ISSN (ONLINE):2456-5717
International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
Vol.4, Issue.6, June 2018

Open End Winding Transformer for Voltage Compensation using fuzzy logic controller

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***Abstract* – The proposed project consists of a dynamic voltage restorer (DVR) composed of two conventional three-phase inverters series cascaded through an open-end winding (OEW) transformer, denominated here DVR-OEW. The DVR-OEW operating with either equal or different dc-link voltages is examined. The proposed topology aims to regulate the voltage at the load side in the case of voltage sags/swell, distortion, or unbalance at the grid voltage. A suitable control strategy is developed, including space-vector analysis, level shifted PWM and its equivalent optimized single-carrier PWM, as well as the operating principles and characteristics of the DVR. Comparisons among the DVR-OEW and conventional configurations, including a neutral-point clamped converter-based DVR, are furnished. The main advantages of the DVR-OEW compared to the conventional topologies lie on: 1) reduced harmonic distortion, 2) reduced converter losses, and 3) reduced voltage rating of the power switches. Simulated and experimental results are presented to validate the theoretical studies using MATLAB/SIMULINK.**

***Keywords:* power quality, voltage sag/swell, space-vector analysis, open-end winding.**

I. INTRODUCTION

Power quality has a hard impact on distribution power systems (DPS). Every year, it is estimated that the industry and commerce sectors lose billions of dollars [1] due to issues related to low power quality. Such problems are directly associated with voltage sag. Even considering other types of troubles (i.e., flickers, harmonic currents, etc.) that can lead the DPS to a poor power quality, voltage sag is still reported as the major power-quality problem [2]–[6]. Voltage sag correction is required for applications that range from a few hundred watts to several megawatts [7]. A Dynamic Voltage Restorer is used to compensate the supply voltage disturbances such as sag and swell.

The DVR is basically composed of injection transformers, protection circuit, bypass thyristor, passive filters, voltage source inverter (VSI), and energy storage. The Dynamic Voltage Restorer is connected between the supply and sensitive loads, so that it can inject a voltage of required magnitude and frequency in the distribution feeder. The Dynamic Voltage Restorer is operated such that the load voltage magnitude is regulated to a constant magnitude, while the average real power absorbed/ supplied by it is zero in the steady state. The capacitor supported Dynamic Voltage Restorer is widely addressed in the literature [8-13]. The instantaneous reactive power theory (IRPT) [6], sliding mode controller [9], instantaneous symmetrical components [2, 13] etc., are discussed in the literature for the control of DVR. In this project a new control algorithm is proposed based on the current mode control and proportional-integral (PI) controllers for the control of Dynamic Voltage Restorer. The extensive simulation is performed to demonstrate its capability, using the MATLAB with its SIMULINK and Power System Block set (PSB) toolboxes.

II POWER QUALITY

Power quality is the combination of voltage quality and current quality. Thus power quality is concerned with deviations of voltage and/or current from the ideal. Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency However, in practice, power systems, especially the distribution systems have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many Power quality problems.

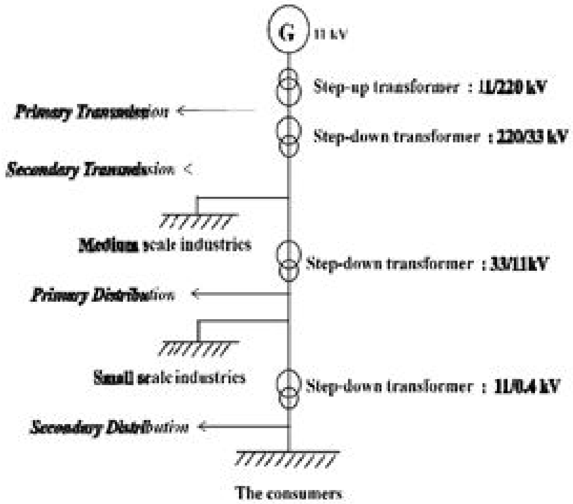

Figure 1.single line diagram of power supply system

Voltage dip: A voltage dip is used to refer to short-term reduction in voltage of less than half a second. Voltage sag: Voltage sags can occur at any instant of time, with amplitudes ranging from 10% to 90% and duration is lasting for half a cycle to one minute. Voltage swell: 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. Voltage 'spikes', 'impulses' or 'surges': These are terms used to describe abrupt, very brief increases in voltage value. Voltage transients: They are temporary, undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time. Harmonics: The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies

