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Modeling and Simulation of Multi Layer Feed Forward Neural Network Controller Based Dynamic Voltage Restorer for Voltage Sag Mitigation

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ABSTRACT

Voltage Sag/Swell are the most important Power quality issues which occur due to the utilization of increased number of sophisticated loads in Industrial and Electrical distribution system. Now-a- days Industrial loads are generally based on Power electronic devices which are very sensitive to voltage disturbances. Hence it is mandatory to provide high quality power supply since; failures due to these power quality issues have adverse effect on production time and cost. The Dynamic Voltage Restorer (DVR) is most important Custom Power Device (CPD), with its effective and reliable dynamic capabilities, when connected in between load end and source end, can compensate for voltage sag and hence maintaining the line voltage to its nominal value. This paper depicts the modelling and simulation of DVR with Neural Network controller to mitigate the voltage sag in industrial and electrical distribution system. The proposed controller provides optimal mitigation of voltage sag. Simulation is performed using MATLAB/Simulink; to demonstrate that DVR maintains the load voltage level to the nominal value by injecting a suitable voltage level during the occurrence of voltage sag.

Keywords: *Voltage Sag, Dynamic Voltage Restorer (DVR), Custom Power Devices (CPD), Neural Network.*

1. INTRODUCTION

The main concern of the consumer is cost, quality, continuity, and reliability of the supply for various loads in industries and electrical distribution system. Now-a-days, there are hundreds of generating system and thousands of different kinds of loads interconnected through long transmission and distribution networks.

Power quality is generally described as the suitable characteristics of electrical energy supplied to load that allows maintaining the continuity of supply, without causing faults in the components [1]. Poor quality supply affects, in minor or major grade, several devices and consequently the different process in industries, where the economic consequences could be very important [2].

Voltage sags are the most frequent and important power quality issue in electrical supply and as per the IEEE 1159 standard it is defined as sudden reduction of rms voltage from 10% to 90% of the nominal level, with duration of half cycle to one minute. Main reason for the occurrence of voltage sags are connection/disconnection of large loads, starting of large motors, overloads etc. Voltage swell is defined as the sudden rise in rms value of voltage from 110% to 180% of nominal value with duration of half cycle to one minute [3].voltage swells are not as frequent as voltage sags. This fault occurs with the disconnection of large loads or capacitor banks, for Example, it can occur on the unfaulted phases during single phase to ground faults [4].

The most effective and cost effective method to mitigate the voltage sag is the introduction of DVR at network-equipment interface. The main purpose of connecting a DVR is to inject a dynamically controlled voltage in series with the three phase supply through the 3 single phase transformer to provide the necessary correction in load voltage. The effectiveness of DVR generally depends on three basic criteria: (1) Method to obtain reference voltage. (2) Design of Voltage source converter (VSC). (3) Energy storage device.

Proper control of DVR is needed to obtain the best compensation result. In recent years, the controller using linear control strategies are utilized. In case of linear controllers such as PI controllers, the system equations are linearized at a particular operating point and then tuned based on these linearized models. PI controllers are tuned in order to obtain best possible result. The main demerit of using linear controllers is the degradation in its performance as the operating condition changes. So these

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linear controllers can be replaced by non linear controllers which provide control over wide range of operating conditions but they are more difficult to implement as compare to linear controllers [8, 9]. Also, Non linear controllers such as neural network and fuzzy based controllers require a large data base that characterise the operation of the system with logical analysis rather than mathematical analysis to the control system. This paper depicts the utilization of Artificial Neural Network (ANN) based controller and its proper performance for mitigation of voltage sag in industrial and electrical distribution system. The simulation is performed in MATLAB/Simulink environment.

