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Power Quality Improvement using Dynamic Voltage Restorer with Hybrid Fuzzy Control Technique

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Abstract: *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, nonstandard voltage, current or frequency that results in a failure or miss operation of end user equipment. The steady-state PQ characteristics of the supply voltage include surges and spikes. Voltage sags and swells are the common events on the electric power network. Voltage sags and swells are the common events on the electric power system. The common causes of voltage sag are short circuit or faults in power system, at starting of large loads and faulty conductor. These problems can be mitigated with voltage injection method using custom power device, Dynamic Voltage Restorer (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. 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. In this Project 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 by using. In extension proposed DVR is subjected to operate under hybrid fuzzy logic controller using Matlab/Simulink software.*

Keywords— Dynamic Voltage Restorer, Energy storage System, Total Harmonic Distortion, Fuzzy Logic Controller.

I. INTRODUCTION

Power electronic devices contribute an important part of harmonics in all kind of applications, such as power rectifiers, thyristor converters and SVC. The updated PWM techniques used to control modern static converters such as machine derives, power factor compensators, or active power filters do not produce perfect waveforms, which strongly depend on the semiconductors switching frequency. Voltage or current converters as they generate discrete output waveforms, force the use of machines with special isolation, and in some applications large inductances connected in series with the respective load. In other words, neither the voltage nor the current waveforms are as expected. Also, it is well known that distorted voltages and current waveforms produce harmonic contamination, additional power losses, and high frequency noise that can affect not only the power load but also the associated controllers.

Both electric utilities and end users of electrical power are becoming increasingly concerned about the quality of electric power. Power quality is an umbrella concept for multitude of individual types of power system disturbances. The issues that fall under this umbrella are not necessarily new. What is new is that engineers are now attempting to deal with these issues with a systems approach rather than as individual problems. One important and noticeable change seen is that the quality of electricity supplied is now subject to legislation which considers it to be no different from other goods and services.

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Just a few years ago, momentary power outages, sags, swells, surges had relatively little effect on most industrial processes. Today, manufacturing systems, sensitive elementary, and precision electronic equipment can be disturbed, halted, or even damaged by voltage sag of two or three electrical cycles. Production losses can soar. Power Quality problems evidence themselves in a variety of ways such as: Computer shut down, malfunction of errors, PLC (Programmable Logic Controller) malfunction or errors, variable speed drives tripping out, racing or blinking digital clocks, etc. These can give problems ranging from inconvenience to loss of manufacturing capability with substantial loss in income Understanding Power Quality and the range of associated problems becomes very important to mitigate the problems.

In this section, the enhancement of three phase voltage and reactive power is carried out with DVR when a non-linear and unbalanced load conditions are connected in the simulink block-set. A five-level inverter is used to trigger the operation of DVR for the different load disturbance assessment by PWM technique.

A. Control Scheme of 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

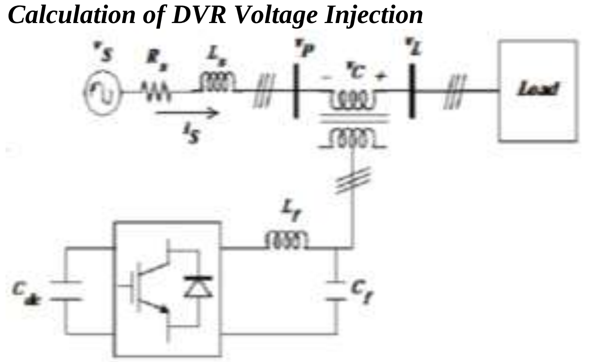

Fig.1.DVR series connected topology.

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, 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 VL is considered as a reference;

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

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

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

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.

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

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

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

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 Project, two control techniques have been proposed which are proportional integral (PI) controller and fuzzy logic (FL) controller.

A. Proportional-Integral Controller

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Volume 04 Issue 02
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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 KP, 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, Ki 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:

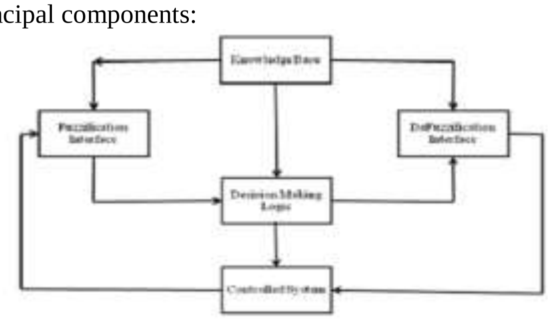

Fig.2: Basic structure of FL controller.

