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Power Quality Enhancement Using T-inverter Based Dynamic Voltage Restorer

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ABSTRACT

Power quality problems which cause serious issues on utility and customer is discussed. Dynamic Voltage Restorer (DVR) using T-inverter is used for the mitigation of Voltage sag and Voltage swells. In this paper, method of Trans-inverter (T-inverter) based DVR is proposed. When T-inverter has improving Boost function ratio and it's effectively voltage gain. The PQ problem occurs on the system, T-inverter based DVR has to be automatically detect and injected required the voltage in distribution line. Simulation carried out by Matlab/Simulink and it's verified the performance of the model.

Keywords: DVR, T-inverter, Voltage sag, Voltage swell

1. INTRODUCTION

A growth of electronic equipment's on utilities loads are becoming more sensitive in form of voltage sags, Voltage swell, flicker, harmonics and interruptions. These problems to overcome devices like DVR, DSTATCOM, and UPQC. DVR is most effective solution for PQ problem at distribution side.

The amplitudes of the Voltage sags ranges from 10 – 90% and it can occur at any instant. The duration of the sag lasts for about half cycle to one minute [3,5]**.** The Voltage swell differs from the Voltage sag and it can be defined as an increase in rms voltage or current at the power frequency for durations ranging from 0.5 cycles to 1 min. The magnitudes are between 1.1 and 1.8. Swell magnitude is also described by its remaining voltage and in this case it will be always greater than 1.0 [4, 5].

Voltage sags are considered more important comparing to Voltage swells since the swells are very less common in distribution systems. Voltage sag and swell can cause severe problems to the sensitive equipment. It may lead to equipment failure or even shutdown and sometimes it leads to large current unbalance that could blow fuses or trip breakers.These cause severe effects and sometimes it can be very expensive for the customer and it ranges from minor quality variations to production downtime and damage of equipment [7].

Among many methods to mitigate voltage sags and swells, the most efficient method to mitigate is considered to be the use of a custom power device. Few of the events which cause swells includes Switching off a large inductive load or energizing a large capacitor bank.

This paper introduces T-inverter based DVR and its operating principle. Then, a simple control method is used to compensate voltage sags and swell. At the end, MATLAB/SIMULINK model based simulated results were presented to validate the effectiveness of the proposed control method of DVR.

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2. DYNAMIC VOLTAGE RESTORER

The most severe disturbancesamong the power quality problems are voltage sags.The concept of custom power devices which is a recently introduced concept helps to overcome these problems. Of all the custom power devices, the most efficient and effective modern custom power device used in power distribution networks is the dynamic voltage restorer (DVR). In order to regulate the load side voltage, DVR with T-inverter is a recently proposed series connected solid state device that injects voltage into the system [7,8]. 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 with T-inverter can also be added with other features like: line Voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

3. DVR AND PRINCIPLE

Fig 1 shows the schematic diagram of DVR. It consists of an Injection transformer, Harmonic filter, Storage devices, a Voltage source converter (VSC), DC charging circuit and control and protection system

The main tasks of injection transformer are: It connects the DVR to the distribution network via the HV-windings and transformers and couples the injected compensating voltage generated by the voltage source converters to the incoming supply voltage. Eliminating the harmonic presented in compensating voltage, generated by the voltage source converter is one of the main task of the harmonic filter. To supply the necessary energy to the VSC via a dc link for the generation of injected voltages is the purpose of the storage devices [10,11]. A Voltage source converter is a power electronic device consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. The DC charging circuit has two main tasks. The first task is to charge the energy source after a sag compensation event. The second task is to maintain dc link voltage at the nominal dc link voltage.

4. PRINCIPAL OF OPERATION

To inject dynamic voltage and to compensate the sagging occurrence is the basic function of the DVR. The operation of DVR can be categorized into two modes; standby mode and injection mode [8]. In standby

