PAMUKKALE ÜNİVERSİTESİ MÜHENDİSLİK FAKÜLTESİ
PAMUKKALE UNIVERSITY ENGINEERING COLLEGE
MÜHENDİSLİK BİLİMLERİ DERGİSİ
JOURNAL OF ENGINEERING SCIENCES
YIL : 2003
CİLT : 9
SAYI : 2
SAYFA : 207-214

# AN APPLICATION EXAMPLE ; FAULT DIAGNOSIS IN POWER SYSTEM

**Özgür COŞAR, İlhan KOŞALAY**
TRT, Haber Dairesi Bşk.lığı, No: 153, (3. Grup Baş Mühendisliği) Oran/Ankara

Geliş Tarihi : 01.07.2002

## ABSTRACT

There are a lot of protective devices in electrical transmission and distribution systems which are monitored and data are collected from these devices via Supervisory Control and Data Acquisition System (SCADA). distribution systems are more complicated when compared with transmission systems. However, SCADA is not available in most distribution systems where phones from the customers are used as alarms. In the cases where SCADA is not available experiences of the dispatchers and the information from customers becomes important. In this work a user friendly software is developed for even unexperienced dispatchers.

**Key Words :** Fault diagnosis, Artificial neural network, Application software

## BİR UYGULAMA ÖRNEĞİ ; GÜÇ SİSTEMLERİNDE ARIZA TESPİTİ

## ÖZET

Elektrik iletim ve dağıtım sisteminde birçok koruma ekipmanı kullanılmaktadır. Bu ekipmanlardan gelen bilgiler SCADA sistemi aracılığıyla görüntülenir ve toplanır. Bununla birlikte birçok dağıtım sisteminde SCADA mevcut değildir. Böyle sistemlerde tüketicilerden gelen telefonlar ihbar olarak kullanılır. Birçok halde kontrol merkezlerindeki personel hata tespiti konusunda tecrübelidir. SCADA'nın mevcut olmadığı hallerde müşterilerden gelen bilgiler ve personelin tecrübesi büyük önem kazanmaktadır. Bu çalışmada deneyimsiz personelin bile kolaylıkla kullanabileceği bir yazılım geliştirilmiştir.

**Anahtar Kelimeler :** Hata tespiti, Yapay sinir ağları, Uygulama yazılımı

## 1. INTRODUCTION

Today electrical energy is used by nearly every equipment that we are using. Loss of electricity even for a small amount of time causes many problems. For industry, loss of electricity means loss of money. For people, it means loss of ability to work and live comfortably.

Electricity is transmitted and distributed through complex systems. Companies that provide electricity try to provide electrical energy as reliable as possible. Transmission system is equipped with protective devices which are used for the reliable and continues flow of electricity. These protective devices are monitored and data are collected from these devices via Supervisory Control and Data Acquisition System (SCADA). When an error occurs in transmission system data via SCADA is used for diagnoses.

On the other hand, distribution systems are more complicated when compared with transmission systems. SCADA is not available in most cases. So fault diagnoses is a problem in distribution systems. Telephones from the customers are used as alarms. In control centers dispatchers have experience on fault diagnoses. They use their experiences and the information from customers with the alarms from SCADA where available.

In this work, a software which can be used for a tool for power system dispatchers is proposed. One can draw single line diagram of power system, save the drawn configuration, train the system for the drawn configuration for faults and test the system for given protective device alarms.

In this software feed forward with error back propagation artificial neural network approach for fault diagnosis is used. Software is developed with Microsoft Visual Basic 5.0. All data files are stored as text files with special extensions.

## 2. FAULT DIAGNOSIS PROBLEM

As electrical energy becomes more important in our life, need of uninterrupted power becomes more important. Companies try to achieve this. In control centers system is monitored by data taken from SCADA. This data, depending on the capabilities of SCADA, contains information on relay status, circuit breaker status, voltages and current readings etc. Data continuously come to control center. When a fault occurs amount of data gets larger. As dispatchers should give a decision in a short time they need tools to help them in this process.

### 2. 1. Previous Work

In literature since 1969, T. J. Kraynak and T. E. Dy Liacca, many solutions are proposed. Mainly there are two different approaches to the problem: Rule based systems and neural network based systems.

