Distribution Load flow using Artificial Neural networks

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ABSTRACT

Many methods have been developed for transmission and distribution load flows. Most of these methods are useful for off line applications. Much preference was given to transmission system load flows than distribution systems. But, with the changes in the operating structures of distribution systems and penetration of distributed generations in to the distribution systems, much attention has been given to distribution system analysis. Also due to the development of smart city concept, there is a need to develop faster load flow methods suitable for online applications. In this work, a new formulation for distribution load flow is developed by using the Artificial Neural Networks (ANN). The proposed method is tested on 33-node balanced and 10-node unbalanced distribution networks. The results obtained from the proposed method are compared with the results obtained from forward/backward sweep algorithm and modified distribution load flow using network topology.

Keywords: Distribution systems, Distribution load flow, Artificial Neural Networks, Forward/backward sweep algorithm.

1. INTRODUCTION

The electric power industry has traditionally been divided into three sections: generation, transmission and distribution. At the generation stage, electricity is produced from conventional and non conventional sources. Then, the electric power is injected into the transmission system which is configured as an interconnected network of transmission lines and control devices. Finally, at the distribution stage, the power is taken from the transmission system and delivered to consumers at specific standards of quality and reliability. These three stages together generation, transmission and distribution are generically known as a power system. The transmission system is definitely different, in both its operation and characteristics, from the distribution system. Whereas the latter draws power from a single source and transmits it to individual loads, the transmission system handles the major blocks of power system. The main difference between the transmission system and the distribution system shows up in the network structure. The transmission system tends to be a loop structure and distribution system is generally radial structure. Since, majority of the distribution systems are radial in structure, In this work attention has been given to methods exploiting the radial structure of the systems. There are number of load flow techniques available in the literature for transmission systems. The methods used for transmission systems are failing to converge for distribution system because of their high R/X ratio. Many researchers have suggested modified versions of the conventional load flow methods for solving load flow of distribution networks. But, the failed to achieve promising results. In the literature various methods have been developed for distribution load flows. These methods are broadly divided in to to groups viz. (1) applied to balanced networks using single phase representation of the network and (2) applied to unbalanced networks using the detailed three phase representation of the networks. In [1], a direct power flow solution for radial distribution networks has been developed. It exploits the topology information in developing the algorithm. It also proposed a unique branch and node numbering scheme. The developed method is extended to meshed and unbalanced distribution networks also. A simple and efficient method for solving distribution networks is presented in [2]. It involves only the evaluation of simple algebraic expression of receiving-end voltages. In [3], a new algorithm for solving the radial distribution networks was proposed. The algorithm uses the basic principle of circuit theory and can be easily understood. A new algorithm to solve the radial distribution system by considering the voltage dependency of static loads and line charging capacitance is developed in [4]. The method is based on the forward and backward voltage calculations by using polynomial voltage equations and Krichoff's law for each branch. In [5], a direct approach to solve the distribution load utilizing the topology information of the network is developed. It is simple and demonstrated for balanced networks. It also extended for three phase circuits also. A new method by utilizing the backward sweep algorithm on Kirchoff's current law and Kirchoff's voltage law for evaluating the node voltages iteratively has been proposed in [6]. In this approach, computation of the branch current depends only on the current injected at the neighboring node and the current in the adjacent branch. In [7], a new method to solve distribution system load flow by using simple algebraic matrix equations is derived. The equations in this formulation are developed from the power balance equations. This method adopted rectangular coordinate system to achieve better convergence. The method has been tested on radial and meshed networks. A new problem formulation to solve the three phase distribution load flow by utilizing the radial structure of the networks is presented in [8]. Distinguishing feature of the new problem formulation is it significantly reduces the number of power flow equations as compared to the conventional formulation. In [9], a rigid approach to three phase distribution power flow analysis for large-scale distribution systems is proposed. This approach is oriented toward applications in distribution system operational analysis rather than planning analysis. The solution method is the optimally ordered triangular factorization YBus (implicit ZBus Method) which not only takes advantage of the sparsity of system equations but also has very good convergence characteristics on distribution problems. A new power flow method for solving weakly meshed distribution and transmission networks, using the multi port compensation technique and basic formulation of Kirchoff's laws was developed in [10]. In [11], a new formulation of the distribution load flow by using the current injection equations in rectangular form is developed. This formulation composed of 6x6 block matrices and retain the same structure as the nodal admittance matrix. Most of the methods discussed above are based on the conventional approaches and suitable for off line applications. But, very few are developed methods suitable for online applications. However, these methods were developed by assuming the availability of measurements from the RTU based SCADA. But, with the development of synchrophasor based WAMS using Phasor Measurement Units (PMUs), it become possible to get data measurements as fast as one frame per second. The availability of direct measurement of the power system states, through PMUs, has triggered a paradigm shift in various system monitoring applications. Considering the limitations of various methods and also various opportunities for improving the system performance, in this work a new formation for distribution load flow using ANNs is developed. In Sectin-2 details of the ANNs used in the proposed method, in Section-3 results obtained from the case studies were presented. Finally, in Section-4 conclusions of the proposed work are presented.

