Comprehensive monitoring cycle classification of centralized monitoring substations based on knowledge map and competitive neural network

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Abstract. The influencing factors of the comprehensive monitoring cycle of the centralized monitoring substation are analyzed, including the voltage level of the substation, the frequency of centralized monitoring defects, equipment operation situation, the importance of the substation, the operation environment and the average load of the equipments. Those information can be obtained by constructing the knowledge map of centralized monitoring. On this basis, a comprehensive monitoring cycle classification method based on competitive neural network is proposed, and machine learning method is used to achieve a scientific and reasonable classification of comprehensive monitoring cycle of the substations. The simulation results show that the method is feasible and effective.

1. Introduction

Comprehensive monitoring of substation refers to the comprehensive inspection of centralized monitoring substations by the on duty supervisor, which includes the operation condition of substation equipment. The time requirement for comprehensive monitoring is at least twice for each value of 330kV and above substation and at least once for each value of 220kV and below substation. For the power supply company, the operation condition level, operation characteristics and the possibility of defects of each substation are different. The same comprehensive monitoring cycle is not conducive to improve the efficiency and management level of centralized monitoring.

"Tianjin electric power company monitoring operation management regulations" pointed out that "under the following circumstances, the on duty supervisor should strengthen the monitoring of relevant controlled substations and equipment, shorten the monitoring cycle: new equipment put into operation; serious defects occur to the equipment; in case of thunderstorm, gale, fog, hail and other bad weather..." This regulation only aims at the special situation of power grid or equipment operation, and does not explain how to determine the monitoring cycle of each substation under normal conditions. With the development of social economy, the number and scale of substations are constantly expanding. The comprehensive monitoring cycle of centralized monitoring substations should be differentiated. The monitoring of substations with high importance and many hidden dangers should be strengthened. The limited human resources on duty should be used to complete the growing workload of substation monitoring.

Based on the analysis of the influencing factors of comprehensive monitoring cycle of centralized monitoring substations and constructing the knowledge map of centralized monitoring to obtain the
above information, this paper proposes a classification method of comprehensive monitoring cycle of centralized monitoring substations based on competitive neural network. According to the inherent attributes of each substation, the comprehensive monitoring cycle is classified by using artificial intelligence, so as to improve the quality and efficiency of centralized monitoring and improve the reliability of power grid operation.

2. Influencing factors of comprehensive monitoring cycle

The influencing factors of comprehensive monitoring cycle of centralized monitoring substations include the following aspects according to the influence from large to small:

1. Voltage level of substation. The higher the voltage level is, the larger the power supply area of the substation is, and the greater the pivotal role it plays in the power grid. Accordingly, the comprehensive monitoring cycle should also be shorter.

2. Frequency of centralized monitoring defects. The centralized monitoring defects include the centralized monitoring defects that can be found through the alarm window of the monitoring system and the centralized monitoring defects that cannot be found through the alarm window. For example, the “abnormal protection device” signal action of a switch, the “light gas alarm” signal action of a main transformer, etc., for example, the telemetry value of a bus voltage can not be refreshed normally, the remote adjustment of a main transformer tap fails, and the telemetry value of main transformer oil temperature is abnormal, etc. If the centralized monitoring defects are not found and handled in time, it may cause serious consequences such as substation equipment fault trip, protection override action, substation full stop and so on. Therefore, the higher the frequency of centralized monitoring defects, the more monitoring should be strengthened.

3. Equipment operation condition. If the equipment has defects but has not been eliminated (not exceeding the time limit for defect elimination), some pre-test data are close to, meet or exceed the attention value in the regulations, the equipment has bad working condition records[1], or the equipment has a long service life, the comprehensive monitoring cycle should be shortened.

4. Importance of substation. The importance of substation mainly depends on the level of power supply and whether there are important users, sensitive users, electric heating users, flood control users and other power users. The higher the level of power supply in the area where the substation is located, the higher the requirements of users on the reliability of power supply of power grid, and the more serious the consequences caused by equipment fault tripping or forced outage due to defects and other reasons. Therefore, it is necessary to strengthen the monitoring, that is, to arrange a shorter comprehensive monitoring cycle.