Most of the work in literature use information from circuit breakers and relays which are gathered via SCADA systems. In some of the works voltage and current readings are also used. Data from sequence of event recorders are used in some proposed solutions where data is available.

Talukdar et al. (1986) developed a program for helping operators in control centers in fault diagnosis operations. Their work was depending on development of an expert system using knowledge based approach. Their system was found of two modules. One of which is discrete event simulator and other is diagnostician. They used experiences of operators to build the knowledge base of their system.

Cardozo and Talukdar (1988) developed their system further and introduced a distributed expert system for fault diagnosis. Again this was a knowledge based system which had rules describing system operation. With the help of using distributed architecture they were able to reach considerable speed in diagnosis.

Eickoff et al., (1992) developed a knowledge based alarm handling and fault location in distribution networks in 1992. System they proposed was a knowledge based system. One of the important features of their proposal was that knowledge they used was independent of the topology. This is important as the topology in distribution networks changes frequently.

Systems that are briefly explained above share some basic properties:

- They all use knowledge based systems which is implemented with IF THEN ELSE statements. This slows down the diagnosis as the power distribution network needs a lot of rule for its description.
- They do not take into account the ambiguity in data. Data collected via SCADA may include errors due to communication lines or even the protective equipment may have misoperated. To overcome these problems new methods have been used in the fault diagnosis problem.
- Rule based systems are mainly domain specific. So changes in network configurations requires changes in rules that define the network.

Neural network is one of the alternative method which has been used in pattern recognition problems. Fault diagnosis can be thought as a pattern recognition. Since when a fault occurs a number of protective device is expected to operate.

One disadvantage of neural network in fault diagnosis in power distribution network is the long training time. As the changes in distribution network occur frequently, neural network should be trained again with each change. In some applications distribution network is divided into smaller regions and diagnosis is carried out separately for each region. This speed up training process as the region is smaller. Need of retraining is decreased as the possibility of a change in a smaller region of distribution network decreases.

Fuzzy logic is another method used in fault diagnosis. It gives the chance to handle the uncertainties in the system. Fuzzy logic is used with rule based systems to make them more powerful.

Some hybrid methods are also proposed which uses rule based systems with neural networks.

Rodrigues et al., (1999) propose a system for fault diagnosis in power system which uses artificial neural networks. Their system uses feedforward with error back propagation network. They have divided the power network into regions. This speeds up training process and also need of retraining due to changes in power network decreases.

Monsef et al., (1997) developed a system which uses fuzzy rule based expert system for fault diagnosis. Their system process information using common sense rules and natural language statements. With the help of fuzzy logic their system is able to take the ambiguity of data collected into account.

Yang et al., (1995) developed a system which is a good example of hybrid systems: "Power system distributed on-line fault section estimation using decision tree based neural nets approach". This proposed solution is interesting. It uses neural networks, but training time of the network is too short.

Reason of this is that in the proposed system mainly decision tree is used. Diagnosis is made by this decision tree and for easy programming this decision tree structure is implemented with neural networks. Hence weights are not calculated during training process.

In this work a feedforward error back propagation neural network based system is developed for fault diagnosis in electric power distribution network. Main advantage of the system is that it leaves the drawing of the network to the operators. By this it is possible to divide complete network into smaller regions which speeds up training.

Power system equipment are protected by relays and circuit breakers. Different types of relays are used in protection. When a fault occurs relay sense the fault and sends trip signal to the circuit breaker. Circuit breakers do not sense the fault. They are expected to operate, trip, and open the circuit with the signal they get from relays. In the work power system equipment are divided into two groups. In the first group there is equipments which are protected and in the second group there is the ones which are used to protect.

## 2. 2. Description of Features of the Software

Microsoft Visual Basic 5.0 is used in the development of the proposed system. System is designed modularly so that any further enhancement can be made easily. There are mainly 3 modules in the system. These are:

- Power Distribution Network Drawing Module
- Feed Forward Error Back Propagation Neural Network Training Module
- Fault Diagnosis Module

### 2. 2. 1. Power Distribution Network Drawing Module

Aim in designing this module was to give the easiest way for drawing a power system network. It is thought that operators will be familiar with Windows environment so drag and drop type drawing is implemented. There is a tool bar (Figure 1), which can set to be either hidden or unhidden from options menu, which has icons symbolizing power system equipment.

