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Artificial neural network based load flow analysis of radial distribution system in Kurdistan region

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ABSTRACT

Today electric energy is the most commonly used source in the world. Power flow (load flow) analysis is conciderd as the backbone of any power system analysis and design; they have a great necessity for operating systems, future planning, fault analysis, and contingency analysis. For better utilization of electrical power, off-line modeling and simulation of power systems using powerful software are essential and significant task especially in developing countries and regions. Therefore, this paper performs a comparison study of conventional and non-conventional load flow techniques for a 24-Bus radial distribution system in the governorate of Sulaymaniyah. The conventional power flow techniques include the Newton-Raphson (NR), and Gauss-Seidel (GS) techniques, while the non-conventional load flow technique utilizes the artificial neural network (ANN). Modeling, simulation, and analysis of the 24-Bus feeder are performed using MATPOWER simulation tool. The MATPOWER and neural network techniques are implemented independently, and it has been proved that ANN model efficiently estimated the power flow analysis for the system mentioned above, the high regression values of nearly 0.999 indicates that the ANN model can be used as an efficient tool to perform power flow analysis.

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1. INTRODUCTION

Basically, a power system is a very complex and highly interconnected network, consisting of power generation plants, transmission lines, transformers, distribution plants, and energy consumers. Providing invariably high-quality service to the consumers is an essential requirement for power systems [1]. Grid operators highly consider the steady state behavior of power systems to estimate the performance of the power system and determine if the power system performs properly from both generation and load aspects. The steady state behavior of power systems can be obtained from the power flow analysis to identify the best operation of existing systems, required control algorithm, future planning and designing the future expansion, power flow analysis indicates the most effective way to do that. The load flow analysis involves computation of the magnitude and phase angle of the voltages across all buses in electric power system except the slack bus. The power flow through the transmission line can be determined where the voltage magnitude and phase angles for all buses are known. The most used algorithms used for load flow solution are Gauss-Seidel (GS), Newton-Raphson (NR), and fast decoupled (FD) load flow [2]–[5]. Ashrith *et al.* [6] examined the GS, NR, and FD methods to determine the steady-state operating conditions, GS was best option for small systems as it converged adequately, The accuracy and computational efficiency of the NR and FD methods worked more efficiently with medium scaled seystems.

Also, artificial neural network (ANN) models have appeared and effectively worked in solving power system load flow analysis [7], [8]. Compared to the available deterministic iterative algorithms, results obtained efficiently from the ANN model, and it can be adapted to various problem sets in different applications [9], [10]. While deterministic approach can perform load flow using its own load flow input data set and generates the corresponding load flow output dataset [11], ANN can be applied in the power flow analysis after it has been trained very well with a load flow input data set and corresponding output dataset [12]. However, after the ANN model is trained, it works like the deterministic model [11]. Jaiswal *et al.* [13] the load flow analysis methods based on artificial neural network is applied on IEEE 30, 57, and 118 bus systems, comparing results to conventional method results, the intelligent power flow technique results are more accurate. Investigating the performance of micro grid system focusing on load flow studies, shows that the load flow calculations using the modern intelegence methods like ANN experience high efficiency and minimum losses when compairing with conventional method [14]. Rani and Rao [15] suggested a neural network with multilayer feed forward for online power flow assessment under data uncertainty, the observed results shows that multilayer feed forward neural network results is very similar to the interval arithmetic technique. An extensive review is implemented on most traditional and non conventional technique load flow solutions, the aim was evaluating their strengths and weaknesses, and its concluded that NR is the most effective between conventional methods and non conventional artificial intelegence methodes tend to be computationally quick [16]. Well proved deterministic load flow algorithms, such as NR and GS methods, can provide the training input-output dataset for an ANN [14].

This article aims to study power flow problem using the conventional methods (NR and GS) and the Neural-Network approach, power flow solutions presented using developed ANN, NR and GS on 24-Bus radial distribution system, determining the best way to perform power flow solution is another objective of the work. The results show that power flow analysis can be carried out using the ANN with minmum errors when compairing the actual values of bus voltage and the ANN output. Using ANN in load flow analysis for power systems solves many problems, the ANN techniques have the advantage of needing few parameters to obtain more efficient solution with low computational time with very high accuracy, despite it is insensitivity to initial values for input variables on the other hand traditional load flow techniques (NR and GS) are very complex at designing, failed to converge and needs large controlling parameters, moreover the purpose of using ANN is to make a network that works perfectly even when new instances that never experienced or trained previously. The required datasets for training ANN are generated by a well-known conventional method of N-R technique and it is used to train proposed ANN in MATLAB tool.

2. PAPER STRUCTURE

This paper is structured as the following: section3 introduces the proposed methodologies and Section 4 provides details of a case study for the power flow. Results of the proposed techniques are presented and discussed in Section 5. Finally, conclusions are drawn in Section 6.

