Modeling, Simulation and Comparative Analysis of PI-Fuzzy Controllers Based Dynamic Voltage Restorer

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Abstract
In this paper, voltage compensation scheme for Dynamic Voltage Restorers (DVR) is examined with particular focus on a new method used to minimize the rating of the Voltage Source Converter (VSC) used in DVR. A new control technique is proposed to control the capacitor-supported DVR. The control of a DVR is explained with a reduced-rating VSC. The voltage that is used for compensation is obtained from the respective controllers. Here, synchronous reference frame theory is used for the conversion of voltages from rotating vectors to stationary frame. The compensation of the voltage sag, swell, and harmonics is explained using a self-supported capacitor based DVR.

Keywords
Dynamic Voltage Restorer (DVR), Power Quality, Unit Vector, Voltage Harmonics, Voltage Sag, Voltage Swell

I. Introduction

In modern industrial devices most of the devices are based on electronic devices such as programmable logic devices and electronic drives. The power electronic devices are very sensitive to disturbances and become less affected to power quality problems such as voltage sags, swells and harmonics in the entire problems is considered as one of the majordisturbances to the equipment [1]. The problem of low power quality like voltage sag for sensitive loads can be better solved by power electronics based Dynamic Voltage Restorer. With DVR, the power system can be operated without sag, swell and the power supply by flexibly changing the distribution configuration after the occurrence of a fault. The DVR is a series compensator device based on a Pulse Width Modulated (PWM) Voltage Source Inverter (VSI), which can be generated or absorbed real or reactive power [2]. The condition of Voltage sags caused by faults is, influenced on sensitive loads. The DVR injects the individual voltages to restore and it maintain sensitive load voltage to its normal value. The combination of the custom power device DVR with PI and Fuzzy controller for the power quality improvement in the transmission system is described here for operation of DVR in power quality improvement [3].
Power quality problems such as voltage sags, swells, and other distortions to the outputwaveform of the source voltage affects the operation. Methodologies such as use of custom power devices are used to provide protection against power quality problems. The Custom power devices are of three categories such as series-connected compensators i.e., Dynamic Voltage Restorers (DVRs), shunt-connected compensators [4-5] i.e., distribution static compensators, and a combination of series-connected and shunt-connected compensators are known as Unified Power Quality Conditioner (UPQC). Dynamic voltage restorers can control the flow of load voltage from sag, swell, and harmonics in the source voltage. Therefore, it can protect the loads at user end from tripping and losses [6].

II.Operation of DVR

Dynamic voltage restorer is a series compensation device used to protect the load from the point of common coupling from various power quality disturbances. DVR has the ability to control line voltage harmonics, reduction in transients, fault current, voltage sags and swells. Problems faced regarding the power quality are voltage sags and swells.

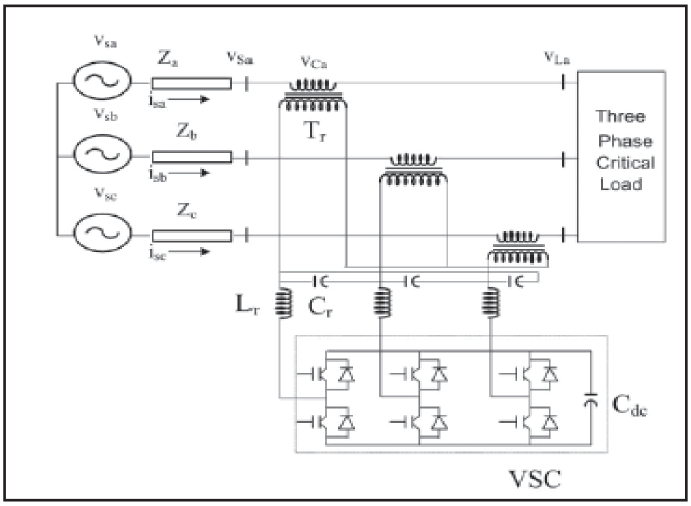

Fig. 1: Schematic Diagram of Proposed DVR System

The vital components are that DVR which injects the desired voltage and controller circuit that controls the load voltage of the transmission system are explained as follows:

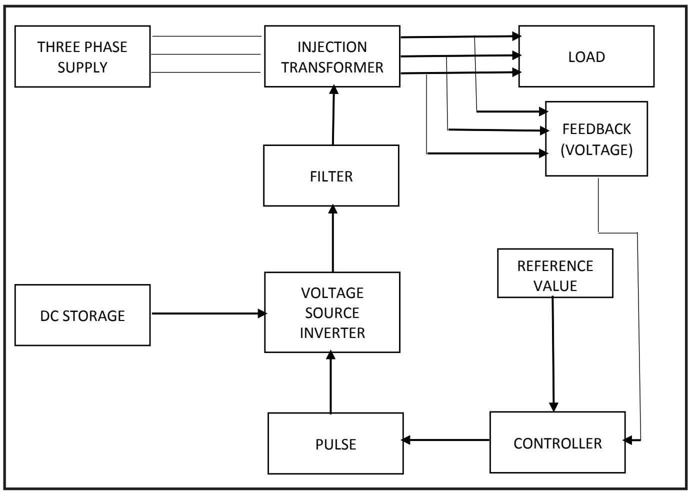

Fig. 2: Block Diagram of Proposed System

A. Injection Transformer

It consists of a three phase transformer or three single phase transformers which control the transient energy from source side to the load side. Injection transformer couples the DVR to the distribution system through the voltage windings.Injection transformer provides electrical isolation and boost of voltage to the transmission system. In a 3-phase system, either 3 single phase units of injectiontransformer or 3-phase injection transformer can be used for the voltage injection. While choosing the injection transformer, the desired amount of expected maximum output voltage is major significance, both economically and technically.

B. Filter

Filters are the circuits comprising of combination of passive elements like resistors, inductors andcapacitors. Filters perform signal processing operations to eradicate the unwanted frequency signals and then to improve the desired signal output. LC type filters is used to correct the harmonics from Voltage source inverter to provide the desired compensation in the required phase in transmission system which is boosted by DVR.

C. Energy Storage System

The purpose of storage systems is to protect load side devices from faults caused by power quality disturbance. Energy storage systems provide the desired energy to the VSI through a dc link for the production of injected voltages. There are various types of storage systems such as superconducting magnetic energy storage system, DC batteries, flywheel energy storage systemand batteryenergy storage system. The Capacity of the energy storage system directly determines the duration of the voltage sag and swell which is mitigated by the DVR. From the above mentioned storage systems, batteries are more commonly used and can be highly effective if high voltage configuration is employed.

D. Voltage Source Inverter

VSI forms the major block of compensating device. It performs the conversion process of power from DC to AC. VSI generally consists of fully controlled semiconductor power switches to form a single phase or three phase methods.Single phase VSI generally consists of four semiconductor switches in two arm in order to generate the ac output.Three phase VSI is a six step bridge type inverter that employs a minimum of six thyristors where a step change means a change in the firing from one thyristor to the other thyristor in proper sequence.

E. Control Circuit

There are various control techniques of the DVR have been implemented for power quality improvement in the transmission system. The DVR is employed with a control system to mitigate voltage sags, swells and reduce harmonics.The control strategy depends on the type of load connected in the transmission system. The main purpose is to maintain constant voltage in the transmission system where the load is affected by power quality disturbances. Here we use two types of controllers namely PI controller and Fuzzy logic controller. Both controllers are implemented in a new technique i.e., self-supported capacitor technique. Both controllers performance are analyzed and the best compensation method is used in the transmission system.

