Dynamic Voltage Restorer For Voltage Sag Mitigation Using Pi With Fuzzy Logic Controller

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ABSTRACT

This paper deals with terminology and various issues related to 'power quality problems'. This problem occurs in voltage sags, swells, harmonics, surges, sustained over voltage and under voltage originated from power system can often damage / or disrupt computerized process. The main occurrence of voltage sag and harmonics disturbed in power quality improvement and overcome by custom power device called dynamic voltage restorer (DVR). The DVR normally installed between the source voltage and critical or sensitive load. The vital role of DVR depends on the efficiency of the control technique involved in switching circuit of the inverter. In this paper, performance improvement of the DVR based PI with Fuzzy Logic Controller using MATLAB/SIMULINK software. The performance of the DVR works well both in balance and unbalance conditions of voltages.

Keywords - Dynamic Voltage Restorer, Pulse Width Modulation (PWM), PI with Fuzzy Logic Controller, Voltage Sag, Voltage Source Converter.

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 appropriate 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 it 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 PWM inverter. The components of control system unit are dq0-transformation, Phase-lock-loop (PLL) and the PI with FL Controller. PI Controller is a feedback controller which drives the plant to be controlled with a weighted sum of the error (difference between output and and desired set-point) and the integral 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 must respond very fast on the request from abruptly changing reference signals. In the literature, FL control of DVR based on dq synchronous reference frame (SRF). In three-phase supply voltages are transformed into d and q coordinates. The reference values for V_d and V_q are compared with these transformed values and then voltage errors are obtained. FL controllers evaluating 9 linguistic rules
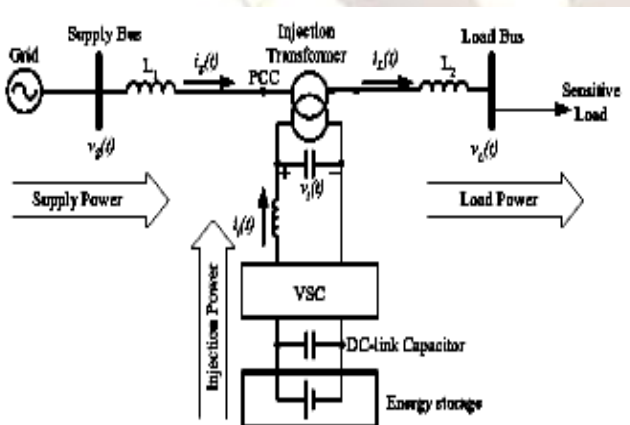
process these errors. Resulting outputs are re-transformed into three-phase domain and compared with a carrier signal to generate PWM inverter signals. [4]

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 tool 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 to gives added advantage of faster response as compared to the conventional one. [5]

II. BASIC CONCEPTS OF DYNAMIC VOLTAGE RESTORER

A DVR is a solid state power electronics switching device consisting of either MOSFET or IGBT, a capacitor bank as an energy storage device and injection transformers. It is linked in series between a distribution system and a load that shown in Fig.1. The basic idea of the DVR is to inject a controlled voltage generated by a forced commuted converter in a series to the bus voltage by means of an injecting transformer.

A DC to AC inverter regulates this voltage by sinusoidal PWM technique. All through normal operating condition, the DVR injects only a small voltage to compensate for the voltage drop of the injection transformer and device losses. However, when voltage sag occurs in the distribution system, the DVR control system calculates and synthesizes the voltage required to preserve output voltage to the load by injecting a controlled voltage with a certain magnitude and phase angle into the distribution system to the critical load.[9]

III. PROPOSED DVR CONTROL IMPLEMENTATION

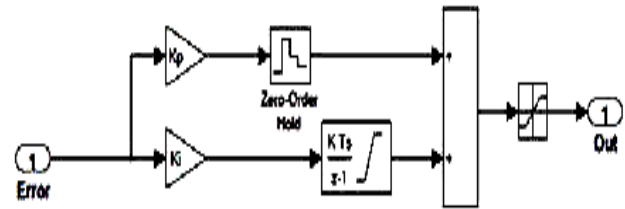A. Proportional-Integral (PI) Controller

Fig. 2: Discrete PI Controller

Discrete PI Controller shown in Fig.2 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 K_P, called proportional gain.

