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Analysis of DVR Performance for Voltage Flicker Mitigations in Distribution System Using Fuzzy Logic as a Controller

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Abstract— Power Quality problem is an occurrence as a nonstandard voltage, current or frequency that results in a failure or mis-operation of end user equipment. The steady-state PQ characteristics of the supply voltage include surges and spikes, sags, harmonic distortions, and momentary disruptions. Voltage sags and swells are the common events on the electric power network. These problems can be mitigated with voltage injection method using custom power device, Dynamic Voltage Restorer (DVR). In this paper we design a Dynamic Voltage Restorer (DVR) which is utilized for power quality improvement. Here we propose two control techniques which are the Proportional Integral (PI) Controller and Fuzzy Logic (FL) Controller. Results of both the controllers are assessed to know which the best power quality solution is.

Index Terms— Dynamic voltage Restorer, Voltage sag, voltage swell, harmonics, PI Controller, Fuzzy logic controller, PWM converter.

I. INTRODUCTION

Electronic devices function properly as long as the voltage of the supply system feeding the device stays within a consistent range. There are several types of voltage fluctuations that can cause problems, including surges and spikes, sags, harmonic distortions, and momentary disruptions [2]. Voltage sags and swells are the common events on the electric power network [3]. The common causes of voltage sag are faults or short circuit, in the system, starting of large loads and faulty wiring [4]. Voltage sag is not a complete interruption of power; it is a temporary drop below 90 percent of the nominal voltage level. Most voltage sags do not go below 50 percent of the nominal voltage and they normally last from 3 to 10 cycles or 50 to 170 milliseconds.Voltage swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min.[5]

A series connected converter based mitigation device, the Dynamic Voltage Restorer(DVR), is the most economical and technically advanced mitigation device proposed to protect sensitive loads from voltage sags. In this paper, DVR which consists of injection transformer, filter unit, Pulse Width Modulation (PWM) inverter, energy storage and control system is used to mitigate the voltage flickers in the power distribution system. Here we propose two control techniques which are the Proportional Integral (PI) Controller and Fuzzy Logic (FL) Controller.

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A. Control Schemeof DVR

A DVR is connected in series with the linear load to compensate for the harmonics and unbalance in the source voltages and improve the power factor on the source side (at PCC).[7]The major objective of the control strategy is to ensure that the load bus voltages remain balanced and sinusoidal (positive sequence). Since the load is assumed to be balanced and linear, the load currents will also remain balanced (positive sequence) and sinusoidal. An additional objective is to ensure that the source current remains in phase with the fundamental frequency component of the PCC voltage. This requires that the reactive power of the load is met by the DVR. It is also possible to arrange that DVR sup- plies a specified fraction of the reactive power required by the load such as microprocessors.

B. Calculation of DVR Voltage Injection

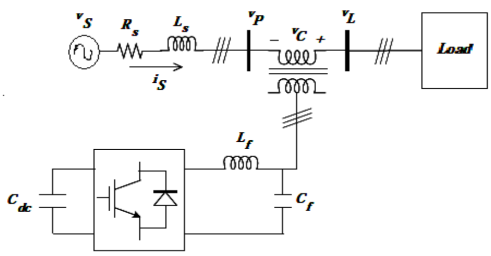

Fig.1: DVR series connected topology

When voltage drop occurred at load, DVR will inject a series voltage through transformer so that load voltage can be maintained at nominal value as shown in Fig.1. Thus,

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \qquad (1)$$

$$I_L = \left[\frac{P_L + jQ_L}{V_L} \right]^* \qquad (2)$$

If VL is considered as a reference;

$$V_{DVR}\angle\alpha = V_L\angle 0 + Z_{th} I_L \angle(\beta - \theta) - V_{th}\angle\delta \qquad (3)$$

Here α, β, and δ are the angle of *V*DVR, *Z*th and *V*th, respectively and θ is the load power factor angle with

$$\theta = \tan^{-1}\left(\frac{Q_L}{P_L}\right) \qquad (4)$$

Thus, the power injection of the DVR can be written as

$$S_{DVR} = V_{DVR} I_L \qquad (5)$$

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 dqo transformations or parks transformations is used in voltage calculation. The dqo transformation is a transformation of coordinates from the three phase stationary coordinate system to the dq rotating coordinate system.[8] This dqo method gives the information of the depth (d) and phase shift (q) of voltage sag with start and end time.

