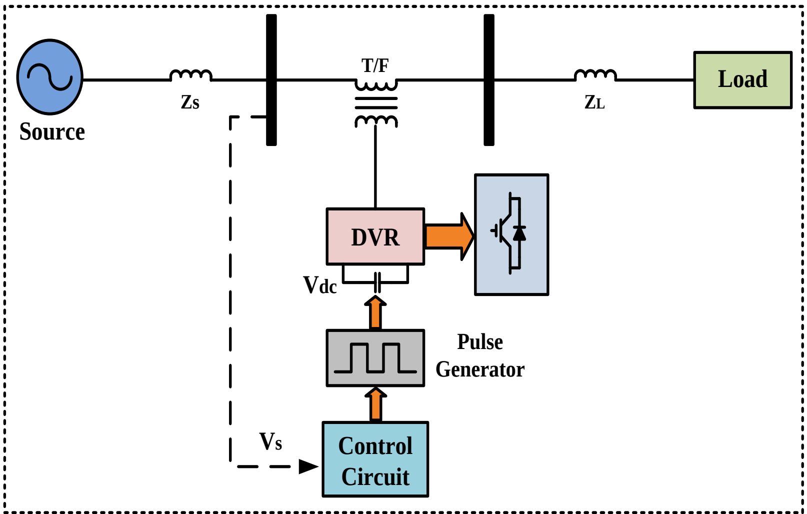

Figure 2. Schematic circuit of DVR

3. Proposed Novel Control Strategy for DVR

The novel control strategy for suppression of sag, swell and voltage harmonics in distribution system is shown in figure 3. 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 ob tained. 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 squareroot 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 4 shows the overall schematic arrangement of DVR with proposed novel control strategy.

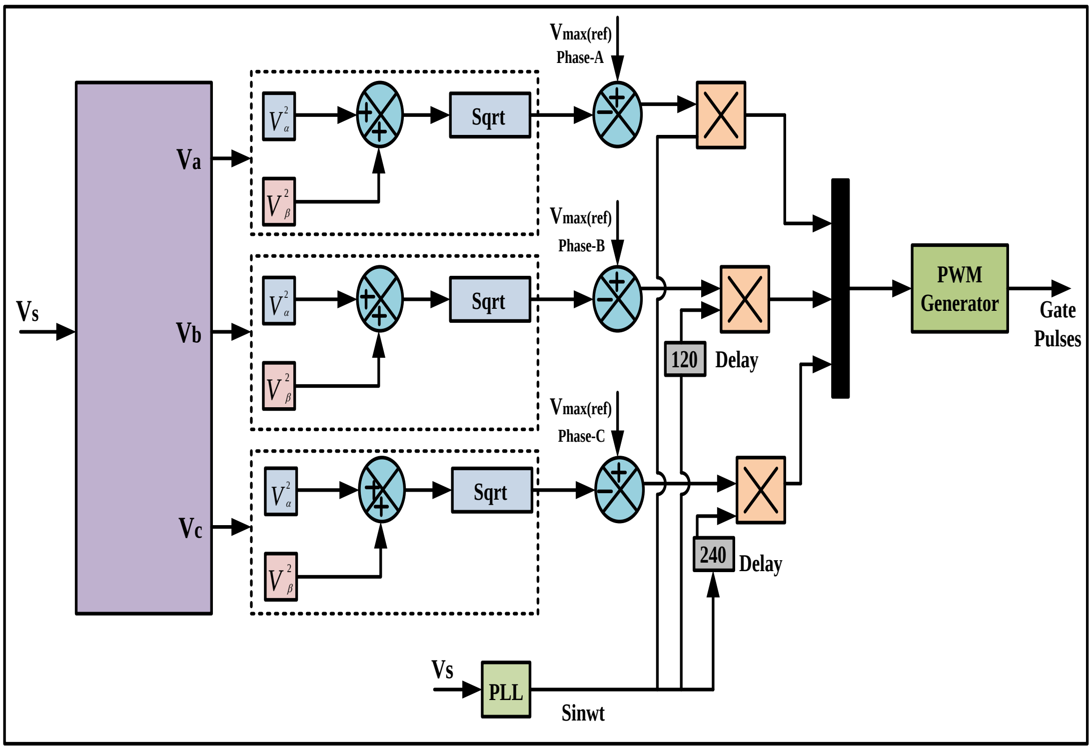

Figure 3. Proposed novel Control for DVR to compensate voltage harmonics

4. Results and Analysis

Table 1 shows the system parameters used to design simulin models and results.