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, K_i and then was integrated to give an accumulated offset that have been corrected previously.[7]
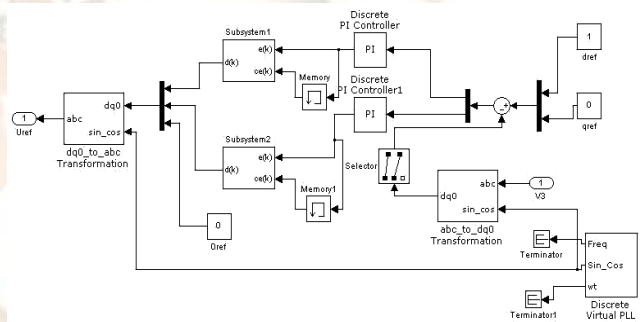

Fig. 3: Control circuit using PI with fuzzy logic controller

Fig.3 shows the control circuit designed in Matlab/Simulink software. The input of the controller come from the output voltage, V3 measured by three-phase V-I measurement at Load in pu. V3 is then transformed in dq term (expressed as instantaneous space vector). The voltage sag is detected by measuring the error between the dq-voltage and the reference values. The d-reference is set to rated voltage whilst q reference is set to zero. The dq components of load voltage are compared with the reference values and the error signal is then entering to PI controller. Two PI controller block are used for error signal-d and error signal-q separately. For error signal-d, K_P is set to 40 and K_i is set to 100 whilst for error signal-q, K_P is set to 30 and K_i is set to 150 respectively. All the gains selected use to tune up the error signal d and q so that the signal is stable and well responses to system disturbances. The outputs of the PI controller then are transformed back into V_{abc} before forwarded to PWM generator.

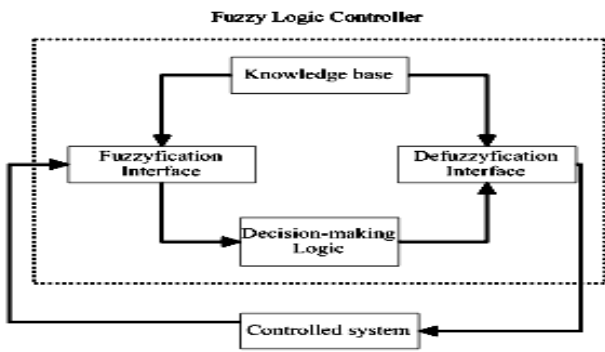B. Fuzzy Logic Controller (FLC)

Fig. 4: Basic configuration of FL controller

Unlike Boolean logic, fuzzy logic allows states (membership values) between 0 or 1. Its major features are the use of linguistic variables rather than numerical variables. Linguistic variables, defined as variables whose values are sentences in a natural language (such as small and big), may be represented by fuzzy sets [6]. The general structure of an FLC is represented in Fig.4 and comprises 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 block are used for error signal-d and error signal-q as shown in Fig.3. The process also same as before except the controller now is Fuzzy Logic. For both blocks (error signal-d and q) the FL controller consists of three linguistic variables from input which is; Negative (N), Zero (Z) and Positive (P). Each parameter from linguistic variables for error signal is shown in Fig.5. For delta error, there are three linguistic variables, Negative (N), Zero (Z) and Positive (P). Both variables can be depicted as in Fig.6.
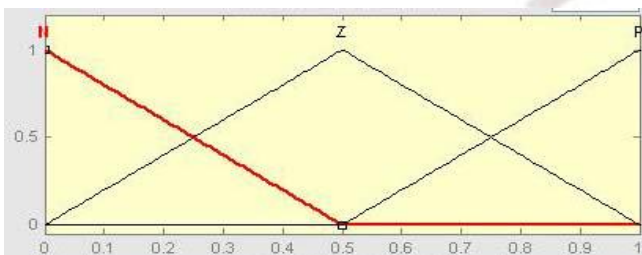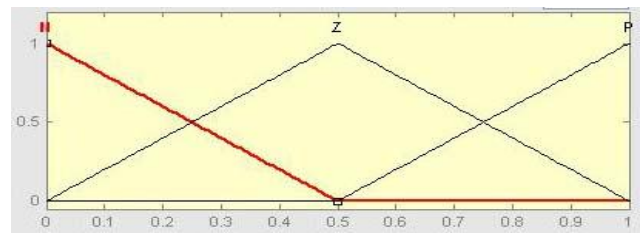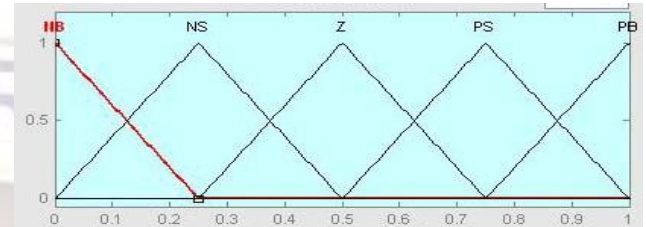

Fig. 6: Linguistic variables from delta error

Positive Small (PS), Fig.7. Shows each parameter for output signal.