• 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 Project, 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.

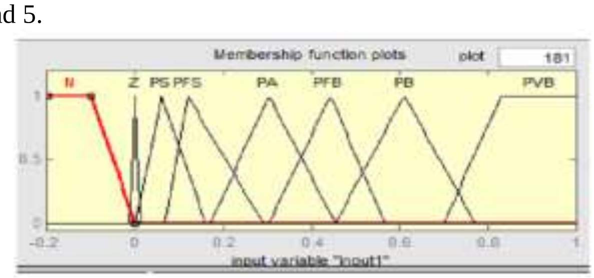

Fig.3: Error as input

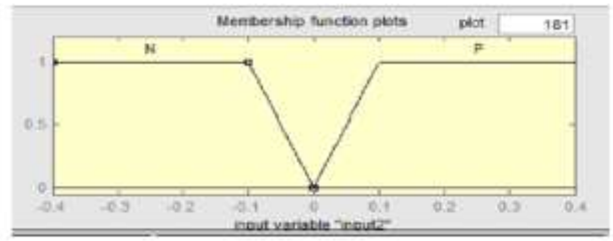

Fig.4: Change in Error as input.

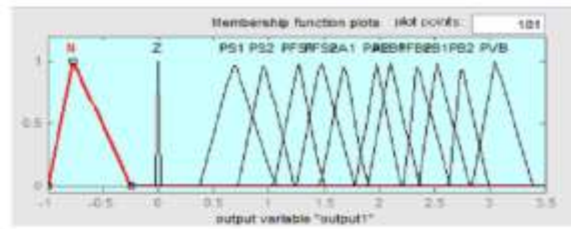

Fig.5: Output variables to defuzzyfication process.

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

DE \ E	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. BLOCK 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, 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.

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Volume 04 Issue 02
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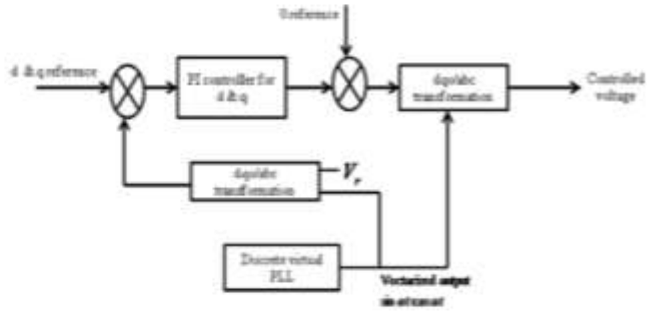

Fig.6: Simulation Diagram of a PI Controller

IV. Block Diagram of Fuzzy Controller

The simulation block diagram DVR with Fuzzy controller is shown in Figure.7. Two fuzzy controller block are used for error signal-d and error signal-q separately.

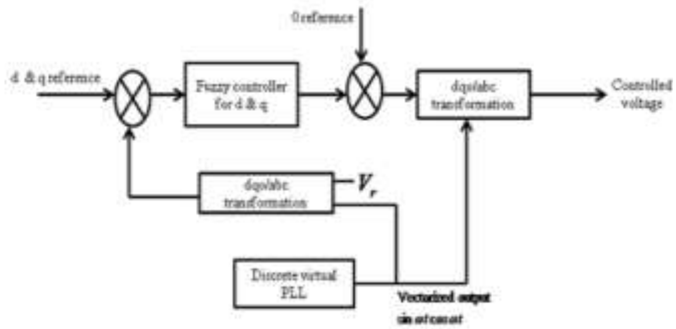

Fig.7: Simulation Diagram of a Fuzzy Logic Controller.

V.HYBRID FUZZYCONTROLLER

This paper investigates two fuzzy logic controllers that use simplified design schemes. Fuzzy logic PD and PI controllers are effective for many control problems but lack the advantages of the fuzzy controller. Design methodologies are in their infancy and still somewhat intuitive. Fuzzy controllers use a rule base to describe relationships between the input variables. Implementation of a detailed rule base increases in complexity as the number of input variables grow and the ranges of operation for the variables become more defined. We propose a hybrid fuzzy controller which takes advantage of the properties of the fuzzy PI and PD controllers and a second method which adds the fuzzy PD control action to the integral control action.