Table 1. System Paprameters

Parameter	Value
Frequency	50 Hz
Load Pow er	10 KW
DC Link voltage	550 V

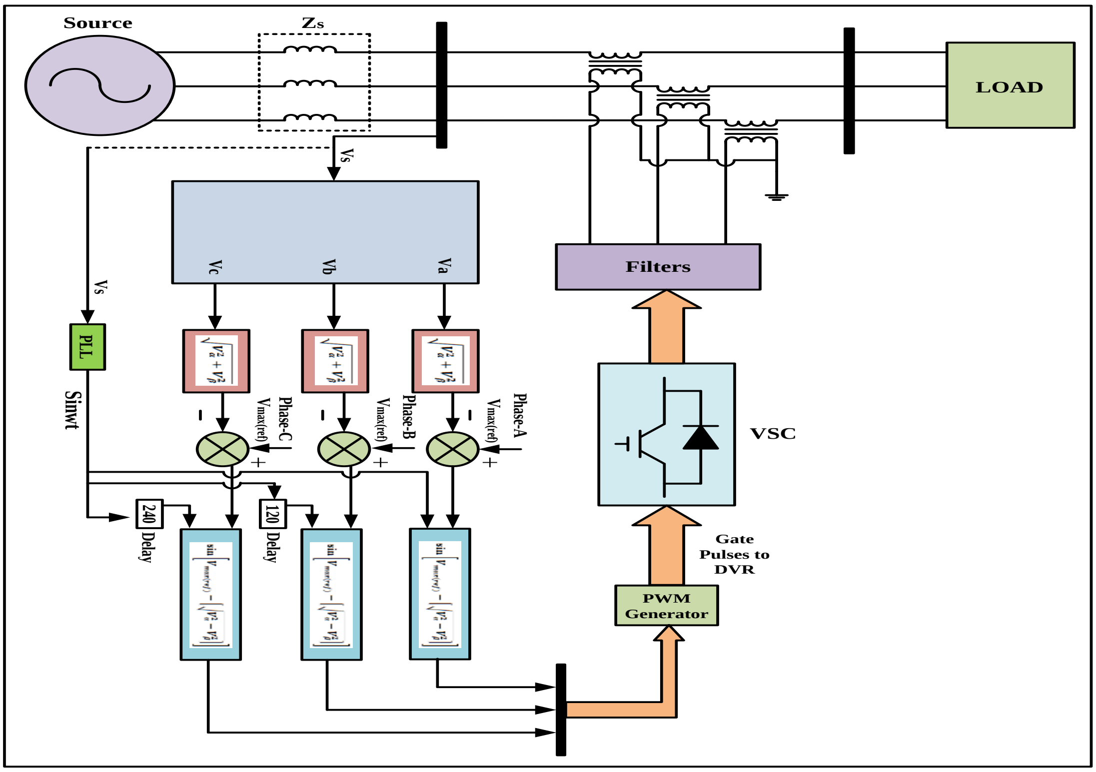

Figure 4. Overall schematic arrangement of DVR with proposed novel control strategy

4.1. Compensation of Voltage Sag

Figure 5 shows the Simulink result of three-phase source voltage having voltage sag from duration 0.1 sec to 0.2 sec. During this time duration, DVR sends compensating signals to point of common coupling as in figure and thus the load voltage profile is maintained constant as shown in Figure 5.

