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The Application of Neural Network on The Contingency Analysis of Iraqi Super Grid Network

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Abstract

Many of the problems that occur on electrical power system can cause serious trouble with in such a quick time period that the operator (in control room) could not take action fast enough. This is often the case with cascading failures. Because of this aspect of power system operation, modern operation computers are equipped with contingency analysis programs that model possible system troubles before they arise. Therefore, this work has developed an Artificial Neural Network technique to alarm the operators in control room to any outage in power system elements (Generating unit or Transmission line) depending upon the results of AC load flow after each separation in these elements.

The aim of this work is to improve the database system of Iraqi Control Centers by adopting the facility of the Artificial Neural Network (ANN) technique to identify the transmission line or the generation unit separate's in the electrical network. The work comprises four major parts which are; the development of the load flow program using Newton-Raphson Method, building the structure of Neural Network program (Radial Basis Function Neural Network), the engagement between the two programs, and the development of Visualization Technique for presenting the results via using Matlab language (Version 6.5). After the Engagement between the Visualization and other programs, the network under consideration (Iraqi Super Grid Network 400Kv) was studied and analyzed.

تطبيق الشبكة العصبيةِ على تحليل الاضطراب للشبكة الكهربائية العراقية

الخلاصة

العديد من المشاكل التي تحدث في انظمة القدرة الكهربائية يمكن ان تسبب اضطرابات خطيرة في وقت قصير قد لا يتمكن المشغل(في غرف السيطرة) خلاله من اتخاذ الفعل المناسب والسريع. وهذه الحالة يمكن ان تسبب حالات فشل متعاقبة. و بسبب هذا الوجه في عمل نظام القدرة, جهزت الحاسبات العملية الحديثة ببرامج تحليل الاضطراب (Contingency Analysis) والتي تقوم بتشكيل المشاكل الممكن حدوثها في النظام قبل حدوثها. لذلك طور هذا البحث تقنية الشبكة العصبية الاصطناعية (ANN) للانذار العاملين في مركز السيطرة لاي انقطاع في عناصر شبكة القدرة (محطة توليد او خط نقل) إعتِماد على نتائج برنامج سريان الحمل(AC load flow)بعد كل عملية فصل في عناصر الشبكة.

إنّ هدفَ هذا العملَ هو تحسين نظامَ قاعدةَ البيانات في مراكزِ السيطرة العراقيةِ بتَبنّي تقنيةِ الشبكة العصبيةِ الإصطناعيةِ (ANN) لتمييز خط النقل او محطة التوليد انفصل عن الشبكة

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الكهربائية. يشمل البحث أربعة أجزاءِ رئيسيةِ و هي :تطوير برنامج سريان الحمل باستخدام طريقة نيوتن رافسن (Newton Raphson), بناء هيكلية الشبكة العصبية (Radial Basis Function) Network, الربط بين البرنامجيين السابقيين و تطوير تقنية مرئية لتقديم النتائج بالاعتماد على مميزات لغة Matlab (نسخة 6.5). بعد عملية الربط بين البرامج السابقة و تقنية Visualization, تم دراسة وتحليل الشبكة الكهربائية العراقية (400Kv) باستخدام البرامج السابقة.

1. Introduction

The function of a power system is to generate electric energy economically and with the minimum ecological disturbance and to transfer this energy over transmission lines and distribution networks with maximum efficiency and reliability for delivery to consumers at virtually fixed voltage and frequency [1]. The objectives delivered from this function can be expressed in the following:
Economy, Expansion and Security, which it presented by **Quantity** (the system must be dimensioned to satisfy the maximum demand, also there must be reserves in order to cope with various contingencies without interrupting supplies) and **Quality** (this is basically achieved by keeping voltage and frequency within defined limits).

An early centralization of remote control and monitoring of electrical power system from a control center was implemented due to the fact that an electric network is spread over a large area and generation, transmission, distribution and utilization of energy are a process that is continuous in any time. Although the load varies and faults occur in a probability manner, in the total production to actual current consumption and that the quality of service, especially its reliability and security, meet strict requirement.

Increasing the size and complexity of the power system has gradually changed the requirement for control and monitoring systems. The rising cost and labor and lack of trained personnel have contributed towards the development from a simple system of the remote control of single power station or transformer substation to the modern computer-based energy management network [2].