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can be even or odd multiples of the sinusoidal fundamental frequency. Flickers: Visual irritation and introduction of many harmonic components in the supply power and their associated ill effects.

III DYNAMIC VOLTAGE RESTORER

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

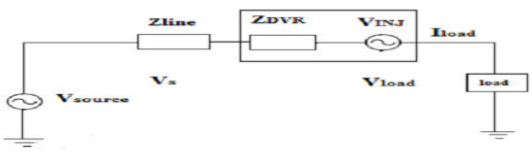

Figure 2. Block diagram of DVR

The general configuration of the DVR consists of an Injection/ Booster transformer, a harmonic filter, Storage devices, a voltage Source converter (VSC), DC charging circuit, a control and Protection system.

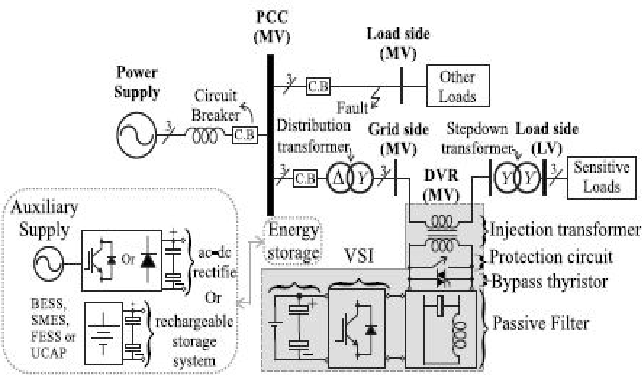

Figure 3. Typical application of DVR in a Medium voltage distribution system

The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its main tasks are: 1. It connects the DVR to the distribution network via the HV-windings and transform and couples the injected compensating voltages generated by the voltage source

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converters to the I incoming supply voltage. 2. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

A VSC is a power electronic system consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. In the DVR application, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing.

IV CONTROL SCHEME

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.

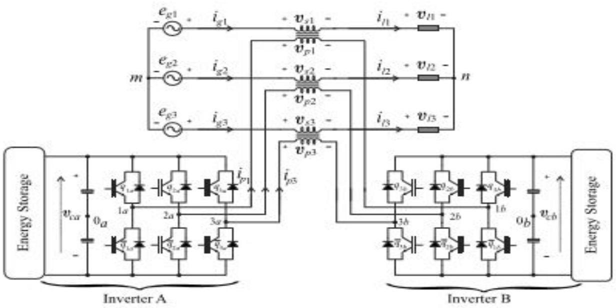


Figure 4. Location of DVR

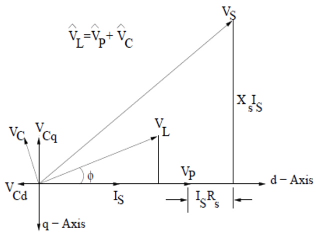


Figure 5: Phasor diagram for the system

The Synchronous Reference Frame (SRF) approach is used to generate the reference voltages for the DVR. The above figure shows the control scheme using SRF. The PCC voltages are transformed into d-q components using the following equations.

$$V_{lq} = -V_{ld} \tan \emptyset$$

$$\begin{bmatrix} V_{p\alpha} \\ V_{p\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{-\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{pa} \\ V_{pb} \\ V_{pc} \end{bmatrix}$$

