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# Load Flow Solution For Power Distribution System Using Artificial Neural Network

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***Abstract*— In this paper, load flow solution for power distribution system using Artificial Neural Network (ANN) is presented. The ANN solution algorithm and flowchart are presented along with detailed description of the ANN model structure, training, and validation in MATLAB software. The model was developed for the IEEE 33-bus system load flow analysis. First, the load flow of the IEEE 33-bus network was calculated by using Newton Raphson (NR) algorithm in order to generate the input datasets for the ANN model development and evaluation. The two main outputs from the ANN model are bus voltage and the phase angle. The results show that the values of bus voltage and the phase angle obtained by Newton Raphson and ANN are very close to each other, and the error between them is minimal, hence, the developed neural network can be used to accurately carry out load flow analysis. From the result it was discovered that out of the 33 bus in the case study power network, bus 3, 5, 6,8, 9,11, 12,15, 17,19, 23,25, 26,27, 28, 30, 32 and 33 voltages fall below the acceptable voltage tolerance margin of ±5%. This indicates that these buses could have some voltage stability issues. However, further investigation is needed before any bus can be declared the weakest in any power system.**

***Keywords*— *Load Flow, Power Distribution System, Phase Angle, Artificial Neural Network, Newton Raphson Method, Bus Voltage***

## 1.0 Introduction

As experts seek to address the power shortage problem in Nigeria, they engage in various aspects of power system analysis using different relevant approaches [1,2,3,4, 5,6,7,8, 9, 10, 11, 12, 13, 14]. While in some cases, off the shelf software tools like PVSyst and HOMER (Hybrid Optimization of Multiple Energy Resources) software can be used to analyse renewable energy systems, Power System Analysis Toolbox (PSAT) package can be used for load flow analysis, for power system design, development of algorithms and other key analysis essential for power system planning [15,16,17,18,19,20,21,22,23,24,25].
Interestingly, among many solution options, Artificial Neural Network (ANN) and related intelligent algorithms have been among the most widely used approach in power system studies [26,27,28,29,30,31]. Over the years, intelligent algorithms like ANN have been widely applied in many disciplines including power systems [31,32,33,34]. Like other intelligent algorithms, ANN also has wide applications in computer systems, software solutions, embedded systems, wireless networks, Internet of Things and smart systems applications where it has been shown to compete favourably with other alternative solution options [35,36,37, 38,39,40, 41,42,43, 44, 45,45, 46, 47,48,49,50,51,52,53]. It has also been applied in communication industries, in clustering of communication end devices and sensor nodes, in handoff and call dropping management, in outlier detection as well as in routing and media access control. In the power industry, ANN algorithm can be applied in load demand forecasting for planning new power installations or expansion planning for an existing system [54,55,56]. It has also been applied in time series analysis of renewable energy resources for renewable energy feasibility studies and for the design and evaluation of renewable energy systems [57,58, 59,60, 61,62, 63,64, 65,66, 67,68, 69,70, 71,72, 73]. In addition, it can also be applied in energy deficit analysis, evaluation of optimal location of power systems installation, distribution of load centres among other applications [74,75]. In all, in numerical solutions requiring iterative approach, ANN algorithm performs favourably when compared with deterministic iterative solutions like Newton Raphson method, bisection method, fixed point method and other notable deterministic iterative numerical solution approaches.
Accordingly, in this paper, the focus is on the application of ANN model in load flow analysis [76,77,78]. Load flow analysis is highly needed in the planning and design of power systems. It is also required in the power system expansion planning. It enables the power system engineers to evaluate the effect loss of power generating station and also the effect of loss of transmission line on the power flow in the network. Also, the reactive power compensation

impact on the bus voltages is also evaluated through the load flow analysis. The results of voltage and power profile dataset obtained from load flow analysis are also used in computing the losses in the power network. Accordingly, in this paper, Artificial Neural Network (ANN) method is employed in conducting load flow analysis for a power distribution system. Basically, ANN is a data driven model, as such, the load flow analysis is first conducted using the Newton Raphson (NR) method [79]. Then the ANN model is developed to predict the load flow results generated using the NR method. This is the training phase of the ANN model. After the ANN model is trained, the resultant ANN model can take power system load flow input dataset and then generate the corresponding load flow output dataset.