3. MATERIALS AND METHODS

The feeder bus is a node that connects more than one line, load, or a generator. In a power system, every bus has the following variables: voltage magnitude, voltage phase angle, real power, and reactive power, two of these variables are always known and the other two must be calculated by using specified equations [17]. In addition, bus feeders are classified into three types: slack bus, voltage control (PV) bus, and load bus (PQ), as listed in Table 1.

Table 1. Types of feeder buses

Bus types	Variables			
	P	***Q***	***V***	***δ***
Slack	Unknown	Unknown	known	known
Generator	known	Unknown	known	Unknown
Load	known	known	Unknown	Unknown

Steady state power supplied by various buss in any power system can be illustrated in terms of nonlinear set of equations, many numerical formulations were proposed and used in the last decades in order to solve load flow analysis non linear eauations. As mentioned previously, the most frequently used iterative techniques are the GS, the NR, and the FD [18], three techniques are used to perform load flow on a 24-Bus radial distribution system each technique implemented seperaitly, using the data of the mentioned system as an input. The initial work stage in performing power flow analysis is building the Y-bus admittance matrix using information from the transmission lines and the transformers of the system mentioned [19]. To study the power system, network a nodal formula using the Y-bus can be given in (1).

$$I = Y_{Bus}V \tag{1}$$

In (1) can be expressed in a generalized form for an n bus system using (2).

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \qquad \text{for } i = 1,2,3, \dots \dots, n \tag{2}$$

The apparent power and the current delivered to the bus (i) are given by (3) and (4):

$$P_i + jQ_i = V_i \; I_i^{\,*} \tag{3}$$

$$I_i = \frac{P_i + jQ_i}{V_i^{\,*}} \tag{4}$$

Substituting (3) and (4) in to (2), (5) is determined.

$$\frac{P_i + jQ_i}{V_i^{\,*}} = V_i \sum_{j=1}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij} \; V_j \quad ; \quad j \neq i \tag{5}$$

The complex power injection of the system is given by (6) and (7).

$$S_i = S_{Gi} - S_{Di} \tag{6}$$

$$S_i = \sum_k^n S_{ik} - S_{Di} \tag{7}$$

In (6) and (7): k = 1, 2 … n; i = 1, 2… n. Similarly, the phasor of current injections is given by (8), (9), and (10).

$$I_i = I_{Gi} - I_{Di} = \sum_k^n Y_{ik} V_{ik} \tag{8}$$

$$S_i = V_i \; I_i^{\,*} = V_i \sum_k^n Y_{ik}^{\,*} \; V_k^{\,*} \tag{9}$$

$$S_i = \sum_k^n |V_i| \; |V_k| \; e^{j\delta ik}(G_{ik} - jB_{ik}) \tag{10}$$

Separation of the power flow formulation into real and imaginary parts is given by (11), (12), and (13).

$$S_i = P_i + jQ_i = \sum_k^n |V_i| \; |V_k| \; e^{j\delta ik}(G_{ik} - jB_{ik}) \tag{11}$$

$$P_i = \sum_k^n |V_i| \; |V_k| \, [G_{ik} \cos(\delta ik) + B_{ik} \sin(\delta ik)] \tag{12}$$

$$Q_i = \sum_k^n |V_i| \; |V_k| \, [G_{ik} \cos(\delta ik) - B_{ik} \sin(\delta ik)] \tag{13}$$

In (11), (12), and (13) use iterative methods to solve the load flow problems. Therefore, the following subsections provide review of the general forms for three different solution techniques: GS, NR and ANN [20].

3.1. Gauss-Sidel method

This method is an iterative method of solving a set of nonlinear algebraic equations [20]. The method iteratively solves these nonlinear equations and calculates the voltage magnitude and phase angle at each bus until convergence is achieved since the error reaches acceptable range [21], based on the system nodal voltage of (14),

$$|I| = |Y_{Bus}||V| \tag{14}$$

The GS method uses iterative method for solving the power flow formula of (15). The superscripts (*) and (T) denote the conjugates and transpose processes respectively [20]-[23].

$$|P + jQ| \;\; = |\, V^{T}||Y_{Bus}{}^{*}\, V^{*}| \tag{15}$$

This technique is widely used because of its simplicity and less time required for computation of one iteration, but it has convergence problem because of the large number of iterations, Also G-S is sensitive when selecting slack bus, as the convergence speed is dependent on it.