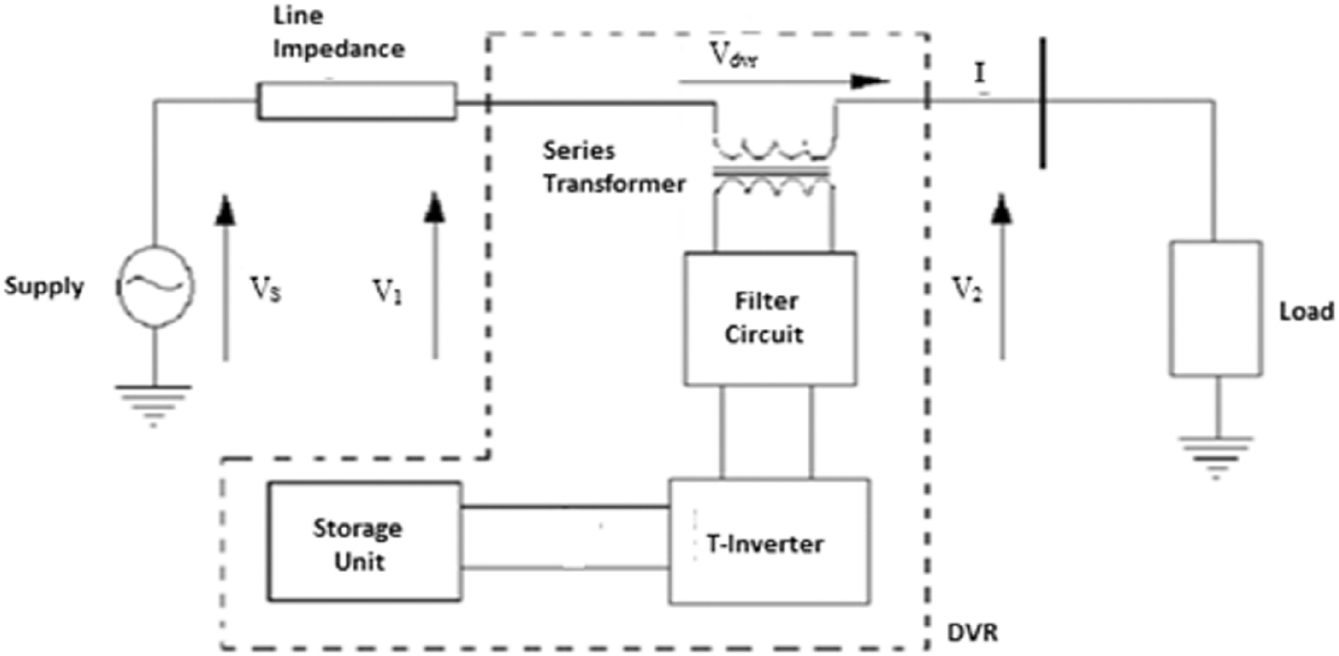


Figure 1: Schematic diagram of DVR

mode, a small voltage is injected in the short circuit operation to cover voltage drop due to transformer reactance losses. The DVR turns into injection mode as soon as sagging is detected. Voltageis injected in series with load of required magnitude and for phase compensation.

5. SIMULATION DIAGRAM OF TRANS-INVERTER:

The proposed improved T-inverter is with continuous input current and with Buck-boost capability. It is created by connecting a transformer with the capacitor and a inductor between the DC source and the inverter bridge. Therefore it consists of a one capacitor(C) and two inductors (L1, L2). The main characteristics of this inverter are,

1. Continuous input current
2. Higher boost factor can be obtained
3. If increasing the turns-ratio of the transformer the voltage Buck-boost can be possible.

The Proposed improved T-inverter has extra shoot-through zero states in addition to the conventional two zero states and six active states in a conventional voltage-source inverter [11,12]. The operating principles of the T-inverter is similar to the conventional Z-source inverters. For the purpose of analysis, the operating states are simplified into shoot-through and non shoot -through states.