2. ARTIFICIAL NEURAL NETWORKS

The use of neural networks offers the following useful properties and capabilities.

- **Non linearity**

A neural network, made up of an interconnection of nonlinear neurons, is itself nonlinear. Moreover, the non linearity is of a special kind in the sense that it is distributed throughout the network. Most real systems, including power systems are nonlinear, so this property is very desirable for its application in power systems.

- **Input-output mapping**

A popular pattern of learning called learning with a teacher or supervised learning involves modification of the synaptic weights of a neural network by applying a set of labeled training samples or task examples. Each example consists of a unique input signal and a corresponding desired response. The network learns from the examples by constructing an input-output mapping for the problem. In power system voltage security analysis, the traditional approach's which are widely used to generate those training samples.

- **Adaptively}**

Neural networks have a built-in capability to adapt their synaptic weights to changes in the surrounding environment. In particular, a neural network trained to operate in a specific environment can be easily retrained to deal with minor changes in the operating environmental conditions. Moreover, when it is operating in a no satisfactory environment, a neural network can be designed to change its synaptic weights in real time.

- **Fault tolerance}**

A neural network has the potential to be inherently fault tolerant in the sense that it performance degrades gracefully under missing or erroneous data. The reason is that the information is distributed in the network; the errors must be extensive before catastrophic failure occurs.

Based on the various benefits of neural networks discussed above, a multi-layer feed–forward ANN consists of an input layer, one hidden layers, and an output layer was developed to perform the distribution load flow. Key features of the various layers of an ANN were discussed below. Appropriate selection of input variables is the key to the success of ANN applications. Usually heuristic knowledge is required in choosing input variables. For distribution load flow type problems, loads at various buses play important role in the final solution. Hence, In this problem load at various buses are considered as inputs to the neural network. The number of neurons in the hidden layer depends on the number of training vectors and the number of unknown weights and biases to be evaluated. Computational power of the ANN is a result of the addition of hidden layers. But there are no general guidelines to determine the number of hidden layers and neurons. In our studies, 1.5 times the number of input neurons are considered and given promising results. The determination of the output layers is quite straight-forward and depend on the number of outputs required from the solution. In this work, the output of the solution are the voltage magnitudes only. Hence, the number of output neurons are equal to the size of the system under consideration.

2.1 Training of the ANN

Every ANN requires proper training before actually implemented in the systems. The training of the neural network requires patterns from the existing methods. A pattern is a set of inputs and corresponding outputs. In this work, various patterns were developed by using conventional forward/backward sweep algorithm. Two types of training patterns are developed in this problem. One by changing the loads at all the buses by small increments in each step from 80% of the base case loading to 120% of the base case loading, and the second by changing the loads randomly between ±20% of the base case loadings. Around 600 to 700 patterns are developed for each system. Among all the patterns, 80% are used for training and 20% are used for testing the network.

3. CASE STUDIES

In this work, to verify the performance of the proposed method studies have been carried out on two distribution networks. They are (1) 33-node balanced distribution network and 10-node unbalanced distribution network. Results of the various case studies were as follows.

3.1 33-node balanced distribution network

The data for this system was taken from [12] and line diagram is shown in Figure 1.

