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A latest Approach to Multifunctional Dynamic Voltage Restorers Implementation for Emergency Control and Protect Consumers in Distribution Systems

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Abstract:- *The dynamic voltage restorer (DVR) is one of the modern devices used in distribution systems to protect consumers against sudden changes in voltage amplitude. In this paper, emergency control in distribution systems is discussed by using the proposed multifunctional DVR control strategy. Also, the multiloop controller using the Posicast and P+Resonant controllers is proposed in order to improve the transient response and eliminate the steady-state error in DVR response, respectively. The proposed algorithm is applied to some disturbances in load voltage caused by induction motors starting, and a three-phase short circuit fault. Also, the capability of the proposed DVR has been tested to limit the downstream fault current. The current limitation will restore the point of common coupling (PCC) (the bus to which all feeders under study are connected) voltage and protect the DVR itself. The innovation here is that the DVR acts as virtual impedance with the main aim of protecting the PCC voltage during downstream fault without any problem in real power injection into the DVR. Simulation results show the capability of the DVR to control the emergency conditions of the distribution systems.*

I. INTRODUCTION

Voltage sag and voltage swell are two of the most important power-quality (PQ) problems that encompass almost 80% of the distribution system PQ problems. According to the IEEE 1959–1995 standard, voltage sag is the decrease of 0.1to 0.9 p.u. in the rms voltage level at system frequency and with the duration of half a cycle to 1 min. Short circuits, starting large motors, sudden changes of load, and energization of transformers are the main causes of voltage sags.

According to the definition and nature of voltage sag, it can be found that this is a transient phenomenon whose causes are classified as low- or medium-frequency transient events. 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 using the DVR to improve the PQ and compensate the load voltage.

In previous, work done on DVR performance and 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. Also, the in-phase compensation method can be used for sag and swell mitigation. The multiline DVR can be used for eliminating the battery in the DVR structure and controlling more than one line. Moreover, research has been made on using the DVR in medium level voltage. The closed-loop control with load voltage and current feedback is introduced as a simple method to control the DVR. Also, Posicast and P+Resonant controllers can be used to improve the transient response and eliminate the steady-state error in DVR. 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 and it eliminates the steady-state voltage tracking error. The state feedforward and feedback methods, symmetrical components estimation, robust control, and wavelet transform have also been proposed as different methods of controlling the DVR.

In this paper, a multifunctional control system is proposed in which the DVR protects the load voltage using Posicast and P+Resonant controllers when the source of disturbance is the parallel feeders. On the other hand, during a downstream fault, the equipment protects the PCC voltage, limits the fault current, and protects itself from large fault current. Although this latest condition has been described using the flux control method, 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. But in the proposed method when the fault current passes through the DVR, it acts like series variable impedance (where the equivalent impedance was a constant).

The basis of the proposed control strategy in this paper 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. Also, a feed forward loop will be used to improve the dynamic response of the load voltage. Moreover, to improve the transient response, the Posicast controller and to eliminate the steady-state error, the P+Resonant controller are used. But in case the fault current passes through the DVR, using the flux control algorithm, the series voltage is injected in the opposite direction and, therefore, the DVR acts like series variable impedance.

II. DVR COMPONENETS AND ITS BASIC OPERATIONAL PRINCIPALS

A typical DVR-connected distribution system is shown in Fig. 1, where the DVR consists of essentially 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 harmonics due to switching function in the inverter are eliminated. It should be noted that when using the DVR in real situations, the injection transformer will be connected in parallel with a bypass switch (Fig. 1). 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. Also, this switch can be in the form of two parallel thyristors, as they have high on and off speed. A financial assessment of voltage sag events and use of flexible ac transmission systems (FACTS) devices, such as DVR, to mitigate them is provided. It is obvious that the flexibility of the DVR output depends on the switching accuracy of the pulse width modulation (PWM) scheme and the control method. The PWM generates sinusoidal signals by comparing a sinusoidal wave with a sawtooth wave and sending appropriate signals to the inverter switches. A further detailed description about this scheme can be found in

