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# Enhancement of Power Quality Using Dynamic Voltage Restorer Based on E-Z Source Inverter

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**ABSTRACT**: The device used to phase out voltage sags and a swell in the distribution lines is the Dynamic Voltage Restorer (DVR). The DVR can restore the load voltage within few milliseconds by injecting series voltage which is actually missing voltage in to system through series connected booster transformer, when it is subjected to voltage sags. Generally DVR can be connected to grid through inverter topologies such as Voltage Source Inverter (VSI) or Current Source Inverter (CSI). Tradition inverters (VSI /CSI) suffers from problem of limited output voltage(below dc link voltage), limitation on switching of upper and lower switches simultaneously and filter is needed to give sinusoidal output. All these problems get eliminated if embedded EZ-source inverter is used. This paper presents control strategy for DVR based on EZ source inverter. It has been observed that switching losses and harmonics are reduced drastically.

**KEYWORDS:** DVR, Current Source Inverter, EZ source inverter, Power Quality, Voltage Source Inverter, Voltage sag.

## I. INTRODUCTION

The term power quality has become one of the most common expressions in the power industry during the last few years due to extensive losses in power industry in terms of energy and money. Voltage sag and swell have been one of the most important power quality problems because of which there is malfunctioning of end user's equipment which in turn causes interruption to the production [1]. Out of which voltage sags are more common as compared to voltage swell. Dynamic voltage restorer is best solution to mitigate problem related with voltage sag and swell. DVR gives good output voltage with low harmonic levels whenever it is incorporated with VSI topology. [2] But there are certain demerits which are associated with conventional VSI is that ac output voltage is limited which cannot be exceeded ac input voltage which makes this topology as buck type output characteristic and therefore the output voltage range and further required voltage injection capability is limited. In addition to this, problem of shoot through or cross conduction may destroy whole device and EMI causes mis-gating which again leads to shoot through problem and kills reliability. We can prefer CSI also but again the demerits of traditional CSI includes same problem as given in VSI. Hence to defeat the above problems of the traditional VSI and current source inverter (CSI), an impedance source inverter (Z source inverter) is presented that can be use for implementing dc-to ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversions and applications. Z-Source inverter is a single-stage converter. It also performs both buck-boost energy conversions utilizing the LC impedance network. It employs a unique impedance network to couple either the converter main circuit to power source and load or another converter. This feature cannot be observed in the traditional voltage and current-source converters where a capacitor and inductor are utilized, respectively [3].

## II. LITERATURE SURVEY

Dugan R. C. [1] in his book describes a consistent terminology that can be used to describe power quality variations. John Godsk Neilsen [2] in his thesis first gives an introduction to relevant power quality issues for a DVR and power electronic controllers for voltage dip mitigation. Thereafter the operation and the elements in a DVR are described. The basics of Z source inverter along with its advantages as compared to CSI and VSI is explained in paper published by Fang Zheng Peng [3]. Rosli Omar, et al. [4] describes the problem of voltage sags and swells and its severe impact on non linear loads or sensitive loads. The proposed control scheme of dq0 algorithm is simple to design. Basic concept of

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Embedded Z source inverter along with its shoot and non shoot through condition is explained by the paper i.e. Embedded EZ-Source Inverters published by Poh Chiang Loh, Feng Gao [5]. N.Gurusakthi, R.Sivaprasad [6] and K Ravi Chandrudu [7] gives application of E-Z source inverter and its performance attributes using induction motor drive. Deokar S.A. [8] implemented with feed forward pre-sag/swell voltage control method to regulate the output voltage of pulse width modulated (PWM) voltage source converter (VSC). The proposed controller maintains a constant load voltage under the multiple balanced/unbalanced dynamic PQ disturbances. Nielsen, J.G. [9] explained the design and a new control method of a DVR. The DVR is also tested at medium voltage level (10 kV) and methods to initiate voltage dips are described and implemented. Different test results at 10 kV level show that the DVR keep the voltage to a sensitive load fixed in the case of voltage dips. SNV Ganesh [10] presents different control strategies for DVR i.e. Park's transformation.

