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Modeling and Simulation of Dynamic Voltage Restorer Using Proportional Integral Controller to Compensate Voltage Sag in Electrical Distribution System

[1]Yogesh Popat, [2]Prof. Aashish Sahu

[1]Rungta College of Engineering & Technology, Bhilai, India

[1]Rungta College of Engineering & Technology, Bhilai, India

Email: [1] yogeshpopat28@gmail.com, [2]bkashishsahu@gmail.com

ABSTRACT

Power quality is an important area of concern in present scenario due to the utilization of modern sensitive and sophisticated loads which are connected to the distribution system. This paper presents modelling and simulation of Dynamic Voltage Restorer (DVR) with pi controller using MATLAB/SIMULINK. One of the major power quality problems of sag is dealt in this paper which is harmful for the industrial customers as it causes malfunctioning of several sensitive electronic equipments. DVR is Custom power Device (CPD) which provides the series compensation in the electrical network to improve voltage disturbance in electrical distribution system. The proposed scheme allows flexibility in cost and simplicity in design. Simulation results are also illustrated to understand the performance of DVR under voltage sag fault condition.

***Keywords**: Custom Power Device (CPD), Dynamic Voltage Restorer (DVR), PI Controller, Voltage Sag, Power Quality*

I. INTRODUCTION

In present scenario Electrical power system is AC in nature i.e., the voltage generated by stations has a sinusoidal waveform with a constant frequency. When the power is generated it is desired that it energizes all electrical equipments. So, it is desired by the user to have constant sinusoidal wave frequency, shape and symmetrical voltage with a constant RMS value to continue the satisfactory generation and distribution, also the power in electrical distribution system has to travel long through conducting wires so there is a possibility that any abnormal condition in the network can change the power quality and thus its suitability decreases for any further application. Voltage magnitude is an important factor that determines the electrical power quality [1]. Hence it is mandatory to improve electrical power quality before it is utilized by the sensitive load. This process of power quality improvement results in overall efficiency improvement and eliminates variation in the industry have resulted more complex instruments that are sensitive to voltage disturbances. Earlier the major focus for reliability of power system was on the system that generates power and transmits power. But in present scenario electrical distribution system receives more attention because in most of the cases network failures account for about 90% of average customer interruptions and also huge amount of financial losses may happen with the loss of productivity and competitiveness, if any disturbance occur in distribution system.

The main power quality issues are voltage swell, interruptions, voltage sag, transient, harmonics and phase shift. Among all these electrical disturbances the voltage sag is considered as most harmful because the loads are very susceptible to temporary changes in voltage. Voltage sag (voltage dip) is short duration reduction in voltage magnitude from 10% to 90 % as compared to nominal value which lasts from half a cycle to few seconds. Voltage dip with duration of less than half a cycle is called transient. The voltage sag may be caused by switching operation associated with temporary disconnection of supply, the flow of heavy current associated with the start of temporary disconnection of supply motor loads. Main cause of momentary voltage dip is lighting strokes. The effect of voltage dip on equipments depends on both its magnitude and its duration. Some of the possible negative effects of voltage dip are extinction of discharge lamps, incorrect operation of control devices, tripping of contractors, speed variation in motors, commutation in Line commutated inverters and computer system crash.

Some customers are in need to have higher electrical power quality level provided by modern electrical network, hence huge efforts have been under taken to full fill customer's need. Initially for the system's reliability and power quality improvement, flexible AC transmission system (FACTS) devices like Static synchronous Compensator (STATCOM), Static Series Compensator (SSSC), Unified Power flow controller (UPFC), Inter Line Power flow Controller (IPFC), etc. were utilised. Basically these devices have been developed for transmission system but at present all these devices are generally utilised in electrical distribution system and also called Custom Power Devices (CPD). Distribution Static Synchronous Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR) and Active power filter (APF) are some of the examples of CPDs. By utilising all these devices power quality issues are reduced to great extent.

The characteristic of sag is concerned with the remaining voltage magnitude and sag duration also the magnitude of voltage sag has more effect than the sag duration on electrical system [2]. Voltage sag is generally within the limit of 40% of nominal voltage in industry.