During the shoot-through state

$$V_{L1} = V_{C1}$$

$$V_{L2} = nV_{L1} = nV_{C1}$$

The peak dc link injected voltage can be written as,

$$V_{inj} = \frac{N_P}{N_S} * V_{in}$$

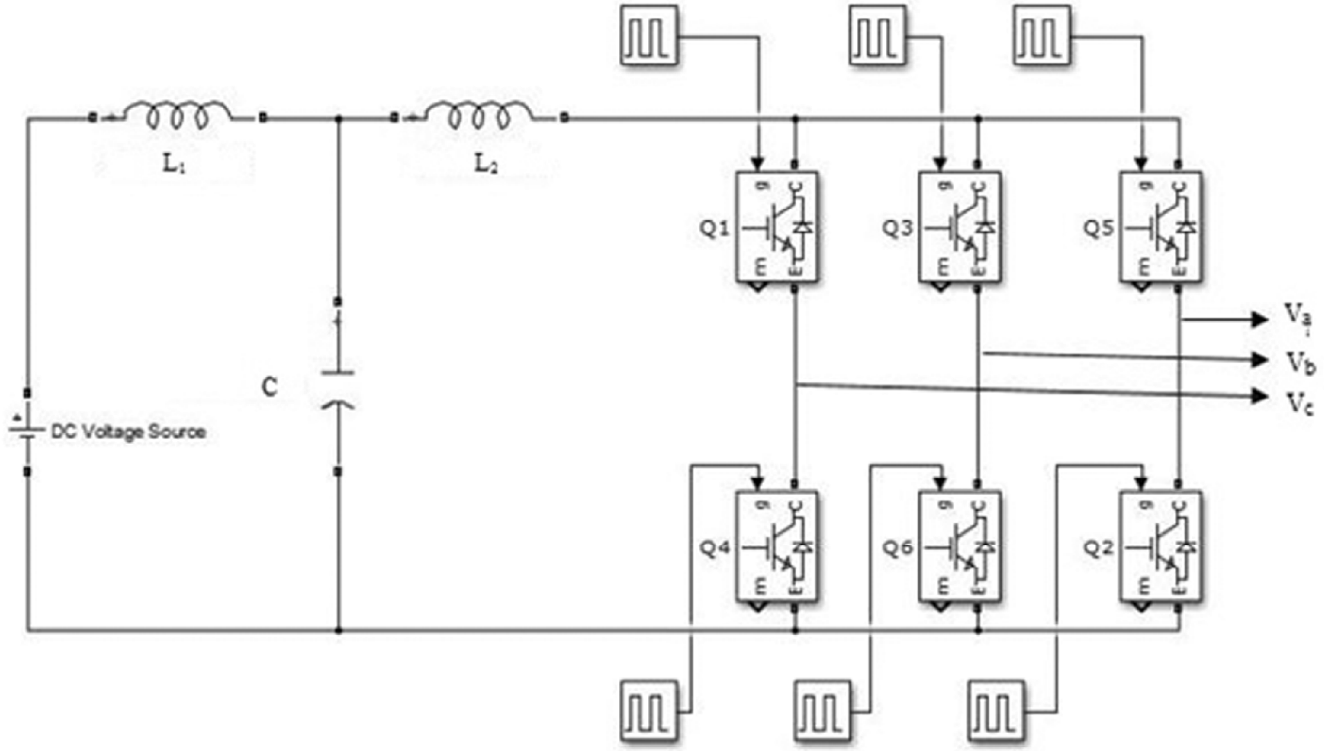


Figure 2: Circuit diagram of T-inverter

The boost factor can be written as,

$$B = \frac{1}{1 - nD_o}$$

Therefore by comparing these equation the improved T-inverter has higher boost than the conventional Z source inverter by the use of transformer. When n = 0, the improved T inverter will work normally as a conventional Z source inverter. But when n1 the boost ability of the improved T inverter is higher and can be increased by increasing the turns ratio of the transformer. On the other hand this improved T inverter uses a smaller shoot-through duty cycle to produce the same boost factor as the conventional Z source inverter. Thus a higher modulation index is used to have a better output waveform.

When we use constant boost control [1, 2, 13], the constant duty cycle of the shoot-through state of this inverter can be written as,

$$D_o = \frac{1 - \sqrt{3}m}{2}$$

Where, M = Modulation Index

The proposed improved T inverter lowers the voltage stress on the dc link, current stress flow to the transformer windings and diode, and input current ripple. However, the voltage stress on the diode and the current stresses across the main power circuit during the shoot-through state of the improved T inverter are higher. This is because it has a stronger power capability at a high modulation index.

6. TEST SYSTEM DESCRIPTIONS

In order to show the performance of the DVR with T inverter in voltage sags and swells mitigation, a simple radial distribution network is simulated using MATLAB/SIMULINK. The parameters of the main components are listed in the table 1.

A three-phase 13kv, 50Hz programmable voltage source is connected to a feeder of length 10 km, and it is step down to 415v, 50 Hz through 13kV/415V transformer at Point of Common Coupling (PCC). A nonlinear load of resistance 40 and inductance 100 mH is connected to PCC.

The DVR with T-inverter is connected in series with PCC and nonlinear load with the help of an injection transformer. The primary side of injection is connected in series with the load and secondary side is connected in delta to the DVR. In order to see the voltage sag, three phase fault is applied to the system. The DVR with T-inverter uses-commutating IGBT solid-state power electronic switches to mitigate voltage sags in the system. The voltage controlled T inverter is used to produce compensating voltage. These inverters are connected to the common DC voltage source. The DC voltage source is an external source of supplying DC voltage to the inverter for AC voltage generation.

Table 1
Test System Parameters

Parameters	*Ratings*
Supply Voltage	13kV/50HZ
Load Transformer Rating	11Kv/415v
Series Transformer Turns Ratio	1:1
DC Source Voltage	5Kv
Load Resistance	40 Ω
Load Inductance	100mH