## III. THEROTICAL CONCEPT

### A. Dynamic Voltage Restorer:

A Dynamic Voltage Restorer (DVR) is a type of switching converter which is basically DC-to-AC solid-state switching converter. It is used to maintain distribution side voltage where sensitive equipments are connected. Basically it injects three single phase AC output voltages. This is in series with the distribution feeder. The important condition is that this voltage should be in synchronisms with the voltages of the distribution system [4]. DVR can restore the voltage quality by injecting required amount of voltages which is also called as missing voltage. This injected voltage is having controllable magnitude, phase angle, and frequency into the distribution feeder on instantaneous real time basis via a series-injection transformer. Following fig.1 shows schematic diagram of DVR.

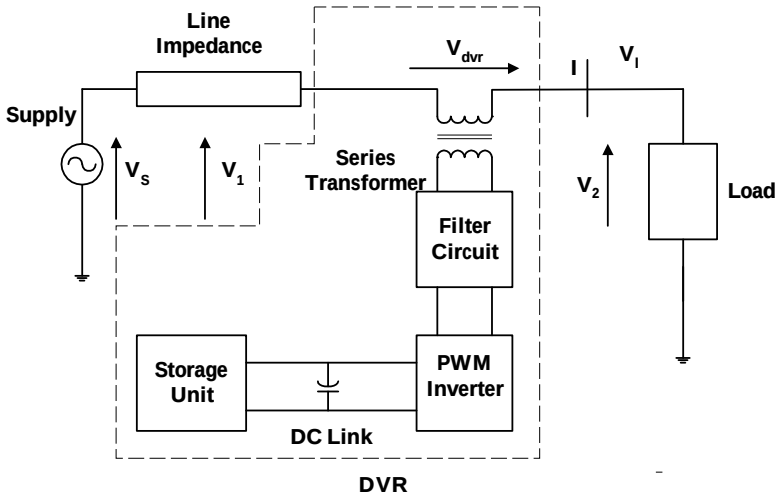


Fig. 1: Schematic diagram of Dynamic Voltage Restorer

### B. EZ source inverter:

As compared to any traditional VSI and CSI, there is one additional switching state is present in Z and EZ source inverter viz. shoot through or cross conduction condition i.e. when the d.c. supply in inverter gets shorted through power devices of the same link. Hence we can prefer Z source inverter. Instead of using an external *LC* filter in case of Z source inverter, there is an alternative family of embedded Z-source (referred to as EZ-source in short, where "E" is included to represent "embedded") inverters, which adopts the concept of embedding the input DC sources within the *LC* impedance network, using its existing inductive elements for current filtering in voltage-type EZ source inverters, and its capacitive elements for voltage filtering in current-type EZ-source inverters [5]. The proposed 2 level EZ–source is as shown in Fig.2.

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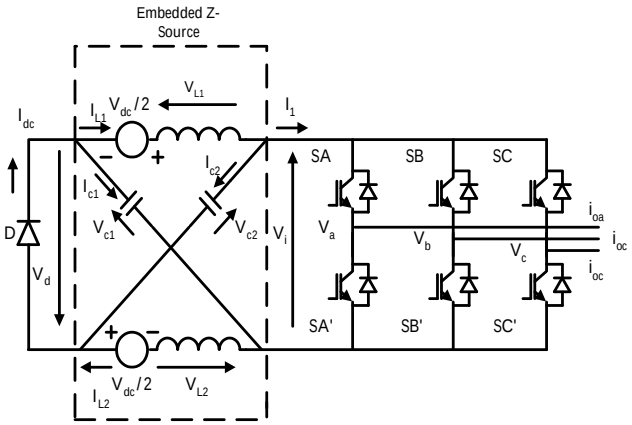


Fig.2: Two level EZ source inverter.

