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Power Quality Enhancement in Power Distribution system using Artificial intelligence based Dynamic Voltage Restorer

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Abstract: The power quality enhancement is very mandatory with the newer generation load equipments, whose performance is very sensitive to power quality disturbances especially with voltage sag, Harmonics and Interruption. The power electronic based power conditioning devices can be the effective solution to enhance the quality of the power supplied to the power distribution system. The series connected Dynamic Voltage Restorer (DVR) is one of the effective solution to mitigate power quality problems in the distribution system. In this paper, the Artificial Neural Network (ANN) controlled DVR is designed and the performance of the rectifier load connected system is investigated with conventional Proportional-Integral (PI) controller. The Levenberg-Marquardt (LV) Back propagation algorithm is used to implement the control scheme of the Voltage Source Inverter (VSI). The ANN is trained offline using data from PI controller. In addition to the compensation of voltage sag and harmonics, the DVR is also used to protect a linear load from various disturbances in the source voltage. Three different types of faults with two level of voltage sag are analyzed and the performance of DVR with these disturbances is modeled using MATLAB/SIMULINK. The comprehensive result of the PI and ANN controllers are also presented.

Keywords:
Artificial Neural Network (ANN), Custom Power Devices (CPDs), Dynamic Voltage Restorer (DVR), Proportional-Integral (PI),Power Distribution system, Power Quality (PQ).

1. Introduction

The present electric power distribution system have rising of electronics, electrical devices are flattering smaller and more sensitive to power quality deviations [1]. The load equipments of the modern generation are more sensitive than the equipment used in the past. The deficiency of power quality can initiate production loss, economic loss and environmental effect. The sags, swells and harmonics are the most important and frequently occurring power quality problems in the distribution system. The CPDs are used in the power distribution system to mitigate the above mentioned power quality problems. In addition to that the CPDs are also used to compensate reactive power, current harmonics filtering, load current balancing and power factor correction [2].The performance of CPDs for instance DVR in electric power distribution system to amendment the PQ is greater significance. The DVR is able to compensate load voltage from the incoming distorted source voltage [11].

The use of neural network, fuzzy logic, and genetic algorithm in power conditioning devices are the newest techniques for the fastest response. Neural networks are composed of numerous elements operating in parallel, which is, inspired by biological nervous systems. In general, the network function is determined mostly by the connection between elements. To obtained a particular function by training neural network through adjusting the value of

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weights between elements. The neural network is trained offline using data from conventional PI controller [5]. It will provide fast dynamic response

In this paper, an ANN controlled DVR is modelled for PQ enhancement in a three-phase, three wire, power distribution system. A three leg VSI is used to inject or absorb the appropriate voltage through an LC filter and an injection transformer to compensate load voltage from the distorted supply voltage.TheLevenberg-MarquardtBack propagation algorithm is used to implement the control scheme of the VSI. Initially the data from PI controller is stored in workspace. These saved data is trained offline using ANN. In addition to that, the DVR is also used to protect the sensitive linear load. The simulation results show the effectiveness of the voltage restoration and its performance investigation of both control techniques.

2. Configuration

The proposed DVR system composed of VSI, LC filter, Energy storage, controller and an injection Transformer as shown in figure 1. The VSI inject an appropriate voltage to restore a sensitive load voltage through an injection transformer and LC filter from an external energy storage unit.

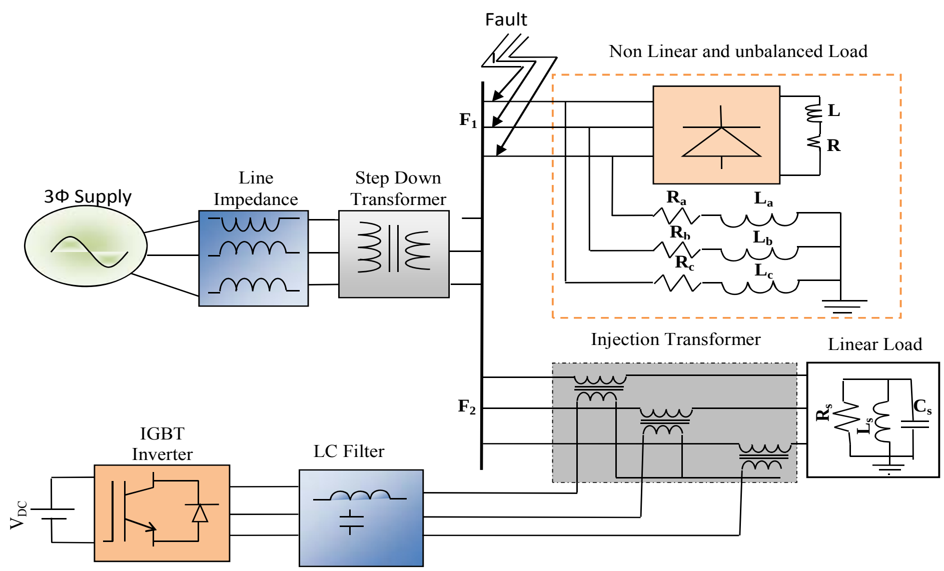

Figure 1. DVR topology using VSI

The VSI converts the input DC supply to the 3Φ controllable AC supply. The IGBT (Insulated Gate Bipolar Transistor) based VSI gives an output with higher frequency harmonic content waveform. To mitigate this problem and provide good power quality supply an LC filter is used. The LC filter is sited next to the VSI, to reduce the switching harmonics. So the harmonic free supply is passing through the series transformer and it will also reduce the rating of the injection transformer. Individual 1Φ Transformer is used for all the three phases. The higher rating of the transformer having lower harmonics but the cost of the transformer linearly increases with its rating.