3.2. Newton-Raphson method

The most technique used for power flow solution is NR; it is fast in computation with accurate results, and the system size does not effects so much on the number of iterations. The draw backs of this method are difficulties of solution techniques, which require higher computational time per iteration. The NR iterative method formulates and solves the power flow described using (16) in terms of the Jacobean matrix elements (J1, J2, J3, and J4).

$$\begin{vmatrix} \Delta P \\ \Delta Q \end{vmatrix} = \begin{vmatrix} J1 & J2 \\ J3 & J4 \end{vmatrix} \begin{vmatrix} \Delta\delta \\ \Delta V \end{vmatrix} \tag{16}$$

In (16), ΔP and ΔQ refer to the difference between the calculated value and the specified value of the real and reactive power of the feeder bus, respectively. ΔV and $\Delta\delta$ represent the voltage magnitude and voltage phase angle of the feeder bus, respectively [20], [22].

3.3. Artificial neural network

Many times conventional techniques are not appropriate for load flow solution that is why new techniques such as ANN are presented to perform load flow solution in power systems. This recent technique has the ability to apply in small and large systems with high reliability. The Artificial neural network is an effective computational tool that can be used for solving nonlinear equations [24], [25]. ANN, is also has very high level of accuracy when performing calculations [26]. A neural network (NN) model consists of a set of neurons in highly interconnected layers [18]. These layers may be an input layer, output layer and one or several hidden layers, as shown in Figure 1 [27], the input layer contain number of input neurons which describe the input parameters to ANN model. The second layer usually named hidden layer contains neurons of hidden layer that are connected to the neurons in the output layer, the third (or output) layer is the layer which represent the ANN model output response [28].

The connections between the neurons are called vector weights which represent the signal strength. The main feature of an ANN is its ability to learn complex non-linear relationship between the inputs and the outputs. ANN uses series training procedure and can modify itself to the data application [29]. When the construction of the network is achieved for a specified application, random weights are selected to start the training process. In the training process, both the inputs and the outputs are provided. The network then processes the inputs and compares the output results against the desired outputs and the weights are adjusting accordingly and repeatedly [27].

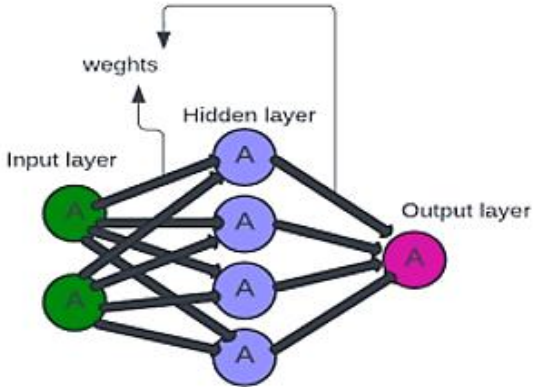

Figure 1. A neural network model

Neurons have many activation functions, among these functions of the neurons; purline and tansigmoied activation function which is the most commonly used [30], is used in hidden layer neurons and in the output layer neurons. The training is performed with the Levenberg Marquardt based back propagation neural network (BPN) algorithm. The Levenberg-Marquardt algorithm is specially designed to give a minimum value of the mean squared error (MSE) and best prediction results [31]. The MSE is calculated using (17) based on the values of desired output, Yi, and the actual output, Yĩ, of the ANN [32]. Finally, ANN is ready to perform the power flow analysis. The process of training an ANN to perform a steady state power flow analysis is shown in the flow chart in Figure 2.

$$\mathrm{MSE} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} (Y_i - \tilde{Y_i})^2 \tag{17}$$

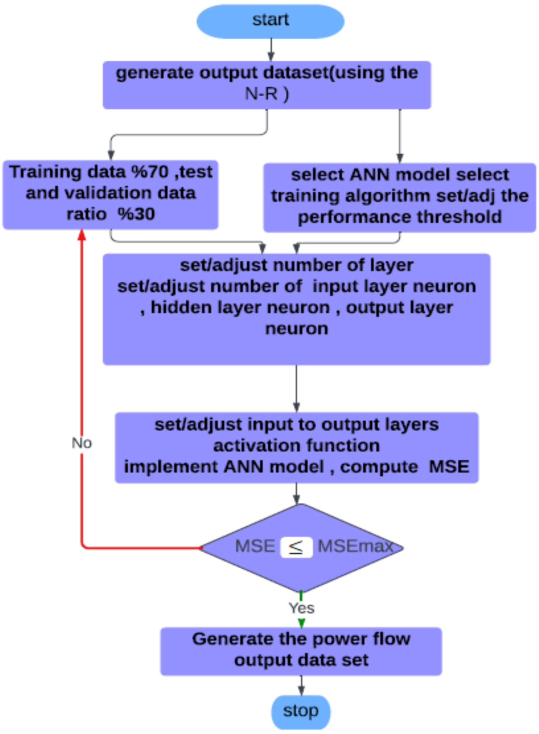

Figure 2. ANN power flow analysis model flowchart for calculating voltage and phase angle

4. CASE STUDY

This section performs a comparison study of the conventional power flow methods of G-S and N-R with the non-conventional ANN based approach using a 24-bus radial distribution system. The distribution system is supplied from a high voltage Shahid Substation (33/11 kV) in Slemany city of, Kurdistan rejoin-Iraq and it consists of 24 buses. The slack bus is assigned to the bus 1 of the system network, while the rest 23 buses are the load buses. Figure 3 shows the simulated system using power system analysis tool (PSAT).