2. Contingency Analysis

As a part of static security analysis Contingency Analysis (CA), is an available tool to get reliable and secure operation of a power system. It is the study of a system under contingencies, line outages, generator outages ……etc. Typical CA models are single-element outage (one-transmission line outage or one generator outage (opened)), multiple-element outage (two-transmission line outage or one-transmission line outage and one generator outage, etc) and sequential outage (one outage after another)[3,4]. These changes can be

either due to load demand variations, disconnecting lines and generating units for maintenance or faults event, planned rescheduling of power generation. The effect of these disturbances must be investigated both during system planning and operations.

The operators of control centers identify which line or generation outage will cause flows or voltage to fall out side limits. To predict the effects of outages, contingency analysis procedure checks all lines and voltages in the network against their respective limits [5].

3. Contingency Analysis Methods:

For a large system, simulation of line and generating unit outages constitutes an important element of the system security evaluation problem. This becomes clear if we know that each simulation is time consuming, and for a large system, hundreds of events (lines or generating units) will be studied. So the simulation for each contingency must be as fast time as possible. The method of calculations after the simulation also must be fast [6, 7, and 8].

The most difficult methodological problem in treating contingency analysis is the speed of solution of the model used. The logical problem is the selection of all true outages. If each outage case study is solved in 1 minute and several hundred outages concerned, it would take hours before all cases could be reported.

The problem of studying hundred of possible outages becomes very difficult to solve if it is desired to present the results quickly. One way to gain speed of solution in a contingency analysis procedure is to use an approximation model of the power system under consideration.

There are three essential methods for solving the problems of contingencies:

1. Network Sensitivity Method.
2. AC Power Flow Method
3. DC Power Flow Method.

This work depends on AC Power Flow (Newton Raphson NR) Method to solve power flow problem because this method is mathematically superior to the Gauss-Seidel method and is less prone to divergence with the problem of ill conditions. Added to that, the fast decoupled depends upon counting with Jacobian approximation to obtain a reasonable approximation that is independent of voltage magnitude and angle (***As a result Newton-Raphson is more exact from the fast decoupled method with approximately the same convergence time)*** [5].

4. Radial Basis Function Networks (RBFN) [9]:

Radial Basis Function Network (RBFN) emerged as a variant of artificial neural network in late 80's. Radial Basis Function Networks (RBFNs) are feed-forward networks trained using a supervised training algorithm. They are typically configured with a single hidden layer of units whose activation function is selected from a class of functions called Basis Functions. While similar to Back Propagation (BP) in many respects, radial basis function networks have several advantages. They usually

train much faster than back propagation networks. They are less susceptible to problems with non-stationary inputs because of the behavior of the Radial Basis Function hidden units. **Broomhead** and **Lowe** (1988), **Moody** and **Darken** (1989) were the first to exploit the use of radial basis functions in the design of neural networks.

4.1. The Structure of the RBF Networks [9]:

The Radial Basis Function Network (RBFN) comprises one of the most used network models. Figure (1) shows an RBFN with inputs $(u_1, \ldots . u_n)$and outputs $(X_1, \ldots \ldots X_M)$. The arrows in the figure symbolize parameters in the network. Radial Basis Function model consists of three layers: the input, hidden and output layers.

4.1.1 Input Layer:

First layer in RBFN is the input layer, which made up of source nodes (sensory units or neurons) which are represented by input vector (u).

4.1.2 Hidden Layer:

Second layer in RBFN is the hidden layer which is composed of nonlinear units that are connected directly to all of the nodes in the input layer and center of it represented in equation (1) by (c_i). Each hidden unit takes its input from all the nodes at the components at the input layer.

The distance between the neuron center for basis function (in hidden layer) and the input vector is calculated as:

$$d_i = \|u - c_i\| \qquad \ldots\ldots. (1)$$

Using the Euclidean distance.

The sigmoid activation functions utilizing basis functions in the hidden layer, which are locally responsive to input stimulus. These hidden nodes are usually implemented with a Gaussian Function (equation (2)).

$$h_i = G(d_i, \sigma_i) = \exp\left(-\frac{d_i^2}{2\sigma_i^2}\right) \qquad \ldots.. (2)$$

Where h is output of each hidden layer units.

4.1.3 Output Layer:

The last layer in radial basis function is the output layer. Each output node represented unique task and has it own hidden to output weights. The output of the neuron is then formed by applying the basis function to this distance. The RBFN output is formed by a weighted sum of the neuron outputs and the unity bias. The transformation from the input node to the hidden unit is nonlinear.

