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Research Article

Modelling and Simulation of SVM Based DVR System for Voltage Sag Mitigation

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Abstract: The aim of this study is to design and simulate three phase DVR system using MATLAB simulink. SVM based DVR is proposed to reduce the sag on the transmission line. The SVM based DVR injects voltage into the line to compensate the voltage drop. Sag is created by connecting a heavy load in parallel with the existing system. This sag will be compensated by injecting the inverter output through an injection transformer. The results of simulation are compared with the theoretical results.

Keywords: Fast fourier transform, injection transformer, matlab simulink, space vector modulation, three phase dynamic voltage restorer, total harmonic distortion, voltage sag

INTRODUCTION

The two most important power quality problems that encompass almost 80% of the distribution system is the voltage sags and voltage swells. According to IEEE 1959-1995 standard, the voltage sag is the decrease of 0.9 to 0.1 p.u. in the rms voltage level at system frequency and with the duration of half a cycle to 1 min (Martinez and Arnedo, 2006). The main causes of voltage sags are short circuits, starting large motors, sudden changes of load and energisation of transformers (Heine and Khronen, 2003).

The voltage sag is a transient phenomenon whose causes are classified as low or medium frequency transient events (Martinez and Arnedo, 2006). In recent years, considering the use of sensitive devices in modern industries, different methods of compensation of voltage sags have been used. One of these methods is by using the DVR to improve the power quality and compensate the load voltage.

Previous studiess involve different aspects of DVR performance and different control strategies have been found. These methods mostly depend on the purpose of using DVR.

In some methods, the main purpose is to detect and compensate for the voltage sag with minimum DVR active power injection (Choi *et al*., 2000). Also, the in phase compensation method can be used for sag and swell mitigation (Benachaiba and Ferdi, 2008). For eliminating the battery in the DVR structure and controlling more than one line the multi line DVR can be used (Vilathgamuwa *et al*., 2006). Research has been made on the DVR in medium level voltage (Nielsen *et al*., 2004). The control of DVR under frequency variations (Jindal *et al*., 2008) and harmonic mitigation (Newman *et al*., 2005) are also in the area of research. The closed loop control with load voltage and current feedback is introduced as a simple method to control the DVR in Vilathgamuwa *et al*. (2002). The transient response is improved and the steady-state error in DVR is eliminated using Posicast and P+Resonant controllers. The Posicast controller is a kind of step function with two parts and is used to improve the damping of the transient oscillations initiated at the start instant from the voltage sag. The P+Resonant controller consists of a proportional function plus a resonant function. It eliminates the steady state voltage tracking error (Li *et al*., 2007a, c). The different methods of controlling the DVR includes the state feedforward and feedback methods (Kim and Sul, 2005), symmetrical components estimation (Marei *et al*., 2007), robust control (Li *et al*., 2007b) and wavelet transform (Saleh *et al*., 2008).

In all of the above mentioned methods, the source of disturbance is assumed to be on the feeder which is parallel to the DVR feeder. In this paper, a multifunctional control system is proposed. When the source of disturbance is the parallel feeders, the DVR protects the load voltage using Posicast and P+Resonant controllers. But during a downstream fault, the equipment protects the PCC voltage, limits the fault current and protects itself from large fault current. The DVR proposed there acts like a virtual inductance with a constant value so that it does not receive any active power during limiting the fault current. When the fault

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current passes through the DVR, it acts like a series variable impedance.

In this study, the basis of the proposed control strategy is that when the fault current does not pass through the DVR, an outer feedback loop of the load voltage with an inner feedback loop of the filter capacitor current will be used. To improve the dynamic response of the load voltage, a feedforward loop will be used. Also to improve the transient response, the Posicast controller and to eliminate the steady state error, the P+Resonant controller are used. The series voltage is injected in the opposite direction and therefore, the DVR acts like a series variable impedance.

The above literature does not deal with SVM based DVR system to compensate the sag. This study proposes SVM based inverter for the control of sag.