2. TYPICAL TOPOLOGY OF DVR

The main function of DVR is to control the value of voltage applied to the load by injecting a voltage with appropriate characteristics, so that the nominal load voltage is maintained even when a fault or disturbances are present in the supply. In DVR, VSC is connected in series with the supply by means of coupling transformer as shown in figure 1. The load voltage is the sum of voltage of the grid and the injected voltage by DVR, that is,

(a) $V_L = V_S + V_{DVR}$

DVR is composed of following elements:

Voltage Source Converter (VSC): It supplies energy during compensation of voltage. Different kinds of energy storage systems such as batteries, capacitors etc are used to deliver the stored DC energy generally the Insulated Gate Bipolar Transistor (IGBT) is used in the structure of converter controlled by Pulse Width Modulation Techniques.

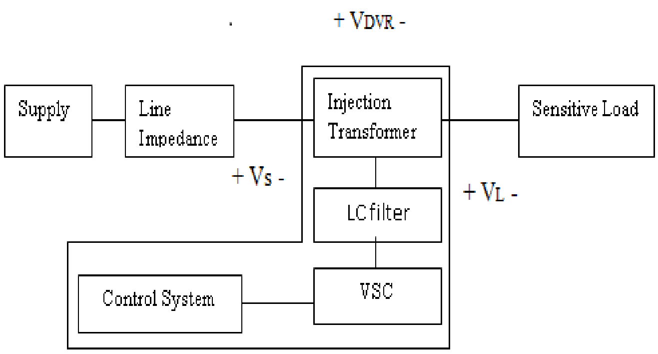

Figure 1 block Diagram of DVR

Passive LC filter: It consists of Inductances L, Capacitances C, used to eliminate the high frequencies in the inverter output.

Injection Transformer: It is a three phase transformer. Its low voltage winding is connected to the line in series and the high voltage winding is connected to the output of LC filter coming from three phase inverter. It is also important that the injection transformer may cause the voltage drops that must be under consideration during the control of DVR. The extent of energy storage is determined by the power given by the inverter and maximum duration of voltage disturbance. Generally, the controller is designed to work in certain range of maximum to minimum duration of the event [9].There are other topologies of DVR which have no energy storage unit and the injected power is provided through a transformer from the grid via a rectifier [10]. Location of DVR is shown in figure 4.DVR is connected in primary distribution feeder. This location of DVR compensates the certain group of customer by faults on the adjacent feeder shown in figure 2. 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. Magnitude of Voltage Sag at PCC in radial system is given by the following equation,

(b) $U_{Sag} = Z_f / (Zs + Z_f)$

Z_f indicates the impedance between the PCC and the fault including line and fault impedance and Zs indicates the source impedance including the transformer impedance.

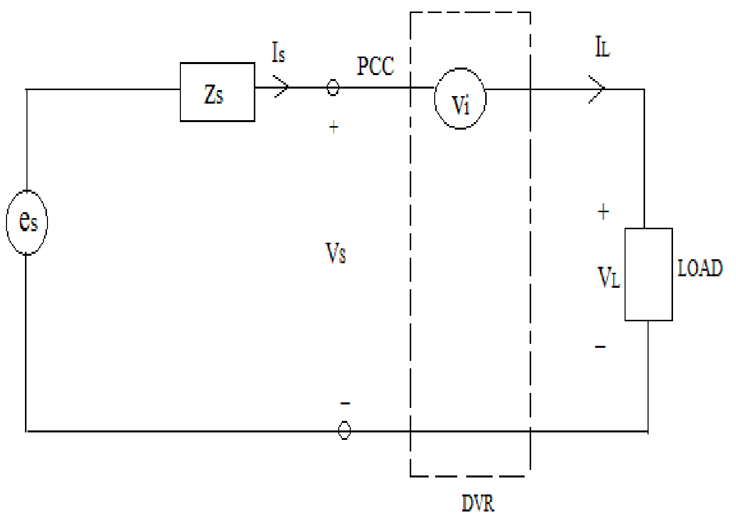

Figure 2 Location of DVR

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The voltage sag energy is defined mathematically by the following equation

$$\text{(c) } Evs = \int_0^T x^2 dt \text{ where } x = 1 - \frac{V(t)}{Vnom}$$

Where V is the magnitude of voltage and Vnom is the nominal voltage and T is the duration of sag.