**Shoot-Through condition:**

Fig. 3 shows shoot through condition in which diode D is in blocking state. Equations are as follows: [6]

$$(S_A = S'_A, S_B = S'_B, S_C = S'_C = ON \; ; D = OFF)$$

$$v_L = V_C + \frac{V_{dc}}{2} \; V_i = 0, V_d = V_D = -2V_C \qquad (1)$$

$$i_L = -i_C \; , i_i = i_L - i_C \; , i_{dc} = 0 \qquad (2)$$

**Non shoot-Through condition:**

In case of non shoot through active or null state, the redrawn equivalent circuit is shown in Fig.4 with diode D conducting and the inverter bridge and external (usually inductive) load replaced by a current source, whose value is nonzero for active state and zero for null state. Using this equivalent circuit, the second set of state equations is derived as follows. [7]

$$(S_A \neq S'_A, S_B \neq S'_B, S_C \neq S'_C \; ; \; D = ON)$$

$$v_L = \frac{V_{dc}}{2} - V_C \; , \; V_i = 2V_C, V_d = V_D = 0 \qquad (3)$$

$$i_{dc} = i_L + i_C \; , \; i_i = i_L - i_C \; , i_{dc} \neq 0 \qquad (4)$$

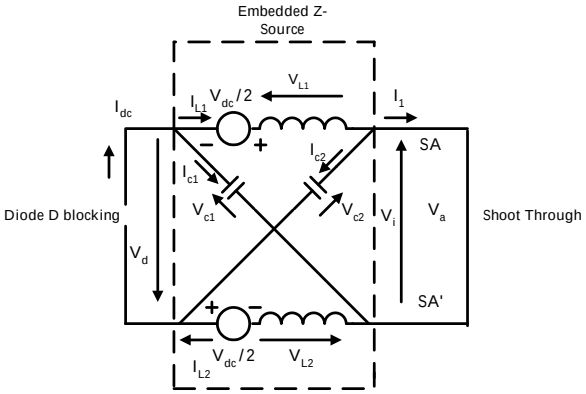


Fig.3: Two level EZ source inverter with shoot through condition.

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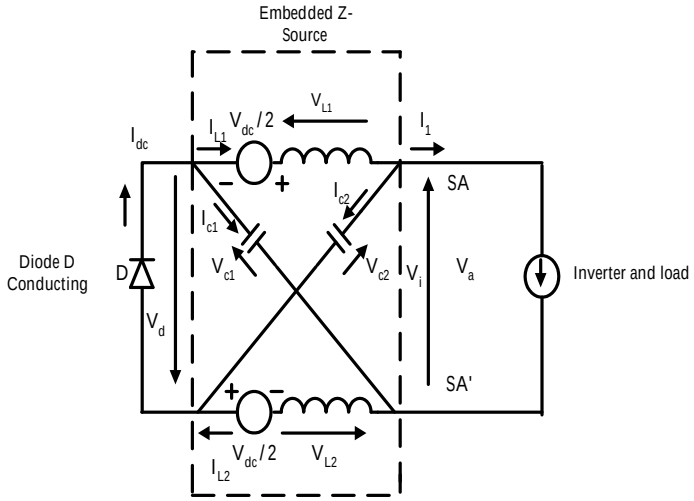


Fig.4: Two level EZ source inverter with non shoot through condition.

## IV. CASE STUDIES BASED ON SIMULATION

**A. Distribution line model without DVR when fault occurs on load side (voltage sag condition):**

Following fig.5 shows distribution line model without DVR when fault occurs on load side. Here fault is created on load side. In the fault, transition time given is 0.15 to 0.2. Breaker resistances is 0.66 which gives 40% of voltage sag and consider that there is switching in all three phases. During transition time i.e. during 0.15 to 0.2 time period, fault occurs. Hence there will be drop in load voltage value and in supply voltage.

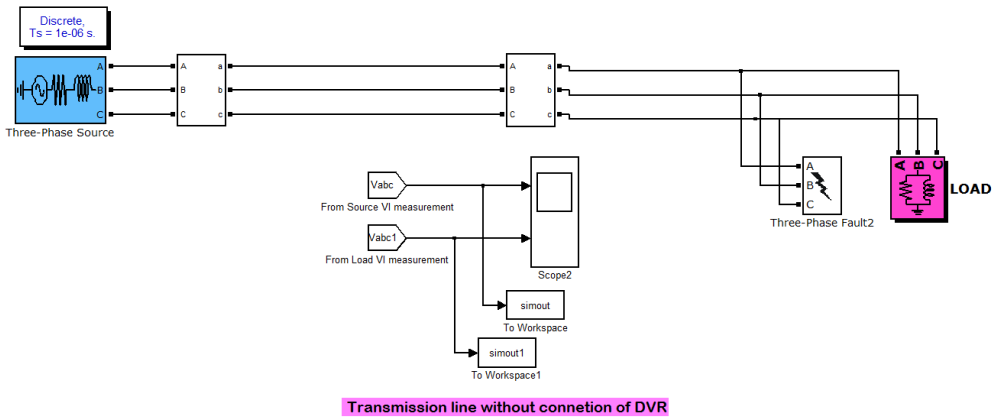


Fig.5: MATLAB simulation of distribution line model without DVR when fault occurs on load side.

