# Comparative Analysis of ZSI based DVR Topology with different Control Strategies

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***Abstract***— *The Paper presents different control strategies for Z - Source Inverter fed Dynamic Voltage Restorer (ZSI-DVR). The praposed DVR topology dynamically compensates the voltage sag, voltage swell and voltage interuptions and maintains the required level of voltage to the load .The conventionl DVR topology performance has been extended by incorporating the Hybrid Control techinques like PI and Nuero-Fuzzy . The performance of DVR with different control strategies have been compared using MATLAB/SIMULINK environment.*

**Keywords—** FACTS; DVR; ZSI; PID, FUZZY Controllers; Nueral Networks

## I. INTRODUCTION

The modern world Complex Power System, consists of large number of loads supplied by more number of generating units, suffers with optimality and quality power supply to the consumers. The main concerned of load center is to have reliable and quality power supply. Even though there are advances in power sector, which provides reliable supply but suffers to deliver quality power .Generally distribution side abnormalities are due to non linear loads, motor starting, load variations, faults, and load switching [1]. The ultimate reason for high quality power demand by the industries is to have successful working characteristics of their machines [2]. Failure to provide Quality power may cause shutdown of industries which in turn leads to financial loss [3, 4 ].

In distribution network, the most frequent abnormalities are voltage sag and swells [5].The sudden decrease or increase of voltage with a duration of few cycles can be defined as voltage sag and swell respectively. The IEEE standard description of voltage sag and swell are given by IEEE 519-1992 and IEEE 1159-1995[6] as shown in the Table I.

| Type of Disturbance | Duration | Voltage |
|---|---|---|
| Voltage Sag | 0.5 – 30 cycles | 0.1 – 0.9 pu |
| Voltage Swell | 0.5 – 30 cycles | 1.1 – 1.8 pu |

Table 1: Voltage Sag and Swell Definition.

The proposed ZSI-DVR is a versatile cost effective model capable of eliminating the voltage abnormalities.The proposed control strategies for ZSI-DVR shown in Fig .1 provides the following features

1) Voltage Sag elimination.
2) Voltage Swell elimination.
3) Supply from Solar energy unit during voltage interruptions.
4) Harmonic reduction in Source and Load Voltage.

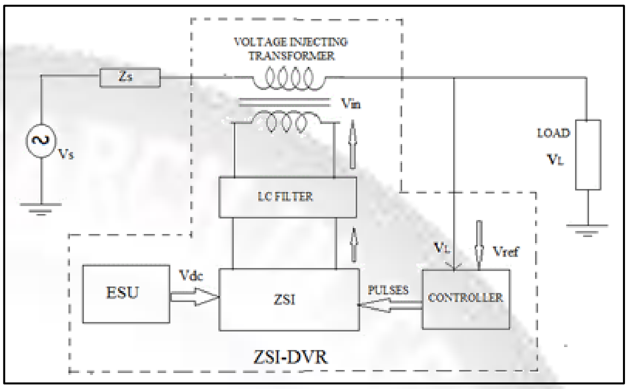


Fig. 1: Block Diagram of ZSI-DVR

In this paper, Section II illustrates the ZSI-DVR model, Section III describes different proposed control strategies .Section IV extensively presents the simulated outcomes of proposed model.

## II. ZSI BASED DVR

Fig .2 shows the proposed ZSI-DVR model .This model presents a single phase system which can be easily improved to three phase system. The proposed model consists of energy storage unit, lattice impedance network, voltage source inverter (VSI), LC filter and series voltage injection transformer.

### A. Energy Storage Unit

The Energy storage unit provides the required real power during the compensation of voltage sag[7]. Generally super capacitors, fly wheels, lead acid batteries are used as batteries. Lead acid batteries are mostly preferred due to their high performance. The required amount of energy demand depends on voltage abnormality, load MVA requirement and control strategy applied