The effectiveness of the two PID fuzzy controller implementations, PD and PI fuzzy controllers have the same design disadvantages as their classical counterparts. Therefore, in some cases a fuzzy PID controller maybe required. The fuzzy PID controller entails a large rule base which presents design and implementation problems. First, a reduced rule fuzzy PID scheme was implemented to take advantage of both PD and PI control actions. Some further research is required for the process of switching between the control actions. The second fuzzy PID control scheme used only the PD portion with an integral term added to eliminate steady-state error. Results from simulations of both control schemes demonstrate the effectiveness of the PID controllers.

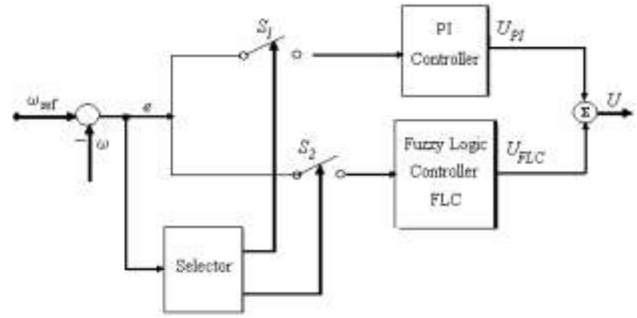

Fig.8 Simulation diagram of hybrid fuzzy logic controller.

VI. 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 of4.6milliohms 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 0.019s to 0.085s and as well 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 HYBRID FUZZY LOGIC controller which is the combination of 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.

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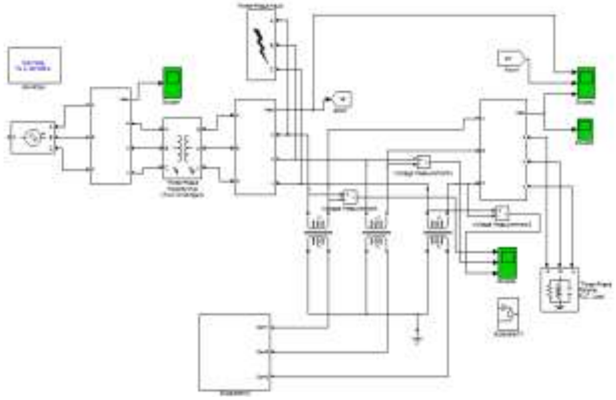


Fig.9: Matlab/Simulink Circuit for Proposed DVR with hybrid fuzzy controller.

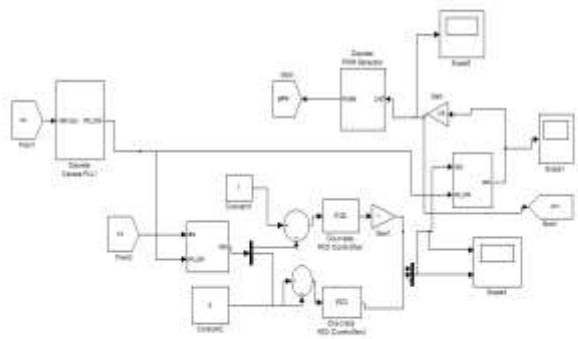
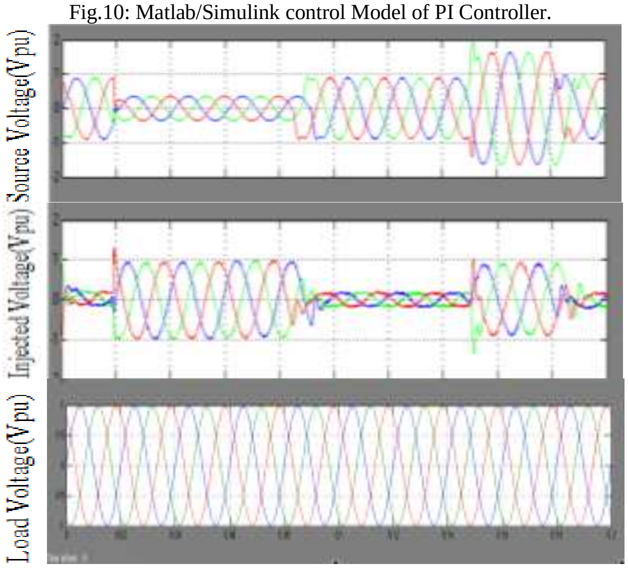


Fig.10: Matlab/Simulink control Model of PI Controller.