4.2 Training Algorithms [9]:

RBFN are used mainly in supervised applications, in which we are provided with a set of data samples (training set) for which corresponding network outputs are known. Given input, output pattern $(u^k, A^k), k = 1,2, \ldots . K$ the aim of data interpolation is to approximate the function $\boldsymbol{A}$ from which the data is generated and it can be described by:

$$J(w, c) = \sum_{k=1}^{k} \|A^k - f(u^k)\|^2 \qquad \ldots.. (3)$$

Where

$$A = \sum_{i=1}^{L} w_i\, G(\|u - c_i\|) + r(u) \qquad \ldots.. (4)$$

A : represent approximation function and $r(x)$: represent residual function.

4.2.1 Adjusting the widths:

In its simplest form, all hidden units in the RBF network have the same width or degree of sensitivity to inputs. However, in portions of the input space where there are few patterns, it is sometime desirable to have hidden units with a wide area of reception. Likewise, in portions of the input space, which are crowded, it might be desirable to have very highly tuned processors with narrow reception fields. Computing these individual widths increases the performance of the RBF network at the expense of a more complicated training process.

4.2.2 Adjusting the centers:

Remember that in a back propagation network, all weights in all of the layers are adjusted at the same time. In radial basis function networks, however, the weights into the hidden layer basis units are usually set before the second layer of weights is adjusted. As the input moves away from the connection weights, the activation value falls off. This behavior leads to the use of the term "center" for the first-layer weights. These center weights can be computed using Kohonen feature maps, statistical methods such as K-Means clustering, or some other means. In any case, they are then used to set the areas of sensitivity for the RBF network's hidden units, which then remain fixed.

4.2.3 Adjusting the weights:

Once the hidden layer weights are set, a second phase of training is used to adjust the output weights. This process typically uses the standard steepest descent algorithm. Note that the training problem becomes quadratic once if **c**i's (radial basis function centers) are known [10].

4.3 Applications [11]:

As can be seen, the RBFNs are employed mostly in classification Problems. The main classification problem involving RBFN is the pattern recognition problem. Time-series analysis is the second most common application area for RBFN. Many pattern recognition experiments show that the RBFNs are superior over other neural network approaches in:

1- Approximating nonlinear mappings effectively.

2- The training time is quite low compared to that of other neural network approaches such as the multi-layer perceptron, because training of the two layers of the network is decoupled.

3- Producing classification accuracies from 5% to 10% higher than accuracies produced by the back propagation algorithm.

4- Identifying regions of sample data not in any known class because it uses a nonmonotonic transfer function based on the Gaussian density function.

5. The proposed program

The proposed program divided into three parts:

5.1 The Power Flow Program

Load flow program by using AC power flow/The Newton-Raphson method because we are found to be more efficient particularly when based on the idea of calculating the corrections while taking account of all the interactions. The number of iterations required to obtain a solution is independent of system size, but more functional evaluations are required to each iteration [5, 12].

The output of the load flow program is values of voltage magnitude and phase angle for each Bus, active and reactive power for each transmission line. Figure (2) shows the flow chart for load flow program.

5.2 Designing of the Artificial Neural Network Structure:

In order to prepare the input data for the ANN structure a subroutine was written in Matlab language (Version 6.5) to arrange the data in order to suite the structure of the ANN as shown in Figure (3).

In the process of training the Neural Network (***input for neural network is outputmatrix from load flow program and output target for it is ones matrix (+ ve sign for diagonal element and – ve for other element, see equation*** (5)).

$$T = \begin{bmatrix} 1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{bmatrix} \quad \text{..... (5)}$$

Where T: Target matrix for RBFN.

The corresponding outputs generated by the Neural Network are compared with target outputs. The difference of the training error from that pattern is used as the basis for a system that modified the network weights. The weights are modified to RBFN rule, which is expected over the course of training, to minimize the difference between the actual outputs of the network and the designed outputs that are coded in the criterion section of the patterns. When the training finished, the program will have the ability to discover the position of the faulty element during the abnormal conditions in the power system. Figure (4) shows the flow chart of RBFN structure.

