

Power flow analysis by Artificial Neural Network

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Abstract: Computer based methods used to analysis the power systems are developed instead of the steady state of mathematical methods. By the development of computer technology, solution of the network problems gets easier. Increment of the necessity to electrical energy by the development of technology, whereas the increment rate of raw energy sources doesn't enough, it have made it mandatory to use the energy sources efficiently. Interconnected networks formed by the connection between not only the domestic sources and customers, but also between the different countries for the optimization and for the efficient use of the sources. Electrical engineers faced by the planning and optimization problems of developing interconnected networks. By this way, the requirement of the use of intelligent systems and computer analysis of power systems has become inevitable. In this study, power flow analysis the of a power system that consist five busbars performed by designed neural network. Results are compared by the results that gained by the analysis with classic Gauss-Seidel method of the same system, then the success of the neural network is investigated.

Keywords: Power Flow Analysis, Artificial Neural Networks, Gauss-Seidel Method

1. Introduction

Development and getting complication of electrical power systems cause the necessity of detailed studies on planning and operating sections. Studies on this area expose a concept called power flow. Power flow can be described as calculations on defining characteristic properties of steady state operating situation of energy transmission systems. Power flow analysis on a transmission system includes the calculations of power flow and voltages for specified node or busbar situations. These calculations are also necessary for both dynamic and steady state behavior of power systems [1]. The power flow algorithm used on balanced and three phase energy systems under steady state conditions, based on the following rules:

- Generators supply all loads and total power loss of power lines. They cannot exceed their nominal active and reactive power capacities.
- Voltage amplitudes of all busbars are about nominal voltage limits.
- Power lines and transformers cannot overload.

In power flow analysis, calculations are made by characteristic values of various components such as busbars, generators, power lines and transformers on power system. [2, 3]

1.1. Describe of Power Flow Problem

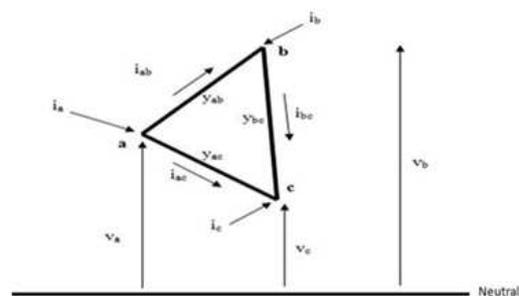


Figure 1. Single Phase Presentation of Three Node System

If k and j are described as any two nodes, v_k is voltage between node k and neutral; y_{kj} is admittance between nodes k and j; i_{kj} is current flows from node k to node j and i_k is current flows to node k, then

$$i_a = i_{ab} + i_{ac} \tag{1}$$

$$i_a = (v_a - v_b)y_{ab} + (v_a - v_c)y_{ac} \tag{2}$$

$$i_a = v_a(y_{ab} + y_{ac}) - v_b y_{ab} - v_c y_{ac} \tag{3}$$

can be written. Similarly

$$i_b = -v_a y_{ba} + v_b (y_{ba} + y_{bc}) - v_c y_{bc} \quad (4)$$

$$i_c = -v_a y_{ca} - v_b y_{cb} + v_c (y_{ca} + y_{cb}) \quad (5)$$

In these equations if

$$\begin{aligned} y_{ab} + y_{ac} &= y_{aa} \\ y_{ba} + y_{bc} &= y_{bb} \\ y_{ca} + y_{cb} &= y_{cc} \end{aligned} \quad (6)$$

then

$$\begin{aligned} i_a &= y_{aa} v_a - y_{ab} v_b - y_{ac} v_c \\ i_b &= -y_{ba} v_a + y_{bb} v_b - y_{bc} v_c \\ i_c &= -y_{ca} v_a - y_{cb} v_b + y_{cc} v_c \end{aligned} \quad (7)$$

The matrix form of these equations can be written as

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} y_{aa} & -y_{ab} & -y_{ac} \\ -y_{ba} & y_{bb} & -y_{bc} \\ -y_{ca} & -y_{cb} & y_{cc} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \text{ or } I = Y \cdot V \quad (8)$$

