Update of an early warning fault detection method using artificial intelligence techniques

Conference or Workshop Item

UK.ISSN 0963-3308 - REFERENCE NO : 1997/050

Update of an Early Warning Fault Detection Method Using Artificial Intelligence Techniques

K C P Wong, H M Ryan, J Tindle

(University of Sunderland)

ABSTRACT

This presentation describes a research investigation to access the feasibility of using an Artificial Intelligence (AI) method to predict and detect faults at an early stage in power systems. An AI based detector has been developed to monitor and predict faults at an early stage on particular sections of power systems. The detector for this early warning fault detection device only requires external measurements taken from the input and output nodes of the power system. The AI detection system is capable of rapidly predicting a malfunction within the system. Artificial Neural Networks (ANNs) are being used as the core of the fault detector. In an earlier paper [11], a computer simulated medium length transmission line has been tested by the detector and the results clearly demonstrate the capability of the detector. Today's presentation considers a case study illustrating the suitability of this AI Technique when applied to a distribution transformer. Furthermore, an evolutionary optimisation strategy to train ANNs is also briefly discussed in this presentation, together with a 'crystal ball' view of future developments in the operation and monitoring of transmission systems in the next millennium.

INTRODUCTION

As a result of increasing competition in the electrical power industry and the requirement for quality power supply, adequate fault detection is becoming vitally important to both companies and consumers. One of the strategies to ensure low running cost is the general avoidance of supply interruption wherever possible. Conventional fault studies are concerned mainly with a 'what if ' scenario i.e. on considering what would happen after a fault occurred, identifying its location and accessing the nature and degree of damage. In contrast, if potential faults could be identified by an appropriate early warning system before a catastrophic fault actually occurs, the chance of power interruption would be greatly reduce. However, few studies have been made concerning early fault detection (EFD) techniques as used by Wong [1]. In a typical power system, the states (voltages and currents) of most bus bar nodes are monitored and gradual changes are analysed. However, in general, because of the complexity of recorded data, faults cannot be easily recognised at an early stage. These faults can often be disguised initially by the complexity of power system operational data. The purpose of using the EFD system is to provide an early warning to the operator when potential faults are identified.

At the heart of the EFD system is a hierarchical ANNs structure [2], comprising a network of ANNs, which can be employed to monitor the states of some important components in power networks, such as switchgear and transformers. Each of the individual ANNs is trained to detect minor changes to a component or a equivalent circuit component in a power system model. In the training process, a sufficient number of training patterns are presented to the ANNs repeatedly until the problem is generalised. A training pattern effectively consists of a series of numbers which inform the ANNs what the outputs states should be when identical, or similar, patterns are presented at the input of the ANN. In this case, the training patterns are the states at both ends of the monitored power system section under slightly different 'known' working conditions. The small variations of voltages and currents resulting from small degradation of component values, at sending and receiving ends of the monitored power system section, can be derived, under simulation, or selected from the power industry recorded data. As some of the equivalent components of a power system model do not physically exist, or are inaccessible, they cannot be measured directly by simple measurement methods. Thus, the application of an intelligent technique, such as an ANN method , is obviously desirable. The principle of the EFD method can be applied to various sections of a power system. A typical over-simplified example will now be given to illustrate this application.

The high voltages and currents carried by transmission lines in power systems are subject to small changes in state, caused by partial faults, often too trivially small to trigger the conventional protection warming systems. However, these small scale changes may develop and eventually lead to major faults. If, for example, the protective layer for an underground transmission line had an undiscovered partial fault, due to road works damage, the cable could become progressively corroded and, in time, its electrical characteristics could change gradually, eventually leading to a short-circuit and this fault could "black-out" a large area. However, for a network with early warning fault monitoring, the interruption of power supply to certain sections of network could possibly be prevented. The gradual change of impedance of the transmission line provides vital information which can be continuously

Presented at IEE Colloquium on "Operational Monitoring of Distribution and Transmission Systems (Digest No. 1997/050)
Savoy Place, London, 28 January 1997

monitored and analysed by the EFD technique to provide an early detection capability. This approach could alert the operator before the main fault actually occurs enabling, in some situations, appropriate action to be taken, e.g. providing power supply from another circuit and switching out the endangered line prior to a more detailed investigation.