The power flow simulation model of both the conventional and the non-conventional techniques are implemented using MATLAB software. Table 2 lists power flow analysis results obtained using G-S, N-R and ANN methods. Input-output data sets obtained from the deterministic N-R method is then used to train and validate the ANN and then perform the power flow analysis. Two ANN models are used, one model to calculate the magnitude and the phase angle of the load bus voltage, and the other model to obtain the power flow through the transmission lines connected between two specified buses in the system.

4.1. Output voltage of ANN model

The input dataset of the first ANN model were (P1-Q1, P2-Q2, P3-Q3… Pn- Qn) for all load buses. The corresponding output data set was (V1-δ1, V2-δ2, V3-δ3….Vn-δn). The system consists of 23 load buses, so the ANN model has 46 inputs and 46 outputs, and a large number of the load flow processes were performed repeatedly using the N-R method. The real and the reactive power loads increased simultaneously to 200%at all load buses of the 24-bus system in order to obtain data set for ANN. All these data sets are stored, the results then prepared to be used as an input and output set for training and validating the ANN model. 70% of these data is used learning process or training the ANN model, 15% for validating, and 15% for predicting the results. After the successful training of the ANN model, the ANN-(BPN) is ready for predicting the magnitude and the phase angle of bus voltage with a high precision and a minimum execution time for any given input load data.

Figure 4 shows a screen shot of the ANN model used in the study. The neural network is formed with a pure line transfer function (PURLIN) in the hidden layer using 20 neurons. The training is performed using the Levenberg-Marquardt based back propagation algorithm. The network is designed by 46 inputs corresponding to the active and reactive power load of 23 buses, and 46 outputs for the voltage magnitude and the phase angles for all 23 buses.

Figure 5 shows the MSE performance of the ANN model during the training and the validation. It is clear from the figure that the MSE decreased from order of 10^{-2} at the start to order of 10^{-4} after a number of iterations. A MSE of 6.89 x10^{-5} can be observed at epoch (iteration) 127, which is an acceptable value for ANN training and validation [32]. The correlation between the inputs and the output of the ANN model is illustrated using the regression plot of Figure 6, the correlation results are obtained from the data used and collected in the training, validation and test all processes separately and all training validating testing in (All) together of the ANN model. It can be noticed that the relationship between the input variables and output variables is approximately 0.999, which is sufficiently high value, values above 0.988 confirms that the ANN model is good therefore; the ANN model can be used to carry out power flow analysis on the system [33].

