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Total Harmonic Distortion (THD) Analysis of Neural Network Controller Based Dynamic Voltage Restorer for Voltage Sag Mitigation

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ABSTRACT

This paper depicts the reduction in level of total harmonic distortion (THD) with Neural Network controller based Dynamic Voltage Restorer for Voltage sag mitigation. In present scenario modern industrial devices and devices in electrical distribution system are mostly based on devices such as electronic drives, microprocessors and programmable logic controllers (PLC) etc. These devices are very sensitive to power quality disturbances. Hence it is required to provide a high quality output power to these devices for their satisfactory operation. Failing to provide a good quality output power to the industrial load may affect the loads badly and sometimes may lead to the complete shutdown of particular equipments or complete industry which results in major financial loss to the industry concerned. So stable, reliable, defect free and high quality uninterruptible power supply must be guaranteed from the supplier or utility side. But the blame for degraded power supply must not be solely put on to the supplier side; it is observed that in most of the cases the reason or the conditions of disrupting the output power quality are generated within the industry. One of the examples of such condition is non linear loads within the plants which may cause transients which may affect the output power quality.

Keywords: *Voltage Sag, Dynamic Voltage Restorer (DVR), Programmable logic controllers (PLC), Neural Network.*

1. INTRODUCTION

Power quality is an important area to be focused in present era; it becomes important due to the sophisticated devices connected to the electrical distribution system and these are much sensitive to quality of supply. Many of the modern processes in industries require large number of electronic devices. As these electronic devices are much sensitive to disturbances, hence industrial loads become less tolerant to power quality issues such as voltage sags, voltage swells and harmonics. Voltage sags are considered to be the most severe power quality disturbance to the industrial loads. Swells and over voltage leads to over heating or even destruction of industrial load such as motor drive. These equipments are very sensitive to harmonics due to dependency of their control on zero crossing or peak value of the supply voltage. The study describes the different control structure for correcting the power quality issue in electrical distribution system by a strong and effective power electronics based device called Dynamic Voltage Restorer. At present the utilization of sophisticated power electronic devices have increased tremendously due to which the quality of the power supply has become a major concern to utilities and consumers. In all the types of power quality disturbances voltage sag is the most common issue in the electrical distribution system. This disturbance is caused generally due to the starting of a large induction motor or due to switching effect [1].

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.

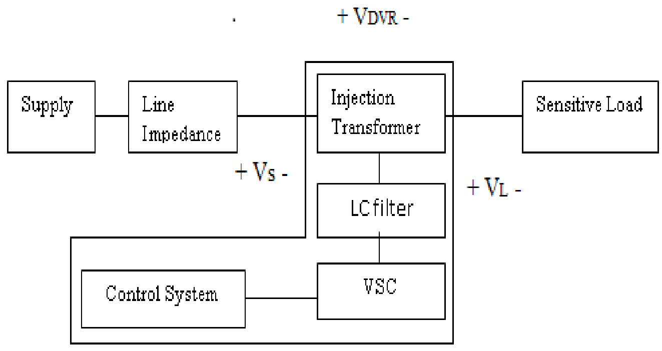

Figure 1 block Diagram of DVR

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.

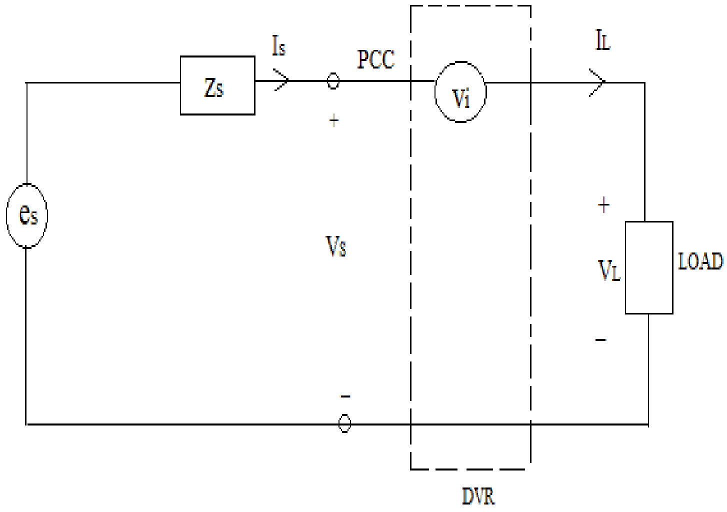

Figure 2 Location of DVR

The voltage sag energy is defined mathematically by the following equation

(c) $Evs = \int_0^T x^2 dt$ 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.