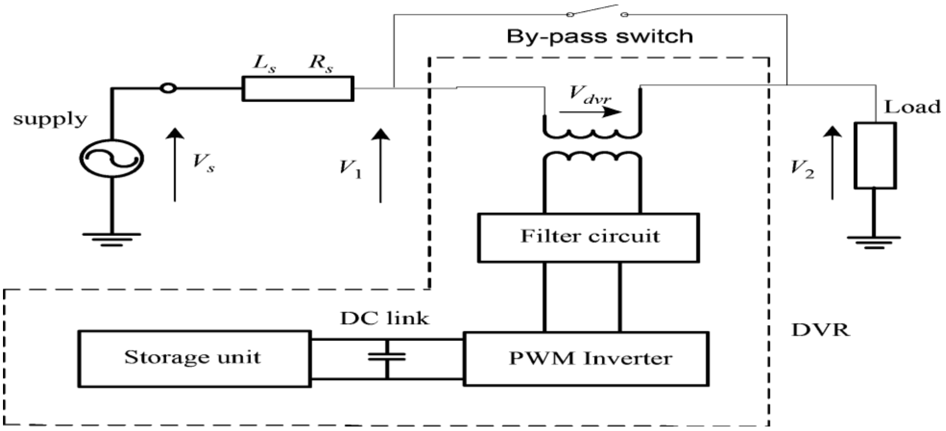


Fig. 1. Typical DVR-connected distribution system.

2.1 Basic Operational Principle of DVR

The phasor diagram in Fig. 2, shows the electrical conditions during voltage sag, where, for clarity, only one phase is shown. Voltages, and are the source-side voltage, the load side voltage, and the DVR injected voltage, respectively. Also, the operators I, , , and are the load current, the load power factor angle, the source phase voltage angle, and the voltage phase advance angle, respectively. It should be noted that in addition to the in-phase injection technique, another technique, namely “the phase advance voltage compensation technique” is also used. One of the advantages of this method over the in-phase method is that less active power should be transferred from the storage unit to the distribution system. This results in compensation for deeper sags or sags with longer duration

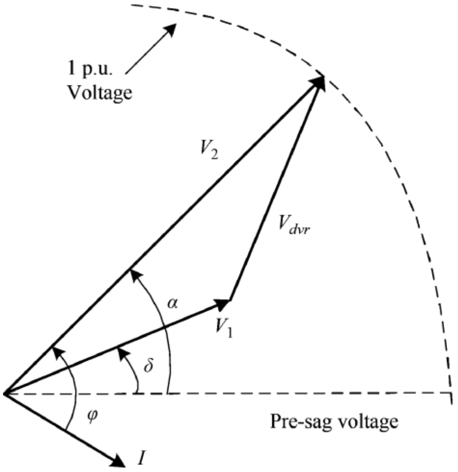


Fig. 2. Phasor diagram of the electrical conditions during a voltage sag.

As Fig. 3 shows, 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 L_f of , a resistance R_f of , and a capacitance C_f of . Also, the DVR injection transformer has a combined winding resistance R_t, a leakage inductance of L_t , and turns ratio of The Posicast controller is used in order to improve the transient 1:n.

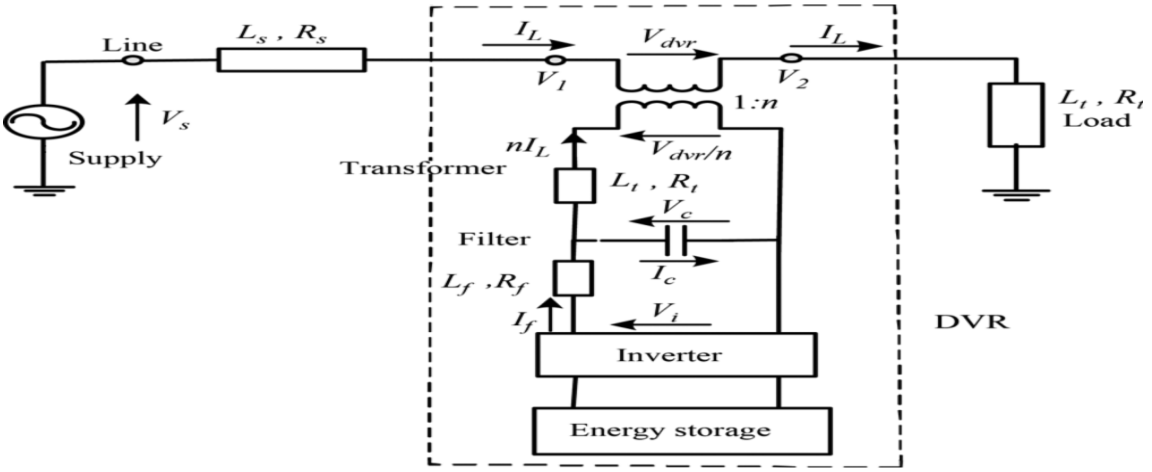


Fig. 3. Distribution system with the DVR.