Following fig.6 shows voltage sag condition i.e. reduction in load side voltage due to fault and hence there is also reduction in supply voltage.

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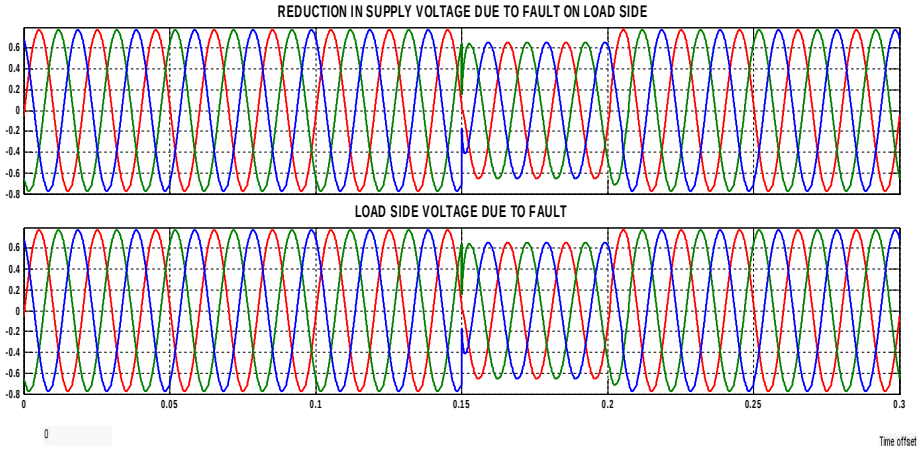


Fig. 6: Simulation result of voltage sag having distribution line model without DVR when fault occurs on load side.

**B. Case-I) MATLAB simulation of DVR based on EZ source inverter when fault near load side:**

A DVR is connected to the system through a series booster transformer with a transformation ratio equal to 1:1. The DVR is based on three phase voltage EZ source inverter with LC output filter to remove high frequency voltage components. An R-L load is considered. In this circuit the DVR is connected in between supply (PCC) and load. The DVR is connected to the system through injecting transformer. After supply block, three phase VI measurement block is connected to measure voltages. A feed forward connection is given through this VI measurement block to the voltage regulator block. A voltage reference is given to this voltage regulator block. The feed forward measurement of supply voltage value is compared with a reference value and the error signal is given to the PWM generator block. PWM output is connected to IGBT of EZ source inverter block where the firing pulses of IGBTs are controlled by PWM technique. The inverter block gets a dc source through dc voltage source block connected to the inverter. Inverter output is connected to injecting transformer through LC filter. LC filter block is used to filter out harmonics in inverted waveform. Following fig. 7 shows MATLAB simulation of DVR based on EZ source inverter when fault is created near load side.

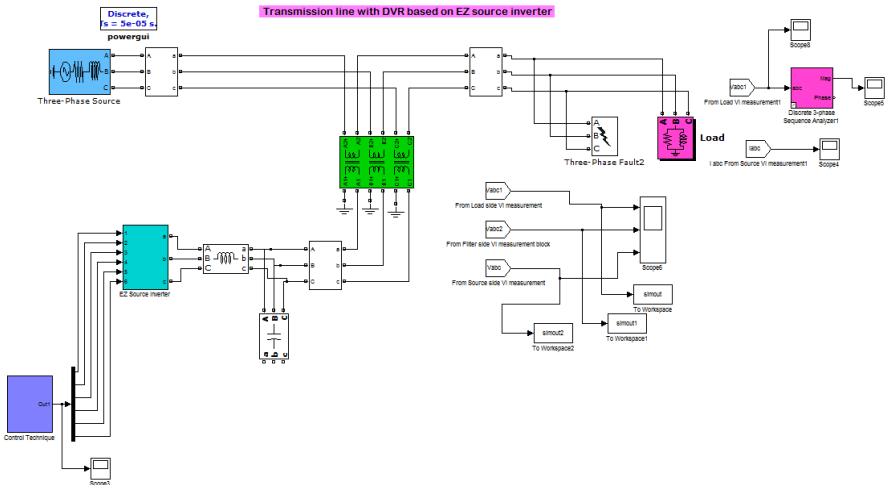


Fig. 7: MATLAB simulation of DVR based on EZ source inverter when fault near load side.