3. POWER FLOW STUDY IN DVR

The DVR must be controlled in such a manner that the voltage across the load is sinusoidal and equals the desired level. Hence the DVR must be capable of injecting the voltage difference between the supply and ideal desired voltage across the load. The load voltage and source voltage are considered to be in phase and this condition can be achieved by injecting a voltage in phase opposition or in phase with supply voltage. Under the voltage sag condition; this causes a bidirectional power flow through the booster transformer. The positive or negative voltage must be injected by the DVR, according to the voltage sag and supply voltage amplitude due to which the reactive power is supplied or absorbed by the DVR. In this study the load is considered to be non linear with power factor of 0.9. The single phase DVR circuit is shown in figure below.

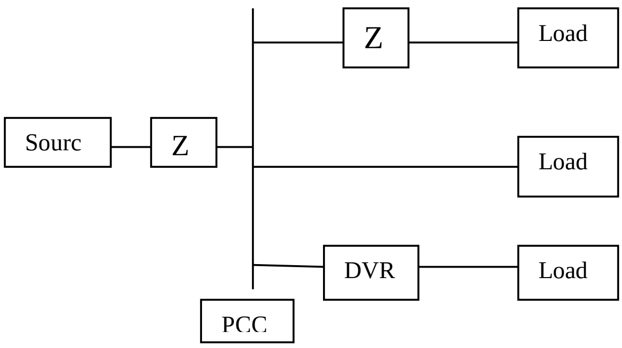

Figure 3 Location of DVR

In figure e_S and I_S is the supply voltage and current respectively Vs is the voltage at the point of common coupling (PCC), Vi is the voltage injected by DVR and V_L and I_L is the load voltage and current respectively. V_L is taken as phase reference and $\cos\Phi_L$ is the power factor corresponding to the load. It can be said that

(1) $V_L = V\angle 0°$

(2) $i_L = I_L\angle{-\Phi_L}°$

(3) $V_S = V_L(1 + K)\angle 0°$

(4) $K = (V_S - V_L)/V_L$

Where K is the voltage fluctuation factor at the point of common coupling. The injected voltage by DVR is given by

(5) $V_i = V_L - V_S = -K V_L\angle 0°$

Assuming the DVR to be lossless, active power at the connecting point is equal to the active power required by load. This can be expressed as follows

(6) $P_S = P_L$

(7) $V_S I_S = V_L I_L \cos\Phi_L$

(8) $V_L(1+K) I_S = V_L I_L \cos\Phi_L$

(9) $I_S = I_L(1+K)^{-1}\cos\Phi_L$

Equation 9 indicates that the supply voltage depends on both K, $\cos\Phi_L$ factor and the load current I_L. Apparent power absorbed by the DVR is given by

(10) $S_i = V_i I_S$

(11) $P_i = V_i I_S \cos\Phi_S = -K V_L I_S \cos\Phi_S$

(12) $Q_i = V_i I_S \sin\Phi_S$

If $Q_i = 0$ then p.f = 1at load side

(13) $P_i = V_i I_S = -K V_L I_S$

Normal Operation

In this case the DVR does not exchange any reactive or active power with the network. Following vector diagram illustrates the normal operating condition

For Voltage Sag Condition

In Sag condition $V_S<V_L$ and as per equation (4), where K<0, it depicts that the active power is injected by DVR to the network. Also at the voltage sag time, reactive power is absorbed by the DVR through booster transformer. Following vector diagram illustrates the voltage sag condition.

