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PERFORMANCE EVALUATION AND COMPARISON OF ARTIFICIAL NEURAL NETWORK INTEGRATED SHUNT ACTIVE POWER FILTER

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ABSTRACT

The newly developed Artificial Neural Network control method has been compared with PQ method in their harmonic mitigation capability. The simulation is simulated in the MATLAB/SIMULINK environment. A six-IGBT three phase voltage source inverter is used with a hysteresis controller as a Shunt Active Power Filter. Meanwhile, our ANN based model is developed from the data taken from the PQ method model, replacing the PI controller used in PQ method with ANN block. This comparison will give us an insight on the effectiveness of our new technique and its advantages and disadvantages. The adaptability and fault tolerance inherent in ANN alongside Shunt Active Power Filter can open doors to a new realm of research into harmonic mitigation. This paper is a first step in that direction, giving us a hint on what to improve in future. The simulation results indicate that artificial neural network can improve the performance of Shunt APF.

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

INTRODUCTION

The world has reached a point in time where every sector of our life depends on power electronics devices, in spite of their degrading effect on the power quality. Thus arose a need to decrease this effect and a new field of study saw the light of the day. Researchers came up with many techniques to decrease the voltage sags, swells and harmonics, among which harmonic filters of both passive and active types found their use. According to 519-1992

- IEEE Standard for Harmonic Control in Electric Power Systems, the acceptable level of harmonic in a power system is limited to 5.0% total harmonic distortion (THD) with each individual harmonic limited to 3% [1].

With so many harmonic mitigation techniques available in present times, it is more crucial than ever to select the best possible technique to be employed in terms of cost, size and mitigation capability. Hence comparison of different harmonic mitigation techniques becomes essential. A comparison of passive and active filters by Lukas Motta shows active power filters to be superior to passive power filters in terms of flexibility, versatility, current harmonic mitigation and higher level harmonic mitigation [5]. However Shunt Active Power Filters (SAPF) also have many control methods such as DQ method, PQ method and Fuzzy Logic method. Also, with the tremendous increase in capabilities of Artificial Intelligence (AI) and Machine Learning (ML), using their power to progress in this field has yielded a new control method incorporating Artificial Neural Network (ANN). A comparison of ANN control method with PQ method is conducted in this research paper to evaluate the performance of newly developed ANN control method.

HARMONICS

A wave or signal that has a frequency that is an integral multiple of the frequency of the same reference wave or signal is called a harmonic. This term may also be used to describe the relationship between the frequency of a signal or wave and the frequency of the reference signal or wave, as part of the harmonic series. The first, or initial, harmonic, is the basic frequency or original wave. Higher harmonics are the harmonics that follow. Every harmonic has a fundamental frequency, and at that particular frequency, the total number of harmonics likewise exhibits periodicity. In electrical systems, non-linear loads and devices are the main source of harmonics. Non-linear loads draw current differently from an ideal sinusoidal waveform which is present in semiconductor devices like diodes and transistors. Nowadays, by means of modern equipment, harmonics up to 63rd can be measured. But the most regularly found harmonics are between 3rd to 25th [7].

A system's Total Harmonic Distortion (THD) is often employed to quantify the harmonics that are present in the system. The harmonic content of a signal or waveform is measured by total harmonic distortion, or THD. It calculates the waveform's departure from a pure sinusoidal shape by comparing the fundamental frequency's amplitude to the amplitudes of its harmonic components. THD, which may be expressed as a percentage or a ratio, is a vital measure for evaluating the quality of electrical power. The following formula is used to determine THD:

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

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.

The power system's harmonic voltage restrictions are set by the international harmonic standards IEEE 519 and IEC 61000.3.6. In power systems, THD limitations for voltage and current can be as low as 6% for individual harmonics and as high as 5% to 8% for total current.

Adverse effects of Harmonics:-

1. Harmonics can distort the voltage waveform, causing departures from the ideal sinusoidal shape. This can result in voltage swings, which can impair the functioning of sensitive equipment.

2. Overloading of Conductors, Transformers, and Other Electrical Components: Harmonic currents can overload conductors, transformers, and other electrical components, resulting in increased heating and probable equipment damage.

3. Poor power quality caused by harmonics can cause interruptions in sensitive equipment, decreased operating efficiency, and lights flicker.

4. High harmonic levels can cause electromagnetic interference, which can disrupt neighbouring electrical equipment and communication networks.

Harmonic mitigation strategies are divided into three groups: passive harmonic filters, active harmonic filters, and hybrid harmonic filters. Passive filters consist of tuned harmonic filters, converter circuits using greater pulse numbers, and series reactors. They consist of a capacitor and an inductor, connected in series to prevent harmonic currents from entering the system and direct the flow of harmonic power through the low impedance circuit [6]. Active harmonic filters function by monitoring the load current, filtering the fundamental frequency, analysing the frequency, and injecting a reverse current to reduce harmonic distortion. They typically remove harmonics up to the 50th order and can achieve values of 5% or less. The controller portion of the Active Harmonic Filter is its primary component, which has two steps: performing a fast fourier transform to calculate the amplitude and phase angle of each harmonic order, and directing the filter to inject the inverse waveform to remove the harmonics.

Active filters are better than passive filters due to multiple reasons such as adaptability, precision, and improved power factor [5].

Series active power filters are highly sophisticated electrical tools used to lower harmonic distortion and fix power factor issues in power systems. They are connected in series with the load or distribution line that needs harmonic correction, recognizing voltage distortion brought on by harmonic currents moving through the impedance of the distribution line. These compensating currents are designed to counteract fluctuations in reactive power and harmonic components associated with voltage. The main purpose of series APF is to ensure that the sensitive loads are protected from voltage sags as well as voltage swells [4].

Shunt active power filters (SAPF) are used in power systems for improving power quality and eliminating harmonic distortion. They actively compensate for harmonic currents and reactive power in real time and are parallel-connected to the load they protect. Shunt APF continuously keeps track of the current waveform at the connecting location, recognizing harmonic frequencies and their magnitudes. Based on the detected harmonic content, the shunt APF generates compensatory electrical currents that are 180 degrees out of phase with the recorded harmonic currents, negating the harmonic components [2].

PQ THEORY

This extraction technique originally proposed by Akagi [3]for three phase systems is one the most commonly used harmonic current extraction techniques. A transition from a stationary reference system in (a, b, c) coordinates to a (α, β) coordinate system is implemented via the P/Q theorem. It is equivalent to a transformation that is done algebraically called Clarke's transformation, where the (α, β) coordinates are orthogonal to each other and a fixed reference system is also produced.

Using Clarke's transformation, the voltage and current are transformed from abc to α-β coordinates.. This can be seen in (1) and (2)

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \end{bmatrix} \quad \text{.....................(1)}$$

$$\begin{bmatrix} v_{c\alpha} \\ v_{c\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix} \quad \text{…………........(2)}$$

The voltages and currents vectors are expressed by:

$$\vec{v} = v_{s\alpha} + jv_{s\beta}$$
$$\vec{i} = i_{c\alpha} + ji_{c\beta}$$

.....................(3)

Thus, we may compute the active power (p), which is the real portion of the complex power, and the reactive power (q), which is the imaginary component of the complex power by the equation given below, by specifying the complex power s = $\vec{v}\vec{i}$ and accounting for the previous transformations.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix}$$

.....................(4)

The instantaneous powers p and q are stated as follows when the voltages are sinusoidal and feeding a non-linear load, which is the scenario examined in our system.:

$$P = \bar{P} + \tilde{P}$$
$$Q = \bar{Q} + \tilde{Q}$$

.....................(5)

With:

$\bar{P}, \bar{Q}$: Power that is associated with the fundamental components of active and reactive currents

$\tilde{P}$, $\tilde{Q}$: Power associated with the sum of current's harmonic components

In the (α, β) frame, the current may be divided into three parts: the total of the harmonics, the active and reactive components at the fundamental. This results in the equation that follows:

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix}\begin{bmatrix} \bar{P} \\ 0 \end{bmatrix} + \frac{1}{\Delta}\begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix}\begin{bmatrix} 0 \\ \bar{Q} \end{bmatrix} + \frac{1}{\Delta}\begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix}\begin{bmatrix} \tilde{P} \\ \tilde{Q} \end{bmatrix}$$

.....................(6)

Reactive and harmonic currents must be included in the reference signal of the shunt active power filter in order to correct for the harmonic currents produced by the non-linear loads. The reference currents in this instance are determined by:

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix}\begin{bmatrix} \tilde{P} \\ \bar{Q} + \tilde{Q} \end{bmatrix}$$

.....................(7)

Clarke's inverse translation yields the reference compensation currents:

$$\begin{bmatrix} i^*_{c1} \\ i^*_{c2} \\ i^*_{c3} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix}$$

.....................(8)

ARTIFICIAL NEURAL NET

Artificial Neural Network (ANN) controllers are used in shunt APF to lower harmonics formed in the distribution system. Shunt active power filters improve the functionality of the conventional controller and make use of smart controllers by supplying pulses that are regulated, required for the IGBT inverter using an ANN-based technique. In the proposed method, the voltage across the DC link of a shunt connected filter is maintained mostly by capacitor energy, which reduces the transient reaction time when the load varies abruptly. The MATLAB environment was used to generate the whole power system block set model for the proposed plan. Simulations are performed using MATLAB, and the results show that the THD is reduced by the ANN-controlled filter from 29.71% to 2.27%. The results of the simulated experiment additionally show how very successful the novel control mechanism is at reducing harmonics. The simulated experiment's outcomes also demonstrate how effective the unique control method is at lowering harmonics [8].