TIME(S)

Fig.11: Sag and swell Mitigation Using DVR with PI Controller in Three Phase to Ground fault.

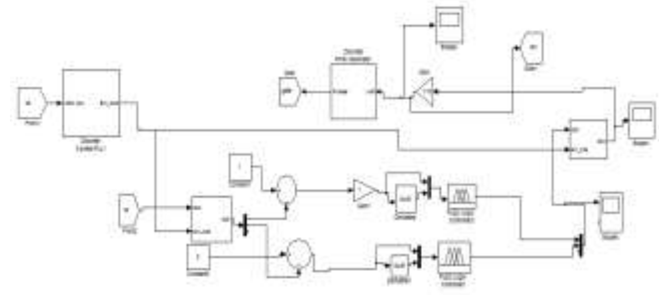
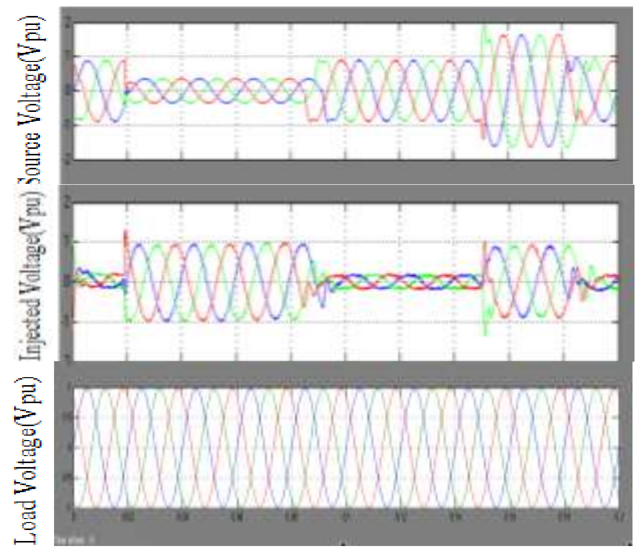


Fig.12: Matlab/Simulink control Model of Fuzzy logic Controller.



TIME(S)

Fig.13: Sag and swell Mitigation Using DVR with fuzzy Controller in Three Phase to Ground fault.

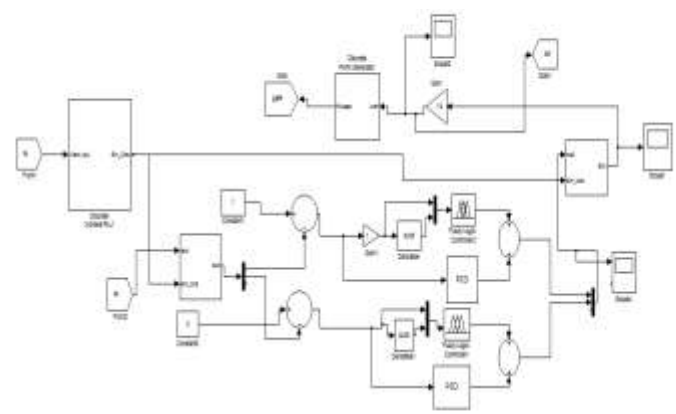


Fig.14: Matlab/Simulink control Model of Hybrid Fuzzy Controller.

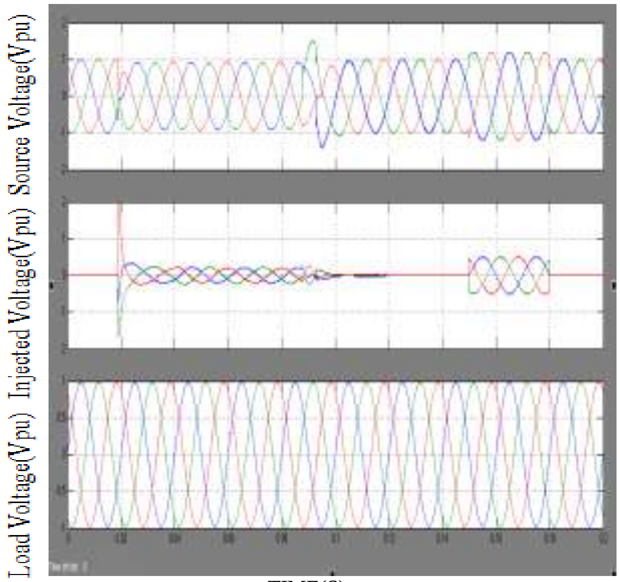


Fig.15:Sag and swell Mitigation Using DVR with HYBRID FL Controller in Three Phase to Ground fault.