The operating voltage of the proposed system is 415V, 50Hz. Initially the 11KV source voltage is stepped down to 415V by step down transformer. The value of voltage and current presented in this paper are converted into per unit (p.u.). All the parameters used in the simulation model of the proposed system are given in the Appendix. The voltage sag is initiated by faults on the feeder-1(F_1), so the voltage drop occurred at the feeder-2(F_2).

Whenever the voltage sag is detected at F_2, the DVR will inject a compensating voltage through an injection transformer. Hence the voltage at F_2 is always sinusoidal and balanced.

Two loads are connected in the distribution system: Linear load (parallel resistive, inductive and Capacitive load), Non-Linear and unbalanced load (Three phase diode bridge rectifier connected to resistive and Inductive, non linear resistive and inductance load). The Rectifier load which is connected in the F_1 is non linear and unbalanced. The presence of non linear and unbalanced loads at F_1, the voltage at F_2 is distorted. Similarly the fault at the F_1 causes sag at F_2. In the absence of the DVR, the voltage flowing through the F_2 is also distorted.

The DVR is connected in series with the linear sensitive load through an injection transformer. Consequently the series compensating device can tolerate voltage sag and short term interruptions. The injection transformer is also used to boost up the injecting voltage. The DVR is also functioning as a series active filter to mitigate harmonics present in the F_2. So that the rms value of F_2 is sinusoidal and balanced.

3. DVR control strategy

Control strategy is the main part of the DVR system. The main function of a DVR control system is to detect the disturbances occurring in the system and compute the missing voltage to generate gate pulses using Discrete PWM generator, then the IGBT inverter converts the input DC voltage to a sinusoidal AC voltage through an LC filter and injection Transformer. The compensating voltage injected by the DVR system is stopped, only after the absence of the sag disturbance. In this work, the park's transformation is used to calculate the missing voltage. The abc to dqo transformation is transformed the 3Φ stationary coordinate system to dq rotating coordinate system. In abc_to_dq0, the following transformation is used.

$$V_d = \frac{2}{3}\left[V_a \sin \omega t + V_b \sin\left(\omega t - \frac{2\pi}{3}\right) + V_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (1)$$

$$V_q = \frac{2}{3}\left[V_a \cos \omega t + V_b \cos\left(\omega t - \frac{2\pi}{3}\right) + V_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (2)$$

$$V_0 = \frac{1}{3}\left[V_a + V_b + V_c\right] \quad (3)$$

The dq coordinate which is compared with the reference value, will calculate the disturbance in the dq coordinate and these can be transformed again to abc coordinate. The Phase Locked Loop (PLL) measures the system frequency and gives the phase synchronous angle θ for the dq coordinate system. In this work, two different control techniques which are ANN and PI controller are proposed. The comprehensive result for the above mentioned controllers are presented to investigate the performance of each controller in the proposed system.

A. PI Controller

A controller is required to control or to operate DVR during the fault conditions only. The linear load voltage is sensed and forwarded through a sequence analyzer. To eliminate zero sequence components from abc components is the advantage of abc to dqo transformation. The d- coordinate and q-coordinate have separate PI controller. The PI controller is a feedback controller which controlled by the summation of the error and integral of that values as shown in figure 2.

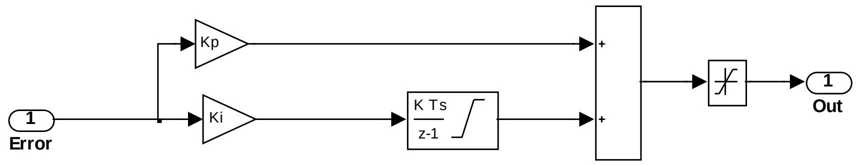

Figure 2. PI Controller

The input of the PI controller is the error between actual voltage (F_2 voltage) and the reference voltage. The reference voltage for d-coordinate is 1 p.u. and q-coordinate is 0 p.u. The proportional and integral gains of the d-coordinate PI controller are 40 and 154 respectively. In q-coordinate PI controller the proportional gain is 25 and its integral gain is 260. The PI controller output is converted to 3 phase voltage and is forwarded to discrete PWM pulse generator. The generated pulse is given to the VSI to trigger IGBT switches.

B. ANN Controller

To improve the performance of the compensating device, a multilayer back propagation type ANN controller is used. The matlab toolbox is used to train ANN. The training algorithm used in the ANN controller is Levenberg Marquardt Back propagation algorithm. Gradient Descent (GD) Method is the first order optimization algorithm and it is used to find a local minimum of a given function. This method is robust when it starts far of the final minimum; however it has poor final convergence. The LM back propagation algorithm is the second order optimization and it interpolates between the GD and the Gauss Newton (GN) algorithm. The LM algorithm is more robust and it finds a solution even if it does begin very far from the final optimum. The LM algorithm is the best by comparing GN algorithm and GD method [12].

