Analysis and design of DVR performance for voltage sag mitigation

T. Naveen Kumar
naveen.7412@gmail.com

ABSTRACT:
This paper deals with terminology and various problems concerning ‘power quality issues’. Voltage sags and swells are the normal activities on the electric power network. These issues can be mitigated with voltage injection procedure utilising custom power device, Dynamic Voltage Restorer (DVR). In this paper we design a Dynamic Voltage Restorer (DVR) which is utilized for power quality growth. Here we advocate two control procedures that are the Proportional integral (PI) Controller and Fuzzy common sense (FL) Controller. Results of each the controllers are assessed to understand which the best power quality solution.

KEYWORDS-Dynamic Voltage Restorer, Pulse Width Modulation (PWM), PI with Fuzzy Logic Controller

I. INTRODUCTION

Voltage sags are now one of the most important power quality problems in the power distribution systems. A voltage sag is a momentary decrease in rms ac voltage (0.1-0.9 p.u. of the nominal voltage), at the power frequency, of duration from cycles to a few seconds. Most voltage sags are caused by remote faults, such as single line-to-ground fault, double line to ground fault and three phase fault on the power distribution system. [2]. Recently, power quality problems become a major concern of industries due to massive loss in terms of time and money. Hence, there are always demands for good power quality, which positively resulting in reduction of power quality problems like voltage sag, harmonic, flicker, interruptions and harmonic distortion. Preventing such phenomena is particularly important because of the increasing heavy automation in almost all the industrial processes. High quality in the power supply is needed, since failures due to such disturbances usually have a high impact on production costs.

There are number of methods to overcome voltage sags. One approach is to use Dynamic Voltage Restorers with energy storage. The DVR is a power electronics device that is able to compensate voltage sags on critical loads dynamically. By injecting an inappropriate voltage, the DVR restores a voltage waveform and ensures constant load voltage. The DVR consists of Voltage Source Converter (VSC), injection transformers, passive filters and energy storage (lead acid battery). The Dynamic Voltage Restorer (DVR) with the lead acid battery is an attractive way to provide excellent dynamic voltage compensation capability as well as being economical when compared to shunt-connected devices. The DVR is a custom power device that is connected in series with the distribution system. The DVR employs MOSFETs to maintain the voltage applied to the load by injecting three-phase output voltages whose magnitude, phase and frequency can be controlled. [3]. Control unit is the heart of the DVR where its main function is to detect the presence of voltage sags in the system, calculating the required compensating voltage for the DVR and generate the reference voltage for PWM generator to
trigger on the PWMinverter. The components of control system unit aredq-0-transformation, Phase-lock-loop (PLL) and thePI with FL Controller. PI Controller is a feedbackcontroller which drives the plant to be controlledwith a weighted sum of the error (differencebetween output and and desired set-point) and theintegral of that value. [1].

A new fuzzy logic (FL) method has been applied to custom power devices, especially for active power filters. The operation of DVR is similar to that of active power filters in that both compensators mustrespond very fast on the request from abruptly changing reference signals. In the literature, FL control of DVR based on dq synchronous referenceframe (SRF). In three-phase supply voltages are transformed into d and q coordinates. The reference values for Vd and Vq are compared with these transformed values and then voltage errors are obtained. FL controllers evaluating 9 linguistic rules process these errors. Resulting outputs are retransformed into three-phase domain and compared with a carrier signal to generate PWM invertersignals. [4]

This paper presents the modeling and simulation of a PI with FLC-based DVR under voltage sag phenomena. In this case, the PI with fuzzy logic controller has been incorporated instead of conventional other controller. The simulation tools is the MATLAB/Simulink Power System Blockset (PSB). The capability of DVR to mitigate the voltage sag is demonstrated by MATLAB simulation. The addition of PI with fuzzy logic control gives added advantage of faster responses compared to the conventional one. [5]

II. CONTROL TECHNIQUES FOR DVR

The fundamental roles of a controller in a DVR are to detect the voltage sag occurrence in the system; calculate the compensating voltage, to generate trigger pulses of PWM inverter and stop triggering when the occurrence has passed. Using RMS value calculation of the voltage to analyze the sags does not give a fast and accurate result. In this study the dq transformations or park transformations is used in voltage calculation. The dq transformation is a transformation of coordinates from the three phase stationary coordinate system to the dq rotating coordinate system. [6] This dq method gives the information of the depth (d) and phase shift (q) of voltage sag with start and end time.

\[ V_o = \frac{1}{3} (V_a + V_b + V_c) = 0 \] \hspace{1cm} (1)

\[ V_d = \frac{2}{3} \left[ V_a \sin \alpha + V_b \sin \left( \frac{2\pi}{3} - \alpha \right) + V_c \sin \left( \frac{2\pi}{3} + \alpha \right) \right] \] \hspace{1cm} (2)

\[ V_q = \frac{2}{3} \left[ V_a \cos \alpha + V_b \cos \left( \frac{2\pi}{3} - \alpha \right) + V_c \cos \left( \frac{2\pi}{3} + \alpha \right) \right] \] \hspace{1cm} (3)

After conversion, the three-phase voltage Va, Vb and Vc become two constant voltages Vd and Vq and now, they are easily controlled. In this paper, two control techniques have been proposed which are proportional integral (PI) controller and fuzzy logic (FL) controller.

