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POWER QUALITY ANALYSIS AND IMPROVEMENT USING SHUNT ACTIVE POWER FILTER WITH NEURAL NETWORK & MACHINE LEARNING

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ABSTRACT

Presented research paper delves into the pivotal realm of Power Quality Improvement, employing a sophisticated and innovative approach: the integration of Shunt Active Power Filter (SAPF) with Artificial Neural Network (ANN) and Machine Learning (ML) techniques. The convergence of SAPF technology with ANN and ML not only enhances the accuracy and efficiency of power quality monitoring but also facilitates adaptive and intelligent control strategies for optimal compensation. The analysis and modelling is done in MATLAB Simulink, A six IGBT Voltage Source Inverter (VSI) based Shunt Active Power Filter (SAPF) with hysteresis control is used to generate compensating current for harmonic mitigation at the point of common coupling (PCC). PQ method is used for this process employing a PI controller. The training data is collected from this model for our Machine Learning (ML) model. The PI controller is then replaced with the ML model to provide an improved, ANN based method for power quality improvement.

Keywords:- APF, SAPF, THD, IGBT, PCC, ANN, VSI, ML

INTRODUCTION

In an era characterised by an ever-growing dependence on electronic devices and an escalating demand for energy, the stability and quality of power supply have become paramount concerns. Power quality, or more precisely, a power quality disturbance, is broadly defined as any variation in power (current, voltage or frequency) that conflicts with the regular functioning of electrical equipment. The vulnerability of the end-use system determines the required degree of power quality [3]. Because it has direct influence on the reliability, efficiency, and safety of electrical systems, ensuring good power quality is a fundamental concern for utilities, businesses, and consumers. Even small swings in power quality can cause electronic equipment malfunctions, data loss, and costly downtime. Power quality difficulties in industrial settings can lead to production losses, poor product quality, and diminished worldwide market competitiveness. Power quality has a significant impact on the stability and efficiency of modern power grids. Issues related to power quality, such as voltage sags, reactive power fluctuations and harmonics, can lead to detrimental effects on sensitive electronic equipment, resulting in operational inefficiencies, increased downtime, and economic losses. To address the vital necessity of power quality, standards that apply to both industrial and residential environments have been devised. IEEE 519, IEEE 1159, IEC 61000 series, and EN 50160 are examples of standards that establish specified voltage and current guidelines to prevent malfunctions, damage, and safety issues in electrical equipment. Maintaining acceptable power quality requires adherence to these guidelines. As industries and infrastructure continue to evolve, the need for effective power quality analysis and improvement mechanisms becomes increasingly pressing.

LITERATURE SURVEY

HARMONICS:

The idea of harmonics pertains to steady states, whereby the waveform under analysis is presumed to repeat indefinitely [9]. Basically, harmonics are current or voltage waveforms whose frequencies are integer multiple of fundamental frequency (2x, 3x, 4x, etc.). These harmonics are created by a variety of sources, including non-linear loads and devices. These days, by use of modern devices, up to 63rd harmonics are measurable. But the most regularly found harmonics are between 3rd to 25th [7].

Harmonics are mostly created by non-linear loads and devices in electrical systems. Because of the existence of semiconductor devices such as diodes and transistors, non-linear loads draw current in a manner that deviates from the ideal sinusoidal waveform.

The harmonics present in a system are often quantified by the system's Total Harmonic Distortion (THD). THD is a measure of the harmonic content of a signal or waveform. It measures a waveform's deviation from its pure sinusoidal shape by comparing the amplitudes of the harmonic components to the amplitude of the fundamental frequency. THD is a critical measure for analysing the quality of electrical power and is stated as a percentage or a ratio. THD is calculated using the following formula:

$$THD = \sqrt[2]{\frac{I_2^2 + I_3^2 + I_4^2 + \ldots\ldots + I_n^2}{I_1^2}}$$

Where,

I_1 is the amplitude of the fundamental current (the first harmonic).

$I_2, I_3, I_4 \ldots I_n$ are the amplitudes of the harmonic components of current at frequencies $2f, 3f, 4f, \ldots . nf$ respectively.

International harmonic standards IEC 61000.3.6 and IEEE 519 Establish limits for the harmonic voltages in the power system. THD limits for current and voltage in power systems can be around 5% to 8% for total current and 6% or lower for individual harmonics.

Harmonics in an electrical power system can have a number of negative consequences on both equipment and power quality. Inductive loads are perceived by low frequency harmonics as having a low impedance, resulting in larger harmonic currents and higher I^2R losses. It can distort the voltage waveforms, causing voltage fluctuations and potentially damaging sensitive electronic equipment. It causes overheating in electrical equipment, leading to reduced equipment lifespan and potential failures. Harmonics can lead to power quality problems, affecting the efficiency and reliability of the power distribution system.

Filters:

Harmonic mitigation is required to keep the power system's quality and efficiency. Filters are used to mitigate harmonics, and several types of filters are used for this purpose. Filters are basically devices or systems that are employed allowing certain parts to flow while restricting or blocking others.

In this paper we will be mainly focusing on power filters.

Passive Power Filter:

It functions by adding impedance to a range of harmonic frequencies, allowing them to be redirected or consumed before they can damage delicate loads and equipment. To increase power quality and shield equipment from harmonic damage, passive power filters are frequently utilised. Inductors and capacitors are used together to provide passive power filters. The way these parts are connected results in a resonant circuit at a certain harmonic frequency or frequencies. Targeting particular harmonics that are common in the power system is the goal of the tuning of the inductors and capacitors. They are made to have high impedance at some frequencies while having low impedance at those harmonic frequencies. The impedance provided by the filter is very low at the harmonic frequencies at which it is intended. Harmonic currents are redirected away from the equipment linked downstream as a result. The impedance produced by the inductors and capacitors is encountered by the harmonic currents that the filter has deflected. These harmonic currents may be absorbed or released as heat in the filter components, depending on the design. The passive power filter significantly lowers harmonic distortion in the power system by deflecting or absorbing harmonic currents. This prevents delicate equipment and keeps the voltage waveform in good condition.

Tomá Hruby et al. (2014) [10] provide measured results of two different types of broadband passive power filters powered by the Pacific 3120ASX programmable three-phase power source and compare them to those of a simulation model created using the EMTP-ATP program. This demonstrates that, provided the supply voltage quality is good, the tested filters are quite effective. The filter's performance is also impacted by the voltage quality at the coupling.

Active Power Filter:

Modern electrical technology called an active power filter is used to reduce harmonic distortion in power supplies. Active power filters, in contrast to passive power filters, actively combat and remove harmonic currents from the system using active electronic components and control algorithms. As a result, they are quite good at handling harmonic problems in complicated and dynamic power situations. The current waveform at the connecting point is always being watched by active power filters. In real time, they determine the harmonic frequencies and their magnitudes. The active power filter produces opposing currents that are precisely out of phase with the harmonic currents detected based on the harmonic measurements.The harmonic components are essentially cancelled by these opposing currents. The system receives the generated counteracting currents and sends them in parallel with the non-linear loads or other harmonic sources. The active power filter prevents harmonic currents from compromising the quality of the power by neutralising them in this way. The injected currents are continuously adjusted by active power filters to meet the varying harmonic content in the system. Even when the load circumstances alter, this adaptive control assures effective harmonic abatement..

According to Kritika Sharma et al. (2020) [5], active filters introduce harmonic voltage or current components that are parts of supply lines or non-linear loads, and they categorise APFs based on the type of converter and the categories of load that are depicted in the figure:

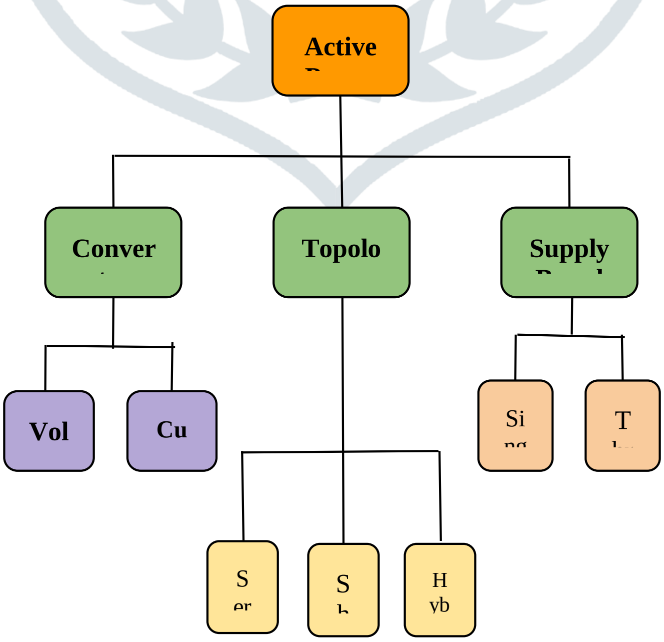


Figure 1. Types of active power filter

Lukas Motta et al. (2016) [6] employed a PQSine Active power filter to compare active and passive power filters. The Active Power Filter is tested with a variety of electrical loads and applications. The study concluded that active filters outperformed passive filters for a variety of reasons, including flexibility, accuracy, and enhanced power factor.

Series Active Power Filter:

Enio R. Ribeiro et. al. (2006) [2] used a series active power filter as a voltage compensator to reduce harmonic voltage. The topology of their system is shown in figure.

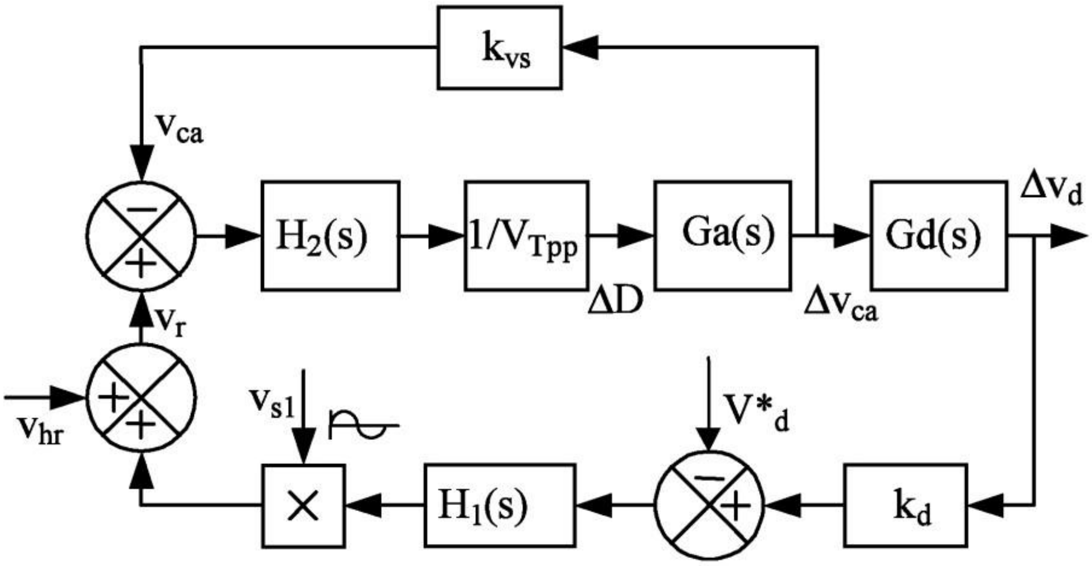


Figure 2. Series active power filter as a voltage compensator

Shunt Active Power Filter:

Salem Rahmani et. al. (2006) [8] presents a three-phase shunt active power filter used in power distribution networks to dampen harmonic propagation. It was discovered that the voltage detection-based active filter designed for harmonic reduction should be mounted on a power distribution line's end bus. It was also established that the shunt active power filter has more viability and efficacy than the series active power filter in damping down harmonic propagation in power distribution systems. The control block diagram is shown in figure.