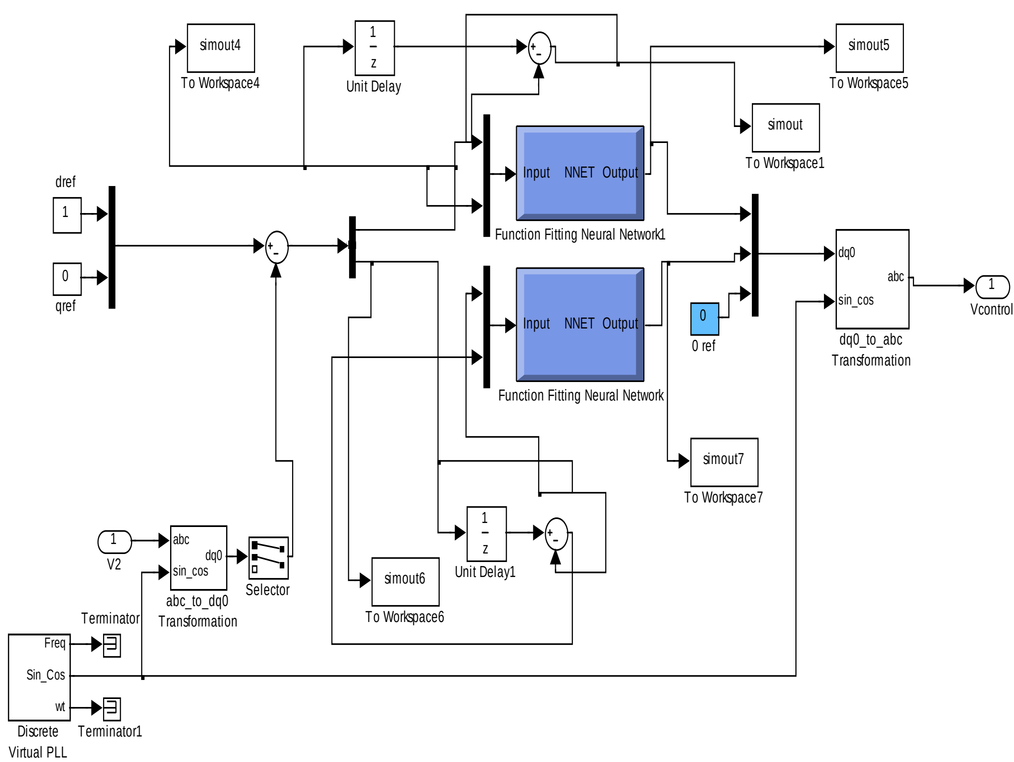

Figure 3. Control circuit with ANN Controller

Faster convergence, low memory required and capable learning are also the advantages of using Levenbergmarquardt back propagation algorithm [9]. All the values are used to train the ANN are taken from conventional PI controller. The designed ANN controller has 3 layers composed of 2 input layers, 10 hidden layers and 1 output layer. The input of the ANN controller is the error and change in error signals from both d and q coordinates system, which is the difference between actual value and reference value. The minimization of the error is the target expected in ANN controller. The output of the ANN controller, is converting dqo to abc components. Mean square error is the performance function of the ANN controller, which is the error between input and target values.

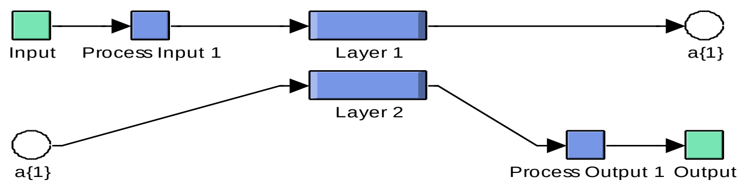

Figure 4. ANN Controller

The ANN training is stopped, if the number of maximum epoch to train is reached or the time is beyond the maximum limit or the performance is minimized to the goal or the performance gradient falls below minimum gradient or initial blending factor (mu) beyond maximum mu or the performance of the validation has increased more than the Maximum validation failures. In this work the number of epoch required to train the ANN in d-coordinate is 67 and the best validation performance is 0.00030248 at epoch 61. In q-coordinate the total number of epochs is 81 and the best validation performance is 0.032883 at epoch 75. The ANN is trained offline and it is designed to control the DVR. After the completion of offline training the generated ANN controller is placed in the replacement of PI controller as shown in figure 3 and figure 4.The Discrete PWM (Pulse Width Modulation) pulse generator generates firing pulses to trigger IGBT switches.

4. Results and discussions

The Modelling of Dynamic voltage restorer with PI and ANN control was simulated using Matlab/Simulink. In this simulation model we have a system in which two parallel feeders F_1 and F_2. In the feeder $F_1$the nonlinear rectifier load and unbalance load are connected. In F_2 the linear RL load is connected and it is considered as a sensitive load. In the feeder $F_2$the series connected CPD is connected in series with the F_2 to protect linear load from various voltage disturbance from the source voltage or from F_1. Here DVR system is connected to the distribution system using a booster or injection transformer. PI control based Dynamic voltage restorer is shown from figure 5 to 10.

The Compensation of 3Φ fault with 50% sag using PI controller based DVR which is shown in figure 5. The first two wave shapes in the entire figure presented in the results, represents input source voltage in volts (V) and F_2 load voltage in volts with respect to time. The next two wave shapes are injected voltage in volts and F_2 load current in amps (A). The last wave shapes represents uncompensated load voltage (F_1 load voltage) in volts. All the values of voltage and current presented in the test system are converted into per unit. The perfect series compensation is to inject only the required amount of voltage, which is the difference between the source voltage and load voltage. It can be seen in figure 5 the amount of voltage sag created is 0.5 pu, so the voltage injected by the DVR is 0.05 pu. The 1:10 ratio of booster transformer is used for injecting voltage to the system, so 0.05 pu injection is equal to 0.5 pu. After compensation the load voltage and current at F_2 are fundamental, balanced and undistorted. In the steady state operation it does not inject any voltage in the distribution system.

