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Fuzzy Based Multiloop Controller for DVR in Distribution System

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Abstract--The Dynamic Voltage Restorer (DVR) is one of the custom power device used in distribution systems to protect from sudden disturbances in load voltage amplitude at the consumers side. In this paper the emergency control in distribution systems with fuzzy approach is proposed for DVR control strategy. Also, the multiloop controllers are posicast; P+Resonant controller and the fuzzy controller are used in order to improve the transient response and to eliminate the steady state error in DVR. The proposed controller's circuit is applied to some disturbances in load voltage caused by induction motor and 3-phase short circuit faults. The fuzzy, posicast and PR controllers are proposed and they are designed in MATLAB and the results are shown.

Keywords - DVR, Posicast and P+Resonant and Fuzzy controllers.

I. Introduction

The Power Quality problems mainly are the Voltage sag and swells. About 80% of Power Quality problems are caused by the sag and swell. Main causes of voltage sags are short circuits, starting large motor, sudden changes of load and energization of transformers [i]. Different aspects of DVR performance and different control strategies have been found. The closed loop control with load voltage and current feedback is used as a simple method to control the DVR. Posicast controller is used to reduce the transient response, while the Proportional + Resonant controller is used to reduce steady state error response. The fuzzy logic control is applied here to further improvement of the transient response. The proposed control strategy is that an outer feedback loop of the load voltage with an inner feedback loop of the filter capacitor current will be used, when the fault current does not pass through the DVR. When the fault current is passed through the DVR, the series voltage is injected in the opposite direction and therefore the DVR acts like series variable impedance [x].

II. Dynamic Voltage Restorer (DVR)

A FACTS device improves the reliability and quality of power transmission by simultaneously enhancing both power transfer volume and stability. The custom power enhances the quality and reliability of power that is delivered to customers. The quality may contain a combination of specifications of the following [i].

- Frequency of rare power interruptions.
- Low harmonic distortion in the supply voltage.
- Low flicker in the supply voltage.
- Low phase unbalance.
- Frequency of the supply voltage within specified limits.

One of the modern devices which is used to restore the voltage and protect consumers from various disturbances is DVR. The DVR injects a set of three phase AC voltages in series and synchronized with the distributed feeder voltages of the AC system. The amplitude and phase angle of the injected voltages are variable there by allowing control the active and reactive power exchanges between DVR and AC system within limits. DVR consists of a Voltage Source Converter a switching control scheme, a DC energy storage device and an injection transformer connected in series with the AC system. This controller is suited for solving variety of power quality and reliability problems including Voltage sag and swell, power factor correction etc.,[x]

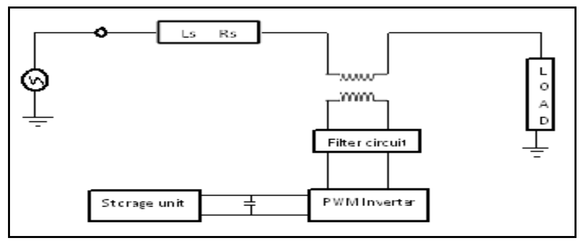

Fig: 1 DVR connected to the distribution system

Before injecting the inverter output to the system, it must be filtered so that harmonics due to the switching that when using the DVR in real situations, the injection transformer will be connected in series to the line [ii]. A switch is also placed in parallel to the injection transformer because when there are no disturbances in the load voltage then the injection transformer is short circuited through the switch. The DVR system show in Fig. 1 controls the load voltage by injecting an appropriate voltage in series with the system using the injection series transformer. In most of the sag compensation techniques, it is necessary that during compensation, the DVR injects some active power of the system. Therefore, the capacity of the storage unit can be a limiting factor in compensation, especially in long term sags. Due to the existence of semiconductor switches in the DVR inverter, this piece of equipment is nonlinear. However, the state equations can be linearized using linearization techniques. In this paper, the simulations are performed with two types of loads: 1) a constant power load and 2) a motor load.