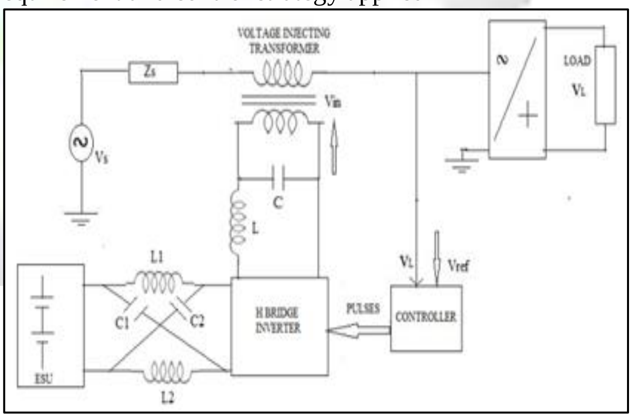


Fig. 2: Praposed ZSI-DVR Model

### B. Z Source Inverter

Z Source Inverter consists of lattice structured impedance network fed at DC link side .Unlike the traditional Voltage source and Current Source inverters, ZSI has both Buck and Boost capabilities. They increases reliability as they immune to EMI noise .It acts as 2nd order filter which requires less values of inductance and capacitance .It also provides constant DC voltage to the inverter[8,9]. Multiple Pulse Width modulation is used to control the ZSI operation .ZSI has five switching modes, which are given in Table II

| S4 | S3 | S2 | S1 | Mode | Remarks |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | Active Mode | DC source voltage is applied to load |
| 0 | 1 | 1 | 0 | | |
| 0 | 1 | 0 | 1 | Zero Mode | The inverter output voltage is shorted through S1S3 or S2S4 |
| 1 | 0 | 1 | 0 | | |
| 0 or 1 | 0 or 1 | 1 | 1 | Shoot Through Mode | Two switches on single leg are turned on |

Table 2: Switching modes of Single Phase ZSI

In the Symmetrical lattice impedance network, the valid equations given by

$$C1 = C2 = C \quad (1)$$

$$L1 = L2 = L \quad (2)$$

At this condition

$$L1 = IL2 = IL \quad (3)$$

$$VC1 = VC2 = VC \quad (4)$$

The input voltage to the inverter is given by,

$$Vi = \beta \, Vdc \quad (5)$$

Where β is the boosting factor and Vdc is the dc source voltage.

Here the boosting factor is given by

$$\beta = 1 \Big/ 1 - 2\left(\frac{T_O}{T}\right) \quad (6)$$

Where T is the switching period and $T_O$ is the shoot through mode application period.

### C. LC Filter

Passive LC Filter consists of a Capacitor and an Inductor. It can be connected at inverter side or hive voltage winding side of injection transformer. The switching harmonic components in injecting voltage are filter out by LC Filter [10] . Preferably LC Filter is placed at inverter side .This causes reduction in higher order harmonics and voltage stress on injection transformer.

### D. Voltage Injection Transformer

In general step up transformers are used as by the inverter to the required level of voltage and Voltage Injection transformer .It step up the low voltage applied injects into the line he DVR maximum compensation limit depends on rating of the Voltage injection transformer.

## III. DVR CONTROL STRATAGIES

The DVR purpose to maintain is to maintain voltage quality by adjusting the voltage magnitude, shape and phase. DVR eliminates the voltage disturbances by voltage restoration, which involves injection of required amount of energy into the line [11] .In Fig .2 Vs is the supply voltage before compensation, $V_L$ is the load voltage after compensation and $V_{in}$ is the injected voltage.DVR Injected Voltage is give by

$$Vin = V_L - V_S \quad (7)$$

In this paper the proposed DVR uses the in phase compensation technique. Here the load voltage is assumed to be in phase with pre sag voltage In this technique only voltage magnitude is compensated. The controller receives the load voltage and reference voltage. Based on the difference in two voltages, it generates the pulses to the inverter using PWM technique. Now inverter injects the corresponding amount of energy into the line through the injection transformer. The amount of voltage injected depends on boosting factor given in Eqn.6

Following are the different control strategies used for DVR.

### A. PI Controller

The PI controller regulates the difference between the actual and reference values .The function of proportional controller responds quickly where as integral controller is slower but removes the offset between reference and actual value.

### B. Nuero Fuzzy Controller

Another more efficient combination is Neuro Fuzzy controller, which had proven its robust controlling quality in different areas [12].Here a two layer Neural network is fed through fuzzy controller. The fuzzy controller [13] converts un precise information into a well defined space.

These values are applied to Neural Network to have an efficient controlling .

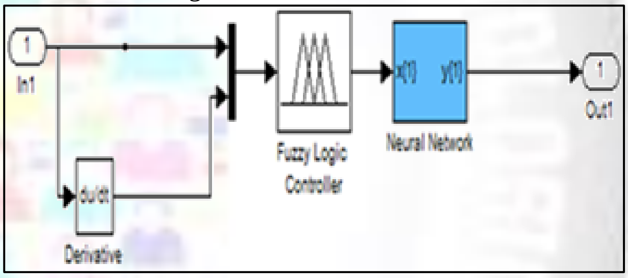


Fig. 4: Nuero-Fuzzy Controller

## IV. SIMULATION RESULTS

The proposed ZSI-DVR model is simulated in MATLAB/SIMULINK. The Simulink model of ZSI-DVR with different Control strategies is shown in Fig.5.