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 [2].

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 [2,3, 4].

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.

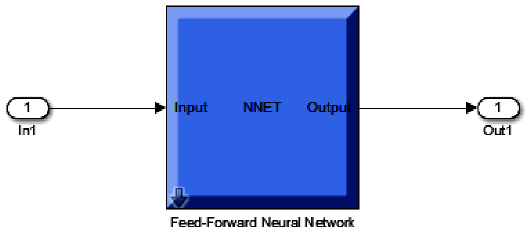

Figure 6 Developed simulation model of NN controller.

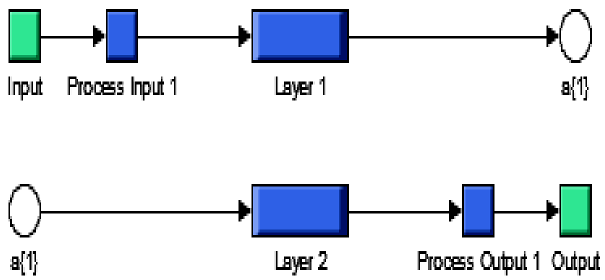

Figure7 Internal architecture of NN controller.

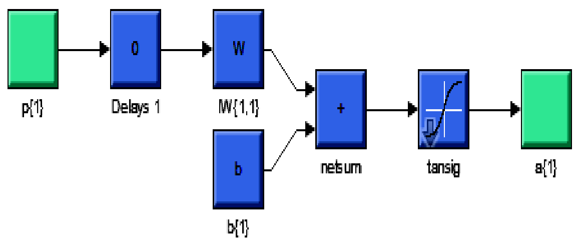

Figure 8 Internal architecture of Layer one.

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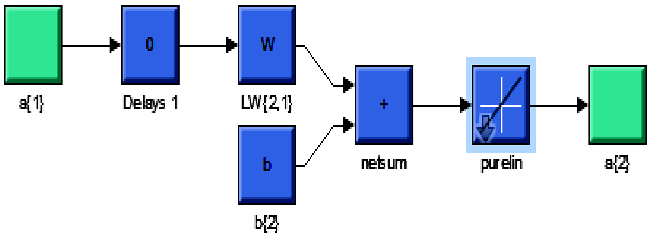

Figure9 Internal architecture of second Layer

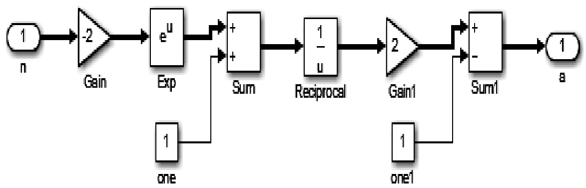

Figure10 Transfer function (tansig) used in first layer

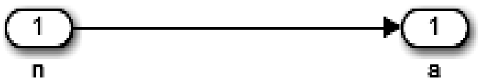

Figure11 Transfer function (purelin) used in second layer

After the modelling of NN controller, the generated control signal is analysed. Figure 12 shows the control signal generated by NN controller in response to the error signal obtained from outer loop subtraction.