2. CONFIGURATION OF DVR

Wide area solution is needed to compensate the sag which in turn results in improvement in power quality. A new method is using DVR [3]. DVR is a solid state power electronic device which is connected in series to the power system. The basic process of compensating the voltage sag includes the detection of voltage sag and then missing voltage value is injected in series to the bus as shown in figure 1. DVR is specifically designed for heavy loads ranging from a few MVA to 50MVA or higher, unlike UPS [4,5]. In order to mitigate the voltage problem, DVR is one of effective and efficient CPD, having merits such as flexibility and cost effectiveness.

DVR is a solid state power electronic device which is connected in series to electrical system. DVR consist of Energy storage unit, Voltage Source Inverter (VSI), Injection transformer, control unit. The components of DVR are shown in figure 1.

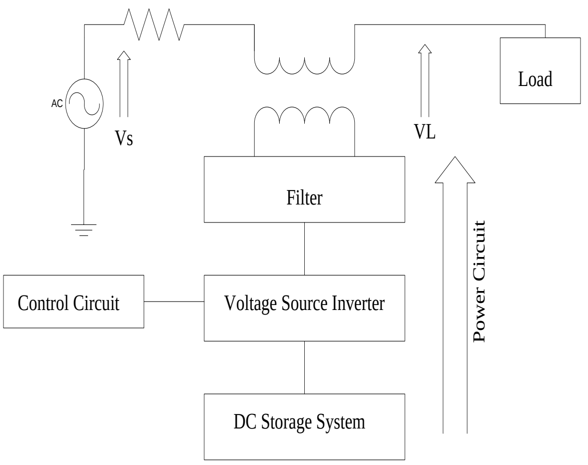

Figure1. Components of DVR

DVR is connected in between the load and supply as shown in figure 1 and 2.the main function of DVR is to increase the load side voltage to make the load free from any kind of power disruption. Other than voltage sag compensation DVR also performs other functions such as reduction of transient, fault current limitation and line voltage harmonic compensation

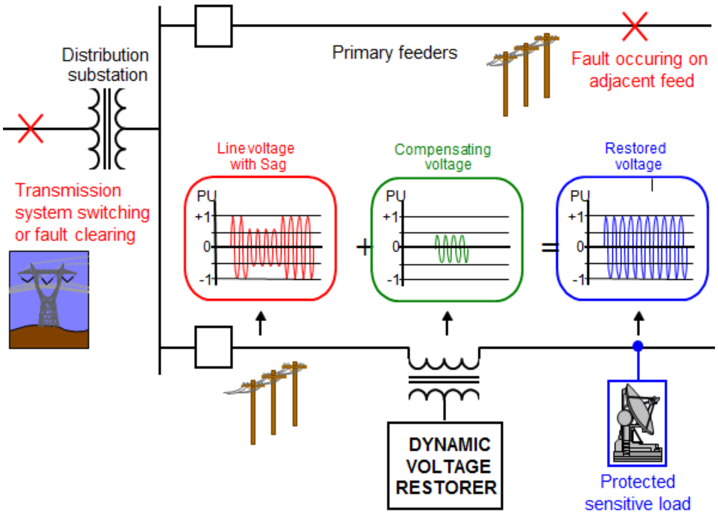

Figure2. Basic principle of operation

Following are the main components of DVR-

Energy Storage unit - The energy required by the VSI is supplied by the auxiliary supply (Energy source) which will be converted to alternating quantity and then it is fed to injection transformer. Batteries are generally used for this purpose and duration of sag which can be compensated is determined by the capacity of the battery.

Voltage Source Inverter – Output Voltage which is variable in nature is obtained by this unit. A VSI is a power electronic device consisting of a switching device such as battery. Sinusoidal voltage at any required magnitude, phase and frequency is generated by VSI. The voltage control is done by modulation of waveform of output voltage within the inverter.

Injection Transformer – Series injection transformer consists of three single phase transformers which are utilised to inject missing voltage to the system. The correct selection of electrical parameters of series injection transformer ensures the maximum reliability and effectiveness. In this paper three single phase transformers instead of single three phase transformer are connected and each transformer is connected in series with each phase of the distribution level. The series injection transformer also ensures the isolation between line and DVR system.