The parameters used in the proposed ZSI-DVR model are presented in the Table III. The proposed model has been simulated for three different control strategies. Three controllers performance have been simulated and their results are compared.

Fig. 6, Fig.8, and Fig.10 shows the simulated results of three control strategies

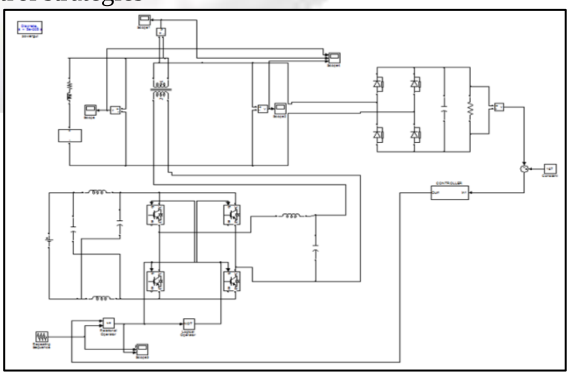

Fig. 5: Simulink model of proposed system

| S.No | Parameters | Ratings |
|---|---|---|
| 1 | Source voltage | 1-phase 200v,50HZ |
| 2 | Source impedance | $R_S$ = 0.1ohm,$L_S$ = 0.001mH |
| 3 | LC Filter | L = 2mH , C = 0.1μF |
| 4 | Z network | L = 1mH , C = 1μF |
| 5 | Voltage Injection Transformer | 100/240V,50 Hz |
| 6 | Battery | Vdc = 100V |

Table 3: System Parameters

Case1: Here PI controller is used to inject the required voltage in the line using ZSI-DVR. In Fig 6 The voltage interruption is created between 0.2 to 0.28 sec.25% of voltage swell is created between 0.28 to 0.6sec and 25% of voltage sag is created between 0.8 to 1 sec. All the three abnormalities in the voltage are compensated.

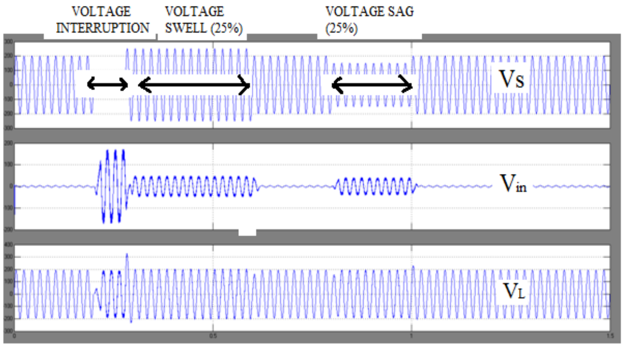


Fig. 6: Source Voltage, Injected Voltage and Load Voltage of ZSI-DVR model with PI Controller

Fig. 7(a) and 7(b) shows the %THD of Load Voltage and Source Voltage with PI controller.