$$V_0 = \frac{1}{3}(V_a + V_b + V_c) = 0 \qquad (6)$$

$$V_d = \frac{2}{3}\left[V_a \sin\omega t + V_b \sin\left(\omega t - \frac{2\pi}{3}\right) + V_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right] \qquad (7)$$

$$V_q = \frac{2}{3}\left[V_a \cos\omega t + V_b \cos\left(\omega t - \frac{2\pi}{3}\right) + V_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right] \qquad (8)$$

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.[9] 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.[10] This control technique relies on human capability to understand the systems 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:

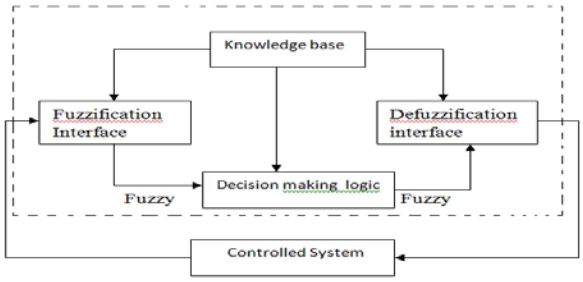

Fig.2: Basic structure of FL controller

- 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. Error and Change in Error are the inputs to the fuzzy controller are shown below.

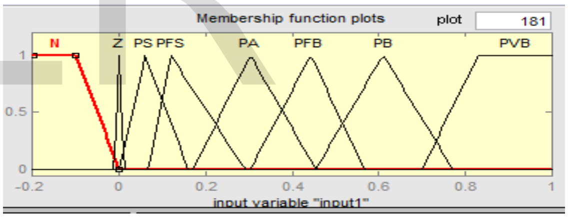

Fig.3: Error as input

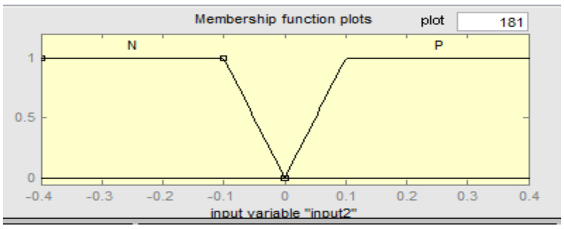

Fig.4: Change in Error as input

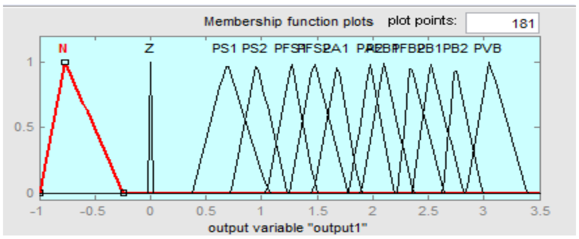

Fig.5: Output variables to defuzzyfication process

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

E / DE	N	Z	PS	PFS	PA	PFB	PB	PVB
N	N	Z	PS1	PFS1	PA1	PFB1	PB1	PVB
P	N	Z	PS2	PFS2	PA2	PFB2	PB2	PVB

III. Simulation Results

Simulation studies are carried out to analyze the performance of DVR for voltage sag conditions in a distribution system. Here we consider a distribution line with a source voltage of 11kv and it is stepped down to a voltage of 415v using a three phase transformer. The load is considered as an RLC load with voltage of 415v. A three phase to ground fault with fault resistance of 4.6ohms and an external source voltage of 1000v is said to be introduced into the system. Due to this voltage sag is said to be introduced into the system for a period of 0.0019s to 0.085s and a swell is introduced into the system for the time period of 0.15 to 0.18secs. The 3rd order and 5th order harmonics are said to be introduced into the system. The voltage sag, swell and harmonics are said to be mitigated in the distribution line using a DVR with conventional Proportional Integral (PI) controller and Fuzzy Logic (FL) controller. Comprehensive results are presented to assess the performance of each controller as the best power quality solution. The simulations have been carried out using MATLAB/Simulink.