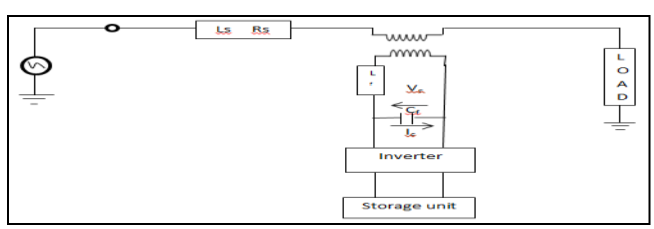

Fig. 2 DVR in the Distribution system.

As Fig. 2 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 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, turns ratio of 1: n. 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.

III. Design Of Controllers

The posicast controller is a control method of feed forward that dampens oscillations other than transient specifications which are allowed. The function of the posicast controller is that splits the original step input command in to two parts. The first part is a scaled step that causes the first peak of the oscillatory response to precisely meet the desired final value. The second part of the reshaped input is full scale and time delayed to precisely cancel the remaining response, the causing the system output to stay at the desired value [vi]. The block diagram of posicast open loop control is given below. The transfer function of posicast controller is given by

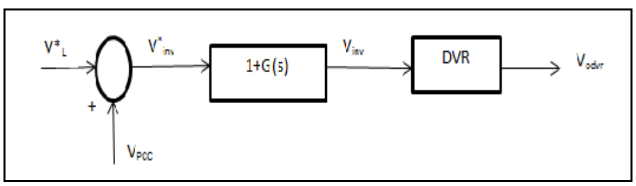

Fig. 3 Block diagram of posicast controller.

The transfer function for a practically used posicast controller is given by

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

Where δ is the peak over shoot and T_d is the period of damped response signal.

P+Resonant controller is used to eliminate the steady state voltage tracking error. PR controller transforms the integral part to be resonant at the frequency of the sinusoidal of the reference signal, by that frequency. The transfer function of PR controller is mathematically expressed as

$$G_R(s) = K_p + \frac{2K_I\omega_{cut}S}{S^2 + 2\omega_{cut}S + \omega_o^2} \quad (2)$$

Where Kp and K_I are the gain constants and $\omega_o = 2*\pi*50$ rad/sec is the controller frequency [v]. Plotting the frequency response, it is taken as 40dB is a finite gain which is high for eliminating the voltage tracking error. The magnitude and frequency response of PR controller is given in Fig. 4.

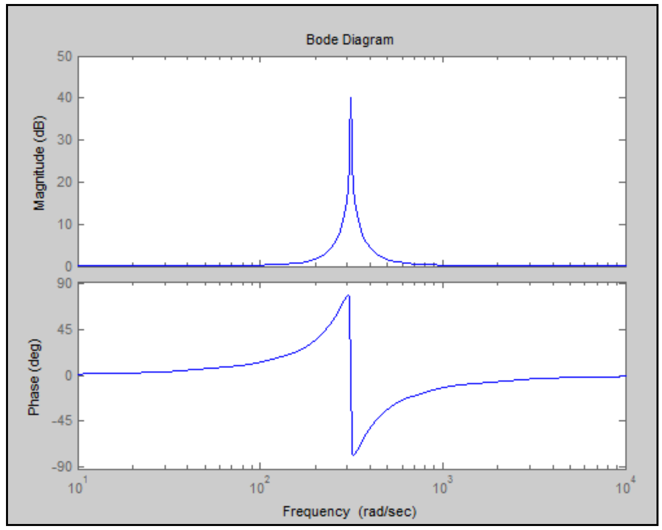

Fig. 4 Magnitude and Phase response of PR controller.

