ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

Performance Analysis of DVR in Power Quality Improvement using PI and Fuzzy Logic Controller

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ABSTRACT: Power Quality problem is an occurrence as a non accurate voltage, current or frequency that results in a failure or mis-operation of end user equipment. The characteristics of steady state power Quality include the momentary disruptions, surges and spikes, sags, and harmonic distortions. Voltage sags and swells are the common events on the electric power system. These problems can be mitigated with voltage injection method using custom power device, Dynamic Voltage Restorer (DVR). In this paper we are design a Dynamic Voltage Restorer (DVR) with Proportional Integral (PI) Controller and Fuzzy Logic (FL) Controller, to improve power quality in power system. The results of both the controllers are compared to know which the best solution for improving the power quality is.

KEYWORDS: DVR, power quality, power system, voltage swell, harmonics, Voltage sag, PI Controller, Fuzzy logic controller.

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 different types of voltage fluctuations that can cause Power quality problems, including, sags, harmonic distortions, surges and spikes and momentary disruptions [2]. Voltage sags and swells are the common events on the electric power system [3]. The common causes of voltage sag are short circuit or faults in power system, at starting of large loads and faulty conductor [4]. Voltage sag is not a complete interruption of power; it is a temporary drop below 90 percent of the nominal voltage level. The maximum 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. The 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.

The DVR was first invented and established in 1996 in USA by Electric Power Research Institute, it is rated as 2MVA for the protection of 4MVA load. DVR without external energy storage unit was proposed by Neilsen & Blaabjerg, in 2005 in that the DVR energy is taken through a shunt converter. A new series power-conditioning system using a matrix converter with flywheel energy storage was proposed by Wang & Venkataramanan in 2009. FL controllers are an attractive choice when precise mathematical formulations are not possible. With the Fuzzy Logic controller the tracking error and transient overshoots can be reduced considerably when compared with the PWM technique. It is very easy to design the controller with the help of fuzzy sets shapes and overlapping. So, the design procedure and performance depends strongly on the knowledge and expertise of the designer (Margo et al, 2008).

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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II.CONTROL SCHEME OF DVR

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.

A. Calculation of DVR Voltage Injection

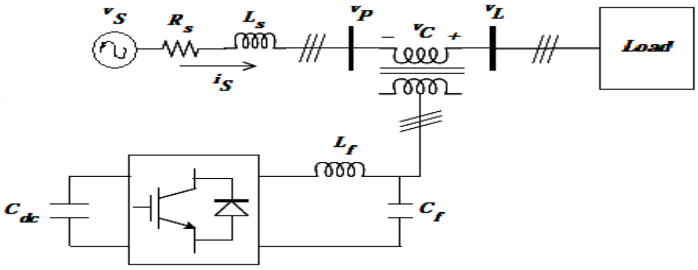

Fig.1: DVR series connected topology

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, the DVR voltage and Load current.

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

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

If V_L is considered as a reference;

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

Here α, β, and δ are the angle of V_{DVR}, V_{th}, and Z_{th} respectively and θ is the load power factor angle with

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

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

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

III. 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.

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

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

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

After conversion, the three-phase voltage V_a, V_b and V_c become two constant voltages V_d and V_q 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 will be adjusted by multiplying the error by constant K_P, called proportional gain [9]. The contribution from integral term is proportional to both the magnitude of error and duration of error. First error will be multiplied by the integral Gain, K_i and integrated to give an accumulated offset that have been corrected previously.

B. Fuzzy Logic Controller

Fuzzy logic (FL) controller is the heart of fuzzy set theory; the 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, imprecise, noisy, ambiguous, or missing input information. [1]