F. PI Controller

The PI controller is a feedback controller that employs the weighted sum of error and its integral value to perform the control operation. The proportional response can be adjusted by multiplying the error with constant K_p called proportional gain. The contribution by integral term is proportional to both the magnitude and duration of error. The error is first multiplied by the integral gain, K_i and then its integrated to give an accumulated offset value that have been corrected earlier. The input to the PI controller is difference between the reference value and error value from the input voltage. The comparison of reference value and the error value of voltage, PI controller adjusts its proportional and integral gains K_p and K_i respectively in order to minimize the steady state error to zero for a step input [7].

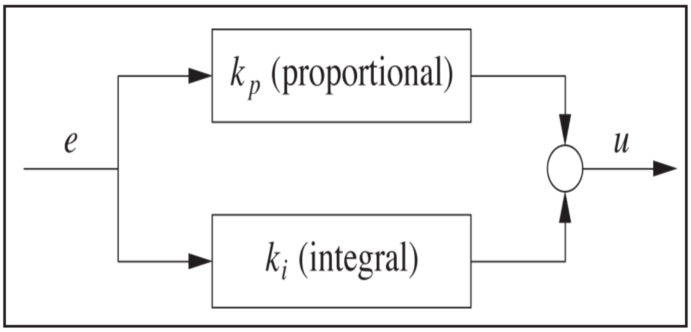

Fig. 3: Block Diagram of PI Controller

G. Fuzzy Logic Controller

The drawback of PI controller is overcome by Fuzzy logic controller. In comparison to the PI controller, this is a non-linear controller which provides satisfactory results by the influence of changing system parameters and operating conditions [9].

The function of fuzzy logic controller is very useful as it does not involve any mathematical modeling and calculations. The performance of fuzzy controller is accepted for improvement in both transient disturbancesand in harmonic reduction. The fuzzy controller comprises of four main functional modules namely, Knowledge base, Fuzzification, Inference mechanism andDefuzzification [10].

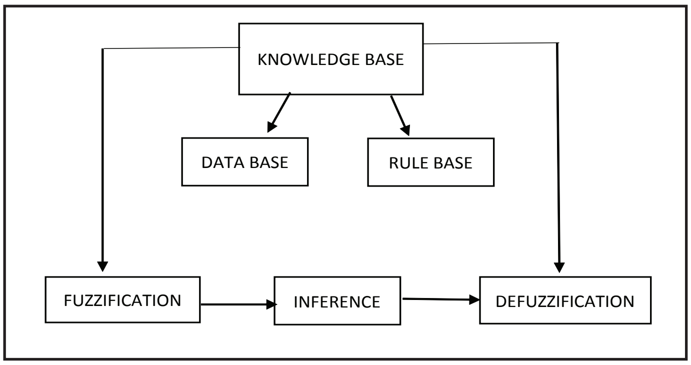

Fig. 4: Block Diagram of Fuzzy Logic Controller

H. Hysteresis Band Current Control

Hysteresis control schemes are based on a nonlinear feedback loop with two level hysteresis comparators. The switching signals are produced directly when the error exceeds an assigned tolerance band. Among the main advantages of hysteresis CC are simplicity, good stability, fast response, good accuracy, outstanding robustness, lack of tracking errors, independence of load parameter changes, and extremely good dynamics limited only by switching speed and load time constant [10].

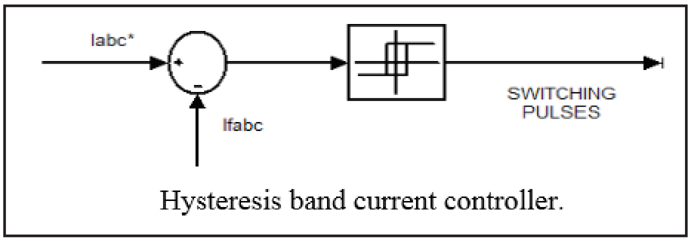

Fig. 5: Hysteresis Control Pulse Generation

III. Design Equations

A. Control of self-supported DVR

The control of self-supported DVR for voltage sags, voltage swells, and harmonics can be achieved by using SRF theory i.e.,