Filter unit – The distortion in the waveform associated with harmonic at the inverter output is caused due to non linear characteristics of semiconducting devices. To reduce the effect of this problem and provide quality supply of energy, filter unit is used.

The inverter side filter is closer to low voltage Side and harmonic source and hence it avoids the harmonic currents from penetrate into the injection transformer. This can cause drop in the voltage and phase shifting in fundamental component of inverter output. Higher transformer rating is required because line side is closer to high voltage side. Filter capacitor will cause increased inverter ratings. The increased filter capacitor provides better harmonic attenuation but the rating of the inverter is related with the capacitor value.

Control Unit – A controller is used for smooth operation of DVR. Voltage sag in the line is detected by DVR and it operates to perform compensation of it. Plant which is to be controlled is driven by PI controller, shown in figure3 with a weighted sum of error, the difference between actual sensed output and desired set point pulse width modulation (PWM) control strategy is applied for switching operation of inverter which results in generation of three phase 50 Hz sinusoidal voltages at the load side. Input of the PI controller is difference between reference voltage and input voltage this difference is also called actuating signal. The output of PI controller is in the form of angle δ, which provides addition phase lead/lag in three phases the output of detector is V_{ref} - V_{in}. The controlled Output results in desired firing sequence.

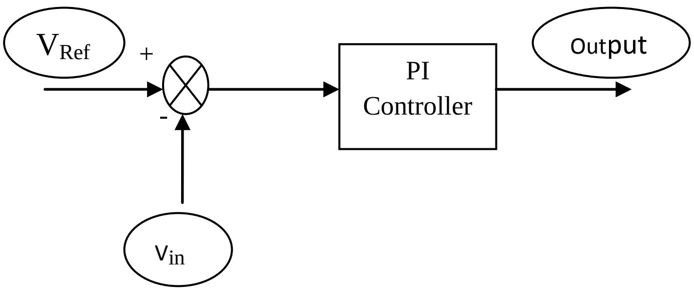

Figure3. Schematic of PI Controller

Location of DVR is shown in figure 4.DVR is connected in primary distribution feeder. This location of DVR compensate certain group of customer by faults on the adjacent feeder as shown in figure 4

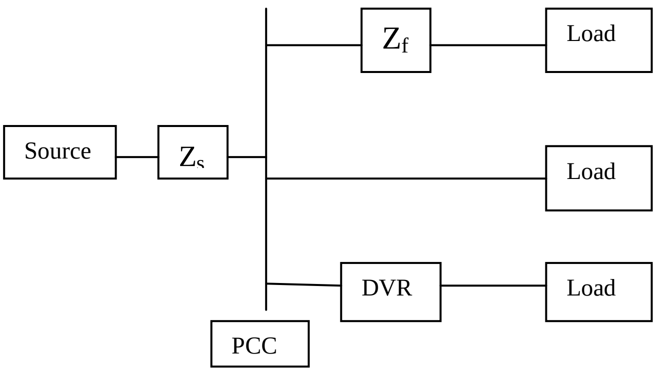

Figure4. Location of DVR

The point of common coupling (PCC) feeds the load and the fault. The voltage sag in the system is calculated by using voltage divider rule [6,7].

3. THEORETICAL CONCEPT

Figure 5 shows the theoretical concept of DVR from the figure below following equations are found

$$V_{DVR} = V_{load} + Z_{line}\, I_{load} - V_{source}$$

The line impedance depends on the fault level of the load. When a fault occurs in the system and the system voltage drops from any specific value then the DVR injects a series voltage i.e. V_{dvr} via the injection transformer so that the voltage can be maintained at required level.