DVR COMPONENTS AND ITS BASIC OPERATIONAL PRINCIPLE

The Fig. 1 shows a typical DVR connected distribution system. The DVR consists of a series connected injection transformer, a voltage source inverter, an inverter output filter and an energy storage device that is connected to the DC link. Before injecting the inverter output to the system, it must be filtered so that the harmonics due to switching function in the inverter are eliminated. When employing the DVR in real situations, the injection transformer will be connected in parallel with a bypass switch. When there is no disturbances in voltage, the injection transformer (hence, the DVR) will be short circuited by this switch to minimize losses and maximize cost effectiveness.

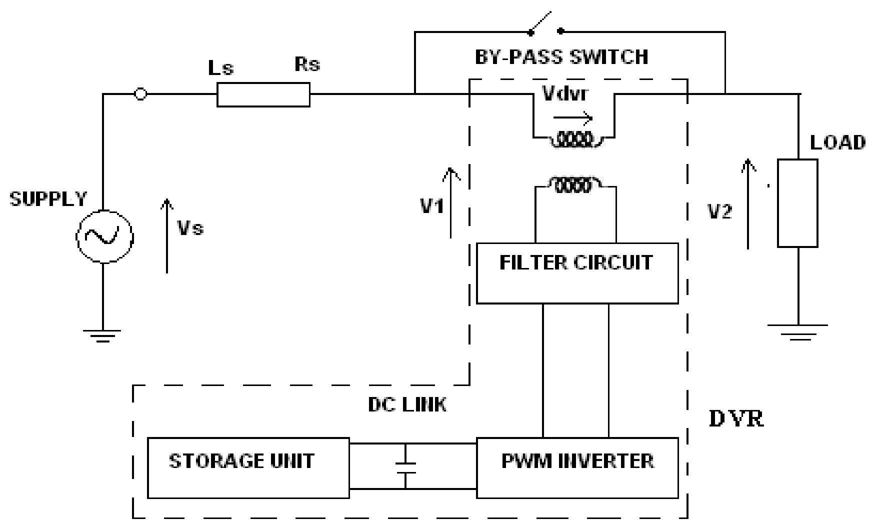


Fig. 1: Typical DVR connected distribution system

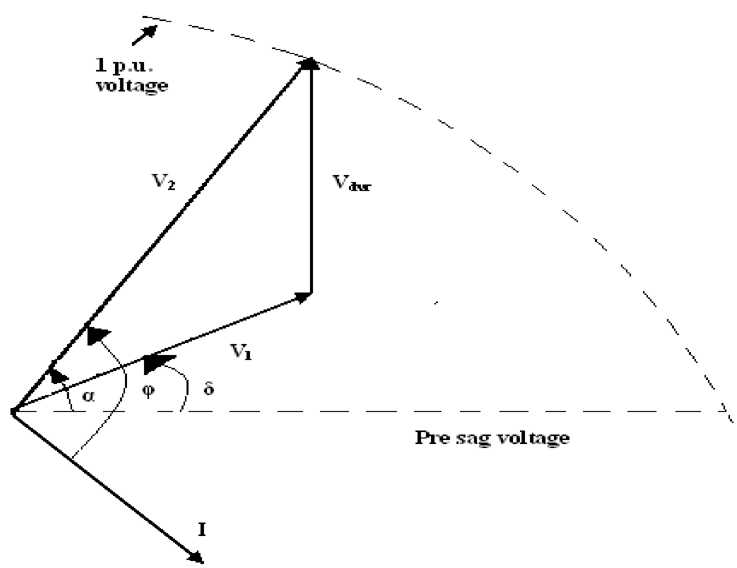


Fig. 2: Phasor diagram of the electrical conditions during a voltage sag

Also, this switch can be in the form of two parallel thyristors, as they have high on and off speed (Awad *et al*., 2004). The voltage sag events and use of Flexible AC Transmission Systems (FACTS) devices, such as DVR to mitigate them is provided in Milanovic and Zhang (2010). It is obvious that the flexibility of the DVR output depends on the switching accuracy of the pulse width modulation scheme and the control method. The PWM generates sinusoidal signals by comparing the sinusoidal wave with the sawtooth wave and sending appropriate signals to the inverter switches. This scheme is described in Rashid (2004).