The Posicast controller is used in order to improve the transient response. Fig. 4 shows a typical control block diagram of the DVR. Note that because in real situations, we are dealing with multiple feeders connected to a common bus, namely “the Point of Common Coupling (PCC),” from now on,V1 and V2 will be replaced with and , respectively, to make a generalized sense. As shown in the figure, in the open-loop control, the voltage on the source side of the DVR is compared with a load-side reference voltage(V_L) so that the necessary injection voltage(V_{inv}) is derived. A simple method to continue is to feed the error signal into the PWM inverter of the DVR. But the problem with this is that the transient oscillations initiated at the start instant from the voltage sag could not be damped sufficiently. To improve the damping, as shown in Fig. 4, the Posicast controller can be used just before transferring the signal to the PWM inverter of the DVR. The transfer function of the controller
can be described as follows:

$$1 + G(s) = 1 + \frac{\delta}{1+\delta}\left(e^{-S^{T_d/2}} - 1\right)$$

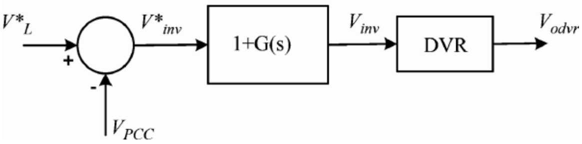


Fig. 4. Open-loop control using the Posicast controller.

Where δ and Td are the step response overshoot and the period of damped response signal, respectively. It should be noted that the Posicast controller has limited high-frequency gain; hence, low sensitivity to noise. To find the appropriate values of and , first the DVR model will be derived according to Fig. 3, as follows:

$$
\begin{aligned}
V_i &= V_c + I_f R_f + L_f \frac{dI_f}{\mathrm{dt}} \\
I_f &= I_c + n.I_t \\
I_c &= C_f \frac{\mathrm{dV_c}}{\mathrm{dt}} \\
V_{\mathrm{dvr}} &= n \left[V_c - n \left(R_t I_t + L_t \frac{\mathrm{dI_t}}{\mathrm{dt}} \right) \right] \\
V_2 &= V_1 + V_{\mathrm{dvr}}.
\end{aligned}
$$

Then, according to above formulas and the definitions of damping and the delay time in the control literature, δ and T_d are derived as follows:

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

=

To eliminate the steady-state voltage tracking error(V_L^*-V_L) a computationally less intensive P+Resonant compensator is added to the outer voltage loop. The ideal P+Resonant com- pensator can be mathematically expressed as

$$G_R(s) = k_p + \frac{2k_I s}{S^2 + \omega_0^2}$$

III. PROPOSED MULTIFUNCTIONAL DVR

In addition to the aforementioned capabilities of DVR, it can be used in the medium-voltage level (as in Fig. 7) to protect a group of consumers when the cause of disturbance is in the downstream of the DVR's feeder and the large fault current passes through the DVR itself.

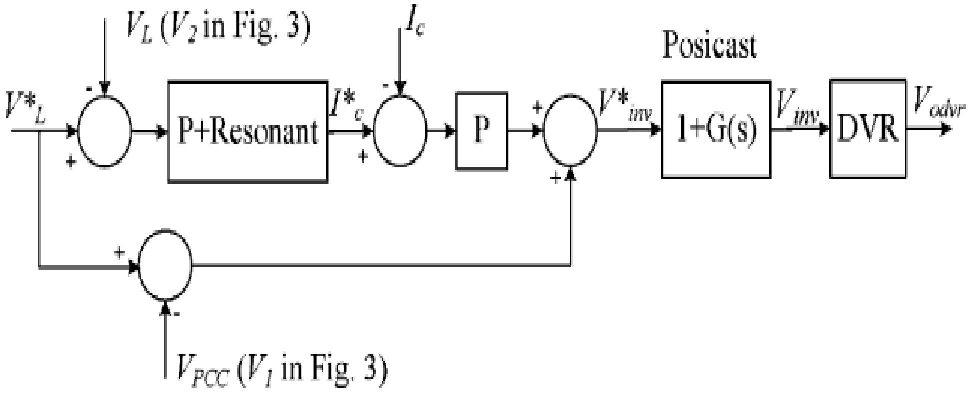
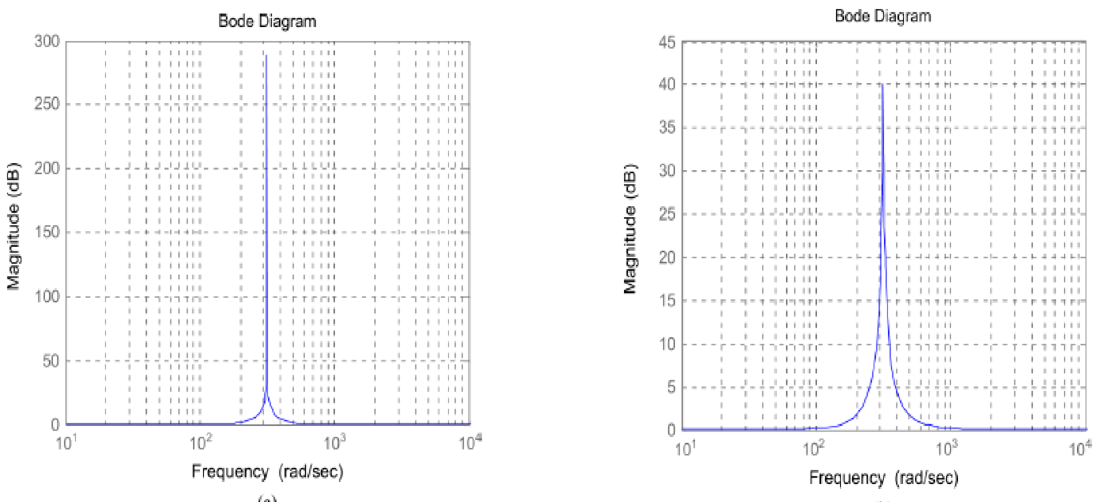