Synchronous reference frame theory [1].
The components of voltages in the d and q axes are

$$V_d = V_{ddc} + V_{dac} \quad (1)$$
$$V_q = V_{qdc} + V_{qac} \quad (2)$$

In order to maintain the dc bus voltage of the self-supported capacitor, a fuzzy controller is used at thedc bus voltage of the DVR and the output is considered as a voltage V_{cap} for meeting its losses

$$V_{cap(n)} = V_{cap(n-1)} + K_{p1} (V_{de(n)} - V_{de(n-1)}) + K_{i1} V_{de(n)} \quad (3)$$

$$V_{de(n)} = V_{dc}^* - V_{dc} \quad (4)$$

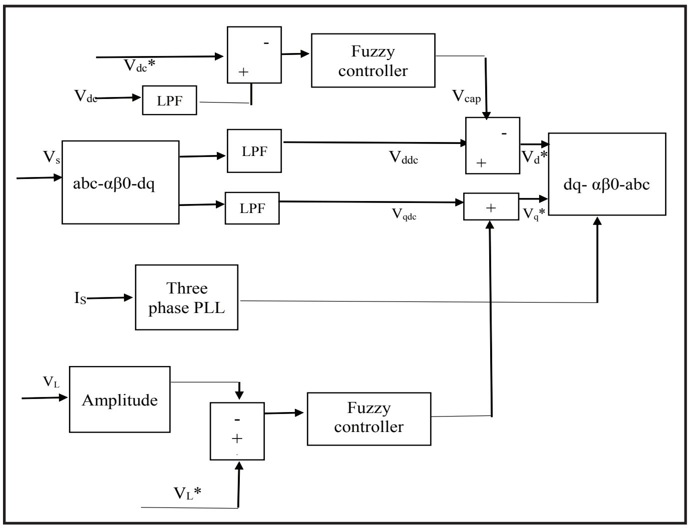

Fig. 6: Self-supported Technique Using SRF Theory

$V_{de(n)}$ is the error between the reference V_{dc}^* and sensed dc voltages $V_{dc(n)}$ at the nth sampling instant. K_{p1} and K_{i1} are the proportional and the integral gains of the dc bus voltage PI controller. The reference d-axis load voltage is therefore expressed as follows (Fig. 6)

$$V_d^* = V_{ddc} - V_{cap} \quad (5)$$

The amplitude of load terminal voltage V_L is controlled to its reference voltage V_L^* using another PI controller. The output of the PI controller is considered as the reactive component of voltage V_{qr} for voltage regulation of the load terminal voltage. The amplitude of load voltage V_L at the PCC is calculated from the ac voltages (V_{La}, V_{Lb}, V_{Lc}) as

$$V_L = (2/3)^{1/2}. (V_{La}^2 + V_{Lb}^2 + V_{Lc}^2)^{1/2} \quad (6)$$

Then, a PI controller is used to regulate this to a reference value as

$$V_{qr} = V_{qr(n-1)} + K_{p2} (V_{te(n)} - V_{te(n-1)}) + K_{i2} V_{te(n)} \quad (7)$$

Where $V_{(te(n)} = V_L^* - V_{L(n)}$ denotes the error between the reference V_L^* and $V_{L(n)}$ actual load terminal voltage amplitudes. K_{p2} and K_{i2} are the proportional and the integral gains. The reference load quadrature axis voltage is expressed as

$$V_q^* = V_{qdc} + V_{qr} \quad (8)$$

IV. Simulation Results

The simulation and results of various blocks in self-supported DVR modelling and results of various blocks also obtained and discussed. The simulation results of this section are generated using MATLAB/Simulink simulation package.