And

$$\begin{bmatrix} V_{pd} \\ V_{pq} \end{bmatrix} = \begin{bmatrix} \cos w_0 t & -\sin w_0 t \\ \sin w_0 t & \cos w_0 t \end{bmatrix} \begin{bmatrix} V_{p\alpha} \\ V_{p\beta} \end{bmatrix}$$

Finally the reference voltages for the DVR is given by

$$\begin{bmatrix} V_{l\alpha} \\ V_{l\beta} \end{bmatrix} = \begin{bmatrix} \cos w_0 t & \sin w_0 t \\ -\sin w_0 t & \cos w_0 t \end{bmatrix} \begin{bmatrix} V_{ld}^* \\ V_{lq}^* \end{bmatrix}$$

$$\begin{bmatrix} V_{la}^* \\ V_{lb}^* \\ V_{lc}^* \end{bmatrix} = \sqrt{\frac{2}{3} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}} \begin{bmatrix} V_{l\alpha}^* \\ V_{l\beta}^* \end{bmatrix}$$

where I_{ld} and I_{lq} are the average values of the d- and q- axis components of the load current, icd is the output of the DC voltage controller and icq is the output of the AC voltage controller (if the bus voltage (Vt) is to be regulated). u is a logical variable equal to (a) zero if PF is to be regulated and (b) one if bus voltage is to regulated. Kq = 1 in the latter case. When PF is to be controlled, Kq is determined by the required power factor as follows.

$$K_q = \frac{Q_S^*}{Q_L}$$

where Q_S is the reference reactive power supplied by the source (at PCC) and Q_L is the average reactive power (at fundamental frequency).

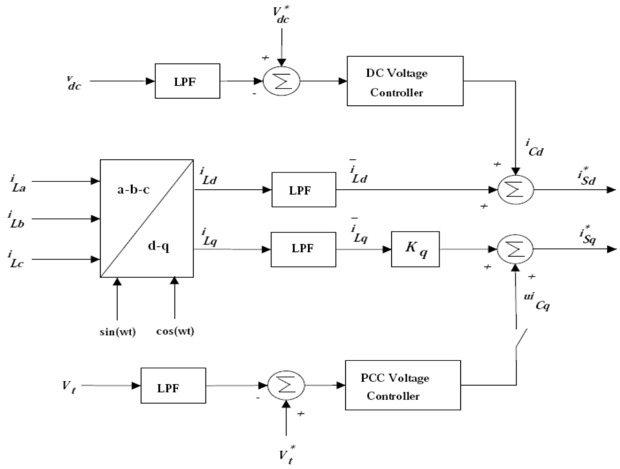


Figure 6. Computation of reference source currents (d and q components)

V CONTROL STRATEGY OF DVR

The proposed algorithm is based on the estimation of reference supply currents. It is similar to the algorithm for the control of a shunt compensator like DSTATCOM for the terminal voltage regulation of linear and nonlinear loads [6]. The proposed control algorithm for the control of DVR is depicted in Fig