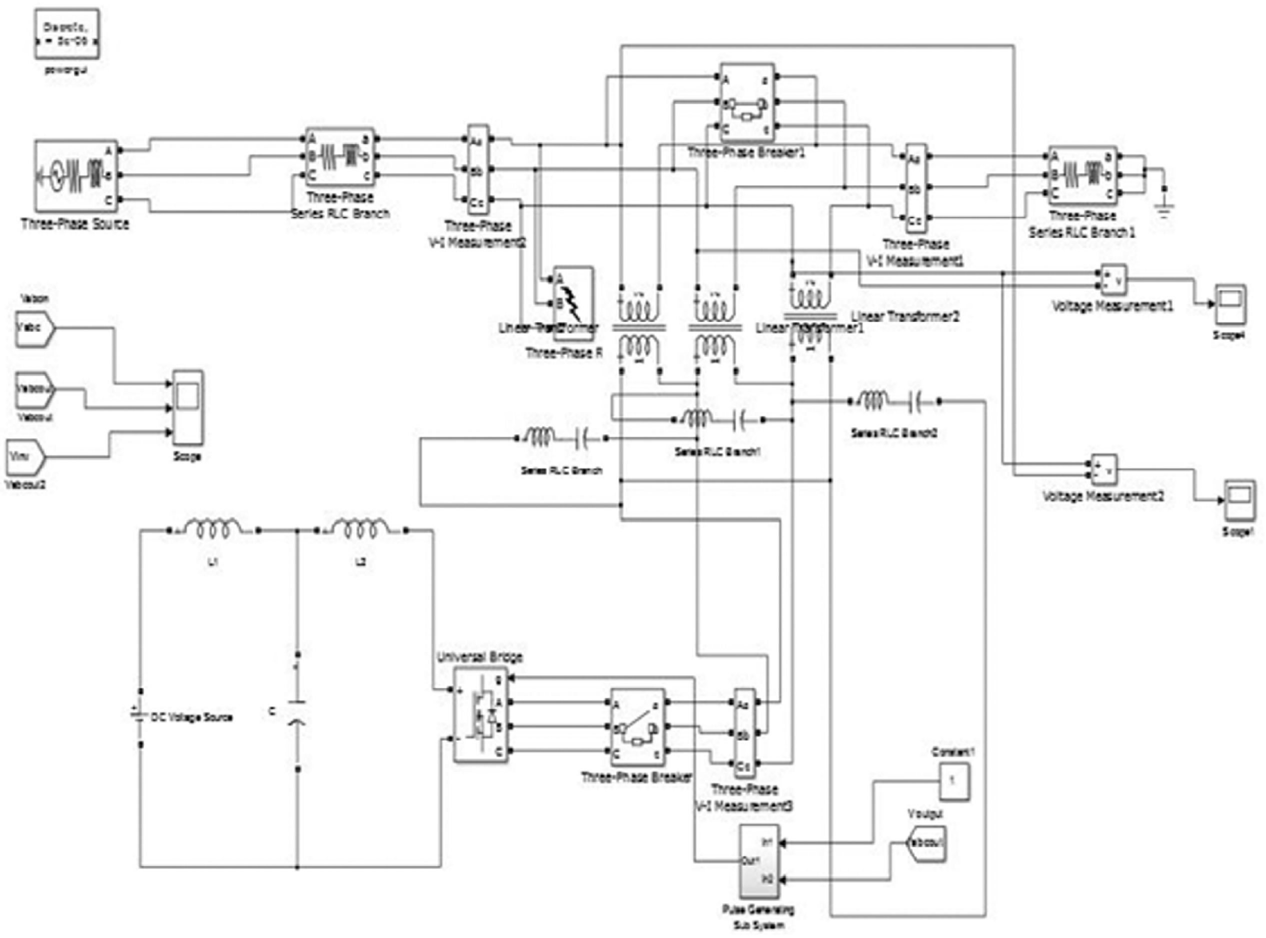


Figure 3: Simulation model of the Test System

The basic function of the DVR is to inject a dynamically controlled voltage into the voltage by means of voltage injection transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage V_L. This means that any differential voltages caused by disturbances in the ac feeder will be compensated by an equivalent voltage. The DVR works independently to any of the types of fault or any event that happens in the system.

7. SIMULATION RESULTS AND DISCUSSION

A detailed system as shown in Figure 4 has been modelled by MATLAB/SIMULINK to study the efficiency of suggested control strategy. The system parameters and constant value are listed in Table. It is assumed that the voltage magnitude of the load bus is maintained at 1 pu during the voltage sags/swells condition. The results of the most important simulations are represented in Figures. The load has been assumed linear with power factor pf = 0.85 lagging and its capacity of 5 KVA.