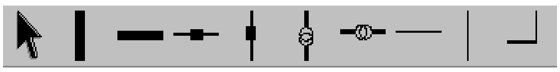

Figure 1. Drawing

For network drawing, operators will first click on the symbol of the equipment to select one, then click on the drawing window to place the equipment on to the window. Each of the equipment has tool tip texts which describe the equipment and help operators. Equipments in the proposed system have property windows from which operators can enter properties of the equipment. Right clicking on the equipment icon and selecting "properties" from pop up menu is enough for displaying property window. New properties can be added easily by a small change in the code. In the following icons and properties of each equipment are described:

### 2. 2. 2 Vertical Bus and Horizontal Bus

Name and rated voltage of the bus are the properties of vertical bus (Figure 2 ). Same properties are used for horizontal bus (Figure 3).

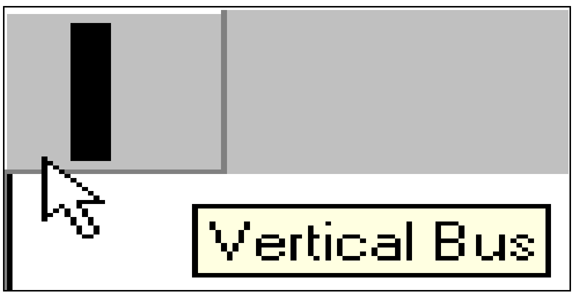


Figure 2. Vertical Bus Icon

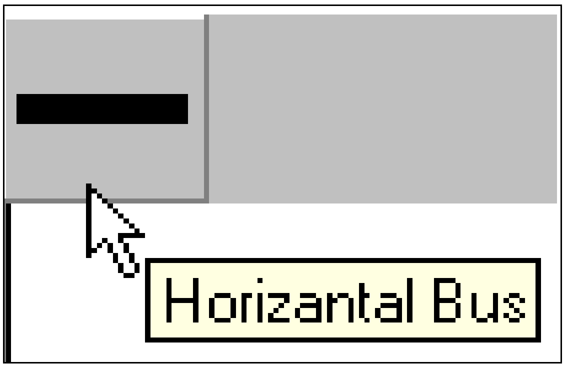


Figure 3. Horizontal Bus Icon

**2. 2. 3. Vertical Circuit Breaker and Horizontal Circuit Breaker**

For both vertical and horizontal circuit breakers Name, Firm, Type, Year, kV, kVA are available as property (Figure 4 and 5).

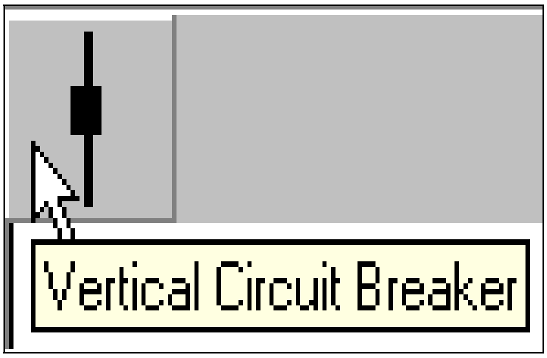


Figure .4 Vertical circuit breaker icon

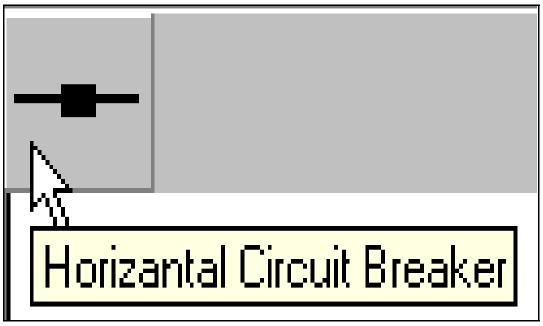


Figure 5. Horizontal circuit breaker icon

Also there is a check box which indicates if the circuit breaker is a line protection circuit breaker or not.