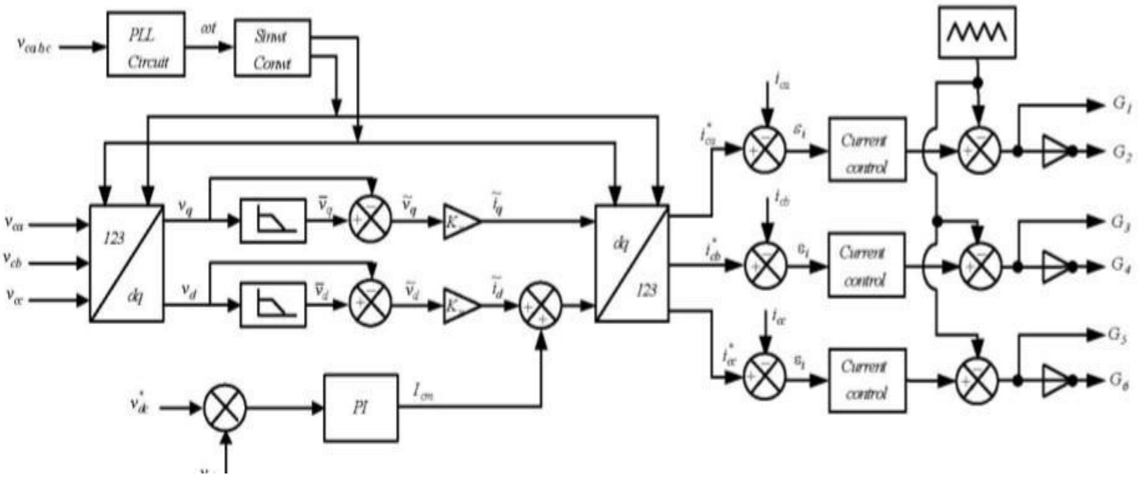


Figure 3. Shunt active power filter used in [5]

In AC distribution networks, the SAPF technology is currently a fully developed solution for neutral current, reactive power, and harmonic current correction. Over the last 25 years, it has changed in terms of different configurations, control schemes, and solid-state devices. In three-phase systems, shunt active power filters are also used to control the terminal voltage and reduce voltage flicker. These goals can be accomplished alone or in combination, depending on the setup, control approach, and needs that must be carefully chosen.Since solid-state AC power regulation is now widely used, power quality problems have also grown in importance. Numerous articles cover topics such as reactive power in electric networks, harmonic source and effect, measurements, analysis, and power quality surveying. A shunt active power filter is thought to be the best tool for reducing power quality issues.

Shunt active power filters can be categorised according to their architecture, number of phases, and kind of converter. A voltage source converter or a current source converter may be utilised in the SAPF. Various VSC circuits can be used to achieve different SAPF topologies. Three-phase, four-wire, and single-phase APF systems make up the third category, which is based on the number of phases [1].

Shunt APF based on Artificial Neural Networks (ANN) controllers for reducing distribution system harmonics. Shunt active power filters use an ANN-based approach to provide the regulated pulses needed for the IGBT inverter, hence enhancing the performance of the traditional controller and leveraging smart controllers. The suggested method primarily uses capacitor energy to maintain a shunt connected filter's DC link voltage, which shortens the transient response time when the load varies suddenly. The MATLAB environment was used to generate the whole power system block set model for the proposed plan. Using MATLAB, simulations are run, and it is observed that the ANN-controlled filter lowers the THD to 2.27% from 29.71%. The findings of the simulated experiment also demonstrate that the innovative control mechanism is highly effective at minimising harmonics and is simple to compute and execute [4].

PROBLEM IDENTIFICATION

Because of inherent harmonic problems, nonlinear loads were traditionally primarily found in heavy industrial settings and were handled by specialists. But non-linear loads are being used far more often these days across a range of industries, including the household. Devices with non-linear loads produce distorted current waveforms because they don't draw current proportional to applied voltage. They may impact the quality of the electricity, which may result in device malfunctions and flickering lights. Computers and industrial machinery like variable frequency motors are two examples of electronics devices. Controlling these loads is essential to preserving consistent power quality. A pulse waveform with a high crest factor is one typical kind of distorted current, which is frequently brought on by devices like switched mode power supply, or SMPS.

Using MATLAB, simulations of three phase transmission line with a three phase full wave AC to DC uncontrolled converter and a unbalanced three phase resistive load are run to witness how non-linear loads affect the waveform of current and voltage of the system and hence the power quality of the system.

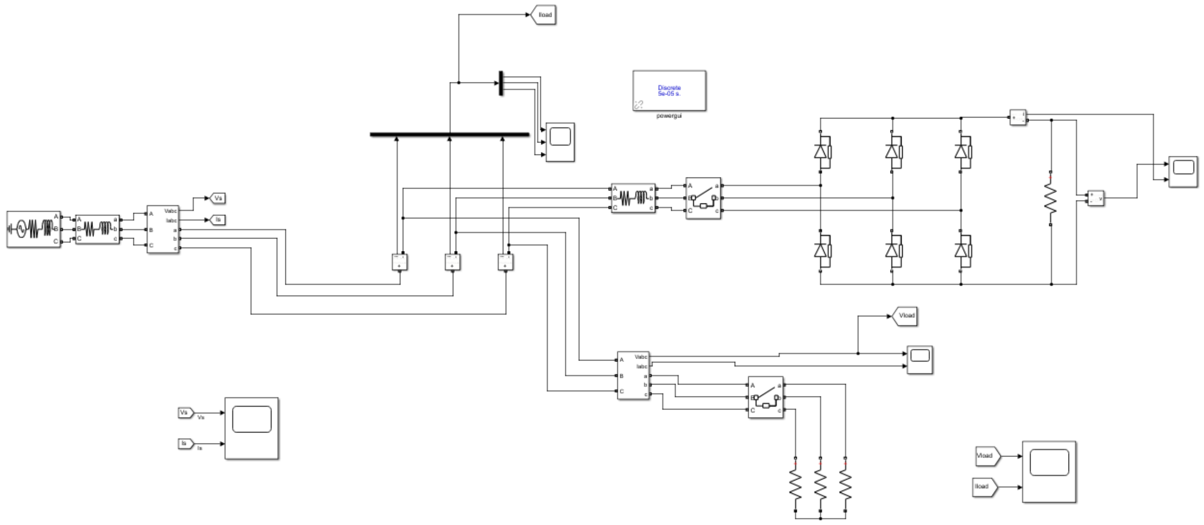


Figure 4. Simulink diagram of a transmission line with both non-linear load and unbalanced load

From the simulation we get the following waveforms of the source voltage and source current as result.

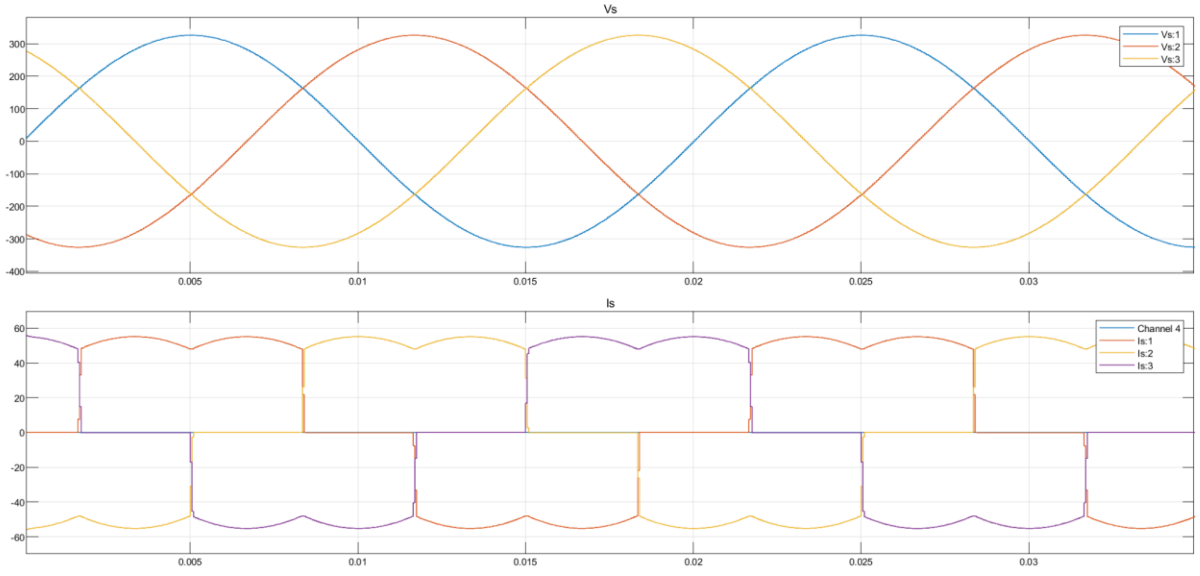
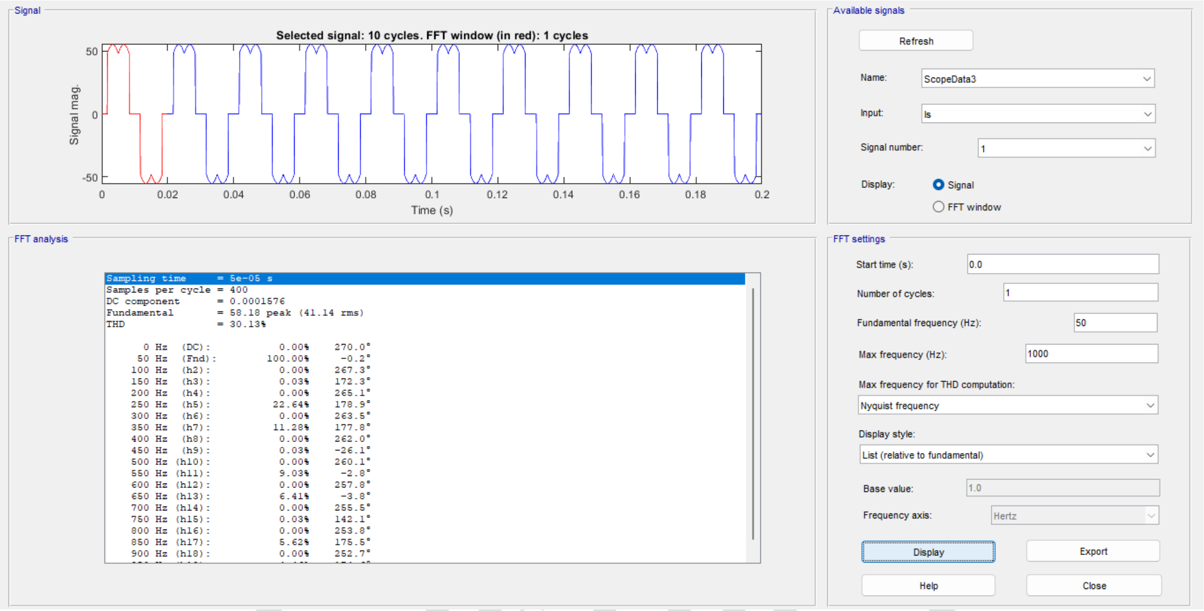


Figure 5. Source current harmonics

It is evident from the above waveforms that the source currenAfter performing the FFT analysis we get a measurement of the harmonic distortion present in the source current waveform in terms of THD.

