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Mitigation of voltage disturbances (Sag/Swell) utilizing dynamic voltage restorer (DVR)

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Abstract

The paper focuses in the working of Dynamic Voltage Restorer (DVR), a series compensating device utilized for mitigating the events of voltage sag and swell which are most crucial and frequent phenomena occurring in transmission and distribution network. The sag and swell have severe impact to industrial customers ranging from disruptions of sensitive loads to substantial economic losses up to millions of dollars. The control algorithm used for detection of voltage disturbance depends on the theory of synchronous reference frame utilizing park's transformation. The sinusoidal pulse width modulation technique is used for the generation of triggering pulses for IGBT's of voltage source inverter. Matlab/Simulink is used for simulation of the proposed methodology and the result of simulation verifies the proposed scheme.

Keywords: Power quality, Voltage sag and swell, Dynamic voltage restorer, Park's transformation, Reference frame theory, Pulse width modulation, Voltage source converter.

Introduction

From the point of view of electricity consumers the basic requirement is the availability of electricity all the time (or in other words a high level of continuity) and safety of the consumer and electrical equipments which could be achieved by providing a high level of power quality.

Maintaining constant voltage and frequency in electrical power system is quite difficult as fluctuation of load is a normal phenomenon for any power system. Until now, most of electrical equipments were also able to perform well at the time of fluctuations in voltage, current and frequency occurring in the supply side. But with advancement in automation and control technology, both electrical and electronic devices have been integrated together to implement control and automation process in industries. It has been observed that Programmable Logic Controller (PLCs), Adjustable-Motor-Speed Drives, Energy, CNC machines, and other power electronic devices helps to increase the production and quality of product concurrently making the cost of product cheaper for the customers. These Kinds of devices hence introduces compatibility related problems as electronic components are more prone to power quality disturbances. As a result of these advancements, loads like process industries, factories become more sensitive to power quality problems which calls for improvements in supply in terms of reliability and quality[1]. Power Quality can be defined in generalised manner as "a set of electrical boundaries that allow equipments to function in its intended manner without significant loss of performance or life expectancy". When the quality of electrical power supplied to equipment is deficient, performance degradation results[2].

Power quality issues include voltage sag, swell, harmonics, transients, flicker, notch, power factor, momentary and sustained interruptions in network. Among these voltage disturbances, sag and swell are one of the important concerns as it may cause domestic or industrial equipment tripping or shutdown, failure of drive systems and many more losses[3].

Electrical Power system faults like a short circuit at heavy load conditions at adjacent feeder, lightening strikes, starting of large induction motors, switching operation of capacitors, intermittent heavy loads can cause the Voltage sag or Voltage dips. Voltage Sag is defined as 'Decrement in rms value from 10% to 90% of voltage below the nominal value lasting 0.5 of a cycle to few minutes[4]. The sag can be balanced or unbalanced with unpredictable magnitudes, which depends on the type of fault in the system. In contrast to this Voltage swell is increase in nominal voltage from about 1.1 to 1.8 pu lasting half a cycle to about a minute. Switching off large loads, energizing capacitor bank etc are treated to be the cause of the voltage swell. Events of voltage sag appear more frequently than the voltage swell in the distribution networks[5]. Components susceptible to power quality disturbances in industrial system, whether electrical or electronic might get fail, blowing off of fuse due to large inrush current, unnecessary tripping of circuit breaker, relays etc leading to process interruption, defective product output or manufacturing loss[5-8].

The custom power devices are introduced at the consumer's end in a distribution network which is more effective among various methods available. These devices utilize the power electronic controllers to assure that the reliable and quality power gets delivered in a system. Some of Custom Power devices are

Dynamic Voltage Restorer (DVR), Uninterruptible Power Supply (UPS), Distribution static compensator (DSTATCOM), Static VAr Compensator (SVC), Super Conducting Magnetic energy storage (SMES), Ferro-resonant voltage regulator[3].

For compensation of the Voltage sag and swell, the DVR provides effective results in terms of the performance at comparatively lower cost, among other devices available[5]. As compared to DVR, SVC lacks active power flow capability; UPS is costly and frequent replacement and maintenance of battery is necessary from time-to-time. SMES on the other hand has a high cost and lower energy capacity, DSTATCOM has larger size. Besides this, DVR is also able to correct the harmonics and power factor in some extent[10].