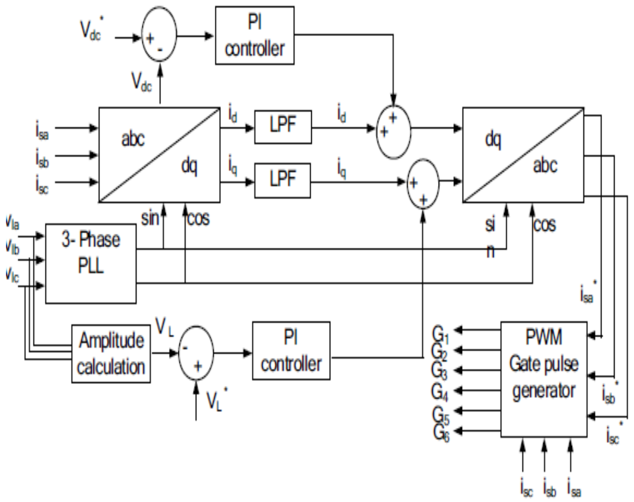


Figure 7. control scheme of the DVR

The series compensator known as DVR is used to inject a voltage in series with the terminal voltage. The sag and swell in terminal voltages are compensated by controlling the DVR and the proposed algorithm inherently provides a self-supporting dc bus for the DVR. Three-phase reference supply currents (isa*, isb*,isc*) are derived using the sensed load voltages (vla, vlb, vlc), terminal voltages (vta, vtb, vtc) and dc bus voltage (vdc) of the DVR as feedback signals. The synchronous reference frame theory based method is used to obtain

ISSN (ONLINE):2456-5717
International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
Vol.4, Issue.6, June 2018

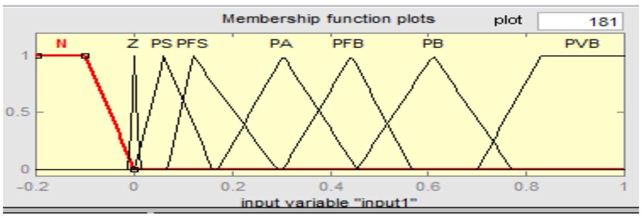
the direct axis (id) and quadrature axis (iq) components of the load current. The load currents in the three-phases are converted into the d-q-0 frame using the Park's transformation as

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{2} \\ \cos\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2\pi}{3}\right) & \frac{1}{2} \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix}$$

A three-phase PLL (phase locked loop) is used to synchronies these signals with the terminal voltages (vta, vtb, vtc). The d-q components are then passed through low pass filters to extract the dc components of id and iq. The error between the reference dc capacitor voltage and the sensed dc bus voltage of DVR is given to a PI (proportional-integral) controller of which output is considered as the loss component of current and is added to the dc component of id. Similarly, a second PI controller is used to regulate the amplitude of the load voltage (Vt). The amplitude of the load terminal voltage is employed over the reference amplitude and the output of PI controller added with the dc component of iq. The resultant currents are again converted into the reference supply currents using the reverse Park's transformation. Reference supply currents (isa*, isb*,isc*) and the sensed supply currents (isa, isb, isc) are used in PWM current Controller to generate gating pulses for the switches. The PWM controller operates at a frequency of 10 kHz and the gating signals are given to the three-leg VSC for the control of supply currents.

VI FUZZY LOGIC CONTROLLERS

The logic of an approximate reasoning continues to grow in importance, as it provides an in expensive solution for controlling know complex systems. Fuzzy logic controllers are already used in appliances washing machine, refrigerator, vacuum cleaner etc. Computer subsystems (disk drive controller, power management) consumer electronics (video, camera, battery charger) C.D. Player etc. and so on in last decade, fuzzy controllers have convert adequate attention in motion control systems. As the later possess non-linear characteristics and a precise model is most often unknown. Remote controllers are increasingly being used to control a system from a distant place due to inaccessibility of the system or for comfort reasons. In this work a fuzzy remote controllers is developed for speed control of a converter fed dc motor. The performance of the fuzzy controller is compared with conventional P-I controller.



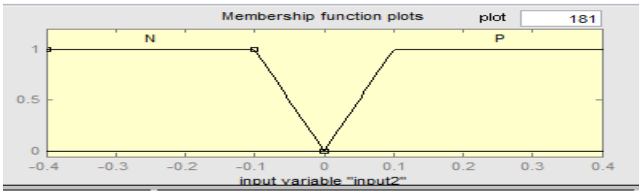


Figure 8. Data for the implemented fuzzy system for DVR.

VII TEST SYSTEM SIMULINK MODELS

The DVR is modeled and simulated using the MATLAB and its Simulink and Power System Block set (PSB) toolboxes. The MATLAB model of the DVR connected system is shown in Fig. The three-phase source is connected to the three-phase load through series impedance and the DVR. The considered load is a lagging power factor load. The VSC of the DVR is connected to the system using an injection transformer.