To eliminate the transients other than the oscillations which are not damped out by the posicast controller Fuzzy controller is used. Fuzzy set provides a systematic calculus to deal with such information and it performs numerical computations by using membership functions. The number of membership functions assigned to each input variable. The fuzzy system used is a first order of Sugeno type which has a single input with Gaussian distribution membership functions. It uses if –Then rules. When the input is error signal to the fuzzy controller, it is the variable of PR controller output. The training is performed by using back propagation algorithm. The block diagram of the controllers is given in Fig. 5.

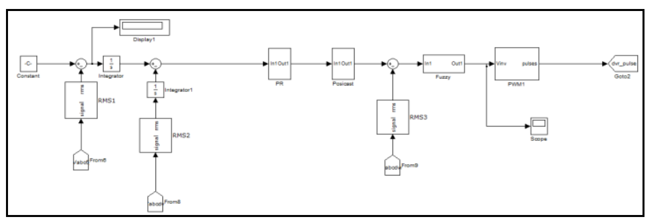

Fig.5 Proposed Control Method.

When the feedback system is applied with in the posicast compensation the sensitivity problem is reduced when compared with the feed forward system [ix], [viii] the classical applications placed Fuzzy and Posicast before the lightly damped system, recent work suggests that Posicast be used with in a feedback system. The proposed control method is a significant departure from classical Posicast. The primary purpose of the Posicast function is to cancel undesirable plant poles, thus minimizing the effect of lightly damped poles in the closed loop response Poles of the closed-loop system would be determined by the remaining open-loop poles and zeros.

IV. Simulation Result

In this, the proposed DVR will be used for emergency control during the voltage sag. The three-phase Short circuit and starting of the induction motor will be considered as the cause of

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distortion in the simulation results.

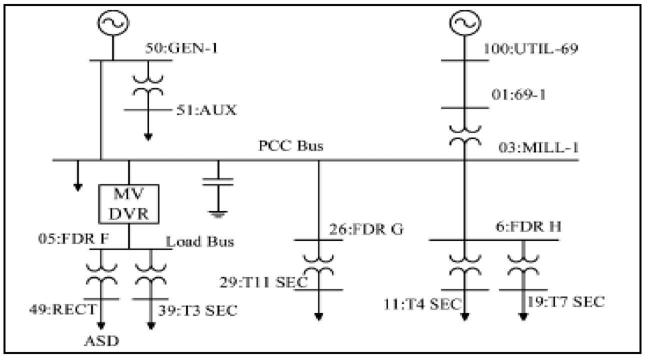
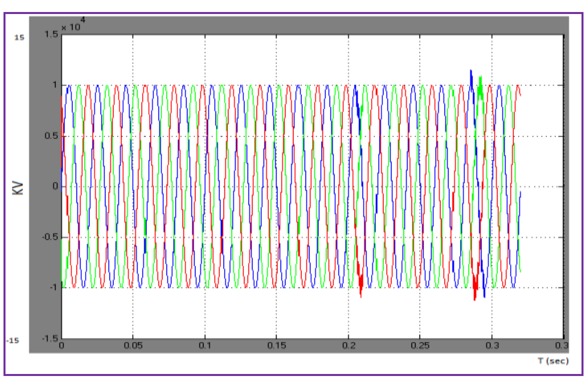


Fig. 6 Test System

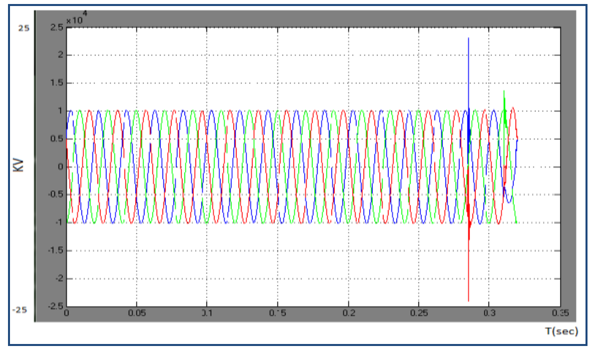
In this, the IEEE standard 13-bus balanced industrial system will be used as the test system. The one-line diagram of this system is shown in Fig. 6. The test system is modeled in MATLAB software. Control methods of Figs. 6 and were applied to control the DVR, and the voltage errors were included as the figures show. Also, the DVR was modeled by its components in the MATLAB software to make more real simulation results. A 12-pulse inverter was used so that each phase could be controlled separately. Detailed specifications of the DVR components are provided in [iii].

