Compensation of Balanced and Unbalanced Voltage Sags using Dynamic Voltage Restorer Based on Fuzzy Polar Controller


Dept. of Electrical Engineering, Institute of Technology Sepuluh Nopember, Indonesia
Dept. of Computer Science and Electrical Engineering, Kumamoto University, Japan
e-mail: margo@ee.its.ac.id

Abstract

Many research were proposed to minimize the number of fuzzy membership function, one of them is fuzzy polar controller method. By using this method, the number of membership function can be minimized. This paper proposed the Dynamic Voltage Restorer based on Fuzzy Polar Control Scheme and blocking zero sequence to compensate both balanced and unbalanced voltage sags. Delta to star connection transformer is used in this system, therefore the zero sequence component does not appear on the load side. The d and q components of the line voltages are converted to polar coordinate. The Simulation results show that the proposed method compensates both balanced and unbalanced voltage sags better than PI controller. Averaged error by fuzzy polar controller is 2.6 % and by PI controller is 4.9 %.

Keywords: Voltage sag, DVR, fuzzy polar

Introduction

Most of problems on power quality are voltage sags and momentary power loss. Longer term outages are rare. Two important parameters of voltage sags are its magnitude and time duration [1].

Commonly, restoring method using Dynamic Voltage Restorer (DVR) is done by compensating the voltage sags using series AC voltage [2,3]. Another method uses injection in phase with the voltage source during voltage sags [4]. When using this method, the size of required energy storage can be minimized, but it can cause phase
shifting compared to pre-voltage sags.

Voltage sags caused by 3 phase short circuit can be compensated by using DVR based on Back Propagation Neural Network (NN) [5,6]. This method compensates the voltage sags perfectly, but time response is longer. Conventional Fuzzy Logic Controller reduces the time response, but it requires many membership functions [7].

Many topics of propose to research are done to minimize the number of membership function, such as fuzzy polar controller. Hiyama shows that the membership function of conventional fuzzy logic controller can be minimized using fuzzy polar method [8].

This paper presents a design of DVR based on fuzzy polar controller to compensate both balanced and unbalanced voltage sags on electric distribution systems.

**Dynamic Voltage Restorer**

The DVR is a custom power device that is connected in series with line of distribution system as shown in Fig. 1. The DVR uses semiconductor devices such as Insulated Gate Bipolar Transistors (IGBTs) and maintains voltage applied to the load by injecting three single-phase output voltages that its magnitude, phase, and frequency can be controlled [5]. These three phase voltages are injected in synchronized with the voltages in the distribution system.

![Figure 1: Block diagram of Dynamic Voltage Restorer](image)

In most sags compensation technique, DVRs are applied to inject active power into distribution line during of disturbance. Therefore, the capacity of energy storage will limit the compensation process, especially for sags with long duration.

Typically, DVR consists of three phase inverter, energy storage, controller and booster transformer. In this paper, fuzzy polar method is applied as a controller. Three phase inverter is controlled by Pulse Width Modulation (PWM).

Figure 2 illustrates the test system in the simulation. This figure shows the sensitive load voltage on distribution system which uses Δ-Y transformer regulated by the DVR based on fuzzy polar controller. Blocking zero sequence component is represented by transformer 2. Sensitive load voltage is represented by load 2. The...
input to the fuzzy polar controller is voltage of bus A. The DVR injects voltage to Bus B through booster transformer. Faults are applied on Bus C which causes voltage sag on Bus A. When voltage sag occurs on Bus A, DVR will take action to inject active power to Bus B. Therefore, Load 2 will be free from voltage sags disturbance.

Control Technique
DVR can be controlled by using any kind of the controllers. In this study, PI and Fuzzy Polar controller were applied to control the DVR and also for comparison studies. The performance of both PI and Fuzzy Polar controller were compared.

In basic applications, Fuzzy controller is used to substitute the conventional PI compensator [9, 10]. In this study, fuzzy polar is utilized as a controller on DVR. Fuzzy polar method have been developed for the application of control on electric power system [8, 11,12,13]. Fuzzy polar consists of some parameters such as proportional-derivative controller. Three basic parameters are derivative multiplier, As, the overlap angle $\alpha$ of the angle membership function, and the fuzzy distance level for the radial member, Dr. The operating point of polar coordinate can be shown in Eq.(1) to (3).

\[ p(k) = [Z_s(k) \ AsZ_a(k)] \quad (1) \]

\[ D(k) = \sqrt{(Z_s(k))^2 + (AsZ_a(k))^2} \quad (2) \]

\[ \theta(k) = \tan^{-1}(As.Z_a(k)/Z_s(k)) \quad (3) \]

This controller is fed the input signal $Z_s$ and takes the derivative of this signal to find $Z_a$. Three other factors involved in the controller are maximum signal control $U_{max}$, sampling time $T$, and delay time $DT$. These parameters are often determined using external criteria. The defuzzification rule for the controllers is shown in Eq. (4) [8].