Here fault is created on load side. In the fault, transition time given is 0.15 to 0.2. Breaker resistances is 1.66 which gives 20% of voltage sag and consider that there is switching in all three phases. During transition time i.e. during 0.15 to 0.2 time period, fault occurs. Hence there will be drop in load voltage value. But if we connect DVR to it, it will inject require amount of voltage and corrects the source voltage waveform.

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**Case-II) Control Strategy for DVR:**

The following control technique based on abc to dq0 (Park's transformation) is used for generation of missing voltage injection and it is simulated in Math works Matlab Simulink. Following fig.8 and fig.9 shows DVR control technique which describes how actually injected voltage is calculated. [8] Line voltage is first converted to dq0 term by using abc to dq0 transformation. This value gets compared with reference or set dq0 value. After comparison of d-voltage and q-voltage with the desired voltage, error d and error q are generated [9]. These error components are converted into abc component using dq0 to abc transformation. The load voltage transformed to $V_d$ ,$V_q$ $and$ $V_0$ base on park transformation. [10] The phase lock loop (PLL) is used to generate unit sinusoidal wave in phase with main voltage. This abc components are given to generate three phase pulses using Pulse Width Modulation (PWM) technique.

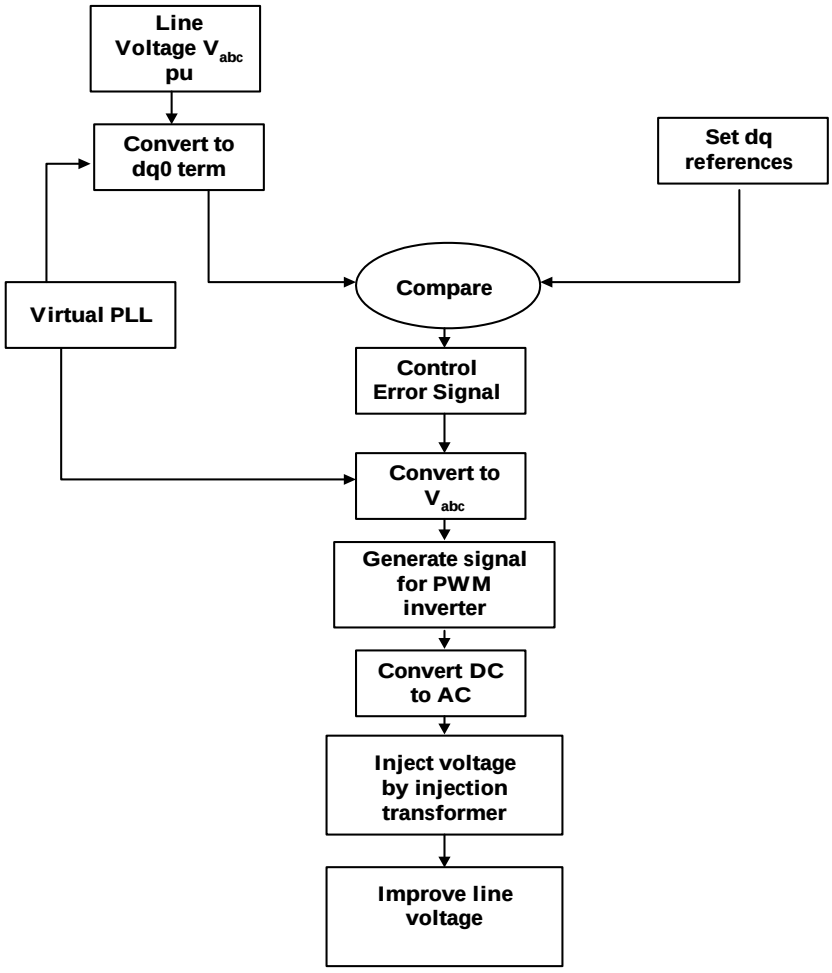


Fig.8: Control strategy of DVR

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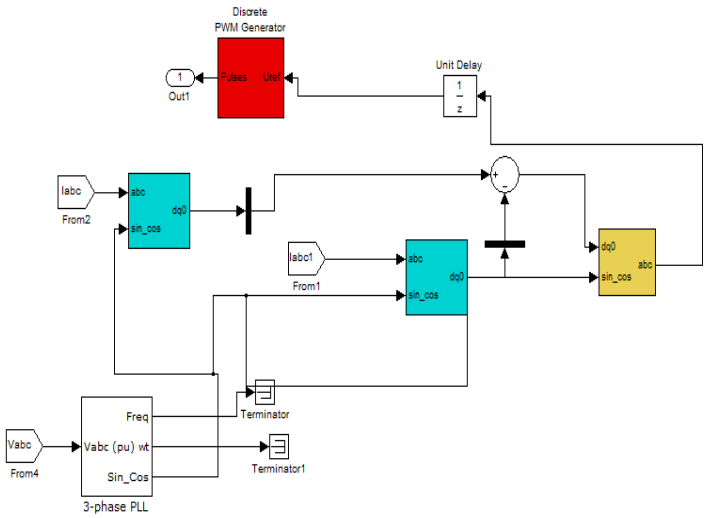


Fig.9: Subsystem of control strategy for DVR for injection of missing voltage.

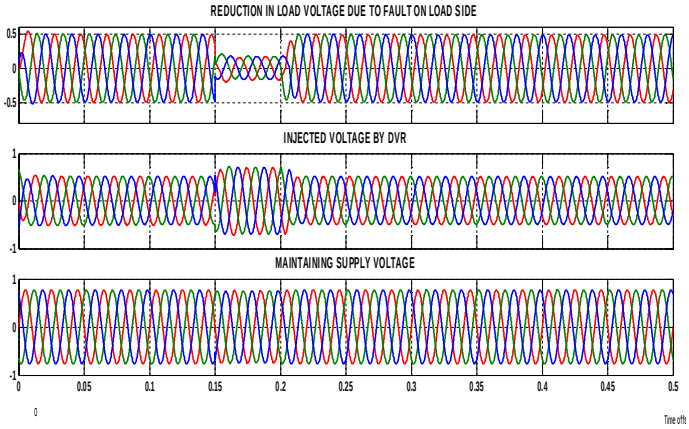


Fig.10: Simulation result of voltage sag having DVR based on EZ source inverter when LLL-G fault on load side.

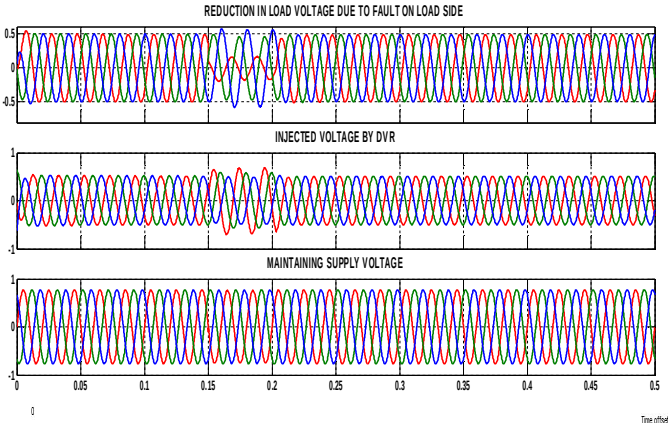


Fig.11: Simulation result of voltage sag having DVR based on EZ source inverter when Single line to ground fault [LG] on load side.