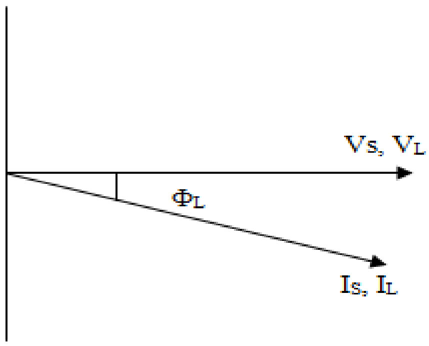

Figure4 Phasor Diagram for normal operation

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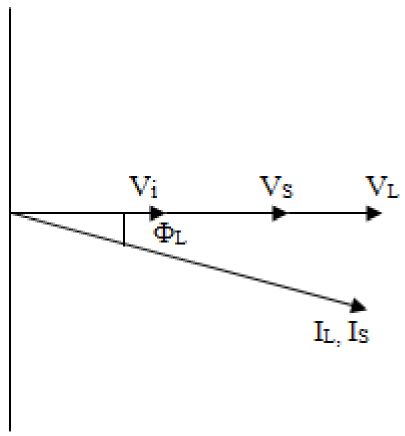

Figure5 Phasor Diagram for Sag Condition

4. MODELING OF NEURAL NETWORK (NN) CONTROLLER

From the Analysis of PI controller it is observed that for real time processing this controller is not reliable because the gain of the PI controller has to be adjusted repeatedly for obtaining the required output so in this paper a Multilayer feed forward Neural Network (MLFNN) controller is proposed to calculate the error signal. For the proper operation following are the fundamental steps for the modelling of neural network controller.

Step 1 – Analysis of the input for NN controller.

Step 2 – Selection of NN controller.

Step 3 – Analysis of the desired output.

Figure 6 shows the developed simulation model of NN controller and its consequent parts.

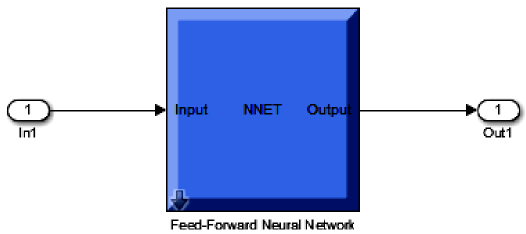

Figure6 Developed simulation model of NN controller.

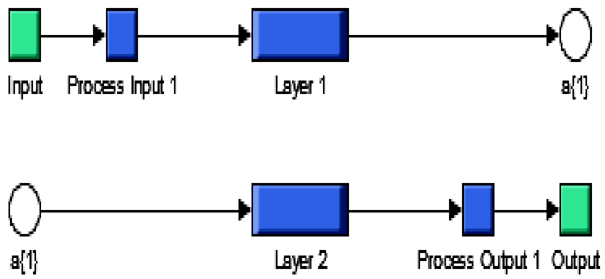

Figure7 Internal architecture of NN controller.

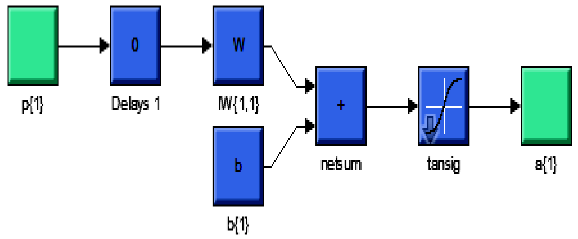

Figure8 Internal architecture of Layer one.