For n node system

$$\begin{aligned} I_1 &= Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + \dots + Y_{1n}V_n \\ I_2 &= Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + \dots + Y_{2n}V_n \\ I_3 &= Y_{31}V_1 + Y_{32}V_2 + Y_{33}V_3 + \dots + Y_{3n}V_n \\ &\vdots \\ &\vdots \\ &\vdots \\ I_n &= Y_{n1}V_1 + Y_{n2}V_2 + Y_{n3}V_3 + \dots + Y_{nn}V_n \end{aligned} \quad (9)$$

For k.th node

$$I_k = Y_{k1}V_1 + Y_{k2}V_2 + Y_{k3}V_3 + \dots + Y_{kn}V_n$$

or

$$I_k = \sum_{j=1}^n Y_{kj}V_j, \quad k = 1, 2, 3, \dots, n \quad (10)$$

In power flow calculations all voltages have to solve. However, currents can be described with complex power and voltage forms. So, for the node k

$$I_k = \frac{S_k^*}{V_k^*} \quad (13)$$

The ‘*’ signed terms refer complex form.

If the busbar 1 selected as slack bus, the voltage calculation for this bus is not necessary, due to it has already described. So, the equation 10 can be written as

$$I_k = \sum_{j=1}^n Y_{kj}V_j, \quad k = 2, 3, \dots, n \quad (12)$$

1.2. Study System

To validate the proposed method, a study system is designed. This system contains a generator, five busbars and different power lines to connect busbars to each other.

Figure 2 shows the study system

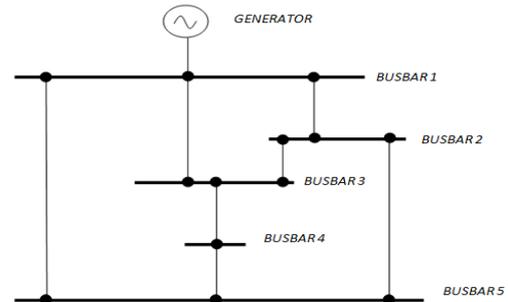


Figure 2. Study System

2. Analytical Analysis of Study System

The study system given in part 1.2 is analyzed by Gauss – Seidel power flow analysis method. [4, 5, 6] An algorithm developed by MATLAB platform used for analysis. Different busbar scenarios are tried to perform the algorithm.

Table 1. Busbar Loading Values (p.u.)

	Busbar 2	Busbar 3	Busbar 4	Busbar 5
P ₁	0.13	0.33	0.39	0.08
P ₂	0.40	0.13	0.21	0.48
P ₃	0.14	0.53	0.16	0.33
P ₄	0.26	0.32	0.26	0.19
P ₅	0.46	0.24	0.34	0.22
Q ₁	0.02	0.21	0.21	0.02
Q ₂	0.12	0.08	0.11	0.25
Q ₃	0.05	0.15	0.11	0.13
Q ₄	0.15	0.18	0.14	0.13
Q ₅	0.25	0.11	0.13	0.17

Due to line parameters given in table 2, system admittance matrix can form as below:

$$Y = \begin{bmatrix} 10.958904 & -3.424658 & -3.424658 & 0 & -4.109589 \\ -j25.997397 & +j7.534247 & +j7.534247 & 0 & +j10.958904 \\ -3.424658 & 11.672080 & -4.123711 & 0 & -4.123711 \\ +j7.534247 & -j26.060948 & +j9.278351 & 0 & +j9.278351 \\ -3.424658 & -4.123711 & 10.475198 & -2.926829 & 0 \\ +j7.534247 & +j9.278351 & -j23.119061 & +j6.341463 & 0 \\ 0 & 0 & -2.926829 & 7.050541 & -4.123711 \\ -4.109589 & -4.123711 & +j6.341463 & -j15.594814 & +j9.278351 \\ +j10.958904 & +j9.278351 & 0 & +j9.278351 & -j29.485605 \end{bmatrix} \quad (14)$$

The busbar loading values given in table 1 are used in algorithm. The algorithm produces voltage amplitudes and angles as given in table 3.