It consists of harmonics causing distortion in the waveform of source current.



```
Sampling time     = 5e-05 s
Samples per cycle = 400
DC component      = 0.0001576
Fundamental       = 58.18 peak (41.14 rms)
THD               = 30.13%

     0 Hz  (DC):           0.00%    270.0°
    50 Hz  (Fnd):        100.00%     -0.2°
   100 Hz  (h2):           0.00%    267.3°
   150 Hz  (h3):           0.03%    172.3°
   200 Hz  (h4):           0.00%    265.1°
   250 Hz  (h5):          22.64%    178.9°
   300 Hz  (h6):           0.00%    263.5°
   350 Hz  (h7):          11.28%    177.8°
   400 Hz  (h8):           0.00%    262.0°
   450 Hz  (h9):           0.03%    -26.1°
   500 Hz (h10):           0.00%    260.1°
   550 Hz (h11):           9.03%     -2.8°
   600 Hz (h12):           0.00%    257.8°
   650 Hz (h13):           6.41%     -3.8°
   700 Hz (h14):           0.00%    255.5°
   750 Hz (h15):           0.03%    142.1°
   800 Hz (h16):           0.00%    253.8°
   850 Hz (h17):           5.62%    175.5°
   900 Hz (h18):           0.00%    252.7°
```

Name: ScopeData3
Input: Is
Signal number: 1
Display: ● Signal ○ FFT window

Start time (s): 0.0
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 6. FFT analysis of current containing harmonics

Hence it is concluded that the introduction of non-linear loads in the system produces harmonics in it.This existence of harmonics in the system can cause numerous problem in the distribution network.It is commonly recognised that the occurrence of harmonics is the main cause of power quality degradation, with nonlinear loads being the cause of the drop.Therefore, undesirable electrical distortions referred here as harmonics can have a variety of detrimental effects on electrical systems.Harmonics can potentially damage devices and create voltage instability when they interact with the system's inherent frequencies. Additionally, they lower the power factor, which increases the likelihood of higher electricity costs. Electromagnetic interference, which interferes with electrical equipment and communication networks, can also be produced by harmonics. Harmonic restrictions are enforced by regulatory organisations to avert these issues; disobedience with these requirements may incur fines and penalties.

The primary requirements for the expected compensation for the case of an APF are the quick and accurate detection of the disturbance signal, the quick processing of the reference signal, and the controller's high dynamic responsiveness. Under conditions such as parameter fluctuations, load disturbance, nonlinearity, and so on, the traditional controller is unable to provide power quality that is sufficient.

PROPOSED METHODOLOGY

A Simulink model of transmission line is created to test our proposed model of Shunt APF with proposed Artificial Neural Network (ANN) control technique. A three phase source is chosen with 400V output at 50 Hz frequency for power supply to the line. The system consists of two different loads, namely a rectifier (non-linear load) and a resistive unbalanced load. These loads act in a way that eventually leads to current harmonics being introduced in the source current of the system.

To uphold the parameters set by the standards of power quality, a way to reduce these harmonics must be found for the system. A Shunt Active Power Filter is thus connected to the transmission to administer compensating current to the system and neutralise the harmonics present in the source current. The Shunt APF used here is a Pulse Width Modulation based VSI based SAPF with hysteresis controller.

In order to create an ANN based control technique we need to collect data to train the neural network. For this purpose, we first use PQ theory with SAPF to collect the required data. The following Simulink diagram is created using PQ theory to accomplish this task.

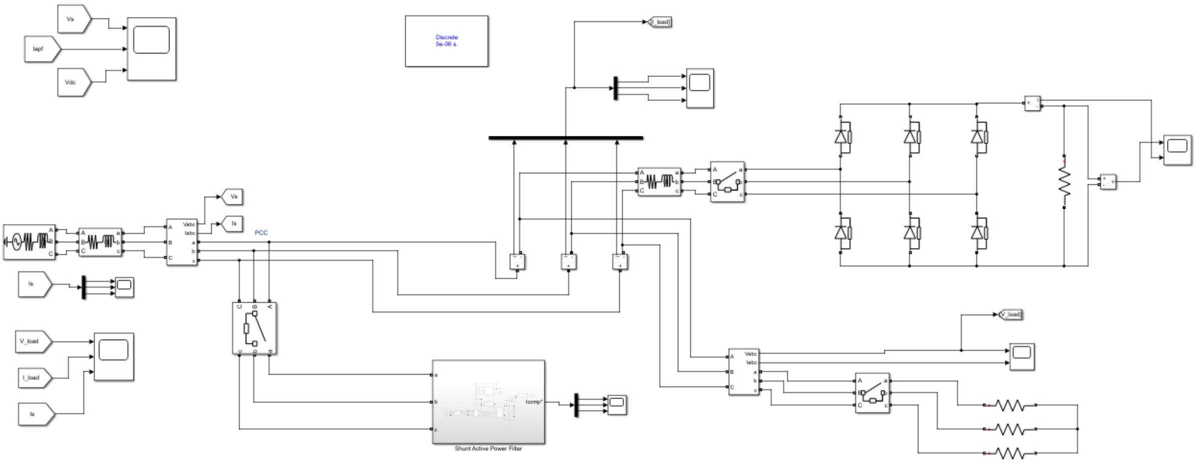


Figure 7. Simulink diagram of transmission line with Shunt APF

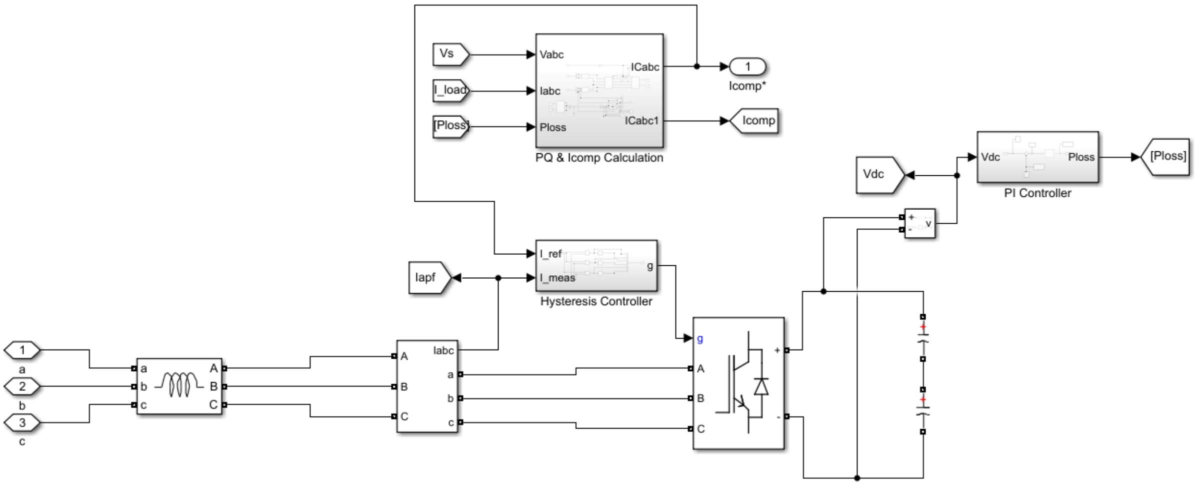


Figure 8. Inside the Shunt APF

An essential part of keeping the function of the power filter optimal is to keep the DC link Capacitor voltage at a constant value. To accommodate this tremendous task, a Proportional-Integral controller (PI controller) is used, which also provides the value of power loss taking place in the inverter bridge for further steps of calculating compensation current. The PI controller action should be very accurate and fast. This is the part of our model that will be later replaced by ANN to improve its performance.

The value of Power loss is sent to the subsystem assigned to calculate the value of compensating current. This block uses the technique of Clarke transformation to simplify the calculations in a three phase rotating frame of reference, by converting it to a stationary frame of reference. The equations used for this conversion are given as:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

The value of instantaneous active and reactive powers are then calculated using the equation

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

This is passed through a low pass filter to remove any AC part present in them.Then they are used for the calculation of compensation current using

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} \widetilde{P} \\ \widetilde{Q} \end{bmatrix}$$

$$\begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix}$$

The actual value of current in the system is then compared with this value in the hysteresis controller to generate the PWM pulse required to control the operation of VSI and generate the compensating current to be injected in the system.

The simulation is run once to gather all the data from the PI controller in the workspace. The value of error (e), the reference voltage (Ref) and output (output) of the PI controller is taken in the workspace.