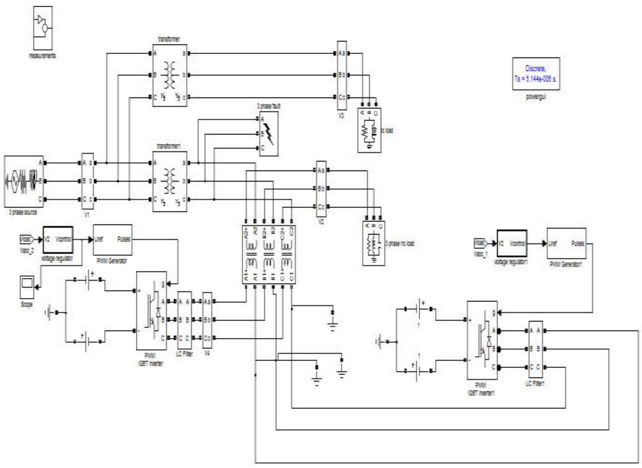


Figure 9. Simulink model of proposed model

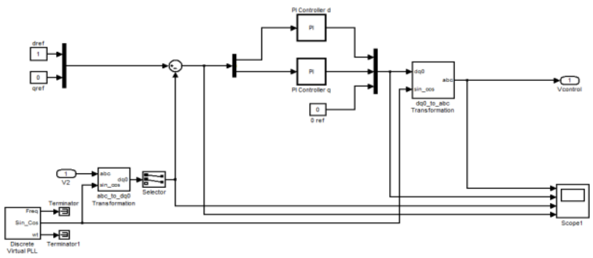


Figure 10. MATLAB based model of the proposed control method

In addition, a ripple filter for filtering the switching ripple in the terminal voltage is connected across In the terminals of the secondary of the transformer. The dc bus capacitor of DVR is selected based on the transient energy requirement and the dc bus voltage is selected based on the injection voltage level. The dc capacitor decides the ripple content in the dc voltage. The system data are given in Appendix.

The proposed control algorithm is modeled in MATLAB. The reference supply currents are derived from the sensed load voltages, supply currents and dc bus voltage of DVR.

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International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
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The output of the PI controller used for the control of dc bus voltage of DVR is added with the direct axis component of current. Similarly, the output of the PI controller used for the control of the amplitude of the load voltage is added with the quadrature axis component. A pulse width modulation (PWM) controller is used over the error between reference supply currents and sensed supply currents to generate gating signals for the IGBT's (insulated gate bipolar transistors) of the VSC of DVR.

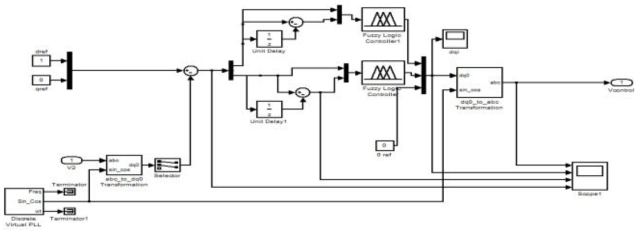

Figure 11. control circuit using fuzzy logic controller

VIII RESULTS

The results of the test system are observed using mat lab/simulink software.