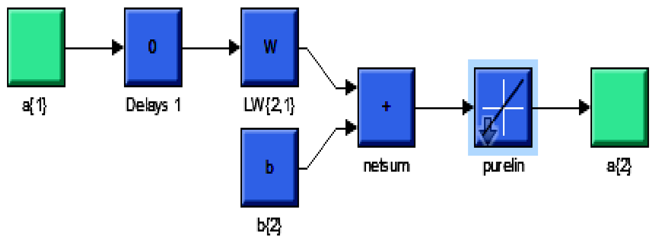

Figure9 Internal architecture of second Layer

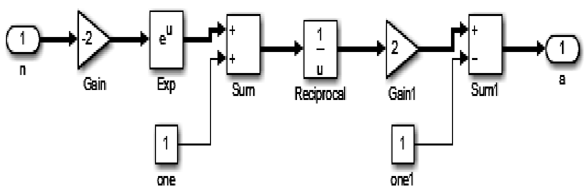

Figure10 Transfer function (tansig) used in first layer

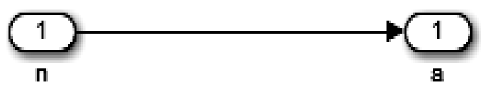

Figure11 Transfer function (purelin) used in second layer

After the modelling of NN controller, the generated control signal is analysed. Figure 12 shows the

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control signal generated by NN controller in response to the error signal obtained from outer loop subtraction.

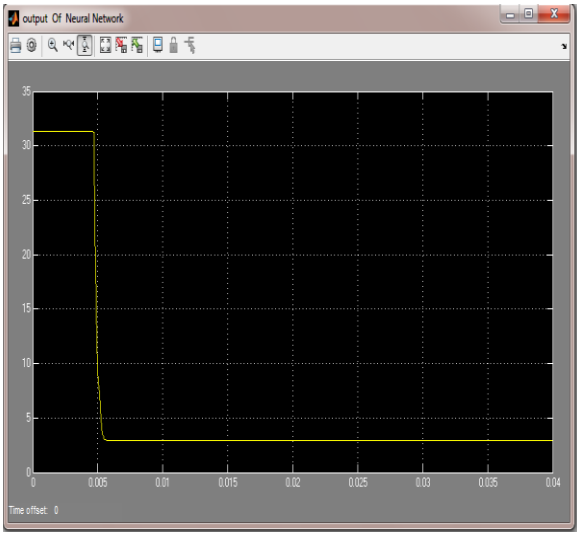

Figure12 Control Signal Generated by NN Controller

Figure shows the efficient control of NN controller, it is nearly observed that at 0.005 seconds output of NN controller is nearly constant to 3 and remain constant for all further values.

5. MLFFNN BASED CONTROLLER ALGORITHM

Multilayer feed forward Neural Network is the most popular topology used now-a-days. [9-10]. This type of network consists of a set of output neurons, called hidden layers. The information is provided to the input layer, which passes through the hidden layers and finally the output is obtained from the output layer. 'w' is the weight matrices by which a three layer MLFNN is interconnected and 'b' is the bias vectors which are the free parameters.
'w' and 'b' is modified by training the NN in such a way that the controller approximates these function to system function, which leads to the minimization of error 'e' which is the difference between actual output 'y' and reference function. Each input in the input column vector 'x' is weighted with an appropriate 'w'. Weighted input and the bias form the input to the transfer function 'f'. 'a' is the activation vector, given by

(14) $a = \sum (w.x + b)$

Here the neurons use the tan-sig function in input layer and the hidden layer, given by

(15) $\text{tansig}(a) = 2(1+e^{-2a})^{-1} - 1$

Purelin is a linear transfer function used in the output layer, given by

(16) $\text{purelin}(a) = a$

In this proposed work, least means square (LMS) algorithm is utilised to supervise training. In this method the learning rule is provided with a set of desired network behaviour.

$\{x_1,y_1\}\{x_2,y_2\}\_\_\_\_\_\ \{x_n,y_n\}$

Here x is an input to the network; y is the corresponding target output. As each input is applied to the target, network output is compared to the target. The error signal is obtained as the difference between the target output and network output. The mean of the sum of these errors are obtained as,

(17) $\varepsilon = (1/n)\sum e(k)^2$

(18) $\varepsilon = (1/n)\sum (y(k) - y'(k))^2$

Here y' is the network output and y is the target output.

