Mitigating Voltage Imperfections with Photovoltaic fed ANFIS based ZSI-DVR in Three Phase System

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Abstract– In recently developed power system models, Power Quality attains utmost importance. This paper makes use of Z source Inverter (ZSI) connected Dynamic voltage Restorer (DVR) with Renewable energy Unit support to mitigating the short duration voltage sag and interruption. Here the voltage source inverter based DVR model is controlled by the signals generated from Synchronous reference frame based (DQ) controller. In this model, for maximum power point tracking (MPPT) in Renewable Energy unit, Perturb and Observation method is opted. DVR control technique for sensitive load voltage harmonic mitigation is analyzed with traditional PI controller and soft computing based Fuzzy and ANFIS controllers. The presented ZSI-DVR model is capable of mitigating voltage sag under variant fault conditions. ANFIS-DQ controller is proposed for effective DVR operation under three different fault conditions. PV fed ZSI aids the DVR performance in mitigating voltage imperfections and also acts as power conditioning device to deliver the active power to the load. The performance of ANFIS-DQ based DVR control technique is studied in SIMULINK (MATLAB) environment.

Keywords: Power Quality, Renewable Energy sources, Power Conditioning Devices, PI, FUZZY and ANFIS controllers.

1. Introduction

The main hurdles for designing an efficient power system for current modern world are power quality (PQ) and pollution free power. The most facing issues in residence and industrial loads regarding PQ are voltage disturbances like voltage sag, power interruption and voltage swell [1-4]. The usual causes for voltage sag are induction motors high starting current, lightening strokes, inrush currents and short circuit faults [3].the No linear loads causes harmonics in voltage and currents which affects the consumer loads [4].

DVR is most cost effective power conditioning device connected in series with the line to mitigate the voltage imperfections such as sag/swell and interruption [5]. In literature PV fed DVR topologies [6-7] proven added advantages over energy storage based DVR topologies [8]. DVR consists of voltage source inverter connected between grid and sensitive voltage, which injects a voltage through injection transformer to compensate the voltage imperfection in sensitive load [9]. The limitations of conventional Voltage source and Current source inverters (VSI & CSI) were discussed in [14-15]. Many researchers proposed different control strategies for effective DVR performance, such as double-vector [16], indirect matrix converter [17], feed-back & feed-forward [18], traditional proportional and integral controller [19], PI-fuzzy controller [20], Neural Network Controller [6]. Z source inverter proven advantages over CSI and VSI [14] in mitigating the voltage sag [6,21] and effective PV integration [15]. IEEE 1159-1995 and IEEE-519-1992 describes the standards and definition of voltage sag/swell. The time window of voltage swell / sag is 10msec to 1min [10-11].

The presented model is a cost effective three phase DVR topology uses ANFIS-DQ controller and proficient in suppressing voltage imperfections. The model also integrates the PV energy into the line without additional power conditioning devices. The key objectives of the proposed model are

- To mitigate the sag and interruption under different fault categories.
- To reduce the harmonics in Load voltage.
- To integrate the PV system to the grid.

The paper is organized as section I gives the literature information about DVR, section II explains the proposed system and its controlling action, section III presents supporting simulated results for the proposed system and section for draws the keys highlights of proposed system.