PROBLEM IDENTIFICATION

The increased integration of non-linear loads in heavy industrial settings has raised concerns about harmonic distortion. However, non-linear loads are becoming increasingly popular in a range of industries, including the household. Devices with nonlinear loads produce distorted current waveforms as they do not draw current in proportion to the applied voltage. They may have an impact on power quality, creating difficulties with gadgets and flickering lights. Computers and industrial equipment, including variable frequency motors, are examples of electronic devices. Controlling these loads is crucial for maintaining a consistent power quality. A pulse waveform with a high crest factor is an example of distorted current, which is commonly created by switched mode power supply (SMPS).

The simulation that we constructed to demonstrate how non-linear loads alter the system's current and voltage waveforms, as a result, power quality is shown below.

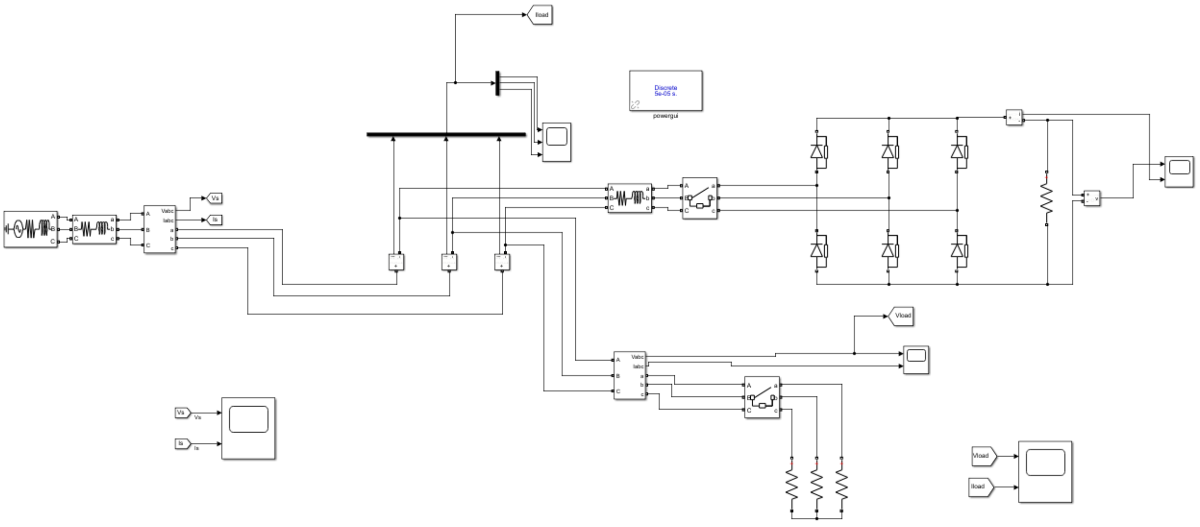


Figure 1. Simulink model of transmission line with non linear loads

Connecting to a three-phase transmission line are a resistive load and an unbalanced three-phase load. The waveform below is the result of this simulation.

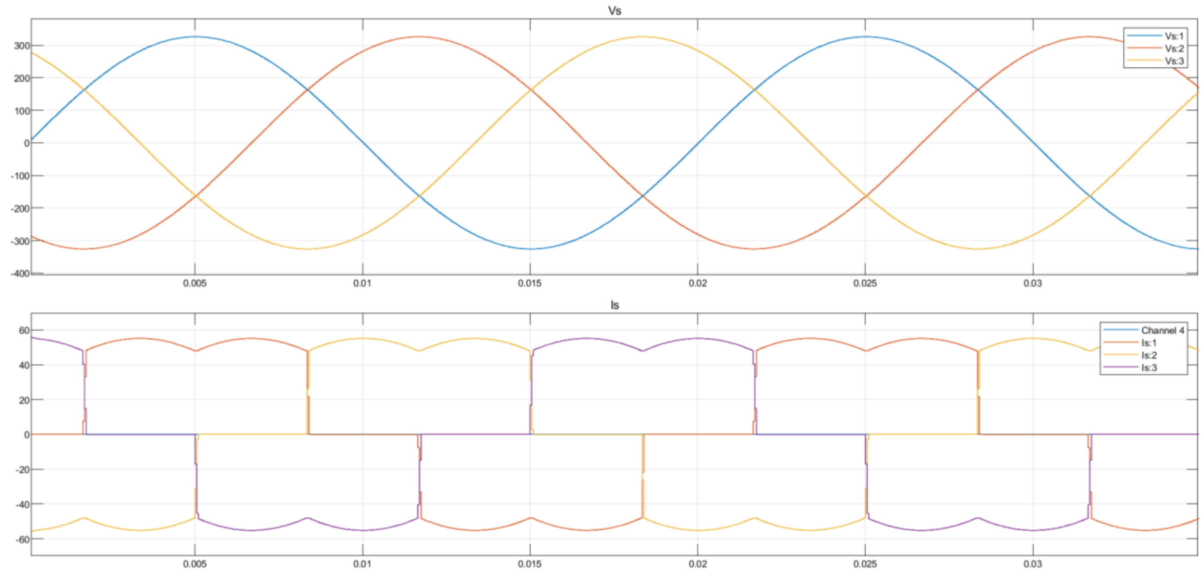
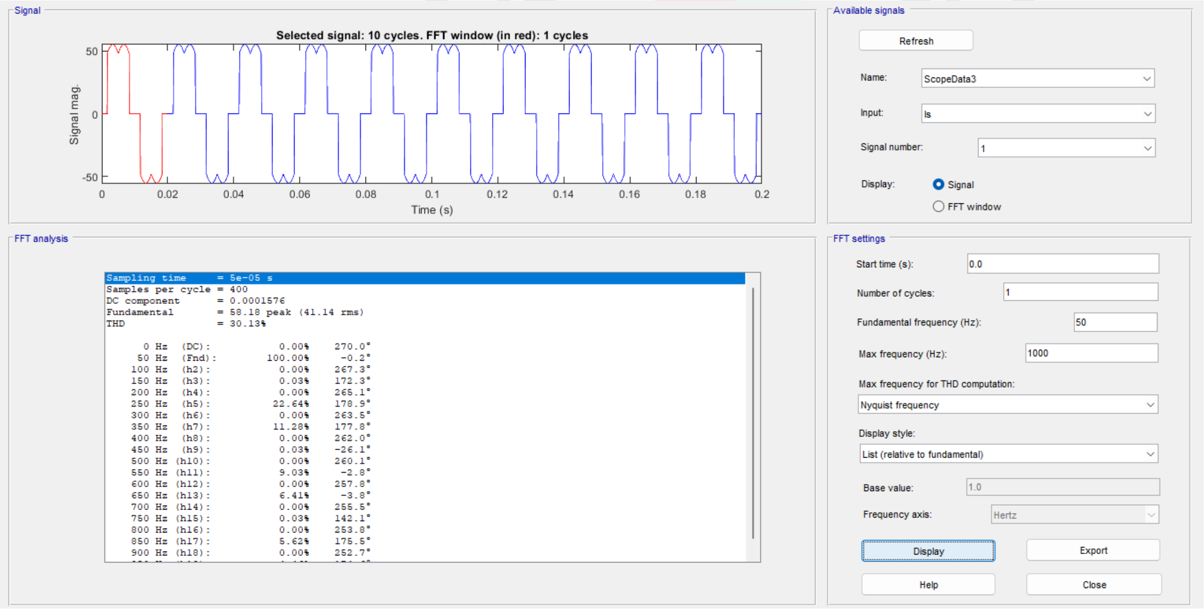


