**CHAPTER FIVE**

**EXPERIMENTAL RESULTS AND DISCUSSION**

* 1. **Overview**

This chapter presents the training and the testing results of the artificial neural network for identification the static security assessment. At the end of the training and testing process, the voltage magnitudes per unit, power system's operating statuses, values of the thermal lines and the errors between ANN and NR method will be calculated at each case. In addition, the percentages of classification accuracy (CA) for every case in the training and testing process.

* 1. **Experimental Setup**

 IEEE 9-Bus System was implemented by Newton-Raphson method using Power World Simulator’s program version 12. Training and testing the specified artificial neural network was performed by using the following characteristics as:

Processor: Intel (R) Core (TM) i3 CPU.

Installed memory (RAM): 3GB

System Type: Window 7 with 32-bit Operating system

MATLAB software tool version (R2011a)

* 1. **Training the Artificial Neural Network by using MATLAB**

 The generated database by the Newton-Raphson method using Power World Simulator’s program are used in the training process. Enter the inputs (the active and reactive powers of the first nine cases) and the outputs (the voltage magnitudes and the thermal limits of the first nine cases) to the artificial neural network by using MATLAB’s program.

an appropriate values of the momentum factor (α), the learning rate coefficient size (η), the desired Mean Square Error, number of iteration (epochs), transfer function and a number of the hidden layers are selected. In addition, the numbers of neurons in every hidden layer are selected as shown below in table 5.1.

Table 5.1: Values for Training Parameters

|  |  |
| --- | --- |
| Desired Mean Square Error | 0.000001 |
| Learning Rate (η) | 0.04 |
| Momentum Factor (α) | 0.3 |
| Maximum Iteration (Epochs)  | 300000 |
| Type of the transfer function  | Sigmoid function  |
| Number of Hidden Layers  | 4 |
| Number of Neurons at the first Hidden Layer | 30 |
| Number of Neurons at the second Hidden Layer | 100 |
| Number of Neurons at the third Hidden Layer | 30 |
| Number of Neurons at the fourth Hidden Layer | 50 |

These training parameters were selected because they produced the best mean square error and the best results. Four hidden layers have been selected with their neurons in each hidden layer according to the characteristics of data base and the degree of their complexity where these layers with their neurons provided the best predicted results.

* 1. **Results of the Training and the Discussions**

At the end of the training process, the training performance of the artificial neural network was calculated as shown in figure 5.1. In addition, the rest of the parameters were determined as shown below in table 5.2.

Table 5.2: Results of training

|  |  |
| --- | --- |
| Best Mean Square Error | 2.8 \* 10 -6 at epoch 300000 |
| Number of Input Neurons  | 24 |
| Number of Output Neurons | 15 |
| Learning Rate | 1.0484 at epoch 300000 |
| Number of Iteration to get Best Mean Square Error | 300000 |

The Mean Square Error (MSE) performance for these layers and the neurones is for the training process is shown below in figure 5.1.



Figure 5.1: Training performance of the neural network.

The best Mean Square Error (MSE) at epoch 300000 is 2.8 \* 10 -6 which is satisfactorily small. This reflects the correct choice of the training parameters for providing a good security to forecast the power system's operating statuses.

The estimation of the training results (the voltage magnitudes and the thermal lines) and the operating statuses (normal state, alert state, emergency state and extreme emergency state) were determined. In addition, the errors between the estimated training results and Newton-Raphson technique were calculated in terms of accuracy as shown below in the tables.

Power system's operating statuses is considered as a normal state “NS” when the voltage magnitude limit is (0.91 < |V| < 1.0) and the thermal line limit is (< 80%).

 The voltage magnitude limit consider as an alert state “AS” when the voltage magnitude limit is (1.0 ≤ |V| < 1.1 or 0.85 < |V|≤ 0.91) and the thermal line limit is (80% - 99%).

The voltage magnitude limit consider as an emergency state “AS” when the voltage magnitude limit is (1.1 ≤ |V| < 1.15 or 0.80 ≤ |V|≤ 0.85) and the thermal line limit is (100% - 109%).

The voltage magnitude limit consider as an extreme emergency state “EES” when the voltage magnitude limit is (1.15 ≤ |V| < 1.2 or 0.8 >|V|) and the thermal line limit is (>110%).