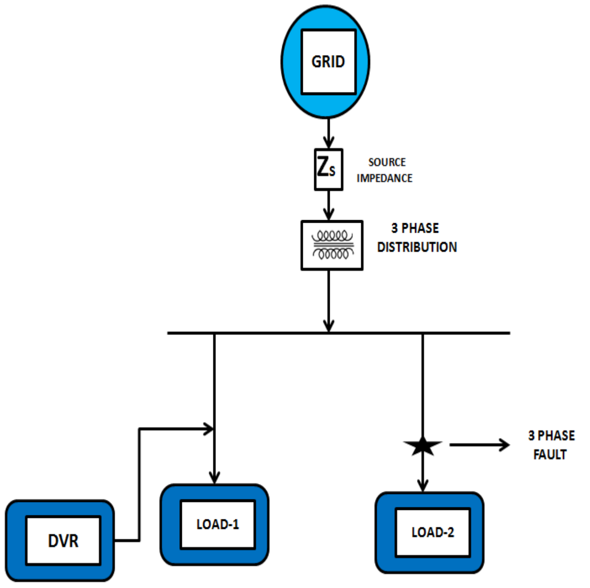

Fig. 1 Block Diagram

2. Description of Proposed System

Fig. 1 presents, block Diagram of proposed model. Here we considered two adjacent feeder lines connected with two different loads (Load-1 & Load-2) supplied by common source. On Line-2, created a fault which in turn causes voltage sag on Line-1. The DVR is connected to Line-1 through the voltage injection transformer to compensate the disturbances in sensitive load-1 voltage. Voltage source inverter, Injection transformer and PV unit are the internal parts of DVR in the presented model. The detailed proposed model is shown in Figure 2.The PV is fed to DVR via ZSI. PV unit comprises of perturbation and observation (P&O) based MPPT controller and boost converter. ZSI-DVR is controlled by ANFIS-DQ controller. The reference signals are generated from ANFIS-DQ controller and gating signal are generated from PWM controller. As the Fault is considered on Line-2, causes voltage disturbance on Line-1 and the voltage and current at common connecting point are given in [3] eqn. (1) & (2).

$$V_{sag} = V_s - I_{sf} X_s \quad (1)$$

$$I_{sf} = \frac{V_{sag}}{X_{L2}} + \frac{V_{sag}}{Z_{L1} + X_{L1}} \quad (2)$$

Where $V_{sag}$and I_{sf} are voltage at common connecting point and source current during sag. X_s is source reactance, X_{L2} line-2 reactance,X_{L2} Line-1 reactance and Z_{L1} is Load-1 impedance.

The control technique description and working of proposed PV fed ZSI-DVR are explained as follows.

2.1 PV Unit

Here, the photovoltaic unit uses P&O based MPPT technique, due to its predominant qualities over incremental conductance method [12]. The connected PV provides the real power required by the DVR to inject the compensating voltage [13]. The output power of the PV unit is given by eqn. (3)

$$P_{pv} = V_{pv} * I_{pv} \quad (3)$$

Where V_{pv} and I_{pv} are PV unit output voltage and current, $P_{pv}$is power output.

2.2 ZSI

ZSI is Lattice structure based impedance network connected at DC link side. ZSI is predominant over traditional inverters because of its combined boost and buck characteristics. ZSI improves system reliability due to its EMI noise immune capability. ZSI behaves like 2nd order filter needs smaller values of inductance and capacitance. It also feeds constant DC link voltage across inverter [14, 22]. ZSI has 3 modes of operation namely Active mode, Zero mode and Shoot through mode [6].

$$\acute{C}_1 = \acute{C}_2 = \acute{C} \quad (4)$$

$$L_1 = L_2 = L \quad (5)$$

In the above condition

$$I_{L1} = I_{L2} = I_L \quad (6)$$

$$V_{C1} = V_{C2} = V_C \quad (7)$$

Inverter input voltage given as,

$$V_i = \beta V_{dc} \quad (8)$$

Where boosting factor is β and dc voltage isVdc.Boosting Factor is given as

$$\beta = 1 / 1 - 2(\frac{T_0}{T}) \quad (9)$$

Here T_0 is time period at shoot through mode and T is switching period

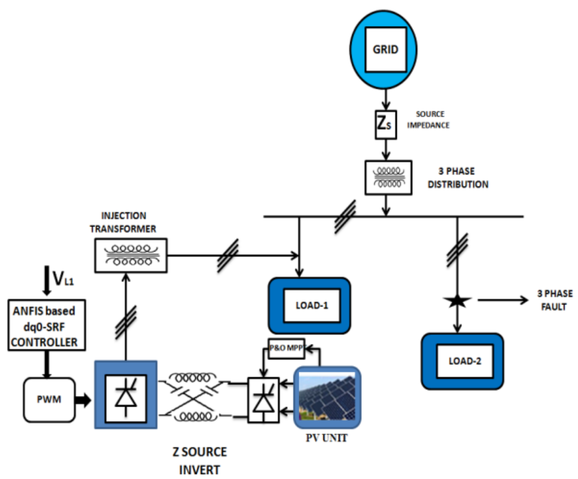

Fig. 2 Proposed System

2.3 Working of DVR controller

V_S, V_{L1}, V_{L2}, and V_{inj} are source voltage, Sensitive Load-1 & 2 voltages and DVR injected voltage. Due to the fault occurred on Line-2 cause's voltage disturbance on Line-1 Load voltage. DVR uses in phase compensation method to compensate disturbances in load voltage. The DVR controller uses dq0-Synchronous reference frame technique to produce reference currents for desired gating pulses to inject the compensated component for maintaining stable load voltage. Detailed control technique is described in Fig. 3. In dq0-synchronous reference frame technique, initially sensed source voltages are converted from abc frame to dq0 frame using park's transformation given in eqn. (10)