Figure 2: Test system for simulation
\[ U(k) = G(D(k))(N(\theta(k)) - P(\theta(k)))U_{\text{max}} \] (4)

Polar form of fuzzy polar is shown in Figure 3, and fuzzy variables are defined in Eq. (1) to (3). \( U_{\text{max}} \) represent maximum permitted control signal. Membership functions of fuzzy polar are shown in Figure 4. Figure 5 is simplified model of fuzzy polar with single input and single output. Actually, there is only one input, \( Z_s \). But, it needs derivative signal \( Z_a \) to convert into the polar coordinate as shown in Figure 3. The output of fuzzy polar \( U \) is determined using Eq. (4).

Figure 6 is the detailed simulation model of voltage regulator block in Figure 2. Block polar d and polar q in Figure 6 are used to convert signal to polar coordinate using Eq. (1) to (3). So, sensing signal in abc coordinate is converted into dq coordinate using Park Transformation. The direct axis voltage error \( \Delta V_d \) and its derivative \( \Delta V_d' \) are considered as the first input fuzzy polar controller. The quadrature axis voltage error \( \Delta V_q \) and its derivative \( \Delta V_q' \) are the second fuzzy polar controller. The voltage reference of the regulator is \( V_{\text{dref}} = 1 \) and \( V_{\text{qref}} = 0 \).

![Figure 3: Polar Form](image)

![Figure 4: Membership function fuzzy polar](image)
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**Figure 5**: Fuzzy polar controller diagram

**Figure 6**: Block diagram of DVR based Fuzzy Polar controller

**Simulation Results**

Simulations are performed in Matlab environment. Fuzzy Polar controller method is simulated using M-file. The total time of the simulation is 4 cycles and the results of simulation are compared with DVR based on PI controller. The parameters of PI controller and Fuzzy Polar controller can be shown in Table 1.

<table>
<thead>
<tr>
<th>No</th>
<th>Pi Parameters</th>
<th>Fuzzy Polar Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Direct input d</td>
</tr>
<tr>
<td>1.</td>
<td>Kp 1.3</td>
<td>As 0.19</td>
</tr>
<tr>
<td>2.</td>
<td>1/Ti 0.9</td>
<td>Dr 0.9</td>
</tr>
<tr>
<td>3.</td>
<td>-</td>
<td>α 90º</td>
</tr>
<tr>
<td>4.</td>
<td>-</td>
<td>Umax 4.0</td>
</tr>
</tbody>
</table>

In this simulation, short circuit during 2 cycles is applied at 0.02 second on Bus C, which causes balanced voltage sags on Bus A. DVR is installed to maintain the voltage at sensitive load, Load 2. 30%, 50%, and 70% voltage sags are applied to examine the performance of the DVR. Figure 7 shows the result when the 50% voltage sags is applied. Figure 8 shows the voltage time response with DVR based on Fuzzy Polar controller, and Figure 9 by PI controller.
Figure 7: 50% Voltage Sags at Bus A caused by 3 phases fault

Figure 8: 50% Voltage Sags Correction using DVR based Fuzzy Polar Controller

Figure 9: 50% Voltage Sags Correction using DVR based PI Controller

The voltage recovery by polar control shown in Figure 8 is about 98%, and by PI in Figure 9 is about 95%. Line to line, line to line to ground fault and single line to
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Ground fault in 2 cycle duration are applied at 0.02 second on Bus C, which causes unbalanced voltage sags on Bus A. The results of compensation are shown in Figure 10 to 15.

**Figure 10**: 50% Unbalanced voltage sag at Bus A caused by line to line to ground fault

**Figure 11**: 50% Unbalanced Voltage Sags Correction using DVR based Fuzzy Polar Controller (caused by line to line to ground fault)

**Figure 12**: 50% Unbalanced Voltage Sags Correction using DVR based PI Controller (caused by line to line to ground fault)

The voltage recovery by polar control shown in Figure 11 is about 97.5 %, and by PI in Figure 12 is about 97 %.
The voltage recovery by polar control shown in Figure 14 is about 98%, and by PI in Figure 15 is about 95.6%.

Another simulations were done to study about the effectiveness of the proposed controller. DVR based on PI controller is also simulated for comparison studies with proposed method. The summary of these simulations can be seen in Table 2. The results of simulation in Table 2 show that DVR based on Fuzzy Polar Controller corrects both of balanced and unbalanced voltage sags properly.