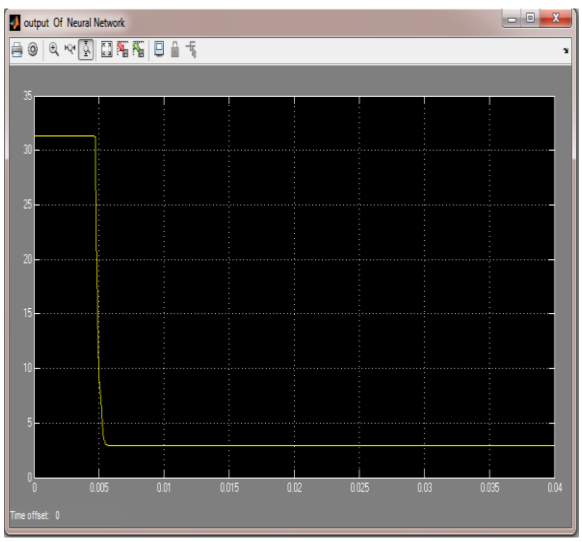

Figure12 Control Signal Generated by NN Controller

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. NEURAL NETWORK CONTROLLER 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) $\varepsilon = (1/n)\sum e(k)^2$

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

Here y' is the network output and y is the target output [2,3]

6. TEST MODEL OF DVR

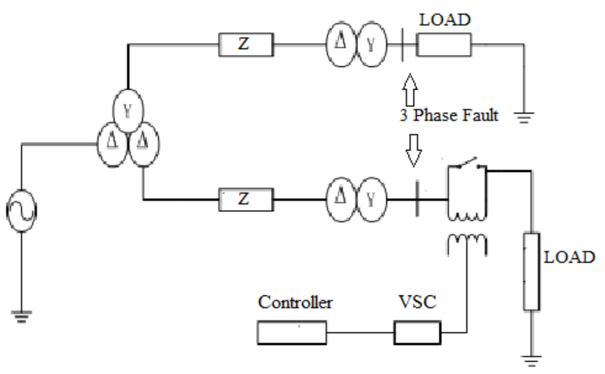

Figure13 DVR Test Model

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

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

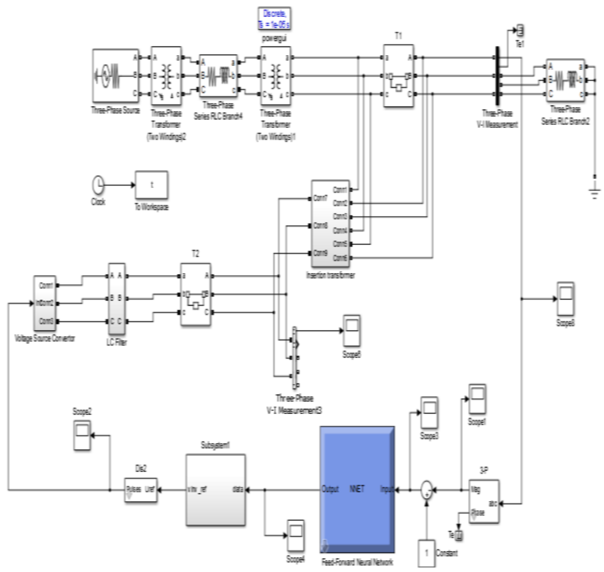

Figure14Actual Simulation Model

7. 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.

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.