The basic operational principle of DVR is detailed. The DVR system shown in Fig. 1 controls the load voltage by injecting an appropriate voltage phasor (V_{dvr}) in series with the system using the injection series transformer. In sag compensation techniques, it is necessary that during compensation, the DVR injects some active power to the system. Hence, the capacity of the storage unit can be a limiting factor in compensation, especially during long term voltage sags.

Figure 2 shows the electrical conditions during voltage sag, where for clarity only one phase is shown. Voltages V_1, V_2 and V_{dvr} are the source side voltage, the load side voltage and the DVR injected voltage respectively.

The operators I, φ, δ, α are the load current, the load power factor angle, the source phase voltage angle and the voltage phase advance angle respectively (Vilathgamua *et al*., 1999). In addition to the in phase injection technique, another technique called the phase advance voltage compensation technique is also used (Vilathgamua *et al*., 1999). One of the advantages of this method over the in phase method is that less active power should be transfeered from the storage unit to the distribution system. This results in compensation for deeper sags or sags with longer durations.

Due to the existance of semiconductor switches in the DVR inverter, this piece of equipment is nonlinear. Using linearization techniques the state equations can be linearized. The dynamic characteristics of DVR is influenced by the filter and the load. Although the modeling of the filter is easy to do, the load modeling is not as simple because the load can vary from a linear time invariant one to a nonlinear time variant one.

Figure 3 shows the distribution system with DVR. Here the load voltage, is regulated by the DVR through injecting V_{dvr}. For simplicity, the bypass switch shown in Fig. 1 is not presented in this figure. Here it is assumed that the load has a resistance R_l and an inductance L_l. The DVR harmonic filter has an inductance of L_f, a resistance of R_f and a capacitance of C_f. Also the DVR injection transformer has a combined winding resistance of R_t, a leakage inductance of L_t and turns ratio of 1 : n.

To improve the transient response the Posicast controller is used. The Posicast controller has limited high frequency gain. It has low sensitivity to noise. To find the appropriate values of δ and T_d, first the DVR model will be derived according to Fig. 3, as follows:

$$\begin{aligned} & V_1 = V_c + I_f R_f + L_f \frac{dI_f}{dt} \\ & I_f = I_c = n.I_l \\ & I_c = C_f \frac{dV_c}{dt} \\ & V_{dvr} = n[V_c - n(R_t I_t + L_t dI_t / d_t)] \\ & V_2 = V_1 + V_{dvr} \end{aligned} \tag{1}$$

According to (1) and the definitions of damping and the delay time in the control literature, δ and T_d are derived as follows:

$$\begin{aligned} & T_d = \frac{2\Pi}{w_T} = \frac{\Pi}{\sqrt{\frac{1}{L_f C_f} - \frac{R_f^2}{4L_f^2}}} \\ & \delta = e^{\xi\Pi/\sqrt{1-\xi^2}} \\ & \delta = e - R_f \Pi \sqrt{C_f} / \sqrt{4L_f - R_f^2 C_f} \end{aligned} \tag{2}$$