5.3 Designing of the Visualization Program:

The visualization map program is a uniform set of programs of digital information stored in the computer and has the ability to be displayed on the screen of computer by using Matlab language. This program contains three parts:

5.3.1 Mapping Program:

This part of the visualized program is consisted of three steps; the first step is the loading of the program picture which represents the system or the background map the network. The second step for this program is drawing of the networks lines and buses with different colors (blue for transmission lines and black for bus at normal conditions). This process, done by writing manually commands, which represents the number of bus bars and the number of lines. These commands which consists information about power system under consideration, include coordinate of bus bar and lines (which are taken from original map and represents the geographic information for the system by using the

command ***([x, y] =ginput (no. of point we want to know position of bus)***

The third step of the program displays the information of any bus or transmission line in the output file of the load flow to the operator for normal and abnormal conditions after each click on the map. The flow chart of the mapping program is shown in Figure (5).

At abnormal conditions (separation of one unit in the bus or transmission line), the number of Neural Network will match the number of the separated elements, then the color of this element will change (red line for transmission line outage and green for unit outage).

5.3.2 Bus Program:

This part represent the connection between the bus output file of load flow program and the visualization program, depending on the Neural Network program .The key word between the two program is the number of bus and the number of outages. So the information of any bus (voltage magnitude and phase angle) will appear to the operator after the clicking on any bus. Figure (6) shows the flow chart of the bus program.

5.3.3 Transmission Line Program:

This part represents the connection between the transmission output file of the load flow program and the visualization program, depending on the Neural Network program. The key word between the two programs is the number of transmission line and the number of outages. The information of any transmission line (Active and Reactive power) will appear to the operator after the clicking on any transmission line. Figure (7) shows the flow chart of the transmission line program.

6.Iraqi Super Grid Network (400Kv):

In this research, the system under consideration is the Iraqi Super Network which comprises 23 bus, 37 transmission lines (T.L) and ten generating stations with different capacities of generation. Figure (8) shows a configuration of this network.

6.1. The Application of the Proposed Program on Iraqi Super Grid Network: The network under consideration (Iraqi Super Grid Network (400Kv)) was studied and analyzed by using the proposed algorithm. After saving output data (voltage magnitude and phase angle for each bus) (see table (2)) in matrix (output matrix). This data was reloaded from RBFN program, then the RBFN trained to save the weights for hidden and output layers to become ready for comparing with the output data of the station (in the load flow file) to describe the abnormal conditions. Figure (9) shows the training of RBFN on Iraqi Super Grid Network.

The first step in building visualize program for Iraqi Super Grid Network is the loading of the map which has the positions for each station in the grid network, see Figure (10). Then by using command (**ginput**) in Matlab language, the coordinates of each station on the map was found and these

values were substituted (station point in visualization program) to draw the lines between these points. See Figures (11) and (12).

All transmission lines were separated respectively. Table (2) shows the results of Line (3-4) separation. Figure (13) shows the separation of (BAJP-BAJG) transmission lines and Figures (14), (15) show the information for bus (BGN4) and the information for transmission (BGS4-BGE4) after clicking on the map.

The second step of the study was the outages of a generating unit in the generating station. At each step, a unit was separated from the generating bus. Figure (16) shows the separation of a unit of (MMDH) station and Figures (17), (18) show the information for bus (BGN4) and the information for transmission (BGS4-BGE4) after clicking on map after the contingency happened.

6.2 Discussion

After the application of the proposed program on Iraqi Super Grid Network, and from the obtained results it was very clear that:

1- the obtained results after each separation of transmission line in Iraqi Super Grid Network show the change in voltage magnitude and phase angle for buses which transmission line located between them and all buses nearest to this transmission line, and There has been no over load in all transmission lines in the network during each separation of the transmission lines (active and reactive power). This gives the idea that the network under consideration has a good configuration except the west area of Iraq (HDTH-Q'IM); this area has a poor connection to the network (radial connection). So the separation of this transmission line caused the divergence of the program, therefore this part of network was connected with the 132 Kv network by a transmission line which is already exist to solve this problem. The parameter of this transmission line is shown in Table (3).after the separation of transmission line (HDTH-QIM), we note that there is a large dropping in voltage magnitude for bus (QIM), because of the separation of this line from the system led to reduction of the reactive power for this line to zero.

Also after analyzing the network during these separations, it was found that the voltage levels of some buses ((AMR4), (HRTP) and (KAZG)) were violated, due to the changes of their active power producing change in phase angle of these buses.

2-During the separation of the generating units, the obtained results show that there is no change in voltage magnitude and phase angle for all buses in the network under consideration.