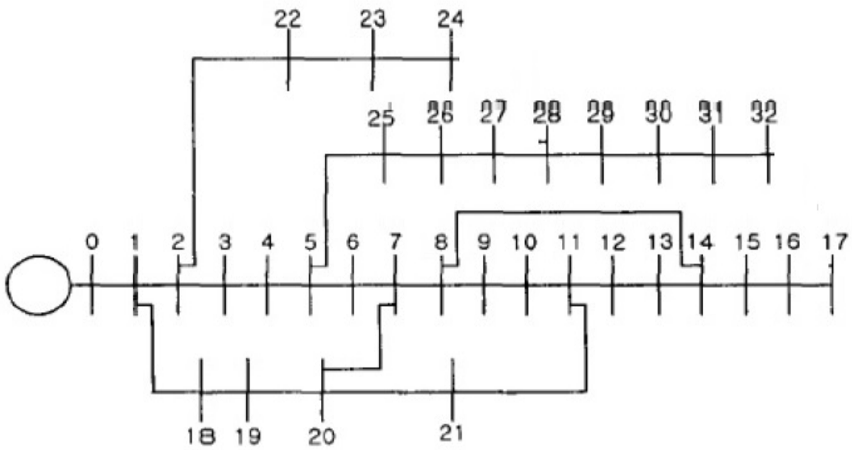

Figure 1: Line diagram of the 33-node balanced distribution network

Studies have been carried out for different load patterns. Results for two cases i.e. at base case loading and at 120% o the base case loading were presented in Table 1.

Table 1: Load flow results of 33- node system

Bus	Base case loading		120% of base case loading	
	Forward/backward sweep	ANN	Forward/backwar d sweep	ANN
1	1	1	1	1
2	0.997	0.997	0.9964	0.9964
3	0.9829	0.9829	0.9792	0.9792
4	0.9754	0.9754	0.97	0.97
5	0.968	0.9679	0.9609	0.9609
6	0.9495	0.9494	0.9383	0.9383
7	0.946	0.9459	0.934	0.934
8	0.9323	0.932	0.9173	0.9173

9	0.926	0.926	0.9095	0.9095
10	0.9201	0.9201	0.9023	0.9023
11	0.9192	0.9194	0.9012	0.9012
12	0.9177	0.9177	0.8994	0.8994
13	0.9115	0.9115	0.8918	0.8918
14	0.9092	0.9091	0.889	0.889
15	0.9078	0.9078	0.8872	0.8872
16	0.9064	0.9063	0.8855	0.8855
17	0.9044	0.9044	0.883	0.883
18	0.9038	0.9037	0.8822	0.8822
19	0.9965	0.9965	0.9957	0.9957
20	0.9929	0.9929	0.9914	0.9914
21	0.9922	0.9922	0.9906	0.9906
22	0.9916	0.9916	0.9898	0.9898
23	0.9793	0.9793	0.9748	0.9748
24	0.9726	0.9726	0.9668	0.9668
25	0.9693	0.9693	0.9628	0.9628
26	0.9475	0.9475	0.9359	0.9359
27	0.945	0.9451	0.9328	0.9328
28	0.9335	0.9335	0.9188	0.9188
29	0.9253	0.9253	0.9088	0.9088
30	0.9218	0.9218	0.9044	0.9044
31	0.9176	0.9176	0.8993	0.8993
32	0.9167	0.9166	0.8982	0.8982
33	0.9164	0.9164	0.8978	0.8978

3.2 10-node unbalanced distribution network

The data for this system was taken from [12] and line diagram is shown in Figure 2. In this case also, studies were carried out at various operating points. But, two case i.e at base case loading and 120% of base case loading were presented in Tables 2-5.

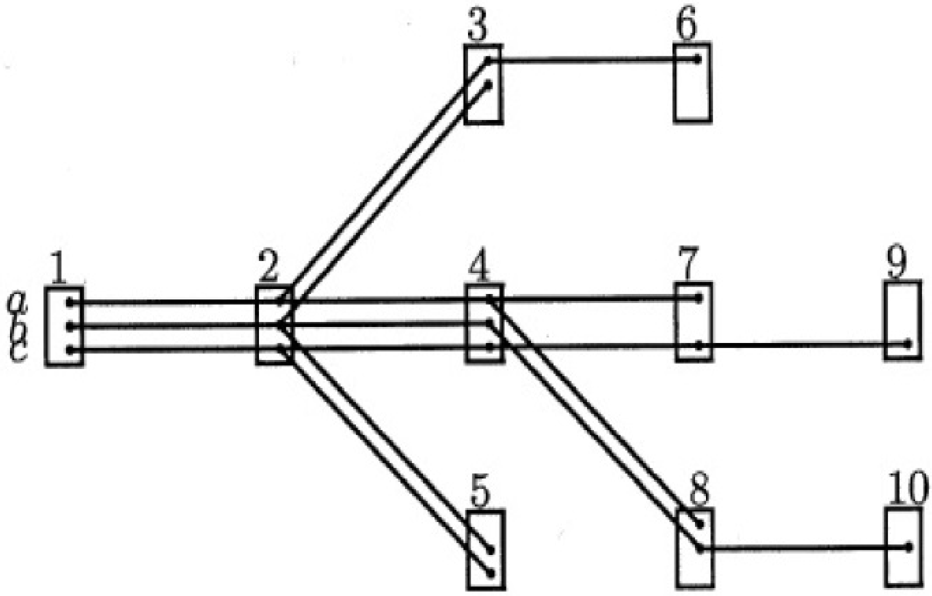

Figure 2: Line diagram of the 10-node unbalanced distribution network

Table 2: ANN based load flow results at base case loading of 10-node system.