Fig. 5. Multiloop control using the Posicast and P+Resonant controllers.



(a) (b)

Fig. 6. Typical magnitude responses of the (a) Ideal and (b) nonideal P+Resonant controller

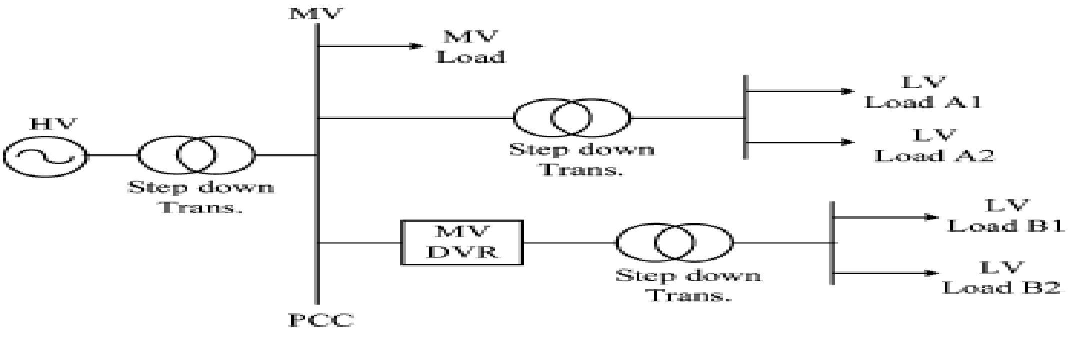
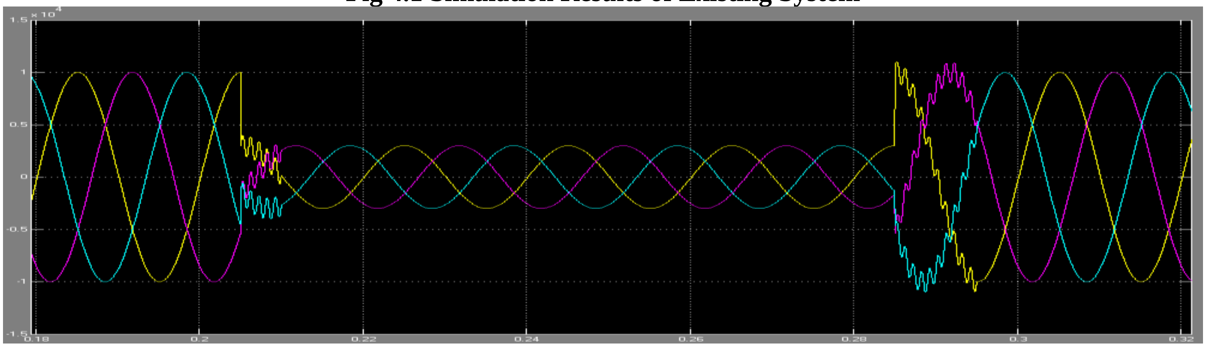


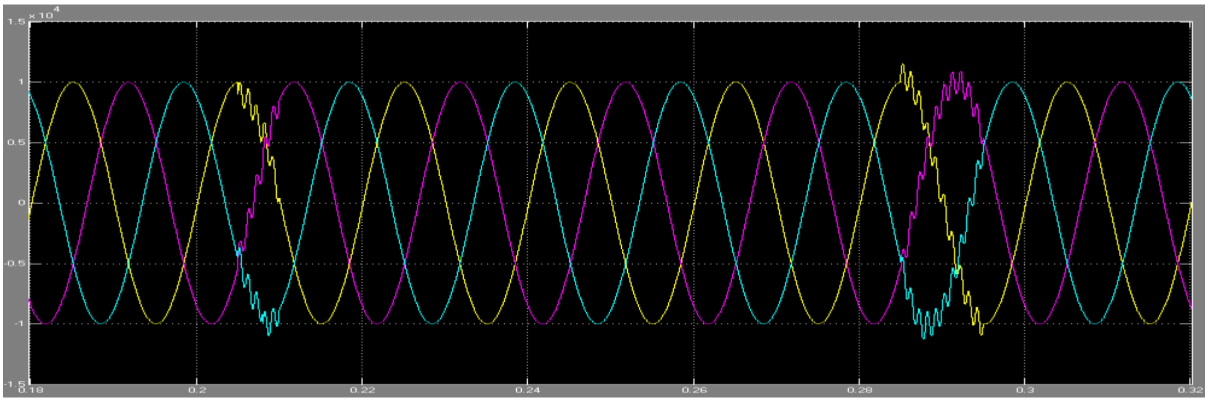
Fig. 7. DVR connected in a medium-voltage level power system.