Table 5.3.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case1)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Load at Bus 5** |  **Load at Bus 7** | **Load at Bus 9** | **Thermal line (1- 4)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (2- 8)**  | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.3505252 | -0.0005252 | 'NS' | 0.5500251 | -2.51E-05 | 'NS' |
| 98 | 108 | 133 | 0.3297847 | 0.0002153 | 'NS' | 0.549593 | 0.000407 | 'NS' |
| 96 | 106 | 131 | 0.3094563 | 0.0005437 | 'NS' | 0.5497093 | 0.0002907 | 'NS' |
| 94 | 104 | 129 | 0.2899338 | 6.62E-05 | 'NS' | 0.5497764 | 0.0002236 | 'NS' |
| 92 | 102 | 127 | 0.2707077 | -0.0007077 | 'NS' | 0.5502329 | -0.0002329 | 'NS' |
| 90 | 100 | 125 | 0.2517225 | -0.0017225 | 'NS' | 0.5500514 | -5.14E-05 | 'NS' |
| 88 | 98 | 123 | 0.2334405 | -0.0034405 | 'NS' | 0.5500977 | -9.77E-05 | 'NS' |
| 86 | 96 | 121 | 0.2154724 | 0.0045276 | 'NS' | 0.5500863 | -8.63E-05 | 'NS' |
| 84 | 94 | 119 | 0.1973909 | 0.0026091 | 'NS' | 0.5494854 | 0.0005146 | 'NS' |
| 82 | 92 | 117 | 0.1801468 | -0.0001468 | 'NS' | 0.5495965 | 0.0004035 | 'NS' |
| 80 | 90 | 115 | 0.1624721 | -0.0024721 | 'NS' | 0.550171 | -0.000171 | 'NS' |
| **Load at Bus 5** | **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (3- 6)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (4-5)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.2806102 | -0.0006102 | 'NS' | 0.3105016 | -0.0005016 | 'NS' |
| 98 | 108 | 133 | 0.2798584 | 0.0001416 | 'NS' | 0.2935128 | -0.0035128 | 'NS' |
| 96 | 106 | 131 | 0.2793308 | 0.0006692 | 'NS' | 0.276429 | 0.003571 | 'NS' |
| 94 | 104 | 129 | 0.2792728 | 0.0007272 | 'NS' | 0.2592222 | 0.0007778 | 'NS' |
| 92 | 102 | 127 | 0.2795147 | 0.0004853 | 'NS' | 0.2422159 | -0.0022159 | 'NS' |
| 90 | 100 | 125 | 0.2792484 | 0.0007516 | 'NS' | 0.2254147 | -0.0054147 | 'NS' |
| 88 | 98 | 123 | 0.2800275 | -2.75E-05 | 'NS' | 0.2087196 | 0.0012804 | 'NS' |
| 86 | 96 | 121 | 0.2807281 | -0.0007281 | 'NS' | 0.193162 | -0.003162 | 'NS' |
| 84 | 94 | 119 | 0.2817693 | -0.0017693 | 'NS' | 0.1769675 | 0.0030325 | 'NS' |
| 82 | 92 | 117 | 0.2836639 | -0.0036639 | 'NS' | 0.1615521 | -0.0015521 | 'NS' |
| 80 | 90 | 115 | 0.2857252 | 0.0042748 | 'NS' | 0.1481931 | 0.0018069 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (5- 6)**  | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (6- 7)**  | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.3896416 | 0.0003584 | 'NS' | 0.2496347 | 0.0003653 | 'NS' |
| 98 | 108 | 133 | 0.3944245 | -0.0044245 | 'NS' | 0.243446 | -0.003446 | 'NS' |
| 96 | 106 | 131 | 0.3987104 | 0.0012896 | 'NS' | 0.238091 | 0.001909 | 'NS' |
| 94 | 104 | 129 | 0.4046497 | -0.0046497 | 'NS' | 0.2332339 | -0.0032339 | 'NS' |
| 92 | 102 | 127 | 0.4097727 | 0.0002273 | 'NS' | 0.2290503 | 0.0009497 | 'NS' |
| 90 | 100 | 125 | 0.4150258 | -0.0050258 | 'NS' | 0.2245268 | 0.0054732 | 'NS' |
| 88 | 98 | 123 | 0.4214957 | -0.0014957 | 'NS' | 0.2205718 | -0.0005718 | 'NS' |
| 86 | 96 | 121 | 0.4262347 | 0.0037653 | 'NS' | 0.2172677 | 0.0027323 | 'NS' |
| 84 | 94 | 119 | 0.4321513 | -0.0021513 | 'NS' | 0.2135697 | -0.0035697 | 'NS' |
| 82 | 92 | 117 | 0.4387307 | 0.0012693 | 'NS' | 0.2103366 | -0.0003366 | 'NS' |
| 80 | 90 | 115 | 0.4417904 | -0.0017904 | 'NS' | 0.2078859 | 0.0021141 | 'NS' |
|  **Load at Bus 5** | **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (7- 8)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (8- 9)**  | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.5487771 | 0.0012229 | 'NS' | 0.5421103 | -0.0021103 | 'NS' |
| 98 | 108 | 133 | 0.5402988 | -0.0002988 | 'NS' | 0.5487568 | 0.0012432 | 'NS' |
| 96 | 106 | 131 | 0.5332185 | -0.0032185 | 'NS' | 0.5552163 | 0.0047837 | 'NS' |
| 94 | 104 | 129 | 0.5250694 | 0.0049306 | 'NS' | 0.5623683 | -0.0023683 | 'NS' |
| 92 | 102 | 127 | 0.518265 | 0.001735 | 'NS' | 0.5693174 | 0.0006826 | 'NS' |
| 90 | 100 | 125 | 0.5115806 | -0.0015806 | 'NS' | 0.5766744 | 0.0033256 | 'NS' |
| 88 | 98 | 123 | 0.5029461 | -0.0029461 | 'NS' | 0.5840972 | -0.0040972 | 'NS' |
| 86 | 96 | 121 | 0.4958435 | 0.0041565 | 'NS' | 0.5910653 | -0.0010653 | 'NS' |
| 84 | 94 | 119 | 0.4891612 | 0.0008388 | 'NS' | 0.5983824 | 0.0016176 | 'NS' |
| 82 | 92 | 117 | 0.4826969 | -0.0026969 | 'NS' | 0.6057817 | 0.0042183 | 'NS' |
| 80 | 90 | 115 | 0.4773375 | 0.0026625 | 'NS' | 0.6132913 | -0.0032913 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (4- 9)**  | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.4396952 | 0.0003048 | 'NS' |
| 98 | 108 | 133 | 0.4230675 | -0.0030675 | 'NS' |
| 96 | 106 | 131 | 0.4084687 | 0.0015313 | 'NS' |
| 94 | 104 | 129 | 0.3923028 | -0.0023028 | 'NS' |
| 92 | 102 | 127 | 0.3787964 | 0.0012036 | 'NS' |
| 90 | 100 | 125 | 0.3636223 | -0.0036223 | 'NS' |
| 88 | 98 | 123 | 0.3497343 | 0.0002657 | 'NS' |
| 86 | 96 | 121 | 0.3369494 | 0.0030506 | 'NS' |
| 84 | 94 | 119 | 0.3233204 | -0.0033204 | 'NS' |
| 82 | 92 | 117 | 0.3110103 | -0.0010103 | 'NS' |
| 80 | 90 | 115 | 0.2978378 | 0.0021622 | 'NS' |