6. TEST MODEL OF DVR

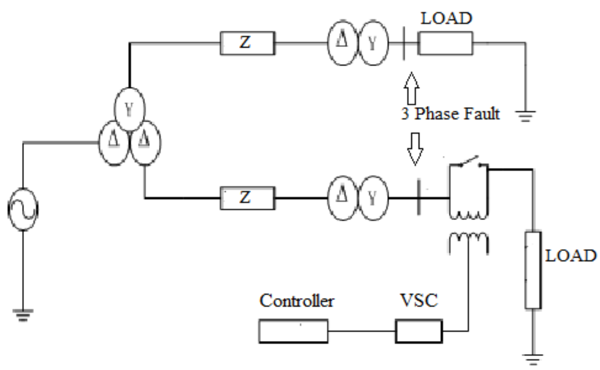

Figure13 DVR Test Model

Single line diagram of the test system for DVR is composed of 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.

7. 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 Ω, Lm = 0.77031 H, Pn = $250e^6$ VA, Fn = 50Hz

8. SIMULATION MODEL

Figure 14 shows the actual simulation model to compensate the voltage sag using Neural Network controller

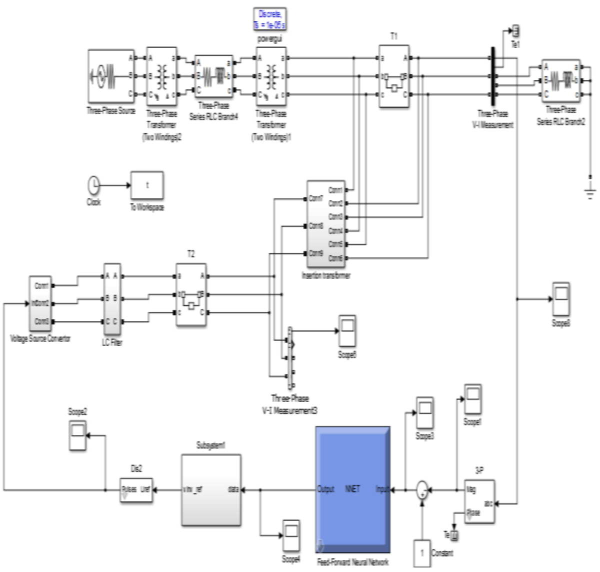

Figure14Actual Simulation Model

9. RESULT & 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 the 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 17.

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 18.From figure it is observed that the output waveform obtained after compensation is purely sinusoidal. Figure 15 shows the firing angle pulse generated by PWM generator. Figure 16 indicates the P.U voltage at load point with three phase fault when DVR is not connected. Figure 19 shows the input voltage to the injection transformer without connecting the DVR.

Also the Total Harmonic Distortion (THD) of DVR without NN controller is 15% which is reduced to 10% by using NN controller. The FFT analysis is shown in figure 20.