This paper gives a brief description of Dynamic Voltage Restorer, its components and the operating principle. Later, a simple scheme based on reference frame transformation method used to control the compensating voltage has been described. Finally, MATLAB/SIMULINK model has been implemented and the simulated results have been presented to validate the adequacy of the proposed control technique for the DVR.

DVR System Configuration: The Dynamic Voltage Restorer is a series compensating solid state device used in the distribution power network for compensating voltage at the load end against voltage sag and swell. The essential parts constituting the DVR are shown in Figure-1: i. Control System, iii. Dc Energy Storage Device Or Dc Source, iii. Voltage Source Inverter (VSI), iv. Harmonic Filter, v. Injection or Booster Transformer.

The fundamental task of the DVR is the injection of compensating voltage Vinj using injection transformer. The voltage is controlled dynamically and generated by an inverter in which forced commutation is used. The voltage injected is the difference between the pre-fault value and sagged value of the supply voltage. That means any differential voltages created by the transient phenomena in the supply bus will be compensated by addition of proportional voltage through the booster transformer. This requires the supply of real/reactive power from the storage device. The turn's ratio of the booster transformer and the ratings of the dc source or the storage device put the limitations on efficiency of the voltage injection capability of the DVR. The voltage compensated by the DVR to maintain load voltage constant, does not depend on the type of the disturbances/ fault occurring in the system, only at one condition that the system does not undergo in complete outage, i.e.; the line breaker does not trip[5].

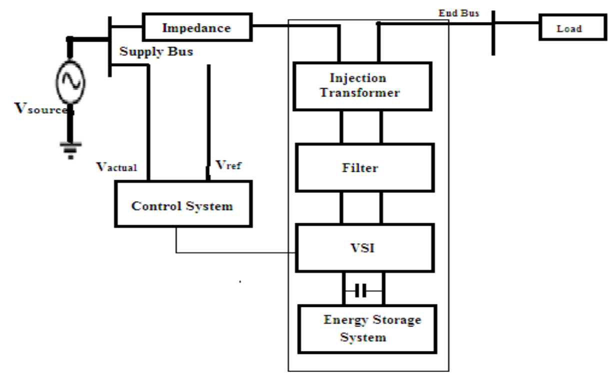


Figure-1: Components of DVR.

Equivalent Circuit of the DVR: The circuit diagram of DVR can be drawn equivalently as shown in Figure-2. Whenever a deviation is detected in the incoming voltage across load (V_s) from the constant reference value required, DVR will add a series voltage to supply voltage with the help of the booster transformer and hence maintains the constant voltage across the load[7].

The series compensated voltage injected by the DVR referring to Figure-2 can be given by equation as follows:

$$V_{inj} = V_{load} + Z_{line} I_{load} - V_s \quad (1)$$

Where: V_{inj} = Injected voltage by DVR, Z_{line} = Line impedance, V_{load} = desired load voltage, I_{load} = Load Current, V_s = Source voltage at any fault condition.

At Normal operating condition V_{load} will b equal to the Vs and DVR injected voltage will be equal to the line voltage drop which is small quantity.

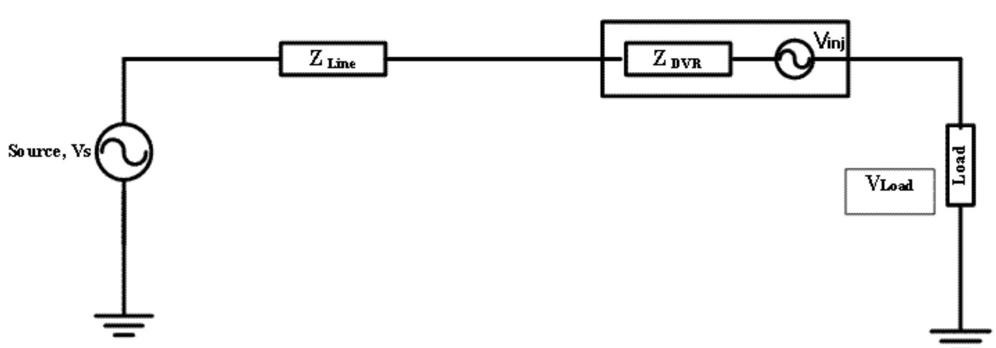


Figure-2: Equivalent Circuit of DVR.