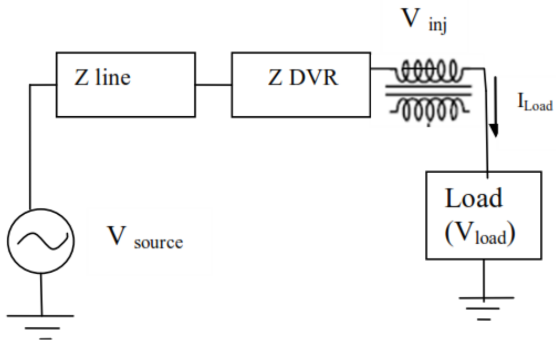

Figure5. Equivalent circuit of DVR

4. PROCESS FLOW CHART

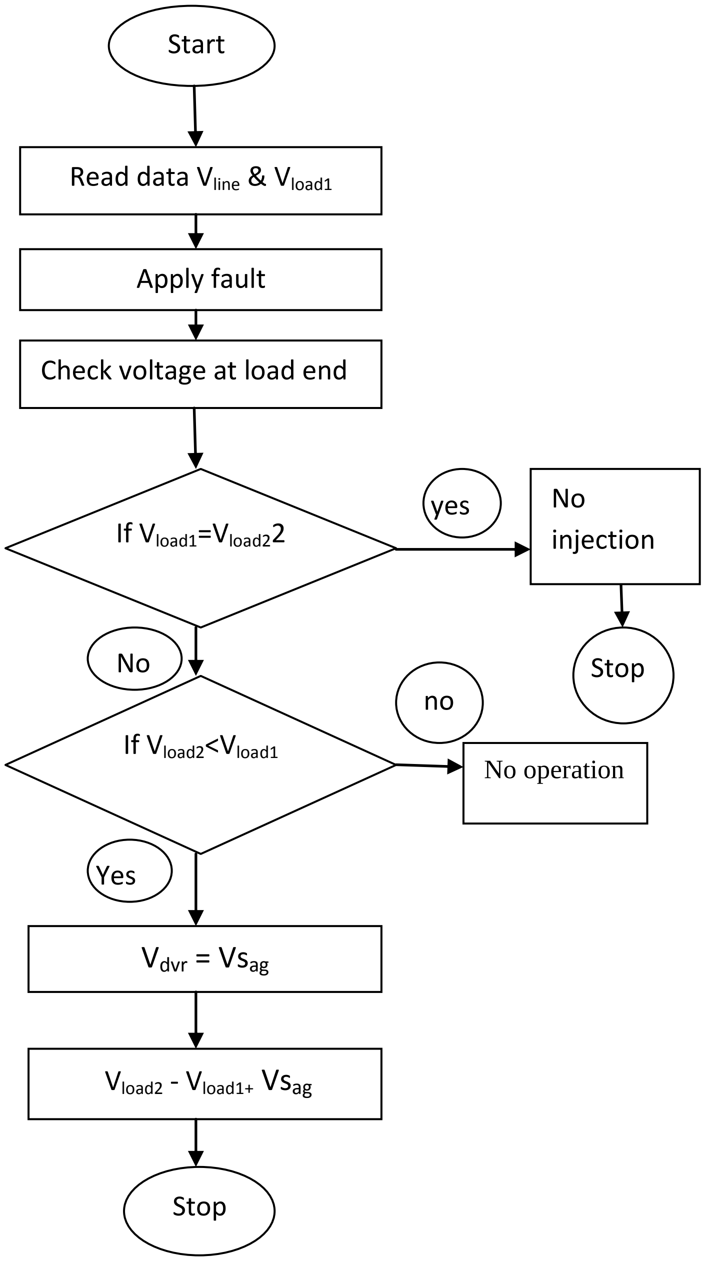

Figure6. Flow Chart

Flow Chart shown in figure 6 Shows the method implemented in this paper. Initially the line voltage & load voltage 1 are measured if both the values are equal then a fault is applied due to which load voltage reduces suddenly to great extent. Again the magnitude of load voltage is measured and it becomes load voltage2. Load voltage1 & load voltage2 are compared and if they are equal then DVR will not operate and no injection of voltage takesplace. But if load voltage2 is less than load voltage1 then DVR will inject the sag voltage and if load voltage2 is greater than load voltage1 DVR will not operate.