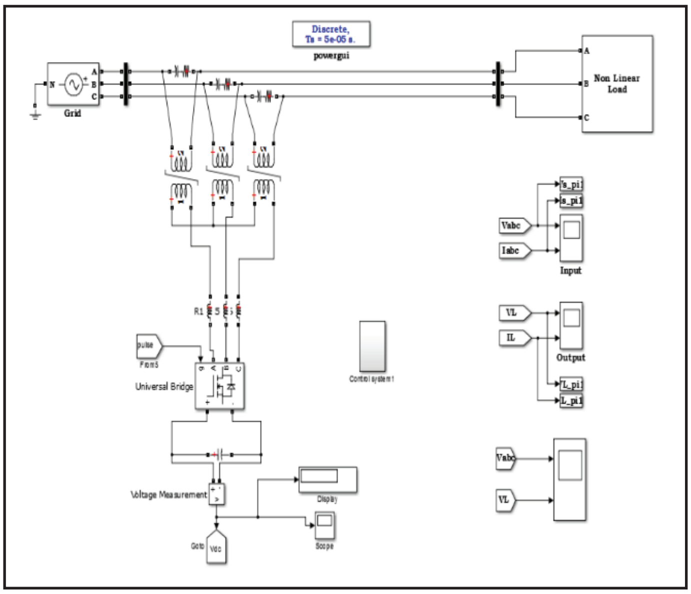

Fig. 7: Proposed System Simulation Model

The DVR based system consisting of a three-phase supply,three-phase critical loads, and the series injection transformers shown and the control system block generally consists of three modes of transformation. They are classified as follows:

- abc to alpha-beta transformation (park's transformation)
- alpha-beta to d-q transformation (park's transformation)
- d-q to alpha-beta transformation (reverse park's transformation)
- alpha-beta to abc transformation (reverse park's transformation)

Initially, the three-phase quantities are translated from the three-phase reference frame to the two-axis orthogonal stationary reference frame using Clarke transformation.Then, these two-axis orthogonal stationary reference frame quantities are transformed into rotating reference frame quantities by using Park transformation. The quantities in rotating reference frame are transformed to two-axis orthogonal stationary reference frame using Inverse Park transformation and then the transformation from a two-axis orthogonal stationary reference frame to a three-phase stationary reference frame is accomplished using Inverse Clarke transformation [8] (Fig. 8).

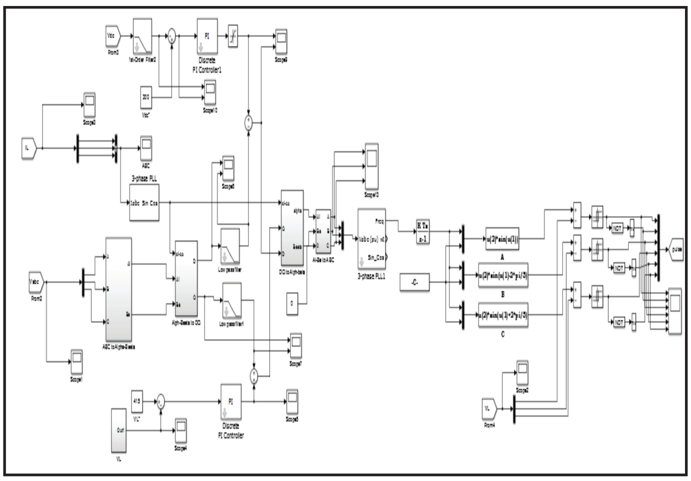
Fig. 8: Control System of Proposed Simulation Model

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The control of DVR is alsomodeled in MATLAB. The reference DVR voltages is derivedfrom sensed PCC voltages and load voltages. A Hysteresis band currentcontroller is used over the reference and sensed DVR voltages to generate the gating signals for the MOSFETs of the VSC of the DVR.The capacitor-supported DVR is modeledand simulated in MATLAB, and their performances of thesystems are compared in three conditions of DVR.

V. Performance of DVR System

The performance of DVR has been analyzed under PI controller and fuzzy controller and also DVR has been found to regulate voltage. DVR reduces harmonics from load voltage very effectively and makes it smooth under the usage of Fuzzy logic controller. The detailed performance of both the PI and fuzzy logic controller is presented as follows.

