MACHINE LEARNING (ML) BASED MITIGATION OF HARMONICS AND POWER FACTOR IMPROVEMENT

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Power Electronics is a branch of Electrical Engineering which has enormous applications in changing the one type of supply into another and also obtaining the different levels of voltages and current based on the requirement. Such an important branch also creates some problems if the same is used for said benefits. The problems created by power electronic converters are injection of harmonics and drawing reactive power from the supply and also creates unbalance in the three phase lines. These three problems were created as the semiconductor devices are used in these power electronic converters and they operate from firing angle for controlling applications. These problems were well eradicated by power filters which are connected in parallel to the system and they are working real time. There are many control techniques and controllers were invented to get the better results. There are many controllers used in these control techniques to obtain the better results. In this paper, the machine learning based fuzzy logic, neural network and neuro fuzzy are postulated and compared with the PI controller.

Keywords: Machine Learning, Fuzzy Logic, Neural Network, Neuro Fuzzy, harmonic mitigation, power factor improvement, unbalance.

1. Introduction

Jain S K [1] explained the design of active filter with the values of inductor, capacitor and reference voltage setting for unit voltage template method. This active filter is efficiently utilized for eradicating harmonics and reactive power. This work was done with a PI controller. A. Benaissa [2, 3] described the fuzzy logic controller. This was implemented on a three phase four leg system which has a neutral separately. It used a multilevel inverter for getting better results. The multilevel used was five levels, this may be optimum at that time. This work was experimented with unbalanced, nonlinear load and with distorted voltage conditions. Raphael et. al. [4] implemented hardware setup with PWM controlling. This was implemented by using an FPGA controller. The frequency used here is 400kHz for the switching

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PWM controller. K. K. Pedapenki [5] has implemented two types of controllers, neural network and fuzzy logic controllers. The unit voltage template method was used in this paper.

Neuro Fuzzy controller [6] was implemented with ANFIS of MATLAB which gives enormous results compared to neural and fuzzy logic controllers. The unit voltage template [7] was explained in detail in this paper with fuzzy logic controller. The modeling of this method was explained in step by step manner. Tareen [8] has implemented mitigation of power quality issues for renewable energy integration with the electrical grid. The paper describes many techniques of power quality when integrating renewable energy with the power grid. Sharma [9] has implemented a modified control strategy for active filters with DC voltage estimation and load current sensor reduction. This method saves a lot of money in reducing the sensors. Janpong [10] has invented the ADALINE based active filter for harmonic detection. Modern machine learning technology was first implemented in this work.

Eslami [11] discussed the mitigation of harmonics and interharmonics for the first time and implemented an active filter to eradicate these problems. Zakaria [12] has implemented a self tuning filter with a neural network controller. This was an initial step for the self tuning method which makes the method automated. Subash Kumar [13] implemented an FPGA based active filter. This method optimises the switching angle control using ANN - SVPWM method. M. Reddy [14] implemented an optimization technique PSO in active filters. This optimises all the parameters and has given the best results compared to previous results. Tao [15] has implemented another optimization technique called gray wolf algorithm. It has given improved results for the active filter. Jai AA [16] integrates a PV system with active filters controlled by machine learning based ADALINE with a neutral power quality strategy. Type II fuzzy logic controller [17, 19] was implemented for sugeno and mamdani methods of fuzzy logic with UVT method. A simulation based power quality has been implemented in [18] with loss optimization in distorted distribution networks.

2. System Modeling

Fig. 1 shows the complete idea of the system [1], [7]. The system contains a three phase supply feeding a three phase nonlinear load means three phase rectifier with RL load controlled by the firing angle α. As the thyristors used in the rectifier, they have nonlinear nature of the VI characteristics and hence, there are harmonic injection, reactive power drawn and imbalance in the three phases in the source currents [8], [9], [14]. These problems were well addressed by an active power filter as shown in Fig. 1. The combination of inductor and capacitor connected in parallel is called filter [18]. To make it active the capacitor is provided in a variable manner maintained by a PWM inverter controlled by a Hysteresis controller and voltage controller.