IV. RESULTS

Fig 4.1 Simulation Results of Existing System



(a)



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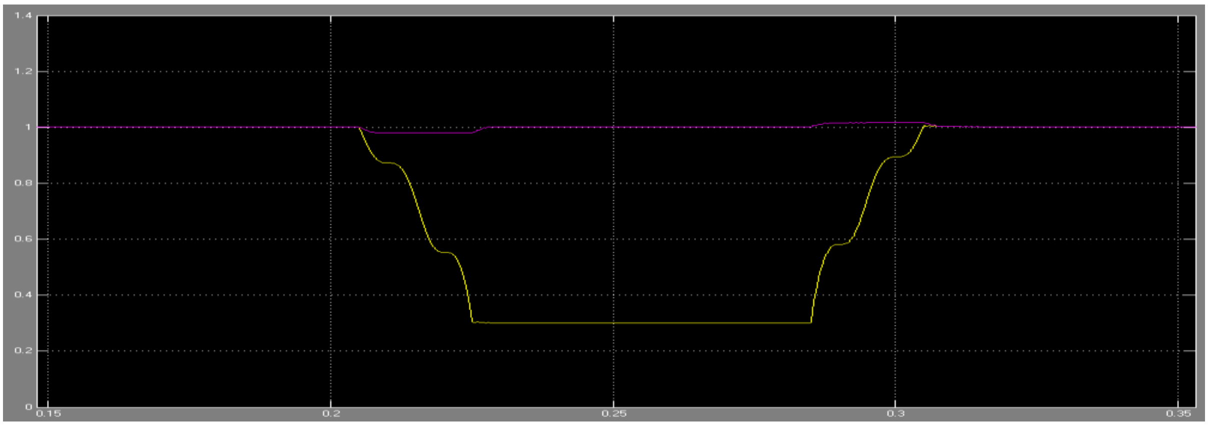
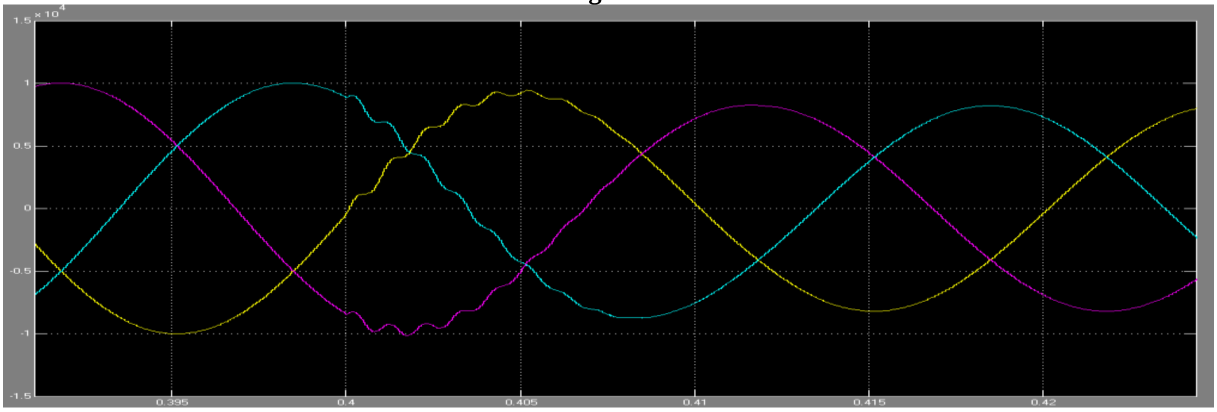
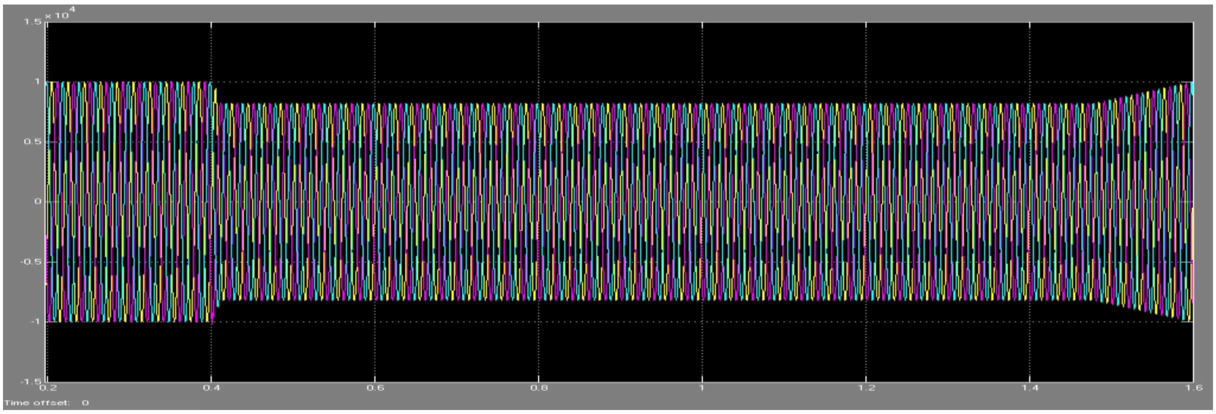