**2. 2. 4. Vertical Transformer and Horizontal Transformer**

For vertical and horizontal transformers Name, Firm, Year, v1, v2, Xpu and S are available as properties**.** (Figure 6 and 7 )

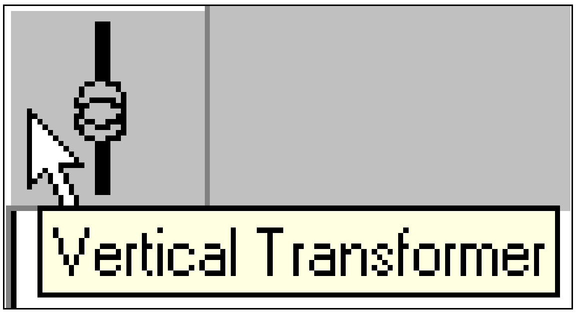


Figure 6. Vertical transformer icon

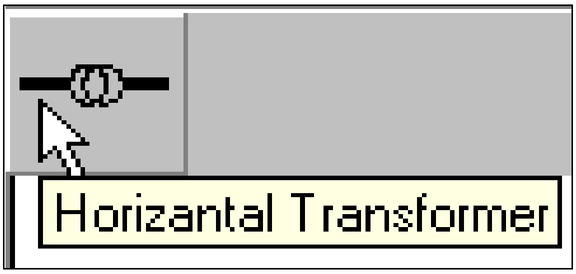


Figure 7. Horizontal transformer icon

**4. 1. 4. Horizontal Line, Vertical Line and First Horizontal then Vertical Line**

Only line name is used as property for each three type of lines. It is shown in Figure 8, 9 and 10 by order.

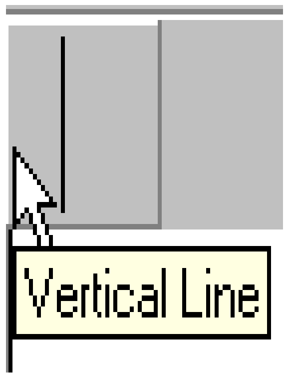


Figure 8. Vertical Line Icon

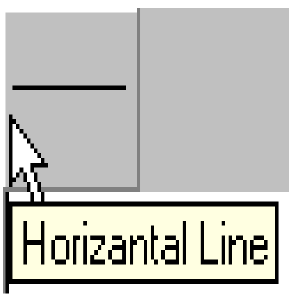


Figure 9. Horizontal Line Icon

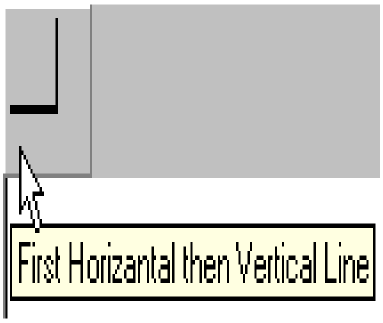


Figure 10. First Horizontal then vertical line icon

Each of the equipment is in red color by default, which symbolizes healthy operation, but operators can change color by simply right clicking on the icon of the equipment and selecting “color” from the pop up menu. When color menu is clicked a color palette appears from which desired color can be selected.

Operators can delete any equipment they want by again right clicking on the icon of the equipment and selecting “delete” from the pop up menu.

Each of the equipment drawn is dragable. Operators can drag any equipment to any place in the network diagram they want. While dragging an equipment mouse pointer turns to a similar icon as the equipment.

After finishing drawing, operators can save the network for further operations. Network configurations are saved as text files with “*.ncf” extension, which stands for network configuration file. Number of each equipment, properties of equipments are saved in an order. Configurations saved before, can be loaded using open menu.

### 2. 3. Feed Forward Error Back Propagation Neural Network Training Module

Configuration drawn should be saved before training, if not operator is warned to do so. Operators can reach training module from “training” sub menu in “neural network” menu. When “training” is pressed operators are faced with a window (Figure 11) from which training data are entered to the system. There are four tabs in this window: Inputs, Outputs, Train Network and NN Model.

### 2. 3. 1. Inputs Tab

Inputs are the protective devices of the network: circuit breakers and relays. Information from them are used for diagnoses as stated earlier. A check box is displayed for each one of the protective device. Names of the protective devices are the ones entered by the operator during drawing. Checking a check box for a circuit breaker means there is an operated signal from that circuit breaker. Checking a check box for a relay means there is a tripping signal from that relay. Total number of inputs is also displayed in the caption of the tab( Figure 11 ).