CASE STUDIES

A recent paper by the authors (UPEC 96, Crete, Greece [11]), which included a brief review of relevant AI methods[1-10], described a feasibility study using an early warning fault detection method. This earlier paper [11] provided a case study which demonstrated that encouraging results were obtained using this approach to investigate a simulated medium length transmission line. Today's presentation provides an update and describes a further case study relating to an early warning fault detection system as applied to a distribution transformer.

A brief description of this new artificial neural networks approach is reproduced and discussed in Table 1 and Figures 1-3 [11], while Table 2 and Figures 4-5 relate to some updated studies for a distribution transformer. Once again, it is demonstrated that the results of this feasibility case study are encouraging. The likely strategic advantages and possible constraints when using the early warning method, incorporating AI methodologies, will be discussed during the presentation.

FUTURE TREND

As we more towards the next millennium it is anticipated that the challenges of; providing improved services to customers, maintaining or improving the quality of supply, linked with seemingly ever ongoing requirements (set by OFFER et al) for cost effective delivery of power, restructuring of the industry and manpower optimisation (i.e. downsizing) will inevitably result in continued and possibly increased priority being focused on accurate fault location, rapid monitoring and restoration of networks. To this end, the present authors consider that the generic nature of modern network techniques will require to be further developed and there will be a convergence of technologies relating to network planning, fault detection/fault location, energy management systems ,GUI's etc., as applied to electricity, telecommunications, water, gas, industries.

These developments will rely on the increasing availability of high performance relatively low cost computers. It will represent exciting new opportunities for power utilities to use advanced computer based modelling, system analysis and optimisation strategies for the management of systems. It is anticipated that these will range from expert system methodologies, neural networks to the application of object oriented methods to power networks covering switching operations, protection, restoration, fault-diagnosis (for remote monitoring and maintenance), reliability and the integration of advanced Energy Management Systems (EMS), GUI's -- which are becoming increasingly dependent on the effective communication and co-ordination of vast quantities of network state information. Advances in high performance communication systems, LANs, enable large complex systems to be effectively integrated for the purpose of control and monitoring.

An ANN may be considered as a greatly simplified model of the human brain which can be used to perform a particular task or function of interest.[3] The network is usually implemented using electronic components or simulated in software on a digital computer. The massively parallel distributed structure and the ability to learn and generalise makes it possible for ANNs to solve complex problems that otherwise are currently intractable. A brief description of what and how neural networks are being employed is given below. For more information relating to ANNs, see [3-6].

1. Neurons And Synapses

A neuron is an information processing unit that is fundamental to the operation of an ANN. Two basic elements can be identified from a neuron; an adder and an activation function. An adder is used to sum up the input signals, weighted by the respective synapses of the neuron. The activation function limits the amplitude of the output of a neuron. It compresses the permissible amplitude range of the output signal to some finite value [3]. For some gradient descent learning algorithms, such as the Back-Propagation learning method (BP), the activation functions are required to be bounded and differentiable.[4] In this work, the standard sigmoid function was selected which bounds its output range between zero and one.

Synapses are simple connection that can either impose excitation or inhibition on the receptive neuron. Knowledge is acquired by the network through a learning process. The synaptic weights are used to store the knowledge. Through the learning process, the synaptic weights of the network are modified in such a way to map the input patterns to the output patterns. [3]

2. Structure of Artificial Neural Networks

The standard Multi-Layer Feedforward (MLF) network is employed as the network architecture in this project. The MLF network is a network of neurons and synapses organised in the form of layers; the input layer, hidden layer and output layer.

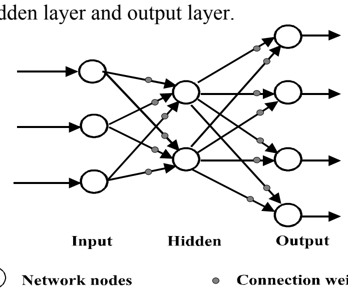


Figure 1. A 3-2-4 multi-layer feedforward network

The function of the input layer is simply to buffer the external inputs to the network. The hidden neurons have no direct connections to the outside world. However, they empower the extraction of higher-order statistics as the network acquires a global perspective despite its local connectivity by virtue of the extra set of synaptic connections and the extra dimension of neural interactions (Churchland and Sejnowski, 1992)[5]. Figure 1 shows the structure of a MLF network.