The summary of error in these simulations are also shown in Figure 16. Figure 17 shows averaged error of the compensation.
Table 2: Percentage of restored voltage and error voltage correction

<table>
<thead>
<tr>
<th>Voltage Sags</th>
<th>Correction by Polar Controller</th>
<th>Correction by PI Controller</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Restoration Error</td>
<td>Restoration Error</td>
</tr>
<tr>
<td>50% GF</td>
<td>98.5%</td>
<td>95%</td>
</tr>
<tr>
<td>70% GF</td>
<td>98%</td>
<td>95.6%</td>
</tr>
<tr>
<td>30% 2F</td>
<td>95%</td>
<td>92%</td>
</tr>
<tr>
<td>50% 2F</td>
<td>97.5%</td>
<td>96.6%</td>
</tr>
<tr>
<td>70% 2F</td>
<td>100%</td>
<td>97.2%</td>
</tr>
<tr>
<td>30% 2FG</td>
<td>95%</td>
<td>92%</td>
</tr>
<tr>
<td>50% 2FG</td>
<td>97.5%</td>
<td>97%</td>
</tr>
<tr>
<td>70% 2FG</td>
<td>100%</td>
<td>96.2%</td>
</tr>
<tr>
<td>30% 3F</td>
<td>92.5%</td>
<td>92%</td>
</tr>
<tr>
<td>50% 3F</td>
<td>98%</td>
<td>95%</td>
</tr>
<tr>
<td>70% 3F</td>
<td>99%</td>
<td>97.5%</td>
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</table>

Figure 16: The error response of DVR

Figure 17: The comparison average error

From the simulations it is clearly recognized that DVR by fuzzy polar works better than DVR by PI controller. Averaged error by fuzzy polar controller is 2.6% and by
PI controller is 4.9%. Fuzzy polar controller can work properly for both balanced and unbalanced voltage sags.

Conclusions
The results of the simulation show that DVR based on Fuzzy Polar Controller can compensate balanced and unbalanced voltage sags in the zero sequence blocking system.

Simulation results show that the proposed method compensates both balanced and unbalanced voltage sags better than PI controller. Averaged error by fuzzy polar controller is 2.6% and by PI controller is 4.9%.

Further study for multifunction of DVR, voltage sags correction and harmonics active filter is now on going to demonstrate the effectiveness of the proposed controller.

Acknowledgement
Authors would like to thank JICA (Japan International Cooperation Agency) for supporting this research. This joint research, between ITS and Kumamoto University and Universities in Eastern part of Indonesia is supported by JICA, under the Project of Research and Education Development on Information and Communication Technology (PREDICT), hosted by Institute of Technology Sepuluh Nopember (ITS) – Indonesia.

References


Biography

Margo Pujiantara was born in 1965. He received his bachelor degree from Institute of Technology Sepuluh Nopember (ITS), Surabaya, Indonesia in 1989. The Master degrees from Institute of Technology Bandung (ITB), Indonesia in 1995. He has been with ITS since 1990 as a junior lecturer in the department of Electrical Engineering. He actively involves in industrial research and applied technologies such as filter design for harmonic distortions. He is currently pursuing the Ph.D. degree at the ITS., Surabaya, Indonesia.

Mauridhi Hery Purnomo received the bachelor degree from Institute of Technology Sepuluh Nopember (ITS), Surabaya, Indonesia in 1985. He received his M.S., and Ph.D degrees from Osaka City University, Osaka, Japan in 1995, and 1997, respectively. He joined ITS in 1985 and has been a Professor since 2004. His current interests include intelligent system applications to electric power systems operation.
control and management. He is a Member of IEEE.

**Mr. Mochamad Ashari** received the bachelor degree from Institute of Technology Sepuluh Nopember (ITS), Surabaya, Indonesia. He has been with ITS since 1990 as a junior lecturer in the department of Electrical Engineering. He received Master and PhD degrees from Curtin University, Australia in 1998 and 2001 respectively. He actively involves in industrial research and applied technologies such as filter design for harmonic distortions, solar home systems for rural areas etc. Dr. Ashari has received research grants from institutions including ADB, JICA, Indonesian Government (Ministry of National Education, Ministry of research and technology). Currently he is the head of Electrical Engineering department. His topic interests include power electronics for industries and renewable energy sources.

**Hendrik Maryono** received his bachelor degree from Institute of Technology Sepuluh Nopember (ITS), Surabaya, Indonesia in 2006. He actively involves in industrial research and applied technologies. He joined National Electric Company in 2007.

**Takashi Hiyama (S.M)** received his B.E., M.S., and Ph.D degrees all in Electrical Engineering from Kyoto University Japan in 1969, 1971, and 1980, respectively. He joined Kumamoto University in 1971 and has been a Professor since 1989. During the period of June 1985 through September 1986, he was at Clarkson University, and was involved with power system harmonic research. His current interests include intelligent system applications to electric power systems operation, control and management and the applications of renewable energy power sources to power distribution systems. He is a Senior Member of IEEE, a member of IEE of Japan and Japan Solar Energy Society.