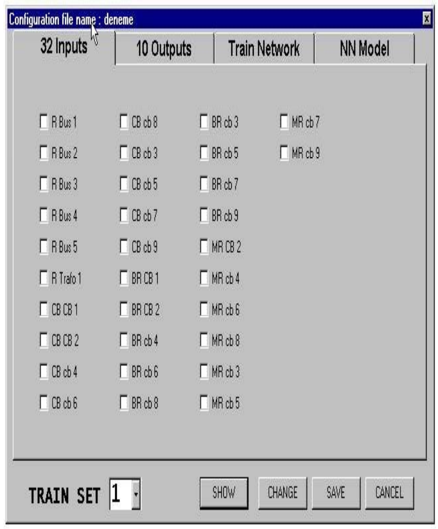


Figure 11. Inputs Tab

### 2. 3. 2. Outputs Tab

In the outputs tab there are option buttons for each one of the equipment which can be faulty: transformers, lines, buses. Total number of outputs is displayed in the caption of the outputs tab (Figure 12). After finishing entering one set of inputs, operators click output tab for entering which equipment is faulty with the entered input data. Operator selects the faulty equipment with clicking to the option box. Lastly “Save” button is clicked for saving training set.

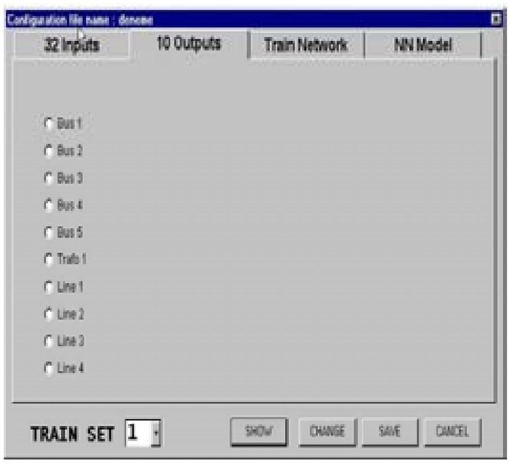


Figure 12. Outputs of NN model

### 2. 3. 3 Train Network Tab

In the train network tab hidden neuron number and maximum error are entered as parameters (Figure 13). By pressing “Train” button training process begins. During training iteration number and error at that specific iteration is displayed on window. When training is finished total time for training and iteration number with the error is displayed for information. Weights are saved for each configuration as text files.

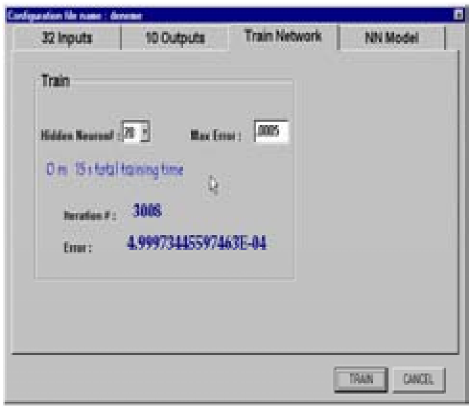


Figure 13. Train Network Tab

### 2. 3. 4. NN Model Tab

In this tab a graphical representation of the neural network is displayed. Red circles represent inputs, blue circles represent hidden layer units and green circles represent outputs. Number of hidden layer units are the ones set during training process. Diagram becomes complicated when number of inputs, outputs and hidden units increases. Not to complicate it further weights are not shown in the diagram. When diagram is larger then the window vertical scroll bar appears in the display window (Figure 14).