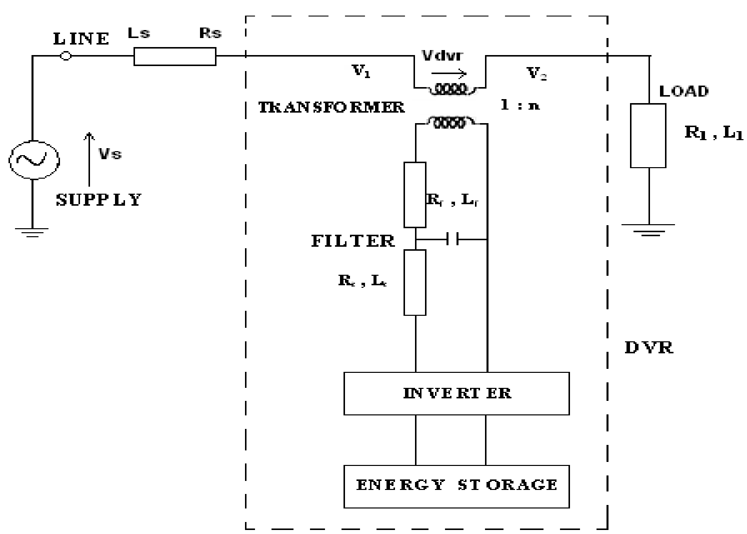


Fig. 3: Distribution system with the DVR

The Posicast controller works by pole elimination and proper regulation of its parameters is necessary. For this reason, it is sensitive to inaccurate information of the system damping resonance frequency. To decrease this sensitivity, the open loop controller can be converted to a closed loop controller by adding a multiloop feedback path parallel to the existing feedforward path. The inclusion of a feedforward and a feedback path is called as two degrees of freedom (2-DOF) control. The 2-DOF control provides a DOF for ensuring fast dynamic tracking through the feedforward path and a second degree of freedom for the independent tuning of the system disturbance compensation through the feedback path. The feedback path consists of an outer voltage loop and a fast inner current loop. The steady state voltage tracking error is eliminated by adding a computationally less intensive P+Resonant compensator to the outer voltage loop. The ideal P+Resonant compensator can be mathematically expressed as:

$$G_R(s) = k_p + \frac{2K_I s}{S^2 + w_0^2} \tag{3}$$

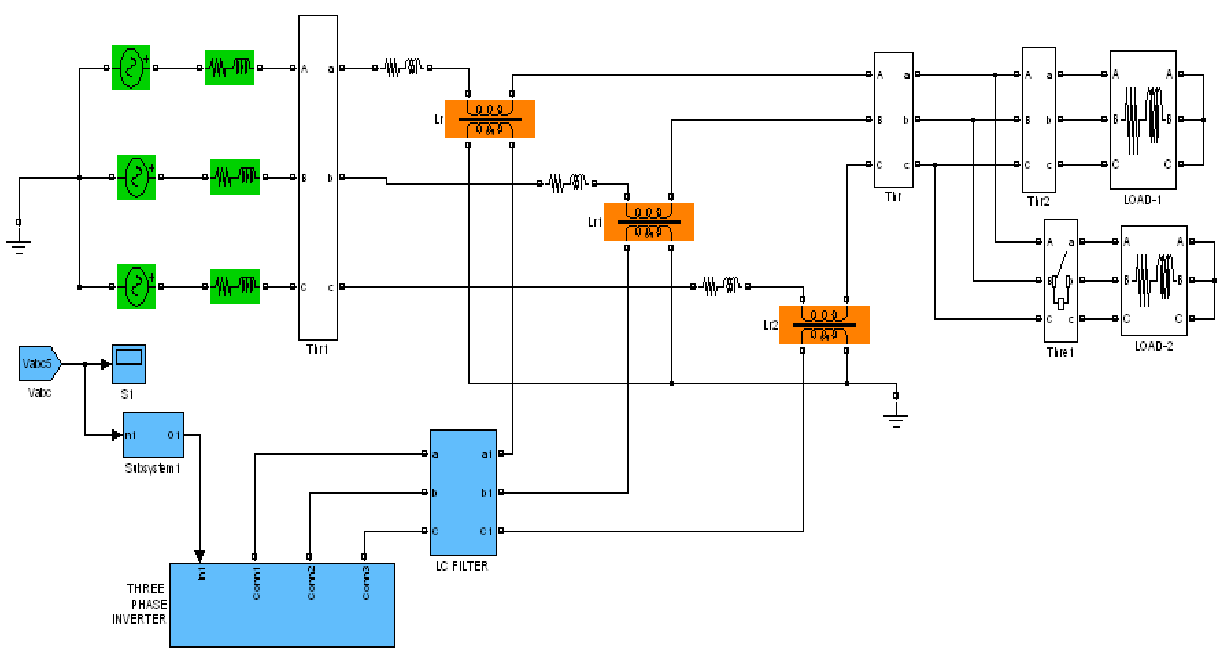
where K_P and K_I are gain constants and $w_0 = 2\Pi * 50$ rad/sec is the controller resonant frequency. Theoritically, the resonant controller compensates by introducing an infinite gain at the resonant frequency of 50 Hz to force the steady state voltage error to zero. The ideal resonant controller, acts like a network with an infinite quality factor, which is not realizable in practice. A more practical (nonideal) compensator is used which is expressed as:

$$G_R(s) = k_p + \frac{2K_I w_{cut} S}{S^2 + 2w_{cut} S + w_o^2} \tag{4}$$

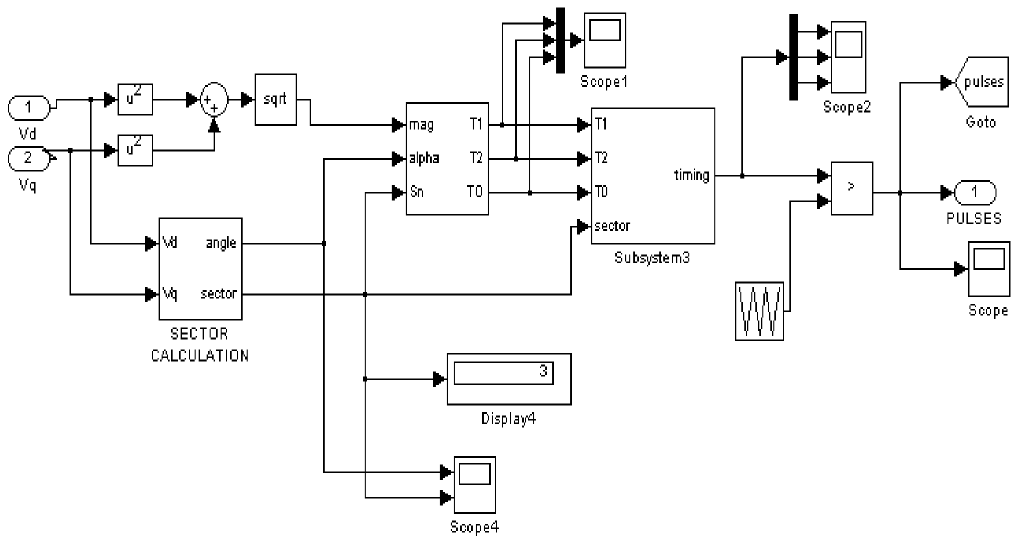
where, w_{cut} is the compensator cut off frequency which is 1 rad/sec.

SIMULATION RESULTS

Three phase DVR circuit is shown in Fig. 4(a). An additional load is connected in parallel with the existing load to create the sag in the transmission line. The inverter in the present system is SVM based inverter. The block diagram of the SVM system is shown in Fig. 4(b). The inverter in the DVR is shown in Fig. 4(c). The three phase voltages are shown in Fig. 4(d). An additional load is applied at 0.25 secs. It is compensated by using a DVR at t = 0.3 sec. The rms voltage across the load is shown in Fig. 4(e). The RMS current through the load is shown in Fig. 4(f). The real and reactive powers in the load are shown in Fig. 4(g, h), respectively. The real and reactive powers increase due to the injection of the voltage. FFT analysis is done for the output voltage and spectrum is obtained. The THD of the output voltage is 1.39%. This is the best injection since the THD is minimum. The frequency spectrum is shown in Fig. 4(i).