Working Mechanism of DVR: The working mechanism of DVR can be classified as:

Standby mode: The full load current passes through the transformer's primary winding. The IGBTs of inverter commutated in a manner to short circuit the primary winding of the transformer. Also the switches are kept triggered in this mode to obtain fast action during fault condition.

Boosting mode: During disturbances as detected in the supply end, DVR adds compensating voltage through the booster/injection transformer[10].

Methodology

The Block diagram representing the Control scheme as proposed for the DVR is shown in Figure-3. For regulating the load voltage during disturbance in the system, the inverter output voltage is adjusted in phase with the supply voltage across the load end. To filter the output voltage of the inverter passive filter consisting of inductor and capacitor is utilized. For detecting the events of the sag or swell, controllers are used in the DVR. Further it calculates the amount of the series compensating voltage and generates the triggering pulses till the time fault is present.

The DVR utilizes dq0 transformation or more commonly known as Park's transformation for control operation[5]. This transformation provides sag depth or error in magnitudes as well as in phase along with beginning and finishing time information of the sag/swell. The error is detected in all of the three phases.

The voltage transformed from abc-frame of reference to the dq0-frame as given by the equation 2. Since system is balanced, the zero sequence components are not considered.

$$\begin{bmatrix} Vd \\ Vq \\ V0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) & -sin\left(\theta - \frac{2\pi}{3}\right) & -sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (2)$$

The angle theta (θ) considered here is the angle between the phase-a axis and the d-axis. d-Axis is at 90 degree lagging to the q-axis.

The sagged voltage is compared with the constant value of load voltage required. The error generated is then processed and referred to as modulating signal, which is used as a control signal for generation of forced commutation pattern for IGBT switches of VSI. Hence DVR used here utilizes the sinusoidal pulse width modulation technique (SPWM). The Phase Locked Loop (PLL) circuit is used to get the instantaneous phase information required for Park's transformation.

Simulink model: A detailed simulation model of proposed system/subsystem which had been implemented using matlab/ simulink to verify effectiveness of DVR under different conditions of sag and swell is shown in Figure-4. Table-1 indicates various system parameters used for the implementation of DVR.

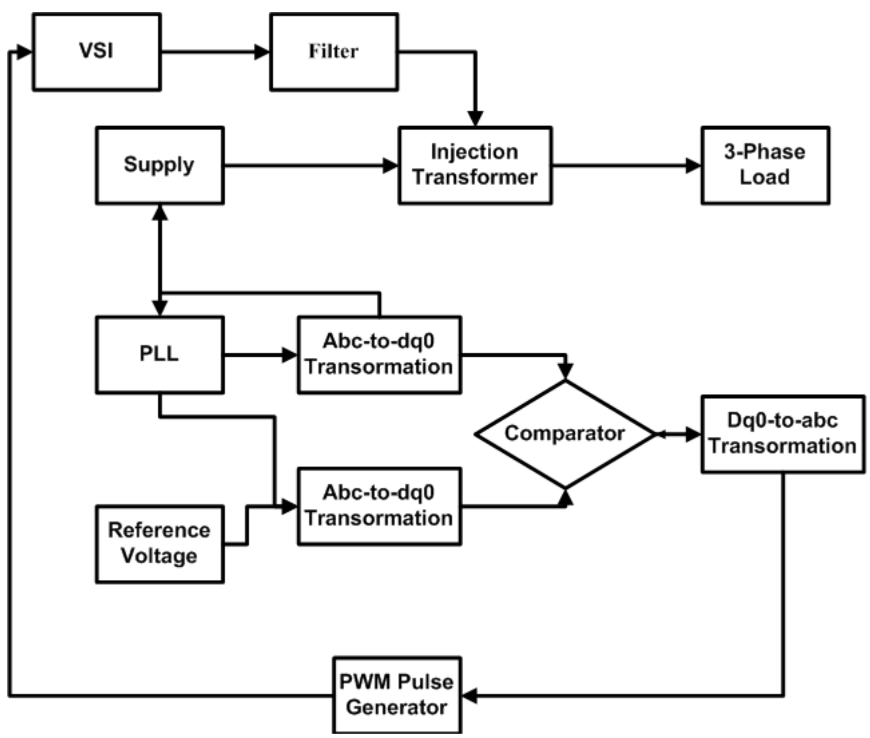


Figure-3: Simulation Block Diagram.