A. Three-Phase Short Circuit

In this part, the three-phase short circuit is applied on bus "05:FDR F". The DVR parameters and the control system specifications are provided in [iv]. At 0.205s, the fault is applied at 0.285s, and the breaker works and separates the line between buses "03: MILL-1"and "26: FDR G," from the system. At 0.305s, the fault will be recovered and, finally, at 0.310s, the separated line will be rejoined to the system by the breaker. The simulation results shown in Fig. 7(a) and Fig. 7(b) are the without fuzzy and with fuzzy respectively. The DVR will start the compensation just after the detection of sag. It is worth noting that the amount and shape of the oscillations depends also on the time of applying the fault.



(a)

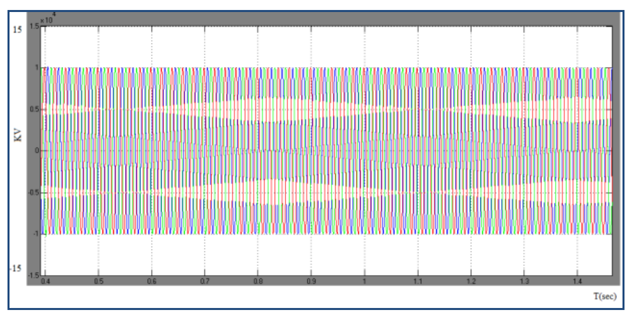


(b)

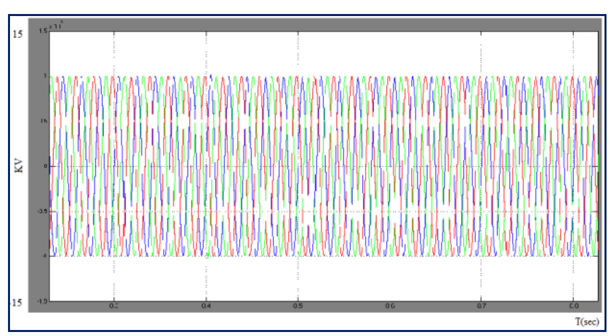
Fig. 7 simulation results of DVR. (a) Load voltage without fuzzy. (b) Load voltage with fuzzy.

B. Induction Motor Starting

An Induction motor is started on "03: MILL-1". By the starting of motor, the starting current will cause the PCC voltage to drop. The simulation result using the DVR without fuzzy controller is shown in Fig. 8 (a). The motor is started at the time of t= 0.405s, at this time the PCC voltage drops to about 0.8p.u. During the period of motor starting, the PCC bus is under voltage sag. To the same control strategy, the fuzzy controller is added and this controller reduces the transients which are present. From the time of t = 1.4s, the speed approaches to the nominal, the voltage also approaches to the normal condition. The DVR keeps the bus voltage at the normal condition, during all of these events also. The simulation result using DVR with fuzzy is shown in Fig. 8 (b). From the instant of motor starting, the DVR ha succeeded in restoring the load voltage in half a cycle.



(a)



(b)

Fig. 8 simulation results of DVR. (a) Load voltage without fuzzy (b) Load voltage with fuzzy.

V. Conclusion

In this paper, a DVR is proposed, and a closed-loop control system is used for its control to improve the DVR response. The better transient response is achieved by applying Fuzzy control techniques to the conventional control technique. The simulation results verify the effectiveness and capability of the proposed DVR for the voltage sags caused by the symmetrical fault and the start of Induction motor.

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