Table 2. Line Parameters

Source Busbar	Target Busbar	R (p.u.)	X (p.u.)	B (p.u.)
Busbar 1	Busbar 2	0.05	0.11	0.02
Busbar 1	Busbar 3	0.05	0.11	0.02
Busbar 1	Busbar 5	0.03	0.08	0.02
Busbar 2	Busbar 3	0.04	0.09	0.02
Busbar 2	Busbar 5	0.04	0.09	0.02
Busbar 3	Busbar 4	0.06	0.13	0.03
Busbar 4	Busbar 5	0.04	0.09	0.02

3. Artificial Neural Network Analysis of Study System

Unlike the traditional calculation methods, Artificial Neural Network (ANN) learns the solution from a data set of training and offers an alternate calculation form. This idea inspired on biological neural system, especially from human brain. [7]

Human brain can be described as nonlinear and parallel knowledge processing system which has ability of learning, consolidation, adaptation and generalization skills.

ANN is a powerful tool for the simulation and prediction of nonlinear problems. A neural network comprises many highly interconnected processing units called neurons. Each neuron sums weighted inputs and then applies a linear or nonlinear function to the resulting sum to determine the output, and all of them are arranged in layers and combined through excessive connectivity. The typical ANN is a back propagation network (BPN) which has been widely used in many research fields. A BPN has hierarchical feed-forward network architecture, and the output of each layer is sent directly to each neuron in the layer above. Although a BPN can have many layers, all pattern recognition and classification tasks can be accomplished with a three-layer BPN. [10]

ANN gathers stores and generalizes information by learning sequence, like human brain. Learning sequence is consisting of learning algorithms which supplies to renew the weights of ANN to reach the target. Generalization is described as the respect of the ANN to unknown data that never seen in both learning and education sequences. ANN is in use at wide variety of applications by its advanced ability on solving complex problems. [8]

In most common form, basic ANN follows the flowchart given in figure 3 below.

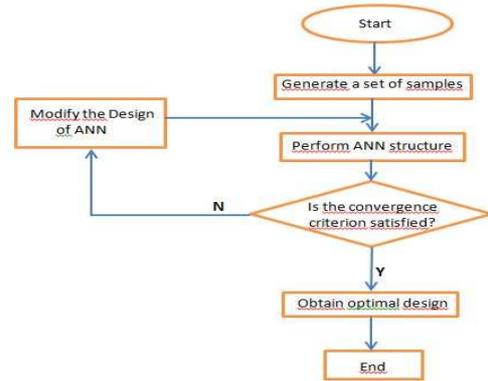


Figure 4 shows the basic form of developed ANN for reference system.

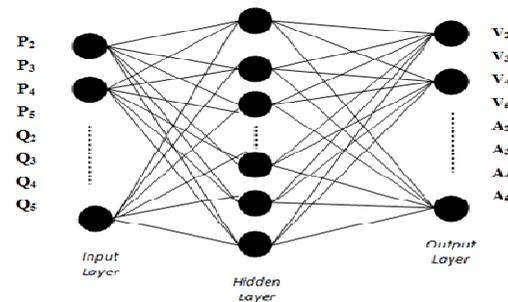


Figure 4. Basic Form of ANN

Also figure 5 shows the internal structure of designed ANN under Simulink platform.

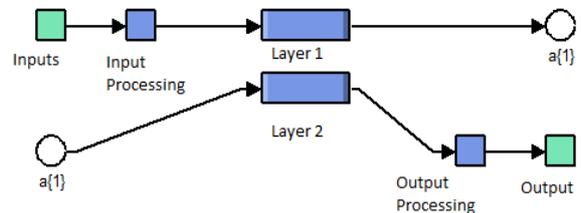


Figure 5. Internal Structure of ANN

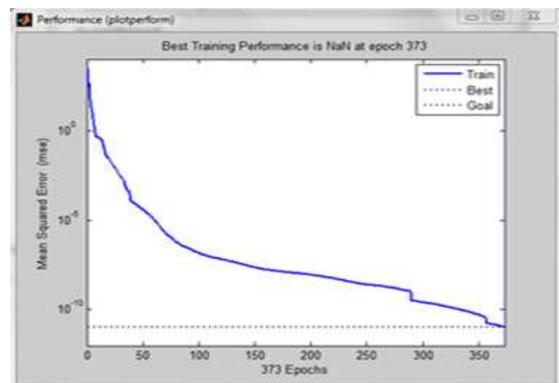


Figure 6. ANN Training Process

ANN is designed for variable busbar loading values. All other parameters are kept constant. The ANN is consisting of one input layer, one hidden layer and one output layer. Active and reactive powers belong to busbars are used in a

one-row matrix form to obtain input parameters. System gives busbar voltages and voltage angels as output. Tansig and purelin functions are used as transfer functions cause of giving the most successful results among others. Tansig is used for hidden layer and purelin is used for output layer. The best result has been obtained by using trainbr as learning algorithm.