Table 5.3.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case1)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Load at Bus 5** |  **Load at Bus 7** | **Load at Bus 9** | **| V4 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V5 | (P.U.)**  | **Errors between ANN and NR** | **Statuses of the Buses** |
| 100 | 110 | 135 | 0.9869775 | 2.25E-05 | 'NS' | 0.9745836 | -0.0005836 | 'NS' |
| 98 | 108 | 133 | 0.9872057 | -0.0002057 | 'NS' | 0.9752385 | -0.0012385 | 'NS' |
| 96 | 106 | 131 | 0.987392 | -0.000392 | 'NS' | 0.9757531 | -0.0007531 | 'NS' |
| 94 | 104 | 129 | 0.9875611 | -0.0005611 | 'NS' | 0.9761304 | -0.0011304 | 'NS' |
| 92 | 102 | 127 | 0.9876278 | -0.0006278 | 'NS' | 0.9763179 | -0.0013179 | 'NS' |
| 90 | 100 | 125 | 0.9877945 | -0.0007945 | 'NS' | 0.9763857 | -0.0013857 | 'NS' |
| 88 | 98 | 123 | 0.9877661 | -0.0007661 | 'NS' | 0.9762731 | -0.0002731 | 'NS' |
| 86 | 96 | 121 | 0.9876903 | -0.0006903 | 'NS' | 0.9759055 | 9.45E-05 | 'NS' |
| 84 | 94 | 119 | 0.987533 | -0.000533 | 'NS' | 0.9752826 | 0.0007174 | 'NS' |
| 82 | 92 | 117 | 0.9872132 | -0.0002132 | 'NS' | 0.9745095 | 0.0014905 | 'NS' |
| 80 | 90 | 115 | 0.9868238 | 0.0001762 | 'NS' | 0.9734658 | 0.0025342 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **| V6 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V7 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 100 | 110 | 135 | 1.0012827 | 0.0017173 | 'AS' | 0.9827505 | 0.0002495 | 'NS' |
| 98 | 108 | 133 | 1.0015874 | 0.0014126 | 'AS' | 0.9834817 | -0.000482 | 'NS' |
| 96 | 106 | 131 | 1.0018991 | 0.0011009 | 'AS' | 0.9841398 | -0.0001398 | 'NS' |
| 94 | 104 | 129 | 1.0022273 | 0.0007727 | 'AS' | 0.9846216 | -0.0006216 | 'NS' |
| 92 | 102 | 127 | 1.0025375 | 0.0014625 | 'AS' | 0.9849638 | -0.0009638 | 'NS' |
| 90 | 100 | 125 | 1.0028355 | 0.0011645 | 'AS' | 0.9852257 | -0.0002257 | 'NS' |
| 88 | 98 | 123 | 1.0031551 | 8.45E-04 | 'AS' | 0.9851921 | -0.000192 | 'NS' |
| 86 | 96 | 121 | 1.0033922 | 0.0006078 | 'AS' | 0.9850859 | -8.59E-05 | 'NS' |
| 84 | 94 | 119 | 1.0035837 | 0.0004163 | 'AS' | 0.9848121 | 0.0011879 | 'NS' |
| 82 | 92 | 117 | 1.0037682 | 0.0002318 | 'AS' | 0.9842412 | 0.0017588 | 'NS' |
| 80 | 90 | 115 | 1.0037889 | 0.0002111 | 'AS' | 0.9836485 | 0.0023515 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** | **Load at Bus 9** | **| V8 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V9 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 100 | 110 | 135 | 0.9973498 | -0.0023498 | 'NS' | 0.9551582 | 0.0018418 | 'NS' |
| 98 | 108 | 133 | 0.9972926 | -0.0022926 | 'NS' | 0.9560716 | 0.0009284 | 'NS' |
| 96 | 106 | 131 | 0.9971479 | -0.0021479 | 'NS' | 0.9567135 | 0.0002865 | 'NS' |
| 94 | 104 | 129 | 0.9968984 | -0.0008984 | 'NS' | 0.9572819 | -0.0002819 | 'NS' |
| 92 | 102 | 127 | 0.9966152 | -0.0006152 | 'NS' | 0.9576201 | -0.0006201 | 'NS' |
| 90 | 100 | 125 | 0.9963055 | -0.0003055 | 'NS' | 0.9581794 | -0.0011794 | 'NS' |
| 88 | 98 | 123 | 0.995893 | 0.000107 | 'NS' | 0.9582057 | -0.0002057 | 'NS' |
| 86 | 96 | 121 | 0.995546 | 0.000454 | 'NS' | 0.9582731 | -0.0002731 | 'NS' |
| 84 | 94 | 119 | 0.9952425 | 0.0007575 | 'NS' | 0.9583923 | -0.0003923 | 'NS' |
| 82 | 92 | 117 | 0.9948755 | 0.0011245 | 'NS' | 0.9580517 | -5.17E-05 | 'NS' |
| 80 | 90 | 115 | 0.9946702 | 0.0013298 | 'NS' | 0.9580461 | -4.61E-05 | 'NS' |

From the tables 5.3.1 and 5.3.2, the values of the thermal lines, voltage magnitudes per unit, power system's operating statuses and the errors between ANN and NR method were determined.

The performance of the feed forward back propagation neural network will be calculated by the classification accuracy (CA) using the error between ANN and NR method. The percentage of classification accuracy (CA) is determined by using equation (5.1).

$Classification accuracy \left(\%\right)=\frac{NO. of samples classified correctly}{total number of samples in each case}\*100$ (5.1)

If the errors for the values of the thermal lines per unit < 0.019 (selected threshold) and the errors for the values of the voltage magnitudes < 0.019 (selected threshold), then the value of the thermal line and the voltage magnitude per unit is correctly predicted.

If the errors for the values of the thermal lines per unit > 0.019 and the errors for the values of the voltage magnitudes > 0.019, then the value of the thermal line and the voltage magnitude per unit is not predicted. These values of the thresholds were selected according to the limits of the statues (normal state, alert state, emergency state and extreme emergency state) for IEEE-9 bus system.

Classification accuracy for case1 at training stage (%) = (165 / 165) \* 100 = 100 %.

Table 5.3.3: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case4 (outage the line (4-5)))