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega t) & \sin(\omega t - 120) & \sin(\omega t + 120) \\ \cos(\omega t) & \cos(\omega t - 120) & \cos(\omega t + 120) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ c \end{bmatrix} \quad (10)$$

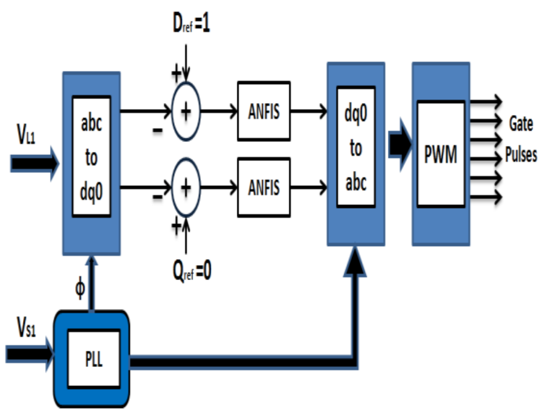

Fig. 3 ANFIS-dq0-SRF based DVR Controller

These dq0 components are compared with reference values (d=1 & q=0) and then response is given to ANFIS controller. ANFIS controller tunes the error signal to generate error free dq components. With inverse park transformation tuned dq0 components are converted back to abc frame given by eqn. (11)

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega t) & \cos(\omega t) & 1 \\ \sin(\omega t - 120) & \cos(\omega t - 120) & 1 \\ \sin(\omega t + 120 & \cos(\omega t + 120) & 1 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} \quad (11)$$

These reference abc frame signals are fed to Pulse width modulator to generate the consequential gate pulses for IGBT based 3 leg VSI. The LC filter used after VSI eliminates the harmonics from inverter into the line. With voltage injection transformer, required compensating voltage is feeded to the line during abnormality in the load voltage. In this model, the dq0 components error signal is tuned with different control strategies to study the harmonic suppression in the load voltage. They are traditional PI controller, Fuzzy controller and ANFIS controller.

2.4 Fuzzy Controller

Fuzzy controller [23] has 3 stages. In Fuzzification stage, crisp variables (error e & change in error Δe) are transformed to fuzzy linguistic variables. Next, at Fuzzy inference stage the corresponding output fuzzy variables are generated based on rules in knowledgebase. The current model uses HP, MP, SP, ZE, SN, MN and HN linguistic variable based rules [23] as shown in Fig.4. Finally in de-fuzzification stage, the output fuzzy variables are transformed into desired signal using centroid method.

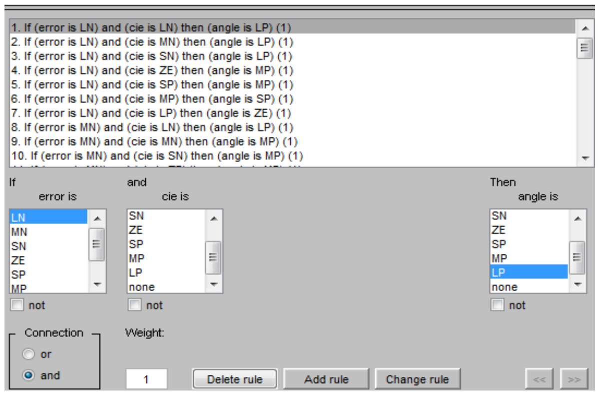

Fig. 4 Fuzzy rules

2.5 ANFIS Controller

ANFIS is a Multi Layer Feed Forward (MLFF) network, which makes use of both Fuzzy inference mechanism [23, 26] and Neural Network's adaptive learning [26] features. Neuro-Fuzzy combination proven its ability in tuning the error signal [12]. The ANFIS structure shown in Fig. 5 and rules used in the proposed ANFIS controller are shown in Fig. 6.