## 2.0 Methodology

### 2.1 Load Flow Solution Using ANN Model

The ANN load flow solution process is an iterative one; hence, for the first iteration the equivalent source bus voltages are initialized. The ANN solution algorithm of the distributed power flow can then be expressed in the following nine steps:

Step 1. Clear all
Step 2. Load the load flow results as gotten from an analytical derivation
Step 3. Split the data into training, validation and test data sets so as to design the artificial network
Step 4. Insert hidden layers which will help process the data by applying complex non-linear functions to them
Step 5. Commence training the model with the data
Step 6. Evaluate the training network performances such as mean squared error (MSE)
Step 7. Do this until there is a convergence
Step 8. If there is no convergence repeat step
Step 9. If there is a convergence obtain the desired results and end the training

The flow chart in Figure 1 illustrates the ANN power flow model. When the power flows are being run on the downstream partitions on the backward sweep, the upstream partitions must wait to receive the post-processed data before they can perform their own power flow. On the forward sweep the same lag occurs for the downstream partitions.

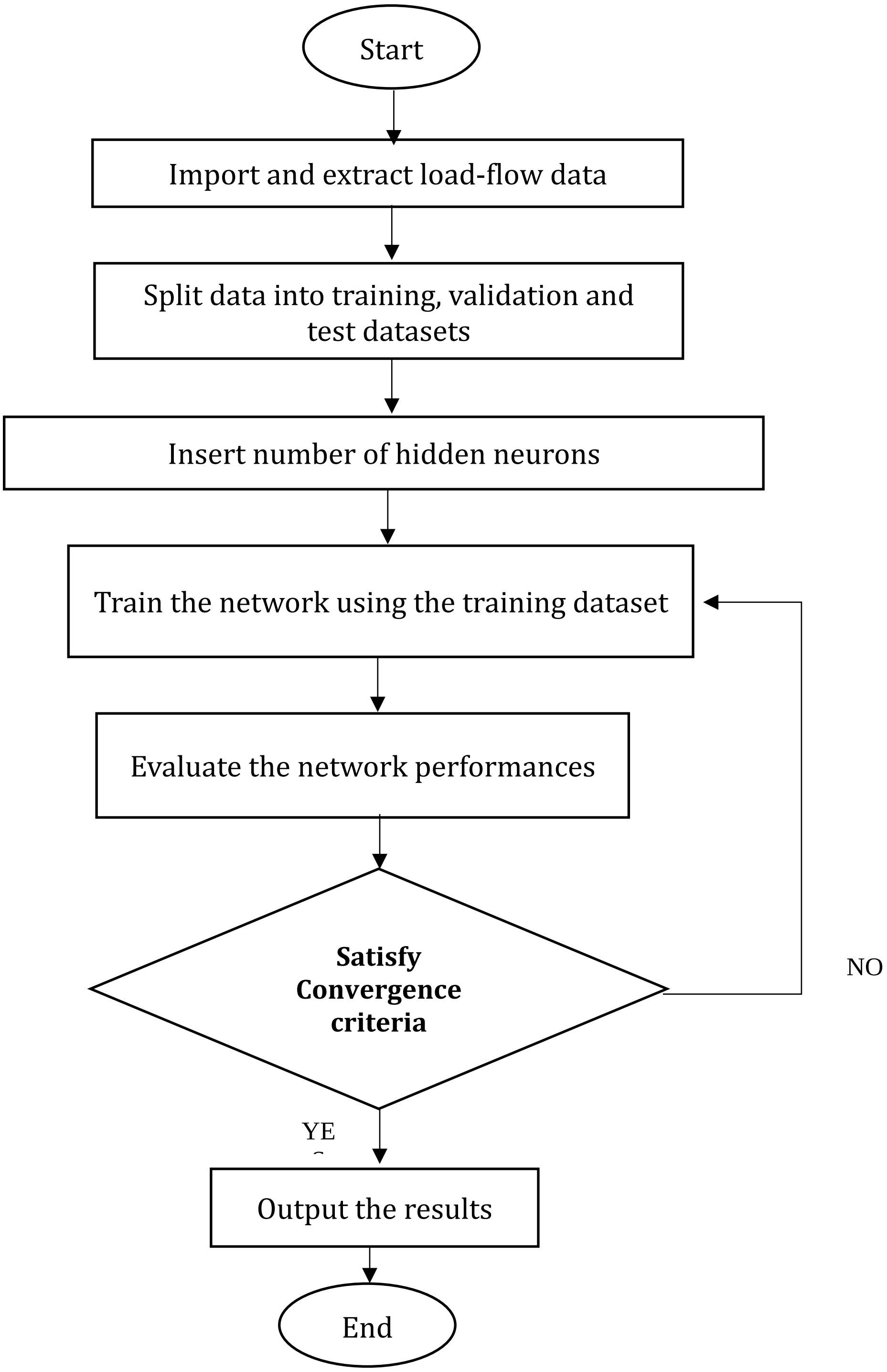

Figure 1: Flow chart of the ANN power flow model

## 2.2 Implementation of the ANN Model in MATLAB

The ANN power flow model is implemented in MATLAB. First, the load flow of the network is calculated by using Newton Raphson (NR) algorithm in order to generate the input datasets for the ANN model development and evaluation. Then, the MATLAB software was used to import the data from the analytical (NR) load flow result which has been saved using a comma separated value (csv) format. During this training procedure, the weighting factors of interconnections and structure of the artificial neutral network parameters are modified uninterruptedly with the aid of a pre-defined training algorithm. After that, the trained artificial neutral network is able to predict the correct output values approximately when given input values.