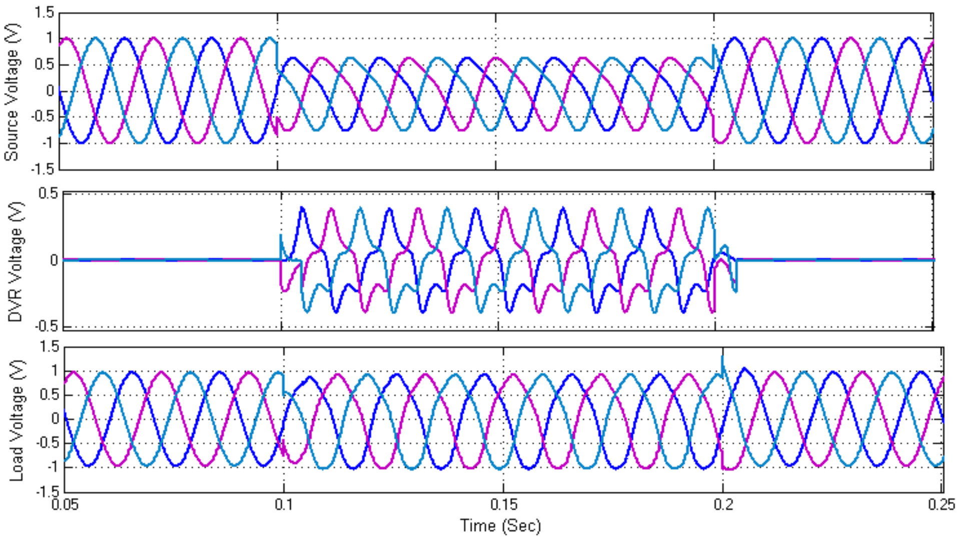

Figure 5. Result showing Source voltage, DVR injected voltage and load voltage

4.2. Compensation of Voltage Swell

Figure 6 shows the Simulink result of three-phase source voltage having voltage swell from duration 0.1 sec to 0.2 sec. During this time duration from 0.1 to 0.2 sec, DVR sends compensating signals to point of common coupling as in figure and thus the load voltage profile is maintained constant as shown in Figure 6.

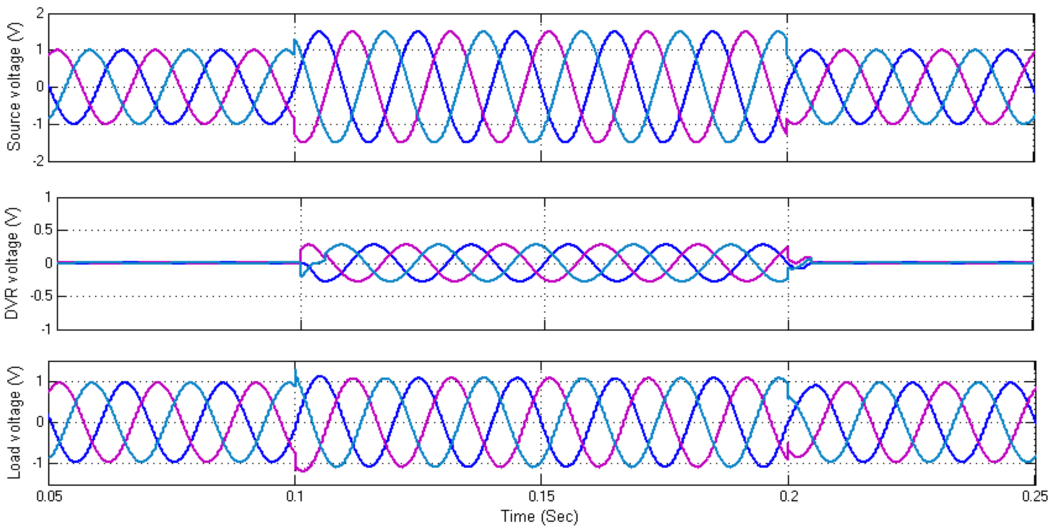

Figure 6. Source Voltage, DVR Voltage, and Load Voltages for swell condition

4.3. Compensation of Voltage Sag and Swell

Figure 7 shows the result of source voltage, DVR voltage and load voltage. Source voltage contains sag and swell. Sag is observed from 0.1 sec to 0.2 sec and swell is observed from 0.3 sec to 0.4 sec. DVR also sends compensating signals at the same time when sag and swell is present in source voltage. Load voltage profile is maintained constant even though the source voltages consists of sag and swell conditions due to compensating signals from DVR.