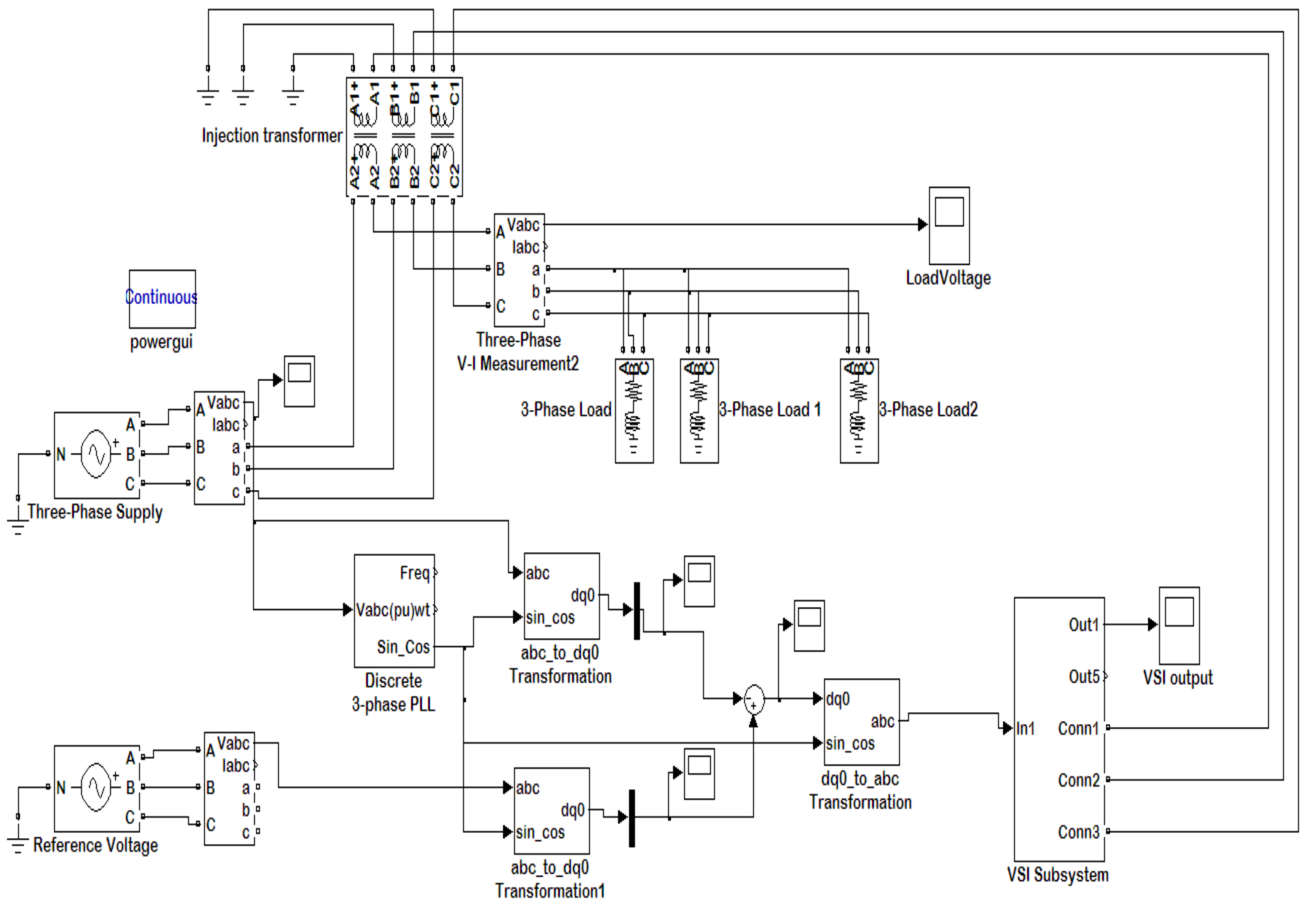


Figure-4: DVR Simulink Mode.