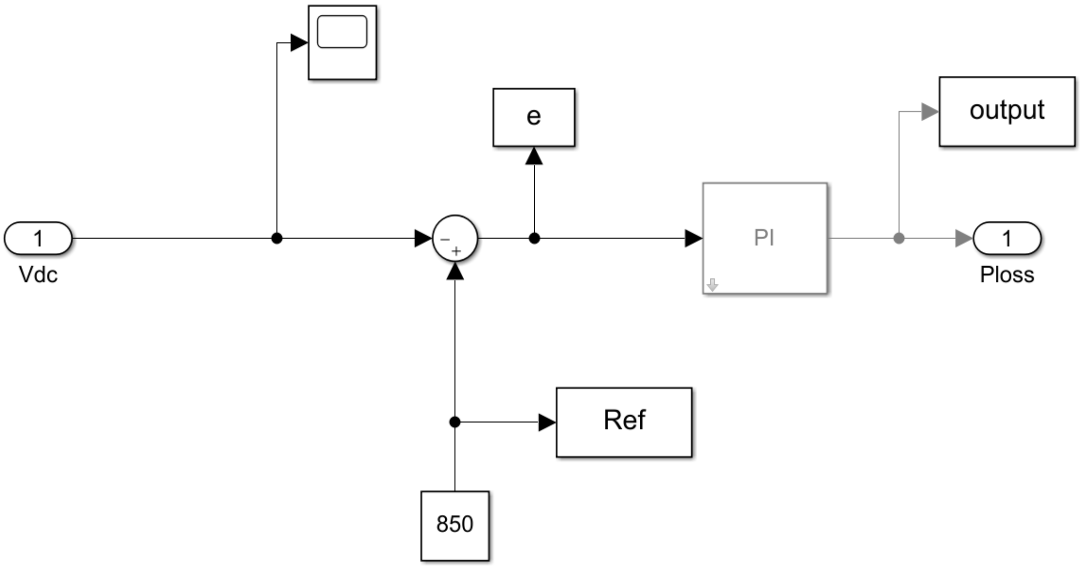
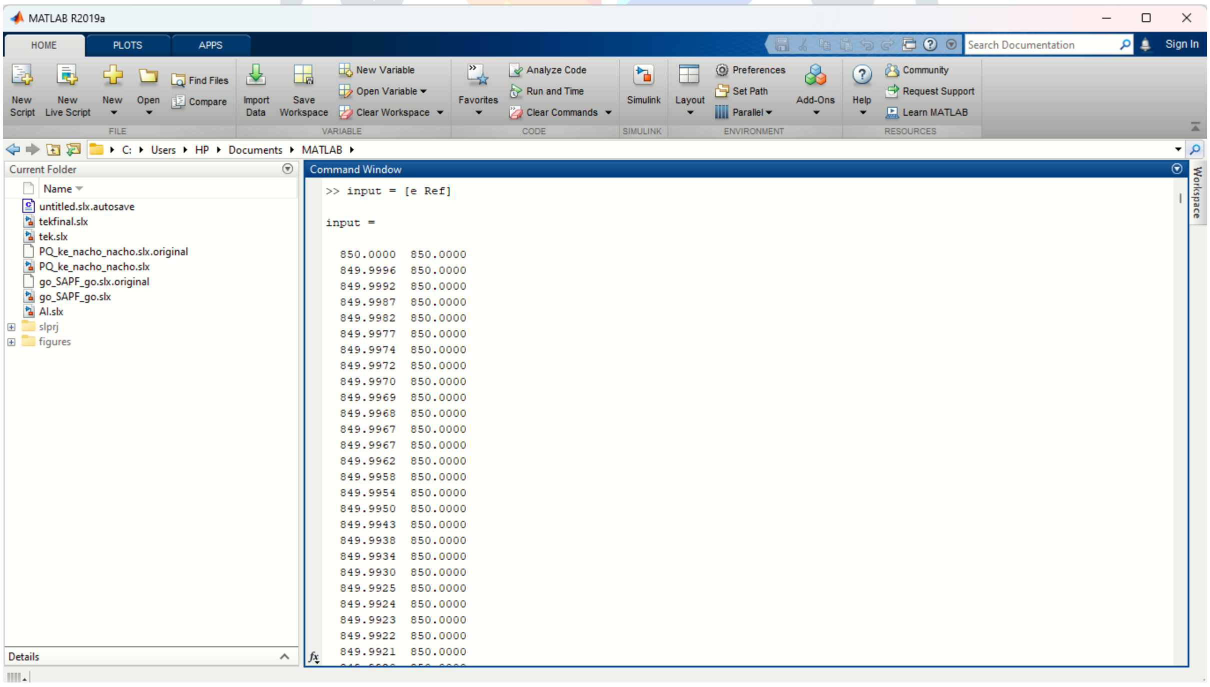


Figure 9. PI Controller

The values of e and Ref are arranged in a 2D matrix. This matrix is the input matrix for ANN training. The target matrix is constructed from values of output. Since we are using supervised learning method for training, therefore we require both input and target matrices. In supervised learning the actual output is compared with the desired output. This error is reduced until it is tolerable and the model is trained.



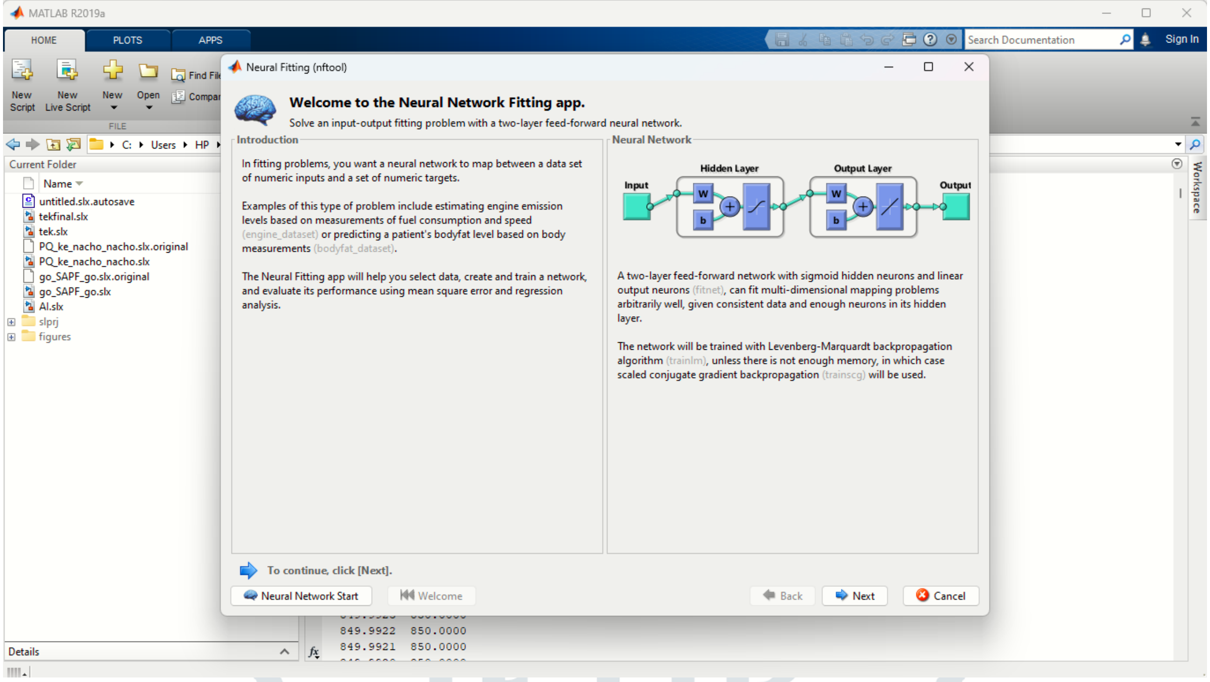
```
>> input = [e Ref]

input =

  850.0000  850.0000
  849.9996  850.0000
  849.9992  850.0000
  849.9987  850.0000
  849.9982  850.0000
  849.9977  850.0000
  849.9974  850.0000
  849.9972  850.0000
  849.9970  850.0000
  849.9969  850.0000
  849.9968  850.0000
  849.9967  850.0000
  849.9967  850.0000
  849.9962  850.0000
  849.9958  850.0000
  849.9954  850.0000
  849.9950  850.0000
  849.9943  850.0000
  849.9938  850.0000
  849.9934  850.0000
  849.9930  850.0000
  849.9925  850.0000
  849.9924  850.0000
  849.9923  850.0000
  849.9922  850.0000
  849.9921  850.0000
```

Figure 10. Input matrix

NN Fitting app available in MATLAB is used to create the Artificial Neural Network.



Neural Fitting (nftool)

Welcome to the Neural Network Fitting app.

Solve an input-output fitting problem with a two-layer feed-forward neural network.

Introduction

In fitting problems, you want a neural network to map between a data set of numeric inputs and a set of numeric targets.

Examples of this type of problem include estimating engine emission levels based on measurements of fuel consumption and speed (engine_dataset) or predicting a patient's bodyfat level based on body measurements (bodyfat_dataset).

The Neural Fitting app will help you select data, create and train a network, and evaluate its performance using mean square error and regression analysis.

Neural Network

A two-layer feed-forward network with sigmoid hidden neurons and linear output neurons (fitnet), can fit multi-dimensional mapping problems arbitrarily well, given consistent data and enough neurons in its hidden layer.

The network will be trained with Levenberg-Marquardt backpropagation algorithm (trainlm), unless there is not enough memory, in which case scaled conjugate gradient backpropagation (trainscg) will be used.

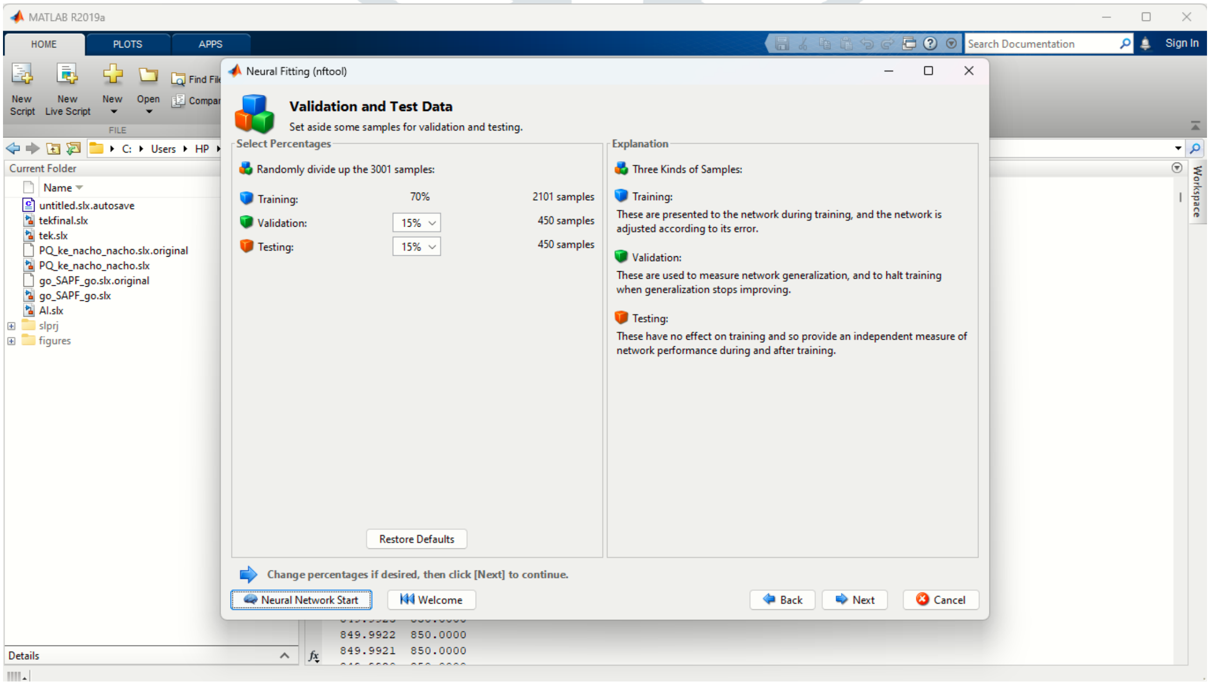
To continue, click [Next].

```
849.9922   850.0000
849.9921   850.0000
```

Figure 11. NN Fitting app

3000 samples were taken to train the network. The data is partitioned into three kinds of samples: Training, Validation and Testing. During training, the network is given training data, and it undergoes modification based on its errors. Network generalisation is measured using validation data, and training is stopped when generalisation no longer improves. Since testing data doesn't affect training, it offers a separate way to gauge network performance both before and after training.