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (1- 4)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (2- 8)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.3592865 | 7.13E-04 | 'NS' | 0.5486795 | 1.32E-03 | 'NS' |
| 98 | 108 | 133 | 0.3409765 | -0.0009765 | 'NS' | 0.5507969 | -0.0007969 | 'NS' |
| 96 | 106 | 131 | 0.321347 | -1.35E-03 | 'NS' | 0.5514868 | -1.49E-03 | 'NS' |
| 94 | 104 | 129 | 0.3005038 | -5.04E-04 | 'NS' | 0.5510634 | -1.06E-03 | 'NS' |
| 92 | 102 | 127 | 0.2799744 | 2.56E-05 | 'NS' | 0.5496012 | 0.0003988 | 'NS' |
| 90 | 100 | 125 | 0.2596425 | 0.0003575 | 'NS' | 0.5487958 | 1.20E-03 | 'NS' |
| 88 | 98 | 123 | 0.2388961 | 0.0011039 | 'NS' | 5.48E-01 | 1.97E-03 | 'NS' |
| 86 | 96 | 121 | 0.2195005 | 0.0004995 | 'NS' | 0.5492389 | 7.61E-04 | 'NS' |
| 84 | 94 | 119 | 0.2011487 | -0.0011487 | 'NS' | 0.5518257 | -1.83E-03 | 'NS' |
| 82 | 92 | 117 | 0.1824728 | -0.0024728 | 'NS' | 0.5567058 | -0.0067058 | 'NS' |
| 80 | 90 | 115 | 0.161803 | -0.001803 | 'NS' | 0.5647418 | -1.47E-02 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (3- 6)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (4- 5)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.3009903 | -0.0009903 | 'NS' | -6.65E-05 | 6.65E-05 | 'NS' |
| 98 | 108 | 133 | 2.99E-01 | 5.44E-04 | 'NS' | 0.0001189 | -0.0001189 | 'NS' |
| 96 | 106 | 131 | 0.2977719 | 0.0022281 | 'NS' | -7.88E-05 | 7.88E-05 | 'NS' |
| 94 | 104 | 129 | 0.2962817 | 0.0037183 | 'NS' | 3.22E-05 | -3.22E-05 | 'NS' |
| 92 | 102 | 127 | 0.2938819 | -0.0038819 | 'NS' | -0.0010265 | 1.03E-03 | 'NS' |
| 90 | 100 | 125 | 0.2920867 | -0.0020867 | 'NS' | -0.0022136 | 0.0022136 | 'NS' |
| 88 | 98 | 123 | 0.2907484 | -7.48E-04 | 'NS' | -0.0011351 | 1.14E-03 | 'NS' |
| 86 | 96 | 121 | 0.2900926 | -9.26E-05 | 'NS' | -0.0004966 | 4.97E-04 | 'NS' |
| 84 | 94 | 119 | 0.2890221 | 0.0009779 | 'NS' | 0.0005908 | -0.0005908 | 'NS' |
| 82 | 92 | 117 | 0.28848 | 1.52E-03 | 'NS' | 0.0033136 | -3.31E-03 | 'NS' |
| 80 | 90 | 115 | 0.291331 | -0.001331 | 'NS' | 0.0213757 | -0.0213757 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (5- 6)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (6- 7)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.712126 | -0.002126 | 'NS' | 0.2094224 | 5.78E-04 | 'NS' |
| 98 | 108 | 133 | 0.6980984 | 0.0019016 | 'NS' | 0.199893 | 1.07E-04 | 'NS' |
| 96 | 106 | 131 | 0.6835434 | -0.0035434 | 'NS' | 0.1897675 | 0.0002325 | 'NS' |
| 94 | 104 | 129 | 0.6685391 | 0.0014609 | 'NS' | 0.1807081 | -7.08E-04 | 'NS' |
| 92 | 102 | 127 | 0.6531885 | -0.0031885 | 'NS' | 0.1708503 | -0.0008503 | 'NS' |
| 90 | 100 | 125 | 0.6386848 | -8.68E-03 | 'NS' | 0.1621184 | -0.0021184 | 'NS' |
| 88 | 98 | 123 | 0.6223251 | -0.002325 | 'NS' | 0.1574355 | 0.0025645 | 'NS' |
| 86 | 96 | 121 | 0.6075287 | 0.0024713 | 'NS' | 0.1530995 | -0.0030995 | 'NS' |
| 84 | 94 | 119 | 0.5915998 | -0.0015998 | 'NS' | 0.1484835 | 1.52E-03 | 'NS' |
| 82 | 92 | 117 | 0.5737565 | 0.0062435 | 'NS' | 0.1448143 | -4.81E-03 | 'NS' |
| 80 | 90 | 115 | 0.5440236 | 0.0259764 | 'NS' | 0.1535037 | -1.35E-02 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (7- 8)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (8- 9)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.8914926 | -0.0014926 | 'AS' | 0.2697485 | 0.0002515 | 'NS' |
| 98 | 108 | 133 | 0.8549386 | 0.0050614 | 'AS' | 0.2904657 | -0.0004657 | 'NS' |
| 96 | 106 | 131 | 0.8216877 | 0.0083123 | 'AS' | 0.3106417 | -0.0006417 | 'NS' |
| 94 | 104 | 129 | 0.7907562 | -0.0007562 | 'NS' | 0.3305621 | -0.0005621 | 'NS' |
| 92 | 102 | 127 | 0.7621597 | -0.0021597 | 'NS' | 0.3521873 | -0.0021873 | 'NS' |
| 90 | 100 | 125 | 0.7347299 | 0.0052701 | 'NS' | 0.3737691 | -0.0037691 | 'NS' |
| 88 | 98 | 123 | 0.7068758 | 0.0031242 | 'NS' | 0.397006 | 0.002994 | 'NS' |
| 86 | 96 | 121 | 0.678922 | 0.001078 | 'NS' | 0.4194575 | 0.0005425 | 'NS' |
| 84 | 94 | 119 | 0.6503932 | -0.0003932 | 'NS' | 0.4422903 | -2.29E-03 | 'NS' |
| 82 | 92 | 117 | 0.6220012 | -0.0020012 | 'NS' | 0.4647114 | 0.0052886 | 'NS' |
| 80 | 90 | 115 | 0.5746541 | 0.0153459 | 'NS' | 0.4839839 | 0.0160161 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (4- 9)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 100 | 110 | 135 | 0.7091267 | 0.0008733 | 'NS' |
| 98 | 108 | 133 | 0.6709519 | -0.0009519 | 'NS' |
| 96 | 106 | 131 | 0.6337167 | -0.0037167 | 'NS' |
| 94 | 104 | 129 | 0.5978009 | 0.0021991 | 'NS' |
| 92 | 102 | 127 | 0.5614629 | -0.0014629 | 'NS' |
| 90 | 100 | 125 | 0.5266275 | -0.0066275 | 'NS' |
| 88 | 98 | 123 | 0.4915749 | -0.0015749 | 'NS' |
| 86 | 96 | 121 | 0.4566653 | 0.0033347 | 'NS' |
| 84 | 94 | 119 | 0.4209778 | -0.0009778 | 'NS' |
| 82 | 92 | 117 | 0.3837537 | 0.0062463 | 'NS' |
| 80 | 90 | 115 | 0.3424019 | 0.0175981 | 'NS' |

Table 5.3.4: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case4 (outage the line (4-5)))