In this study, an ANN model is based on the multilayer perceptron neural network (MLPNN) was developed in MATLAB. The model developed was used for the IEEE 33-bus system load flow analysis. The IEEE 33 load flow artificial neural network (ANN) model is shown in Figure 2. The MLPNN model consists of three layers. The input layer has sixty-six (66) neurons, with each representing the input features. These features are the real and reactive powers for the thirty-three (33) load buses in the IEEE 33-bus system. The hidden layer has ten (10) neurons chosen based on a trial-and-error approach. The output layer consists of sixty-four (64) neurons representing the study's output variables.

The data used for this study were obtained from IEEE 33 bus data. The MATLAB/SIMULINK simulation was used to generate the real power (P), reactive power (Q), bus voltage (V) and the phase angle (θ) for the ANN training, testing and validation. Seventy per cent of the data generated were used for the training. The remaining thirty per cent of the dataset was further split into validation and test sets, with each set containing 15% of the generated data for the case study. The MLPNN model was trained using a back-propagation algorithm. The activation function used between the input and output layers is the purely linear (purelin) function. The hyperbolic tangent sigmoid (tansig) function is used in the hidden layer of the model. The mathematical expressions for these functions are given as.

$$f(z) = \text{purelin}(z) = z \qquad (1)$$

$$f(z) = \text{tansig}(z) = \frac{2}{(1+e^{(-2z)})-1} \qquad (2)$$

The ANN consist of an input layer, a hidden layer and an output layer. Active and reactive powers belonging to bus bars are used in a one-row matrix form to obtain input parameters. System gives bus bar voltages and voltage angels as output. Tansig and purelin functions were used as transfer functions. Particularly, the Tansig is used for hidden layer and purelin is used for output layer. The best result was obtained by using trainlm (Levenberg-Marquardt) as training algorithm. In the simulation, 32 active power values and 32 reactive power values were used to train the developed ANN model. The output values of the model training were voltage magnitudes and angles as well as the load and generator active and reactive powers. The ANN training process ended after 7 iterations.

The rating of the two transformer connected along the line are given in Table 1.