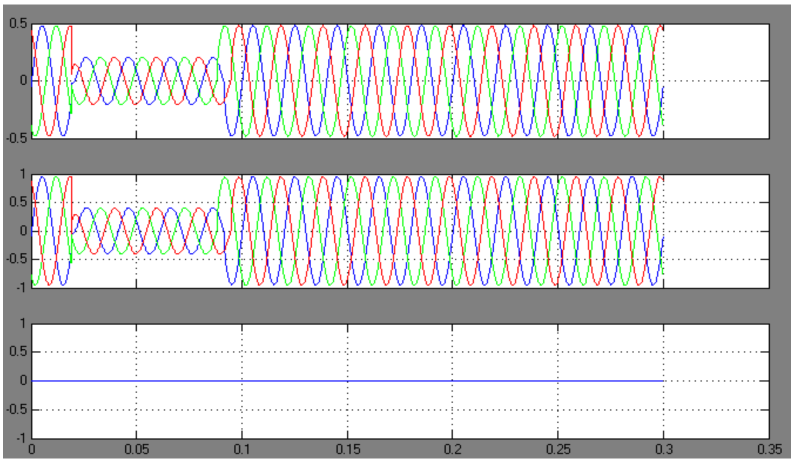

Figure 12.Without dynamic voltage restorer source voltage and injected voltage

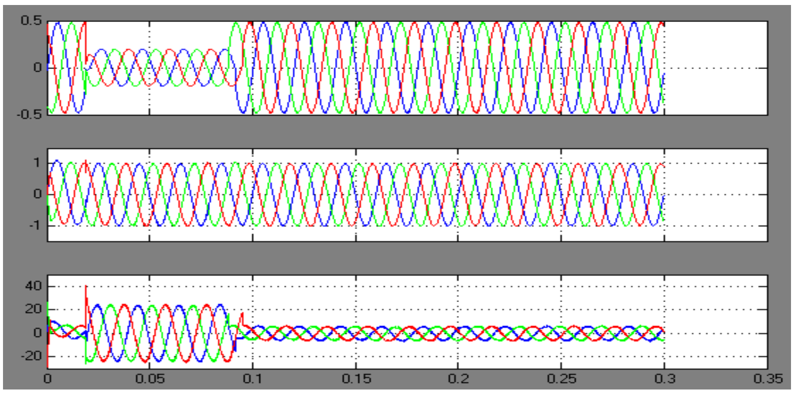

Figure 13.DVR results with PI controller

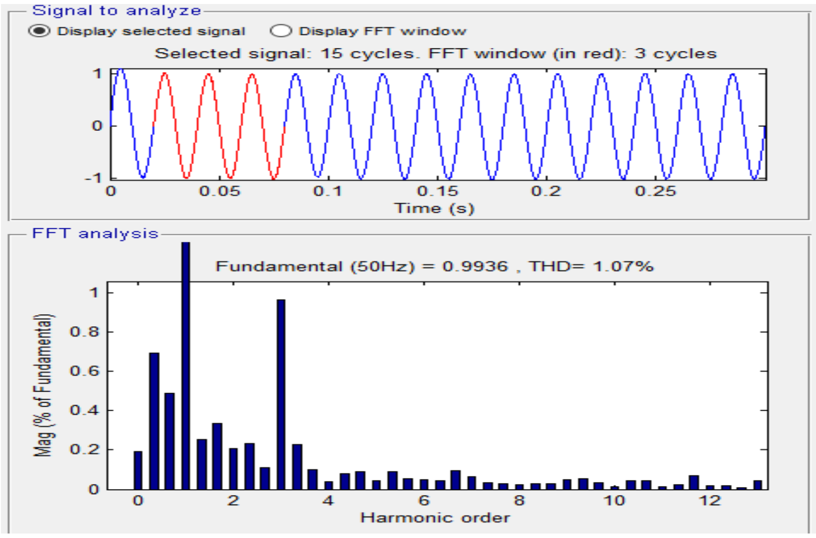

Figure 14. THD for load voltage with PI controller

Now we can observe the following results with fuzzy controller applied to the test system.