A. Complete Simulink Diagram

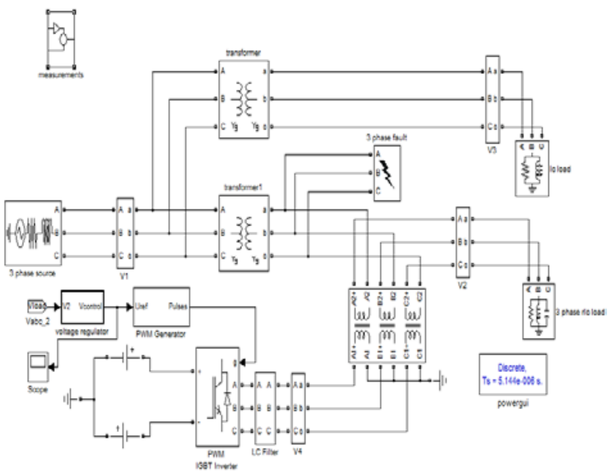

Fig.6: Simulation Diagram of a Distribution System with DVR

B. Simulink Diagram of PI Controller

The input of the controller come from the output voltage, V3 measured by three-phase V-I measurement at Load 1 in pu. V3 is then transformed in dq term (expressed as instantaneous space vector). 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, Kp is set to 40 and Ki is set to 154 whilst for error signal-q, Kp and Ki is set to 25 and 260 respectively.

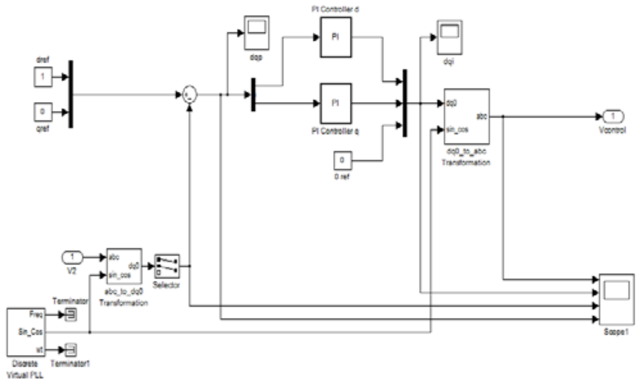

Fig.7: Simulation Diagram of a PI Controller

1. DVR with Three Phase Fault Using PI Controller

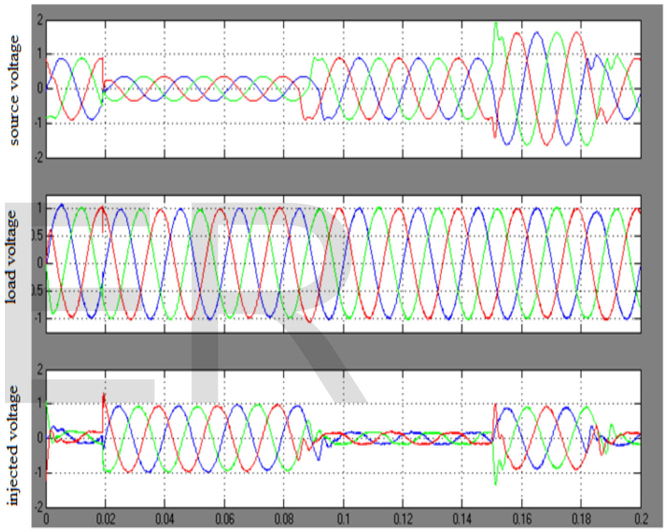

Fig.8: Sag and swell Mitigation Using DVR With PI Controller In Three Phase To Ground Fault

2. DVR For Elimination Of Harmonics Using PI Controller

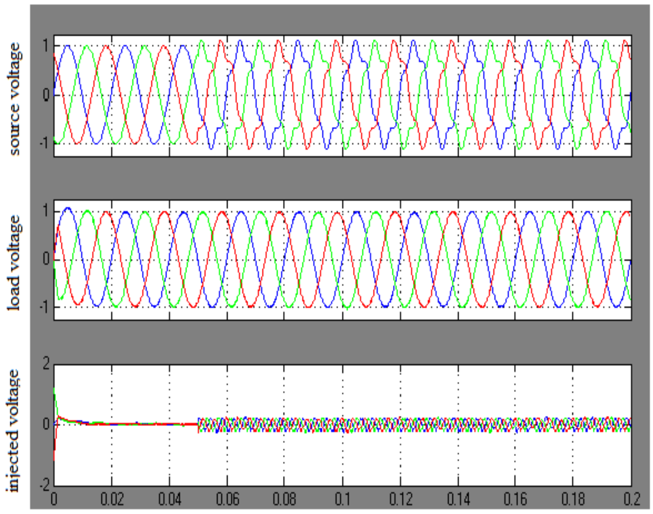

Fig.9.Elimination Of Harmonics In Load Voltage Using DVR With PI Controller

2.