7. 1Results for Simulation Model of DVR Test System with NN Controller

7.1.1 Results for voltage sag fault

7.1.1.1 Results for uncompensated system for balanced voltage sag fault without NN controller

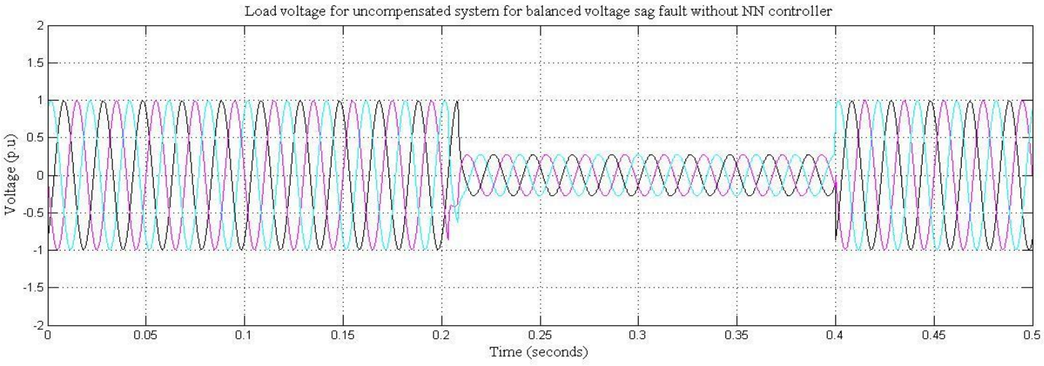

Figure 15 Load voltages for uncompensated system for balanced voltage sag fault without NN controller

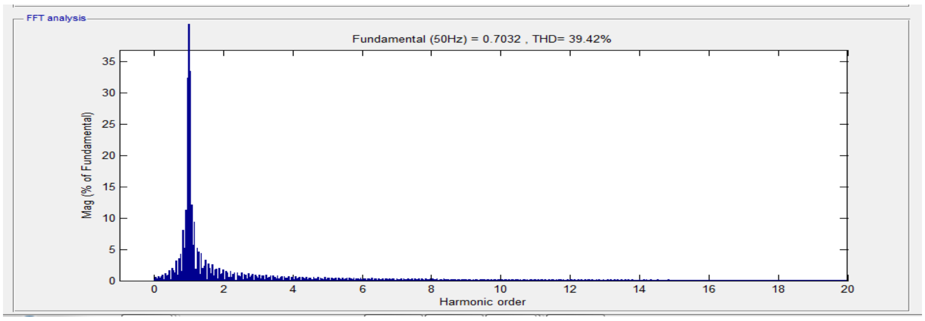

Figure 16 FFT analysis for phase A of Load voltage for uncompensated system for balanced voltage sag fault without NN controller

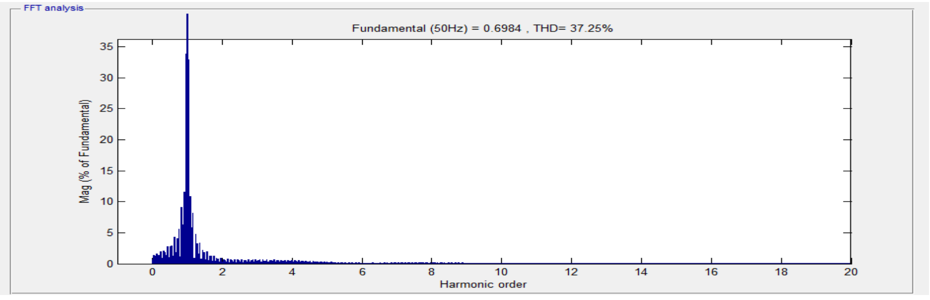

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Figure 17 FFT analysis for phase B of Load voltage for uncompensated system for balanced voltage sag fault without NN controller

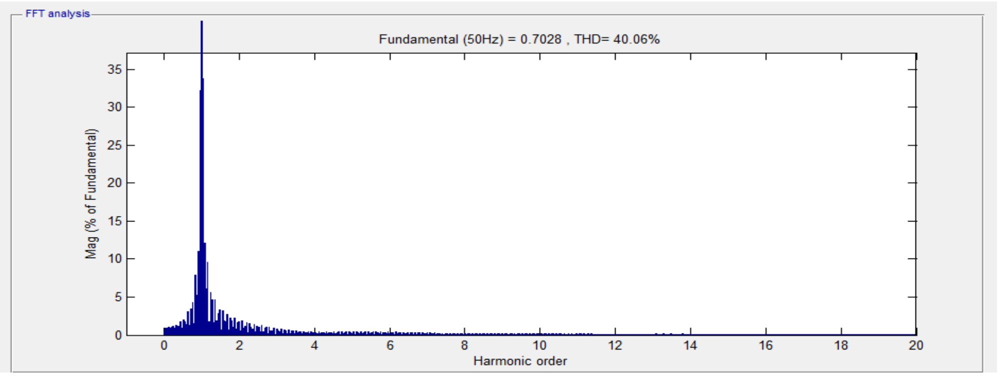

Figure 18 FFT analysis for phase C of Load voltage for uncompensated system for balanced voltage sag fault without NN controller