The source nodes in the input layer of the network supply respective elements of the activation pattern, which constitute the input signals applied to the neurons (computation nodes) in the second layer. The output signals of the second layer are used as inputs to the third layer, and so on, for the rest of the network.

3. Learning Algorithm

The procedure used to perform the learning process is called a learning algorithm, the function of which is to modify the synaptic weights of the network in an orderly fashion so as to attain a desired design objective. Many learning methods have been developed in the last few decades. Detailed information concerning possible ANN learning algorithms can be obtained from [3-5].

Two learning algorithms have been used for this project; the standard back-propagation (BP) method and the genetic algorithm (GA). BP has already been successfully applied by several researchers to solve some difficult and diverse problems by training ANNs in a supervised manner. With regard to the BP method, a training set is applied to the input of the network, signals propagate through the network and emerge as a set of output states. An error term is derived from the difference between the desired and actual output values and synaptic weights are then adjusted in accordance with an error correction rule. As the iteration proceeds, the overall error normally approaches zero.[3]

However, the slow rate of learning and the possible premature convergence are limitations of the standard BP learning method. An alternative to the BP is the GA which is an evolutionary algorithm based on the concept of natural selection and evolution, described in [7], [8]. Evolutionary computing techniques are based upon Darwin's theory of evolution where a population of individuals, in this case potential solutions, compete with one another over successive generations, 'survival of the fittest'. After a number of generations, the best solutions survive and the less fit are gradually eliminated from the population [8]. As the GAs can prevent the local solutions when guided by the parallel search strategy, premature convergence can be avoided. The synaptic weights of ANNs are considered to be the chromosomes of an individual. A population of individuals constitutes a pool of potential solutions.

Chromosomes are traditionally represented by binary numbers and standard crossover and mutation are employed as the reproduction operators under a selection scheme. A mapping process is required to convert binary chromosomes back into real numbers. Each individual (synaptic weights) of the new population will be transferred to the ANNs for evaluation. After the fitness values are calculated, a new generation of weights will be genetically created. This process is repeated many times until the pre-defined precision is met. In many cases, standard GAs cannot be used to solve complex problems [10]. Figure 2 shows a representation of a modified GA training method developed by Wong [1].

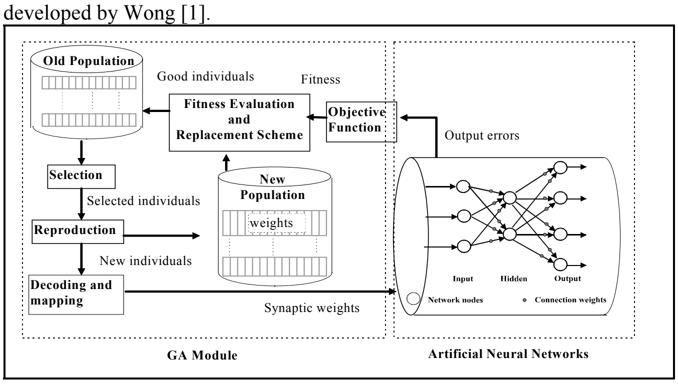


Figure 2. Block diagram of GA training method.

4. Hierarchical Distributed ANNs (HDANNs)

Recently developed HDANNs are advanced neural network architectures [2]. HDANNs consist of several interconnected level of ANNs. The outputs of lower level ANNs are connected to the inputs of higher level ANNs. A typical schematic of a HDANN is shown on Figure 3.

HDANNs manifest a number of superior characteristics over conventional methods, exhibiting faster learning rate, smaller training sets and usually lessen the memory storage required. Most importantly, each of the individual ANNs can be trained separately, 'the divide and conquer approach', with the aid of parallel training, the overall training time can be greatly reduced. HDANNs have been applied to solve multiple fault detection problems in this project. Three independent ANNs are employed to monitor the same section of a power system. Each ANN produces an output identifying the potentially faulty components. The outputs from level 2 are fed into the level 1 (Figure 3) decision making ANNs which will further analyse the output data to produce meaningful instructions for the system operator.