Figure 2. Waveform of source current affected by harmonics

Therefore, there are harmonics present in the source current, which generate distortion in the source current waveform. We obtain a measurement of the harmonic distortion, expressed in terms of THD, of the source current waveform after completing the Fast Fourier Transform analysis.



```
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 3. FFT analysis of source current

Therefore, it can be said that the non-linear loads generate harmonics in the electrical system. When we employ devices like SMPS (Switched-Mode Power Supplies) and other nonlinear loads in our electrical systems, we generate extra frequencies known as harmonics. These harmonics alter the typical sine wave patterns of voltage and current in our power systems, generating a variety of problems. They can reduce mechanical efficiency, resulting in wasted energy and poor performance. Harmonics can also cause voltage instability and even device damage by interfering with their inherent frequencies. They also reduce the power factor, which might result in higher electricity expenditures. Furthermore, harmonics can cause electromagnetic interference that disrupts communication networks and electrical devices. To avoid these issues, regulatory organisations regulate harmonic levels, and failure to comply can result in fines and penalties.

There are some cons related to PI controller which is listed below:-

- **Real Time Monitoring:** PI controller does not adapt to changing system conditions, which sometimes leads to poor power quality whereas by utilisation of Artificial Neural Network (ANN) fitting, can enable the SAPF to adapt to changing system conditions, improving its ability to mitigate power quality issues in real-time.

- **Limited Nonlinear Adaptability:** Variable loads, renewable energy sources, and other variables frequently cause power systems to display nonlinear behaviour. The linear design of a PI controller may make it difficult to adequately handle these nonlinearities, resulting in unsatisfactory power quality improvement performance. ANNs are better at modelling nonlinear relationships, allowing for better adaptability to dynamic system behaviour.

- **Complexity in Dynamic contexts:** Power systems function in quickly changing dynamic contexts. In dynamic contexts, maintaining the manual parameter tweaking that PI controllers demand depending on system variables can be difficult. After being trained, artificial neural networks (ANNs) may function more reliably and adjust to changing circumstances without requiring continual human interaction.

- **Low troubleshooting or maintenance:** PI controllers do not have advanced fault detection and maintenance capabilities. Identifying and managing errors rapidly in power systems is critical to preserving power quality. ANNs may be trained to identify numerous sorts of problems and automatically conduct remedial measures, hence enhancing system dependability and stability.