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **| V4 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V5 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 100 | 110 | 135 | 0.9867206 | 1.28E-03 | 'NS' | 0.8945238 | -2.52E-03 | 'AS' |
| 98 | 108 | 133 | 0.9875292 | 0.0004708 | 'NS' | 0.8961605 | -0.0011605 | 'AS' |
| 96 | 106 | 131 | 0.9881582 | -1.58E-04 | 'NS' | 0.8979594 | 1.04E-03 | 'AS' |
| 94 | 104 | 129 | 0.9885709 | 4.29E-04 | 'NS' | 0.9000085 | 1.99E-03 | 'AS' |
| 92 | 102 | 127 | 0.9890795 | -7.95E-05 | 'NS' | 0.9026991 | 0.0023009 | 'AS' |
| 90 | 100 | 125 | 0.9894266 | -0.000427 | 'NS' | 0.9055782 | 1.42E-03 | 'AS' |
| 88 | 98 | 123 | 0.9896136 | -0.0006136 | 'NS' | 9.09E-01 | 8.06E-04 | 'AS' |
| 86 | 96 | 121 | 0.9897215 | -0.000721 | 'NS' | 0.9128159 | 1.84E-04 | 'NS' |
| 84 | 94 | 119 | 0.9899355 | -0.0009355 | 'NS' | 0.9168748 | -1.87E-03 | 'NS' |
| 82 | 92 | 117 | 0.9900183 | -0.0020183 | 'NS' | 0.921017 | -0.003017 | 'NS' |
| 80 | 90 | 115 | 0.9894417 | -0.0014417 | 'NS' | 0.9256829 | -5.68E-03 | 'NS' |
| **Load at Bus 5** |  **Load at Bus 7** | **Load at Bus 9** | **| V6 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V7 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 100 | 110 | 135 | 0.9857583 | -0.0027583 | 'NS' | 0.9685872 | 0.0034128 | 'NS' |
| 98 | 108 | 133 | 9.86E-01 | -1.95E-03 | 'NS' | 0.9701785 | 0.0028215 | 'NS' |
| 96 | 106 | 131 | 0.986208 | -0.001208 | 'NS' | 0.9719411 | 0.0020589 | 'NS' |
| 94 | 104 | 129 | 0.9865164 | -0.0005164 | 'NS' | 0.9738393 | 0.0011607 | 'NS' |
| 92 | 102 | 127 | 0.9870243 | -2.43E-05 | 'NS' | 0.9756811 | 3.19E-04 | 'NS' |
| 90 | 100 | 125 | 0.9876246 | 0.0003754 | 'NS' | 0.9774294 | -0.0014294 | 'NS' |
| 88 | 98 | 123 | 0.988326 | 6.74E-04 | 'NS' | 0.9792452 | -2.25E-03 | 'NS' |
| 86 | 96 | 121 | 0.9891527 | 0.0008473 | 'NS' | 0.9807796 | -2.78E-03 | 'NS' |
| 84 | 94 | 119 | 0.9901476 | -0.0001476 | 'NS' | 0.9820302 | -0.0030302 | 'NS' |
| 82 | 92 | 117 | 0.991207 | -2.07E-04 | 'NS' | 0.9830613 | -4.06E-03 | 'NS' |
| 80 | 90 | 115 | 0.9921071 | -0.0001071 | 'NS' | 0.9843415 | -0.0043415 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **| V8 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V9 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 100 | 110 | 135 | 0.9886934 | 0.0013066 | 'NS' | 0.9572355 | 1.76E-03 | 'NS' |
| 98 | 108 | 133 | 0.9898733 | 0.0011267 | 'NS' | 0.9593471 | -3.47E-04 | 'NS' |
| 96 | 106 | 131 | 0.9910368 | -3.68E-05 | 'NS' | 0.9604132 | -0.0004132 | 'NS' |
| 94 | 104 | 129 | 0.992097 | -9.70E-05 | 'NS' | 0.960744 | -7.44E-04 | 'NS' |
| 92 | 102 | 127 | 0.9930143 | -0.0010143 | 'NS' | 0.9608716 | -0.0008716 | 'NS' |
| 90 | 100 | 125 | 0.9937166 | -7.17E-04 | 'NS' | 0.9605852 | 0.0004148 | 'NS' |
| 88 | 98 | 123 | 0.9942047 | -0.0012047 | 'NS' | 0.9606259 | 0.0003741 | 'NS' |
| 86 | 96 | 121 | 0.9944493 | -0.0004493 | 'NS' | 0.9607122 | 0.0002878 | 'NS' |
| 84 | 94 | 119 | 0.9945255 | -0.0005255 | 'NS' | 0.9613294 | -3.29E-04 | 'NS' |
| 82 | 92 | 117 | 0.9944717 | -0.0004717 | 'NS' | 0.962688 | -2.69E-03 | 'NS' |
| 80 | 90 | 115 | 0.9945002 | -0.0005002 | 'NS' | 0.9648898 | -4.89E-03 | 'NS' |

Classification accuracy for case4 at training stage (%) = (164 / 165) \* 100 = 99.3939 %.

From these tables of case4, the comparison of estimated and actual bus voltages will be obtained by ANN-based algorithm and traditional NR power flow method at the maximum increase of load level as shown below in figure 5.2.

Figure 5.2: Estimation of bus voltages by NR load flow method and ANN algorithm at the maximum increase of load level for training of case4.

Also from these tables of case4, the comparison between the NR Load Flow and ANN-based algorithm results for thermal lines at the maximum increase of load level as shown below in figure 5.3.

Figure 5.3: Thermal lines in different lines by NR load Flow method and ANN algorithm at the maximum increase of load level for training of case4.

From these both figures (5.2 and 5.3), the estimated bus voltages and thermal lines by used artificial neural network were compared with the actual bus voltages and thermal lines by used Newton-Raphson power flow analysis to prove the ability of prediction where the errors between these two techniques were very small. Because of these small errors between these two methods, ANN demonstrated on its high ability to predict the thermal lines and bus voltages to be uses for real time application.