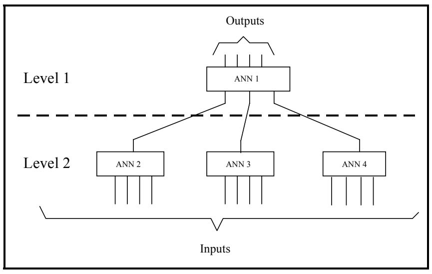


Figure 3. A schematic diagram of HDANNs

TABLE 2 : EXPERIMENTS AND RESULTS.

The characteristics of most passive components of a power systems can be considered to be a system of connected equivalent resistances, inductances or capacitances. An R-L-C equivalent circuit of a distribution transformer was used to construct a model which simulates these characteristics. The schematic diagram is shown in Figure 4. In order to verify the capability and reliability of the early warning fault detection system, the equivalent circuit has been intensively tested under many diverse working condition. Soft faults which are caused by slight changes of one or more impedances were introduced at various location into the R-L-C circuit.

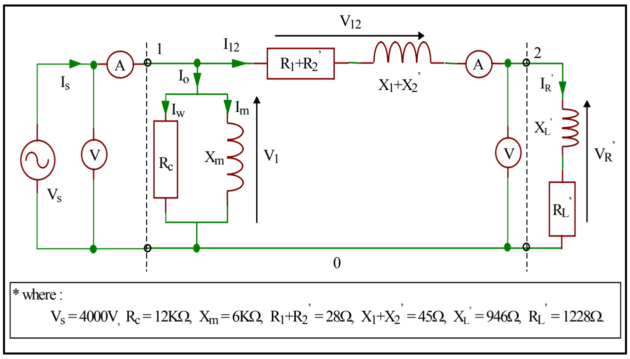


Figure 4. Equivalent Circuit of a Distribution Transformer.

Before the early warning fault detection system can be applied, it must be fully trained. To 'train' the network a training set is applied to the ANN inputs and the learning algorithm invoked so that the output produces the desired response to identify 'soft' faults. Various patterns obtained from different operating conditions are repeatedly submitted to the ANN input units until the problem is fully generalised.

For this example, training patterns for the ANNs unit were constructed based on the following principle. The values of the impedances in the R-L-C circuit were varied in small incremental steps. The changes of impedance of the R-L-C circuit affected states at both the sending and receiving ends of the circuit. By specifying a certain degree of impedance change, for example 10% (see Figure 4 and Figure 5), as a 'soft' fault, the states at both ends of the R-L-C circuit together with a known desired response can be used to form the training pattern for the ANNs unit. The numerical data generated often differs only by very small magnitudes. These relatively small differences in current and voltage values makes it very difficult for the ANNs fault analyser to detect a 'soft' fault state. The solution to this problem is to pre-process the input data for the ANNs unit. A Z-Score pre-processing method, which normalises the data distribution, is applied to maximise the differences among the data. The results from this experiment demonstrated that the pre-processing method is essential to obtain a solution and it also helps to reduce the training process time.

In this example, since soft faults could be occurred at any component in the R-L-C circuit, the magnitudes of V_s, R_c, X_m, R_1+R_2', X_1+X_2', X_L', and R_L' in Figure 4 were all subjected to ±5% to ±50% degradation. When the magnitude of a component was changed by 10% or more, a fault was assumed to exist in that component. In this way, a set of 889 training patterns was carefully selected. The training set was sent to a HDANN structure which consisted of 8 independent ANN units. Each ANN in the lower level was only responsible to monitor a single components and trained separately by standard back-propagation training method. It required from between 13 to 1970 iterations to tune all the ANN units to produce a satisfactory response. The outputs were connected to a final decision making ANN, which further analysed the data and produced more meaningful advice for the system operator.

In the testing phase, the EFD system was examined by over 1500 different testing patterns, in which half had not been seen before. All the test patterns produced very satisfactory responses. Figure 5 shows the comparison curves between the desired and tested responses. As can be seen from the graphs, the desired and corresponding fully simulated results are closely matched with an average accuracy of over 90%. Therefore, it is considered that the system can be used to accurately identify soft fault states.