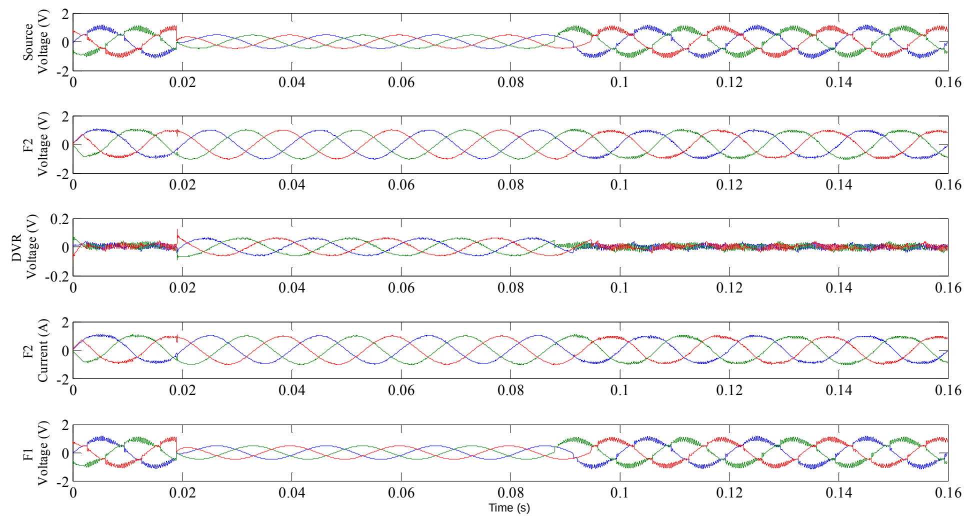

Figure 5. Compensation of 3Φ fault with 50% sag using PI Controller

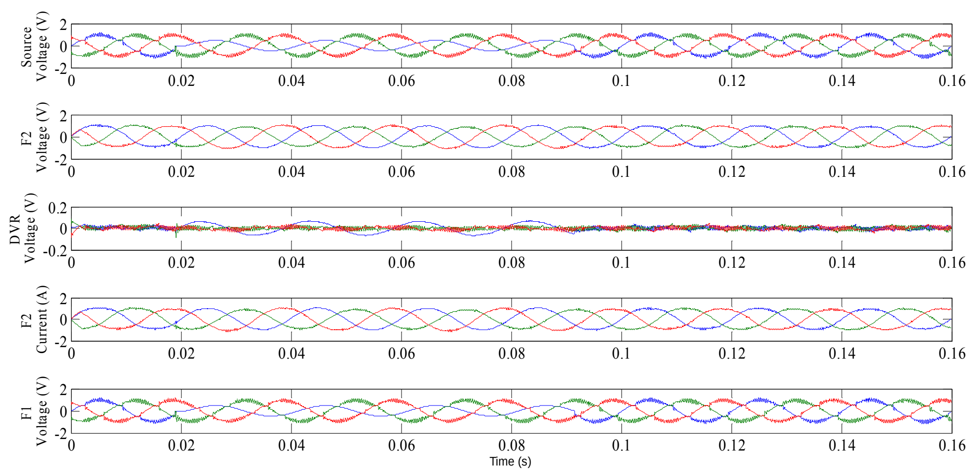

Figure 6. Compensation of single line to ground fault with 50% sag using PI Controller

The duration of fault is from 0.02s to 0.09s at that time the DVR is injected the missing sag voltage. During the fault duration the source voltage and F_1 voltage are distorted heavily due to presence of harmonic component and voltage sag. The Compensation of single line to ground fault with 50% sag using PI controller based DVR which is shown in figure 6. In this type, the fault is applied at Phase A. so that, A phase is only injected by the DVR.

The Compensation of double line to ground fault with 50% sag using PI controller based DVR which is shown in figure 7. In this figure it can be clearly shown that the fault is applied to phase A and phase B. The same phase is injected by the DVR, as shown in the figure 7. Similarly to the above Compensation, the 3Φ fault, single line to ground fault and double line to ground fault with 90% sag using PI controller based DVR, which is shown from figure 8 to figure 10.

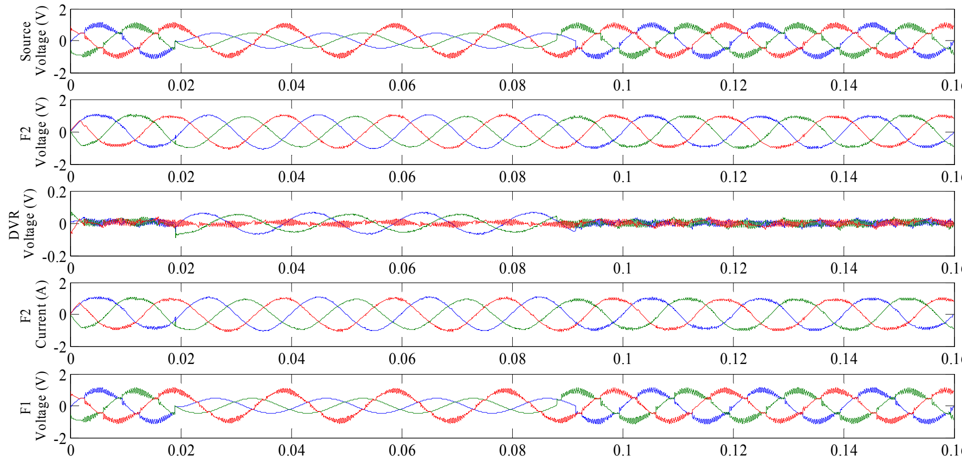

Figure 7. Compensation of Double line to ground fault with 50% sag using PI Controller