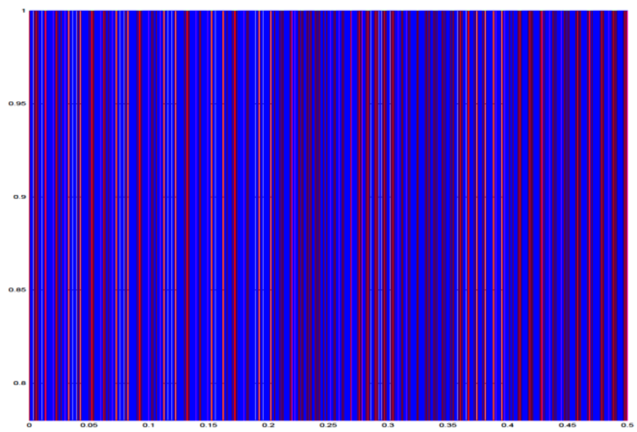

Figure15 Firing pulse generated by discrete PWM generator

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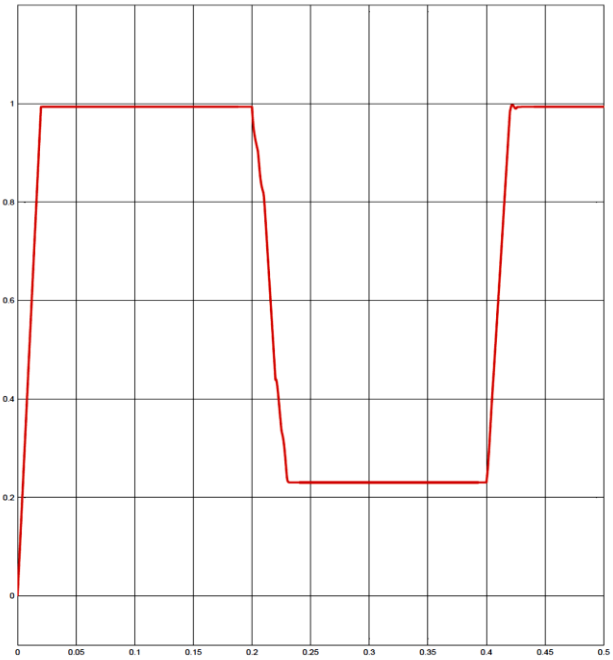