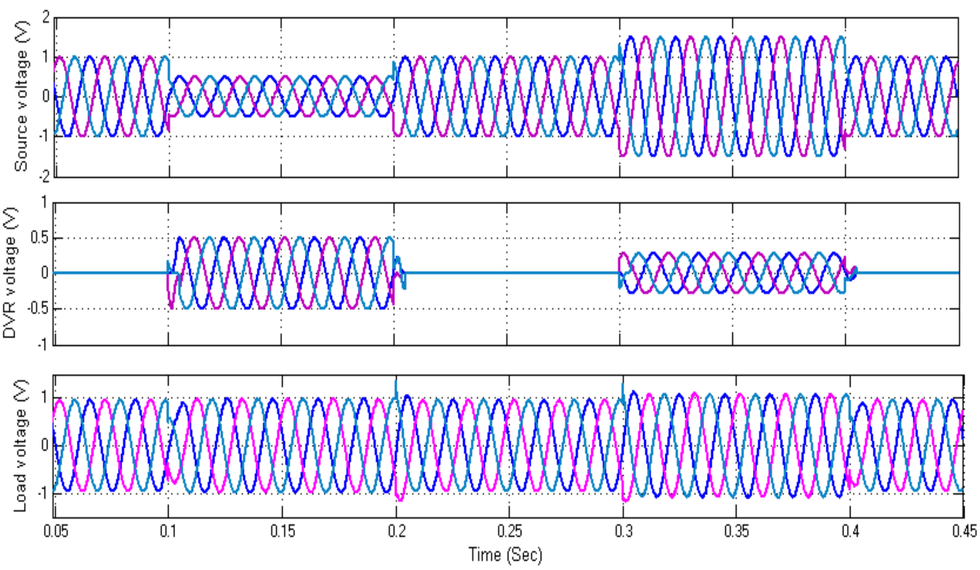

Figure 7. Source Voltage, DVR Voltage, and Load Voltages for sag and swell conditions

4.4. Compensation of Voltage Sag and Voltage Harmonics

Figure 8 shows the Simulink result of three-phase source voltage having voltage sag from duration 0.2 sec to 0.4 sec. During this time duration, DVR sends compensating signals to point of common coupling as in figure and thus the load voltage profile is maintained constant as shown in figure 8. Figure 9 shows the THD in source voltage of 23.09% during sag condition between 0.2 seconds to 0.4 seconds. THD in load voltage during compensation of sag is reduced to 4.42% as shown in figure 10. DVR compensating sag compensates for harmonics and thus load voltage profile is maintained with constant voltage and without harmonics.