- **Problem With Multivariable Systems:** Power systems sometimes contain numerous interrelated factors that impact power quality, such as voltage, current, frequency, and harmonics. PI controllers are primarily built for single-input, single-output (SISO) systems and may struggle to manage multivariable systems adequately. ANNs can handle complicated interactions between numerous factors, allowing for more detailed power quality analysis and control.

PROPOSED METHODOLOGY

In order to compare the PQ method and Artificial Neural Net (ANN) method, two simulations are created. Both the simulations contain the same source, transmission line parameters and loads, the only difference being the absence or presence of ANN. The loads connected to the load are:

1. A three phase diode rectifier as a non-linear load

2. An unbalanced three phase resistive load

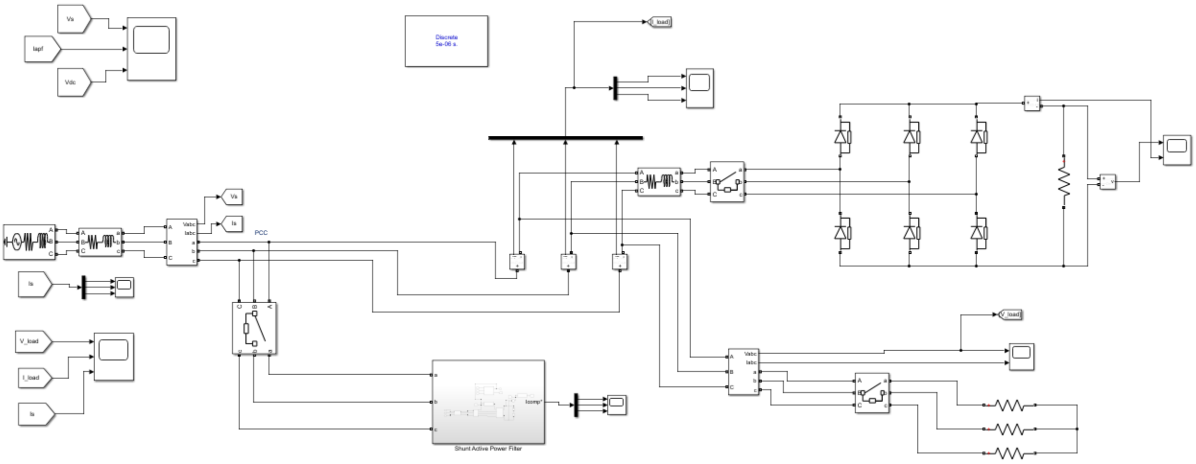


Figure 4. Simulink model of transmission line with non linear loads and Shunt active power filter

The purpose of connecting such specific loads is because they generate significant harmonic distortion in the system, which is useful in analysis of the effectiveness and performance of the shunt APF in different conditions, such as inclusion or exclusion of ANN.

The model of Shunt APF without ANN is shown in the figure below. The PI controller keeps a constant DC link voltage of the six-IGBT Voltage Source Inverter (VSI) while also providing the power loss in it. Thus it is an important part of the model and it is the one we will later replace with ANN.

This value of power loss is used in calculation of compensating current. The other parameters needed for this calculation are the load current and source voltage. Clarke transformation of voltage and current helps in making the calculations easier. The value of compensating current that is obtained here is used in hysteresis controller as a reference current for the generation of Pulse Width Modulated (PWM) gate pulse for the control of VSI. Hysteresis controller achieves this by comparing actual current with reference current. The VSI generates the compensating current for harmonic mitigation which is given back to the source side.

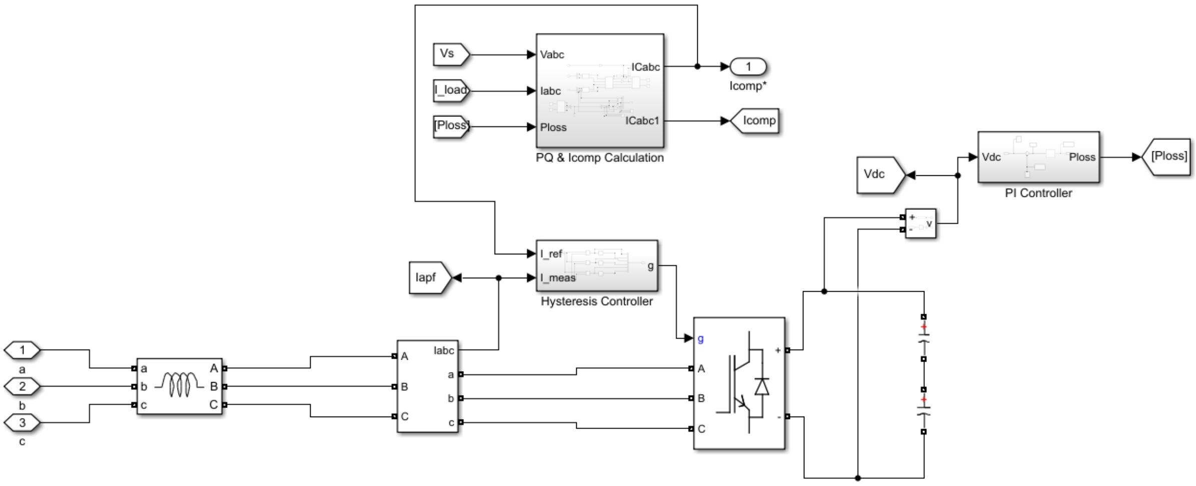
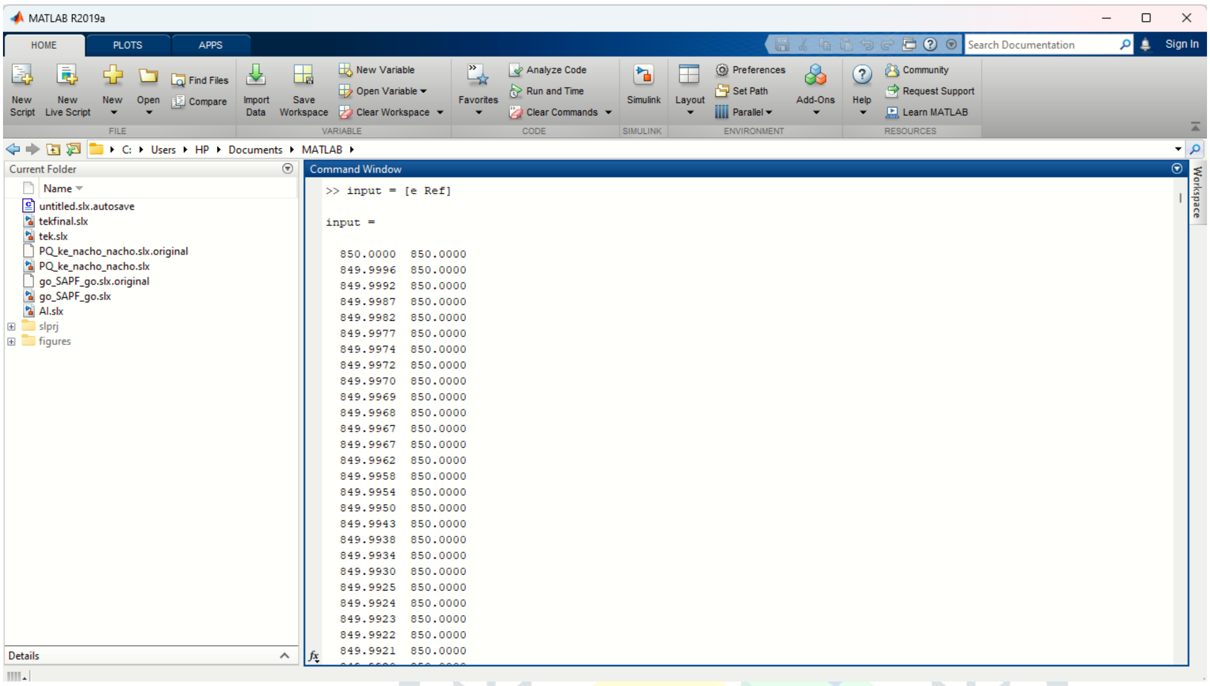


Figure 5. Inside of PI controlled Shunt APF

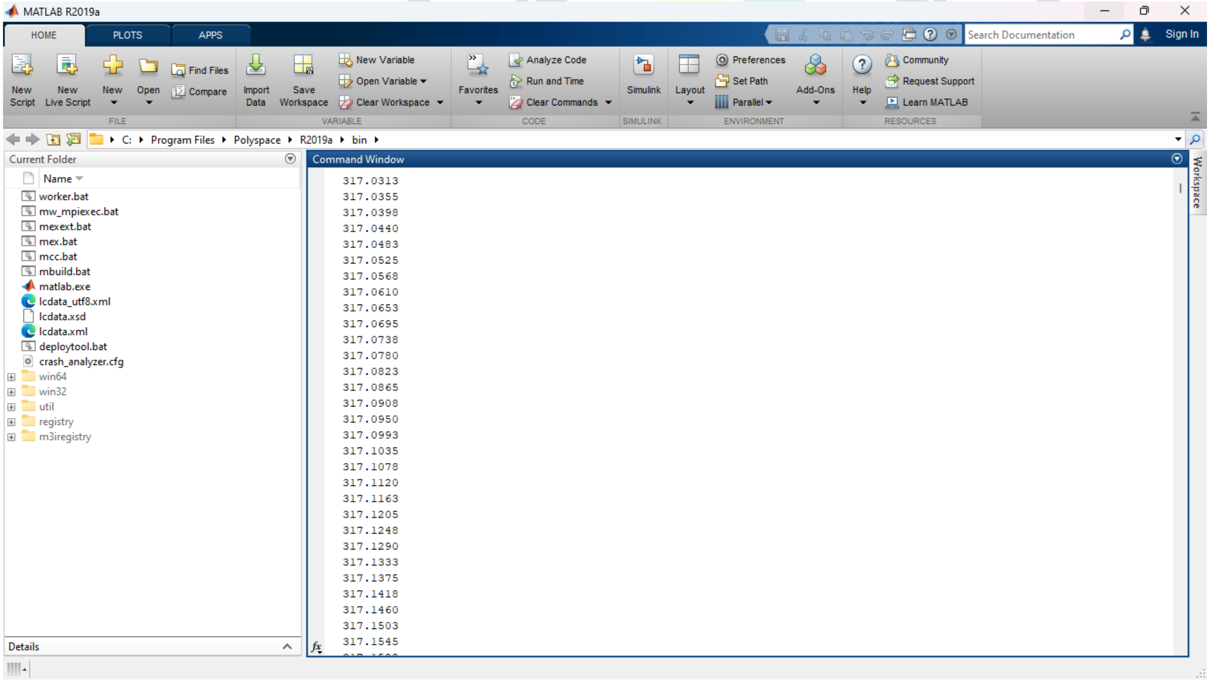
From this simulation we get our results for the PQ method. To obtain the results for ANN based shunt APF, we modify this model to incorporate an Artificial Neural Net in the place of PI controller.

For ANN we have to take two reference values i.e. input matrix and target matrix.



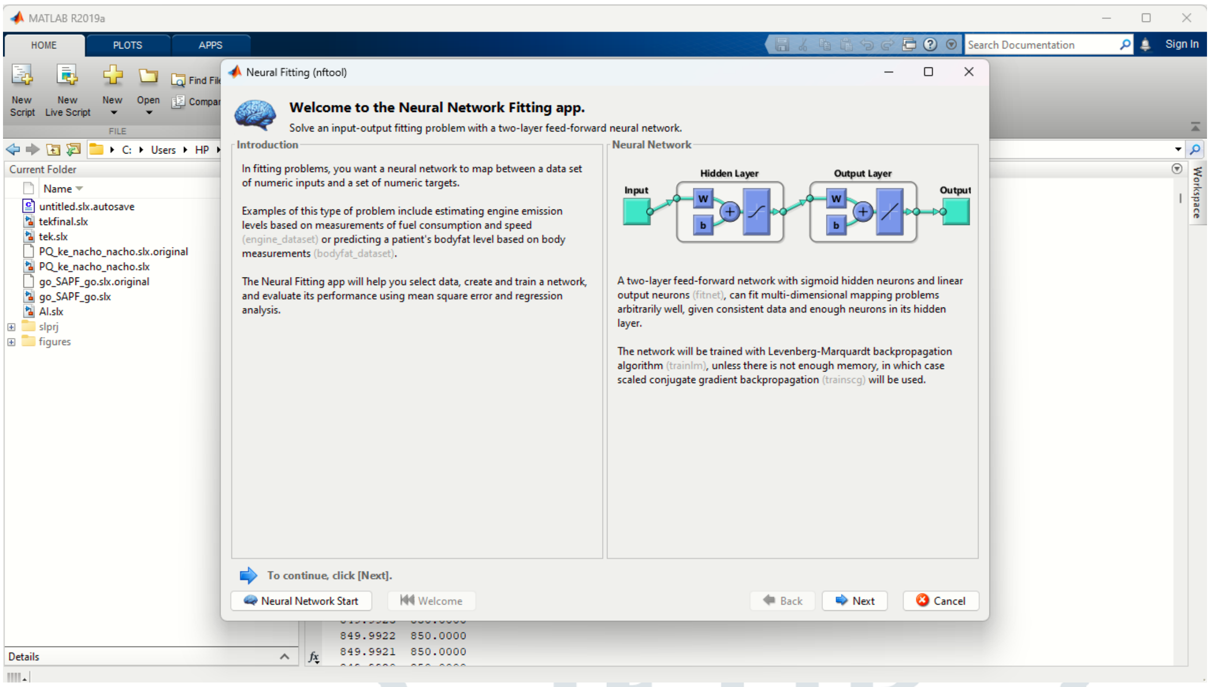
```
>> input = [e Ref]