Table 1: Rule Base

E \ DE	N	Z	P
N	NB	NS	Z
Z	NS	Z	PS
P	Z	PS	PB

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.
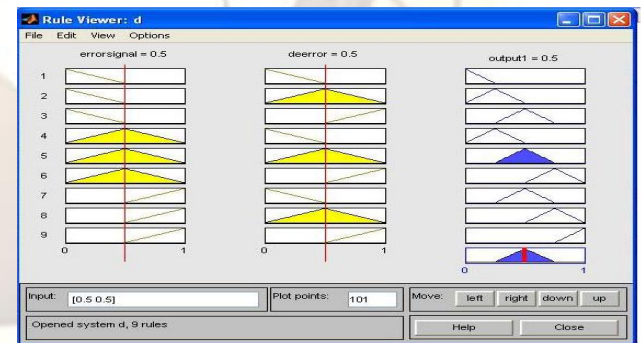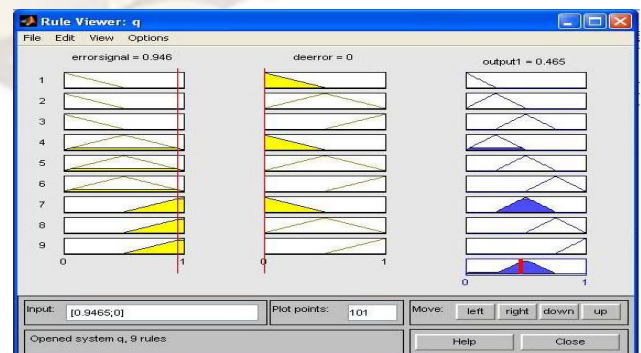

Fig. 8: Rule viewer of d reference
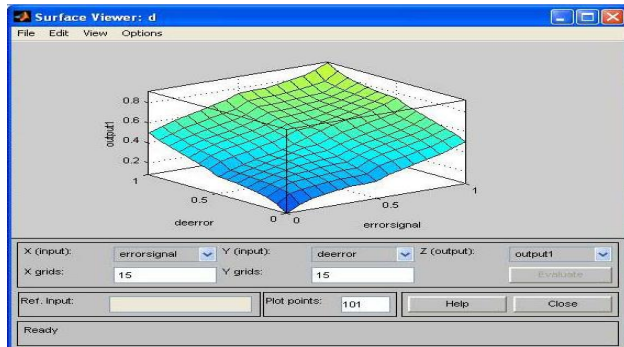

Fig. 9: Rule viewer of q reference

Fig. 5: Linguistic variables from error

Fig. 10: Surface viewer

IV. SIMULATION RESULTS AND DISCUSSION

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.
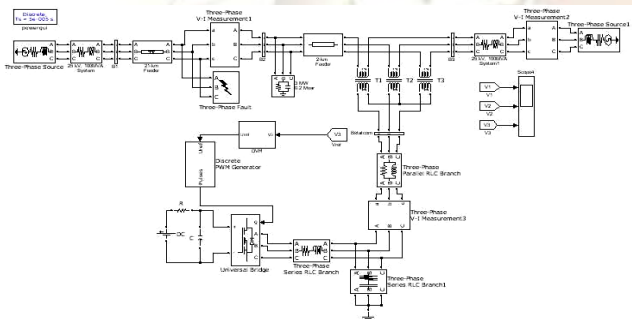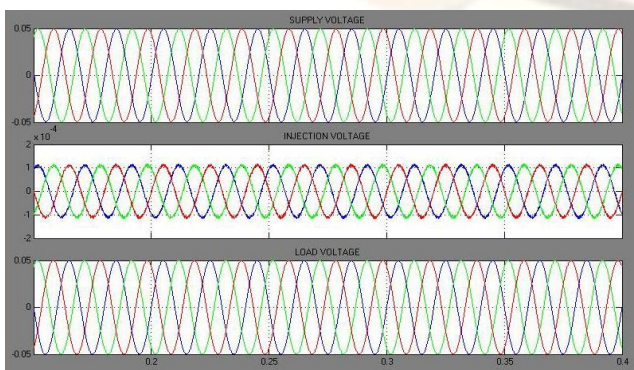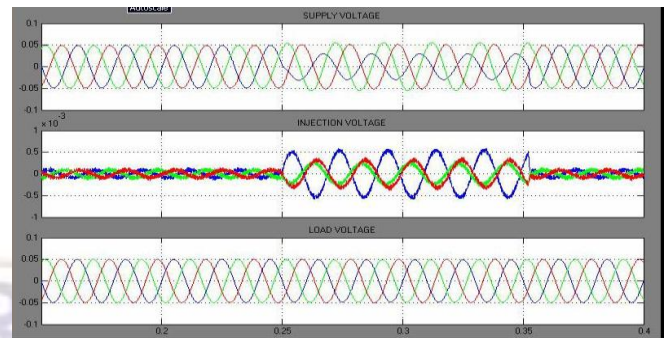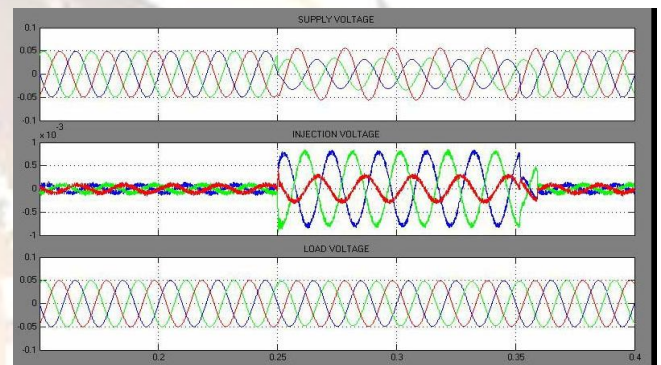