5. TEST MODEL OF DVR

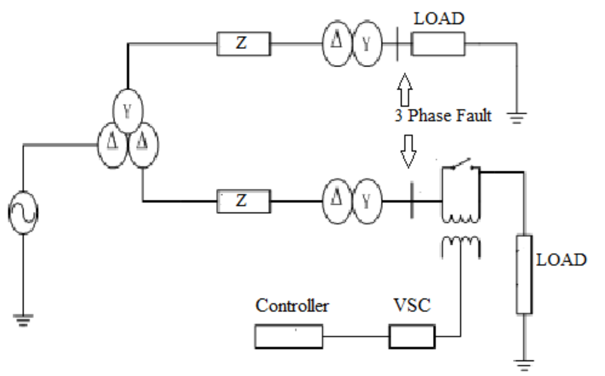

Figure7. DVR Test Model

Single line diagram of the test system for DVR is composed by a 13 kV, 50 Hz generation system, feeding two transmission lines through a 3- winding transformer connected in Y/Δ/Δ, 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ/Y, 115/11 kV The DVR is simulated to be in operation only for the duration of the fault.

6. SYSTEM PARAMETERS

TABLE1. PARAMETERS DURING SIMULATION

System Quantities	Parameters
Source	3 Phase, 13Kv (Phase-Phase), 25Kv Base Voltage
Converter	IGBT based, 3 Arms, 6 Pulse, Snubber Resistance 1e^5 Ohms
PI Controller	Kp=0.0001, Ki=10000, Sampling Time 50μs.
RL Load	R = 0.1 Ohm, L = 0.1926 H
Transformers	Rm = 242 Ώ, Lm = 0.77031 H, Pn = 250e^6 VA, Fn = 50Hz

7. SIMULATION MODEL

Figure 8 shows the actual simulation model to compensate the voltage sag using PI controller

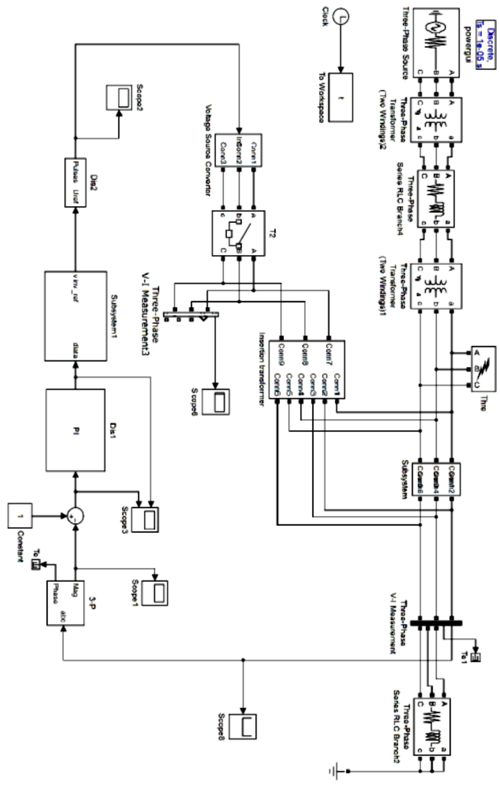

Figure8. Actual Simulation Model

8. RESULT AND DISCUSSION

Here the simulations of DVR test system to compensate the voltage sag are performed using MATLAB/SIMULINK. The performance of the system is analysed for reducing the voltage sag in load voltage in distribution network. Actual Simulation model is shown in figure 8. Following are the two cases of simulation.

Case 1: In this case the simulation is performed when the DVR is not connected to the system and three phase fault is considered for the test system delivering the load. Here fault resistance is 0.66 U and ground resistance is 0.4 U. fault is created for the duration of 0.2 to 0.4 seconds the wave form for this case is shown in figure 11.

Case 2: In this case the simulation is performed with same parameters and conditions as stated above but now the DVR is connected to the system to compensate the voltage sag. Wave form for this case is shown in figure 12.From the figure it is observed that the output waveform obtained after compensation is not purely sinusoidal. Figure 9 shows the firing angle pulse generated by PWM generator. Figure 10 indicates the P.U voltage at load point with three phase fault when DVR is not connected. Figure 13 shows the input voltage to the injection transformer without connecting the DVR. Also the Total Harmonic Distortion (THD) of DVR without PI controller is 15% which is reduced to 10% by using PI controller. the FFT analysis is shown in figure 14.