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 6. Input Matrix



```
  317.0313
  317.0355
  317.0398
  317.0440
  317.0483
  317.0525
  317.0568
  317.0610
  317.0653
  317.0695
  317.0738
  317.0780
  317.0823
  317.0865
  317.0908
  317.0950
  317.0993
  317.1035
  317.1078
  317.1120
  317.1163
  317.1205
  317.1248
  317.1290
  317.1333
  317.1375
  317.1418
  317.1460
  317.1503
  317.1545
```

Figure 7. Target matrix



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

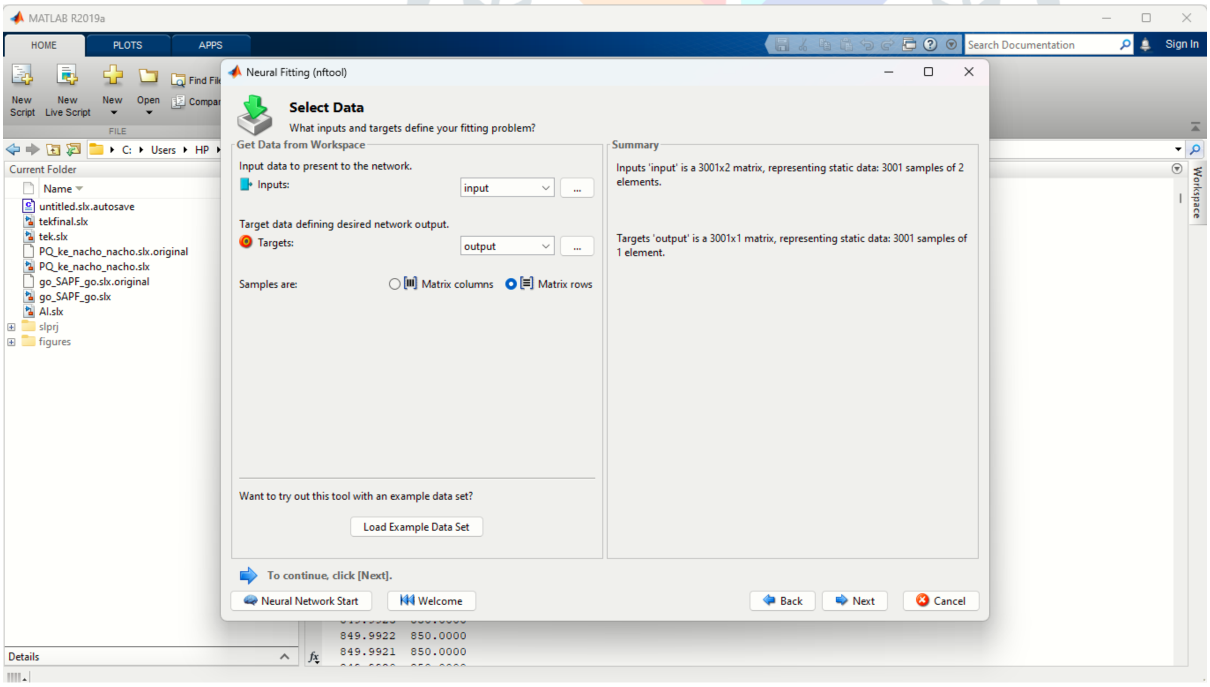
A two-layer feed-forward network with sigmoid hidden neurons and linear output neurons (fitnet), can fit multi-dimensional mapping problems arbitrarily well, given consistent data and enough neurons in its hidden layer.

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].

Figure 8. Neural Net Fitting app

Input matrix has two columns that is basically the error between Vdc and reference value i.e. 850V and target matrix is the output i.e. Ploss. We have taken 3000 samples for training.



Select Data

What inputs and targets define your fitting problem?

Get Data from Workspace

Input data to present to the network.

Inputs: input

Target data defining desired network output.

Targets: output

Samples are: ○ Matrix columns ● Matrix rows

Want to try out this tool with an example data set?

Summary

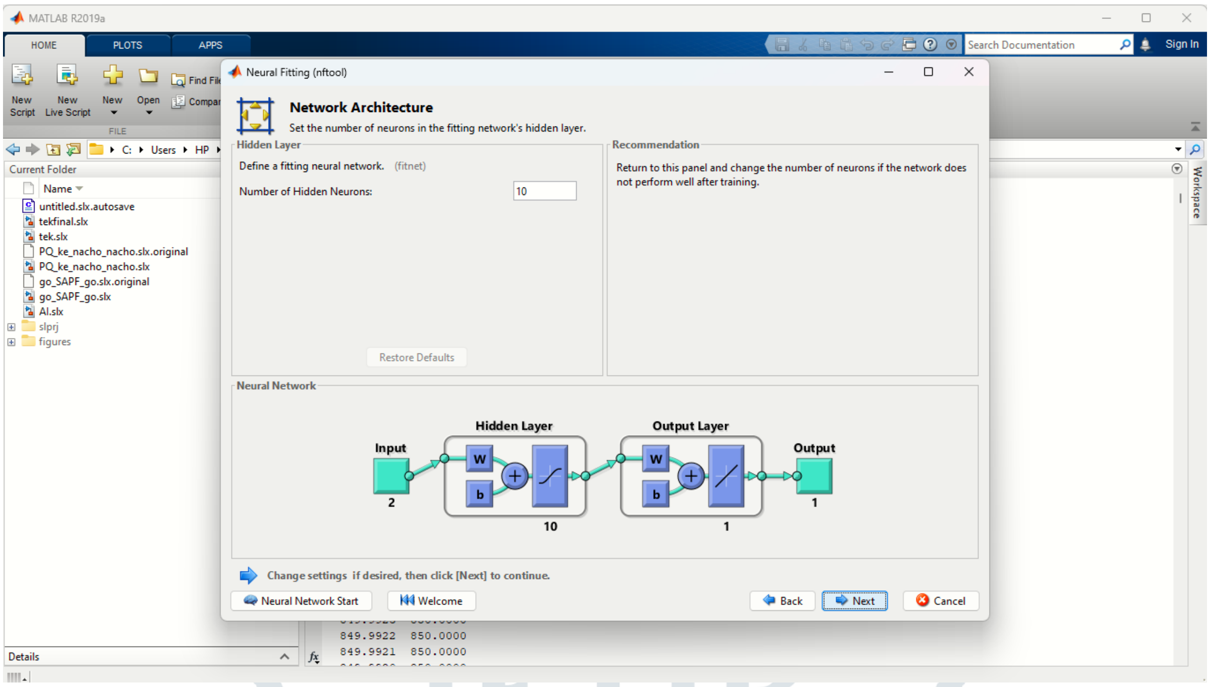
Inputs 'input' is a 3001x2 matrix, representing static data: 3001 samples of 2 elements.

Targets 'output' is a 3001x1 matrix, representing static data: 3001 samples of 1 element.

To continue, click [Next].

Figure 9. Selecting training data

The model consists of 10 hidden neurons. Neurons in the input and output layers are directly linked to the outside world or other components of the system. Hidden layers enable neural networks to understand complicated patterns and correlations within data, allowing them to solve a variety of problems.



Network Architecture

Set the number of neurons in the fitting network's hidden layer.

Hidden Layer

Define a fitting neural network. (fitnet)

Number of Hidden Neurons: 10

Recommendation

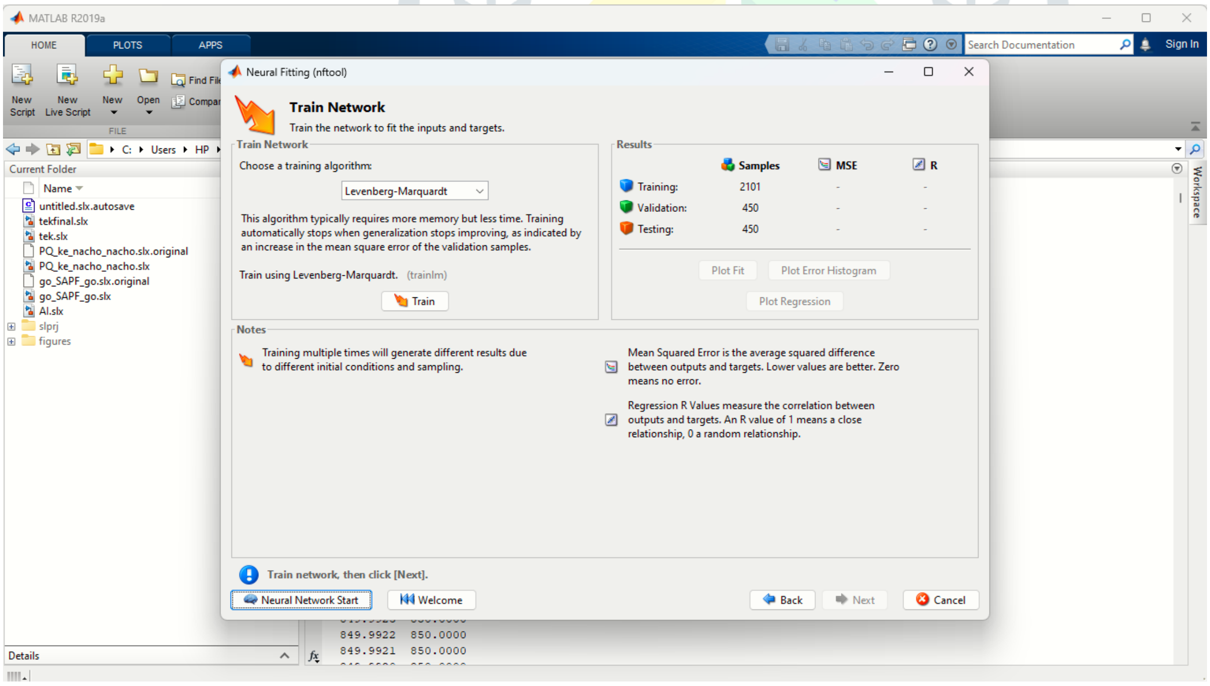
Return to this panel and change the number of neurons if the network does not perform well after training.