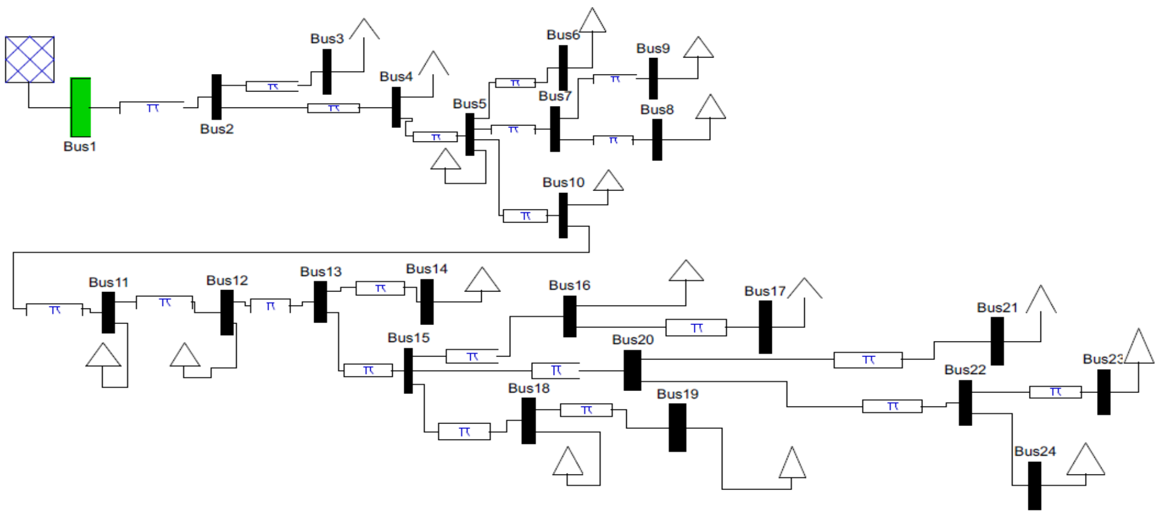

Figure 3. A single line diagram of 24-bus radial distribution system

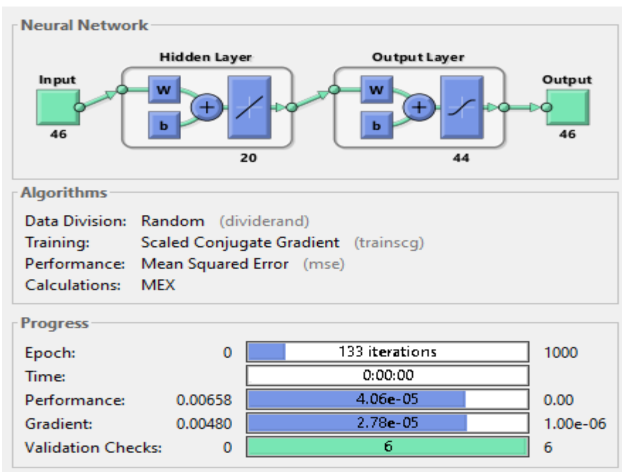

Figure 4. The ANN Model for magnitude and phase angle of the bus voltage

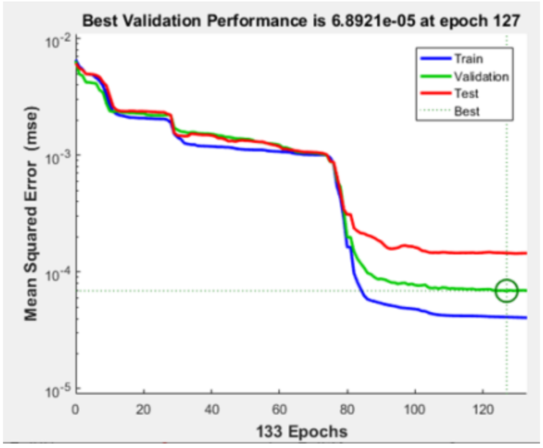

Figure 5. Mean squared error performance during the training of the output voltage ANN model

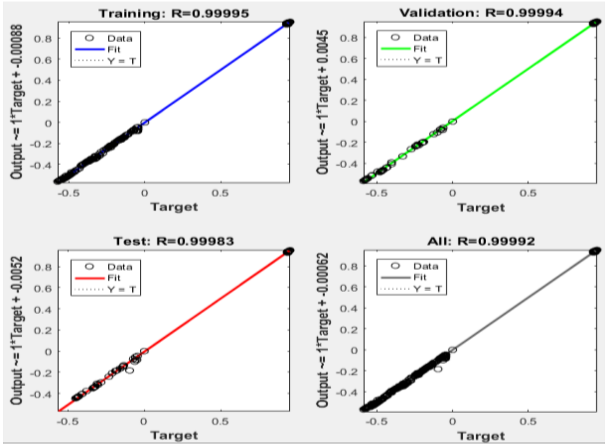

Figure 6. The learning curve for the output voltage in ANN model

4.2. Output power of ANN model

The output power of ANN model is used for determining the power flow of the transmission line. The input datasets are (V1-δ1, V2-δ2, and V3-δ3……Vn-δn) for all existing transmission lines. The corresponding output data set for the transmission line between bus j and bus k are (Pjk-Qjk, Pkj-Qkj……). This is applied to the all-transmission lines. Figure 7 shows the ANN network used to predict the real and reactive power flow in the transmission lines.

The system contains 22 transmission lines, to calculate losses of each transmission line voltage magnitude and phase angle of each sending and receiving end needed for one direction of power flow and the power flow in opposite direction also needed, therefore for each transmission line four input data needed so total input for 22 transmission line will be 88 and 88 output for active and reactive power also needed. A large number of load flow processes are performed repeatedly using the N-R method. The P and Q at all the load buses of 24-bus system are increased simultaneously up to 200% and all of these data sets are stored. Then the results are prepared to represent the input and the output set. The neural network is formed with a transfer function (TANSIG) and 20 neurons in its hidden layer.

The network is designed by 88 inputs corresponding to the voltage magnitude and the phase angle for 23 buses, and 88 outputs for the active and the reactive power flow for 22 transmission lines in the system. The mean squared error performance of the model is shown in Figure 8 Similar to the output voltage ANN model, the MSE of the output power ANN model decreases as the number of iterations increases. And Figure 9 represents the regression values for the training, testing, and validation phases of the ANN model.