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

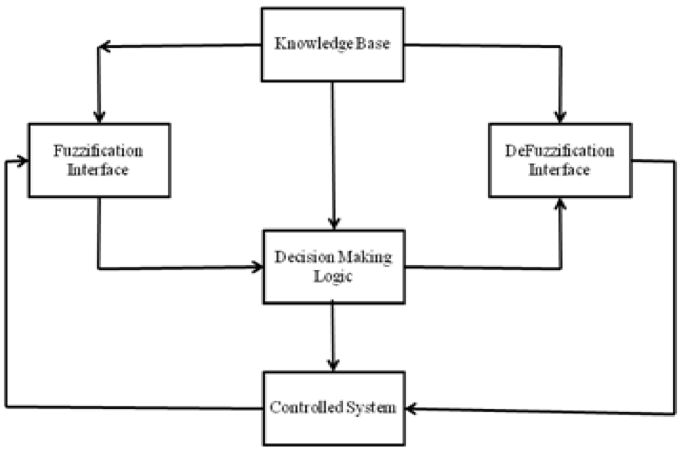

Fig.2: Basic structure of FL controller

- The Fuzzyfication *interface* will converts input data into suitable linguistic values.
- The Knowledge Base is consists of a data base with the necessary linguistic definitions and control rule set.
- A Decision Making Logic will, simulating a human decision process, and interface the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions.
- Defuzzyfication interface is yields a non-fuzzy 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 in figure 3, 4 and 5.

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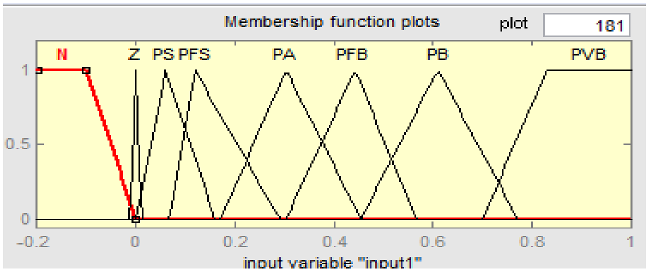

Fig.3: Error as input

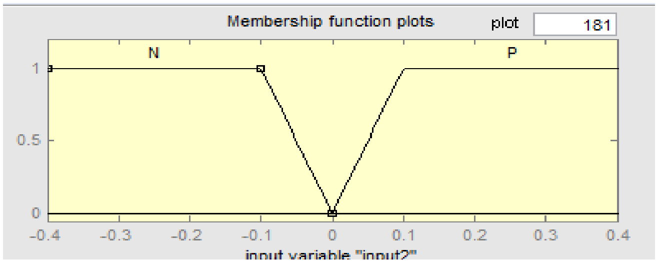

Fig.4: Change in Error as input

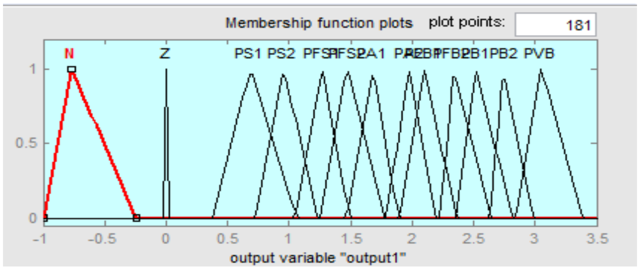

Fig.5: Output variables to Defuzzyfication process

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

IV.SIMULATION RESULTS

The Simulation studies are analyzing the performance of DVR for voltage sag conditions in a distribution power 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 effect voltage sag is said to be introduced into the system for a period of 0.0019sec to 0.085sec and a swell is introduced into the system for the time period of 0.15sec to 0.18sec.

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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. The 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. The simulation diagram of a distribution power system with DVR is shown in figure-5.