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

```
849.9922   850.0000
849.9921   850.0000
```

Figure 10. Selecting number of hidden neurons

Then we will use the Neural Net Fitting app to train the Neural Network using Lavenberg - Marquardt method which is a popular trust region algorithm that is used to find a minimum of a function (either linear or nonlinear) over a space of parameters.



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.

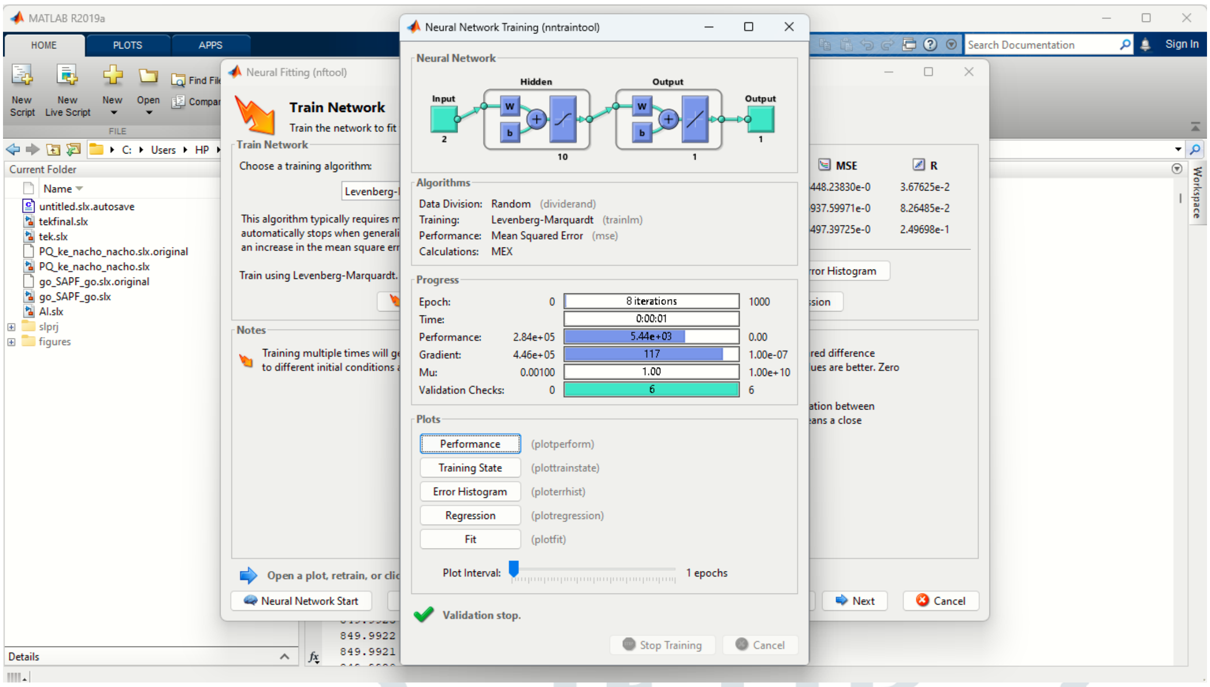
Mean Squared Error is the average squared difference between outputs and targets. Lower values are better. Zero means no error.

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].

```
849.9922   850.0000
849.9921   850.0000
```

Figure 11. Selecting training algorithm



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

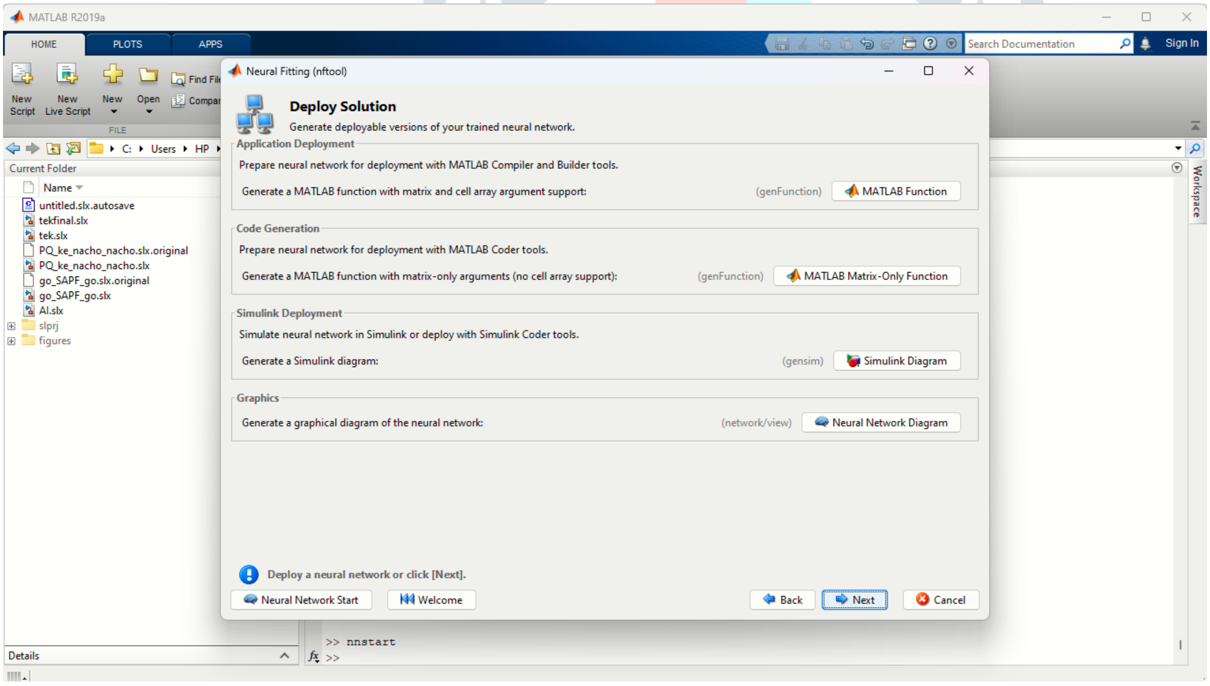
Performance (plotperform)
Training State (plottrainstate)
Error Histogram (ploterrhist)
Regression (plotregression)
Fit (plotfit)

Plot Interval: 1 epochs

Validation stop.

Figure 12. Training process

Then we will get a regression plot. Then we will create a simulink diagram.



Deploy Solution

Generate deployable versions of your trained neural network.

Application Deployment

Prepare neural network for deployment with MATLAB Compiler and Builder tools.

Generate a MATLAB function with matrix and cell array argument support: (genFunction) MATLAB Function

Code Generation

Prepare neural network for deployment with MATLAB Coder tools.

Generate a MATLAB function with matrix-only arguments (no cell array support): (genFunction) MATLAB Matrix-Only Function

Simulink Deployment

Simulate neural network in Simulink or deploy with Simulink Coder tools.

Generate a Simulink diagram: (gensim) Simulink Diagram

Graphics

Generate a graphical diagram of the neural network: (network/view) Neural Network Diagram

Deploy a neural network or click [Next].

```
>> nnstart
>>
```

Figure 13. Exporting ANN model to Simulink

Moreover we will place that NN fitting block in place of the PI controller and then we will do FFT analysis.