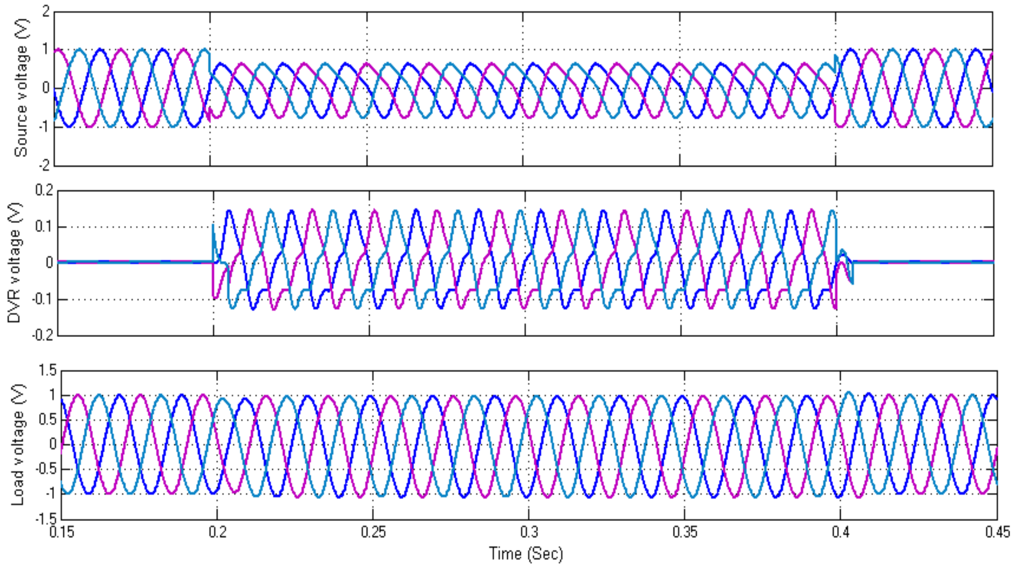

Figure 8. Source Voltage, DVR Voltage, and Load Voltages for sag condition with harmonic compensation

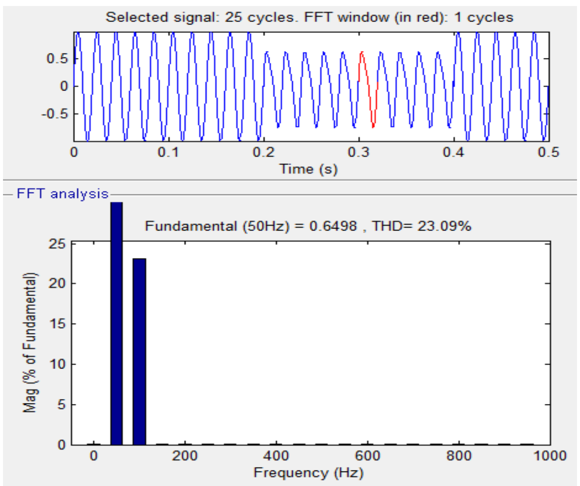

Figure 9. Source voltage THD under sag condition

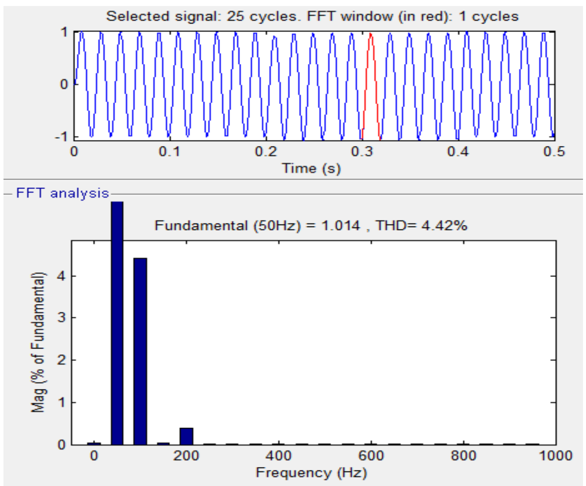

Figure 10. Load voltage THD under sag condition

4.5. Compensation of Voltage Swell and Voltage Harmonics

Figure 11 shows the Simulink result of three-phase source voltage having voltage swell from duration 0.2 sec to 0.4 sec. During this time duration, DVR sends compensating signals to point of common coupling as in Figure 11 and thus the load voltage profile is maintained constant as shown in figure 11. Figure 12 shows the THD in source voltage of 11.11% during swell condition between 0.2 seconds to 0.4 seconds. THD in load voltage during compensation of sag is reduced to 4.81% as shown in Figure 13. DVR compensating sag compensates for harmonics and thus load voltage profile is maintained with constant voltage and without harmonics.