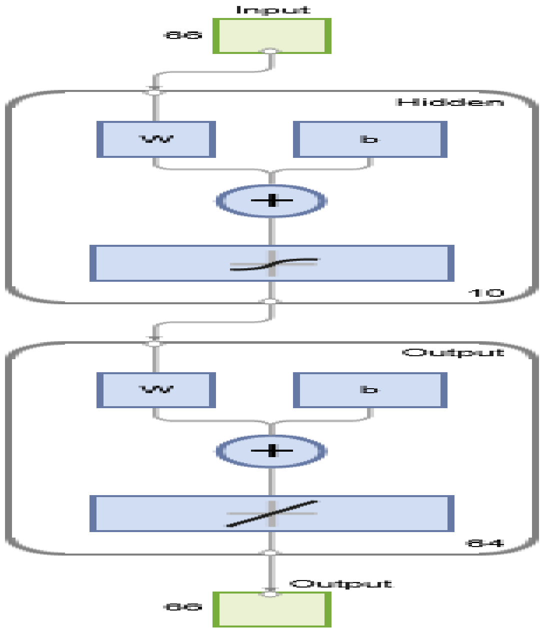

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Figure 2: The IEEE 33 load flow network diagram

Table 1: 132/33kv Transformer Rating

| S/N | Name | S (MVA) | Z (%) |
|---|---|---|---|
| 1 | T1 | 30 | 12.66 |
| 2 | T2 | 60 | 10.28 |

## 3. Results and discussion

The comparison of the load flow results obtained by Newton – Raphson method ( as the base case) and ANN solution methods are shown in Table 2. In Table 2, the values are presented in per unit for the 33 load buses in the IEEE 33-bus system at the base case. The base case refers to the normal operating condition of the system. The results in Table 2 show that the values obtained by Newton Raphson and ANN are very close to each other, and the error between them is minimal, hence, the developed neural network can be used to accurately carry out load flow analysis.

Also, the results presented in Table 2 show that the developed ANN model could accurately predict both voltage magnitude and voltage phase angle of the load buses in the network at the base case. From the result extracts presented in Table 3, bus 3, 5, 6,8, 9,11, 12,15, 17,19, 23,25, 26,27, 28, 30, 32 and 33 voltages fall below the acceptable voltage tolerance margin of ±5%. This indicates that these buses could have some voltage stability issues. However, further investigation is needed before any bus can be declared the weakest in any power system.

The voltage profile of both the ANN and the Newton Raphson for each bus is presented in Figure 3 while Figure 4 gives the graphical representation of the relationship between the actual and predicted voltage phase angles of the buses. The graphical representation of the error of the voltage values between the Newton Raphson and the ANN of the load flow analysis are shown in Figure 5 while Figure 6 shows the graphical representation of the error in phase angle of bus voltage values of test values and the ANN predicted values.