7.1.1.2 Results for compensated system for balanced voltage sag fault with NN controller

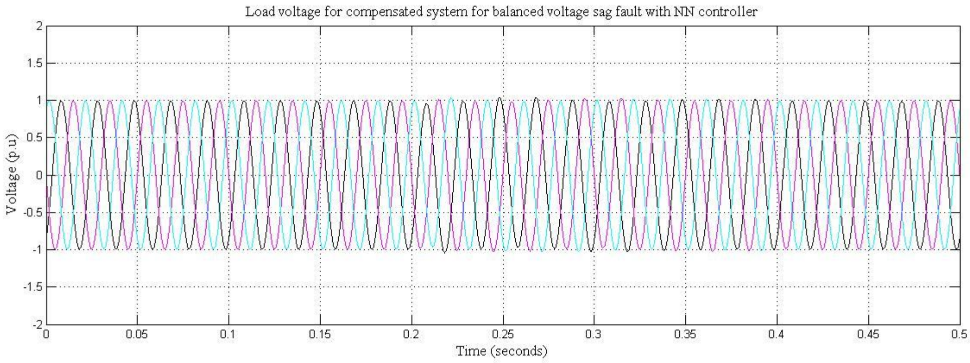

Figure 19 Load voltage for compensated system for balanced voltage sag fault with NN controller

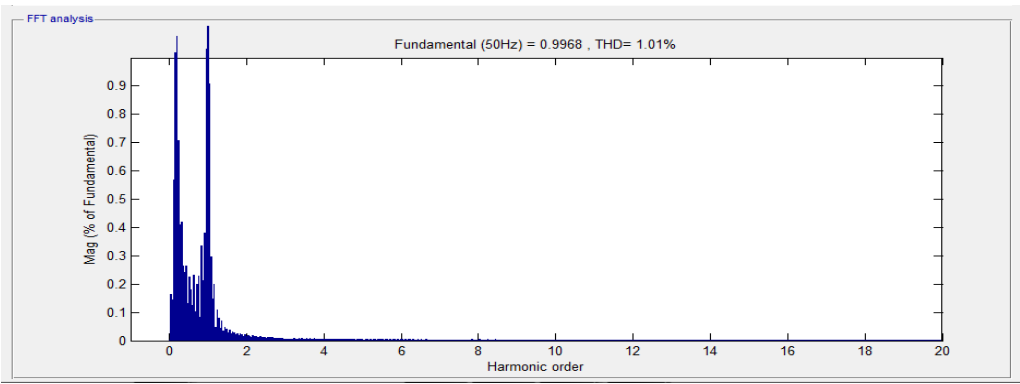

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Figure 20 FFT analysis for phase A of Load voltage for compensated system for balanced voltage sag fault with NN controller

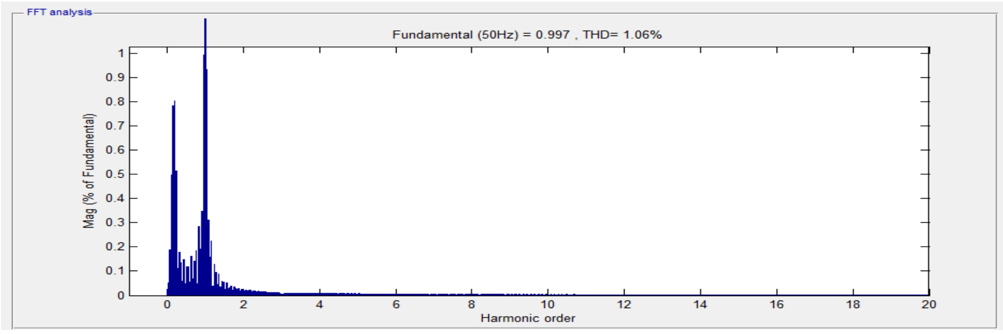

Figure 21 FFT analysis for phase B of Load voltage for uncompensated system for balanced voltage sag fault without NN controller