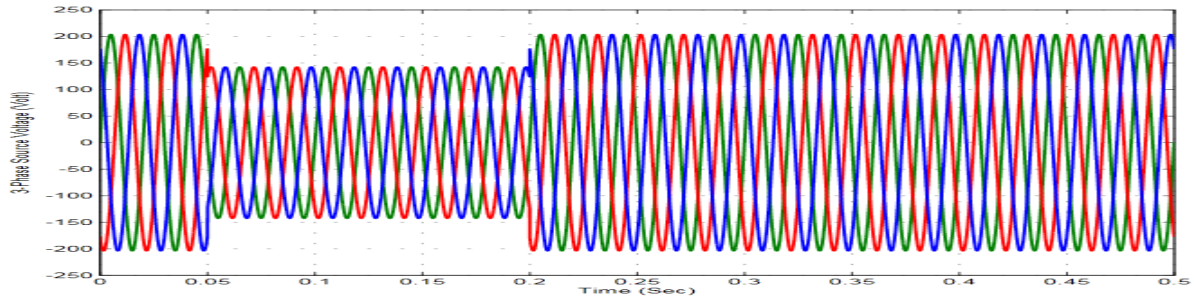
Table-1: Various Parameters of DVR system Components.

S. No.	Name of parameter	Value
1	Main Supply Voltage phase-to-phase (rms)	250 V
2	DC Bus Voltage	100V
3	Filter Inductance	Series: 15 mH, Parallel: 1 mH
4	Filter capacitance	1uF
5	Load resistance	100 Ω
6	Load inductance	60mH
7	Line Frequency	50Hz

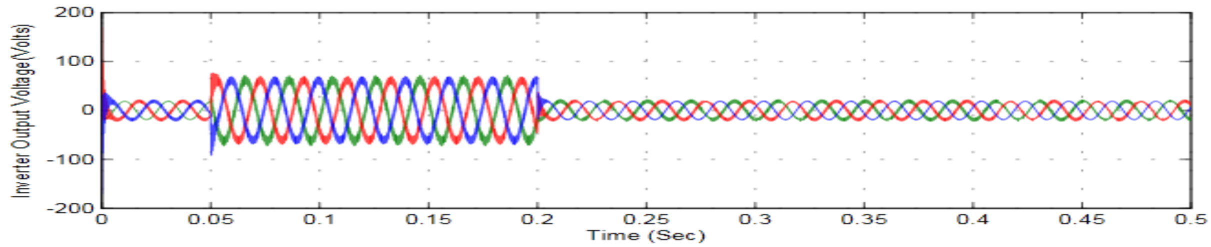
Results and discussion

Voltage Sag: The waveform represented in Figure-5 is simulation of system having balanced sag of 30% in 3-phase voltage. The load voltage is taken as 200V (peak value). The dq0 conversion of the incoming voltage and reference voltage and its difference which is being converted into the abc quantities is shown in the Figure-5. We can observe satisfactory compensation of sagged voltage across the load.

Voltage swell: The simulation result of 40% three phase voltage swell in supply voltage is shown in Figure-6. Similar to sag condition all waveform are shown. We can observe satisfactory compensation.



(a)



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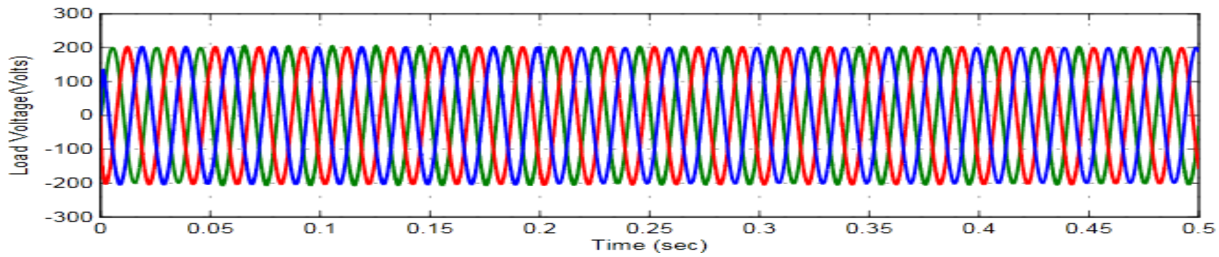