Figure16 P.U Voltage at load point, with 3-Ø fault, without DVR

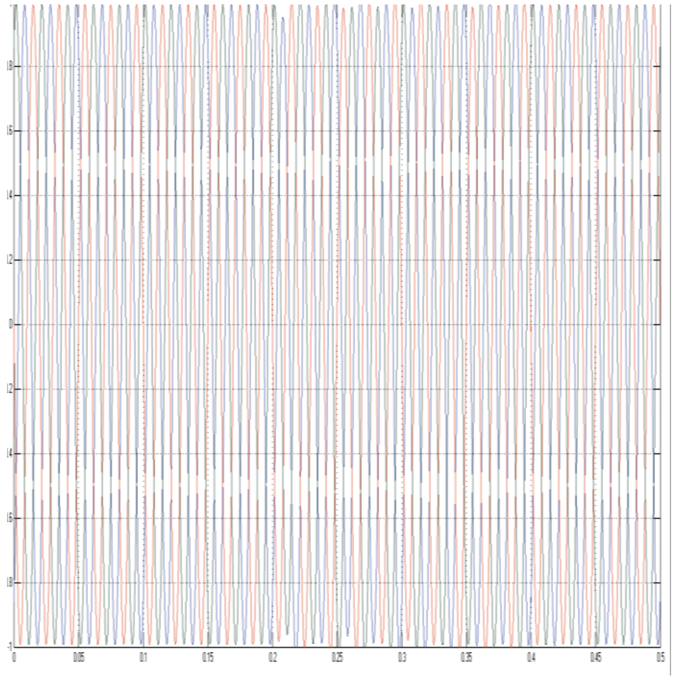

Figure18 3 Phase Voltage at load point, with 3 Phase fault, with DVR

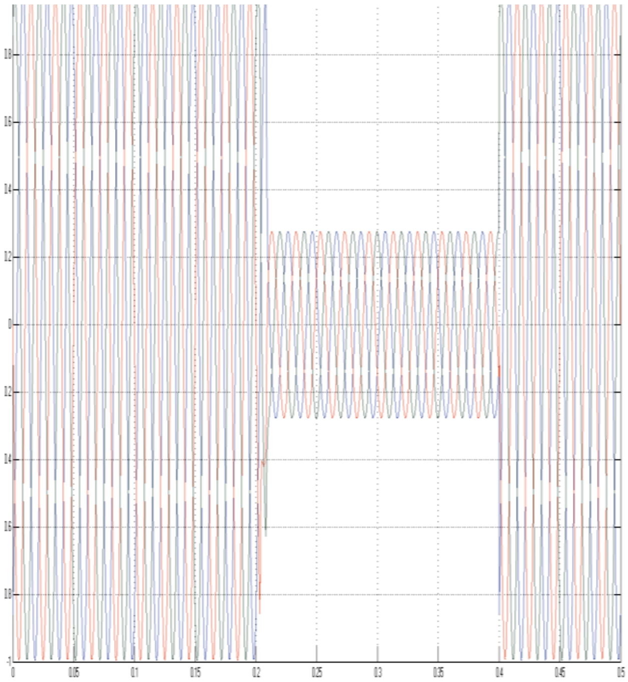

Figure17 3Phase Voltage at load point, with 3Phase fault, without DVR

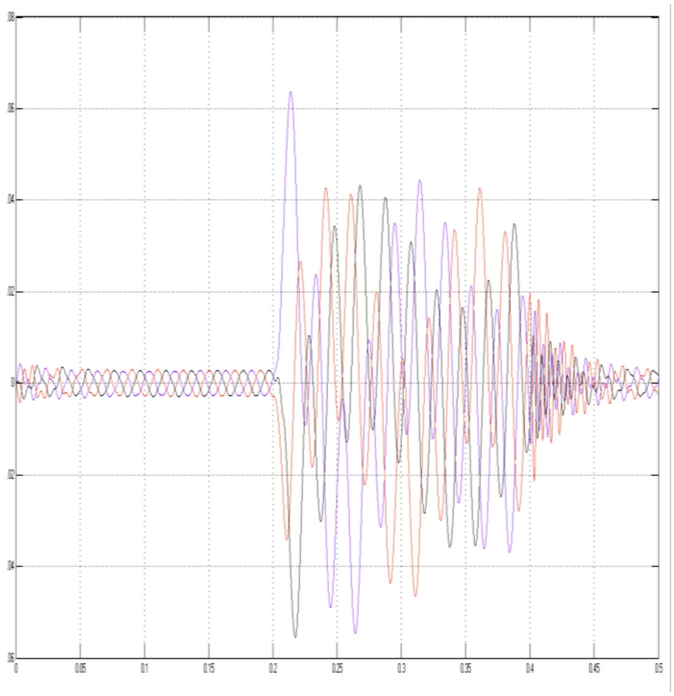

Figure19 Input voltage at injection transformer, without DVR

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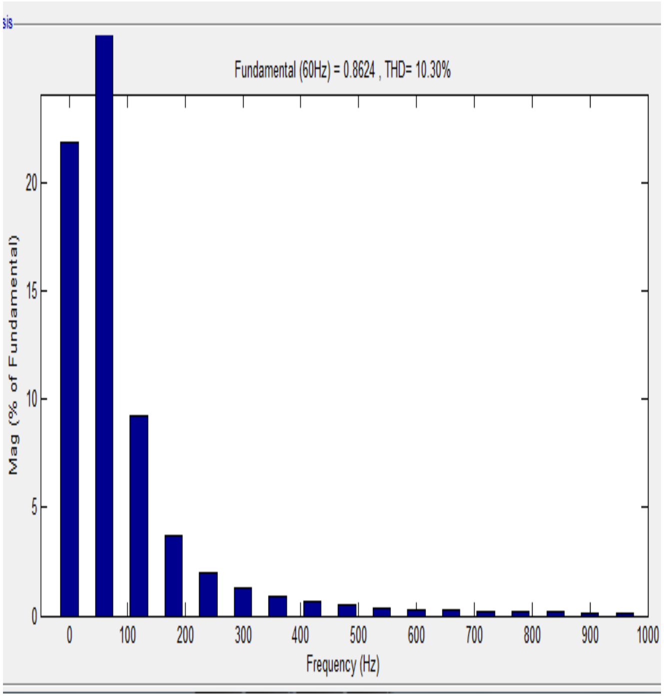

Figure20 FFT analysis

10. 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 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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