Table 1: Comparison of DVR Rating for Sag, Swell and Harmonics Using PI Controller

S.NO	CONDITION	V_{in}	V_o	T.H.D
1	Initial(0.05s)	310	320	7.41
2	Swell(0.15s)	620	315	2.68
3	Sag(0.35s)	300	310	3.79

The above table describes about the operation of DVR using PI controller for mitigating the sag, swell and harmonics.

Table 2: Comparison of DVR Rating for Sag, Swell and Harmonics Using Fuzzy Logic Controller

S.NO	CONDITION	V_{in}	V_o	T.H.D
1	Initial(0.05s)	310	315	7.28
2	Swell(0.15s)	620	320	2.59
3	Sag(0.35s)	300	305	2.90

The above table describes about the operation of DVR using Fuzzy logic controller for mitigating the sag, swell and harmonics. The harmonic distortion in the transmission system using PI controller can be explained from the following graphs.

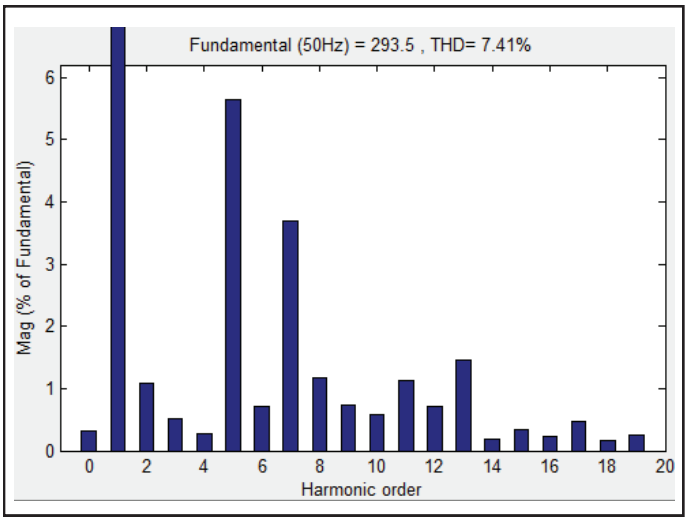

Fig. 9: THD of DVR Based System at Initial Using PI Controller

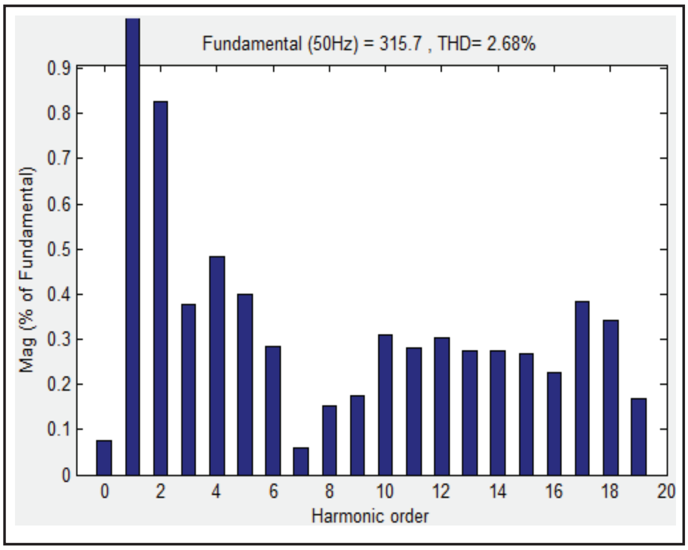

Fig. 10: THD of DVR Based System at Swell Using PI Controller

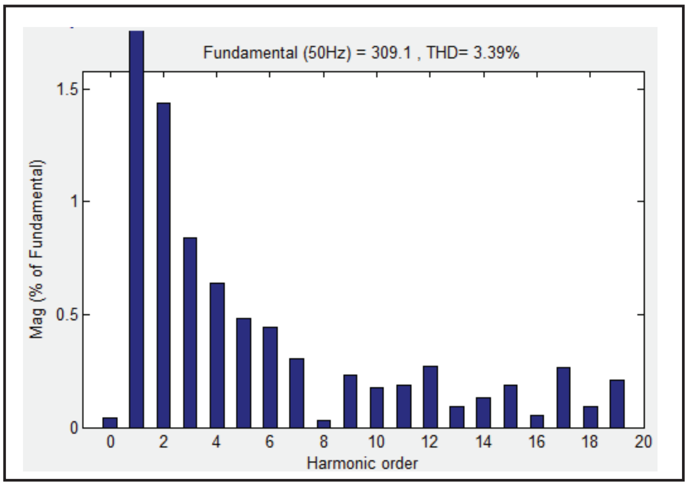

Fig. 11: THD of DVR Based System at Sag Using PI Controller

The harmonic distortion in the transmission system using Fuzzy logic controller can be explained from the following graphs.