The method used in this paper is the voltage template method. The aim of the unit voltage template method is to derive reference phase current signals

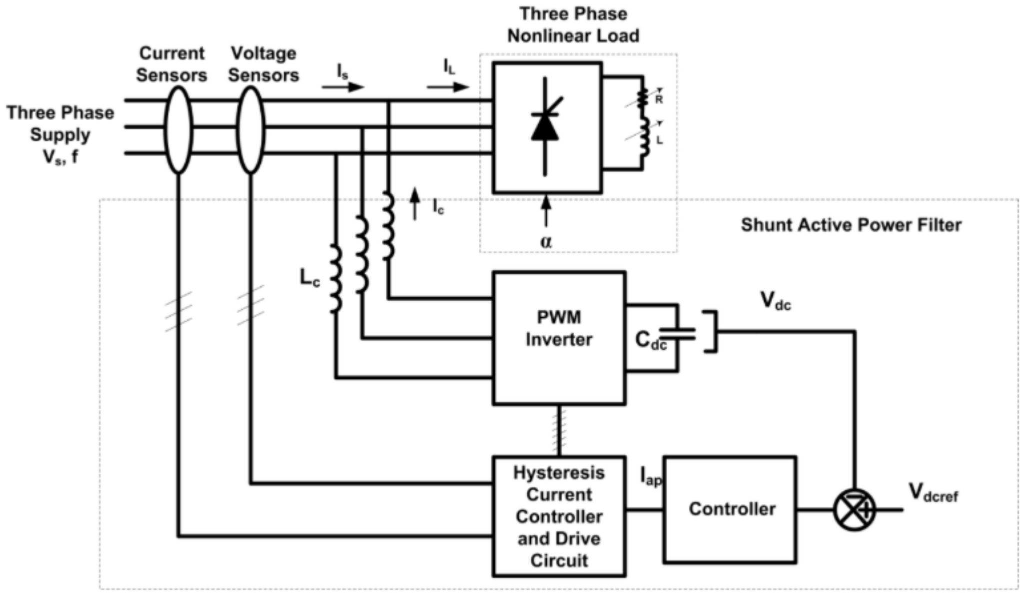

FIGURE 1. Schematic Diagram

$i_{sa,ref}, i_{sb,ref}$ and $i_{sc,ref}$ of the source currents which serve as a template for achieving ideal in-phase and sinusoidal currents at source. For this, the output of the controllers I_{ap} multiplied with unit voltage signals corresponding to the source voltages v_{sa}, v_{sb} and v_{sc}. To obtain unit voltages, the actual source voltages are divided by peak value of the source voltage (V_{in}), found as

$$V_m = \sqrt{\frac{2}{3}(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)} \tag{1}$$

where

$$v_{sa} = V_m sin\omega t \tag{2}$$

$$v_{sb} = V_m sin(\omega t - \frac{2\pi}{3}) \tag{3}$$

$$v_{sc} = V_m sin(\omega t + \frac{2\pi}{3}) \tag{4}$$

Thus,

$$i_{sa,ref} = I_{ap}\frac{v_{sa}}{V_m} \tag{5}$$

$$i_{sb,ref} = I_{ap}\frac{v_{sb}}{V_m} \tag{6}$$

$$i_{sc,ref} = I_{ap}\frac{v_{sc}}{V_m} \tag{7}$$

It may be noted here that the values of V_m and current reference $i_{sa,ref}, i_{sb,ref}$ and $i_{sc,ref}$ are continually updated with corresponding instantaneous values of v_{sa}, v_{sb} and v_{sc} and The reference current signals are compared with corresponding sensed currents and and based on the sign of error, upper or lower device on the corresponding inverter leg is switched ON. The error is processed through a hysteresis band to generate the switching pulsed for inverter devices. The design procedure of getting the parameters of the active power filters as given by Jain S.K. et.al. [1] is followed here to get the filter inductance (L_c) and capacitance (C_{dc}) are computed.