7. Conclusions The Proposed program is applied on the Iraqi Super Grid Network, and from the obtained results, one can realize that the change in voltage magnitude and phase angle for buses which transmission line separated is located between them and

all buses nearest to this transmission line because the change in active and reactive power in the network, the separation of the generating unit cause the change in phase angle for its bus because the relation between the phase angle and active power, and this network has a good configuration except the west region; this region has a poor connection to network (one transmission line between HDTH-QIM stations).

The proposed program has the ability to sense any change in the electrical network dependence upon the change in voltage magnitude and phase angle for each bus, run the power flow program, assigns the position of the fault and displays the results on the screen automatically. The proposed technique is found very affective for the monitoring the electric network; since it develops a new technique for assigning the fault position in the electrical network by using the facilities of the Neural Network.

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Table (1) The Generating Units for Iraqi Super Grid Network at 30/6/2008[13].

Bus Name	No.Of Gen Units	The Max Gen Power(MW)	The Total Power (MW)
BAJP	3	220	660
HDTH	3	110	330
MUSP	4	300	1200
NSRP	4	210	840
HRTP	2	200	400
MMDH	2	193	386
KRK4	2	1*260 1*56	316
QDSG	6	3*73 3*43	348
BAJG	4	159	636
KAZG	6	4*68 2*125	522

Table (2) The Voltage Magnitude and Phase Angle for each Bus in Iraqi Super Grid Network Which are calculated from Load Flow Program.

Bus Name	Line 3-4outage 10 iterations		Outage unit in MMDH(123MW) 10 iterations	
	|V|	δ	|V|	δ
MSL4	0.99866	-1.0031	0.9986	-1.0031
MMDH	1	0.22854	1	0.22854
BAJP	1.02	0	1.02	0
BAJG	1.05	2.6402	1.03	0.047029
KRK4	1.04	1.5349	1.03	0.9155
BGW4	1.057	-3.2171	1.0557	-5.1742
BGS4	1.0637	-3.5335	1.0634	-6.0992
BGE4	1.0607	-3.6697	1.0602	-6.4131
BGN4	1.0648	-3.6002	1.0646	-6.1303
QDSG	1.068	-3.5285	1.068	-6.0428
AMN4	1.0593	-3.6935	1.0589	-6.3764
BGC4	1.0595	-3.6063	1.0585	-5.8061
DAL4	1.0571	-2.9053	1.0553	-6.5129
KUT4	1.0704	-3.4443	1.0702	-6.1021
HDTH	1.05	0.76437	1.04	-0.07246
MUSP	1.066	-3.0601	1.066	-5.6577
BAB4	1.0664	-3.5055	1.0664	-6.1076
KDS4	1.0662	-4.046	1.0661	-6.6603
NSRP	1.05	-1.5576	1.05	-4.3248
AMR4	1.0672	-2.1022	1.0672	-4.9042
HRTP	1.04	-0.2318	1.04	-3.1995
KAZG	1.04	-0.3714	1.04	-3.3279
QIM4	1.0517	0.52403	1.0415	-0.31281

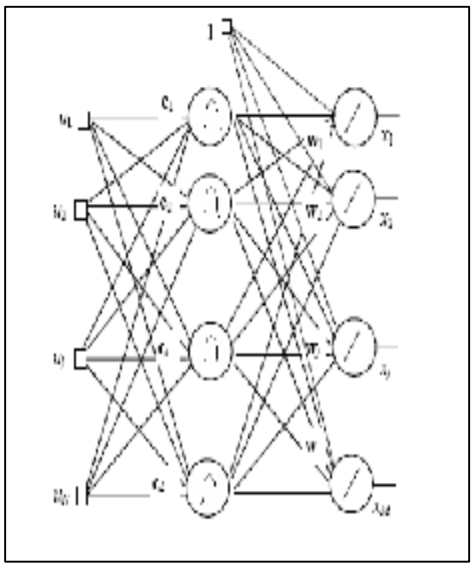

Figure (1) Structure of Radial Basis Function [11]