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

S.No	Conditions	V_{rms}(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
5	Distribution system with DVR using HYBRID Fuzzy Logic controller	0.98

Table.2: Comparison of PI, FL Controller and Hybrid fuzzy logic controller for DVR.

VII.COMPARISON

The Figures 16, 17, 18 show the FFT analysis for source voltage, load voltage and Injected voltage respectively for DVR with PI controller. The Figures 19, 20, 21 show the FFT analysis for source voltage, load voltage and Injected voltage respectively for DVR with Fuzzy controller. The Figures 22, 23, 24 show the FFT analysis for source voltage, load voltage and injected voltage for DVR with HYBRID FUZZY controller.

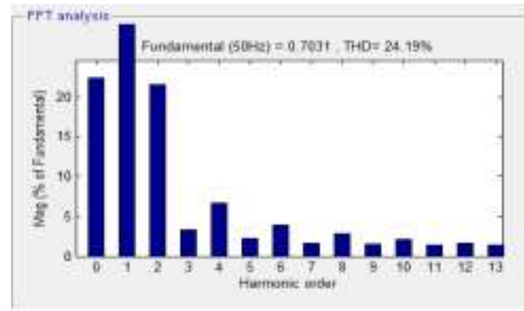


Fig.16: FFT analysis for Source voltage Using DVR with PIController.

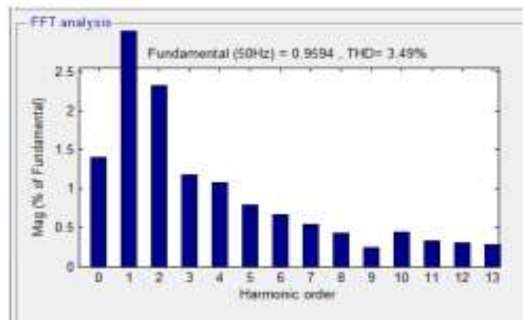


Fig.17:FFT analysis Load Voltage Using DVR with PI Controller.

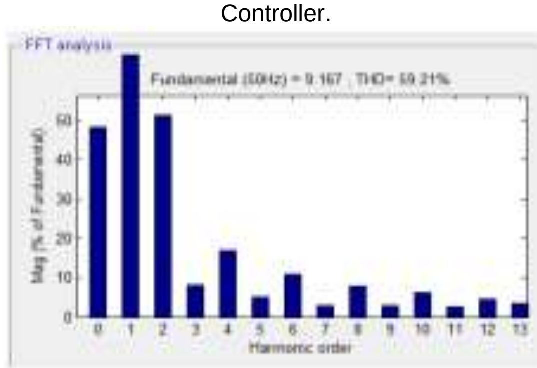


Fig.18: FFT analysis Injected Voltage Using DVR with PI Controller.

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Volume 04 Issue 02
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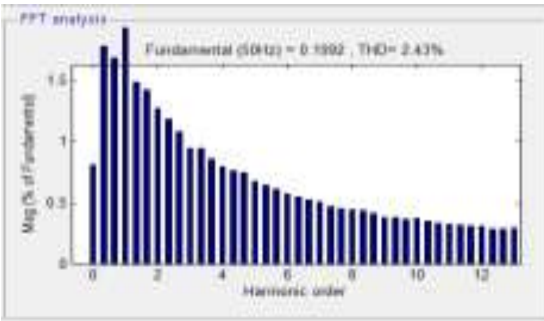

Fig.19: FFT analysis source voltage Using DVR with FL Controller.