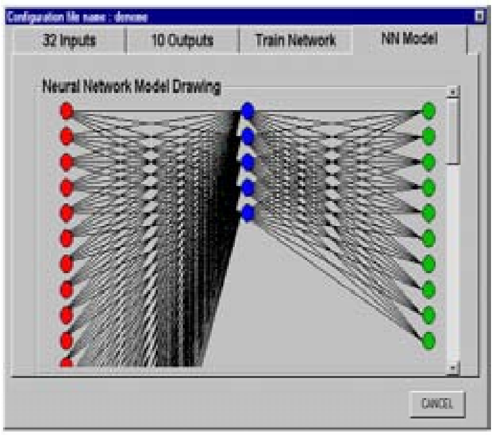


Figure 14. NN Model

### 2. 4. Fault Diagnosis Module

This module simply calculates outputs with the given inputs and weights calculated during training phase. Inputs are entered by operator from a window which is filled with check boxes for each one of protective devices Outputs greater then 0,9 are taken as 1. Results of the test are displayed with a text stating the faulty element. Also color of the faulty element is set to black while color of all other equipment are set to red (Figure 15). By clicking “Details” button operator can learn the exact values of the outputs. By clicking “Test Again” test data input window is displayed again.


Figure 15. Test Results

## 3. TEST RESULT OF THE SOFTWARE

Software developed has been tested on two hypothetical power distribution networks one of which has 8 buses, 3 transformers, 5 lines, 15 circuit breakers and 36 relays (Figure 16), where the second system has 14 buses, 5 transformers, 10 lines, 28 circuit breakers and 67 relays (Figure 17). For hypothetical network 1, system is trained with 19 patterns which include all single fault cases which are cleared with primary protection relays. For hypothetical network 2, system is trained with 29 patterns which include all single fault cases cleared with primary protection relays. Number of hidden layer neurons is set to 5, 10, 20, 30, 40, 50 and 90. Maximum error is set to 0.05 and 0.005 for each test.

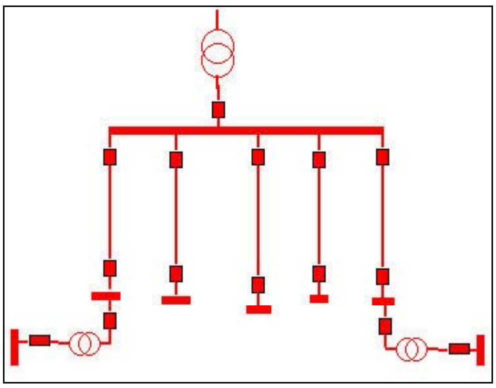

Figure 16. Hypothetical Distribution Network 1

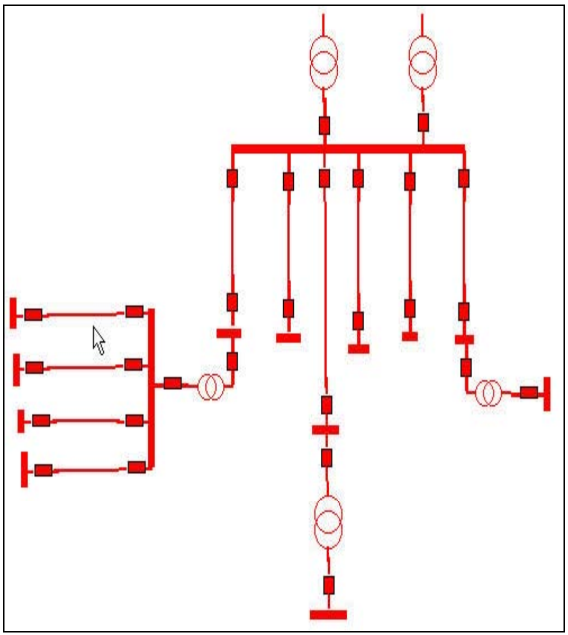

Figure 17. Hypothetical distribution network 2

For network 1, system is tested using 25 patterns. Among these patterns 19 of them were used in training. Rest of the pattern had single or multiple errors in their inputs. Performance of the system with the test inputs for network 1 is shown in Table 1.

Table 1 Training Results of Hypothetical Network 1

| | Maximum Error = 0.05 | | Maximum Error = 0.005 | |
|---|---|---|---|---|
| Number of Hidden Layer Neuron | Training Time Seconds | Number of Iterations | Training Time Seconds | Number of Iterations |
| 5 | 2716 | 100001 | 2648 | 100001 |
| 10 | 79 | 2430 | 662 | 20280 |
| 20 | 46 | 1004 | 363 | 7967 |
| 30 | 40 | 693 | 321 | 5585 |
| 40 | 43 | 635 | 327 | 4521 |
| 50 | 42 | 522 | 309 | 3902 |
| 90 | 176 | 1320 | 329 | 2566 |

It is clear from tables and graphs that as the network becomes larger training time increases, but when the network is divided into appropriate regions satisfactory performance can be taken from the system. System reaches correct results when tested with patterns used in its training. It also gives correct results when there is one wrong data in the case trained with 0.05 maximum error. When trained with 0.005 maximum error it works for 2 wrong data.