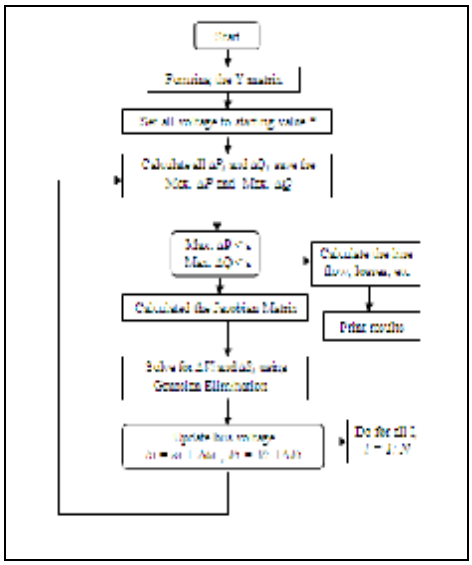

Figure (2) Flow Chart for Newton-Raphson Method

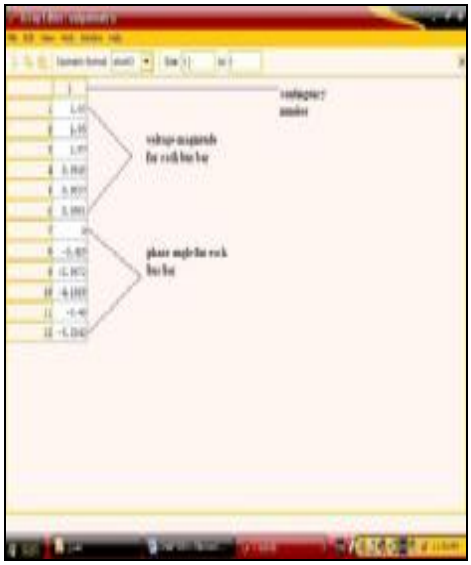

Figure (3) the Output Matrix for Contingency Analysis Program

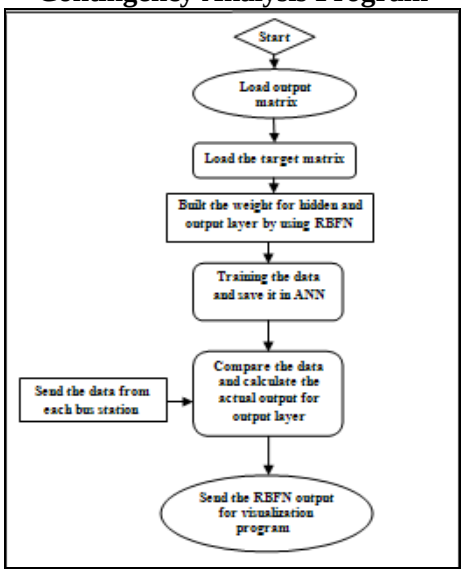

Figure (4) Flow Chart of the RBFN Program.

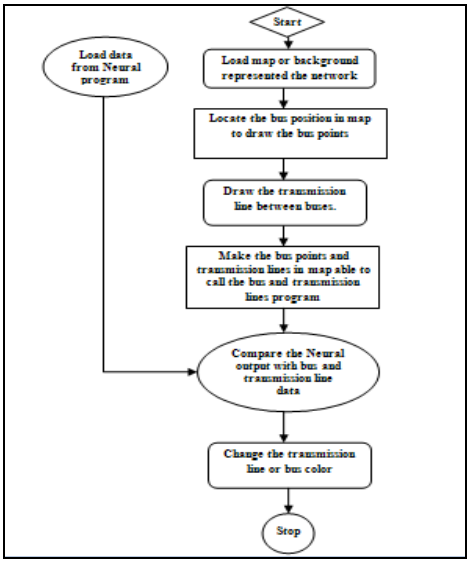

Figure (5) Mapping Program Flow Chart.

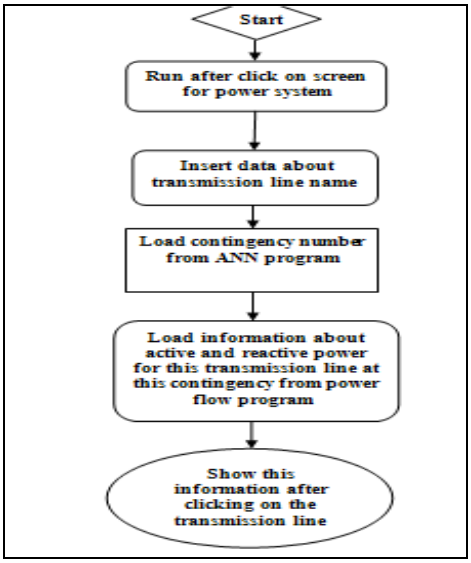

Figure (7) Flow Chart for Transmission Line Program.