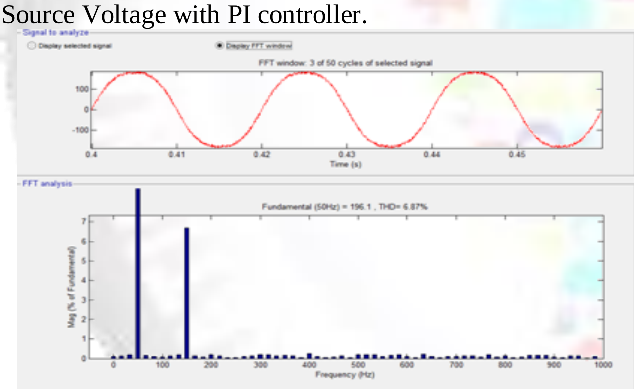


Fig. 7: (a) %THD of Load Voltage is 6.87%

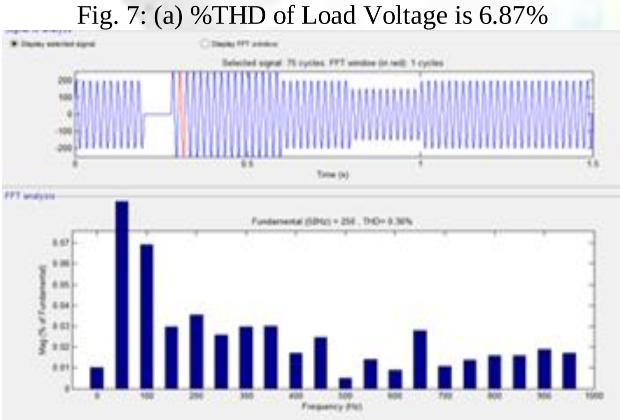

Fig. 7: (b) %THD of Source Voltage is 0.36%

Fig. 7 %THD of a) Load Voltage, b) Source Voltage of ZSI-DVR with PI Controller

Case2: Here controller is used to inject the required voltage in the line using ZSI-DVR. In Fig 6 The voltage interruption is created between 0.1 to 0.2sec. 25% of voltage swell is created between 0.25 to 0.5sec and 25% of voltage sag is created between 0.65 to 0.8sec. All the three abnormalities in the voltage are compensated.

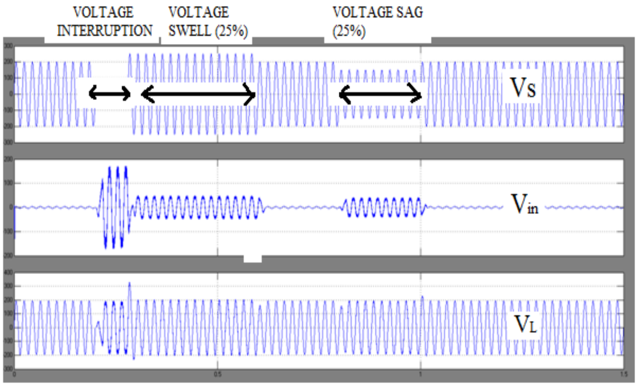


Fig. 8: Source Voltage, Injected Voltage and Load Voltage of ZSI-DVR model with ZN-PID-Fuzzy Controller

Fig. 9(a) and 9(b) shows the %THD of Load Voltage and Source Voltage with PI controller.

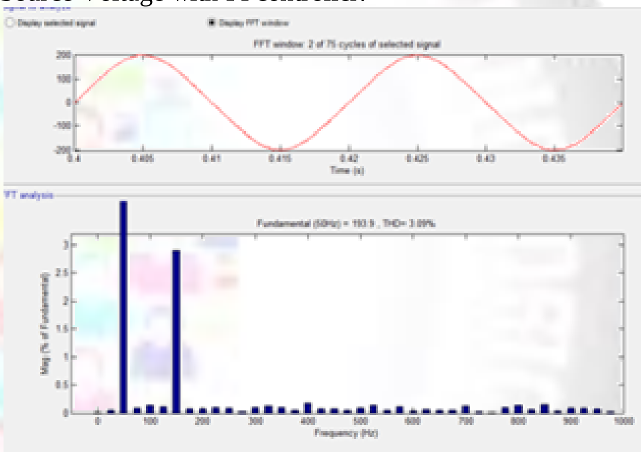


Fig. 9: (a) %THD of Load Voltage is 3.09 %

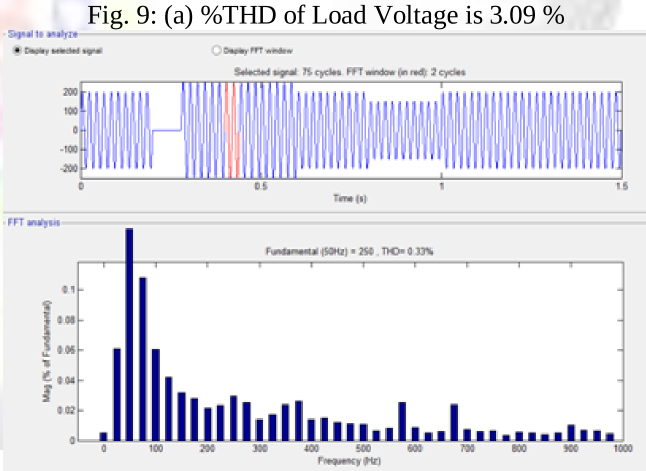


Fig. 9: (b) %THD of Source Voltage is 0.33%

Fig. 9 %THD of a) Load Voltage, b) Source Voltage of ZSI-DVR with ZN-PID-Fuzzy Controller

Case3: Here Neuro-Fuzzy controller is used to inject the required voltage in the line using ZSI-DVR. In Fig 6 The voltage interruption is created between 0.35 to 0.43sec. 25% of voltage swell is created between 0.05 to 0.25sec and 25% of voltage sag is created between 0.65 to

0.9sec. All the three abnormalities in the voltage are compensated.