Fig. 11: Simulink Model of DVR Test System

In this system different fault conditions like normal system, single line to ground fault, double line to ground fault, three phase fault and voltage sag with feeder for the duration of 0.25s to 0.35s with fault resistance is 20 ohms and the ground resistance is 0.001 ohms. The output results for the above system are shown below.
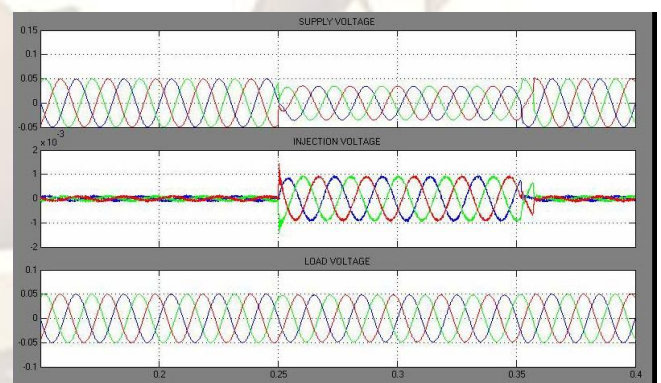

Time (s)
Fig. 12: Normal system (a) Supply voltage, (b) Injection voltage, and (c) Load voltage
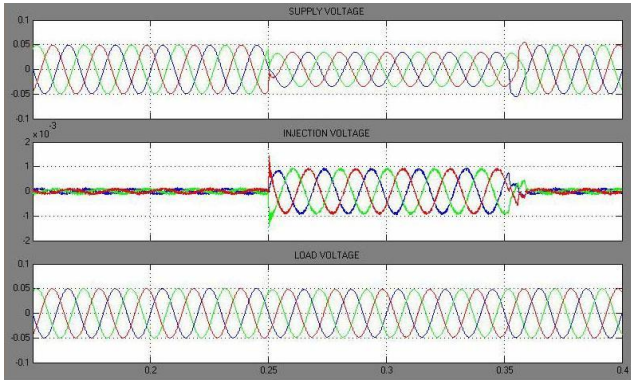

Time (s)
Fig. 13: Single line to ground fault; (a) Supply voltage, (b) Injection voltage, and (c) Load voltage

Time (s)
Fig. 14: Double line to ground fault; (a) Supply voltage, (b) Injection voltage, and (c) Load voltage

Time (s)
Fig. 15: Three phase fault; (a) Supply voltage, (b) Injection voltage, and (c) Load voltage

Time (s)
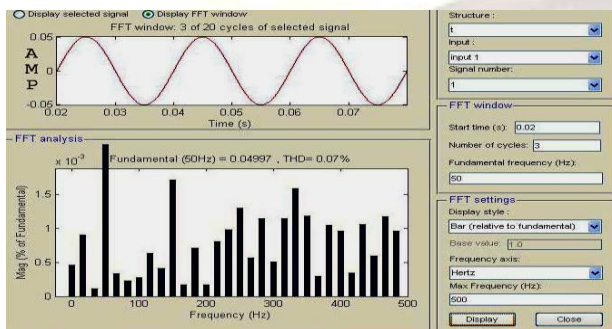Fig. 16: Voltage sag; (a) Supply voltage, (b) Injection voltage, and (c) Load voltage

Fig. 17: THD for load voltage using PI with Fuzzy Logic controller

Table 2: THD for V$_{dc}$

Sl.No.	V$_{dc}$ (V)	THD (%)
1.	250	0.37
2.	200	0.30
3.	150	0.22
4.	100	0.15
5.	50	0.07

V. 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. In this paper, the DVR has shown the ability to compensate for voltage sags at the grid side, this can be proved through simulation. The efficiency and the effectiveness in voltage sags compensation showed by the DVR makes it an interesting power quality device compared to other custom power devices. Therefore, when it comes to implementation, it is crucial to consider these factors, so that the performance of DVR is optimized.

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