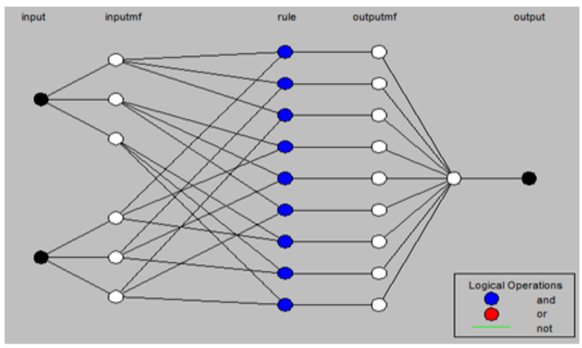

Fig. 5 Structure of ANFIS controller

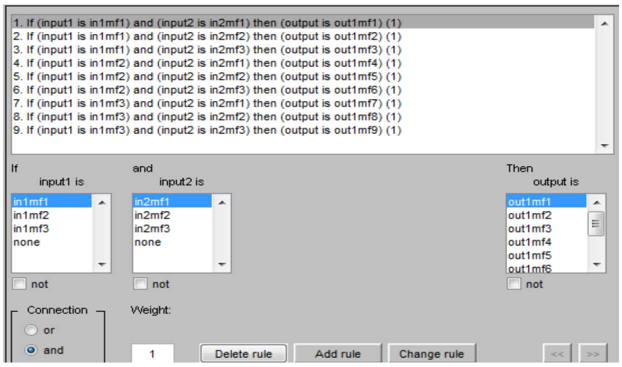

Fig. 6 Rules used in ANFIS controller

3. Simulated Results

The proposed PV fed ANFIS-dq0-SRF based ZSI-DVR controlled three phase system SIMULINK design is given in Fig.7. Here two loads are connected to common source. On Line-2 two fault blocks are connected to create voltage sag and interruption simultaneously. On Line-1, PV_ZSI_DVR is connected through injection transformer. The control signals are generated from ANFIS-DQ controller.

PV unit simulink model used for ZSI-DVR in current proposed system is presented in Fig. 8. The system parameters used in the current DVR model are given in Table 1.

3.1 Mitigation of Voltage Imperfections

The performance of proposed model is studied under 3 different fault cases with proposed AFIS-DQ-ZSI based DVR controller.

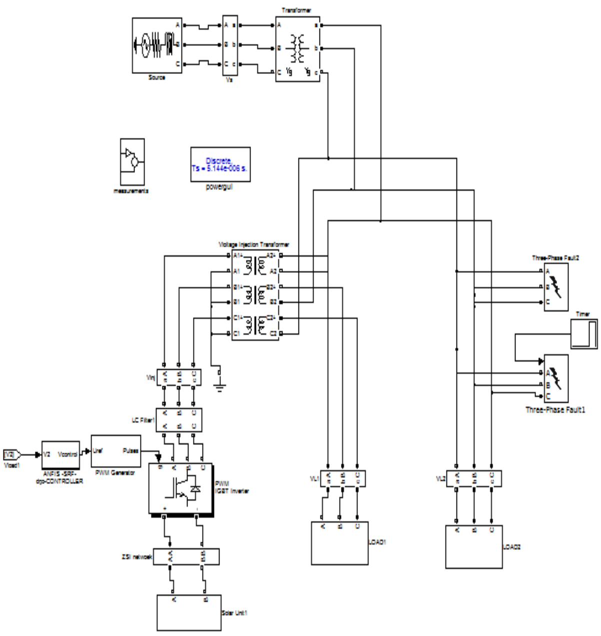

Fig. 7 Proposed System SIMULINK model.

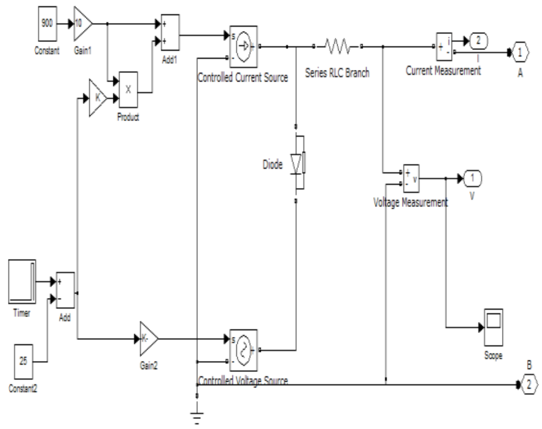

Fig. 8 SIMULINK model of PV Unit.