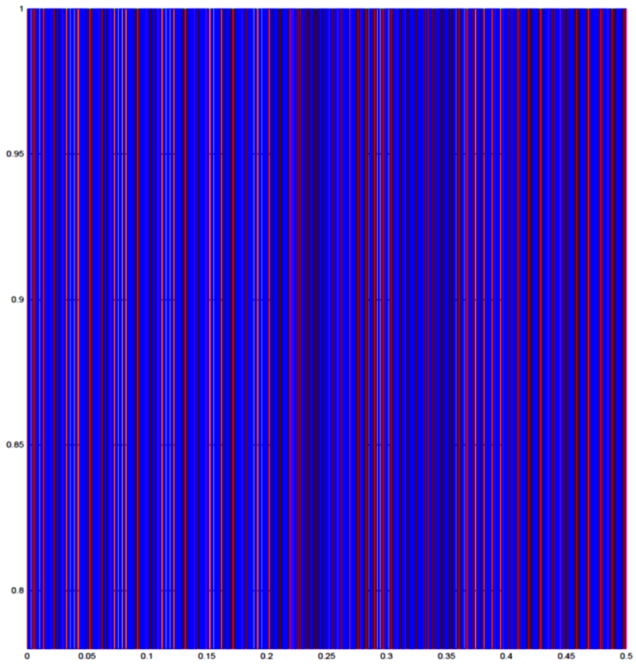

Figure9. Firing pulse generated by discrete PWM generator

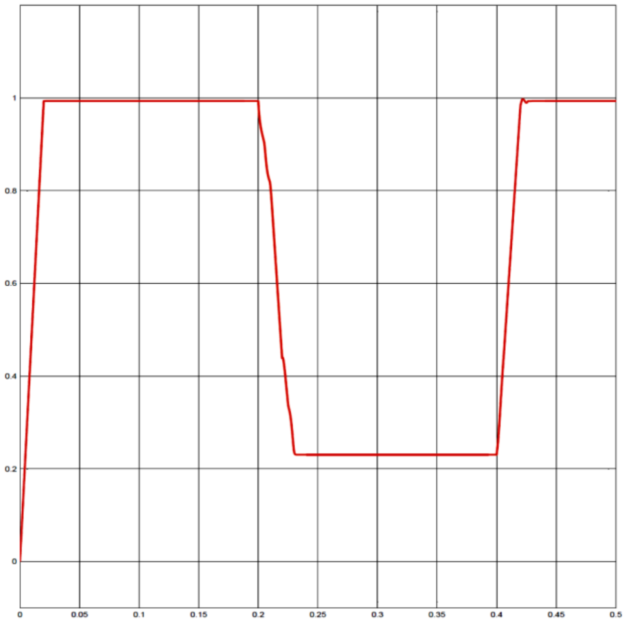

Figure10. P.U Voltage at load point, with 3-Ø fault, without DVR

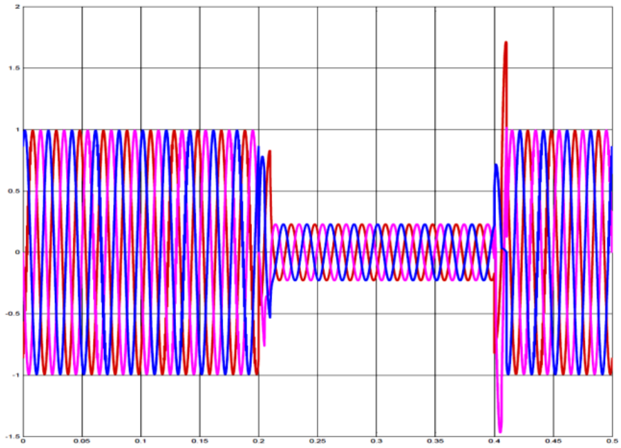

Figure11. 3Phase Voltage at load point, with 3Phase fault, without DVR

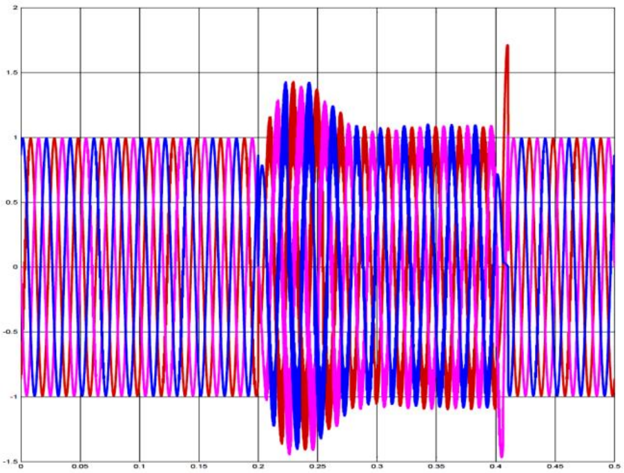

Figure12. 3 Phase Voltage at load point, with 3 Phase fault, with DVR

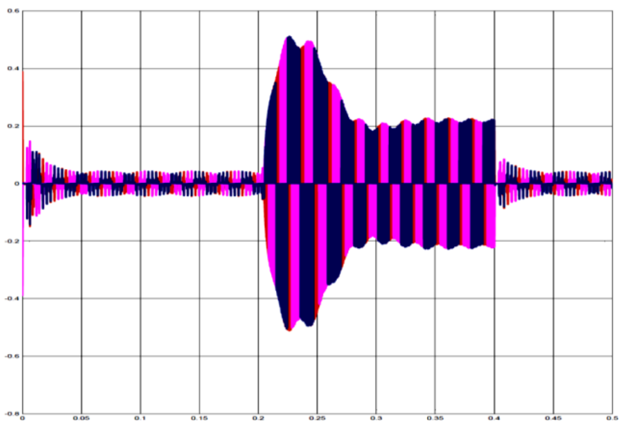

Figure13. Input voltage at injection transformer, without DVR

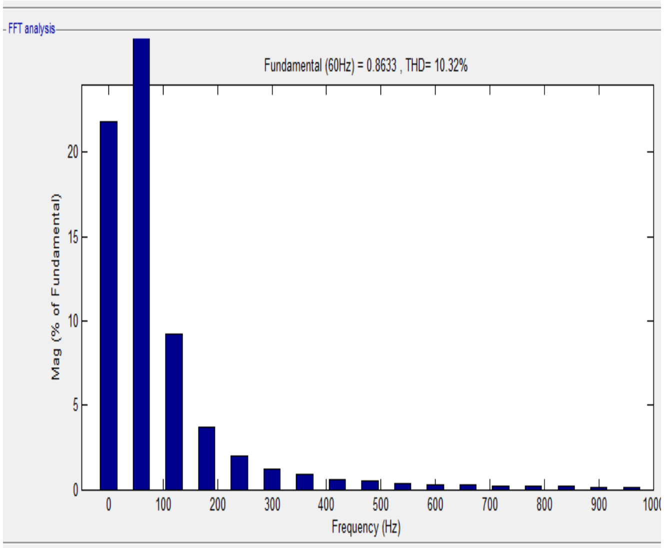

Figure14. FFT analysis

9. CONCLUSION AND FUTURE SCOPE

In this paper, modeling and simulation of DVR is done using MATLAB/SIMULINK software. Thus it becomes easier to construct the large distribution network and analysis of the result shows that the DVR compensates the voltage dip quickly and provides excellent voltage regulation. The dynamic performance capability of DVR increases the number of sensitive equipments to use in the system. Non Linear Controllers such as Neural Network Controller, ANFIS and Fuzzy Controller can be used to get improved result. Simulation can be preformed considering the Dynamic Loads in future.

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AUTHOR PROFILES

1. Yogesh Popat received his B.E (Hons) degree in Electronics & Telecommunication in 2011. Currently he is pursuing M.E in Power Electronics from R.C.E.T, Bhilai, C.G, India
2. Prof. Ashish Sahu received his M.E degree in Power Electronics in 2009.Currently he is working as Assistant Professor at R.C.E.T, Bhilai, C.G, India