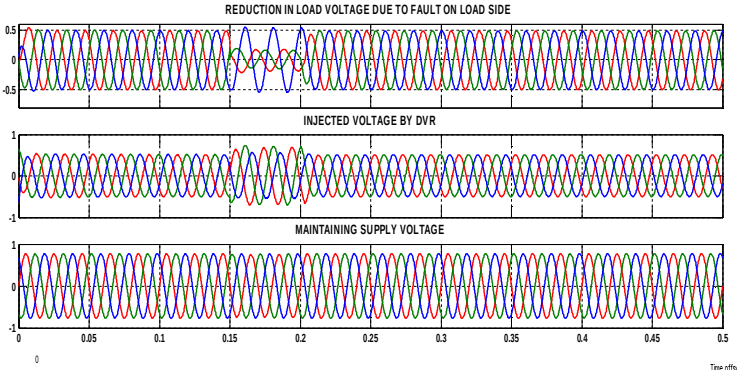


Fig.12: Simulation result of voltage sag having DVR based on EZ source inverter when double line to ground fault [LL-G] on load side.

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Fig. 10, 11 and 12 represents performance of DVR against all kinds of faults viz. LLL-G, LG and LL-G. The DVR is capable of mitigating voltage sag in all kinds of faults. Only required amount of voltage in required phase gets added and voltage is maintained within specified limit.

**C. MATLAB simulation of DVR based on EZ source inverter when sudden increase in load condition:**

Following fig.13 shows MATLAB simulation of DVR based on EZ source inverter when sudden increase in load condition. Here instead of creating fault on load side, circuit breaker is placed. After CB, there is RL load connected. Initially, CB is in open state. In CB, the transition time given is 0.15 to 0.2. Breaker resistances is 1.66 which gives 20% of voltage sag and consider that there is switching in all three phases. During transition time i.e. during 0.15 to 0.2 time period, CB close and total load on system will increase. Hence there will be drop in load voltage value. But if we connect DVR to it, it will inject require amount of voltage and compensate the source voltage waveform. Following table I show parameters that can be used for MATLAB simulation.

TABLE I
SPECIFICATION AND PARAMETERS OF MODEL

| Specifications | System parameters |
|---|---|
| Three phase voltage source | 11 KV |
| Frequency | 50 Hz |
| Booster Transformer turns ratio | 1:1 |
| VA rating of transformer | 500KVA |
| Filter inductance | $L_f$ = 7mH |
| Filter capacitance | $C_f$ = 1 uF |
| 3 phase fault | • Fault on all three phases<br>• Fault resistance =1.66 ohm |
| CB Transition time | [0.15 0.2] |

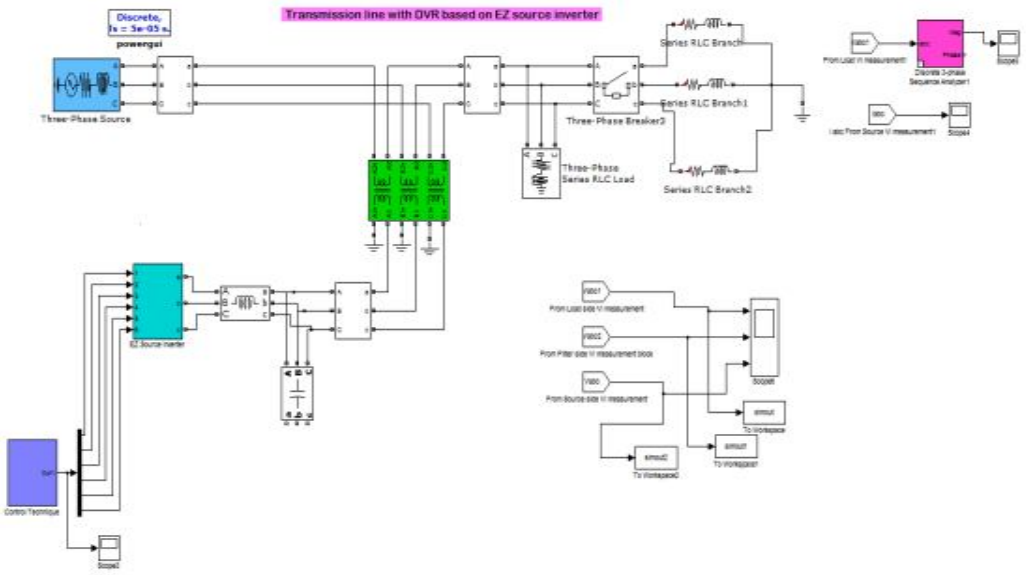


Fig.13: MATLAB simulation of DVR based on EZ source inverter when sudden increase in load condition