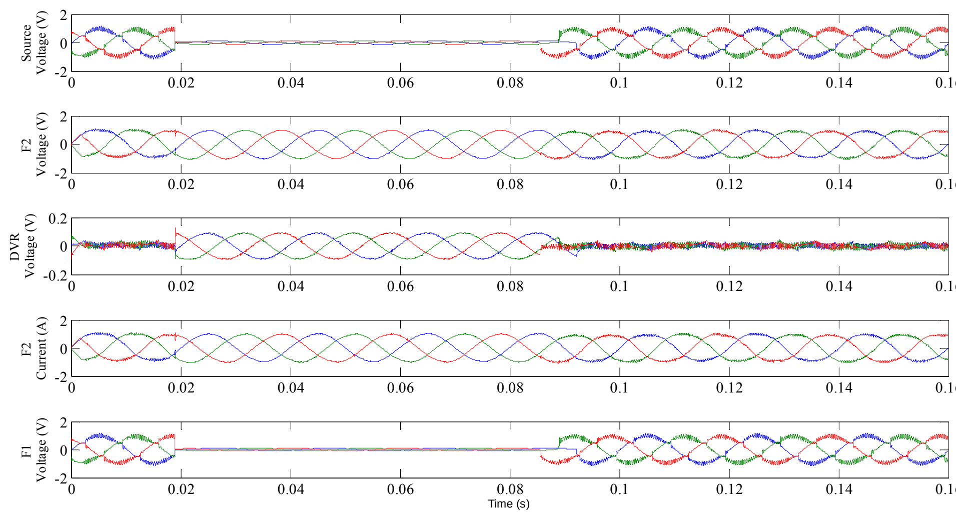

Figure 8. Compensation of 3Φ fault with 90% sag using PI Controller

It can be seen in figure 8 the amount of voltage sag created is 0.9 pu, so that the voltage injected by the DVR is 0.09 pu.

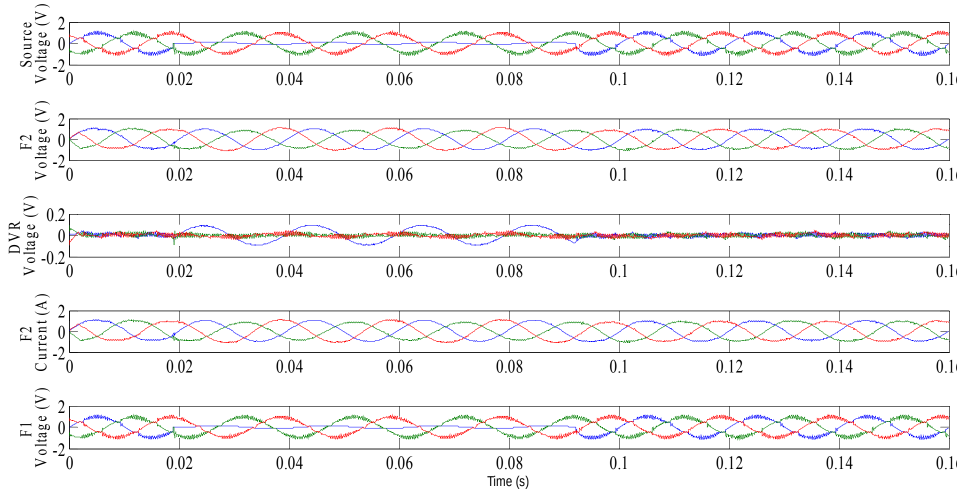

Figure 9. Compensation of single line to ground fault with 90% sag using PI Controller

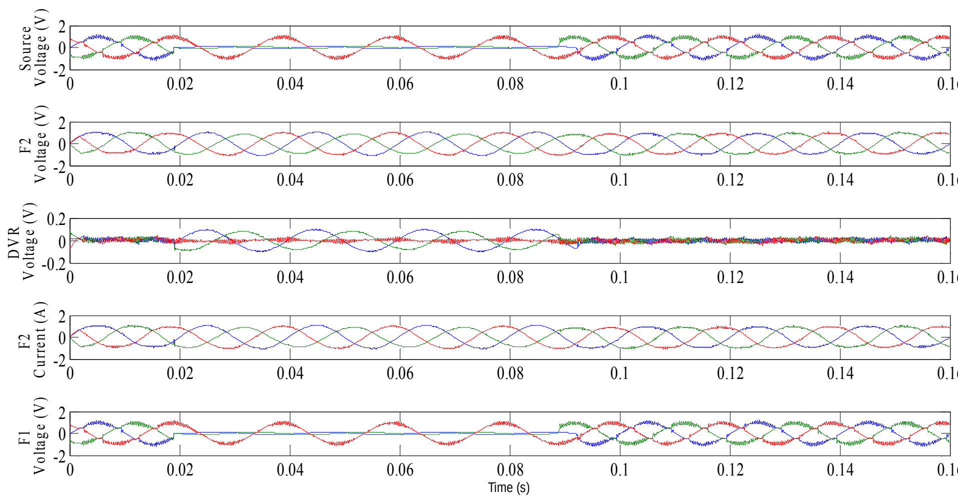

Figure 10. Compensation of Double line to ground fault with 90% sag using PI Controller

The 3Φ to ground fault, single line to ground fault and double line to ground fault are applied and analyzed with PI and ANN controller. The compensation of neural network based Dynamic voltage restorer and the training performance of the ANN controllers is shown from figure 11 to 18.