(a)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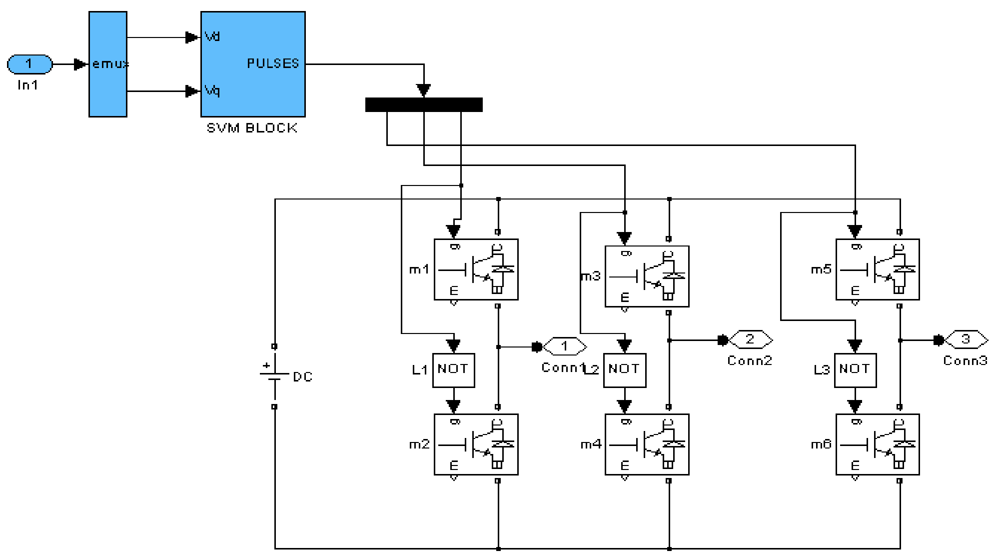
(b)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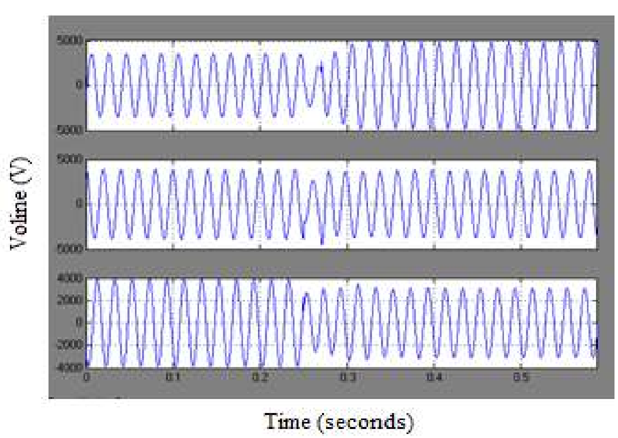
(c)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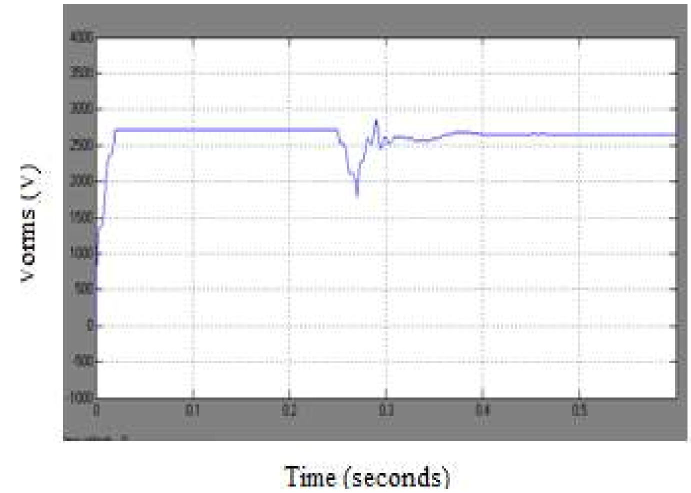
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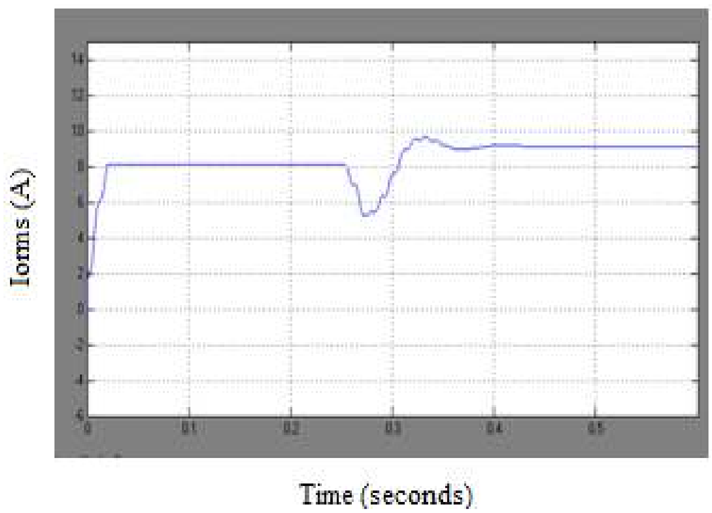
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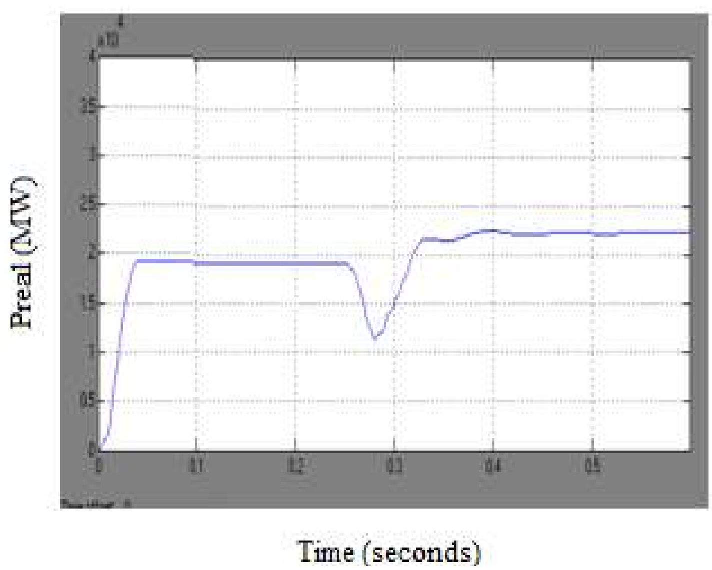
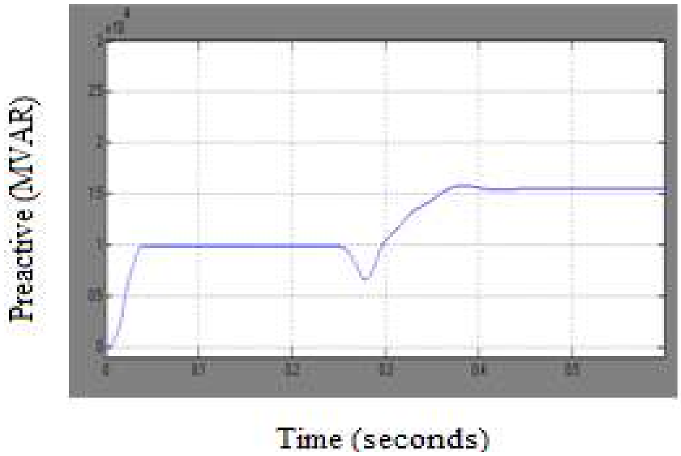
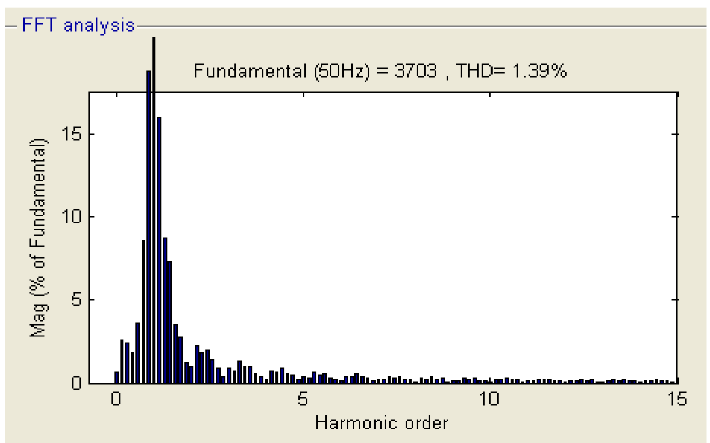

Preal (MW)
Time (seconds)

(g)



(h)



(i)

Fig. 4: (a); Three phase DVR circuit; (b): SVM model; (c): Three phase inverter; (d): Line voltage with change in load; (e): RMS voltage across load with change in load; (f): RMS current through load with change in load; (g): Real power with change in load; (h): Reactive power with change in load; (i):FFT analysis for voltage

CONCLUSION

The three phase SVM based DVR system is designed by using the blocks of simulink. This system is successfully simulated and the results of the load voltage, load current, real power, reactive power and spectrum are presented. The THD is found to be minimum with SVM based DVR system. Thus the SVM based DVR is a viable alternative to the existing DVR systems. The simulation results coincide with the theoritical results.

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