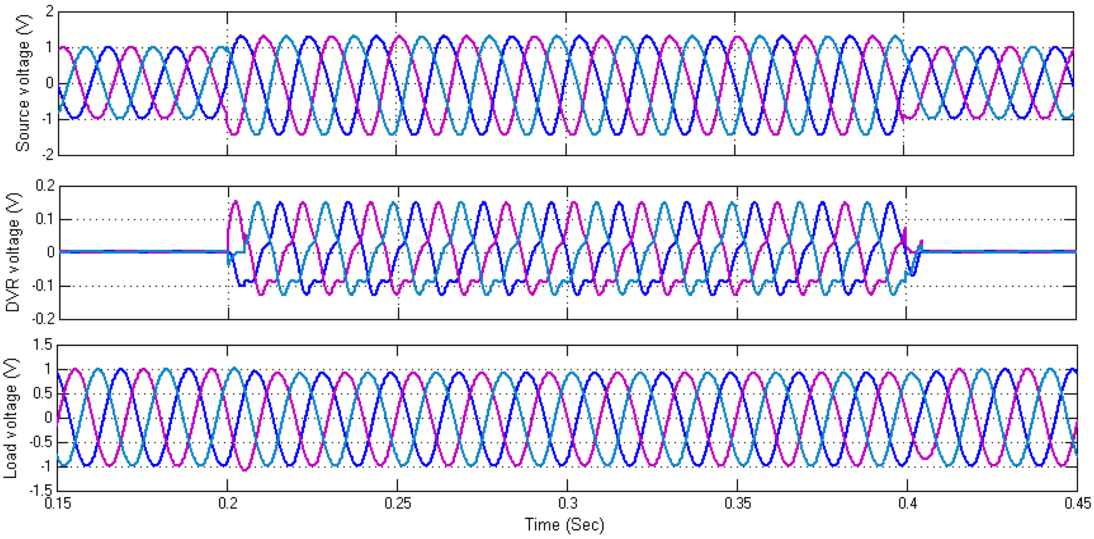

Figure 11. Source Voltage, DVR Voltage, and Load Voltages for sag condition with harmonic compensation

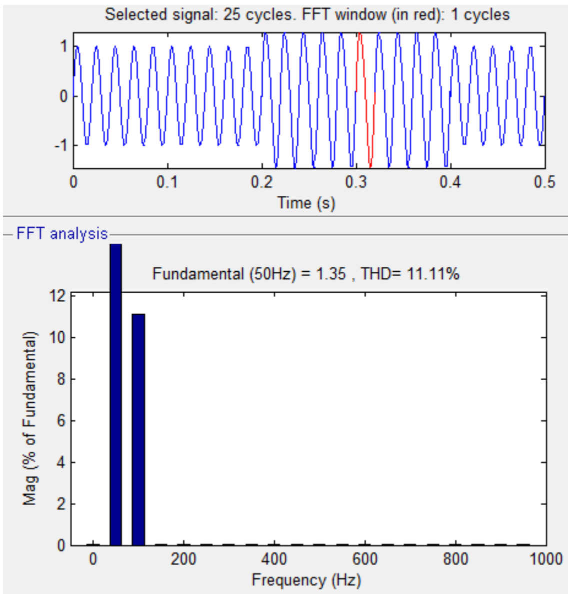

Figure 12. Source voltage THD under swell condition

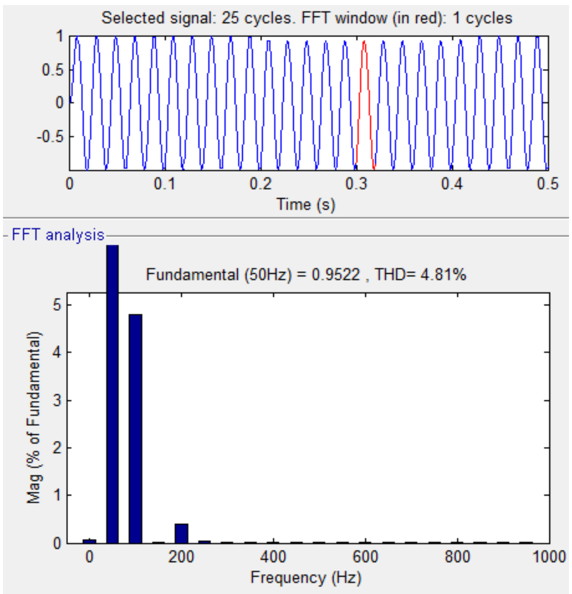

Figure 13. Load voltage THD under swell condition

4.6. Compensation of Voltage Sag, Voltage Swell and Voltage Harmonics

Figure 14 shows the result of source voltage, DVR voltage and load voltage. Source voltage contains sag and swell. Sag is observed from 0.1 sec to 0.2 sec and swell is observed from 0.3 sec to 0.4 sec. DVR also sends compensating signals at the same time when sag and swell is present in source voltage. Load voltage profile is maintained constant even though the source voltages consists of sag and swell conditions due to compensating signals from DVR as shown in Figure 14.