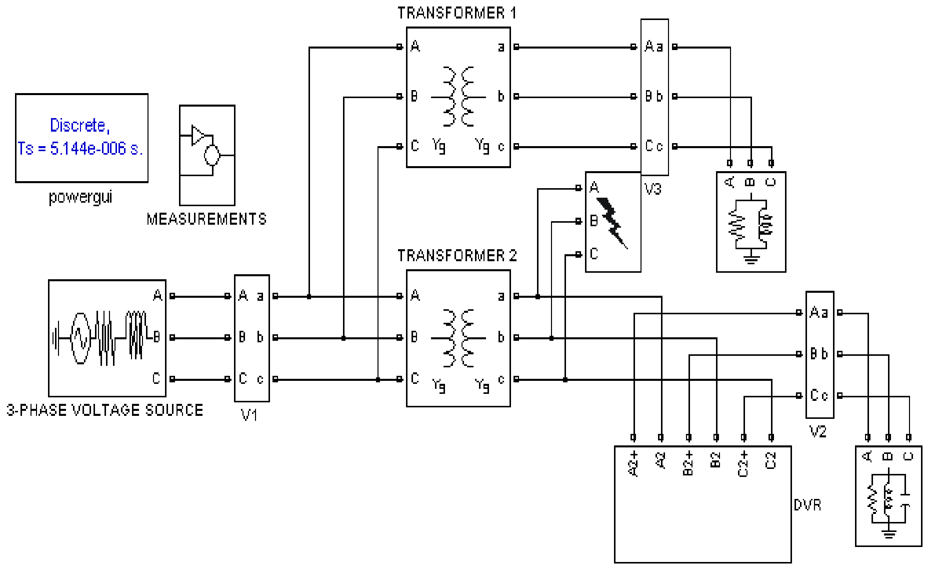

Fig.5: Simulation Diagram of a Distribution System with DVR

A. 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. V_3 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, K_p is set to 40 and K_i is set to 154 whilst for error signal-q, K_p and K_i is set to 25 and 260 respectively. The simulation block diagram DVR with PI controller is shown in Fig-6. The output of PI controller source voltage, Load voltage and injection voltage is shown in figure -7.

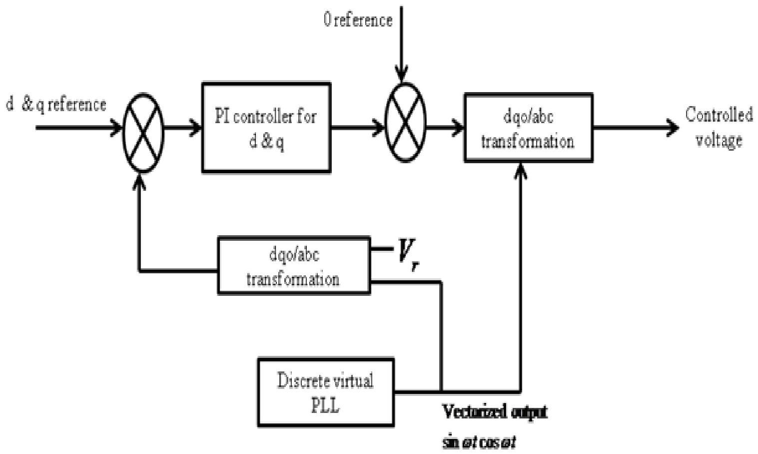

Fig.6: Simulation Diagram of a PI Controller

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ISSN (Online): 2278 – 8875

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DVR for Elimination of Harmonics Using PI Controller

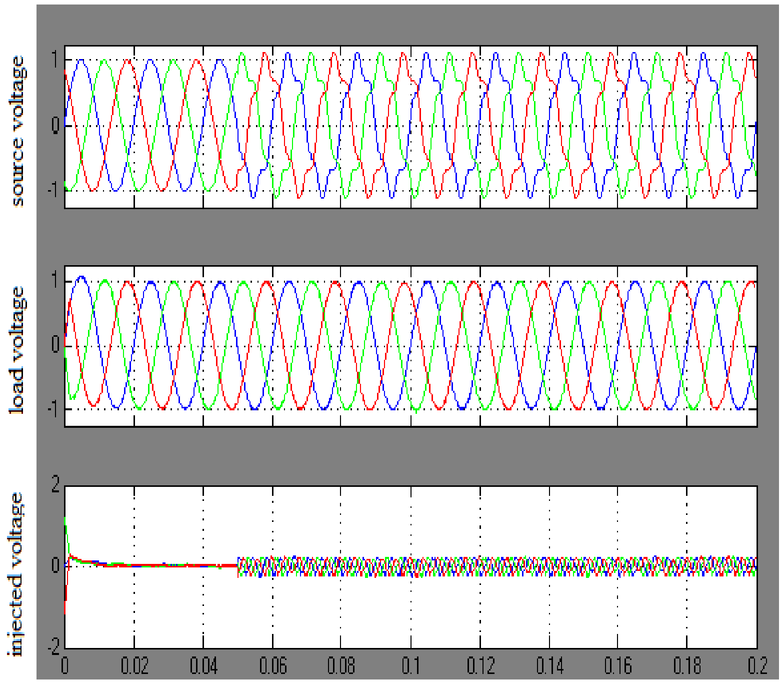

Fig.7.Elimination of Harmonics in Load Voltage Using DVR with PI Controller

B. Simulink Diagram of Fuzzy Controller

The simulation block diagram DVR with Fuzzy controller is shown in Figure-8. Two fuzzy controller block are used for error signal-d and error signal-q separately. The output of Pi controller source voltage, Load voltage and injection voltage is shown in Figure -9.