A. Proportional-Integral Controller

PI Controller is a feedback controller which drives the plant to be controlled with a weighted sum of the error and the integral of that value. The proportional response can be adjusted by multiplying the error by constant KP, called proportional gain. [7]

The contribution from integral term is proportional to both the magnitude of error and duration of error. The error is first multiplied by the integral Gain, Ki and then was integrated.
to give an accumulated offset that have been corrected previously.

B. Fuzzy Logic Controller
Fuzzy logic (FL) controller is one of the most successful operations of fuzzy set theory, its major features are the use of linguistic variables rather than numerical variables.[8] This control technique relies on human capability to understand the system's behavior and is based on quality control rules. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information.[1]

The general structure of an FLC is represented in Figure 2 and comprises of four principal components:

- A Fuzzyfication interface which converts input data into suitable linguistic values.
- A Knowledge Base which consists of a data base with the necessary linguistic definitions and control rule set.
- A Decision Making Logic which, simulating a human decision process, infers the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions and
- A Defuzzyfication interface which yields a nonfuzzy control action from an inferred fuzzy control action.

In this paper, two FL controller blocks are used for error signal $d$ and error signal $q$. Error and Change in Error are the inputs to the fuzzy controller as shown below.

![Fig.3: Error as input](image1)

![Fig.4: Change in Error as input](image2)

![Fig.5: Output variables to defuzzyfication process](image3)
In the decision-making process, there is rule base that linking between input (error signal) and output signal. Table 1 show the rule base used in this FL controller.

Table 1: Rule base

<table>
<thead>
<tr>
<th>DE</th>
<th>E</th>
<th>N</th>
<th>Z</th>
<th>PS</th>
<th>PFS</th>
<th>PA</th>
<th>PFB</th>
<th>PB</th>
<th>PV/B</th>
</tr>
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<td>N</td>
<td>N</td>
<td>Z</td>
<td></td>
<td>PS1</td>
<td>PFS1</td>
<td>PA1</td>
<td>PFB1</td>
<td>PB1</td>
<td>PV/B</td>
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<td>PB2</td>
<td>PV/B</td>
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</tbody>
</table>

III. SIMULATION RESULTS

In order to understand the performance of the DVR along with control, a simple distribution network as shown in Fig. 11 is implemented. There are different fault conditions like normal system, single line to ground fault, double line to ground fault, three phase fault and voltage sag simulated using MATLAB/SIMULINK software. PI with fuzzy logic controller is used for the control purpose. The DVR system connected to the distribution system using a booster transformer.

1) Double-line-to-ground fault with 50% sagging

Fig. 6 Matlab model of DVR with double line to ground fault with 50% Sagging

Fig. 7a. Injection voltage from DVR controlled by PI

Fig. 7b. Injection voltage controlled by FL

Fig. 8a. Output voltage at load 1 after injection voltage from DVR controlled by PI
Fig. 8b. Output voltage at load 1 after injection voltage controlled by FL.

2) Balanced three-phase fault with 50% sagging

Fig. 9. Matlab model of DVR with balanced three-phase fault with 50% sagging

Fig. 10a. Injection voltage from DVR controlled by PI

Fig. 10b. Injection voltage controlled by FL.

Fig. 11a. Output voltage at load 1 after injection voltage from DVR controlled by PI

Fig. 11b. Output voltage at load 1 after injection voltage controlled by FL.
Fig. 12. THD generated when PI controller is applied

Fig. 13. THD generated when FL controller is applied.

IV. CONCLUSION
In this paper, the modeling and simulation of DVR controlled by PI with Fuzzy Logic Controller has been developed using Matlab/Simulink. For the controller, the simulation result shows that the DVR compensates the sag quickly (50μs) and provides excellent voltage regulation. DVR handles different fault condition like normal system, single line to ground fault, double line to ground fault, three phase fault, voltage sag, balanced and unbalanced fault without any difficulties and injects the appropriate voltage component to correct any fault situation occurred in the supply voltage to keep the load voltage balanced and constant at the nominal value.

REFERENCES

Author Profile:

T. NAVEEN KUMAR completed M.E. with specialization in power systems. My Areas of Interest are Power flow control in drives, operation and control of machines.