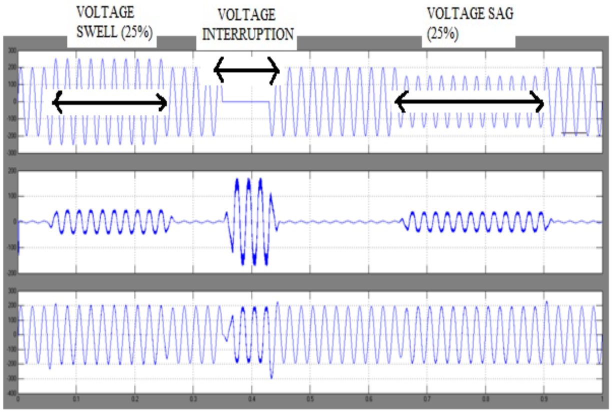


Fig. 10: Source Voltage, Injected Voltage and Load Voltage of ZSI-DVR model with Nuero-Fuzzy Controller

Fig. 11(a) and 11(b) shows the %THD of Load Voltage and Source Voltage with Neuro Fuzzy controller

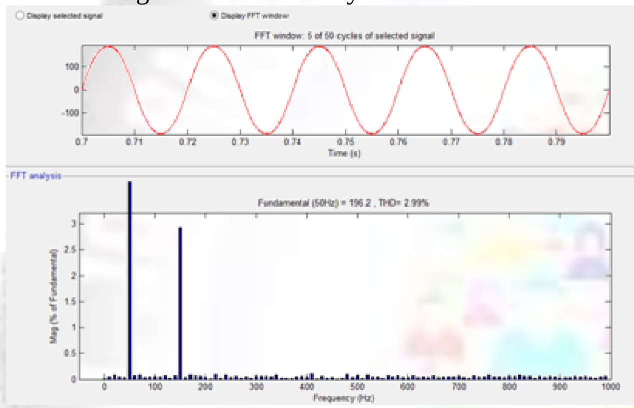


Fig. 11: (a) %THD of Load Voltage is 2.99%

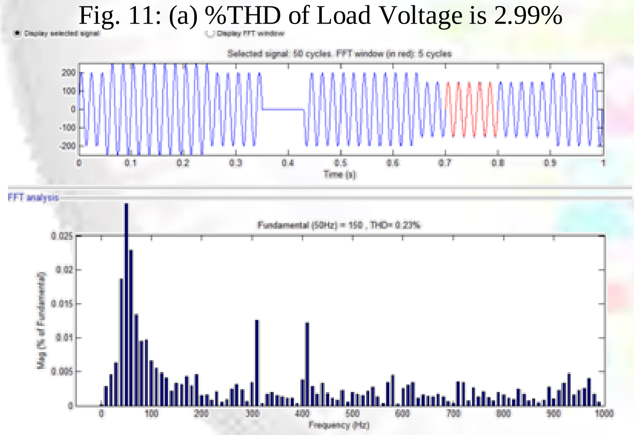


Fig. 11: (b) %THD of Source Voltage is 0.23%

Fig. 11 %THD of a) Load Voltage, b) Source Voltage of ZSI-DVR with Neuro-Fuzzy Controller

| S.No | Type of Controller | Source Volt.(VS) %THD | Load volt (VL) %THD |
|---|---|---|---|
| 1 | PI | 0.36 | 6.87 |
| 2 | Neuro-FUZZY | 0.23 | 2.99 |

Table 3: Comparison of % THD of $V_S$ & $V_L$ for Various control strategies

From the simulated results, we can analyse that all the three controllers are effectively compensating all the three abnormalities in voltage and from table III the Neuro-Fuzzy controlled ZSI-DVR effectively reduces the Harmonics in the Source voltage and load voltage [14].

## V. Conclusion

The proposed ZSI-DVR model effectively compensates the voltage sag, swell and interruptions. The compensated voltage sag and swell are within the IEEE standards. The comparison of different control strategies proves Neuro – Fuzzy is the best method. The proposed model proves that it is cost effective model as it reduces the cost of inductors, due to usage of lower values of Inductance and Capacitance. It also uses simple Hybrid control strategies to compensate voltage abnormalities and harmonics in the source and load voltages. The simulation results compares % THD of Vs and $V_L$ for different controllers i.e ZSI-DVR with PI and Neuro-Fuzzy control schemes.

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