(c)

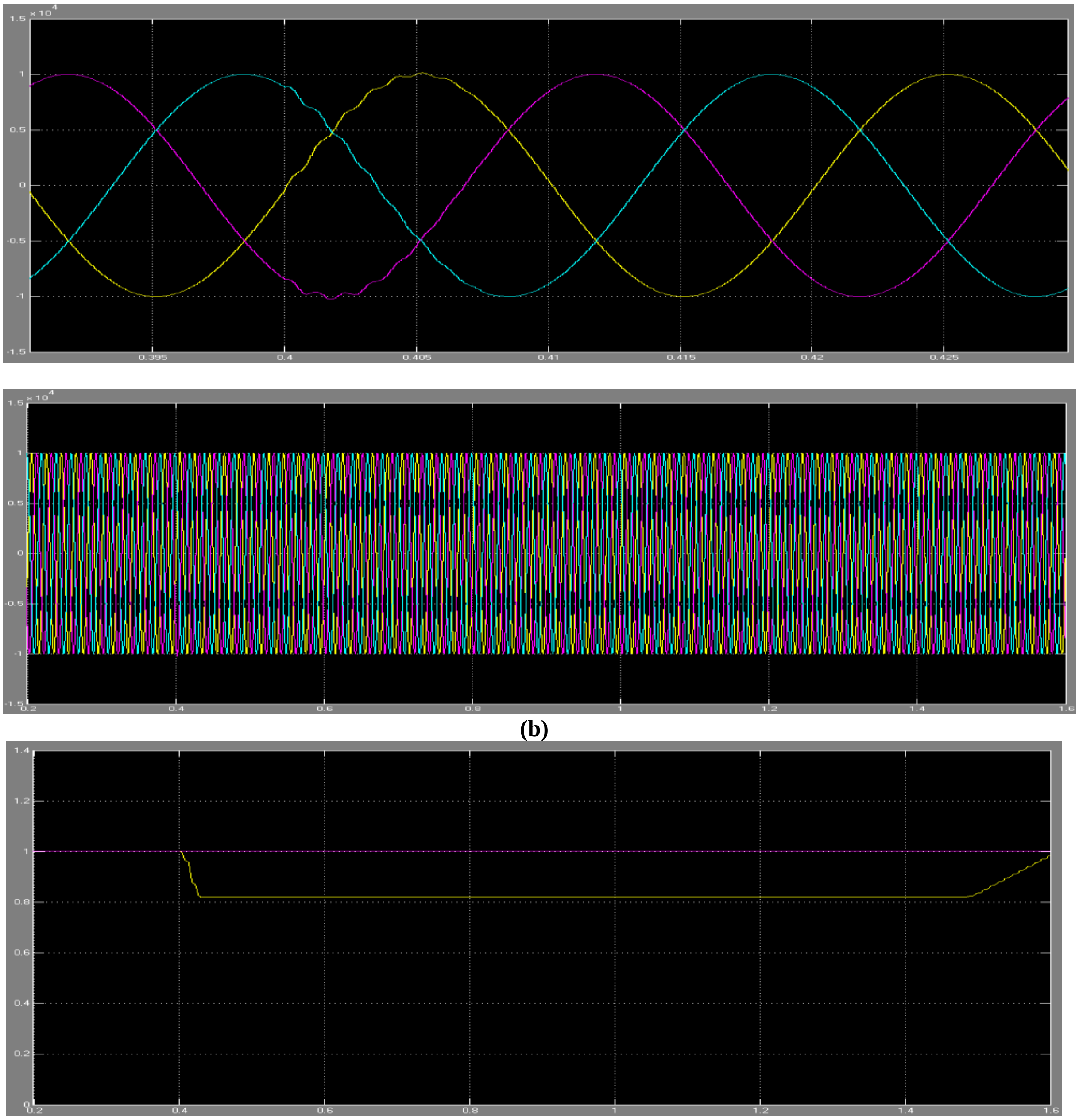
Fig. 4.1 Three-phase fault compensation by DVR. (a) Three-phase PCC voltages. (b) Three-phase load voltages. (c) RMS voltages of PCC and load.

