Balanced Voltage Sag Correction Using Dynamic Voltage Restorer Based Fuzzy Polar Controller

Margo P, M. Heri P, M. Ashari, and T. Hiyama
Dept. of Electrical Engineering, Institute of Technology Sepuluh Nopember, Indonesia
Dept. of Computer Science and Electrical Engineering, Kumamoto University, Japan
margo@ee.its.ac.id

Abstract

Many controllers based fuzzy logic have been applied on electric power system. Frequently, time response of the fuzzy controllers is slowly, because the number of membership functions are too many. Many research are proposed to minimize the number of membership function, such as fuzzy polar controller method. By using this method, number of membership function can be minimized, so the time response of the controller become faster. This paper presents the Dynamic Voltage Restorer (DVR) based Fuzzy Polar Controller Method to compensate balanced voltage sag. Simulation results show that this proposed method can compensate balanced voltage sag better than PI controller.

1. Introduction

Most of problems on power quality are voltage sag and momentary power loss. Longer term outages are rare. Two important parameters of voltage sag are magnitude and time duration.

Commonly, compensation method using DVR is done by using series AC voltage injection to compensate voltage sag. Another method are applied using injection in phase during sag event. By using this method, the use of energy storage can be minimized, but it can cause phase shifting.

Voltage sag which is caused by three phase fault can be compensated by using DVR based Neural Network (NN) [1,2]. This method can compensate the voltage sag perfectly, but it takes long time response. Conventional Fuzzy Logic Controller [3] can reduce the time response, but this controller need too many membership function.

Many research are done to minimize the number of membership function, such as fuzzy polar controller. In reference [4], Hiyama shows that the membership function of conventional fuzzy logic controller can be minimized using fuzzy polar method.

This paper presents DVR based fuzzy polar controller to compensate balanced voltage sag on electric distribution systems. Fuzzy polar controller parameters are constructed to determine the value of injection voltage to compensate voltage drop which is caused by three phase fault. The results of this simulation show that DVR based fuzzy polar controller can compensate balanced voltage sag better than PI controller.

2. Dynamic Voltage Restorer

The Dynamic Voltage Restorer (DVR) is a custom power device that is connected in series with line distribution system, as shown in Fig. 1. The DVR uses semiconductor devices, such as Insulated Gate Bipolar Transistors (IGBTs). It can maintain load voltage by injecting three phase output voltages which magnitude, phase, and frequency can be controlled [1]. These three phase voltages are injected in synchronized with the voltages in the distribution system.

![Fig. 1. Block diagram of DVR](image-url)
during disturbance. Therefore, the capacity of energy storage can become a constraint factor in the disturbance compensation process, especially for sags and long duration fault.

Typically, DVR consists of three phase inverter, energy storage, controller and booster transformer. In this paper, fuzzy polar is applied as a controller, and Space Vector Pulse Width Modulation (SVPWM) is applied as control method on three phase inverter.

Figure 2 shows the sensitive load voltage on distribution system which is regulated by DVR based fuzzy polar controller. Sensitive load voltage is represented by load 2. This figure is used as test system in the simulation. DVR takes voltage signal at Bus A as fuzzy polar input. The DVR injects voltage to Bus B through booster transformer. Three phase short circuits are applied in Bus C which can cause balanced voltage sag in Bus A. When voltage sag occurs in Bus A, DVR will take action to inject active power to Bus B. So, Load 2 will be free from voltage sag disturbance.

3. Fuzzy Polar Controller

In basic applications, Fuzzy controller is used to substitute the conventional PI compensator [5]. In this paper, fuzzy polar is used as a controller on DVR. Fuzzy polar method have been developed for the application of control on electric power system [4,6,7,8].

Fuzzy polar consists of some parameters such as proportional-derivative controller, as shown in Fig. 3. Three basic parameters are derivative multiplier As, the overlap angle of the angle membership function α, and the fuzzy distance level for the radial member, Dr. The operating point of polar coordinate can be shown in Eq.(1) to (3).

\[
p(k) = \frac{Zs(k) AsZa(k)}{(Zs(k))^2 + (AsZa(k))^2} \quad (1)
\]

\[
D(k) = \sqrt{(Zs(k))^2 + (AsZa(k))^2} \quad (2)
\]

\[
θ(k) = \tan^{-1}(AsZa(k)/Zs(k)) \quad (3)
\]

This controller is fed the input signal Zs and takes the derivative of this signal to find Za. Three other factors involved in the controller are maximum signal control U_max, time sampling T, and delay time DT. These parameters are often determined using external criteria. The defuzzification rules for the controllers are shown in Eq. (4) [4],

\[
U(k) = G(D(k)) [N(θ(k)) - P(θ(k))] U_{\text{max}} \quad (4)
\]

Fuzzy variables are defined in Fig.3, Eq. (1) to (3), and U_{\text{max}} represent maximum permitted control signal. Basic Model of fuzzy polar controller is shown in Fig. 4 as follows.

Fig. 4 is simplified model of fuzzy polar with single input and single output. Actually, there is only one input, Zs. But, it needs derivative signal Za to
convert into the polar coordinate, as shown in Fig. 3. The output of fuzzy polar $U$ is determined using Eq. (4).

4. Simulation Result

The total time of the simulation is 5 cycles and the results of the simulation are compared with DVR based PI. In this simulation, one cycle duration of three phase fault is applied at 0.04 second on Bus C, which can cause balanced voltage sags at Bus A. DVR is installed to maintain the voltage at sensitive load (Load 2). 50% and 30% voltage sags are applied to examine the performance of DVR. Fig. 6 shows the voltage time response without DVR when 50% voltage sag is applied. Fig. 7 shows the voltage time response with DVR based PI. Voltage sags correction using DVR based Fuzzy Polar Controller can be seen in Fig. 8. According to the Fig 7 and 8, it is shown that the compensation using DVR based Fuzzy Polar is better than PI Controller.

Table 1 shows the percentage of restored voltage and error voltage correction using DVR based PI and Fuzzy Polar Controller, which are caused by 50% and 30% voltage sags respectively.
### 5. Conclusions

DVR based PI Controller can maintain 50% voltage sags at 110% and 30% voltage sags at 98%. DVR based Fuzzy Polar Controller can maintain 50% voltage sags at 100% and 30% voltage sags at 97%. According to the error average of all simulations, are shown that the performance of DVR based Fuzzy Polar Controller better than DVR based PI Controller. Further study for unbalance correction is being worked to prove the effectiveness of the proposed controller.

### 6. Contribution

This research are dedicated for the development of science and technology. Its result is used to simplified DVR controller device.

### 7. Acknowledgement

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