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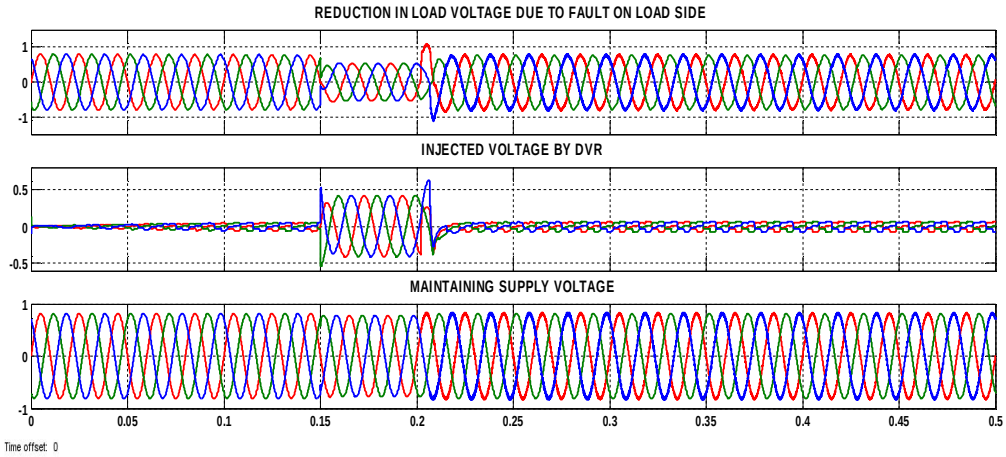


Fig.14: Simulation result of voltage sag having DVR based on EZ source inverter when sudden increase in load condition.

Reduction in the load voltage due to fault is shown in fig.14 at upper side. The missing voltage maintains the supply voltage as shown in above fig. 14.

## IV.THD ANALYSIS

Here we have taken FFT analysis of source voltage at 50 Hz frequency along with 0.1 start time. The maximum number of cycles here are 10. The FFT value of voltage is 0.22%.

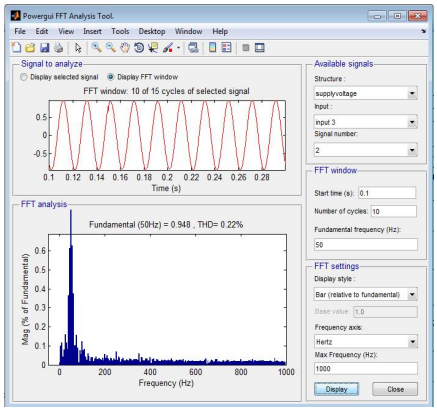


Fig.15: Supply voltage THD analysis=0.22%

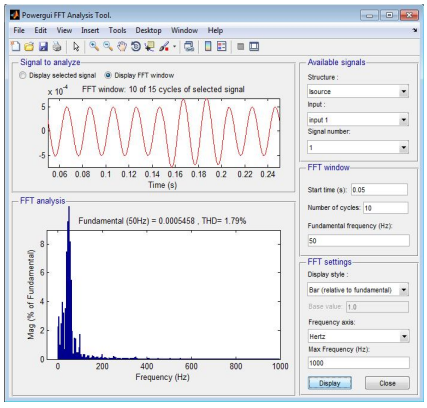


Fig.16: Supply current THD analysis=1.79%

## V. CONCLUSION

This paper presents new inverter topology i.e. EZ source inverter to tackle voltage dip condition. It can also handle both balanced i.e. three phase fault situation [LLL-G or LLL fault] and unbalanced i.e. single or double line-to-line or LG fault situations without any difficulties and appropriate and only required amount of voltage is injected which corrects rapidly any anomaly in the supply voltage. By this, the load voltage gets balanced and maintain at constant nominal value. Also it is found that THD analysis is within permissible limit as per IEEE standards i.e. supply voltage THD value is 0.22% and supply current THD is 1.79%. The main advantage of this DVR is cost required is low and its

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proposed control scheme is simple. Long duration voltage sags/swells can be effectively and efficiently clear by using EZ source inverter based DVR.

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## BIOGRAPHY

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