Fig 4.2





(a)



(b)

(c)

Fig 4.2 Starting of an induction motor and the DVR compensation. (a) Three phase

Fig 4.3 PCC voltages. (b) Three-phase load voltages. (c) RMS voltages of PCC

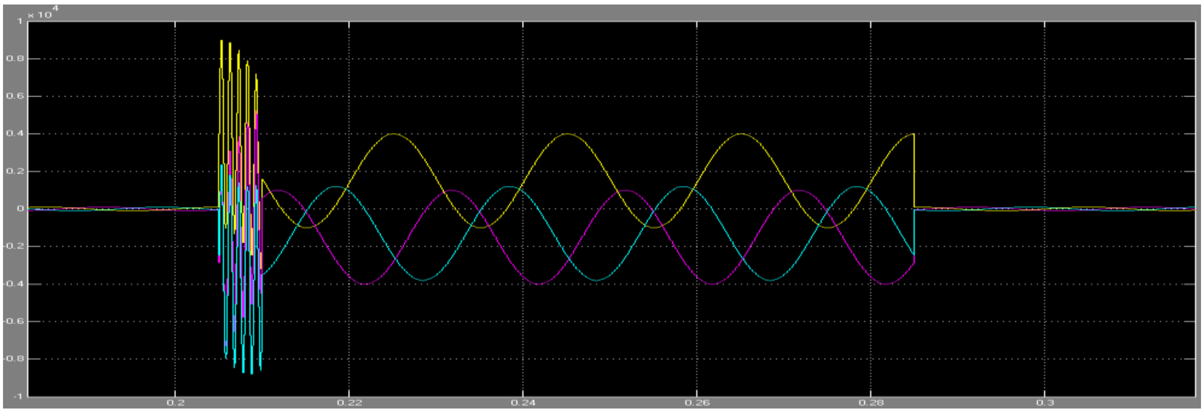
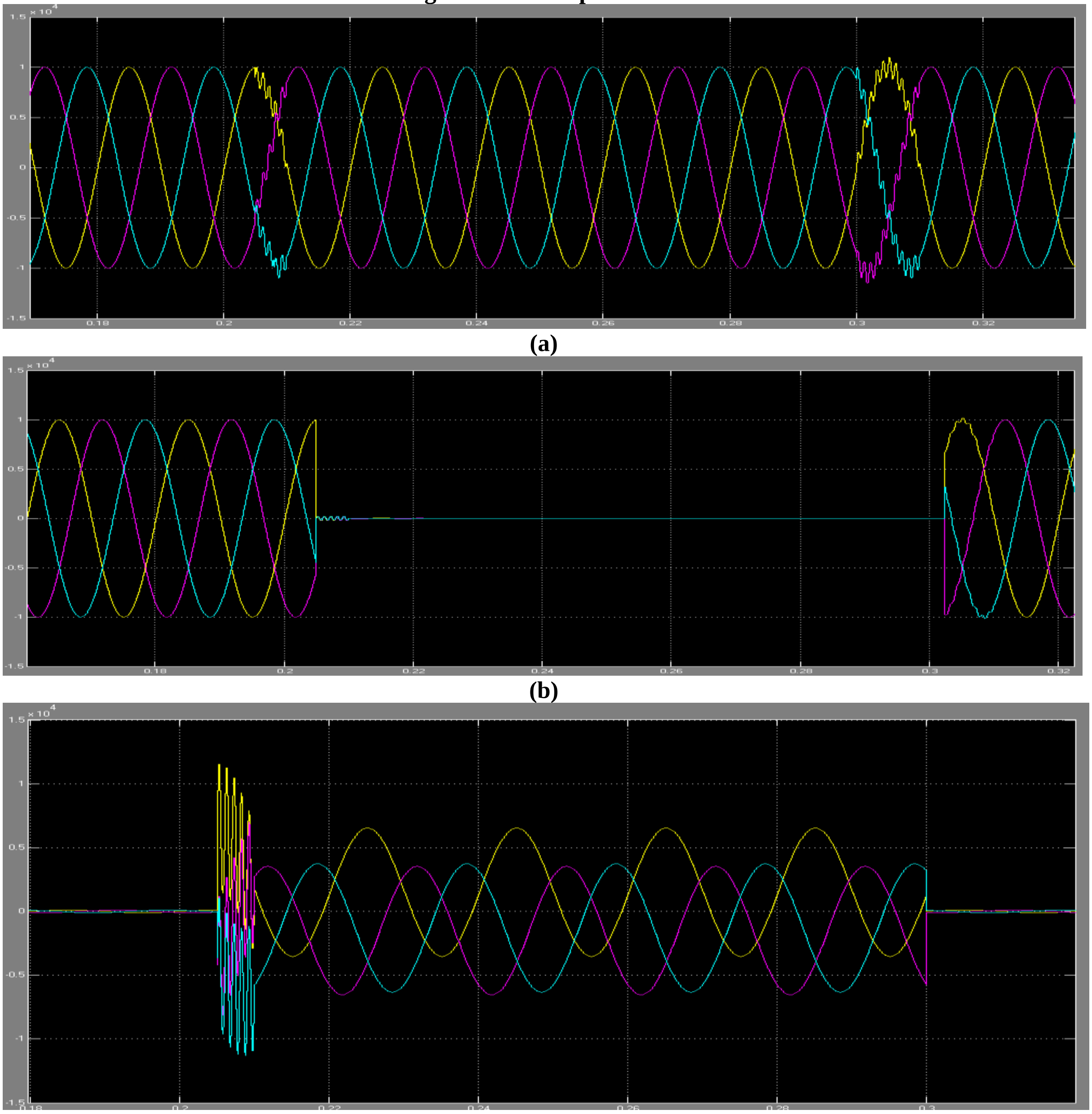