This process is explained through a MATLAB program:

```
function Lc = getL(f,Vs,RAF,mf,Qc,Vdcr)
Lc=(3*0.388*Vs*Vs)/(2*pi*f*RAF*mf*Qc);
Vdcref=(2*sqrt(2)*((3*Vs*Vs)+(2*pi*f*Lc*Qc)))/(3*Vs)
Cdc=(pi*Qc)/(3*sqrt(3)*2*pi*f*Vs*Vdcr)
```

This program takes supply frequency (f), supply voltage (Vs), ripple amplification factor (RAF), frequency modulation (mf), reactive power compensated (Qc) and the maximum peak to peak voltage ripple (Vdcr) in the DC side as the arguments from the command window and gives the, L_c, $V_{dc,ref}$ and capacitance (C_{dc}).

3. **Fuzzy Logic Controller**

The fuzzy logic controller [2], [3], [4] is used in place of the voltage controller. Here, The error generated by reference voltage and voltage across the capacitor is taken as an input and the change in error from current current error to previous error is also taken as second input to the fuzzification block. The fuzzification converts the error and change in error into fuzzified values and the decision has been taken based on the rule base and the decision making block generates the decisions and sends them to the defuzzification block [15], [19]. The defuzzification block will generate the crisp values from the fuzzified values. The parameters used in fuzzy logic controller is tabulated in Table 1.

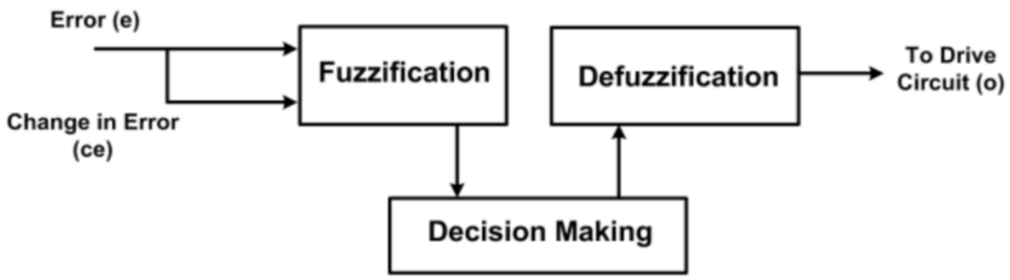

FIGURE 2. Fuzzy Logic Controller

TABLE 1. Fuzzy Logic Parameters

Fuzzy Logic Parameters		
S.No.	**Parameter**	**Parameter Used**
1	Fuzzification	Intuition Method
2	Membership Function	Triangular
3	Defuzzification	Centroid Method

TABLE 2. Data Base of Two inputs

Data Base	**Initial Value**	**Final Value**
Error	**2**	**4**
Small	2	3
Medium	2.5	3.5
Large	3	4
Change in Error	**-0.005**	**0.005**
Small	-0.005	-0.001
Medium	-0.002	0.002
Large	0.001	0.005

4. **Neural Network Controller**

The neural network [5], [10] can also be implemented in place of a voltage controller. The input of this block is the error generated by reference and DC voltages [11], [12] . A neural network contains an input layer and an output layer. There will be hidden layers also to get more sophisticated control. In this context, the number of neuron in hidden layer and output layers are very important. They are obtained by general intelligence [13], [20]. This will be implemented by NFTOOL in MATLAB. There are seven steps in nftool viz. 1. Select a Network, 2. Select Data, 3. Validate and Test Data, 4. Network Size, 5. Train the Network, 6. Evaluate the Network and 7. Save the Results.