bus no.	V(pu)-A	ang-A	V(pu)-B	angB	V(pu)-C	ang C
1	1.0000	0.0006	1.0000	-120.0000	1.0000	119.9992
2	0.9556	-1.2121	0.9930	-120.5689	0.9864	119.9755
3	0.9446	-1.3246	0.9929	-120.6362	0.0000	-0.0003
4	0.9306	-1.9603	0.9917	-120	0.9784	120.0810
5	0.0000	-0.0005	0.9861	-121.1488	0.9842	119.8900
6	0.9190	-1.1926	0.0001	0.0000	0.0000	0.0000
7	0.9236	-2.2037	0.0000	0.0001	0.9749	120.0957
8	0.9227	-1.9986	0.9899	-120.8180	-0.0000	-0.0002
9	0.0000	-0.0006	0.0001	0.0003	0.9671	119.9435
10	0.0000	-0.004	0.9883	-120.8875	-0.0000	-0.0002

Table 3: load flow results using forward/backward sweep algorithm at base case loading of 10-node system.

bus no.	V(pu)-A	ang A	V(pu)-B	angB	V(pu)-C	ang C
1	1.0000	0	1.0000	-119.9993	1.0000	119.9993
2	0.9556	-1.2125	0.9930	-120.5693	0.9864	
3	0.9446	-1.3246	0.9929	-120.6359	0	0
4	0.9306	-1.9605	0.9916	-120.7485	0.9784	120.0815
5	0	0	0.9861	-121.1474	0.9842	119.8910
6	0.9190	-1.1926	0	0	0	0
7	0.9236	-2.0238	0	0	0.9749	120.0954
8	0.9227	-1.9986	0.9899	-120.8178	0	0
9	0	0	0	0	0.9671	119.9435
10	0	0	0.9883	-120.8873	0	0

Table 4:ANN based load flow results at 120% of base case loading of 10-node system.

bus no.	V(pu)-A	ang A	V(pu)-B	angB	V(pu)-C	ang C
1	1.0000	0.000	1.0000	-119.9993	1.0000	119.9993
2	0.9456	-1.4794	0.9915	-120.6882	0.9836	119.9815
3	0.9324	-1.6166	0.9917	-120.7689	0.0001	0.003
4	0.9151	-2.4023	0.9904	-120.9069	0.9740	120.1167
5	0.0000	0.000	0.9837	-121.3886	0.9810	119.8796
6	0.901	-1.4529	0.0001	-0.0002	0.0002	0.0000
7	0.9065	-2.4807	0.0000	-0.0007	0.9697	120.1351
8	0.9056	-2.4504	0.9884	-120.9901	0.0001	0.0005
9	0.0005	0.0002	0.0000	-0.0000	0.9603	119.9505
10	0.0000	0.001	0.9862	-121.0763	0.0000	0.0001

Table 5: load flow results using forward/backward sweep algorithm at 120% of base case loading of 10-node system.

bus no.	V(pu)-A	ang A	V(pu)-B	angB	V(pu)-C	ang C
1	1.0000	0	1.0000	-119.9993	1.0000	119.9993
2	0.9457	-1.4777	0.9918	-120.6882	0.9836	119.9815
3	0.9322	-1.6166	0.9917	-120.7689	0	0
4	0.9150	-2.4023	0.9902	-120.9069	0.9740	120.1167
5	0	0	0.9837	-121.3886	0.9810	119.8796
6	0.9009	-1.4529	0	0	0	0
7	0.9065	-2.4807	0	0	0.9697	120.1351
8	0.9054	-2.4504	0.9882	-120.9909	0	0
9	0	0	0	0	0.9603	119.9505
10	0	0	0.9862	-121.0753	0	0

4. CONCLUSIONS

A new formulation of distribution load flow was developed using the Artificial Neural Networks suitable for balance as well as unbalanced networks. Execution time of this method is less and suitable for online applications. The results obtained for the proposed method and the conventional forward/backward sweep algorithm are comparable and giving promising results.

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