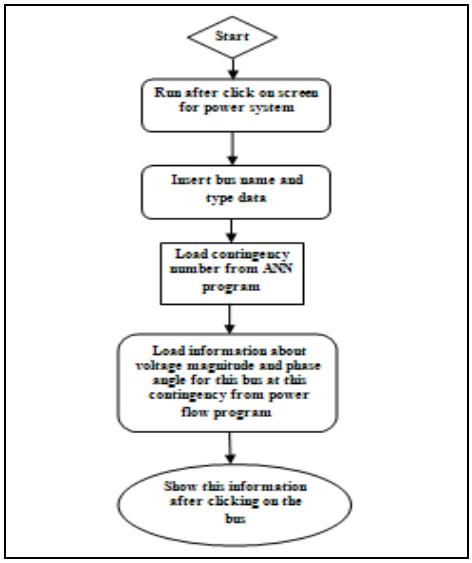

Figure (6) Flow Chart for Bus Program.

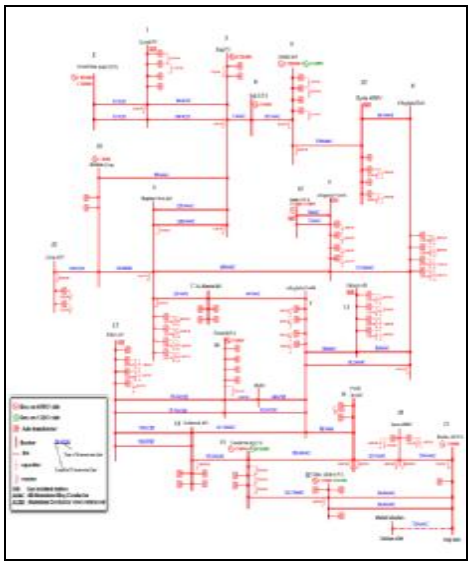

Figure (8) the Iraqi Super Grid (400Kv) [13].

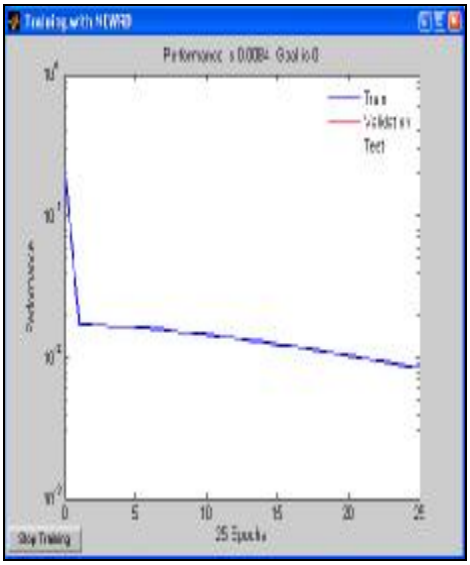

Figure (9) Training of RBFN for Iraqi Super Grid Network.

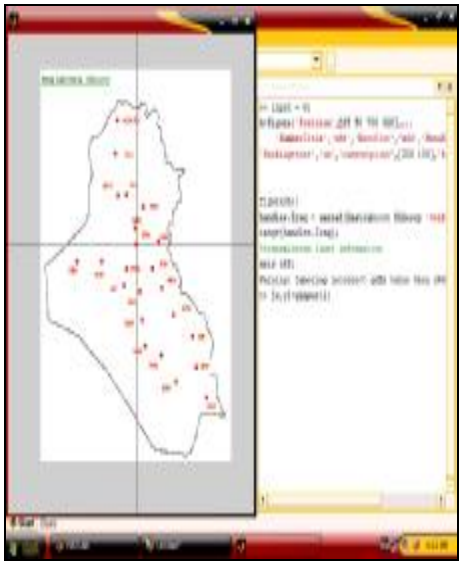

Figure (11) The Calculation of Stations Coordinate.

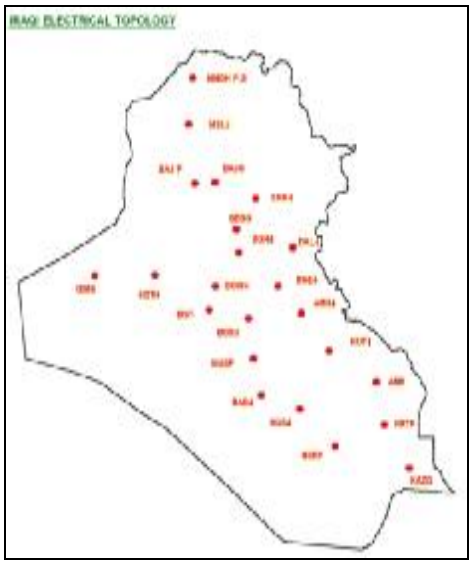

Figure (10) The Map of Iraqi Super Grid Network with The Position of The Station [13].