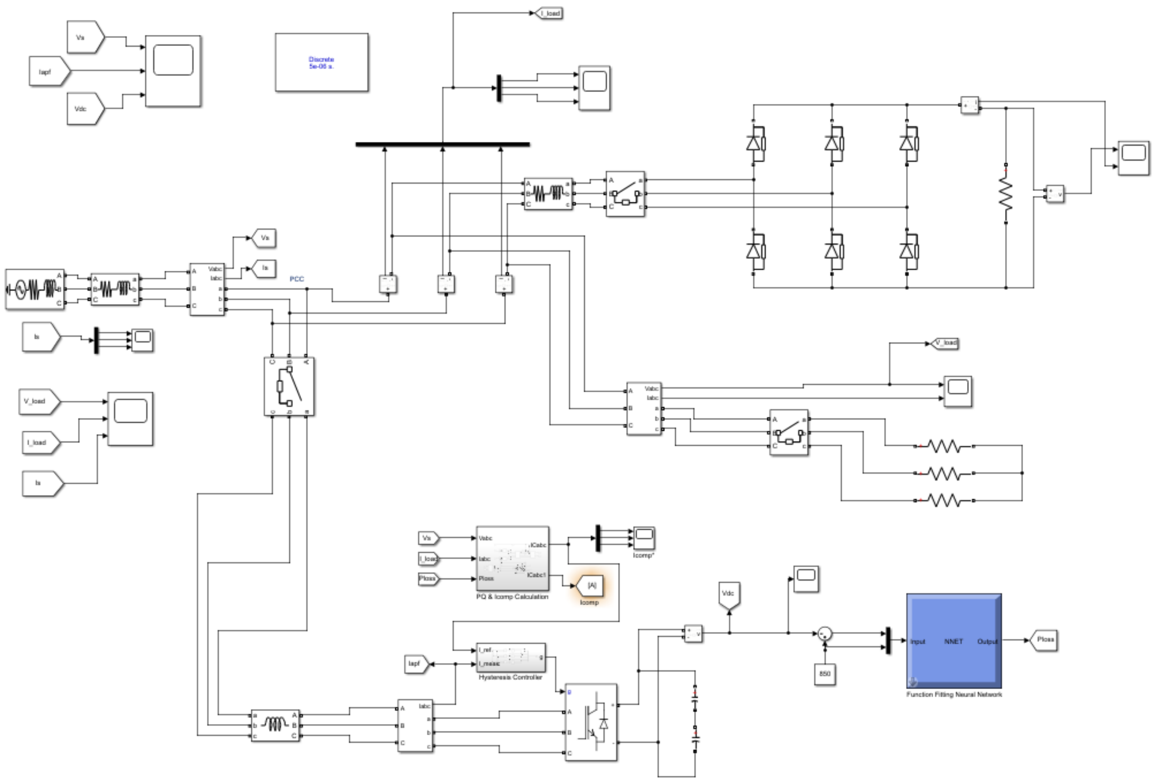
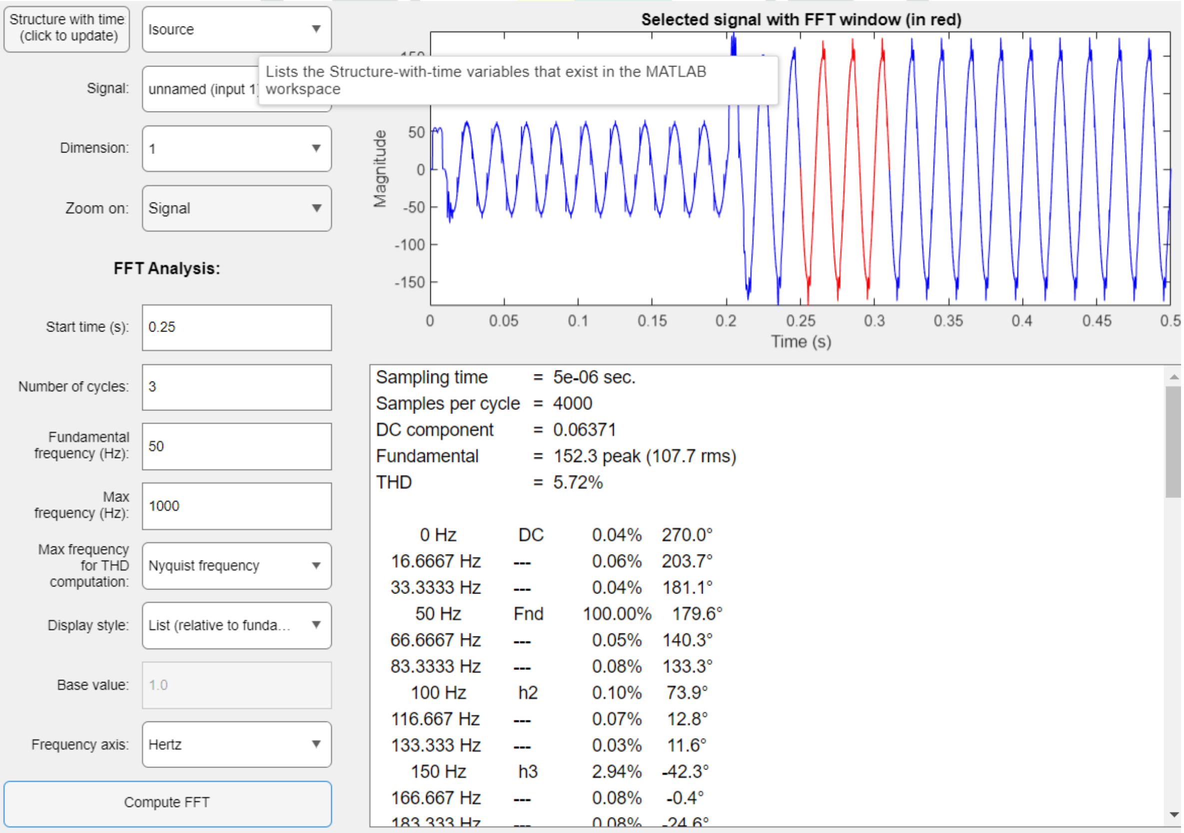


Figure 14. Simulink model of transmission line with ANN controlled Shunt APF

RESULT

The FFT analysis of the system after the inclusion of Shunt Active Power Filter without ANN is shown below:-



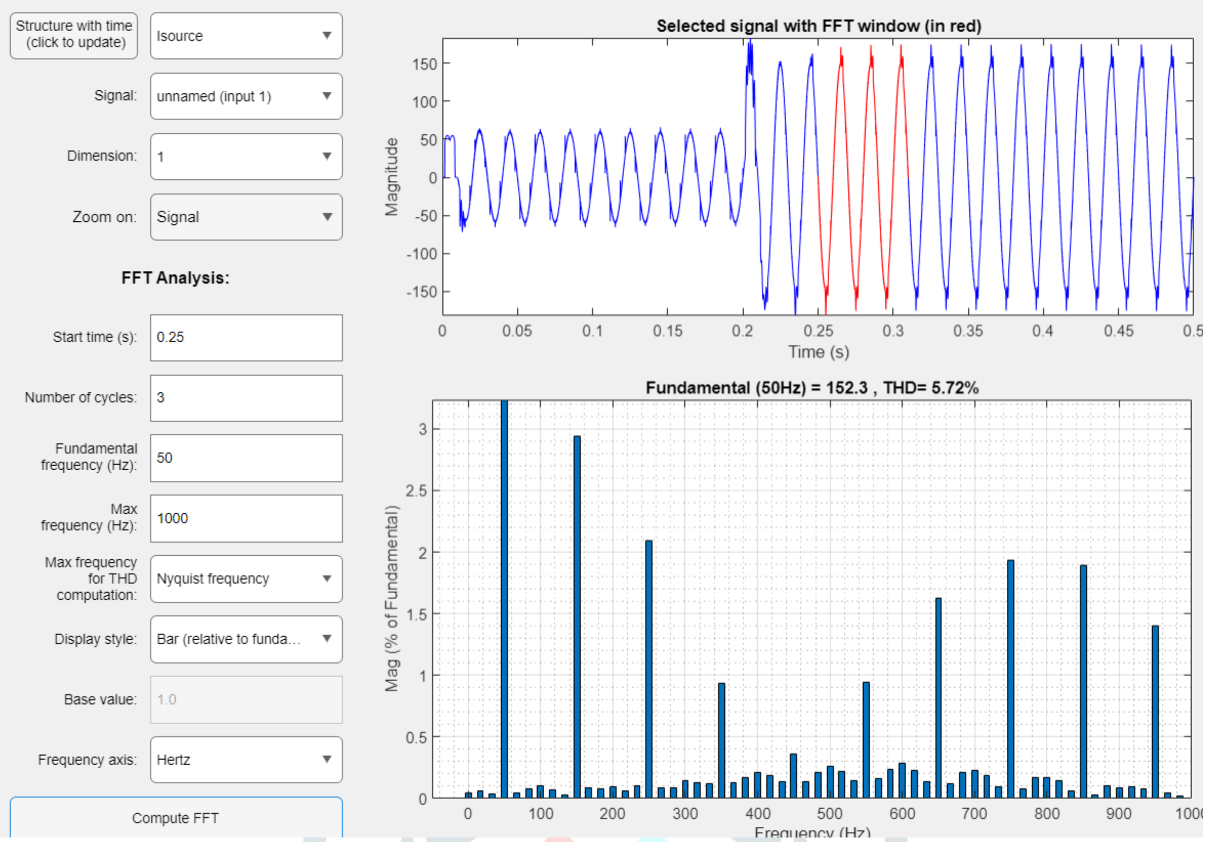
Isource
Signal: unnamed (input 1
Lists the Structure-with-time variables that exist in the MATLAB workspace
Dimension: 1
Zoom on: Signal