Tests are made with a Pentium-III processor PC which has 128 MB of RAM. Each training is repeated three times and average of the results are taken. Results of the tests are shown in Figure 18.

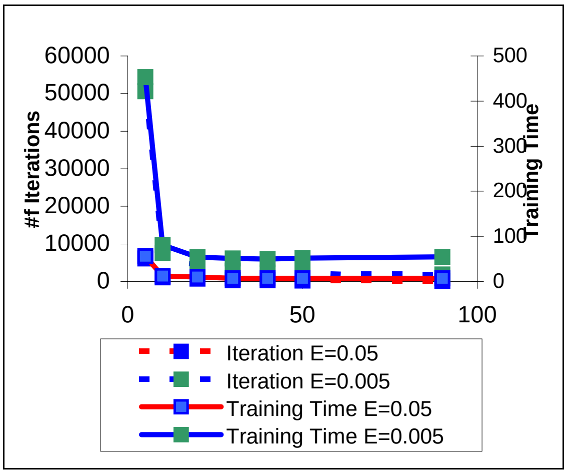


Figure 18. Test Results for Hypothetical Network 2

## 4. CONCLUSION

In this work an artificial neural network approach to the fault diagnosis problem in electrical power distribution network is presented. It overcomes the problems encountered with knowledge based systems.

Artificial neural network are widely used in pattern recognition and classification problems where data contains ambiguity. In fault diagnosis problems proposed systems should be fast enough for real time applications. Presented system is fast enough even on a standard PC.

One of the main disadvantage of the neural network is the long training time. Since configuration of the electrical power distribution network changes frequently training of the system in every change needs a lot of time. In the proposed system it is claimed that with the division of the whole network into smaller regions, this problem can be handled. Configuration of each region can be drawn and saved separately. When a fault occurs the configuration file of the suspected region can be loaded and tested.

Solutions to the fault diagnosis problem usually can not be used in different network configurations. They need a lot of work for customizing. System that is proposed in this work can be used with any configuration. Configuration is drawn by the operator himself. When a change is made operator just loads the configuration file, makes changes and retrain the system. This takes a short amount of time and software is not changed.

Properties of power system equipment is saved with the configuration file. This data can be connected to a database and an inventory of the system can be made with a little effort.

One of the disadvantage of the system is that it works off line. As SCADA data is not available this was a must. However when on-line data is avialable it is possible to change the software to operate with on-line data.

## 5. REFERENCES

Cardozo, E., Talukdar, S. 1988. A Distributed Expert System for Fault Diagnosis, IEEE PWRS, Vol. 3, No.2, 641-646.

Eickhoff, F., Handschin, E., Hoffmann, W. 1992. Knowledge Based Alarm Handling and Fault Location in Distribution Networks, IEEE PWRS, Vol. 7, No. 2, 770-776.

Monsef, H., Ranjbar, A.M., Jadid, S. 1997. Fuzzy Rule-Based Expert System for Power System Fault Diagnosis, IEE Proc.-Gener. Transm. Distrib., Vol. 144, No: 2 , 186-192.

Rodrigues, M. A. P., Souza, J. C. S., Schilling, M.Th. Filho, M. B. D. C. 1999. Fault Diagnosis in Electrical Power Systems Using Artificial Neural Networks, International Conference on Electrical Power Engineering, Budapest.

Talukdar, S., Cardozo, E., Perry, T. 1986. The Operator's Assitant-An Intelligent, Exandable Program for Power System Trouble Analysis, IEEE PWRS, Vol. 1, No. 3, 182-187.

Yang, H., Chang, W., Huang, C. 1995. Power System Distributed On-line Fault Section Estimation Using Decision Tree Based Neural Nets Approach, IEEE PWRD, Vol. 10 (1), 540-546.