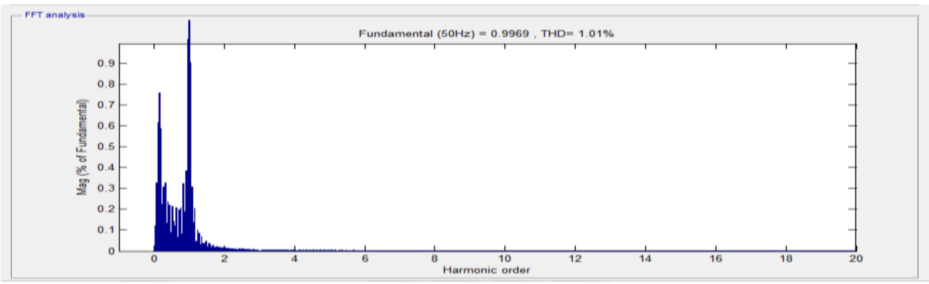

Figure 22 FFT analysis for phase C of Load voltage for uncompensated system for balanced voltage sag fault without NN controller.

7.2 THD Analysis:

Table 2 THD without and with compensation

Phases	THD for voltage sag before compensation	THD for voltage sag after compensation
A	39.42%	1.01%
B	37.26%	1.06%
C	40.06%	1.01%

8. CONCLUSION

In this paper, the total harmonic distortion of compensated voltage sag with neural network controller based dynamic voltage restorer is shown

REFERENCES

[1] Yogesh Popat, Ashish Sahu, "Modeling and Simulation of Dynamic Volatge Restorer using Proportional Integral Controller to compensate Voltage Sag in Electrical Distribution System", ITEE Journal, Volume 3 Issue 4,2014,pp-04-09.

[2] Yogesh Popat, Ashish Sahu, "Modeling and Simulation of Multi Layer Feed Forward Neural Network Controller based Dynamic Voltage Restorer using Proportional Integral Controller to compensate Voltage Sag in Electrical Distribution System", ITEE Journal, Volume 4 Issue 1,2015,pp-17-24.

[3] Rachid Dehini, Adbesselam Bassou, Benachaiba Chellali, "Generation of Voltage References Using MLFNN", PREZEGLAD ELECTROTECHICZNY (Electrical Review), 2012,pp 289-292.

[4] S.S. Choi, B.H. Li and D.M. Vilathgamuwa, "Dynamic Voltage Restoration With Minimum Energy Injection", IEEE Transaction on Power Sytem, Vol. 15, No. 1, Feb 2000, pp- 51-57.

[5] Li Chun, J. Iang Qirong and Xiu Lincheng, "Reactive Power Control of STATCOM using PID Auto Tuning Techniques and Fuzzy Set", Control Theory and Application china, 6th Vol. 17, Dec 2000, pp 856-860.

[7] P. Usharani, "Modeling and Simulation of Multilevel Inverter Based Dynamic Voltage Restorer for Voltage Sag Compensation", Australian Journal of Basic & Applied Science, Feb 2014, pp 162-167.

[8] Md. Riyasat Azim, Md. Asharful Hoque, "A Fuzzy Logic Based Dynamic Voltage Restorer for Voltage Sag Mitigation For Induction Motor Loads", Sep 2011, Vol. 30, No. 8, pp 9-18.

[9] W.Danesh, N. Muktadir, S, Bhowmik, S. Alam, "A Review of Neural Network Methodology To Different Aspects of Electrical Power System, International Journal of Science & Advanced Technology, 2011, pp 1-7.

[10] M.V Rajesh, R. Archana, A. Unnikrishnan, R. Gopikakumari, Jeevamma Jacob, "Evolution of ANN Based Non Linear System Models in MSE and CRLB Senses, World Academy of Science Engineering & Technology 48, 2008, pp-211-215.

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