50 active power values and 50 reactive power values are

used to train the developed ANN. The output values of training are voltage magnitudes and angles which obtained from developed analytical algorithm. Training process ended after 373 iterations. Figure 6 shows training process.

Both analytical and ANN analysis results are shown in table 3. that is given at the end of paper. The table also shows the convergence of analytical and ANN solution methods.

Table 3. Results

Busbar2	Analytical Solution		ANN Solution		Convergence	
	Voltage	Angle	Voltage	Angle	Voltage	Angle
P ₁ Q ₁	0.9781	-1.3706	0.9787	-1.3801	0.0006	-0.0095
P ₂ Q ₂	0.9675	-2.0576	0.9673	-2.0480	-0.0002	-0.0096
P ₃ Q ₃	0.9754	-1.7326	0.9754	-1.7326	0	0
P ₄ Q ₄	0.9689	-1.5432	0.9691	-1.5471	0.0002	-0.0039
P ₅ Q ₅	0.9595	-2.0894	0.9594	-2.0851	-0.0001	0.0043
Busbar3	Analytical Solution		ANN Solution		Convergence	
	Voltage	Angle	Voltage	Angle	Voltage	Angle
P ₁ Q ₁	0.9659	-1.7777	0.9665	-1.7840	0.0006	-0.0063
P ₂ Q ₂	0.9709	-1.7368	0.9705	-1.7305	-0.0004	0.0063
P ₃ Q ₃	0.9660	-2.3877	0.9661	-2.3901	0.0001	-0.0024
P ₄ Q ₄	0.9642	-1.7829	0.9643	-1.7860	0.0001	-0.0031
P ₅ Q ₅	0.9626	-2.0645	0.9624	-2.0595	-0.0002	0.0050
Busbar4	Analytical Solution		ANN Solution		Convergence	
	Voltage	Angle	Voltage	Angle	Voltage	Angle
P ₁ Q ₁	0.9523	-2.5586	0.9537	-2.5688	0.0014	-0.0102
P ₂ Q ₂	0.9563	-2.5405	0.9555	-2.5248	-0.0008	0.0157
P ₃ Q ₃	0.9615	-2.4547	0.9614	-2.4555	-0.0001	-0.0008
P ₄ Q ₄	0.9549	-2.2897	0.9554	-2.2985	0.0005	-0.0088
P ₅ Q ₅	0.9488	-2.9289	0.9486	-2.9214	-0.0002	0.0075
Busbar5	Analytical Solution		ANN Solution		Convergence	
	Voltage	Angle	Voltage	Angle	Voltage	Angle
P ₁ Q ₁	0.9775	-1.3978	0.9788	-1.4195	0.0013	-0.0217
P ₂ Q ₂	0.9634	-2.1474	0.9628	-2.1300	-0.0006	0.0174
P ₃ Q ₃	0.9732	-1.8341	0.9731	-1.8341	-0.0001	0
P ₄ Q ₄	0.9707	-1.4846	0.9713	-1.4961	0.0006	-0.0115
P ₅ Q ₅	0.9643	-1.8833	0.9639	-1.8749	-0.0004	0.0084

4. Conclusion

Main problem of power flow analysis is the necessity of processing too much parameter at same time because of the wide working area. This necessity forced engineers to develop modern methods such as artificial neural networks.

In this paper, power flow analysis of five-busbar system is investigated. First, the analysis is performed by classic analytical method. Then a developed ANN is used to analysis the same system with same parameters. As the results given in table 3 are investigated, it can be seen that proposed method satisfies the convergence limits. The

compared results show that the ANN works properly and can be used in power flow analysis problems.

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