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Multi-BP expert system for fault diagnosis of power system

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ABSTRACT

Fault diagnosis and assessment is a crucial and difficult problem for power system. Back propagation neural network expert system (BPES) is an often used method in fault diagnosis. However, with the layer numbers increasing, BPES becomes time consuming and even hard to converge. To solve this problem, we divide the whole networks into many sub-BP groups within a short depth and then propose a novel Multi-BP expert system (MBPES) based method for power system fault diagnosis. We use two real power system data sets to test the effectiveness of MBPES. Experimental results show that MBPES obtains higher accuracy than two commonly used methods.

1. Introduction

In modern times, power system becomes larger and more complex than before. With its fast development, higher demand for the sustainability and stability of power system is of great requirement. However, some common faults in power system have never been resolved very well and are still hindering the stability of power system, such as transmission fault, network distribution fault, power variable fault (Mizutani et al., 2007). Sometimes, even only one fault could destroy the equipments in power system, and might affect the whole power system. An even worse damage could cause conflagration and casualties, and leading to a huge pecuniary loss. Therefore, it is of great significance to do researches for preventing those faults from power system. And fault diagnosis is a powerful tool to guarantee the safety and reliability of power system.

In power system, transformer is a kind of major equipment and plays an important role in power transmission. It can raise voltage so that power can be transported to the user with less loss. On the other hand, the transformer can reduce power into different voltage levels, which can satisfy variety needs of users. Because of its complex structure and function, transformer is tending to cause fault. Unfortunately, transformer fault is very difficult to predict. Moreover, if some accidents take place in transformer, the whole system has no choice but to stop to check and maintain the equipments. Therefore, it is believed that keeping the transformer running in perfect situation plays a key role in power system diagnosis (Lin and Zeng, 2009). High voltage circuit breaker (over 3 kV) is another important element in power system. It has two main functions, namely controlling and protecting. Firstly, it decides when and which parts of the power system should be started or stopped according to the requirements; secondly, when some errors occur in power networks or equipments, the high voltage circuit breaker will quickly break off the error parts from power system, so that other parts can work without influence. In other words, high voltage circuit breaker is able to control the normal current in power lines, and to deal with the overload current, short-circuit current and other abnormal current within a limited time. When a mistake happens in high voltage circuit breaker, it will usually expand to other parts of the power system and finally lead to a worse accident.

There are some classical artificial intelligence technologies have been used in power system fault diagnosis, for example: the expert system (Ma et al., 2010), artificial neural networks (El-madany et al., 2011; Zhu et al., 2006; Huang et al., 2002; Karthikeyan et al., 2005), decision tree theory (Qu and Gao, 2008) etc. In recent years, some new theories have been applied in this field, such as data mining (Athanasopoulou and Chatziathanasiou, 2009), fuzzy set theory (Lee et al., 2000; Zhang et al., 2010), rough set theory (Li and Wang, 2010, Li et al., 2011), petri-network (Yang et al., 2004), support vector machine (Eristi and Demir, 2010), multi-agent systems (Zaki et al., 2007), and so on. Li and Liu had performed a comprehensive review of the above-mentioned methods (Li and Liu, 2010). They pointed out that there are some problems in the existing intelligent fault diagnosis expert system theology, such as the difficulty for knowledge gaining and managing, low on-line usage of fault diagnosis, high error rate, poor efficiency of inference process, and so on. Back propagation neural network (BPNN) expert system is an often used method in fault diagnosis. In real applications, BPNN usually has many layers. However, the training time of BPNN will grow exponentially with the layer number increasing. While more serious problem is that it is difficult to converge when BPNN has a large number of layers. Another problem is that the diagnostic accuracy

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of BPNN is still not satisfied. To solve those problems, we propose a so called multi-BP expert system (MBPES) method. In MBPES, the whole BPNN networks are divided into many sub-BP groups within a short depth, saying about 5 layers. In this manner, the consumed training time is greatly reduced and it is easy to achieve the convergence of the training process.

In the experiments, we firstly compare the performance of BPNN with different number layers according to a XOR problem. Numerical results show that when the layer number is more than 6, BPNN is very time consumed and even hard to converge. To test the effectiveness of the proposed MBPES method, it is applied to two real power system data sets, namely that the transformer data set and high voltage circuit breaker data set. Experimental results show that MBPES is very efficient, and it is more accurate than two other compared methods.