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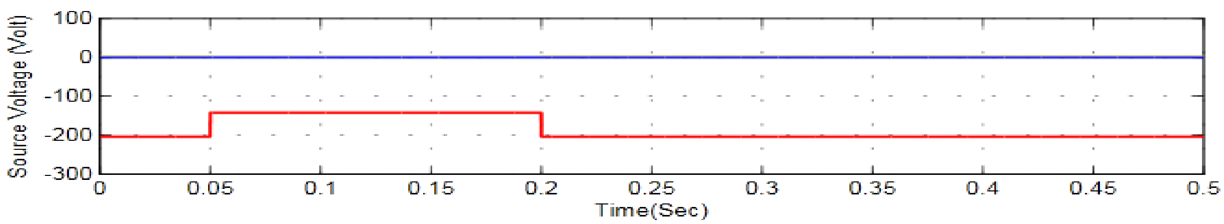
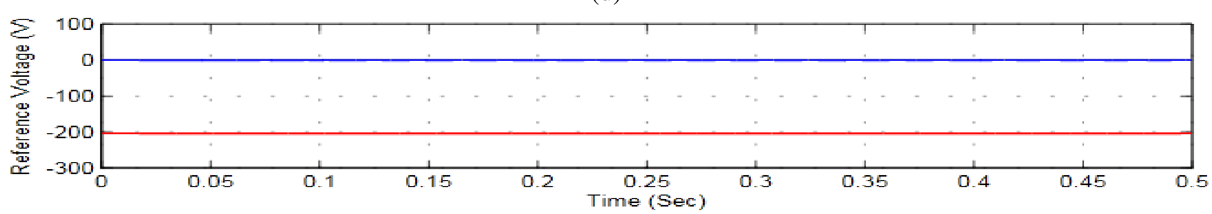
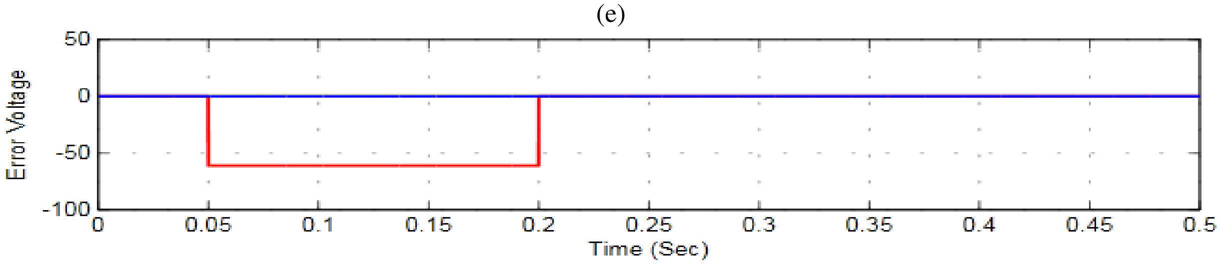


(d)



(e)



(f)

Figure-5: 3-Phase Voltage Sag Compensation. (a) Source Voltage, (b) Boost Voltage, (c) Voltage across Load after Compensation, (d) dq0 transformed Source Voltage, (e) dq0 transformed Reference Value, (f) Error Voltage.