Table 1 Proposed System Parameter Description

S No	Parameter	Value
1	Supply Voltage, Vs	3Ø , 230 V, 50 Hz
2	Load-1	R = 26 Ω L = 30 mH
3	Load-2	R =10 Ω L = 16 mH
4	Photovoltaic Unit	35 V,8 A
5	DC Voltage	300V
6	LC Filter	Rse =0.2 Ω Lse =6 mH Rsh =0.2 Ω Csh =20 µF
7	Z network	L = 1 mH , C = 10 µF

Case 1: 3Ø to Ground Fault

Here, 3Ø to ground fault created between t=0.02 to 0.09 sec. This causes a 25% sag in Load-1 voltage. Interruption is created between t=0.12 to 0.16 sec. The proposed AFIS-DQ-ZSI based DVR controller compensates Load-1 voltage imperfections by injecting the compensating voltage.

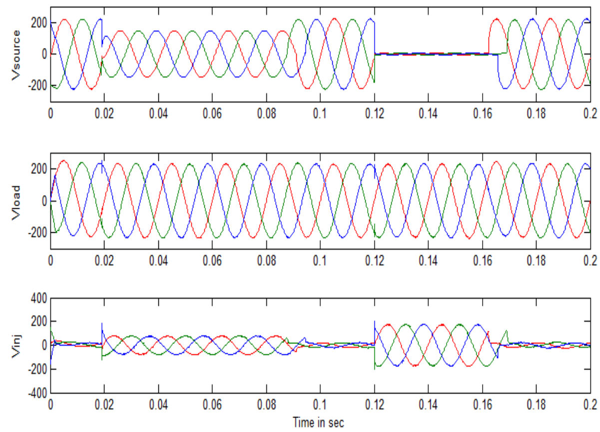

Fig. 9 Source,Load-1, Injected and Load-2 voltages under 3 phase to ground fault with AFIS-DQ-ZSI based DVR controller

Fig. 9 presents Source voltage, Load-1 voltage, DVR injected voltage and Load-2 voltage. The power required by DVR controller is delivered from PV unit.

Case 2: Double Line (2L) to Ground Fault

Here, 2L to ground fault is created between t=0.02 to 0.09 sec. This causes a 25% sag in Load-1 voltage. Interruption is created between t=0.12 to 0.16 sec. The proposed AFIS-DQ-ZSI based DVR controller compensates the Load-1 voltage imperfections by injecting the compensating voltage, which is shown in Fig. 10.

Case 3: Single Line (1L) to Ground Fault

Here, 1L to ground fault is created between t=0.02 to 0.09 sec. This causes a 25% sag in Load-1 voltage. Interruption is created between t=0.12 to 0.16 sec. The proposed AFIS-DQ-ZSI based DVR controller compensates the Load-1 voltage imperfections which is shown in Fig. 11.

3.2 Load Voltage Harmonic Compensation

The suppression of load voltage harmonics is studied with traditional PI and soft computing Fuzzy and ANFIS control techniques.

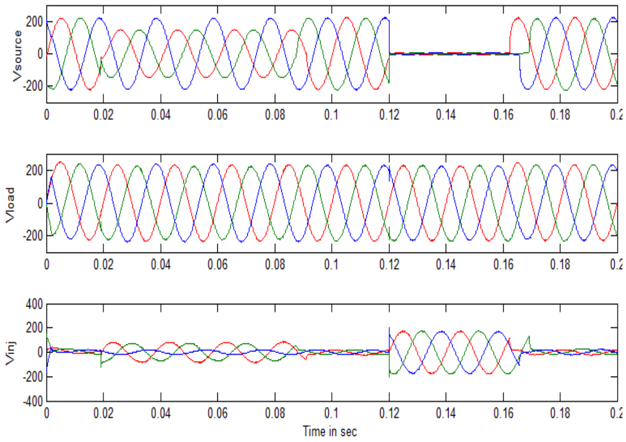

Fig. 10 Source,Load-1, Injected and Load-2 voltages under double line to ground fault with AFIS-DQ-ZSI based DVR controller.

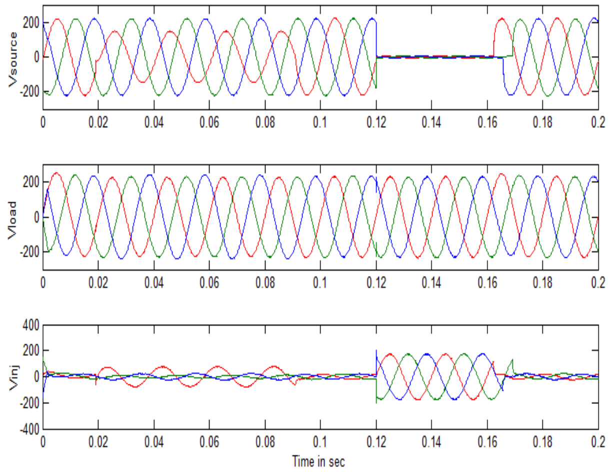

Fig. 11 Source,Load-1, Injected and Load-2 voltages under single line to ground fault with AFIS-DQ-ZSI based DVR controller.