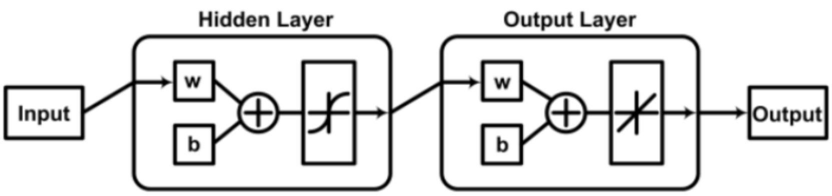

FIGURE 3. Neural Network Controller

The fig. 3 shows the selecting a network, the selecting data coming from the previous controller may be PI in general controlling applications. The data will be segregated into around 70% as training data, 20% as testing data and 10% as

TABLE 3. Neural Network Controller

Neural Network Parameters		
S. No.	**Parameter**	**Parameter Used**
1	No. of Layers	2
2	Names of Layers	Hidden and Output
3	Activation Function for Hidden Layer	Sigmoid
4	Activation Function for Output Layer	Linear

TABLE 4. Neuro Fuzzy Parameters

Neuro Fuzzy Parameters		
S.No.	**Parameter**	**Parameter Used**
1	Training Data	80 Percent
2	Testing Data	10 Percent
3	Number of Inputs	2
4	Number of Membership Functions	3
5	Input Membership Function	Triangular(trimf)
6	Output Membership Function Type	Constant
7	Number of Rules Generated	3X3=9
8	Defuzzification Method	Back Propagation
9	Number of Epochs	100
10	Error Tolerance	0

validating data in general cases. The number of neurons comes under network size and then the network will be trained. The results will be evaluated. If the results are found satisfactory, then save the result and stop the process, otherwise try with a different combination of data and network size and train again. The parameters used in Neural Network controller is tabulated in Table 2.

5. Neurofuzzy Controller

The ANFIS controller [16], [17] has both inputs and outputs under the load data block of ANFIS GUI. The data is loaded from either file or from workspace. The training, checking and testing data are segregated in the type. The data is transferred to generate FIS Block where the data is loaded from file or workspace as per the mentioned load data block, the grid clustering and sub clustering are specified. In train FIS the optimization method, tolerance error percentage and number of epochs required are to be mentioned. At the end of the test FIS, training, testing and checking data was happening. If the results are satisfactory then stop the process otherwise change the parameters and try again until the results are satisfactory [6]. The parameters used in this neurofuzzy controller is tabulated in Table 3.

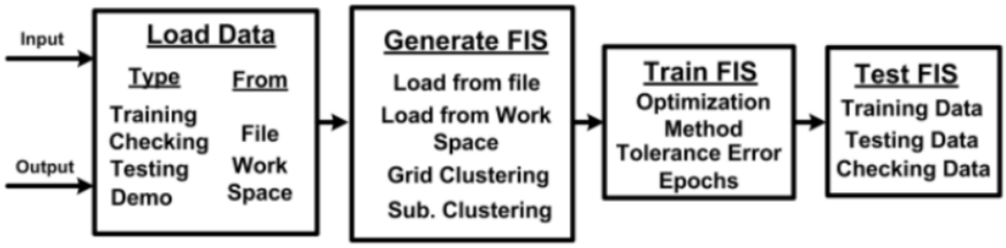

FIGURE 4. Neuro Fuzzy Controller

6. **Results and Discussion**

Fig. 5 shows the four waveforms viz. Load current, compensation current, source current and source voltage. The waveforms are from t=0.1sec to t=0.4sec. It is for one phase for a clear idea of the permanence of the system. The last waveform is source voltage which is constant throughout this time. The active filer is switched on at t=0 only and hence the compensation current appears everywhere in this wave. The load current and source current are same when there is no active power filter and it is like load current only i.e. distorted sine wave. It creates problems in other loads who are utilizing the same supply and hence, it should be cleaned. This cleaning process was done by injecting the compensating current which will be added to load current and hence the source current will be sinusoidal. At t=0.2, the load has been declined and hence all the currents have been reduced. In this context, the time to regain to the original position is to be noted. It seems it is almost zero from normal load to declined load. At t=0.3sec, again the declined load is seized and hence the original load has been regained. Here also the time taken to regain the same shape is very less. It clearly shows the robustness of the system.