We divided the data in the ratio of 70%, 15% and 15% i.e. 70% data for training, 15% data for validation and the rest 15% data for testing. The model consists of 10 hidden neurons.



Neural Fitting (nftool)

Validation and Test Data

Set aside some samples for validation and testing.

Select Percentages

Randomly divide up the 3001 samples:

Training:	70%	2101 samples
Validation:	15%	450 samples
Testing:	15%	450 samples

Explanation

Three Kinds of Samples:

Training:
These are presented to the network during training, and the network is adjusted according to its error.

Validation:
These are used to measure network generalization, and to halt training when generalization stops improving.

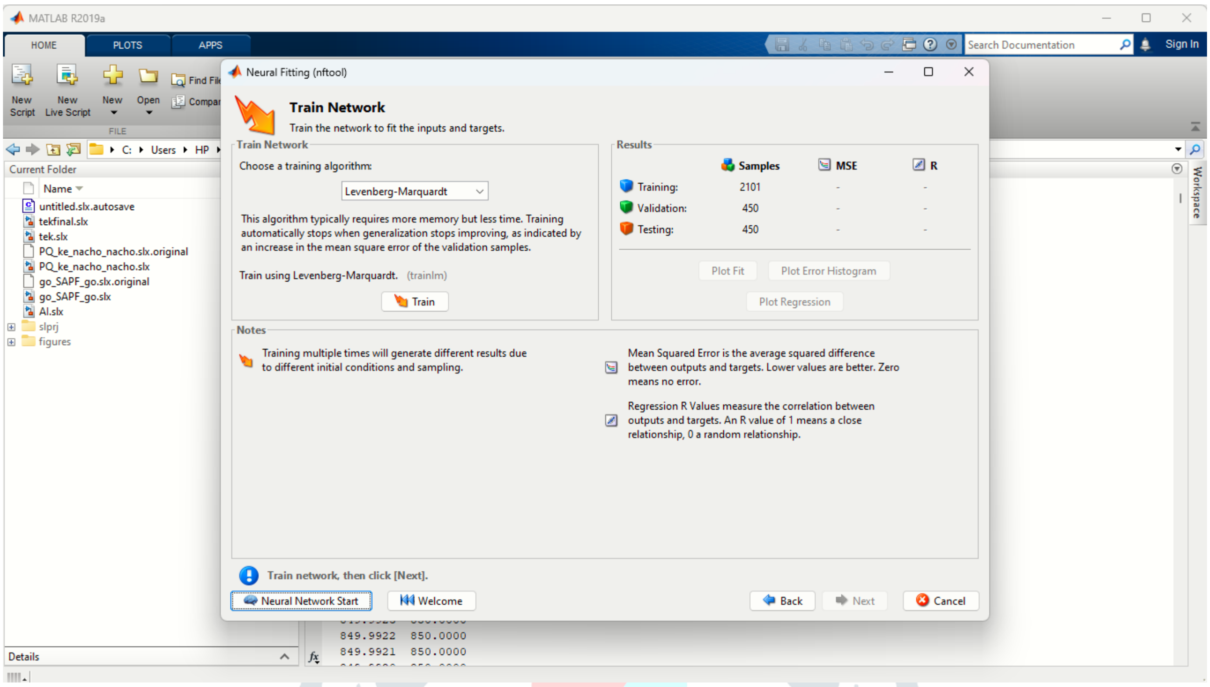
Testing:
These have no effect on training and so provide an independent measure of network performance during and after training.

Change percentages if desired, then click [Next] to continue.

```
849.9922   850.0000
849.9921   850.0000
```

Figure 12. Data splitting in three parts

Levenberg-Marquardt algorithm is used for the training of the ANN model. Usually, this method takes a shorter time while requiring greater memory. When generalisation no longer improves, as seen by a rise in the validation samples' mean square error, training automatically ends.



Neural Fitting (nftool)

Train Network

Train the network to fit the inputs and targets.

Train Network

Choose a training algorithm: Levenberg-Marquardt

This algorithm typically requires more memory but less time. Training automatically stops when generalization stops improving, as indicated by an increase in the mean square error of the validation samples.

Train using Levenberg-Marquardt. (trainlm)

Results

	Samples	MSE	R
Training:	2101	-	-
Validation:	450	-	-
Testing:	450	-	-

Notes

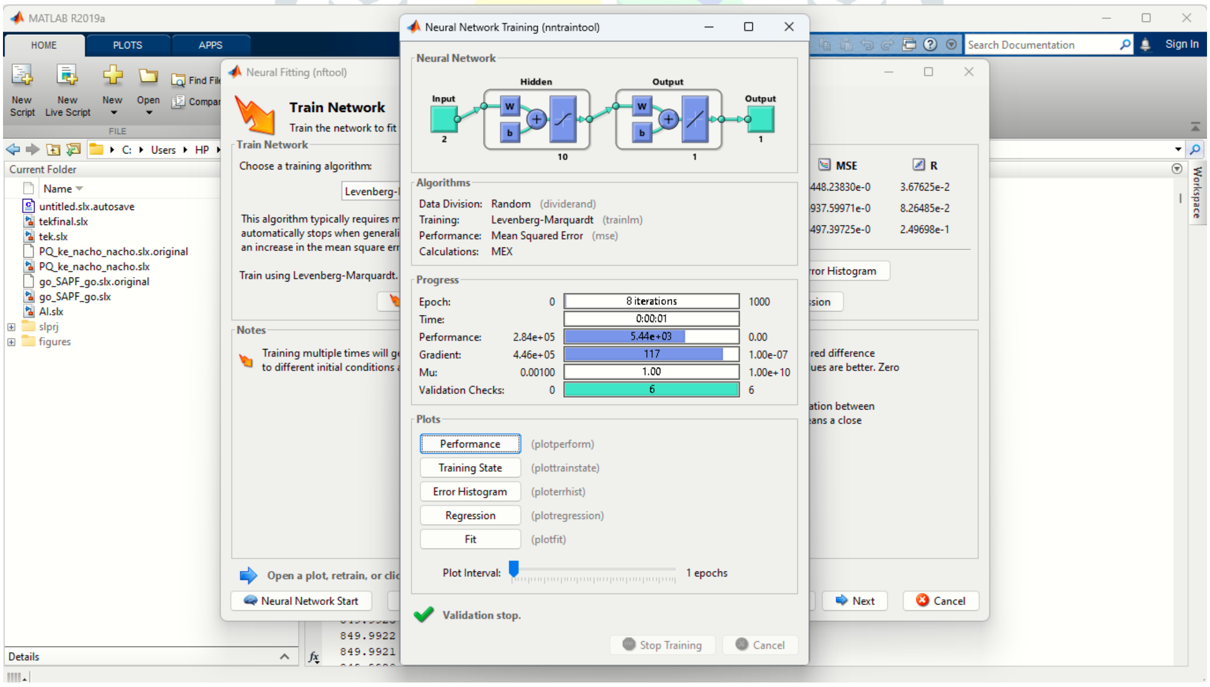
Training multiple times will generate different results due to different initial conditions and sampling.

Mean Squared Error is the average squared difference between outputs and targets. Lower values are better. Zero means no error.

Regression R Values measure the correlation between outputs and targets. An R value of 1 means a close relationship, 0 a random relationship.

Train network, then click [Next].

Figure 13. Training algorithm of ANN



Neural Network Training (nntraintool)

Neural Network

Algorithms

Data Division: Random (dividerand)
Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Calculations: MEX

Progress

Epoch:	0	8 iterations	1000
Time:		0:00:01	
Performance:	2.84e+05	5.44e+03	0.00
Gradient:	4.46e+05	117	1.00e-07
Mu:	0.00100	1.00	1.00e+10
Validation Checks:	0	6	6

Plots

Performance (plotperform)
Training State (plottrainstate)
Error Histogram (ploterrhist)
Regression (plotregression)
Fit (plotfit)

Plot Interval: 1 epochs

Validation stop.

Figure 14. Training process of ANN

At last, after training the ANN model, the model is imported as a simulink diagram. The PI controller is removed from the simulation and it is replaced by the ANN model. The final simulation incorporating Artificial Neural Network is thus created.