DISCUSSION

The concept and methods for EFD or soft fault detection has been outlined and tested. The preliminary results presented have been encouraging and show good potential for the algorithm to be successfully implemented in real power system environments. As fault detection is one of the important processes for reliable operation of any power system, an effective soft detection algorithm could eventually become a standard monitoring application essential for power system operational processes.

During the development process of the early warning fault detection system, it was found that adequate data pre-processing is absolutely essential so that ANN units can efficiently trained. The Z-Score pre-processing method employed in these experiments made the training patterns more distinctly different from each other, hence facilitating analysis by the ANN units.

Another important result of this research is the demonstration of the effectiveness use of HDANN, 'the divide and conquer approach'. Instead of employing a single large ANN unit, several small, independent ANNs were employed. The resulting training time required is about ten times less for the multiple fault testing experiment. In addition, each independent ANN unit can be trained separately. In the case of system reconfiguration, only the affected ANNs units need to be retrained.

Evolutionary computing techniques are being evaluated as an ANN optimisation strategy. Preliminary results show that the standard GAs method works very well for simple logic problems, five to ten time better than BP during training. However, as the complexity increases, performance declines markedly and standard GAs are unable to solve most complex analogue electrical problems. The authors can independently confirm the findings of Yao and Liu [10]; which describe the limitations of GAs for ANN applications, (a) the noisy fitness evaluation problem, (b) the permutation problem (competing conventions problem). The use of Evolutionary Programming (EP) algorithms are currently being investigated to avoid standard crossover operators which are not effective due to the permutation problem. In order to improve the learning efficiency of the EP algorithm, operators designed specifically for the problem domain are being devised. Several new EP operators have been developed, and preliminary results are encouraging.

REFERENCES

[1] Wong P.K.C. & Ryan H.M. & Tindle J : "Power System Fault Prediction Using Artificial Neural Networks", International Conference on Neural Information Processing, September 1996.

[2] Kim K H & Park J K : "Application of hierarchical neural networks to fault diagnosis of power systems", International journal of electrical power and energy systems Vol.15, No.2, p65-70, 1993.

[3] Haykin S : "Neural Networks, A Comprehensive Foundation", Macmillan College Publishing Company, 1994

[4] Patterson D.W. : "Artificial Neural Networks Theory and Application", Prentice Hall, 1996

[5] Chunchland P.S. & Sejnowski T.J. : "The Computational Brain", Cambridge, MA : MIT Press, 1992.

[6] Dasgupta D & McGregor D.R. : "Designing Application-Specific Neural Networks using the Structured Genetic Algorithm", Proceeding of COGANN92 (International Workshop on Combinations of Genetic Algorithms and Neural Networks), IEEE Computer Society Press, 1992.

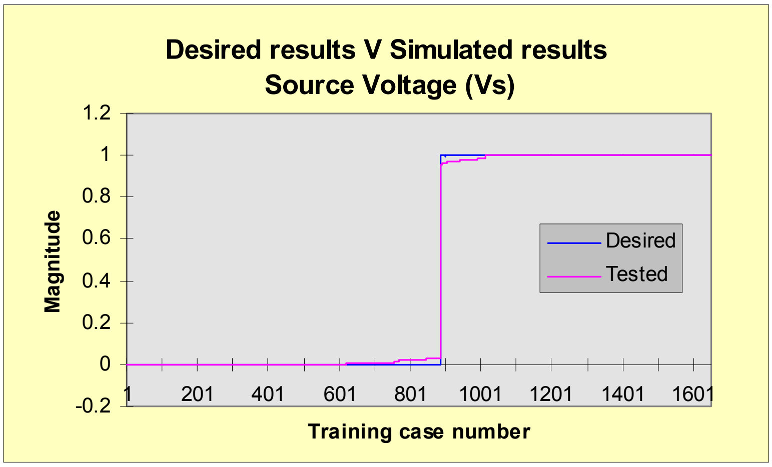
[7] Goldberg D.E. : "Genetic Algorithms in Search, Optimisation & Machine Learning", Addison-Wesley Publishing Company, INC, USA, 1989.