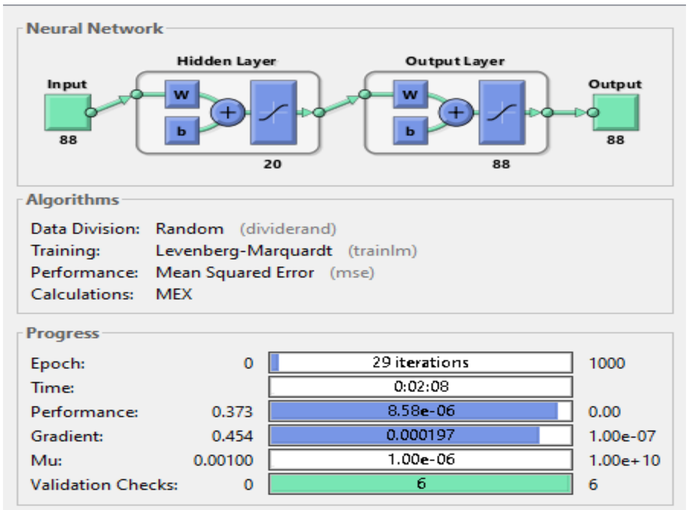

Figure 7. The ANN model for active and reactive power flow

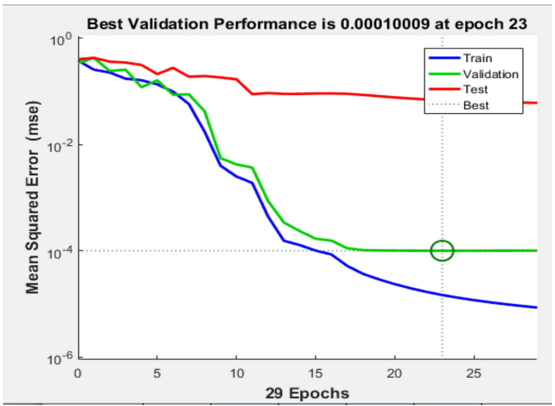

Figure 8. Mean square error behavior during training ANN model

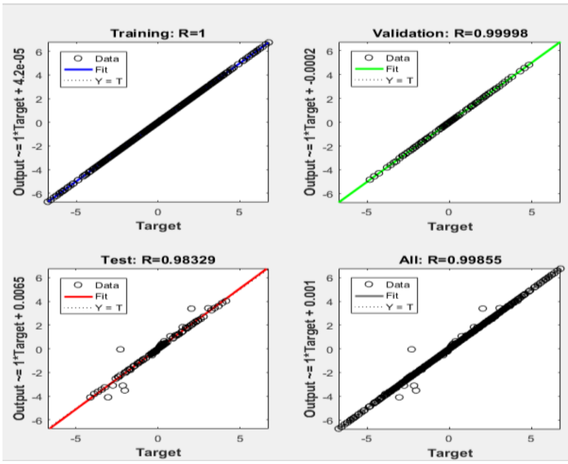

Figure 9. The learning curve of ANN model

5. RESULTS AND ANALYSIS

This section presents and compares the obtained results of the output voltage model and the output power model using the NR, GS, and the ANN model. Figure 10 and Figure 11 show the obtained magnitude and phase angle, respectively, of the buses using the NR, GS, and the ANN method. From Figure10 it is clear that voltage magnitude of number of buses (form bus No.1 to bus No.12) are near to one per unit which indicate that those buses are strong enough and this refers to that those buses are not over loaded, meanwhile buses 18, 19, 20, 21, 22, 23, and 24 have low voltage magnitude and explanation for this is those buss are over loaded and far away from substations. Voltage phase angle of all buses has acceptable value (close to zero) that is because the type of the load does not affect the phase angle.

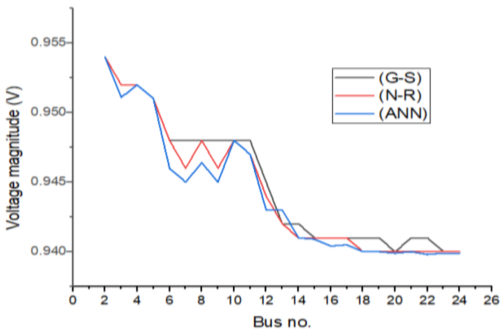

Figure 10. The magnitude of the bus voltage using the GS, NR, ANN power flow analysis models

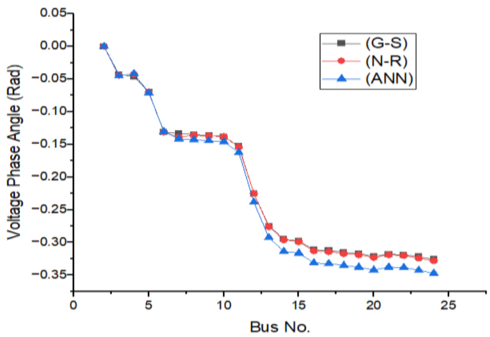

Figure 11. Phase angle of the bus voltage using the GS, NR, ANN power flow analysis models

The numerical values of the output voltages and phase angles using GS, NR and ANN are listed in Table 2, voltages of all buses are in accepted rage values, we can also note that some buses have negative angles (lagging) which means that active power will flow to these buses because, active power will flow always from leading angle to lagging angle. It is clear from Figure 10 that the bus voltage magnitude obtained using the ANN method provides closer results to the N-R than the G-S model. While, Figure 11 shows that the three methods approximately result in the same voltage phase angle results.