Case-1: Fig. 12 Shows the Load-1 voltage % THD with traditional PI controller.

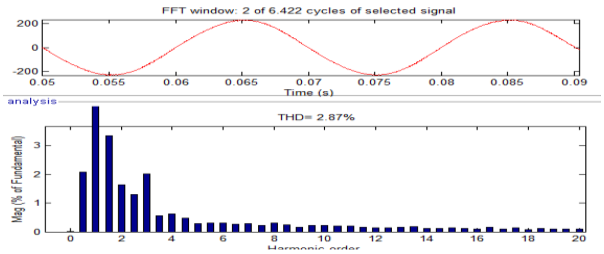

Fig. 12(a) %THD=2.87.

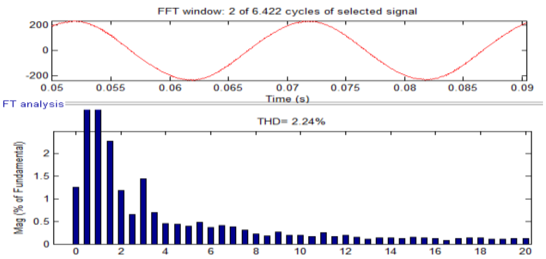

Fig. 12(b) %THD=2.24.

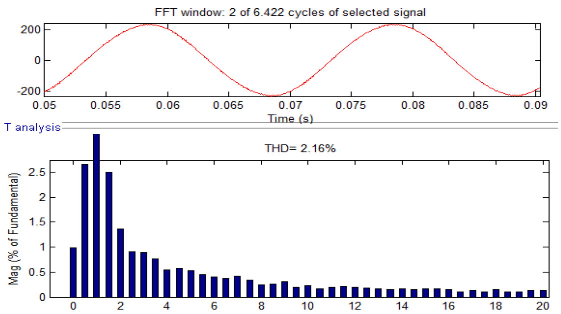

Fig. 12(c) %THD=2.16.

Fig. 12 % THD of Phase-a,-b & -c Load-1 Voltage with traditional PI based controller.

Case-2: Fig. 13 Shows the Load-1 voltage % THD with Fuzzy controller.

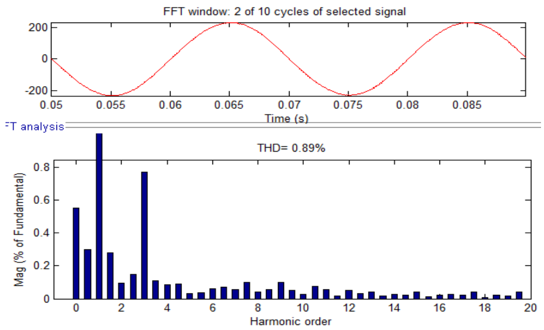

Fig. 13(a) %THD=0.89.

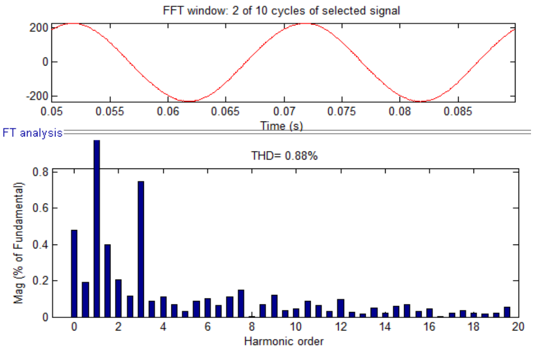

Fig. 13(b) %THD=0.88.