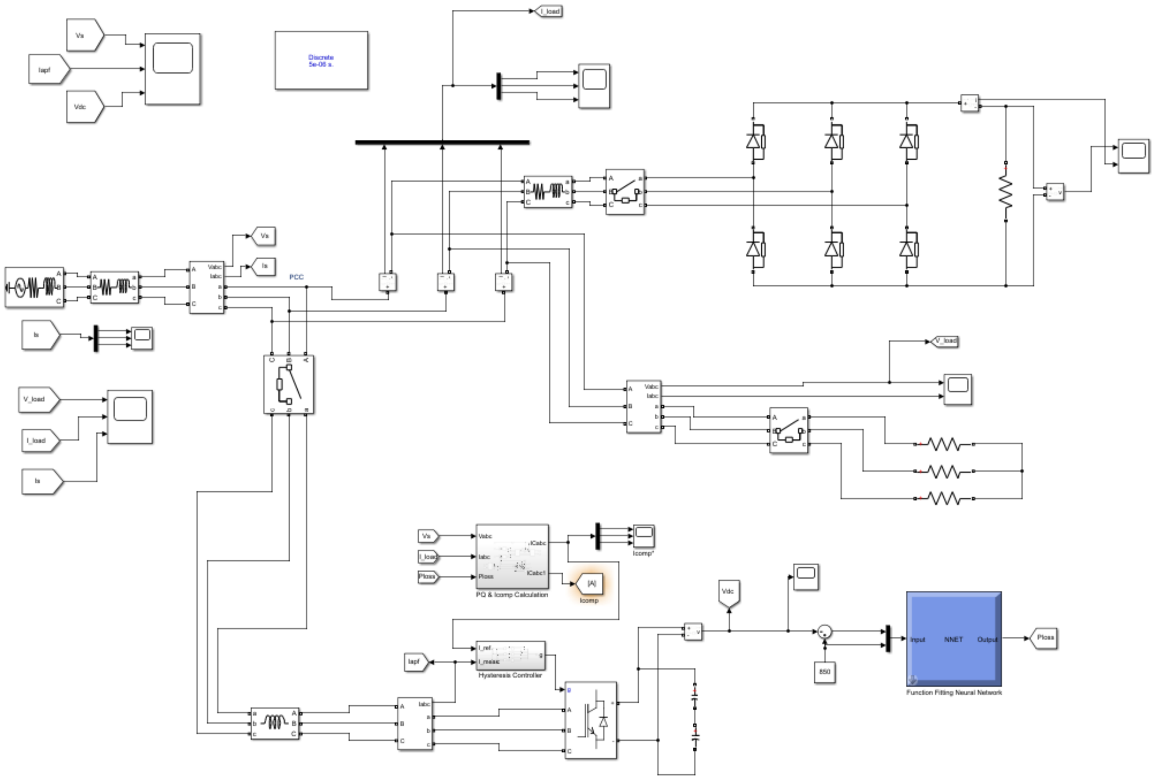
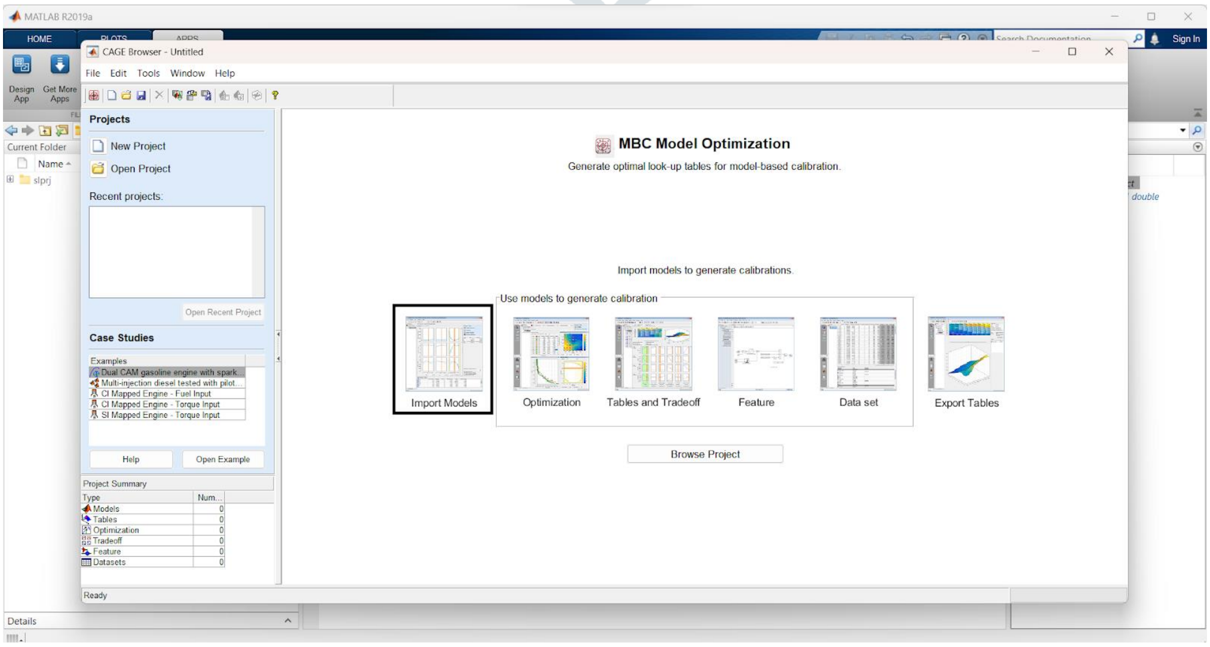


Figure 15. Simulink diagram of Shunt APF with ANN control

MBC optimization of the Network is done by taking the values of frequencies, THDs and phase angles, both with and without connecting Shunt APF. Here we import the data i.e. the values of frequencies, THDs and phase angles when SAPF is not connected. The file we import contains the value of frequencies, THDs and phase angles when SAPF is not connected, another file which contains the value of frequencies, THDs and phase angles when SAPF is connected. By plotting these values in 2D and 3D plot we get our required optimised model. We get a relation between frequency, THD and phase angle in the form of 2D and 3D plot graphs through the optimised model.



Project Summary

Type	Num...
Models	0
Tables	0
Optimization	0
Tradeoff	0
Feature	0
Datasets	0

MBC Model Optimization

Generate optimal look-up tables for model-based calibration.

Import models to generate calibrations.

Figure 16. MBC model optimization

RESULT

The ANN model Regression and error plots are shown below. The training regression is 0.0368, validation regression is 0.0826, testing regression is 0.2497 and overall regression is 0.0369.

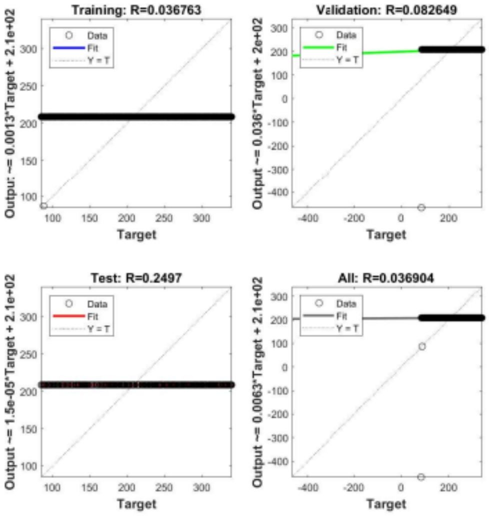


Figure 17. Regression plot

The error histogram shows the errors obtained for various instances.

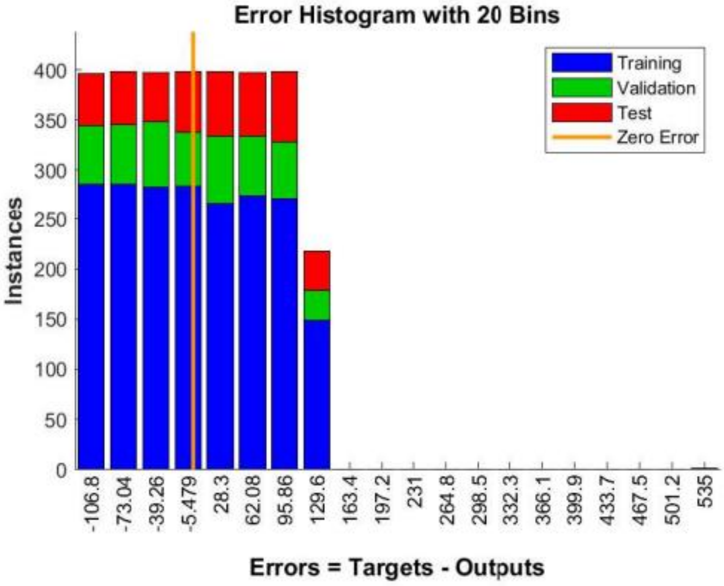
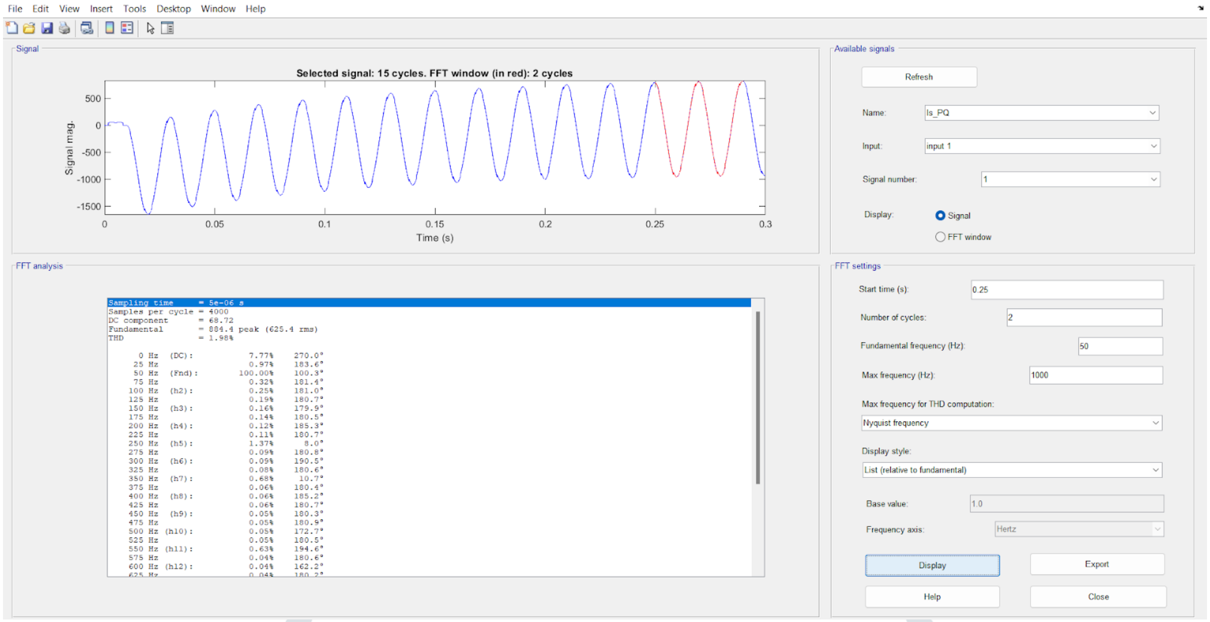


Figure 18. Error Histogram

The FFT analysis of the system after the inclusion of Shunt Active Power Filter with ANN is shown below:-



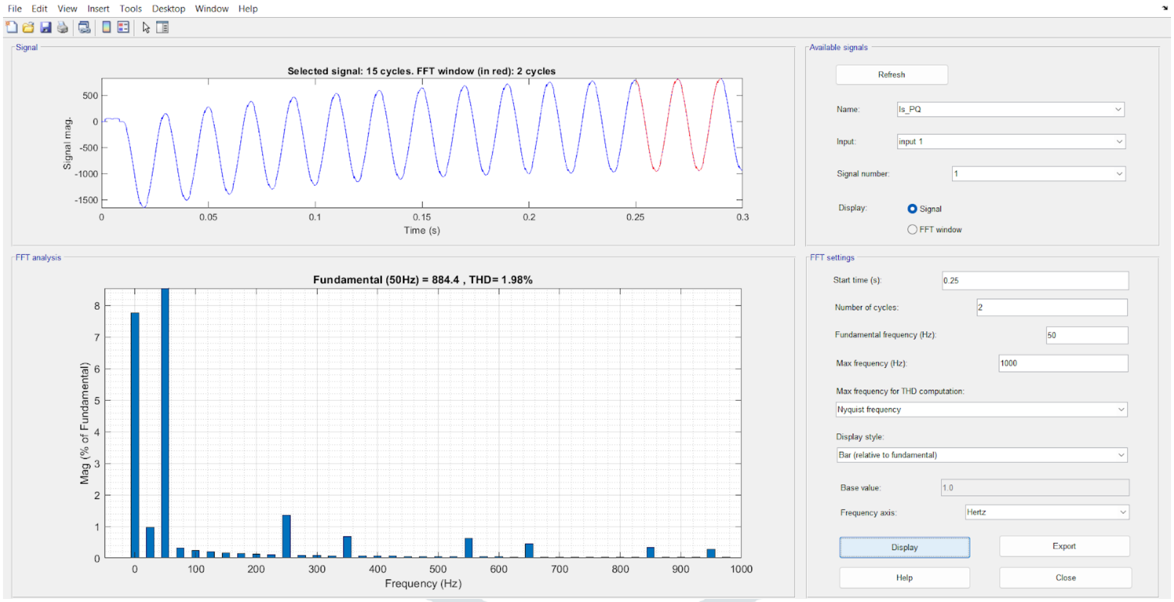
Name: Is_PQ
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window