Table 2: Comparison of load flow results by Newton-Raphson and ANN

| | Newton Raphson power flow values | | Artificial neural network power flow values | | Errors | |
|---|---|---|---|---|---|---|
| Bus No | Voltage V1 | Phase Angle$(\theta_1)$ | Voltage V2 | Phase angle$(\theta_2)$ | Voltage (V2 – V1) | Phase angle $(\theta_2 - \theta_1)$ |
| 1 | 1.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.9862 | 0.0116 | 0.9892 | 0.0215 | 0.0030 | 0.0099 |
| 3 | 0.9270 | 0.0743 | 0.8807 | 0.1535 | -0.0463 | 0.0792 |
| 4 | 0.8924 | 0.1218 | 0.9516 | 0.0569 | 0.0592 | -0.0649 |
| 5 | 0.8607 | 0.1739 | 0.6912 | 0.1727 | -0.1695 | -0.0011 |
| 6 | 0.7693 | 0.2954 | 0.7657 | 0.3038 | -0.0036 | 0.0084 |
| 7 | 0.7277 | 0.3218 | 0.7459 | 0.2749 | 0.0182 | -0.0468 |
| 8 | 0.7236 | 0.3904 | 0.6922 | 0.3473 | -0.0314 | -0.0431 |
| 9 | 0.7036 | 0.4948 | 0.6729 | 0.4404 | -0.0307 | -0.0544 |
| 10 | 0.6954 | 0.5951 | 0.7202 | 0.5715 | 0.0248 | -0.0236 |
| 11 | 0.6981 | 0.6094 | 0.6772 | 0.5641 | -0.0209 | -0.0453 |
| 12 | 0.7032 | 0.6330 | 0.6924 | 0.6331 | -0.0108 | 0.0001 |
| 13 | 0.7077 | 0.7334 | 0.7106 | 0.6874 | 0.0029 | -0.0460 |
| 14 | 0.7053 | 0.7737 | 0.7167 | 0.6992 | 0.0114 | -0.0745 |
| 15 | 0.7085 | 0.8019 | 0.6854 | 0.7100 | -0.0231 | -0.0919 |
| 16 | 0.7135 | 0.8253 | 0.7286 | 0.7858 | 0.0151 | -0.0395 |
| 17 | 0.7150 | 0.8631 | 0.6745 | 0.7032 | -0.0405 | -0.1600 |
| 18 | 0.7170 | 0.8706 | 0.7194 | 0.7814 | 0.0025 | -0.0893 |
| 19 | 0.9821 | 0.0116 | 0.9471 | -0.0330 | -0.0350 | -0.0446 |
| 20 | 0.9543 | 0.0124 | 0.9669 | 0.0097 | 0.0126 | -0.0027 |
| 21 | 0.9486 | 0.0118 | 0.9687 | 0.0519 | 0.0201 | 0.0401 |
| 22 | 0.9432 | 0.0110 | 0.9521 | -0.0207 | 0.0089 | -0.0316 |
| 23 | 0.9198 | 0.0769 | 0.8589 | 0.0477 | -0.0609 | -0.0292 |
| 24 | 0.9094 | 0.0800 | 0.9621 | 0.1136 | 0.0527 | 0.0336 |
| 25 | 0.9042 | 0.0814 | 0.9021 | 0.0817 | -0.0021 | 0.0002 |
| 26 | 0.7635 | 0.3074 | 0.7116 | 0.2973 | -0.0519 | -0.0101 |
| 27 | 0.7568 | 0.3226 | 0.7267 | 0.3204 | -0.0300 | -0.0022 |
| 28 | 0.7226 | 0.3739 | 0.6919 | 0.3523 | -0.0307 | -0.0216 |
| 29 | 0.7025 | 0.4090 | 0.7196 | 0.3578 | 0.0171 | -0.0512 |
| 30 | 0.6971 | 0.4272 | 0.6678 | 0.4040 | -0.0293 | -0.0232 |
| 31 | 0.6815 | 0.4554 | 0.7143 | 0.4098 | 0.0328 | -0.0456 |
| 32 | 0.6776 | 0.4616 | 0.6422 | 0.4323 | -0.0353 | -0.0293 |
| 33 | 0.6746 | 0.4653 | 0.6623 | 0.5172 | -0.0123 | 0.0518 |

Table 3 The buses which the voltages fall below the acceptable voltage tolerance margin of ±5%.

| | **Newton Raphson power flow values** | | **Artificial neural network power flow values** | |
|---|---|---|---|---|
| Bus No | Voltage V1 | Phase Angle $\theta_1$ | Voltage V2 | Phase Angle $\theta_2$ |
| 3 | 0.9270 | 0.0743 | 0.8807 | 0.1535 |
| 5 | 0.8607 | 0.1739 | 0.6912 | 0.1727 |
| 6 | 0.7693 | 0.2954 | 0.7657 | 0.3038 |
| 8 | 0.7236 | 0.3904 | 0.6922 | 0.3473 |
| 9 | 0.7036 | 0.4948 | 0.6729 | 0.4404 |
| 11 | 0.6981 | 0.6094 | 0.6772 | 0.5641 |
| 12 | 0.7032 | 0.6330 | 0.6924 | 0.6331 |
| 15 | 0.7085 | 0.8019 | 0.6854 | 0.7100 |
| 17 | 0.7150 | 0.8631 | 0.6745 | 0.7032 |
| 19 | 0.9821 | 0.0116 | 0.9471 | -0.0330 |
| 23 | 0.9198 | 0.0769 | 0.8589 | 0.0477 |
| 25 | 0.9042 | 0.0814 | 0.9021 | 0.0817 |

| | | | | |
|---|---|---|---|---|
| 26 | 0.7635 | 0.3074 | 0.7116 | 0.2973 |
| 27 | 0.7568 | 0.3226 | 0.7267 | 0.3204 |
| 28 | 0.7226 | 0.3739 | 0.6919 | 0.3523 |
| 30 | 0.6971 | 0.4272 | 0.6678 | 0.4040 |
| 32 | 0.6776 | 0.4616 | 0.6422 | 0.4323 |
| 33 | 0.6746 | 0.4653 | 0.6623 | 0.5172 |