The experiment has been conducted for loading conditions of R value from 16 to 24 Ohm and L value from 16 to 24 mH with four types of controllers PI, FL, NN and NF. It has been conducted for the firing angle of the rectifier from 0 to 60 degrees. The cumulative results have been tabulated in table 1 as shown below. The analysis of these many variations is a little bit tough and hence the simplest analysis has been adopted to keep all parameters constant and concentrate on only one parameter at a time. Fig. 6 shows the source current THD Vs Firing angle for different controllers at R = 20 Ohm and L = 20 mH. It has been clearly shown that all the results look almost alike except the PI controller. It shows the strength of the machine learning based controllers like FL, NN and NF. Of course, the problems of getting membership functions and getting the number of neurons will be cleared in Neurofuzzy and hence, the neurofuzzy has very good results compared to both NN and FL. But, FL and NN are different techniques and there should not be any comparison. In this context, NN plays a great role and obtained good results compared to FL.

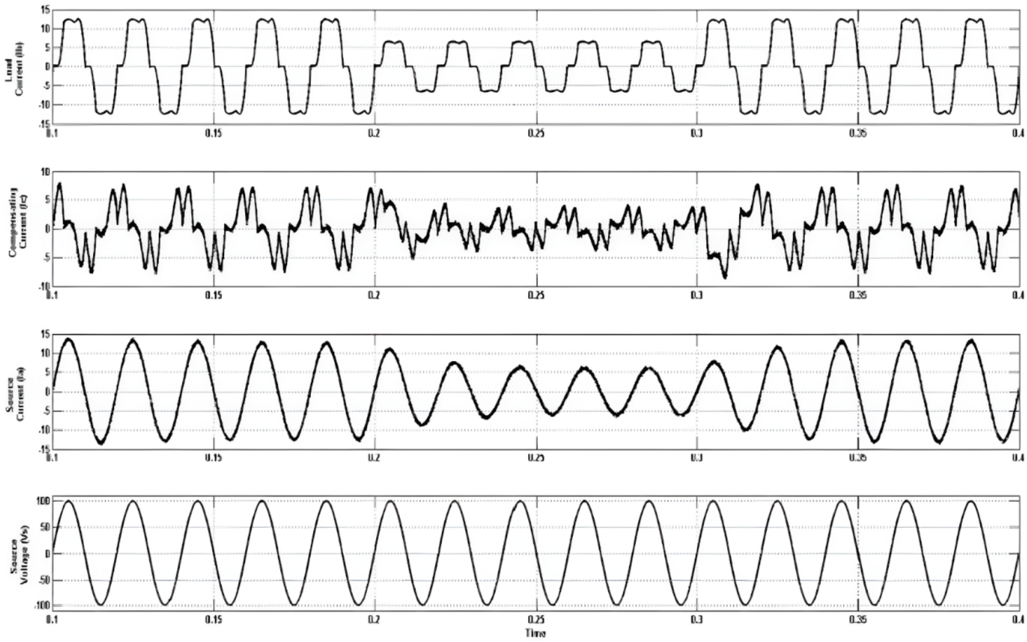

FIGURE 5. Waveforms of load, compensating, source currents and source voltage measuring currents in Ampere and Time in seconds