FFT Analysis:

Start time (s): 0.25
Number of cycles: 3
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to funda...
Base value: 1.0
Frequency axis: Hertz

```
Sampling time      =  5e-06 sec.
Samples per cycle  =  4000
DC component       =  0.06371
Fundamental        =  152.3 peak (107.7 rms)
THD                =  5.72%

      0 Hz       DC      0.04%   270.0°
  16.6667 Hz     ---     0.06%   203.7°
  33.3333 Hz     ---     0.04%   181.1°
     50 Hz       Fnd   100.00%   179.6°
  66.6667 Hz     ---     0.05%   140.3°
  83.3333 Hz     ---     0.08%   133.3°
    100 Hz       h2      0.10%    73.9°
  116.667 Hz     ---     0.07%    12.8°
  133.333 Hz     ---     0.03%    11.6°
    150 Hz       h3      2.94%   -42.3°
  166.667 Hz     ---     0.08%    -0.4°
  183.333 Hz     ---     0.08%   -24.6°
```

Figure 15. FFT analysis of PI controlled SAPF showing individual harmonics



Isource

Signal: unnamed (input 1)

Dimension: 1

Zoom on: Signal

FFT Analysis:

Start time (s): 0.25

Number of cycles: 3

Fundamental frequency (Hz): 50

Max frequency (Hz): 1000

Max frequency for THD computation: Nyquist frequency

Display style: Bar (relative to funda...

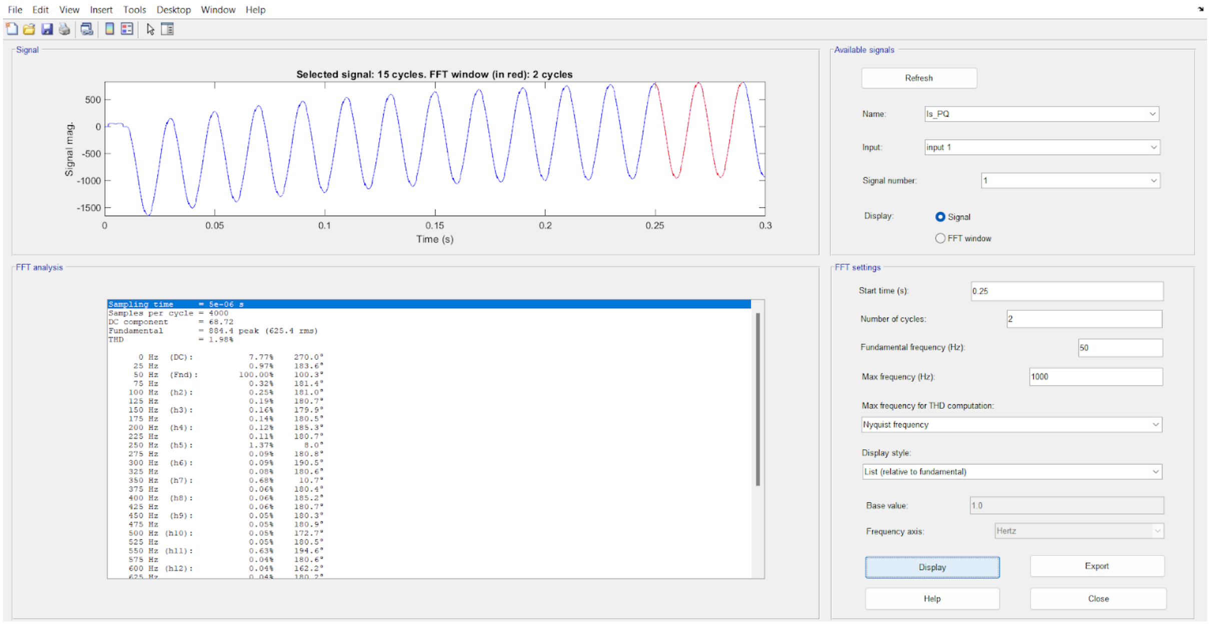
Base value: 1.0

Frequency axis: Hertz

Fundamental (50Hz) = 152.3 , THD= 5.72%

Figure 16. FFT analysis of PI controlled SAPF(without ANN)

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



Selected signal: 15 cycles. FFT window (in red): 2 cycles

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

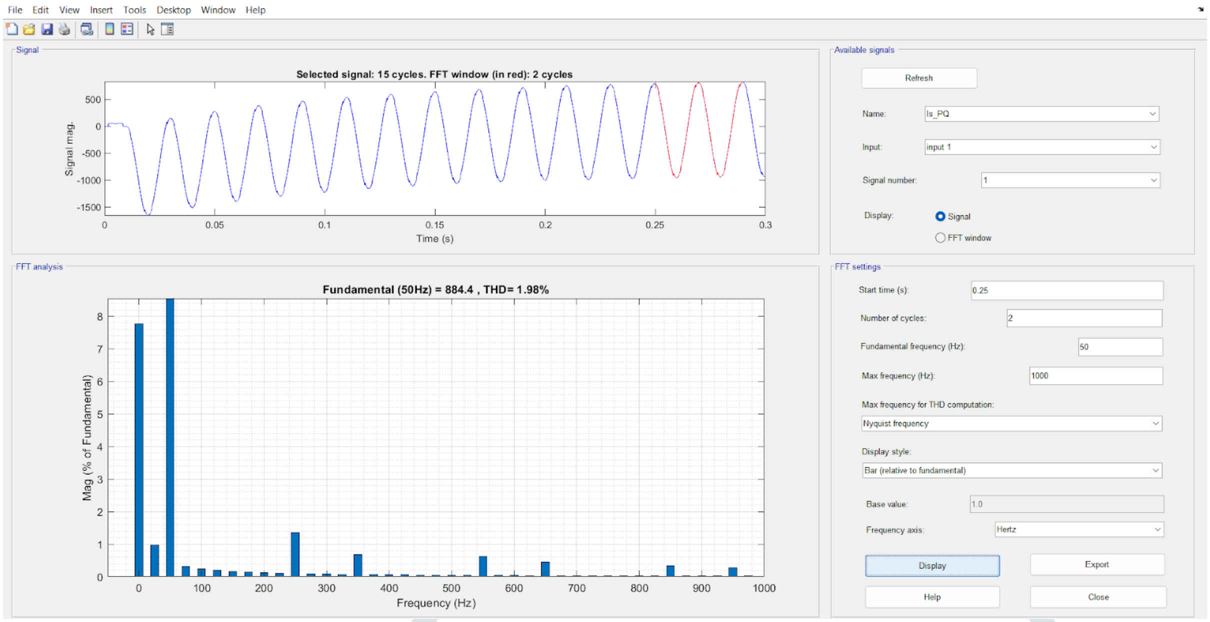
Display style: List (relative to fundamental)

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 17. FFT analysis of ANN controlled SAPF showing individual harmonics



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 18. FFT analysis of ANN controlled SAPF

The THD before the inclusion of ANN control in Shunt Active Power Filter was 5.72% of the fundamental value, which has been reduced to 1.98% of the fundamental value, after the inclusion of ANN control. Thus there is a 65.38% decrease in the THD of the system from its initial value.

Now by collecting above data we have done a comparison of the THD values in the form of a table below:-

THD Values at different frequencies	Fundamental THD Value (in %)	5th Harmonics (in %)	7th Harmonics (in %)	11th Harmonics (in %)
Without SAPF	30.13	22.64	11.28	9.03
PI controlled SAPF	5.72	2.10	0.93	0.95
ANN Controlled SAPF	1.98	1.37	0.68	0.63

Table 1. Comparative analysis of PI controlled and ANN controlled SAPF

CONCLUSION

This research presents a comparative study of two shunt active power filter methods. Harmonic decreases from 30% to 5.72% for the PQ technique and 1.98% for the ANN method when the identical source, transmission line characteristics, and loads are compared between the two methods, demonstrating that the ann approach provides 3.74% more mitigation than the PQ method. From the results, it can be seen that the current total harmonic distortion is better reduced with the ANN controlled active filter. ANN method enables systems to work in dynamic conditions with high effective performance and it can also be used for real time harmonic mitigation with changes in load. Therefore we come to the conclusion that ANN integrated Shunt APF is more advantageous than a Shunt APF with PQ technique.

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