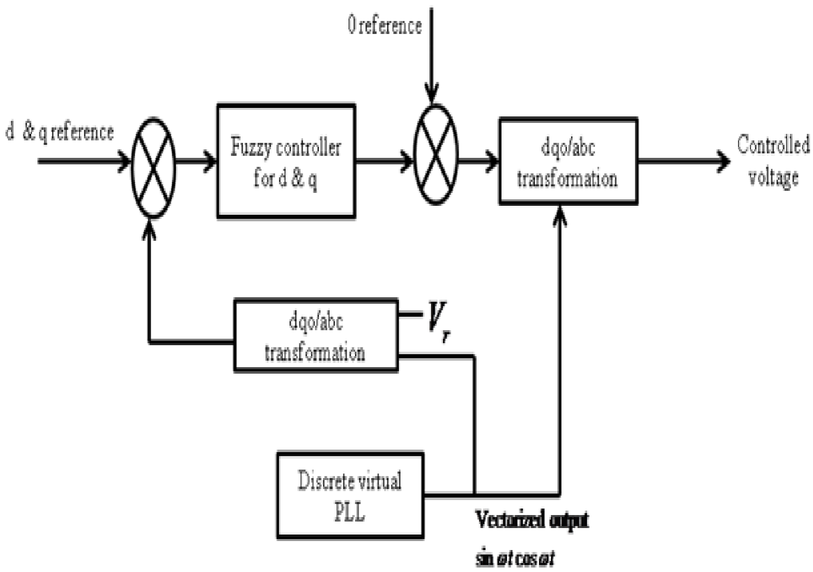

Fig.8: Simulation Diagram of a Fuzzy Logic Controller

DVR with Single Phase Fault Using FL Controller

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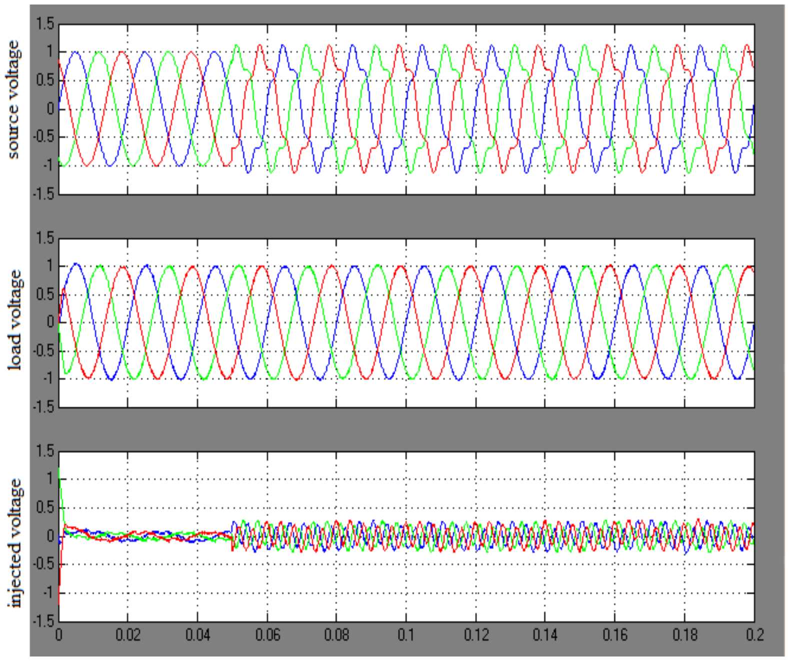

Fig.9.Elimination of Harmonics in Load Voltage Using DVR with FL Controller

C. Comparison

The Figure 10 shows the FFT analysis for source voltage for DVR with PI controller and the THD using that is 24.19%.

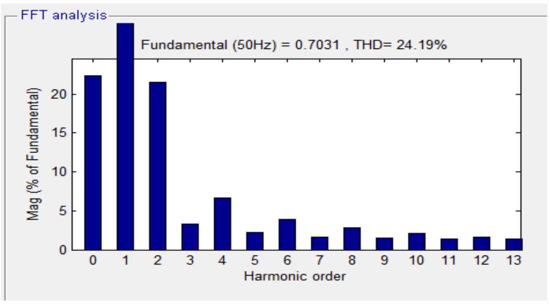

Fig.10: FFT analysis for Source voltage Using DVR with PI Controller

Figure 11 shows the FFT analysis for Load voltage for DVR with PI controller and the THD using that is 3.49%.