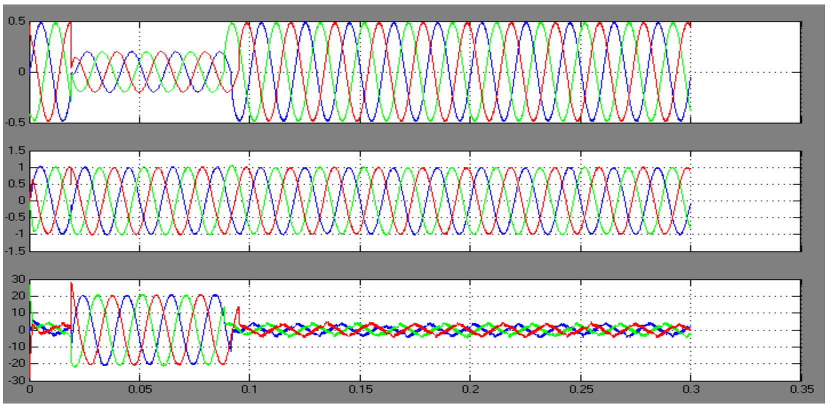

Figure 15. Simulation results using fuzzy controller

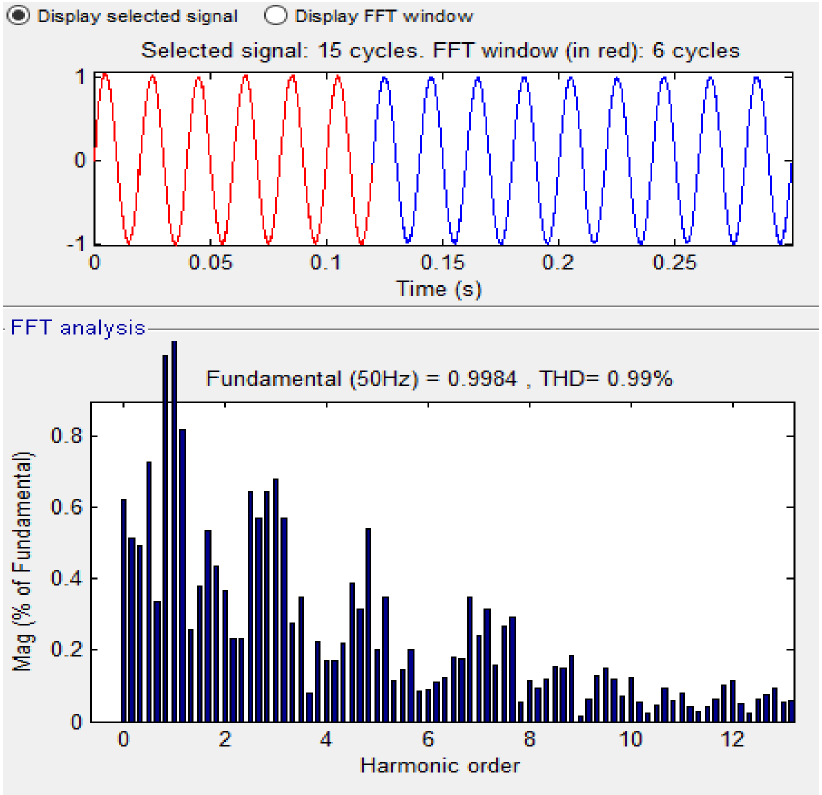

Figure 16. THD with FUZZY controller for both VSCs

VIII CONCLUSION

In this paper, a DVR obtained by means of the series connection of two three-phase inverters through an OEW transformer was presented. The ability of a Dynamic voltage restorer (DVR) to compensate voltage sag depends upon the capacity of energy storage device. Here we had considered a distribution system with a three phase to ground fault. A voltage sag of 0.4V (pu) has occurred in the distribution line and there is said to be a drop in load voltage. Both PI and Fuzzy Logic controller are simulated and performance of DVR is analyzed. Both controllers gave an optimum performance and have the ability to bring the source voltage back to 1.0pu in faulty conditions. The fuzzy logic controller gave a better performance than the PI controller in improving the source voltage to normal conditions. The future scope for the project is design of a DVR with sliding mode control using fuzzy logic as a controller.

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