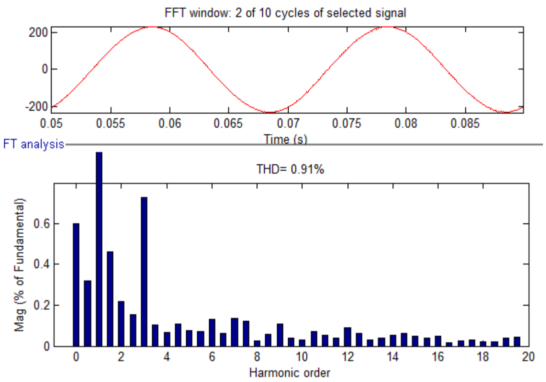

Fig. 13(c) %THD=0.91.

Fig. 13% THD of Phase-a,-b & -c Load-1 Voltage with Fuzzy based controller.

Case-3: Fig. 14 Shows the Load-1 voltage % THD with proposed ANFIS based controller.

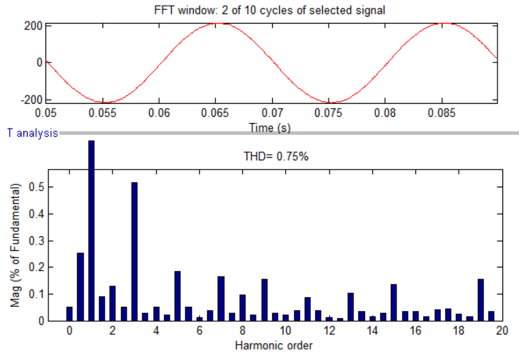

Fig. 14(a) %THD=0.75.

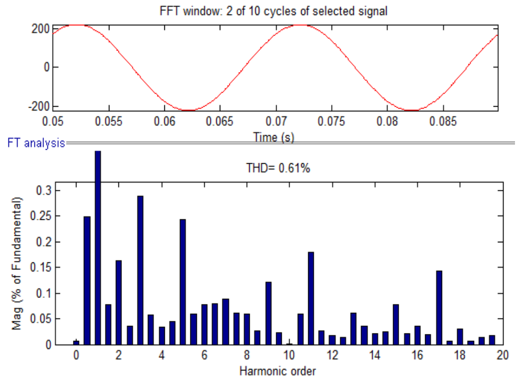

Fig. 14(b) %THD=0.61.

Fig.15 gives the comparative analysis of three control techniques used to mitigate the load voltage harmonics on Line-1. It is proven that ANFIS based controller is predominant over Fuzzy and traditional PI controllers in mitigating the Load-1 voltage harmonics in three phases.

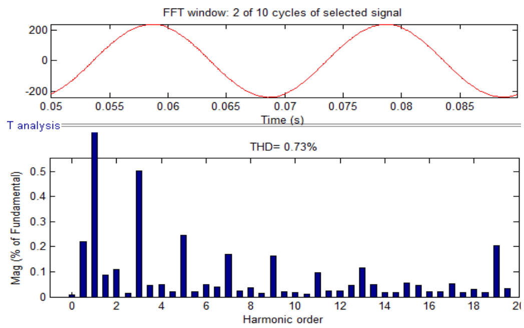

Fig. 14(c) %THD=0.73.

Fig. 14 % THD of Phase-a,-b & -c Load-1 Voltage with proposed ANFIS based controller.

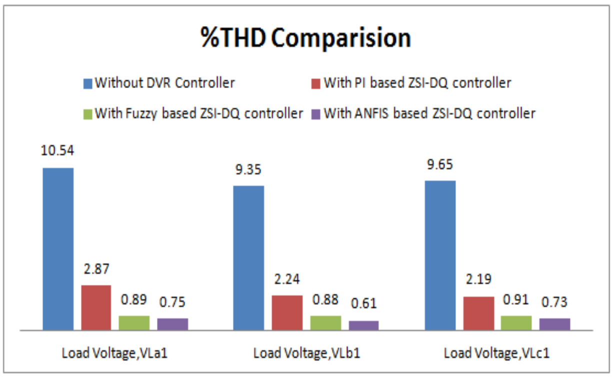

Fig. 15 %THD comparison with different controllers.

4. Conclusion

The proposed model uses the renewable PV source effectively in mitigating load voltage imperfections. ANFIS-dq0-SRF base controller effectively compensates the Load-1 voltage sag and interruptions under three different fault conditions. The model is also studied for harmonic mitigation with traditional PI and soft computing Fuzzy and ANFIS controllers. The ANFIS based controller suppresses the harmonics very well compared to the PI and Fuzzy controllers. The proposed PV fed ANFIS based ZSI-DVR controller able to provide effective harmonic suppression and compensation of voltage interruption and sag.

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