Figure 15 shows the THD in source voltage of 30.01% during sag condition between 0.1 seconds to 0.2 seconds. THD in load voltage during compensation of sag is reduced to 5.60% as shown in figure 16. DVR compensating sag compensates for harmonics also and thus load voltage profile is maintained with constant voltage and without harmonics.

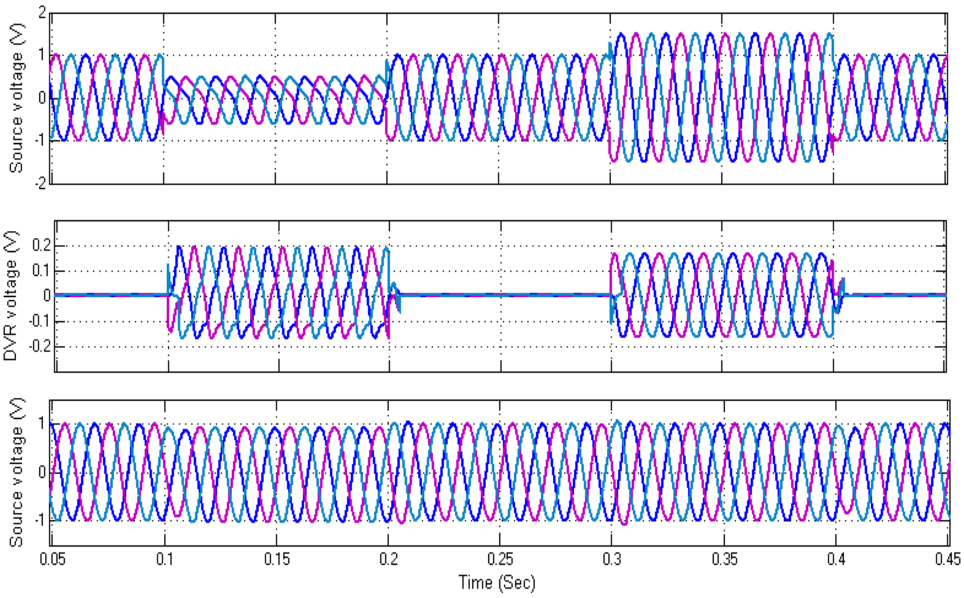

Figure 14. Source Voltage, DVR Voltage, and Load Voltages for sag and swell conditions with harmonics