2. Back propagation expert system

Back propagation (BP) algorithm is one of the most classical and successful learning methods of feed forward artificial neural network, which is based on gradient descent algorithm. For its success, those feed forward neural networks using BP algorithm are always called BPNNs. Fig. 1 shows an architecture of BPNN model with K hidden layers. There are n nodes in the input layer, which is corresponding to the sample vector's dimension. And the inputs of the input layer are the components of the sample's vector. Denote the node's number of the jth hidden layer as N_j, then the outputs of first hidden layer are

$$Y_j^1 = \frac{1}{1-(\sum_{i=1}^{n} X_i \cdot w_{ji}^1)} \quad j=1,\ldots,N_1 \tag{1}$$

And the outputs of the other hidden layers are

$$Y_j^k = \frac{1}{1-(\sum_{i}^{N_{k-1}} Y_i^{k-1} \cdot w_{ji}^k)} \quad k=2,\ldots,K; \quad j=1,\ldots,N_k \tag{2}$$

Suppose the related problem has m expected outputs, then the output layer should have m nodes, and their outputs are

$$Z_j^1 = \frac{1}{1-(\sum_{i=1}^{N_K} Y_i^K \cdot w_{ji}^O)} \quad j=1,\ldots,m \tag{3}$$

Here w_{ji} is the weight between the jth node of one layer and the ith node of its former layer. The weights should be trained before application. The training method could be referred to Rumelhart et al. (1986).

BPNN also can be used as an expert system, which is called back propagation expert system (BPES). In BPES, the rules with the form of IF-THEN in knowledge database are represented by the weights of networks. An example of BPNN expert system is shown as Fig. 2. In the networks, the nodes represented by rectangles are the antecedents or consequents of the rules, while the nodes represented by circles are corresponding to the rules. The initial structure of the networks is generated by rules in knowledge database, as well as the values of the weights. If we could obtain enough known sample data, the weights can be improved by training process, even the topology of the networks might be amended. The training algorithm is the same as that of BPNN.

In BPES networks, each rule creates a 3-layer sub-network. The first layer represents the antecedents of the rule, the second layer represents the transform relationship including only one node, the third layer represents consequent of the rule, also including one node. Therefore, the nesting of different rules may extend the length of the network structure. Unfortunately, it is often the case in the knowledge database. However, when the BPNN networks have more than 5 layers, the training time and iteration number will grow exponentially and even hard to converge. To solve such problem, a called Multi-BP Expert System (MBPES) is proposed in this paper, in which the networks are divided into sub-networks with small scale.

3. Multi-BP expert system (MBPES)

3.1. The structure of MBPES

In a BPNN, a rule is corresponding to a substructure of the networks with 3 layers. Accordingly, 2 and 3 nested rules are corresponding to a substructure with 5 and 7 layers, respectively. Because those BPNN networks with more than 5 layers are difficult to train and even hard to converge, we divide the whole networks into sub-networks with 5 or less layers. Fig. 3 shows the division of a BPNN in serial structure.

However, in real applications, rules are not always nested in serial. For example, the inputs of a rule might be the outputs from other 2 or more rules. For 2 independent rules, the accordingly sub-networks are in parallel. Moreover, the inputs of a rule could come from different rules in different layers. For such a complicated BPNN, we also need to divide it into sub-networks with 5 or less layers, namely that Multi-BP expert system (MBPES). A classical structure of MBPES is depicted as Fig. 4.

3.2. The construction algorithm of MBPES

Given a knowledge base, the structure of the MBPES should be determined firstly. To begin with the construction algorithm of

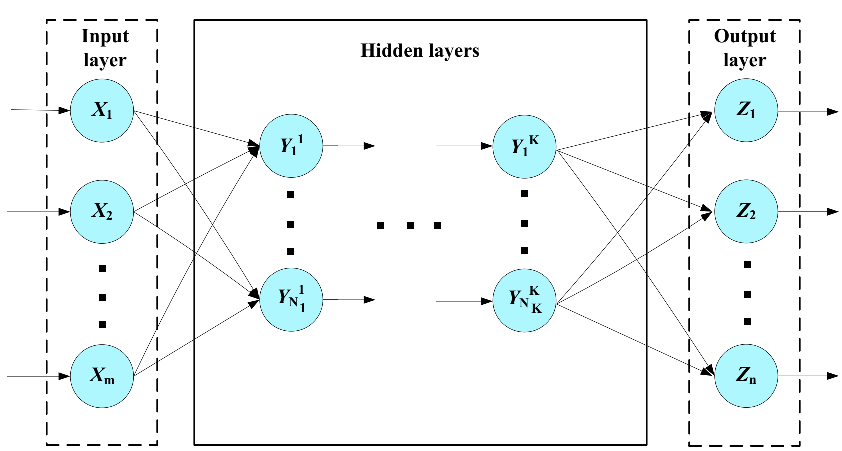

Fig. 1. Architecture of BPNN.