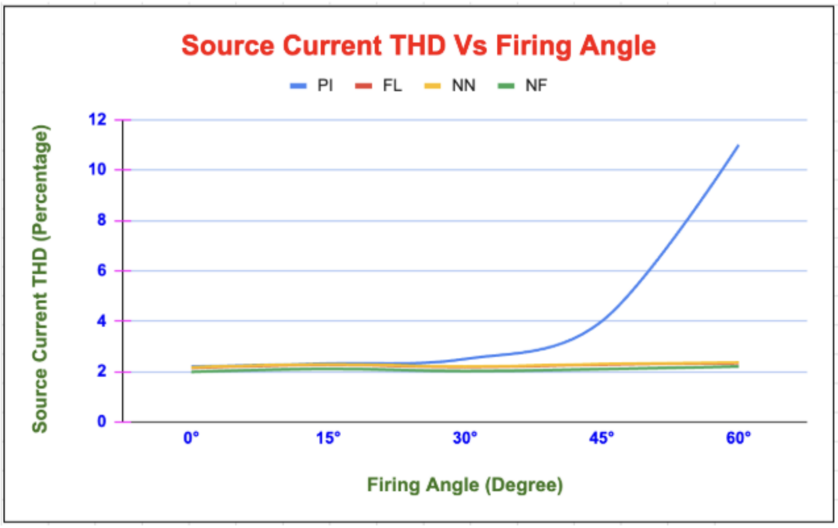

FIGURE 6. Source Current THD Vs Firing Angle

Fig. 7 shows the source current THD versus various loading conditions keeping the firing angle at 30 degree. The experiment has been conducted for various firing angles starting from 0 15 30 45 60 but the active or filter is well organised up to Alpha equal to 30° has been taken for consideration for this graph. The results for 30 degrees from table one has been taken and tabulated in figure 7. it's clearly

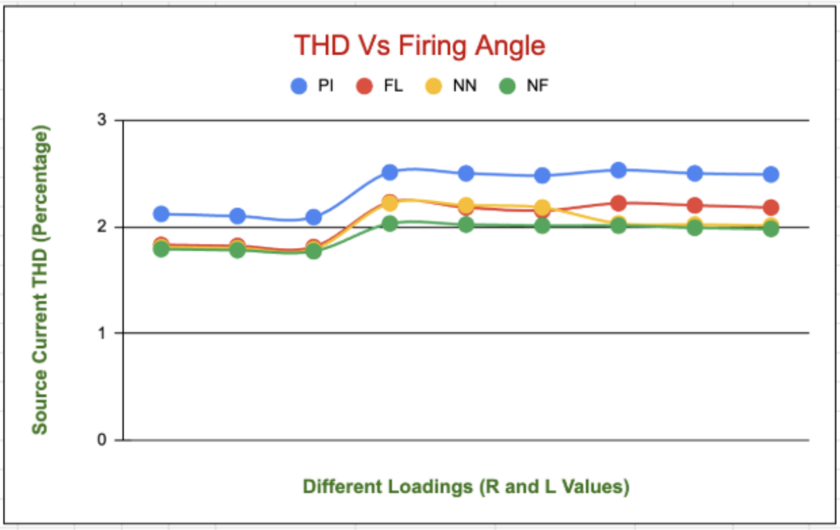

FIGURE 7. Source Current THD Vs Load settings

mentioned that the blue colour LINE which is related to pi controllers has more source current THD compared to all other machine learning based controller like fuzzy, neural network and neurofuzzy controllers.

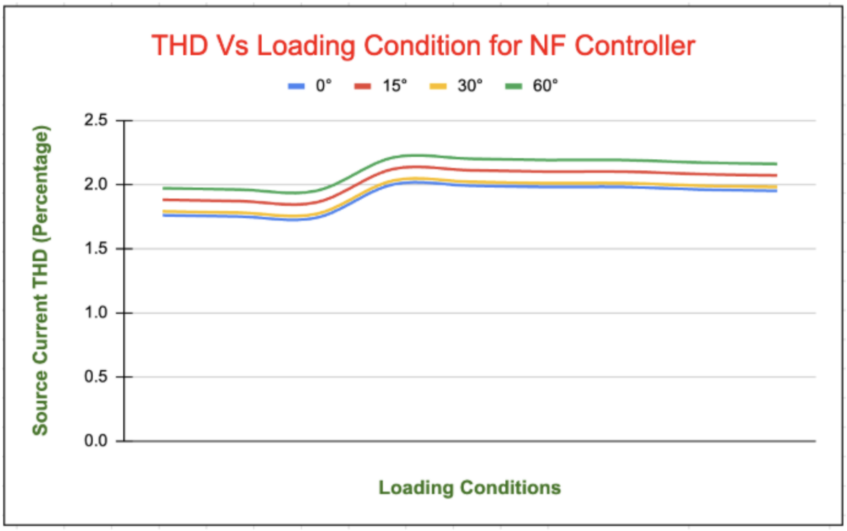

FIGURE 8. THD Vs load conditions for NF Controller

Fig. 8 shows the graph between source current THD and various loading conditions keeping the neurofuzzy controller as the controller. It has been cleared from the table that the neurofuzzy has performed well compared to all other machine learning related controllers and hence neurofuzzy has been taken for consideration in this graph. So the various angles have been taken in this graph like 0 15 30 45

60. It has been shown that the graph related to zero degree contains very less source current THD because it doesn't have any reactive power drawn from the source.