Start time (s): 0.25
Number of cycles: 2
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

```
Sampling time      = 5e-06 s
Samples per cycle  = 4000
DC component       = 68.72
Fundamental        = 884.4 peak (625.4 rms)
THD                = 1.98%

      0 Hz  (DC):        7.77%    270.0°
     25 Hz               0.97%    183.6°
     50 Hz  (Fnd):     100.00%    100.3°
     75 Hz               0.32%    181.4°
    100 Hz  (h2):        0.25%    181.0°
    125 Hz               0.19%    180.7°
    150 Hz  (h3):        0.16%    179.9°
    175 Hz               0.14%    180.5°
    200 Hz  (h4):        0.12%    185.3°
    225 Hz               0.11%    180.7°
    250 Hz  (h5):        1.37%      8.0°
    275 Hz               0.09%    180.8°
    300 Hz  (h6):        0.09%    190.5°
    325 Hz               0.08%    180.6°
    350 Hz  (h7):        0.68%     10.7°
    375 Hz               0.06%    180.4°
    400 Hz  (h8):        0.06%    185.2°
    425 Hz               0.06%    180.7°
    450 Hz  (h9):        0.05%    180.3°
    475 Hz               0.05%    180.9°
    500 Hz (h10):        0.05%    172.7°
    525 Hz               0.05%    180.5°
    550 Hz (h11):        0.63%    194.6°
    575 Hz               0.04%    180.6°
    600 Hz (h12):        0.04%    162.2°
    625 Hz               0.04%    180.2°
```

Figure 19. FFT analysis of system after connecting ANN



Name: Is_PQ
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window

Start time (s): 0.25
Number of cycles: 2
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 20. FFT analysis of system after connecting ANN

The THD before the inclusion of ANN control in Shunt Active Power Filter was 30.13% of the fundamental value, which has been reduced to 1.98% of the fundamental value. Thus there is a 93.43% decrease in the THD of the system from its initial value. Also, the individual harmonic components were also mitigated by following magnitudes from their respective initial individual values - 5th harmonics by 93%, 7th harmonics by 94% and 11th harmonics by 94%. Thus the system’s power quality is improved.

Following 2D graph shows the relation between Frequency and THD when SAPF is not connected:-

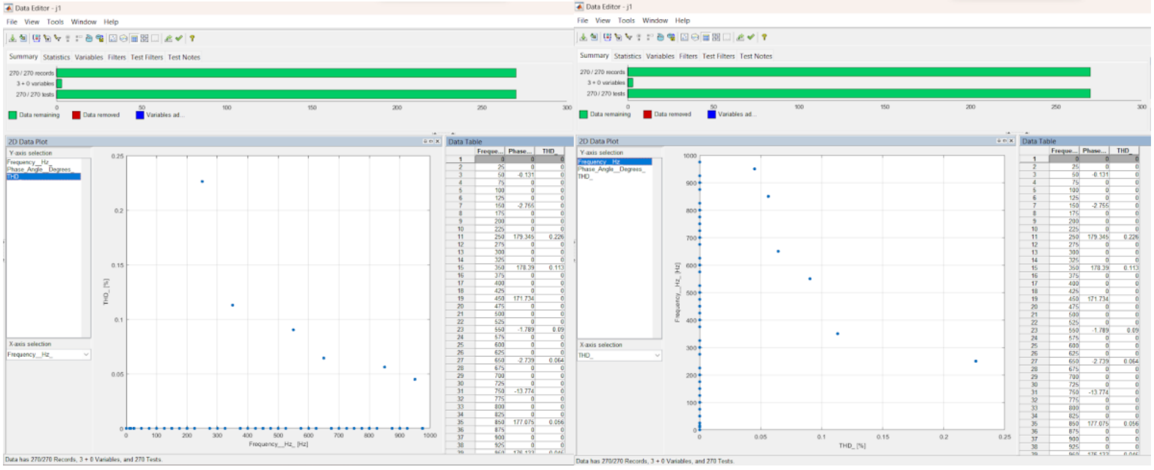


Figure 21. relation between Frequency and THD when SAPF is not connected

Following 2D graph shows the relation between Frequency and THD when SAPF is connected:-

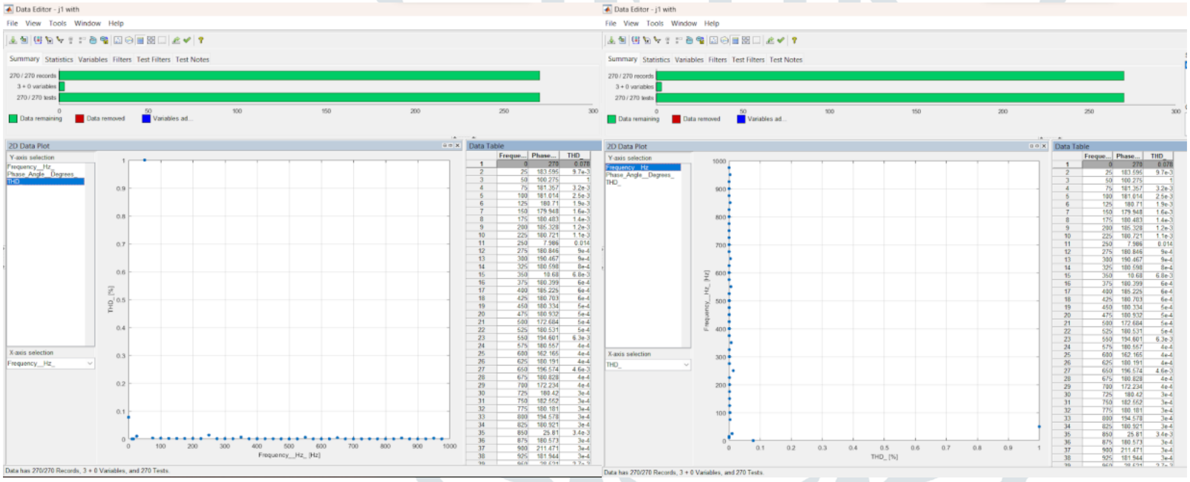


Figure 22. relation between Frequency and THD when SAPF is connected

Following 2D graph shows the relation between Frequency and Phase Angle when SAPF is not connected:-

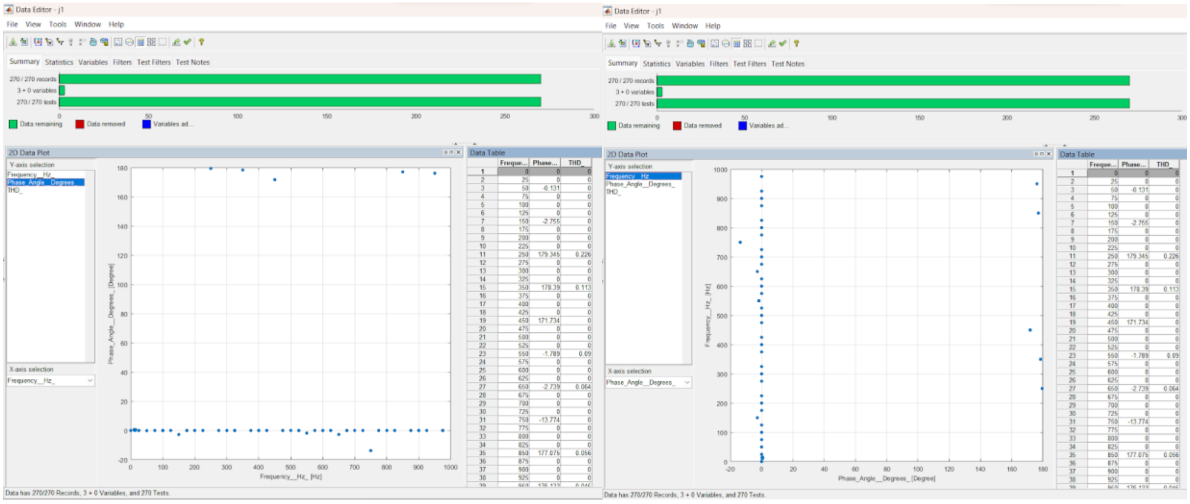


Figure 23. relation between Frequency and Phase Angle when SAPF is not connected

Following 2D graph shows the relation between Frequency and Phase Angle when SAPF is connected:-

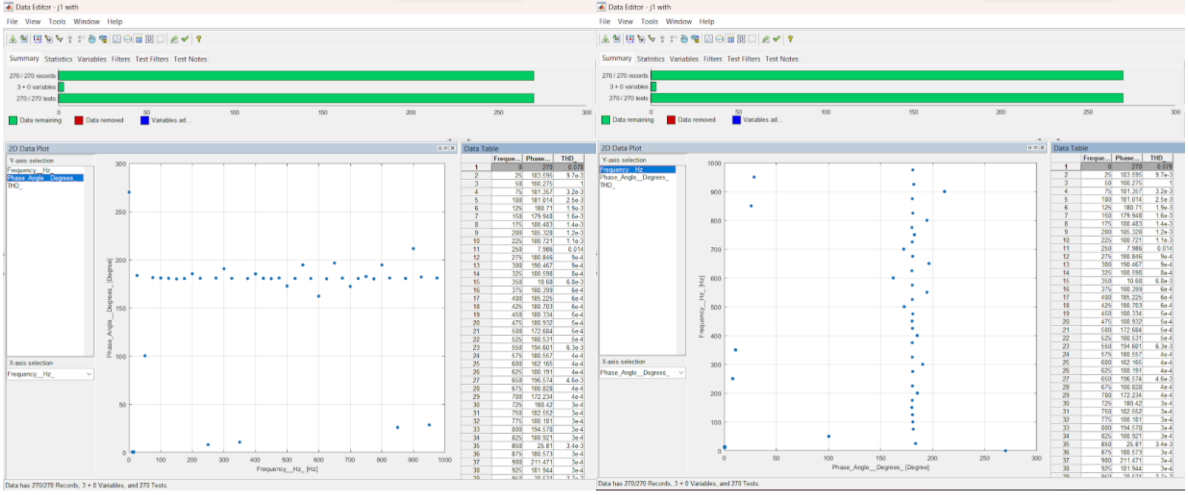


Figure 24. relation between Frequency and Phase Angle when SAPF is connected

Following 2D graph shows the relation between THD and Phase Angle when SAPF is not connected:-