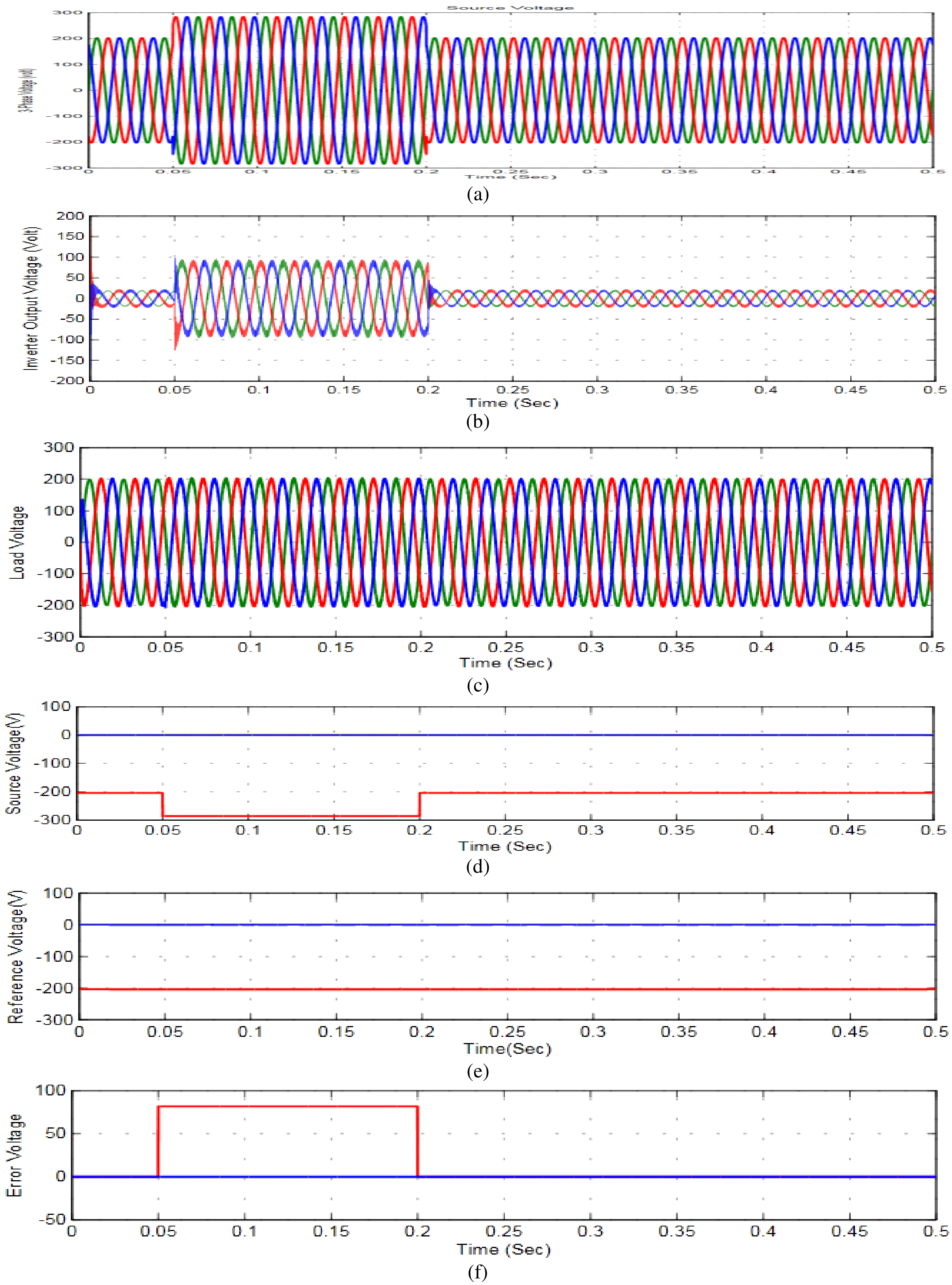


Figure-6: 3-Phase Voltage Swell Compensation. (a) Waveform of Voltage Supplied, (b) Boost Voltage waveform, (c) Waveform of load Voltage made constant, (d) dq0 Converted Source Voltage, (e) dq0 converted Reference value, (f) Error Voltage.

Conclusion

The modelling and simulation of the DVR utilizing reference frame theory and sinusoidal pulse width modulation technique has been done successfully in the Matlab/Simulink environment. The system developed is a 3-phase 200V, 50 Hz distribution network having DVR in between supply bus and load bus. By observing the results of the simulation, it can be inferred that the DVR is able to compensate the voltage sag and swell effectively and gives excellent voltage regulation at the load end.

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