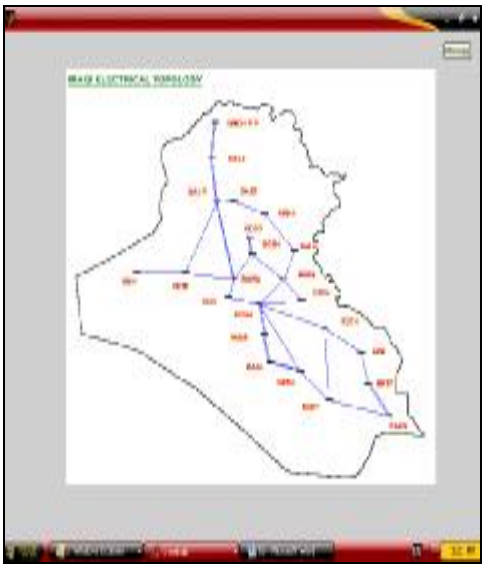

Figure (12) the Iraqi Super Grid Network after Running the Visualization Program

Figure (13) The Transmission Lines (BAJP-BAJG) Outage (The Red line).

Figure (15) The Information of (BGS4-BGE4) After the Separation of (BAJP-BAJG).

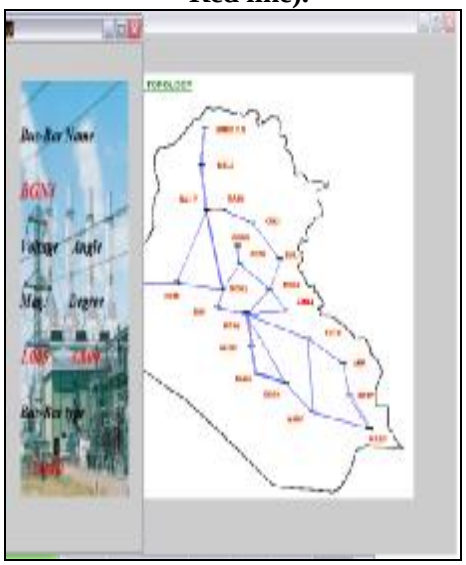

Figure (14) BGN4's Information after the Separation of (BAJP-BAJG).

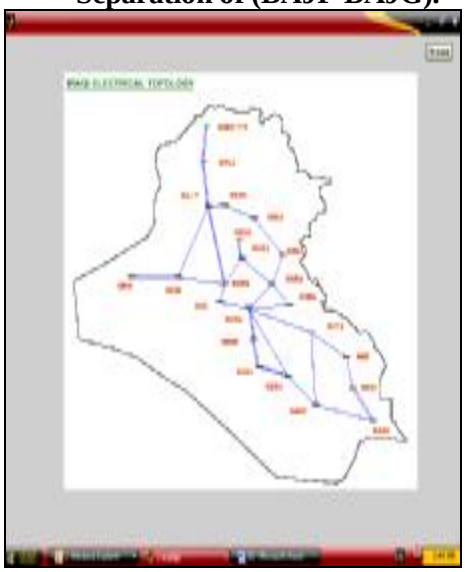

Figure (16) The Separation of One Unit in MMDH Station (Green Line).

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Figure (17) BGN4's Information after the Separation of One Unit in MMDH Station.

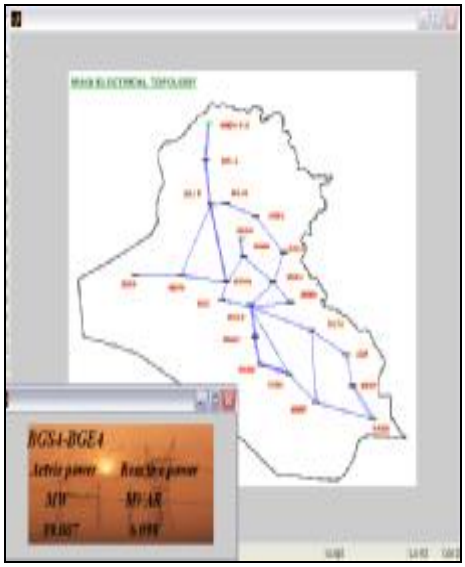

Figure (18) The Information of (BGS4-BGE4) After Separation of One Unit in MMDH Station