The classification accuracy (CA %) of the nine trained cases by using feed forward back propagation neural network will be calculated as shown below in the table 5.3.5 and equation 5.2:

Table 5.3.5: The classification accuracy (CA %) of the nine trained cases.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **(CA %) Case1** | **(CA %) Case2** | **(CA %) Case3** | **(CA %) Case4** | **(CA %) Case5** |
| 100 %. | 96.3636 %. | 98.7878 %. | 99.3939 %. | 100 %. |
| **(CA %) Case6** | **(CA %) Case7** | **(CA %) Case8** | **(CA %) Case9** |
| 100 %. | 100 %. | 100 %. | 98.7878 %. |

$Total Classification Accuracy \left(\%\right)=\frac{Classification Accuracy for each case}{total number of cases}$ (5.2)

CA TOTAL (%)= 893.3331 (%) / 9 = 99.25923333 %.

This percentage indicates that the artificial neural network trained well and the correct choice of the training parameters. Because of this excellent percentage, the artificial neural network will be able to predict its outputs (voltage magnitudes per unit, values of the thermal lines, operating statuses and errors between ANN and NR method) in proper way during the testing stage on specific cases differ from the cases used in the training stage.

the outputs of the artificial neural network (the voltage magnitudes and thermal lines) were classified under specified operating statuses: secure state (normal state) and insecure states (alert state, emergency state and extreme emergency state) to help the system operator to operate the power system at properly and safely and to avoid the dangerous situations that lead to the collapse or the total blackout for that system. The insecure statuses (alert state, emergency state and extreme emergency state) constitute a potential risk on the electrical system, so the insecure statuses will analyze and calculate very carefully as shown below in figure 5.4 and 5.5 respectively:

Figure 5.4: Total percentages of the insecure situations at different buses.

Figure 5.5: Total percentages of the insecure situations at different lines.

In these figures, the vulnerable areas and the most falling in the insecure situations as a result of exposure to serious disturbances (contingencies) are (bus4, bus5, bus6 and bus9) and (line(1-4), line(4-5), line(5-6), line(7-8), line(8-9) and line(4-9)). Therefore, these figures is used to warn the system operator to take the preventive necessary actions with the required speed to prevent the electrical system from sliding into more serious cases that lead to the collapse of parts or the whole system.

* 1. **Testing the Artificial Neural Network by using MATLAB**

The generated database by the Newton-Raphson method using Power World Simulator’s program are used in the testing process. Enter the inputs (891 \* patterns for active powers and 891 \* patterns for reactive powers of the different nine cases) and the final results of training parameters at best mean square error to the artificial neural network by using commands of the MATLAB’s program.

* 1. **Results of the Testing and the Discussions**

At the end of the testing process, the estimated outputs of the artificial neural network (voltage magnitudes per unit, values of the thermal lines, power system's operating statuses and errors between artificial neural network (ANN) and Newton-Raphson (NR) technique) will be calculated as shown in these tables below:

Table 5.6.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case2 (outage the line (2-8)))

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Load at Bus 5** | **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (1- 4)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (2- 8)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.8880299 | -8.03E-03 | 'AS' | -0.0023265 | 2.33E-03 | 'NS' |
| 93 | 103 | 128 | 0.8402215 | -0.0002215 | 'AS' | -0.0016993 | 0.0016993 | 'NS' |
| 89 | 99 | 124 | 0.7909955 | -9.95E-04 | 'NS' | -0.0007511 | 7.51E-04 | 'NS' |
| 85 | 95 | 120 | 0.7460146 | 3.99E-03 | 'NS' | -0.0005872 | 5.87E-04 | 'NS' |
| 81 | 91 | 116 | 0.70099 | -9.90E-04 | 'NS' | 0.0026893 | -0.0026893 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (3- 6)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (4- 5)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.2928586 | -0.0028586 | 'NS' | 6.76E-01 | 4.06E-03 | 'NS' |
| 93 | 103 | 128 | 0.292209 | -0.002209 | 'NS' | 0.6353013 | 4.70E-03 | 'NS' |
| 89 | 99 | 124 | 0.2886115 | 0.0013885 | 'NS' | 0.5989953 | 1.00E-03 | 'NS' |
| 85 | 95 | 120 | 0.2835512 | -3.55E-03 | 'NS' | 0.5610951 | -0.0010951 | 'NS' |
| 81 | 91 | 116 | 0.2791108 | 0.0008892 | 'NS' | 0.5193264 | 6.74E-04 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (5- 6)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (6- 7)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.2271825 | -0.0071825 | 'NS' | 0.5993128 | 0.0006872 | 'NS' |
| 93 | 103 | 128 | 2.16E-01 | -5.85E-03 | 'NS' | 0.5831633 | -0.0031633 | 'NS' |
| 89 | 99 | 124 | 0.2052845 | 0.0047155 | 'NS' | 0.5691061 | 0.0008939 | 'NS' |
| 85 | 95 | 120 | 0.2010454 | -0.0010454 | 'NS' | 0.5571275 | 0.0028725 | 'NS' |
| 81 | 91 | 116 | 0.1983597 | -0.0083597 | 'NS' | 0.543798 | -3.80E-03 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (7- 8)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (8- 9)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.1524651 | 7.53E-03 | 'NS' | 0.2425155 | -2.52E-03 | 'NS' |
| 93 | 103 | 128 | 0.1450814 | 0.0049186 | 'NS' | 0.2295489 | 4.51E-04 | 'NS' |
| 89 | 99 | 124 | 0.1383583 | 0.0016417 | 'NS' | 0.2223053 | -0.0023053 | 'NS' |
| 85 | 95 | 120 | 0.1317602 | -1.76E-03 | 'NS' | 0.2124501 | -2.45E-03 | 'NS' |
| 81 | 91 | 116 | 0.1156208 | 0.0043792 | 'NS' | 0.209129 | -0.009129 | 'NS' |
| **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (4- 9)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 1.0827844 | -0.0027844 | 'ES' |
| 93 | 103 | 128 | 1.0323664 | -0.0023664 | 'ES' |
| 89 | 99 | 124 | 0.9845105 | 0.0054895 | 'AS' |
| 85 | 95 | 120 | 0.9401082 | -0.0001082 | 'AS' |
| 81 | 91 | 116 | 0.8859183 | 0.0040817 | 'AS' |