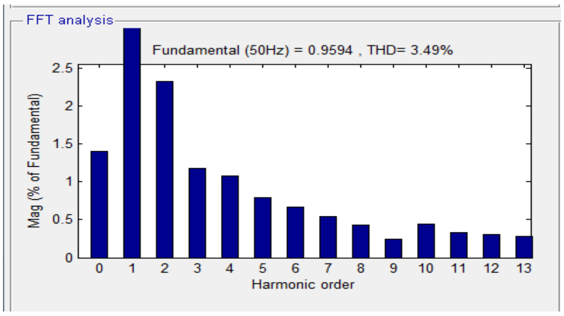

Fig11: FFT analysis Load Voltage Using DVR with PI Controller

Figure 12 shows the FFT analysis for Injected voltage for DVR with PI controller and the THD using that is 59.21%.

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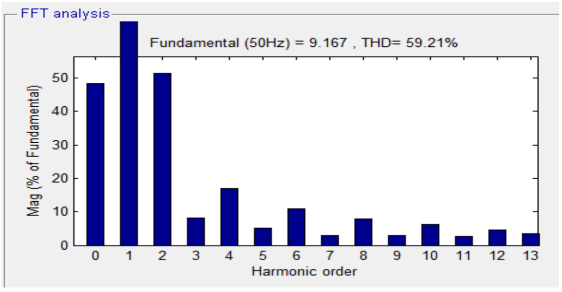

Fig.12: FFT analysis Injected Voltage Using DVR with PI Controller

Figure 13 shows the FFT analysis for source voltage for DVR with Fuzzy controller and the THD using that is 2.43%.

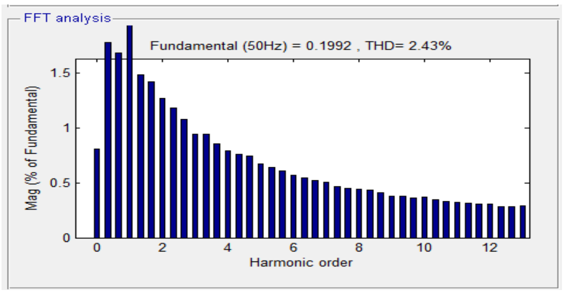

Fig.13: FFT analysis source voltage Using DVR with FL Controller

Figure 14 shows the FFT analysis for Load voltage for DVR with Fuzzy controller and the THD using that is 1.00%.

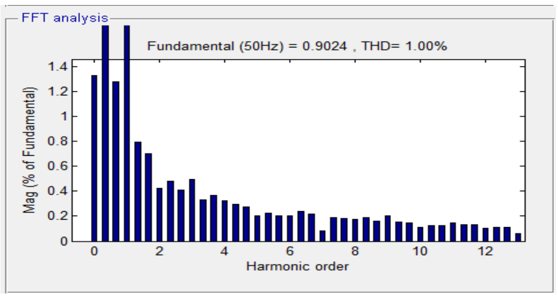

Fig.14: FFT analysis load voltage Using DVR with FL Controller

Figure 15 shows the FFT analysis for Injected voltage for DVR with Fuzzy controller and the THD using that is 2.55%.

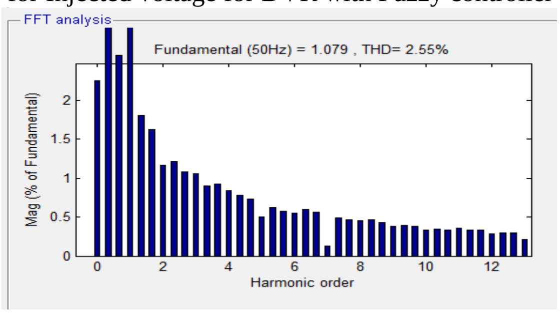

Fig.15: FFT analysis Injected Voltage Using DVR with FL Controller

The comparison of FFT analysis with DVR using conventional PI controller and Fuzzy logic controller is shown in Table-2.

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

S.NO	FFT Analysis	THD % With PI Controller	THD % With FL Controller
1	Source voltage	24.19	2.43
2	Load Voltage	3.49	1.0
3	Injected Voltage	69.21	2.55

V.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 simulation based FFT results are shows, the fuzzy logic controller gave a better performance than the PI controller in improving the load voltage to normal conditions.

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