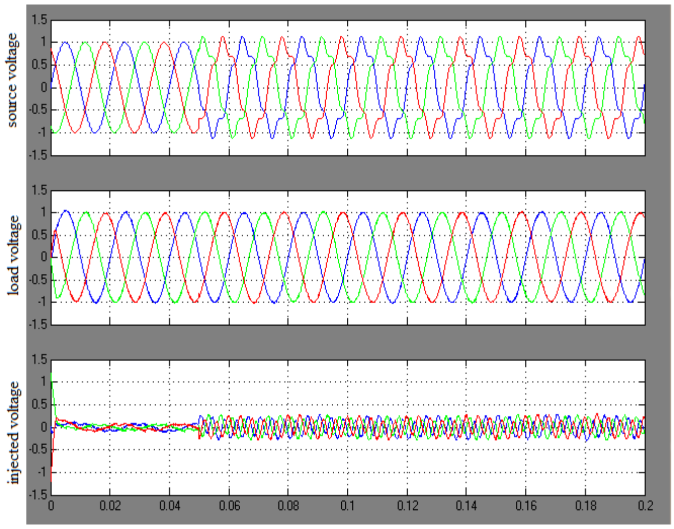

Fig.9.Elimination Of Harmonics In Load Voltage Using DVR With FL Controller

C. Simulink Diagram of Fuzzy Controller

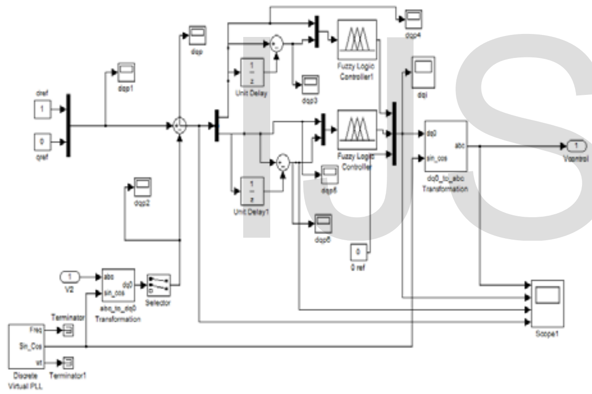

Fig.10: Simulation Diagram of a Fuzzy Logic Controller

1. DVR With Single Phase Fault Using FL Controller

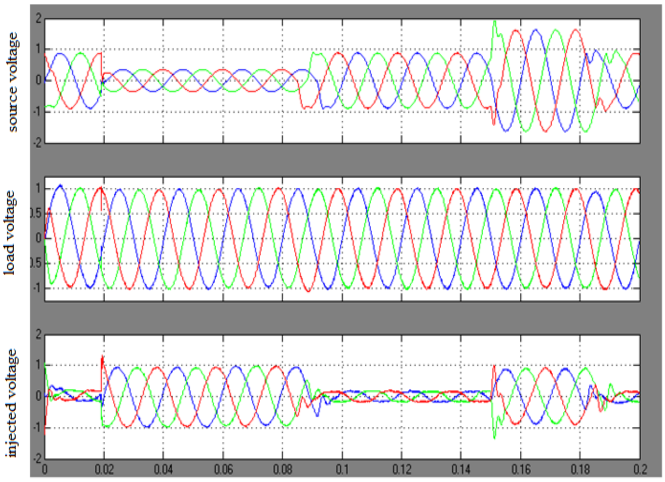

Fig.11: Sag and swell Mitigation Using DVR with FL Controller In Three Phase To Ground Fault

D. Comparison

Comparison of voltage magnitude in per unit with DVR using conventional PI controller and Fuzzy logic controller is shown in the below table.

Table.2: Comparison of PI and FL Controller for DVR

S.No	Conditions	Vrms(pu)
1	Distribution system without fault	1.00
2	Distribution system with fault	0.356
3	Distribution system with DVR using PI controller	0.956
4	Distribution system with DVR using Fuzzy Logic controller	0.972

IV. CONCLUSION

For both PI and FL controller, the simulation result shows that the DVR compensates the sag quickly (70µs) and provides excellent voltage regulation. DVR handles all types, 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. The fuzzy logic controller gave a better performance than the PI controller in improving the load voltage to normal conditions.

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