Table 5.6.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case2 (outage the line (2-8))).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Load at Bus 5** |  **Load at Bus 7** | **Load at Bus 9** | **| V4 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V5 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 97 | 107 | 132 | 0.9787121 | -1.71E-03 | 'NS' | 0.9654186 | -1.42E-03 | 'NS' |
| 93 | 103 | 128 | 0.9806891 | -0.0016891 | 'NS' | 0.9679297 | -0.0009297 | 'NS' |
| 89 | 99 | 124 | 0.9822585 | -1.26E-03 | 'NS' | 0.9701839 | -1.84E-04 | 'NS' |
| 85 | 95 | 120 | 0.9830406 | -4.06E-05 | 'NS' | 0.9719111 | 1.09E-03 | 'NS' |
| 81 | 91 | 116 | 0.9833817 | 1.62E-03 | 'NS' | 0.9736086 | 0.0013914 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **| V6 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V7 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 97 | 107 | 132 | 0.9950651 | -0.0030651 | 'NS' | 9.54E-01 | -3.82E-04 | 'NS' |
| 93 | 103 | 128 | 0.994864 | -0.001864 | 'NS' | 0.9574247 | -4.25E-04 | 'NS' |
| 89 | 99 | 124 | 0.9943649 | 0.0006351 | 'NS' | 0.9603057 | -3.06E-04 | 'NS' |
| 85 | 95 | 120 | 0.9936945 | 0.0023055 | 'NS' | 0.9629748 | 2.52E-05 | 'NS' |
| 81 | 91 | 116 | 0.9930129 | 0.0039871 | 'NS' | 0.9655374 | 3.05E-02 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **| V8 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V9 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 97 | 107 | 132 | 0.9607758 | -0.0017758 | 'NS' | 0.9383615 | 0.0006385 | 'NS' |
| 93 | 103 | 128 | 9.63E-01 | -1.01E-03 | 'NS' | 0.9410327 | 0.0009673 | 'NS' |
| 89 | 99 | 124 | 0.9655331 | 0.0004669 | 'NS' | 0.9446105 | 0.0013895 | 'NS' |
| 85 | 95 | 120 | 0.9679516 | 0.0010484 | 'NS' | 0.9490341 | -3.41E-05 | 'NS' |
| 81 | 91 | 116 | 0.9701013 | 0.0018987 | 'NS' | 0.9543398 | -2.34E-03 | 'NS' |

Classification accuracy for case2 at testing stage (%) = (74 / 75) \* 100 = 98.66667 %.

From these tables of case2, the comparison of estimated and actual bus voltages will be obtained by ANN-based algorithm and traditional NR power flow method as well as the comparison between the NR Load Flow and ANN-based algorithm results for thermal lines at the maximum increase of load level as shown below in figure 5.6 and 5.7 respectively:

Figure 5.6: Thermal lines in different lines by NR load Flow method and ANN algorithm at the maximum increase of load level for testing of case2.

Figure 5.7: Estimation of bus voltages by NR load flow method and ANN algorithm at the maximum increase of load level for testing of case2.

The estimated results obtained from the ANN technique was compared with NR power flow analysis in terms of accuracy. As shown from these figures, the obtained estimated outcomes from the ANN are approximately matching of the results of NR technique and that demonstrates the reliability of artificial neural network in the field of the static security assessment.

Table 5.6.3: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case9 (outage the line (4-9)))

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Load at Bus 5** |  **Load at Bus 7** | **Load at Bus 9** | **Thermal line (1- 4)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (2- 8)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.3411931 | -1.19E-03 | 'NS' | 0.634674 | -1.47E-02 | 'NS' |
| 93 | 103 | 128 | 0.2974166 | -0.0074166 | 'NS' | 0.6156348 | -0.0056348 | 'NS' |
| 89 | 99 | 124 | 0.2520061 | -2.01E-03 | 'NS' | 0.605739 | 4.26E-03 | 'NS' |
| 85 | 95 | 120 | 0.2089985 | 1.00E-03 | 'NS' | 0.5969542 | 3.05E-03 | 'NS' |
| 81 | 91 | 116 | 0.1611838 | -1.18E-03 | 'NS' | 0.5904782 | -0.0004782 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (3- 6)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (4- 5)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.2953426 | -0.0053426 | 'NS' | 6.80E-01 | 2.40E-04 | 'NS' |
| 93 | 103 | 128 | 0.2899816 | 1.84E-05 | 'NS' | 0.5882053 | 1.79E-03 | 'NS' |
| 89 | 99 | 124 | 0.2843009 | -0.004300 | 'NS' | 0.4976458 | 2.35E-03 | 'NS' |
| 85 | 95 | 120 | 0.2806079 | -0.0006079 | 'NS' | 0.4096443 | 0.0003557 | 'NS' |
| 81 | 91 | 116 | 0.2793825 | 0.0006175 | 'NS' | 0.331319 | 8.68E-03 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (5- 6)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (6- 7)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.1704014 | -4.01E-04 | 'NS' | 0.5916351 | 1.84E-02 | 'NS' |
| 93 | 103 | 128 | 1.61E-01 | -1.20E-03 | 'NS' | 0.5612823 | -0.0012823 | 'NS' |
| 89 | 99 | 124 | 0.1731007 | -0.0031007 | 'NS' | 0.5091249 | 0.0008751 | 'NS' |
| 85 | 95 | 120 | 0.2001142 | -1.14E-04 | 'NS' | 0.4543046 | 0.0056954 | 'NS' |
| 81 | 91 | 116 | 0.2457937 | 0.0042063 | 'NS' | 0.4084279 | 1.57E-03 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (7- 8)** | **Errors between ANN and NR** | **Statuses of the Lines** | **Thermal line (8- 9)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.1569826 | -6.98E-03 | 'NS' | 1.1254884 | 1.45E-02 | 'ES' |
| 93 | 103 | 128 | 0.1786647 | 0.0013353 | 'NS' | 1.0916699 | -1.67E-03 | 'ES' |
| 89 | 99 | 124 | 0.2128286 | -0.0028286 | 'NS' | 1.0458613 | 0.0041387 | 'ES' |
| 85 | 95 | 120 | 0.2421638 | -2.16E-03 | 'NS' | 1.0009054 | -9.05E-04 | 'ES' |
| 81 | 91 | 116 | 0.2743141 | 0.0056859 | 'NS' | 0.9585014 | 0.0014986 | 'AS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **Thermal line (4- 9)** | **Errors between ANN and NR** | **Statuses of the Lines** |
| 97 | 107 | 132 | 0.0016181 | -0.0016181 | 'NS' |
| 93 | 103 | 128 | 0.0005793 | -0.0005793 | 'NS' |
| 89 | 99 | 124 | 0.0002327 | -0.0002327 | 'NS' |
| 85 | 95 | 120 | 0.0002812 | -0.0002812 | 'NS' |
| 81 | 91 | 116 | -0.0011778 | 0.0011778 | 'NS' |