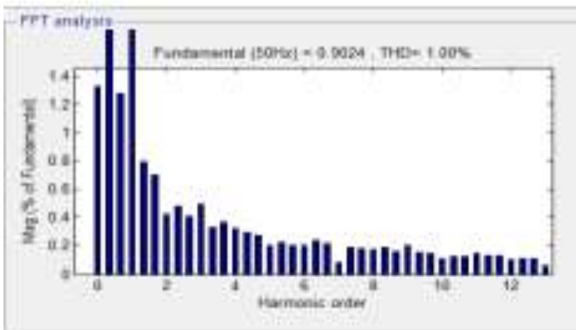

Fig.20: FFT analysis load voltage Using DVR with FL Controller.

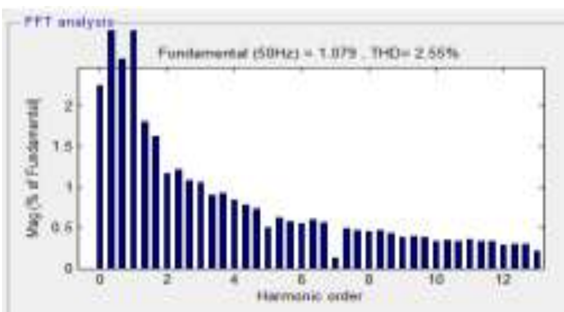

Fig.21: analysis Injected Voltage Using DVR with FL Controller.

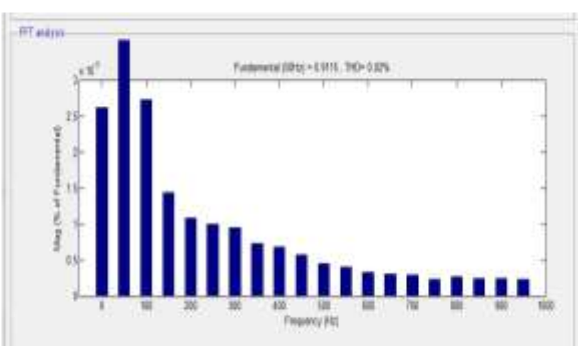

Fig.22: FFT analysis for source voltage by using Hybrid Fuzzy Controller.

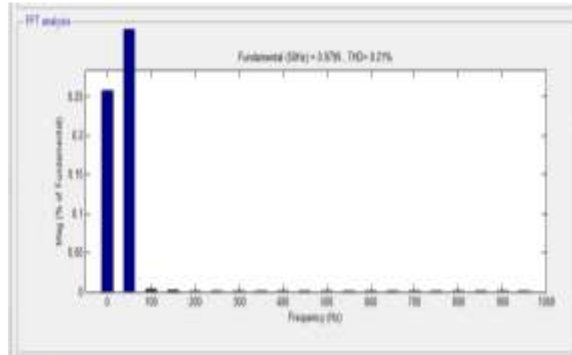

Fig.23: FFT analysis for load voltage by using Hybrid Fuzzy Controller.

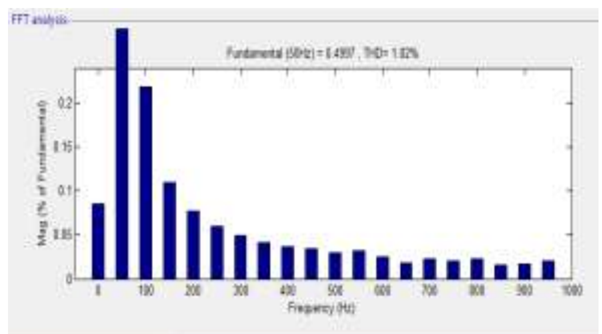

Fig.24: FFT analysis for injected voltage by using Hybrid Fuzzy Controller.

The comparison of FFT analysis with DVR using conventional PI controller and Fuzzy logic controller and HYBRID FUZZY logic controller using DVR is shown in Table-3

S.No	FFT Analysis	THD % for DVR With PI Controller	THD % DVR With FL Controller	THD % DVR With HYBRID FUZZY LOGIC Controller
1	Source voltage	24.19	2.43	0.02
2	Load Voltage	3.49	1.0	0.21
3	Injected Voltage	69.21	2.55	1.02

Table3: FFT analysis Comparison of PI, FL Controller, HYBRID FUZZY LOGIC Controller for DVR.

VIII.CONCLUSION

For the Hybrid fuzzy logic control technique 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 shows, the Hybrid fuzzy logic control the combination of PI and FUZZY logic controller gave a better performance in improving the load voltage to normal conditions.

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