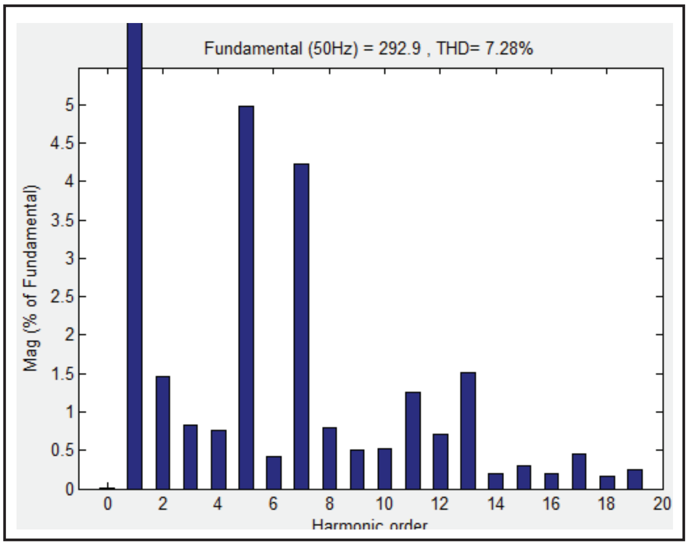

Fig. 12: THD of DVR based system at initial using Fuzzy logic controller

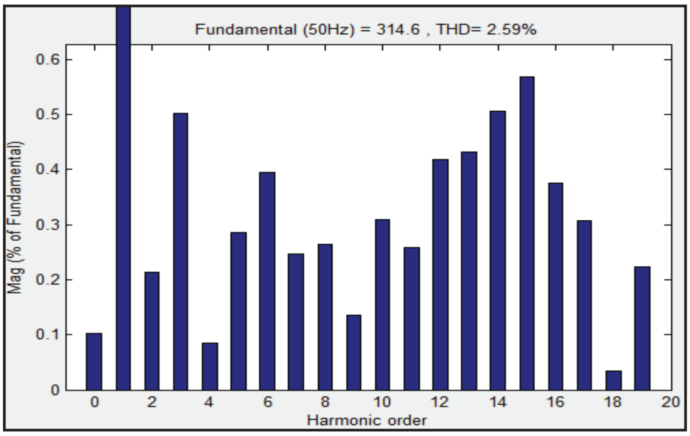

Fig. 13: THD of DVR Based System at Swell Using Fuzzy Logic Controller

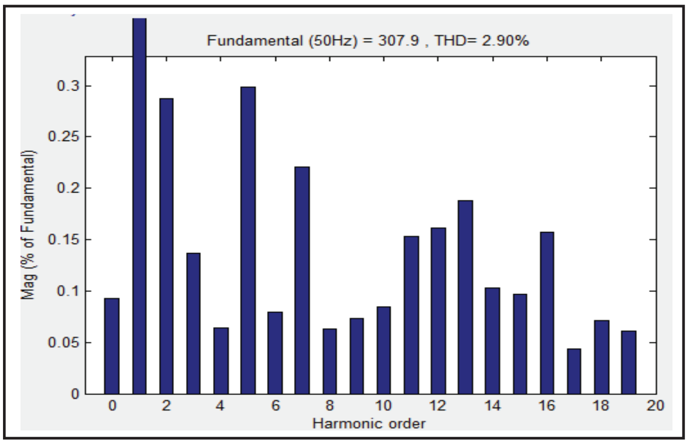

Fig. 14: THD of DVR Based System at Sag Using Fuzzy Logic Controller

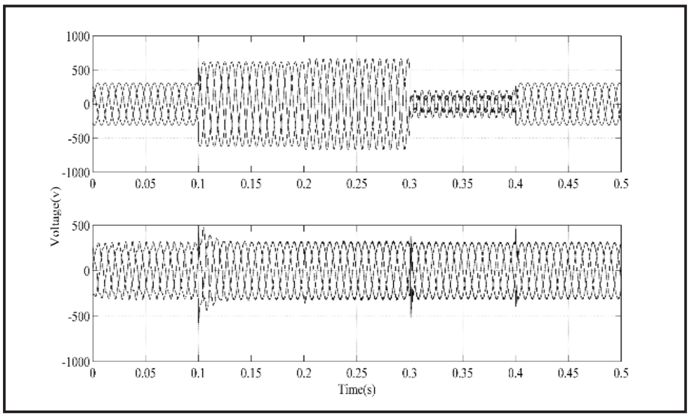

Fig. 15: Proposed Output Under PI Controller

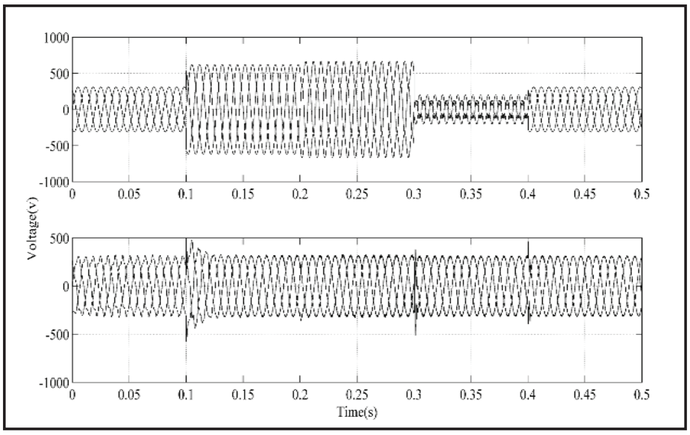

Fig. 16: Proposed Output Under Fuzzy Logic Controller

VI. Conclusion

In this dissertation, DVR has been modelled and simulated in MATLAB environment.The performance of DVR has been analysed under PI controller and Fuzzy logic controller and also DVR has been found to regulate voltage under varying load condition and load unbalancing under both controllers. However DVR reduces harmonics from load voltage very effectively and makes it smooth under the usage of Fuzzy logic controller. It is concluded that DVR has a huge scope in improving power quality in distribution systems.With the increase use in number of sophisticated electronic devices by the industrial customers to increase their efficiency and productivity, it is important to ensure reliable power supply even under the system disturbances. Comparing both controllers, the fuzzy logic technique can be implemented in order to get stable compensation in transmission line. The fuzzy logic method also provides better reduced harmonics compared to the PI controller technique. The fuzzy logic controller is used widely now a days in various industries due to the efficiency compared to other conventional controller methods.

VII. Appendix

Line voltage V = 380V_{rms}.
Frequency f = 50Hz.
Line impedance, R= 1 Ω, C= 0.001F.

PI controller

DC bus voltage PI controller: K_{p1}= 0.15, K_{i1}= 0.1
AC load voltage PI controller: K_{p2}= 0.15, K_{i2}= 0.1

Fuzzy Logic Controller

Display range [-250 250]
Change in error range [-1 1]

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