Table 5.6.4: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case9 (outage the line (4-9)))

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Load at Bus 5** | **Load at Bus 7** |  **Load at Bus 9** | **| V4 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V5 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 97 | 107 | 132 | 0.9988861 | 1.14E-04 | 'NS' | 0.9769206 | 3.08E-03 | 'NS' |
| 93 | 103 | 128 | 0.9996171 | 0.0003829 | 'NS' | 0.981368 | 0.000632 | 'NS' |
| 89 | 99 | 124 | 1.0001421 | -1.42E-04 | 'AS' | 0.9844338 | -1.43E-03 | 'NS' |
| 85 | 95 | 120 | 1.0002362 | -2.36E-04 | 'AS' | 0.9849107 | -9.11E-04 | 'NS' |
| 81 | 91 | 116 | 0.999822 | 1.78E-04 | 'NS' | 0.9837491 | 0.0012509 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **| V6 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V7 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 97 | 107 | 132 | 0.9953472 | -0.0023472 | 'NS' | 9.51E-01 | -3.00E-03 | 'NS' |
| 93 | 103 | 128 | 0.9959265 | -0.0019265 | 'NS' | 0.9530758 | -1.08E-03 | 'NS' |
| 89 | 99 | 124 | 0.996669 | -0.000669 | 'NS' | 0.955458 | -4.58E-04 | 'NS' |
| 85 | 95 | 120 | 0.9973808 | -0.0003808 | 'NS' | 0.9581733 | 0.0008267 | 'NS' |
| 81 | 91 | 116 | 0.9980451 | -4.51E-05 | 'NS' | 0.9612111 | -2.11E-04 | 'NS' |
|  **Load at Bus 5** |  **Load at Bus 7** |  **Load at Bus 9** | **| V8 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** | **| V9 | (P.U.)** | **Errors between ANN and NR** | **Statuses of the Buses** |
| 97 | 107 | 132 | 0.9515041 | -0.0035041 | 'NS' | 0.779472 | -0.007472 | 'EES' |
| 93 | 103 | 128 | 9.53E-01 | -9.63E-04 | 'NS' | 0.7856612 | -0.001661 | 'EES' |
| 89 | 99 | 124 | 0.9555184 | -0.000518 | 'NS' | 0.7937982 | 0.0002018 | 'EES' |
| 85 | 95 | 120 | 0.9586735 | -0.0006735 | 'NS' | 0.8028797 | 0.0001203 | 'ES' |
| 81 | 91 | 116 | 0.9614504 | -0.0004504 | 'NS' | 0.8126439 | -6.44E-04 | 'ES' |

Classification accuracy for case9 at testing stage (%) = (75 / 75) \* 100 = 100 %.

The classification accuracy (CA %) of the nine tested cases by using feed forward back propagation neural network will be calculated as shown below in the table 5.6.5:

Table 5.6.5: The classification accuracy of the nine tested cases.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **(CA %) Case1** | **(CA %) Case2** | **(CA %) Case3** | **(CA %) Case4** | **(CA %) Case5** |
| 60 %. | 98.66667 %. | 58.66667 %. | 98.66667 %. | 98.66667 %. |
| **(CA %) Case6** | **(CA %) Case7** | **(CA %) Case8** | **(CA %) Case9** |
| 100 %. | 100 %. | 100 %. | 100 %. |

Total Classification Accuracy for testing stage (%) = 860.66668 (%) / 9 = 90.51852 %.

This percentage shows the ability of the artificial neural network to determine the estimated voltage magnitudes at various buses and the estimated values of the thermal lines at various transmission lines for different probable disturbances (outage the transmission lines with changing loads). In addition, the percentage of the Classification Accuracy for total nine tested cases can be considered as a good percentage when compared with the other published results of works in this field.

The total spent time to carry out the testing process by ANN was 0.013 second while the spent time by Newton-Raphson power flow analysis was 0.0627 second. Because of these results, the ANN is faster than NR method in predicting the security level of that system. This time indicates the ability of the artificial neural network to identify power system's operating statuses (normal state, alert state, emergency state and extreme emergency state). The testing time is considered a short period, which can enable the system operator to take the preventive necessary actions to prevent the electrical system from sliding into more serious cases that lead to the collapse of parts or the whole system. The most susceptible areas by dangerous contingencies that lead to the insecure statuses will be analyzed and presented in figures 5.8 and 5.9 respectively:

Figure 5.8: Number of Insecure Statuses of testing stage for voltage magnitudes at different buses.

Figure 5.9: Number of Insecure Statuses of training stage for values of the thermal lines at different lines.

In these figures, the numbers of insecure statuses for voltage magnitudes at different buses and the values of the thermal lines at various lines were calculated to help the system operator to reveal the most susceptible areas (buses and lines) for unsafe situations. In addition, to warn the system operator to take rapid and preventive action which it helps to take the operating system back to the secure position and to avoid remaining the system at the unsafe situations that lead to the collapse or the shutdown for that system.

Because of the high accuracy prediction of the training process and a good accuracy prediction of the testing process by using Artificial Neural Network (ANN) technique in determining the security level of the IEEE 9-bus system. Besides that, the average time required ANN is faster than the average time required by NR method and this technique can be utilized for real time application. Therefore, the Artificial Neural Network (ANN) proved of its high potential in the field of the static security assessment to be like a protective shield for warning the system operator from the unsafe instances and to operate the power system at a safe position to ensure arrival of electricity to consumers with high quality and without interruptions. The prediction of classification accuracy at the testing process is considered a good percentage according to [4].

In [4], six transmission lines separated in all cases while eight transmission lines were cutting in all scenarios of this thesis. Each outage of these transmission lines contained (11 \* 12) values of real powers and (11 \* 12) values of reactive powers at the input layer. As well as, (11 \* 12) values of thermal limits and (9 \* 11) values of voltage magnitudes at the output layer where all these values are obtained from the change in the loads of IEEE-9 bus system. Due to these reasons, the average time required by feed forward back propagation neural network and the value of mean square error increased in this system. As well as, the percentage of classification accuracy decreased also.