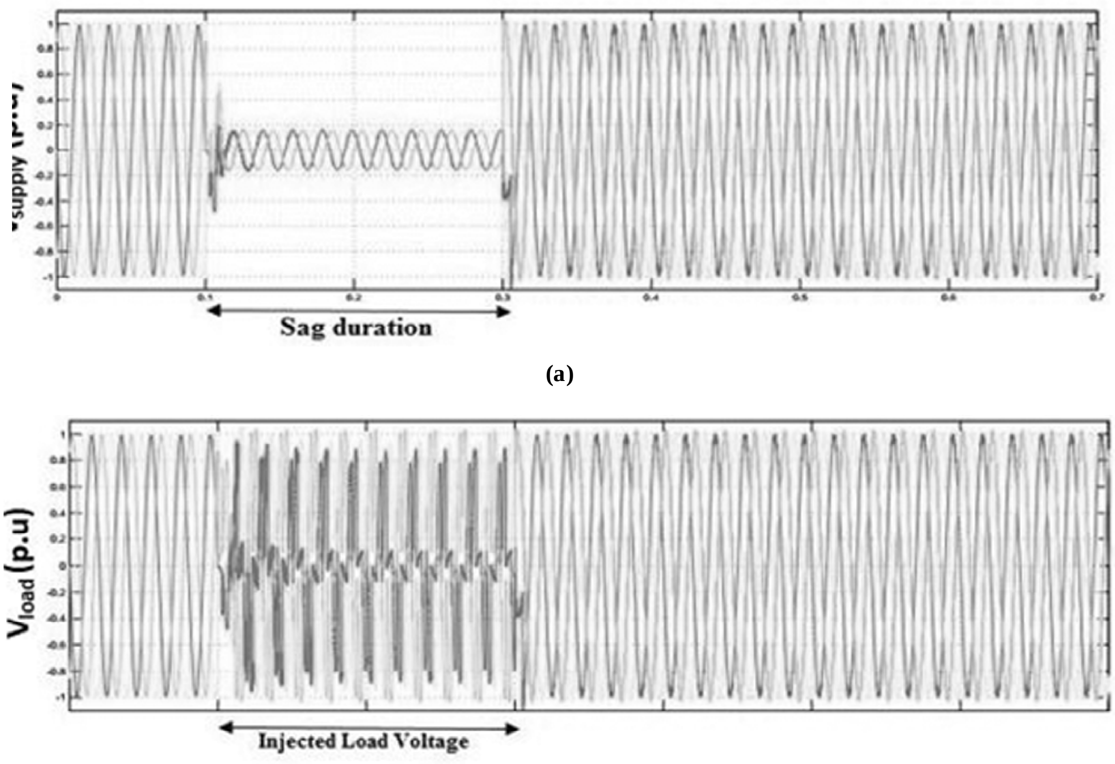
7.1. Voltage Sags

The first part of simulation shows the three phase voltage sag is simulated. The simulation started with the supply voltage sagging as shown in Figure 4. Voltage sag initiated at 0.1s and it is kept until 0.3s, with total voltage sag duration of 0.2s. Figures show the voltage injected by the DVR and the corresponding load voltage with compensation.

As a result of DVR, the load voltage is kept at 1 pu. The voltage sag injected is shown in the figure 4(a). It indicates the sag duration and the time of voltage sag injected in the T-inverter. The corresponding load voltage with compensation can be clearly seen in the results from the figures.

7.2. Voltage swells

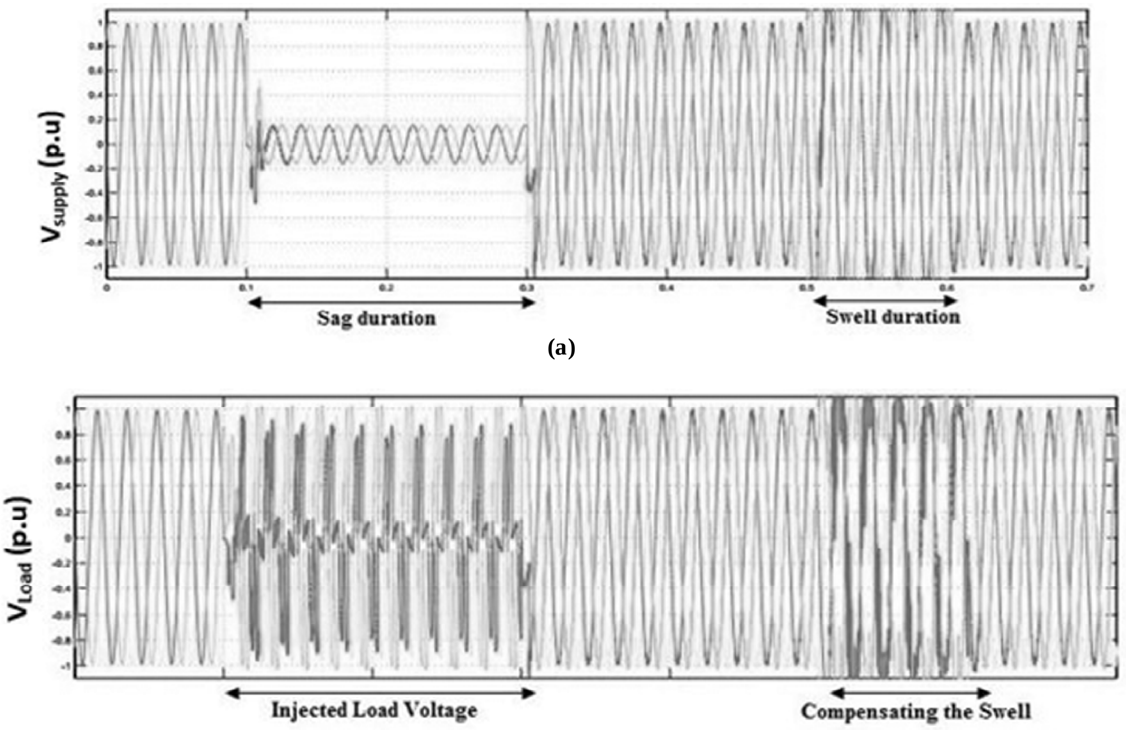
The second part of simulation shows the DVR performance during a voltage swell condition. The simulation started with the supply voltage swell is generated as shown in Figure 5. Voltage swell initiated at 0.5s and