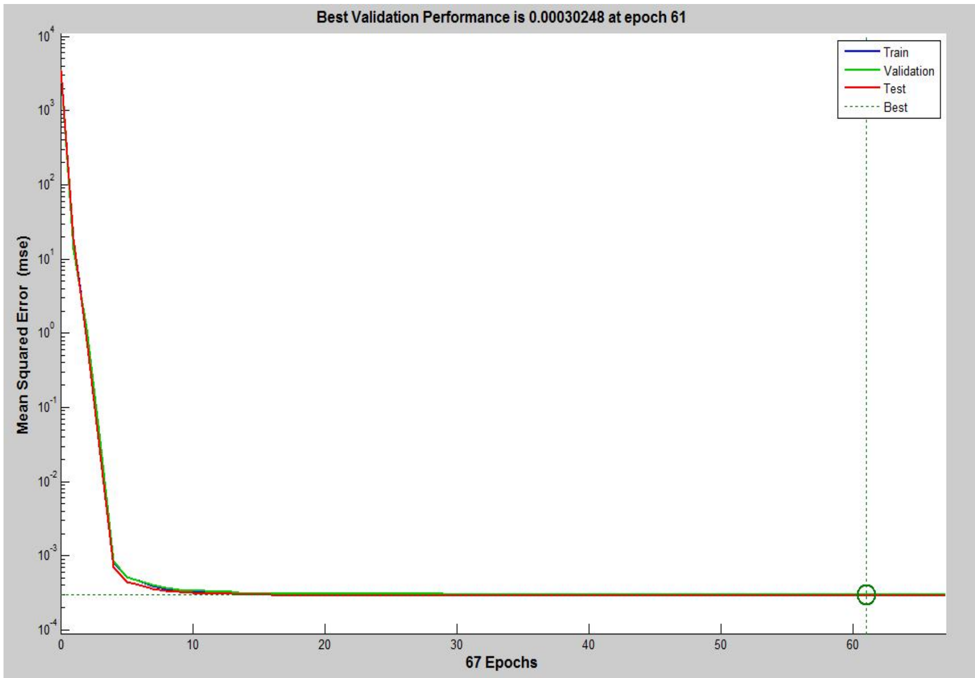

Figure 11. ANN training performance in d-coordinate

The network training is stopped at epoch 67 and 81 due to the performance of the validation fails to improve or it reaches the maximum value.

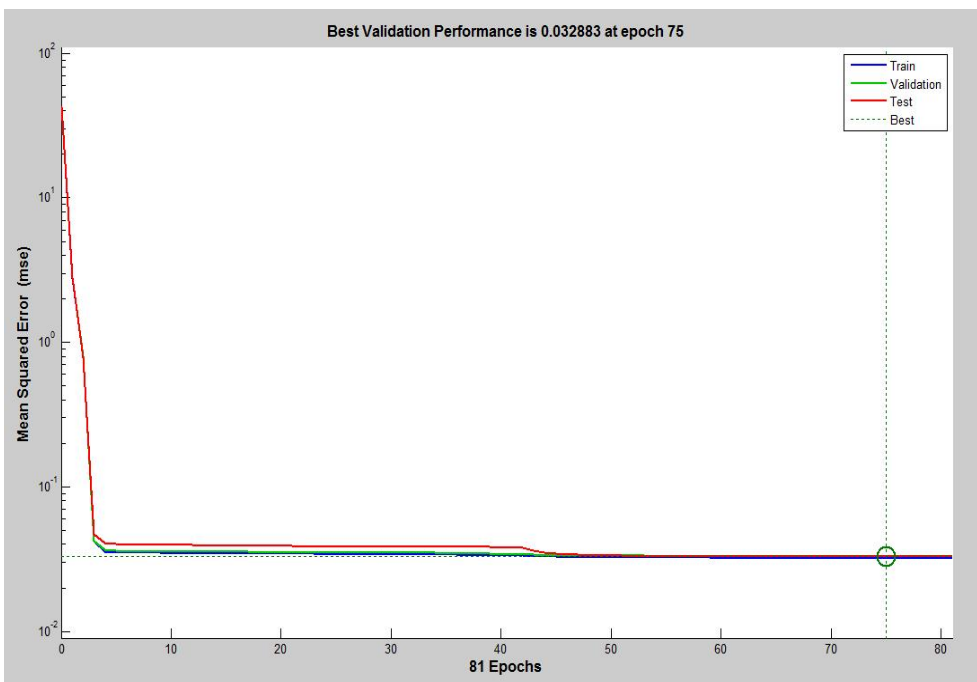

Figure 12. ANN training performance in q-coordinate

The best validation performance in d- coordinate is 0.00030248 at epoch 61 as shown in the figure 11. The best validation performance in q- coordinate is 0.032883 at epoch 75 as shown in the figure 12. The compensation of the DVR with respect to the ANN controller for 50% sag with three types of fault as shown from figure 13 to 15.