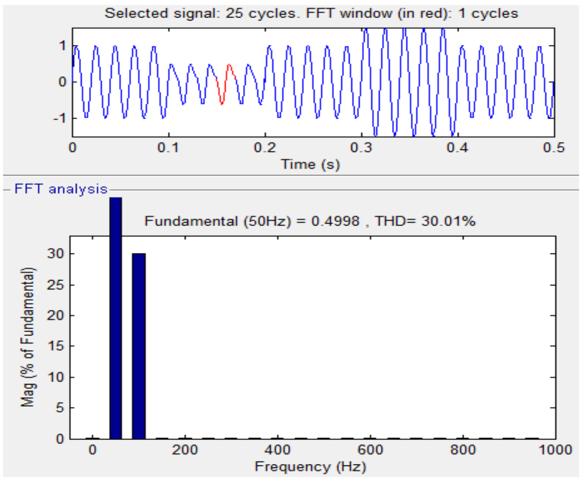

Figure 15. Source voltage THD under sag condition

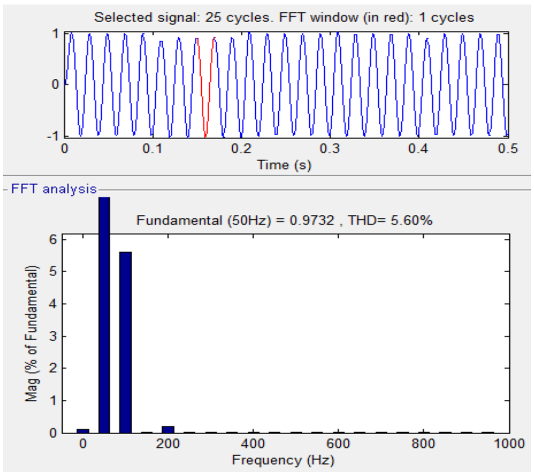

Figure 16. Load voltage THD under sag compensation condition

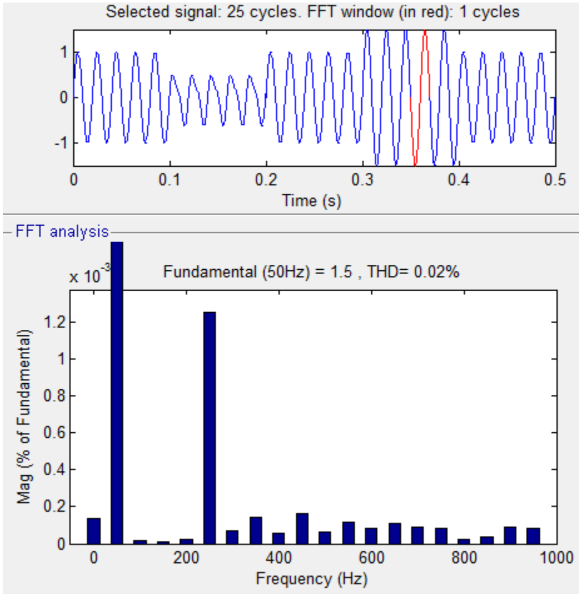

Figure 17. Source voltage THD under swell condition

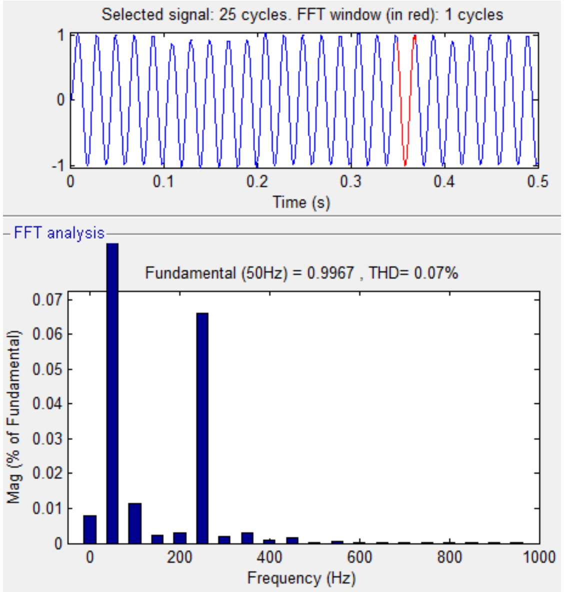

Figure 18. Load voltage THD under swell condition

Similarly, Figure 17 shows the THD in source voltage of 0.02% during swell condition between 0.3 seconds to 0.4 seconds. THD in load voltage during compensation of swell is 0.07% as shown in figure 18 indicating no harmonics in load voltage. DVR compensating swell compensates for harmonics also and thus load voltage profile is maintained with constant voltage and without harmonics. Table 2 represents THD Comparison in source voltage and load voltage during sag/swell compensations.

Table 2. THD Comparison in source voltage and load voltage during sag/swell compensations

Compensation for		THD in source voltage	THD in load voltage
Only Sag		23.09 %	4.42 %
Only Swell		11.11 %	4.81 %
Sag and Swell	During sag	30.01 %	5.60 %
	During swell	0.02 %	0.07 %

5. Conclusion

DVR is a series compensating FACTS device used to compensate voltage quality issues in power distribution system. The paper presents novel control for DVR for compensation of voltage sag, voltage swell and voltage harmonics. Voltage harmonics during sag/swell compensation in source voltage and load voltage were shown in results for all cases. THD in source voltage and load voltage for different compensating conditions were tabulated. Results prove that with novel control strategy for DVR, DVR compensates for sag, swell and also for harmonics.

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