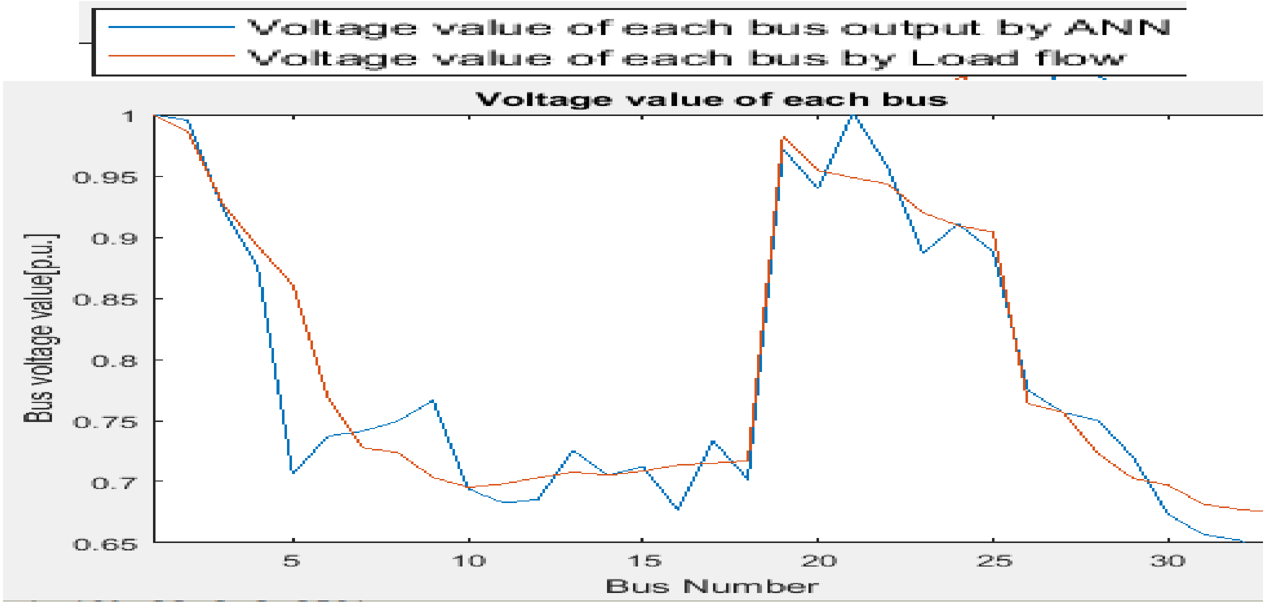

Figure 3: Voltage values for each bus by NR and ANN

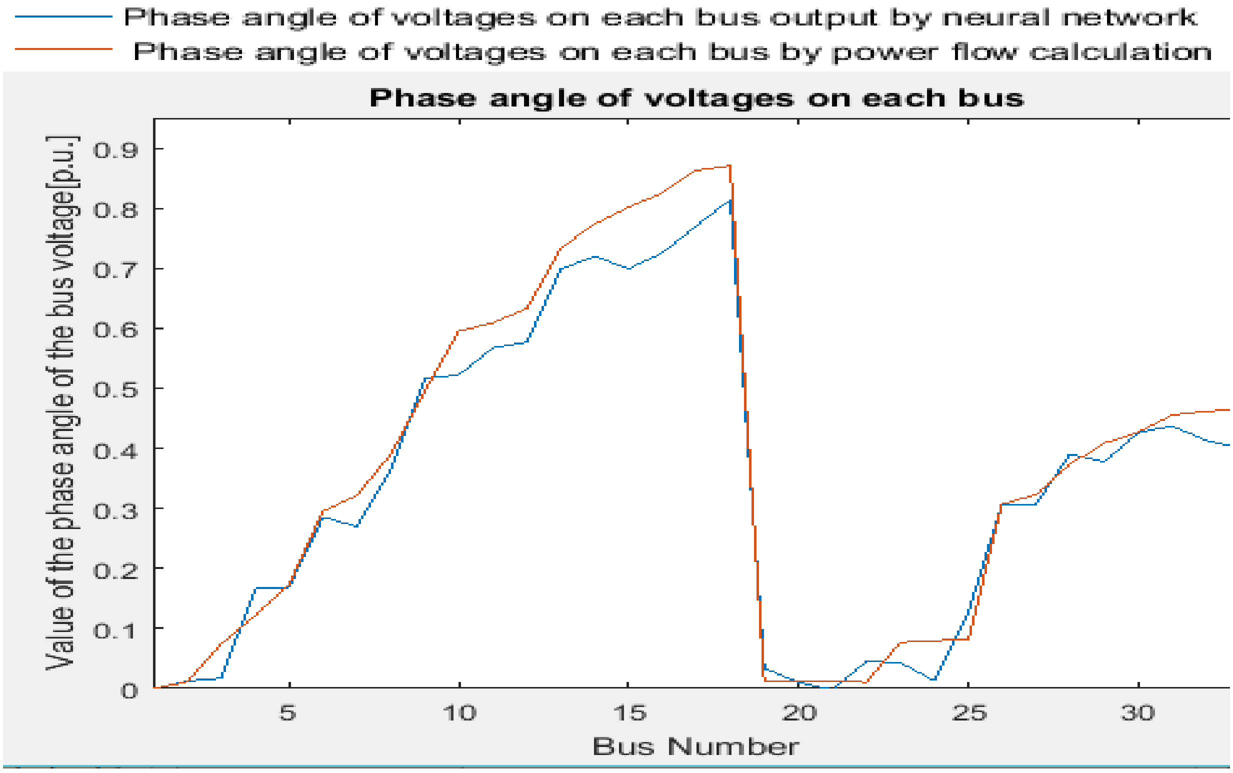

Figure 4: Phase angle of voltage values for each bus of ANN

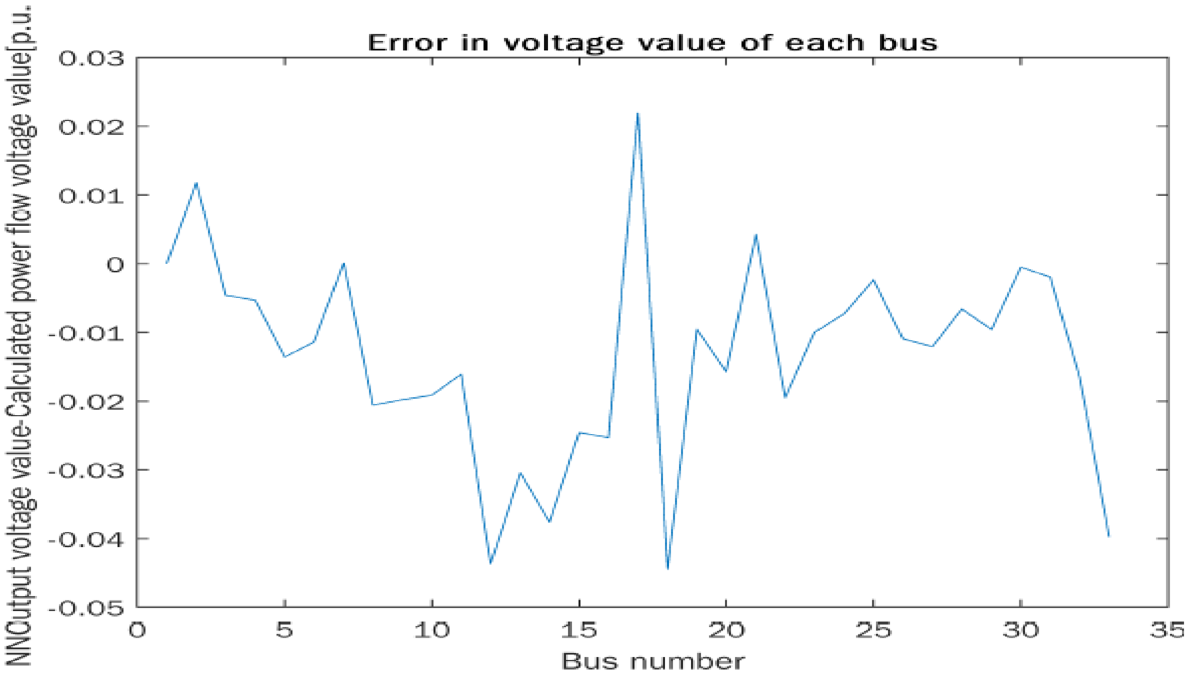

Figure 5: Error in voltage values for each bus by NR and ANN

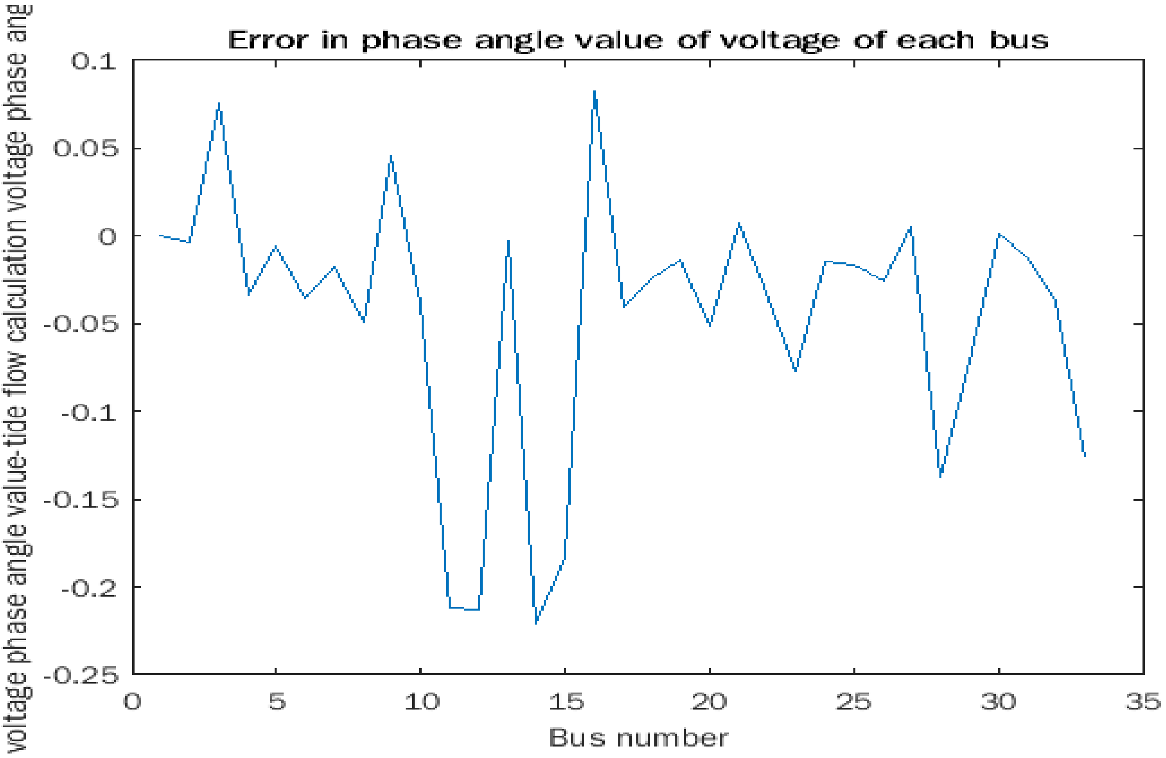

Figure 6: Error in phase angle of voltage values of NR and ANN

## 4. Conclusion

Load flow analysis using artificial neural network (ANN) approach is presented. The load flow data is based on the IEEE 33 bus network. The initial load flow is conducted using the Newton Raphson method. Then the results obtained from the Newton Raphson are used to develop (train and validate) the ANN model. The output considered for the ANN model include the phase angles and bus voltages which are compared with base case values obtained using the Newton Raphson method. In all, the ANN model output is very good as it can effectively predict or estimate the bus phase angles and bus voltages with very little error.

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