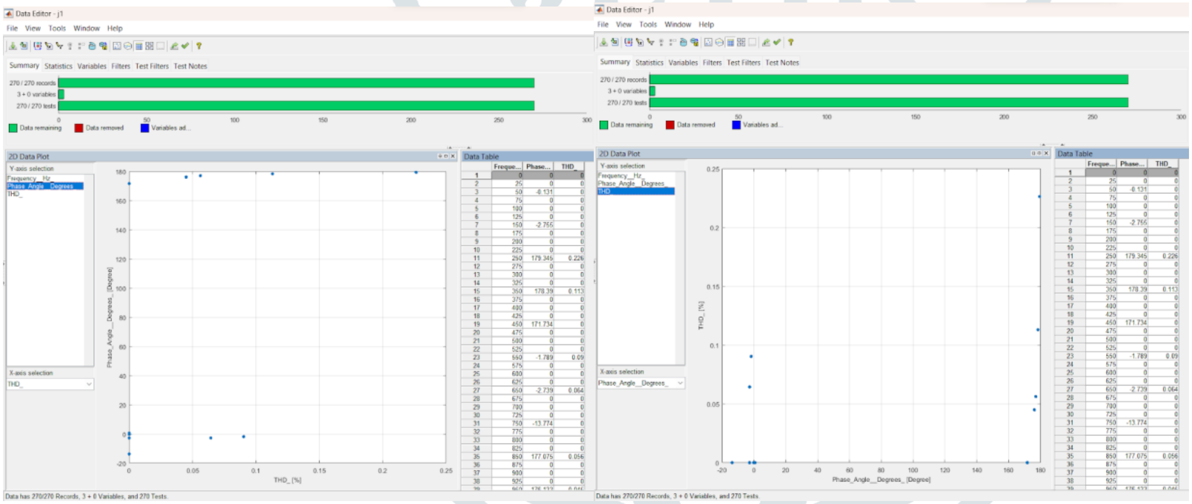


Figure 25. relation between THD and Phase Angle when SAPF is not connected

Following 2D graph shows the relation between THD and Phase Angle when SAPF is connected:-

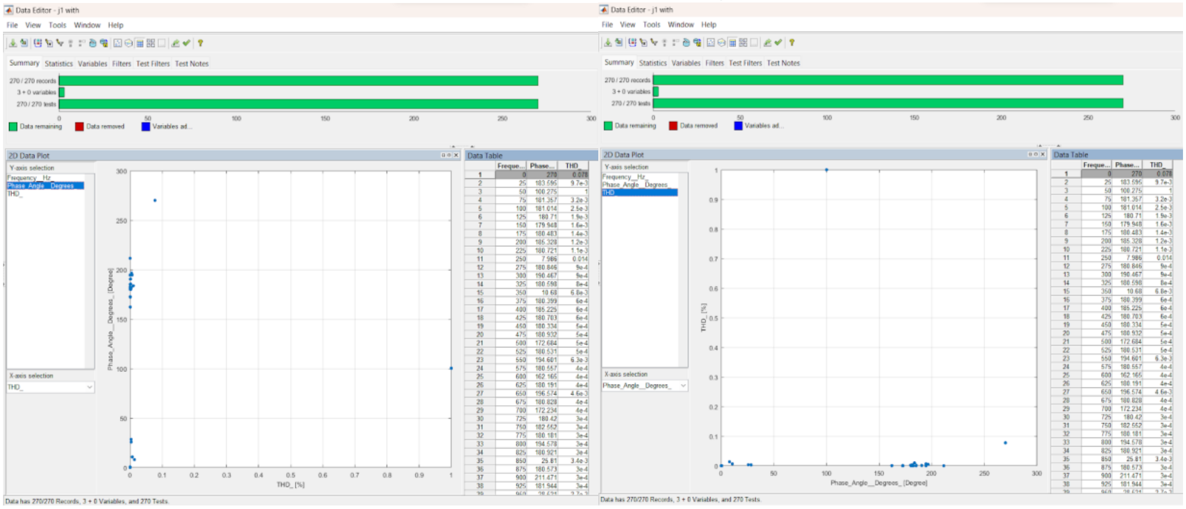
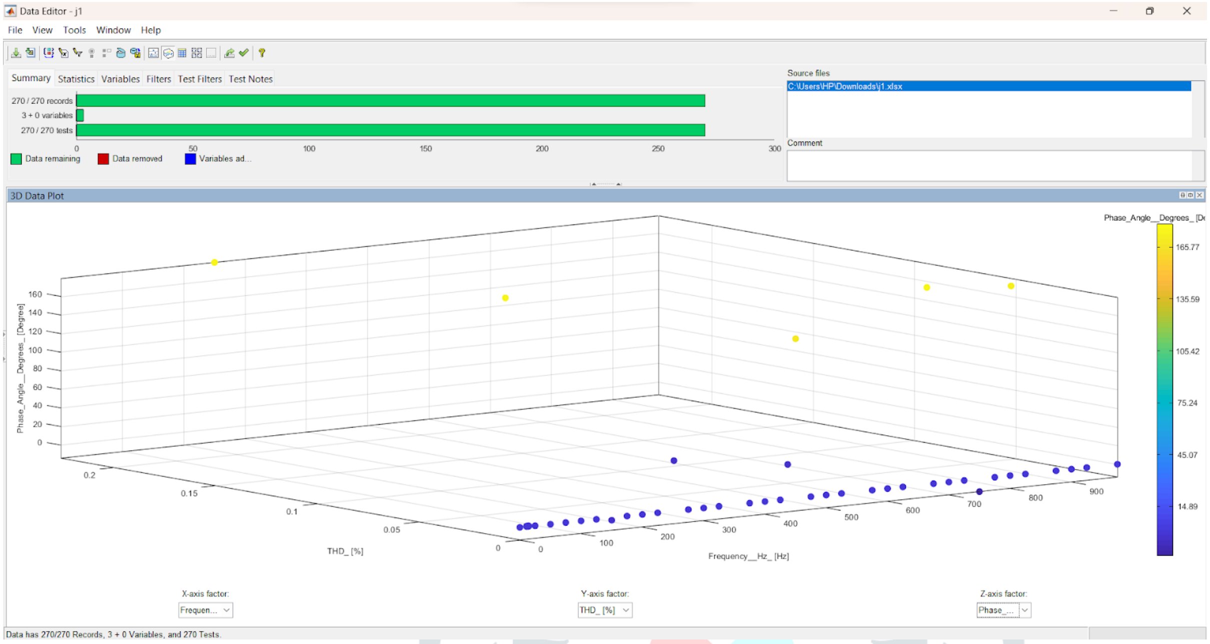


Figure 26. the relation between THD and Phase Angle when SAPF is connected

Now we will plot a graph between frequency, THD and phase angle. We have taken frequency as X-axis, THD as Y-axis and phase angle as Z-axis.

Following 3D graph shows the relation between Frequency, THD and Phase Angle when SAPF is not connected:-

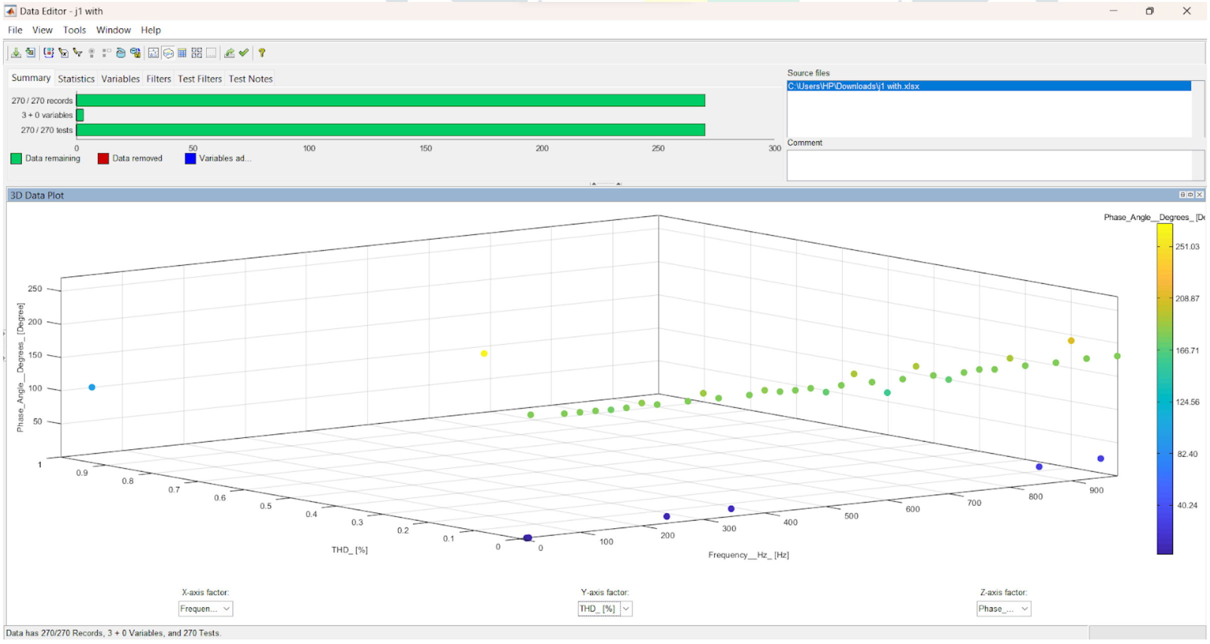


C:\Users\HP\Downloads\j1.xlsx

Data has 270/270 Records, 3 + 0 Variables, and 270 Tests.

Figure 27. relation between Frequency, THD and Phase Angle when SAPF is not connected

Following 3D graph shows the relation between Frequency, THD and Phase Angle when SAPF is connected:-



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Data has 270/270 Records, 3 + 0 Variables, and 270 Tests.

Figure 28. relation between Frequency, THD and Phase Angle when SAPF is connected

CONCLUSION

A control technique for Shunt APFs based on Artificial Neural Network (ANN) has been developed. The ANN model based Shunt APF created in this study has given satisfactory results. Based on the simulation findings, the resulting source current THDs are less than 5%, as specified by the IEEE-519 standard. The final THD is 1.98%

which is an outstanding result in the field of harmonic mitigation proving the model's prowess being greater than most common filters. To speed up the estimation of harmonic components, the Levenberg-Marquardt learning technique was applied. The model is not only effective but also simple in design.

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