A comparison between the N-R and the G-S power flow methods to the ANN model is presented in Table 3. The comparison is performed in terms of the percentage error [24] of the bus voltage magnitude between ANN model and each of the conventional power flow techniques using (18).

$$\%\text{Error} = \left(\frac{actiual\ value - pridicted\ value}{actiual\ value}\right) * 100 \tag{18}$$

Table 2. Load flow results of voltage magnitude and phase angle

Bus No.	(G-S)		(N-R)		(ANN)	
	Voltage magnitude (V)	Phase angle (Rad)	Voltage magnitude (V)	Phase Angle (Rad)	Voltage magnitude (V)	Phase angle (Rad)
2	0.954	0	0.954	0	0.954	0
3	0.952	-0.043	0.952	-0.044	0.9511	-0.0451
4	0.952	-0.046	0.952	-0.0429	0.952	-0.042
5	0.951	-0.07	0.951	-0.07	0.951	-0.0713
6	0.948	-0.131	0.948	-0.131	0.946	-0.1303
7	0.948	-0.133	0.946	-0.139	0.945	-0.1413
8	0.948	-0.135	0.948	-0.136	0.9464	-0.1429
9	0.948	-0.136	0.946	-0.137	0.944	-0.1444
10	0.948	-0.138	0.948	-0.138	0.948	-0.1458
11	0.948	-0.153	0.947	-0.154	0.947	-0.1624
12	0.945	-0.225	0.944	-0.225	0.943	-0.2384
13	0.942	-0.275	0.942	-0.276	0.943	-0.2924
14	0.942	-0.295	0.941	-0.296	0.941	-0.3137
15	0.941	-0.298	0.941	-0.299	0.9409	-0.3163
16	0.941	-0.311	0.941	-0.313	0.9404	-0.3314
17	0.941	-0.312	0.941	-0.314	0.9405	-0.3323
18	0.941	-0.315	0.94	-0.317	0.94	-0.3351
19	0.941	-0.317	0.94	-0.319	0.94	-0.3378
20	0.94	-0.321	0.94	-0.323	0.9399	-0.3422
21	0.941	-0.318	0.94	-0.319	0.94	-0.3377
22	0.941	-0.319	0.94	-0.32	0.9398	-0.3383
23	0.94	-0.322	0.94	-0.324	0.9399	-0.3427
24	0.94	-0.326	0.94	-0.328	0.9399	-0.3471

Table 3. Voltage magnitude percentage errors

Bus No.	Voltage magnitude % Error (ANN and N-R)	% Error (ANN and G-S)
2	0	0
3	0.094537815	0.094537815
4	0	0
5	0	0
6	0.210970464	0.210970464
7	0.421940928	0.421940928
8	0.168776371	0.168776371
9	0.52742616	0.52742616
10	0	0
11	0	0.105485232
12	0.105932203	0.211640212
13	-0.106157113	-0.106157113
14	0	0.106157113
15	0.010626993	0.010626993
16	0.063761955	0.063761955
17	0.053134963	0.053134963
18	0	0.106269926
19	0	0.106269926
20	0.010638298	0.010638298
21	0	0.106269926
22	0.021276596	0.127523911
23	0.010638298	0.010638298
24	0.010638298	0.010638298

It is obvious from the Table 3 that the errors are equal to zero on many buses; the results also indicate that the error between N-R method and ANN method is less than the error between the G-S method and ANN method, that is because N-R method results are more accurate than G-S method consequently the error between N-R and ANN is less than the error between G-S and ANN. Table 4 lists the results of active and reactive power flow between existing buses of the system using the G-S, N-R, and the ANN power flow techniques, it can be used to calculate losses of transmission line. Similar to the bus voltage magnitude results of Figure 10, the table show that the active and reactive power results of the ANN model match very well with the results from the N-R method because the active and reactive power flow depends on bus voltages which is more equate with N-R method. Also, there is a good match between the ANN results and the GS model.