Fig.4.3. Current wave shape due to the three-phase short-circuit fault without

Fig 4.4 DVR compensation.



(a)

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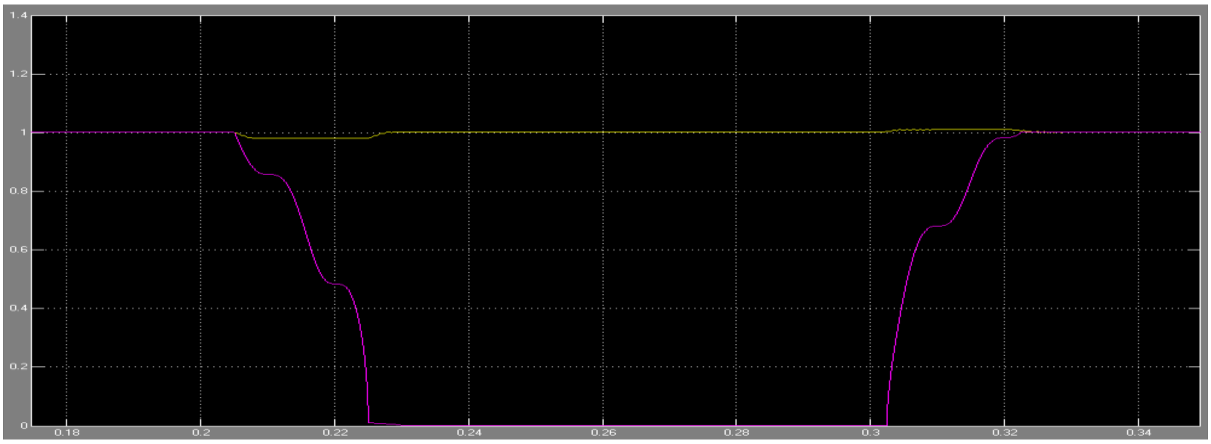

(d)

Fig 4.4 Fault current limiting by DVR. (a) Three-phase PCC voltages. (b) Three-phase load voltages. (c) Three-phase currents. (d) RMS voltages of The PCC and load.

V. CONCLUSION

In this paper, a multifunctional DVR is proposed, and a closed-loop control system is used for its control to improve the damping of the DVR response. Also, for further improving the transient response and eliminating the steady-state error, the Posicast and P+Resonant controllers are used. As the second function of this DVR, using the flux-charge model, the equipment is controlled so that it limits the downstream fault currents and protects the PCC voltage during these faults by acting as variable impedance. The problem of absorbed active power is solved by entering impedance just at the start of this kind of fault in parallel with the dc-link capacitor and the battery being connected in series with a diode so that the power does not enter it. The simulation results verify the effectiveness and capability of the proposed DVR in compensating for the voltage sags caused by short circuits and the large induction motor starting and limiting the downstream fault currents and protecting the PCC voltage.

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