(a)

(b)

Figure 4: Three-phase Voltage Sag: (a) Source Voltage (b) Injected load Voltage



(a)

(b)

Figure 5: Three-phase Voltage Sag/swell: (a) Source Voltage (b) Injected load Voltage

it is kept until 0.6s, with total voltage swell duration of 0.1s as observed from this figure the amplitude of supply voltage is increased about 25% from its nominal voltage. Figure 5 show the injected and the load voltage respectively.

As can be seen from the results, the load voltage is kept at the nominal value with the help of the DVR. Similar to the case of voltage sag, the DVR reacts quickly to inject the appropriate voltage component (negative voltage magnitude) to correct the supply voltage.

Fig 6 and 7 shows the simulation results of the load voltage and inverter output voltage respectively. The new proposed inverter maintain the constant load voltage without any difficulties. The inverter sends required amount of voltage through the transformer. The new proposed system maintains both balanced and unbalanced systems.

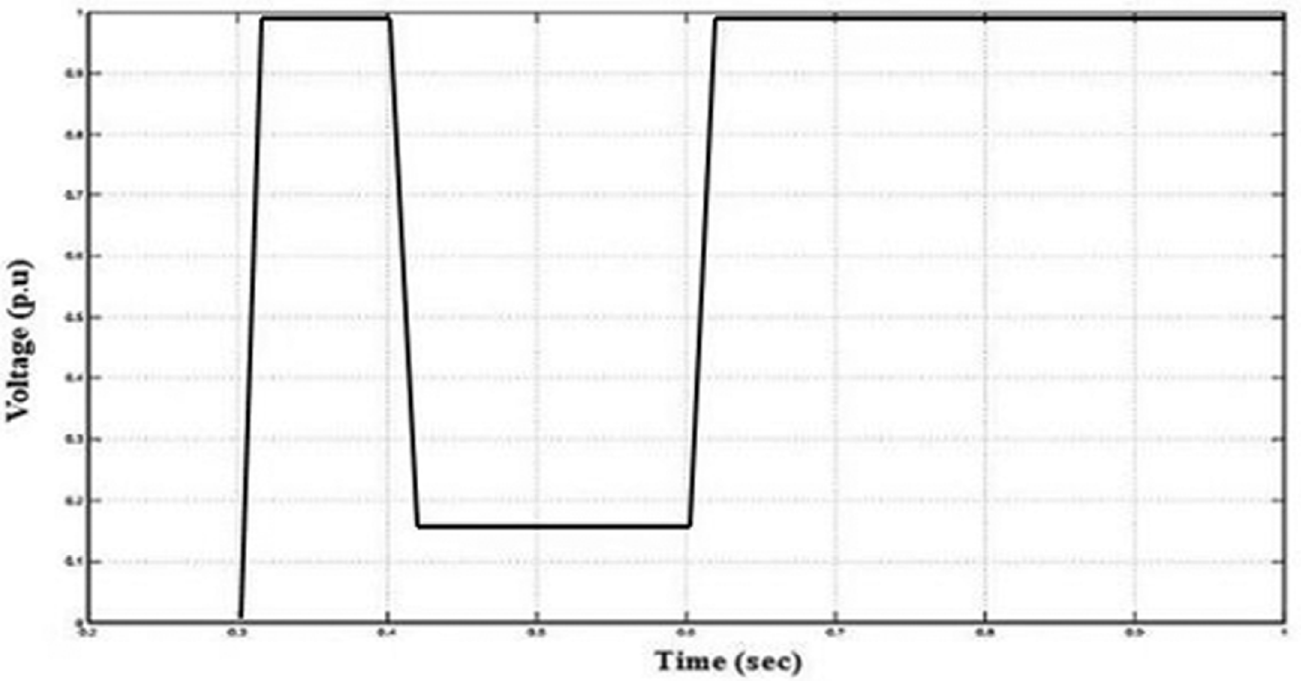


Figure 6: Load Voltage of the System

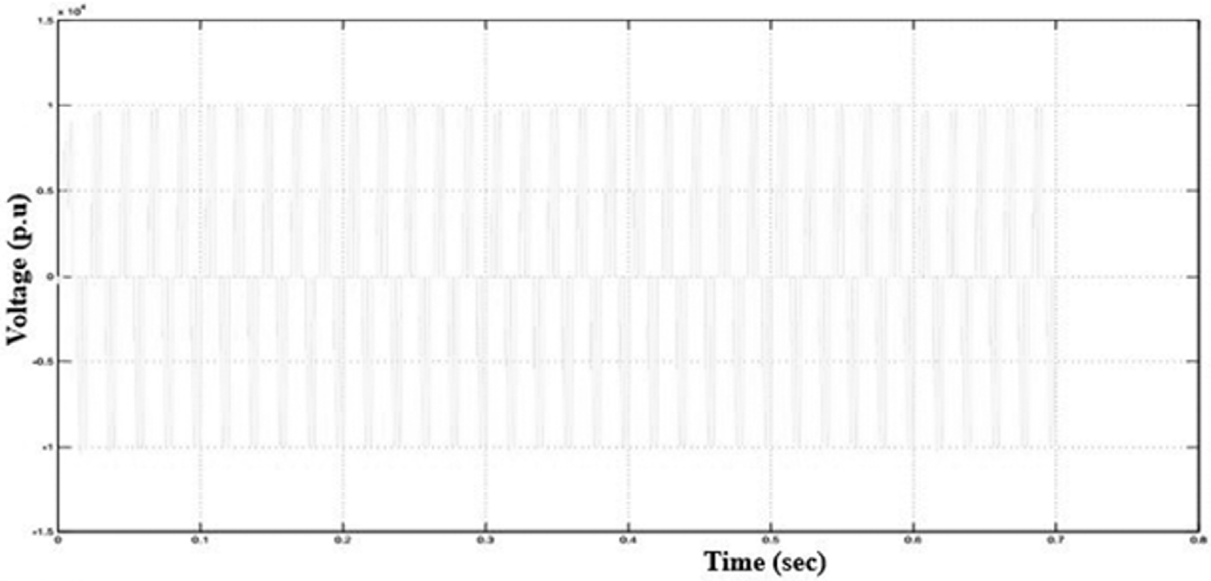


Figure 7: Inverter Output Voltage

From the result, it is clearly visible that the inverter maintains constant load voltage. The transformer acts as the intermediate here. Through the transformer, the inverter is able to send the required amount of voltage. In this newly proposed system, both the balanced and unbalanced systems are maintained to get the best results.

Fig. 8 shows the rms voltage at load point when the system operates with no DVR and a three phase fault is applied to the system. When the DVR is in operation the voltage interruption is compensated almost completely and the rms voltage at the sensitive load point is maintained at normal condition.

Figure 9 shows the THD for the load voltage with DVR for both Voltage sag and swell for the various fault condition. The proposed method gives satisfactory performance and very less THD values.