Table 4. Load flow results of active and reactive power

Rom bus to bus	ANN		N-R		G-S	
	Active power flow	Reactive power flow	Active power flow	Reactive power flow	Active power flow	Reactive power flow
1—2	5.1819	3.2508	5.18	3.25	5.17	3.21
2 –1	-5.1742	-3.2391	-5.17	-3.24	-5.17	-3.24
2—3	0.2789	0.1726	0.28	0.17	0.279	0.169
3—2	-0.279	-0.1733	-0.28	-0.171	-0.279	-0.169
2—4	4.8899	3.0597	4.89	3.06	4.86	3.05
4—2	-4.8799	-3.0569	-4.88	-3.06	-4.88	-3.05
4—5	4.6015	2.8786	4.6	2.88	4.56	2.84
5—4	-4.5897	-2.8612	-4.59	-2.86	-4.549	-2.82
5—6	0.2789	0.1734	0.28	0.172	0.273	0.17
6—5	-0.2793	-0.1731	-0.28	-0.17	-0.273	-0.17
5—7	0.5624	0.3491	0.56	0.35	0.553	0.348
7—5	-0.5627	-0.3493	-0.56	-0.35	-0.534	-0.349
7—8	0.2794	0.1736	0.28	0.172	0.273	0.17
8—7	-0.279	-0.1729	-0.28	-0.171	-0.274	-0.17
7—9	0.2792	0.1735	0.28	0.172	0.278	0.171
9—7	-0.2787	-0.1735	-0.28	-0.173	-0.279	-0.172
5—10	3.4617	2.1596	3.46	2.16	3.455	2.152
10—5	-3.459	-2.1606	-3.46	-2.16	-3.455	-2.151
10--11	3.0065	1.8792	3.01	1.88	3	1.88
11--10	-2.9978	-1.8683	-3	-1.87	-2.999	-1.86
11--12	2.5496	1.5855	2.55	1.59	2.54	1.58
12--11	-2.5378	-1.5792	-2.54	-1.58	-2.53	-1.57
12--13	2.2593	1.4042	2.26	1.4	2.24	1.39
13--12	-2.262	-1.3977	-2.26	-1.4	-2.24	-1.39
13--14	0.4497	0.2802	0.45	0.28	0.44	0.279
14--13	-0.4498	-0.2803	-0.45	-0.28	-0.44	-0.278
13--15	1.808	1.1206	1.81	1.12	1.8	1.11
15--13	-1.7988	-1.1169	-1.8	-1.12	-1.79	-1.11
15--16	0.562	0.3489	0.56	0.35	0.55	0.34
16--15	-0.5619	-0.3493	-0.56	-0.35	-0.55	-0.34
16--17	0.2793	0.1728	0.28	0.17	0.27	0.169
17--16	-0.2793	-0.1734	-0.28	-0.172	-0.27	-0.17
15--18	0.5624	0.3496	0.56	0.35	0.54	0.34
18--15	-0.5625	-0.349	-0.56	-0.35	-0.54	-0.34
18--19	0.2794	0.1729	0.28	0.17	0.27	0.16
19--18	-0.2792	-0.1732	-0.28	-0.17	-0.27	-0.169
15--20	0.678	0.4198	0.68	0.42	0.67	0.41
20--15	-0.6782	-0.4199	-0.68	-0.42	-0.67	-0.41
20--21	0.111	0.0692	0.11	0.07	0.109	0.069
21--20	-0.1117	-0.0707	-0.11	-0.07	-0.108	-0.069
20--22	0.5621	0.3491	0.56	0.35	0.559	0.34
22--20	-0.5623	-0.3496	-0.56	-0.35	-0.558	-0.34
22--23	0.2784	0.1727	0.28	0.17	0.279	0.169
23--22	-0.2794	-0.1718	-0.28	-0.17	-0.279	-0.169
22--24	0.2122	0.1899	0.2133	0.188	0.2132	0.185
24--22	-0.2152	-0.1879	-0.2162	-0.189	-0.215	-0.186

Finally, a comparison is performed for the software implementation of the simulation models between the three load flow techniques. The comparison is performed in terms of the average number of iterations and the required computation time as summarized in Table 5. It is clear that there is a better performance when using ANN techniques compared to the conventional techniques. It can be noticed that the output voltage G-S requires more iteration and more time required which is a drawback of this method, N-R is better than G-S method in number of iteration and computation time, and a comparison in [14] is also proved this achievement , but ANN model technique required less computational time than the N-R and the G-S techniques, also less iteration number than G-S technique therefor, ANN based calculations is been suggested to find load flow computations [16].

Table 5. Number of iterations and computation time of the power flow methods

Method	Iteration	Computation time in (second)
G-S	675	0.41
N-R	153	0.07
ANN (voltage model)	133	0.00
ANN (power model)	29	2.08

6. CONCLUSION

In this work, three power flow methods of G-S, N-R, and a new approach of ANN were used to compare and analyze a 24-bus radial distribution system. A flowchart is presented to describe the function of the ANN model for performing load flow analysis efficiently, from the results, we can conclude that the ANN based load flow methods outperform G-S and N-R conventional load flow calculations in several points, its more accurate, has fast convergences, more simple, take less time to computer after the training finished, also, the ANN load flow solutions does not require initial values. The ANN model was used to predict either the magnitude- the phase angle of the bus voltages and used to predict the active-reactive power of the transmission lines between two buses. The obtained results from the load flow analysis showed close match between the ANN and the well proved N-R power flow techniques. So we can conclude that ANN represents an efficient tool for performing load flow analysis of a radial distribution system.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee; or: The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, warda Ali. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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