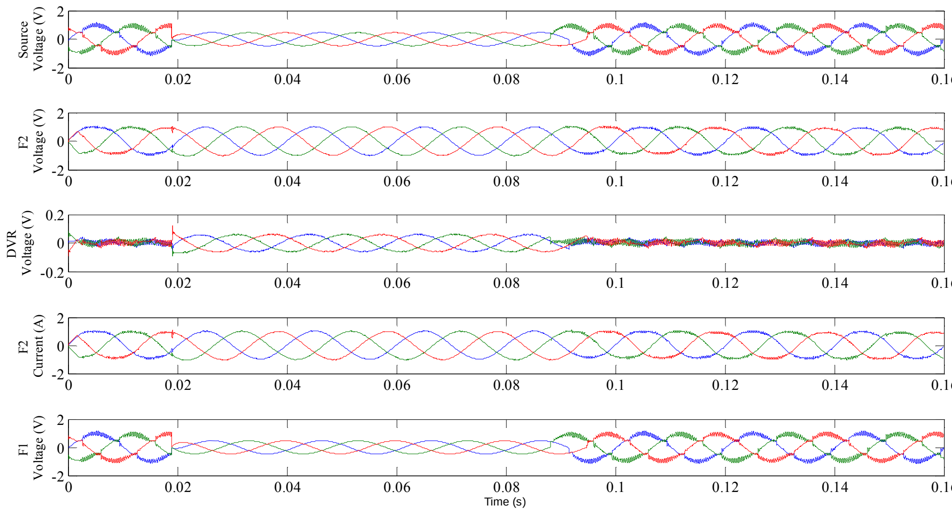

Figure 13. Compensation of 3Φ fault with 50% sag using ANN Controller

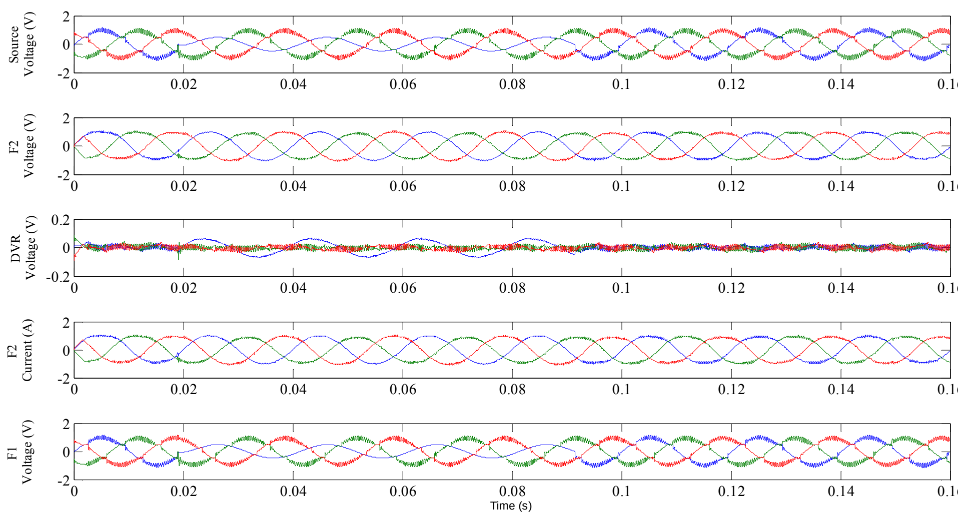

Figure 14. Compensation of single line to ground fault with 50% sag using ANN Controller

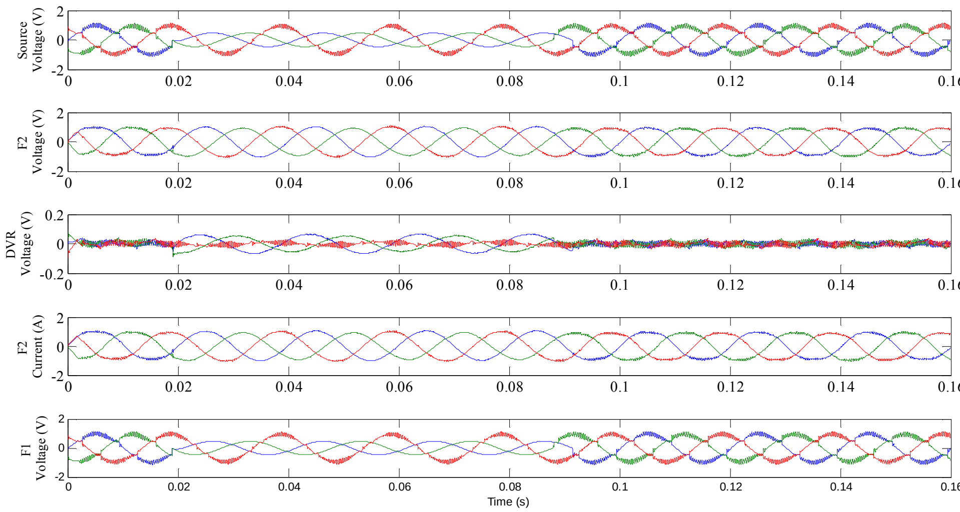

Figure 15. Compensation of Double line to ground fault with 50% sag using ANN Controller

In these figure it can be clearly shown that the source voltage is get distorted by applying fault and an effect of non linear load at F_1. The load voltage at F_2 is pure sinusoidal due to the series compensating device connected to the system. During the fault duration, the ANN based DVR inject the appropriate voltage, after the completion of the fault duration the injected voltage is stopped. The compensation of the DVR with respect to the ANN controller for 90% sag with three types of fault as shown from figure 16 to 18.