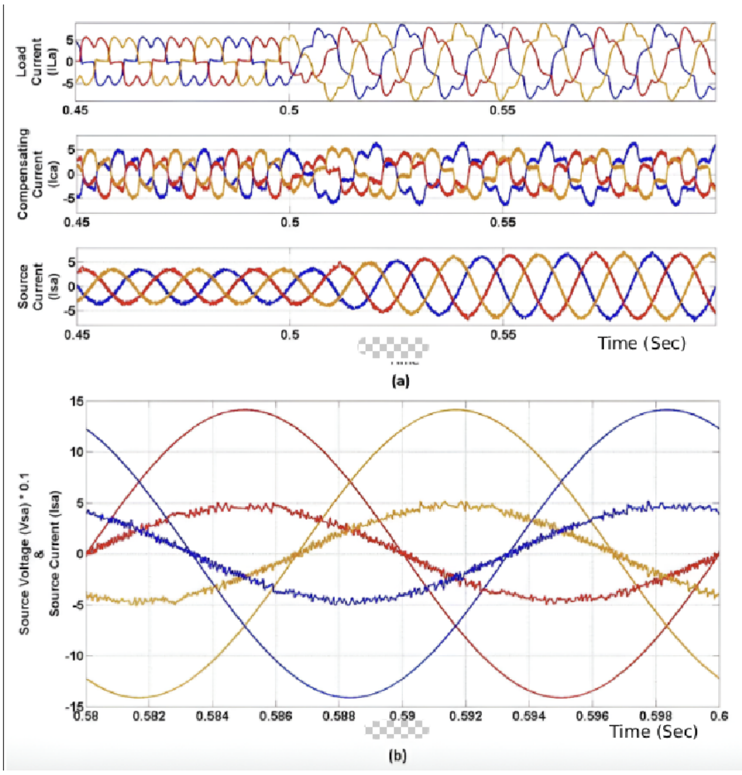

FIGURE 9. (a) Load, compensating and source currents for unbalance in load (b) Zoom in view of source voltages and source current current in Ampere, Voltage in Volt and Time in Seconds

Fig. 9 shows three phase supply, Figure 9(a) contains load current, compensating current and source current. The active power filter has been switched on t= 0 seconds. The unbalance has been created in the three phases at t=0.5 second. Thereby the load current has been distorted from each phases and the compensating current has time to make the source current equal to pure sinusoidal and the amplitude also exactly equal to each of the phases. Fig. 9(b) shows the voltages and currents of three phases for power factor. As the phase difference between the voltage and current of all phases are zero and hence the power factor is unity. It clearly shows that the shunt active power filter mitigates the harmonics, improves the power factor and also eradicates the unbalance created in the three phases.

7. Conclusion

The three problems of using power electronic converters for three phase systems like harmonic generation, reactive power draw and unbalance in phase current has been eradicated by shunt active power filters. The unit voltage template method is used in this paper for simplicity. The implementation of the machine learning based fuzzy logic, neural networks and neurofuzzy controllers were well introduced, implemented and documented. The results show that the neuro fuzzy controller is the best controller for any loading conditions and any firing angle conditions. As per firing angle is concerned, the less firing angle has been given lower THD and the higher firing angle has been given higher THD as reactive power increases. The power factor is also kept at unity in almost all the cases as the unit voltage template method has been taken into consideration. The unbalance created in the three phases is also cleared and set right by the same circuit with no additional efforts. This feature is also given by the UVT method.

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