[8] Paul H & Tindle J : "Passive optical network planning in local access network – An optimisation approach utilising genetic algorithms. British Telcom Technology Journal, April, 1996.

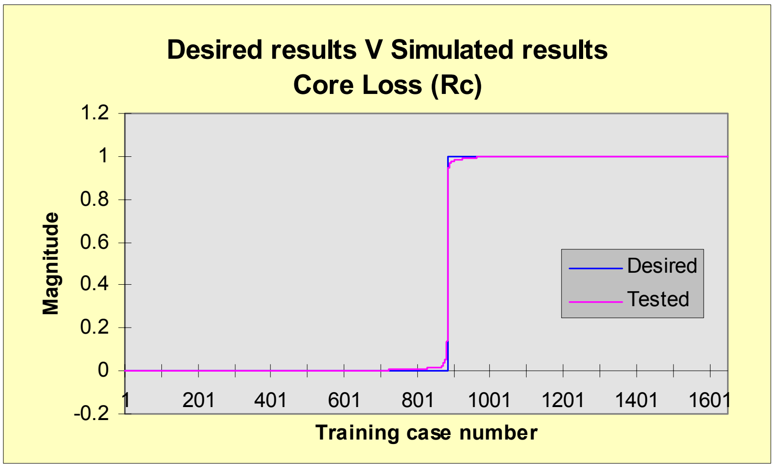
[9] Whitney D & Dominic S & Das R &Anderson C.W, : "Genetic Reinforcement Learning for Neurocontrol Problems", Mechine Learning, Vol 13, P259-284, Kluwer Academic Publishers, 1993.

[10] Xin Yao & Yong Liu, : "Towards Designing Artificial Neural Networks by Evolution", International Symposium on Artificial Life and Robotics, Japan, February 1996.

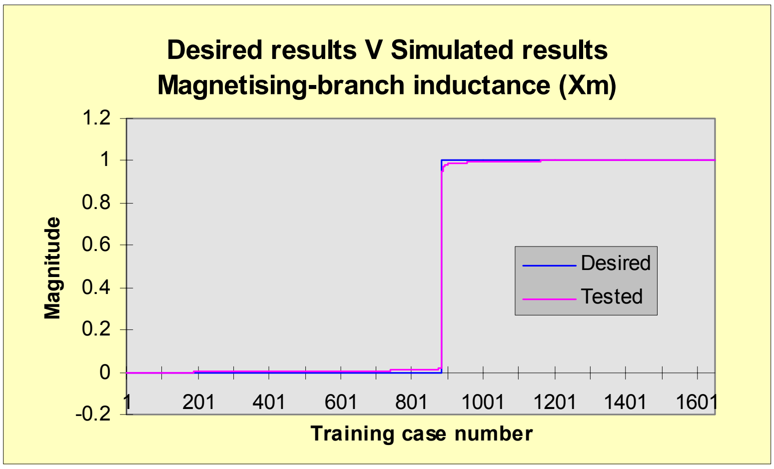
[11] Wong K.C.P. & Ryan H.M. & Tindle J : "Early Warning Fault Detection Using Artificial Intelligent Methods", Universities Power Engineering Conference, Crete, Greece, September 1996.



(a)

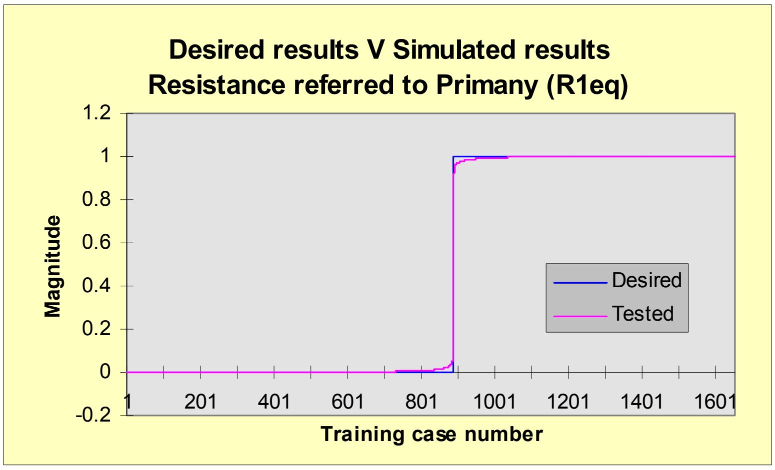


(b)