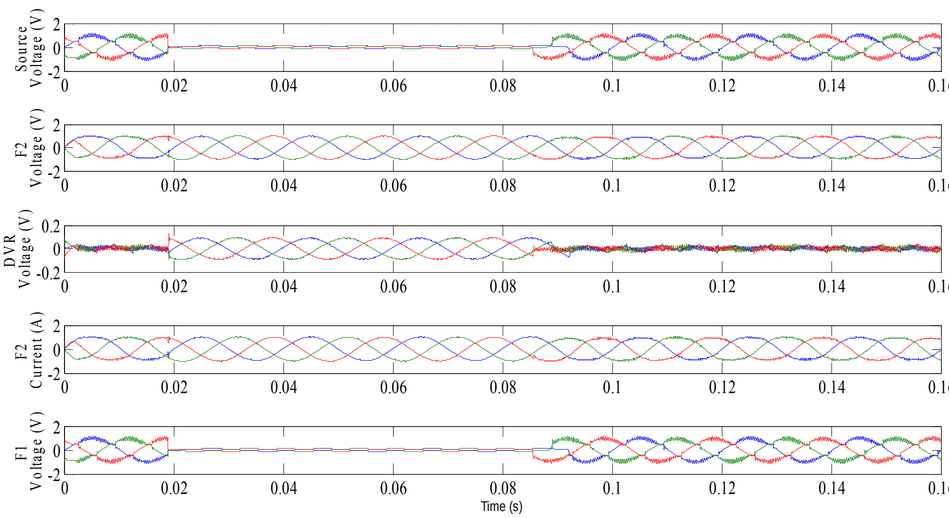

Figure 16. Compensation of 3Φ fault with 90% sag using ANN Controller

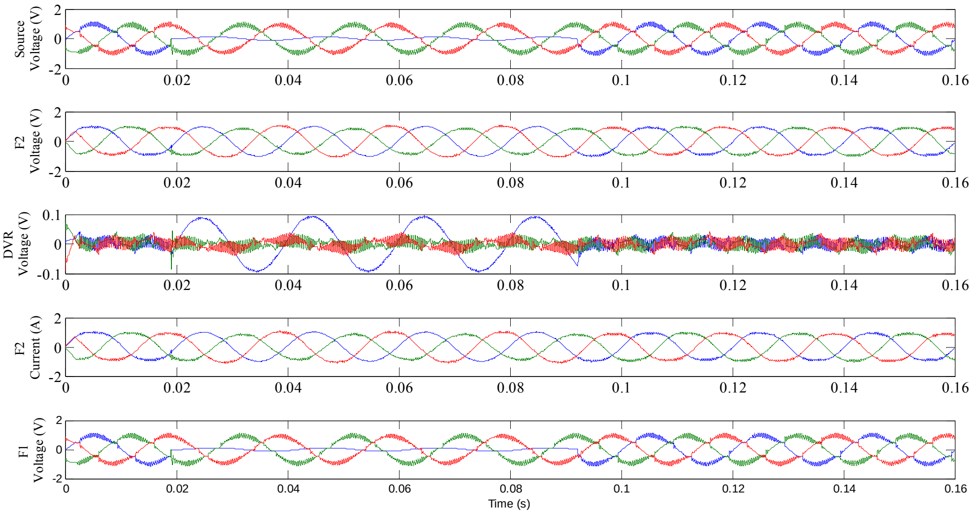

Figure 17. Compensation of single line to ground fault with 90% sag using ANN Controller

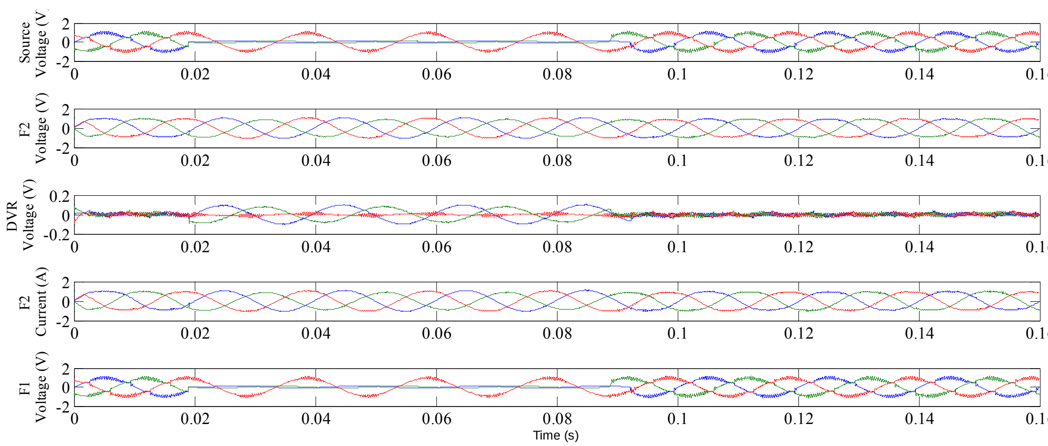

Figure 18. Compensation of Double line to ground fault with 90% sag using ANN Controller

The Total Harmonic Distortion (THD) is measured by using FFT analysis.

Table 1. THD Comparison using PI and ANN

Controller	**Source voltage (THD %)**	**Load Voltage (THD %)**
PI	11.20	2.15
ANN	11.19	2.01

The table 1 shows the comparison of THD with respect to PI and ANN controllers. In comparison to the PI controller the ANN controller has slight improvement in harmonic filtration and it is mention that the THD value for both PI and ANN controller fulfill the IEEE 519:1992 standard.

Conclusion

In this work, the simulation model of rectifier connected power distribution system with Dynamic voltage Restorer controlled by PI and ANN Controller has been developed using Matlab/Simulink. A simple control technique based on park transformation with Discrete PWM generation is proposed for DVR. The results presented in this paper shows that, the harmonics caused by nonlinear load and two levels of voltage sag caused by single line to ground fault, double line to ground fault and three phase fault are effectively compensated by the proposed DVR system. The proposed ANN controller has slight improvement in harmonic elimination when comparing with the conventional PI controller. However the ANN controller has faster response and minimum THD level than the PI controller.

Appendix

Operating voltage: 3Φ, 415V, 50Hz.
Non linear load: 3Φ uncontrolled bridge rectifier with R=200Ω, L=80mH
Unbalanced load: R_a=150Ω L_a=51mH, R_b= 50Ω, L_b=150mH, R_c=75ΩL_c=51mH
Linear load: R_s=2000, L_s=40, C_s=10
Injection Transformer: 1.5kva, 1:10, r1= r_2= 0.00001 pu, x_1=x_2= 0.0003 pu
Step down Transformer: 11KV /415V, r1= r_2= 0.0003 pu, L_1=L_2= 0.001pu
DC voltage: 200V DC
PI controller: KP_d=40, kI_d=154
PI controller: KP_q=25, kI_q=260
LC filter: L=6mH C=20µF

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