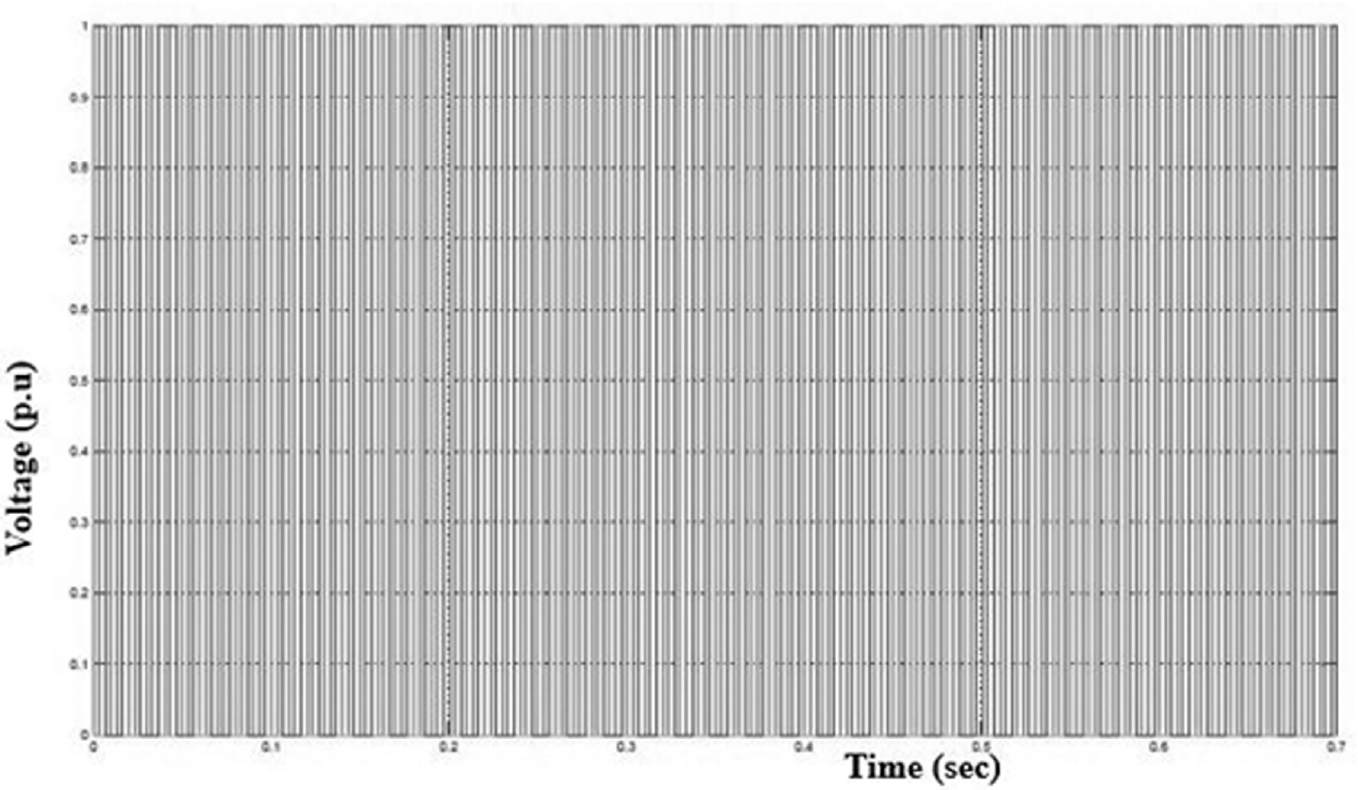


Figure 8: Firing pulse generated by discrete PWM generator

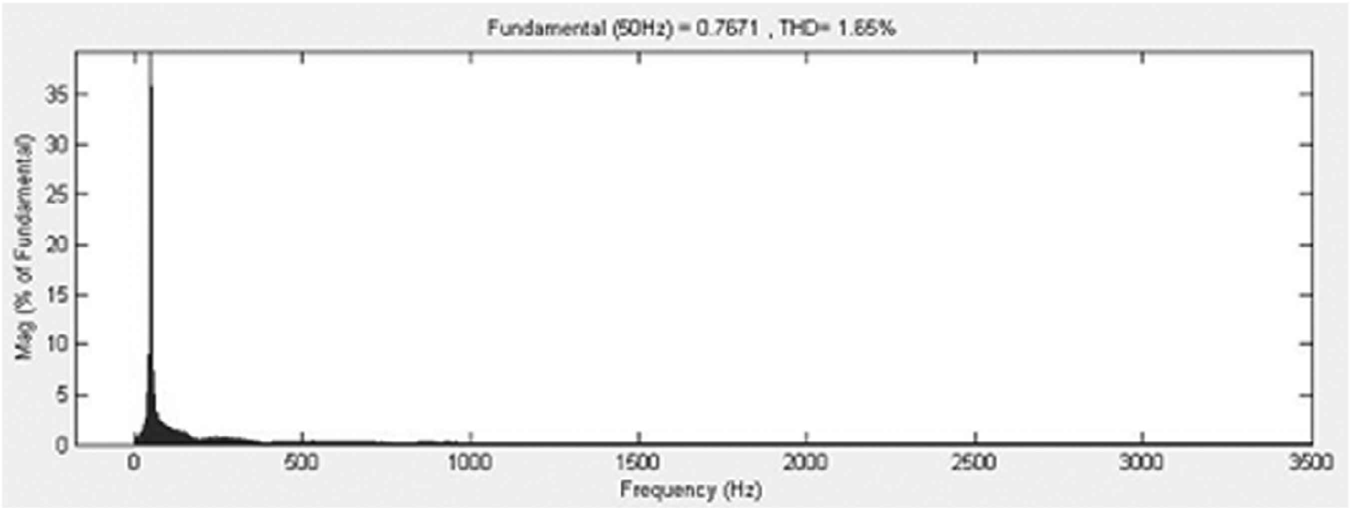


Figure 9: Simulation Results of Total Harmonic Distortion

8. CONCLUSION

From simulation results also show that the DVR with T-inverter compensates the sags/swells quickly and provides excellent voltage regulation. The T-inverter handles both balanced and unbalanced situations without any difficulties and injects the require voltage to keep the load4 voltage balanced and constant nominal value. The main advantage of this T-inverter is low cost and its control is simple. It can compensate long duration voltage sags and swells efficiently. Future work will include a comparison with experimental experiments in order to compare simulation and laboratory results.

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