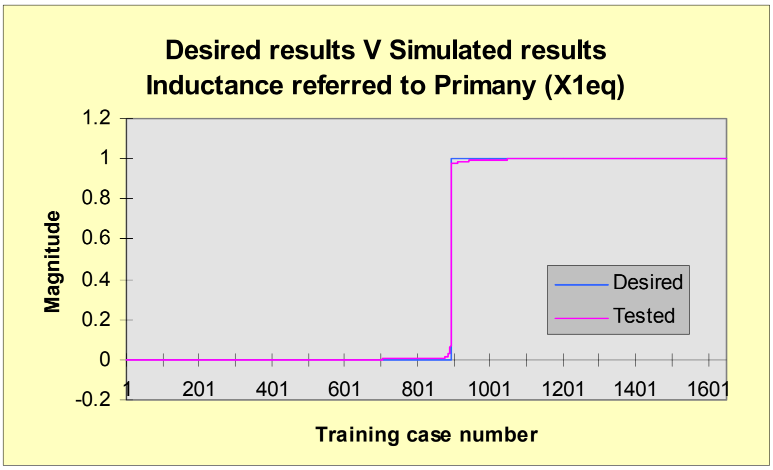


(c)

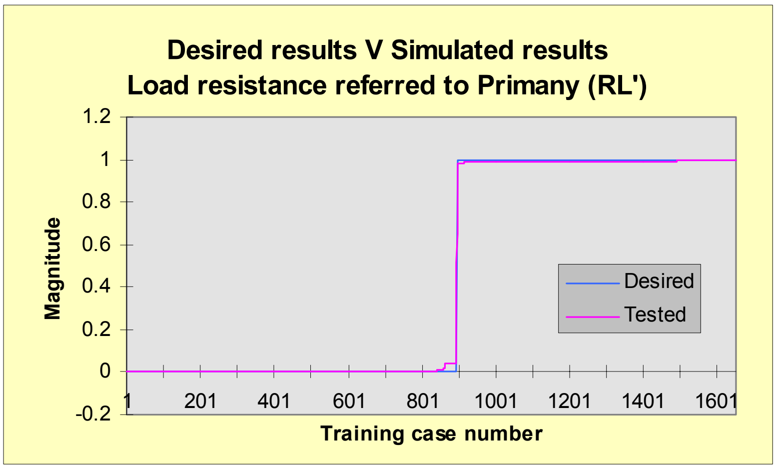
Figure 5. Comparison Between Desired Responses and Tested Responses.



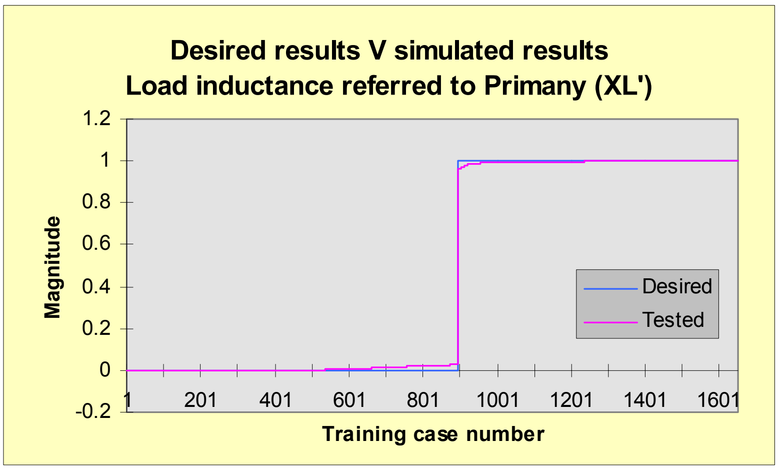
(d)



(e)



(f)



(g)

Figure 5 (continued). Comparison Between Desired Responses and Tested Responses.