5. Operation environment of substation. According to the operation experience, the probability of defects of indoor equipment is significantly lower than that of outdoor equipment. If the substation is an outdoor station, the surrounding environment is relatively bad, or it is in a heavily polluted area and ice area, and often suffers from strong wind, thunderstorm, ice and snow and other weather, it is necessary to strengthen the monitoring and shorten the comprehensive monitoring cycle.

6. Average load of substation equipment. The higher the average load rate of the equipment is, the greater the possibility of defects such as the lower limit of bus voltage and the oil temperature of the main transformer exceeding the allowable value is. Accordingly, the comprehensive monitoring cycle should be shortened, and the hidden dangers should be found and eliminated in time.

The above factors can be obtained by constructing the knowledge map of centralized monitoring.

3. Construction of knowledge map of centralized monitoring

Knowledge map is a knowledge base in essence, and it is a knowledge network that connects entities and attributes through relationships. The basic unit of knowledge map is entity relation entity or entity relation attribute triplet. When knowledge map is represented as graph, entity and attribute exist as nodes, and relationship exists in the form of directed edge connecting two nodes. These triples are combined by common entities or attributes to form knowledge maps with network structure.
Combined with the business requirements of equipment state perception, the key data information of EMS, OMS, monitoring big data, monitoring eventualization, regulation cloud, power grid topology, fault recording and other systems, the knowledge map of centralized monitoring can be built automatically.

The specific steps are as follows: Data preprocessing based on multi-source data is realized by data processing methods such as redundant data cleaning and abnormal data processing; By extracting entity and relationship knowledge from the processed data, the knowledge extraction method based on supervised learning is realized; Through the knowledge storage of extracted entities, attributes and relationships, and knowledge reasoning by using data mining algorithms, knowledge fusion and graph construction are realized; By regularly importing D5000, control cloud, OMS and other system data information, and comparing the changes of plant, station, equipment and other information, the atlas knowledge base is dynamically updated.

At the same time, the information related to the equipment and the topological connection relationship of the equipment in the power grid, such as the type of equipment, the voltage level of the equipment, the power supply company using the equipment, the manufacturer of the equipment, the characteristic parameters of the equipment, the faults and defects of the equipment, the equipment installation plant and lines, are set as nodes, and the relationship between the equipment node and other nodes is set. Such as "voltage level", "installed in", "manufacturer is" and "occurrence" are set as the sides to build a schema with equipment as the core to facilitate the conversion of data from relational data format of table to graph database format. Based on graph data storage, a comprehensive and easy-to-use knowledge base for quality evaluation of power equipment is established, including various supervision and management data such as original account information of power equipment provided by power grid production management system (PMS), defects in operation, non-stop faults and familial defects information, sampling inspection and supervision information, quality rating guidelines, etc, And CIM / E data provided by power grid dispatching automation system (control cloud), including the connection status of stations, lines and related equipment, as well as the operation and maintenance data of power equipment.

Through the data preprocessing method mentioned above, entity recognition can be realized by using the detection and classification of supervised learning. Based on the regulatory cloud, D5000, monitoring big data and monitoring, through the analysis of equipment status and business, the key attribute of equipment status is extracted and defined as equipment tag. The specific entity selection and storage label fields are shown in Table 1.

| Entity type        | Storage label field                                  |
|--------------------|-----------------------------------------------------|
| Substation         | Substation_ID, Voltage_level, Dispatching_organization |
| Transformer        | Transformer_ID, Transformer_name, Substation_ID, Substation_name, Transformer_Operation_time |
| Disconnector       | Disconnector_ID, Disconnector_name, Substation_ID, Disconnector_Operation_time |
| Connection point   | Device_full_name, Device_ID, Device_name, First_node_ID, Second_node_ID, Substation_name |
| Overhaul           | Overhaul_name, Blackout_equipment, Work_content, Work_unit, Overhaul_ticket_type |
| Defect             | Defect_name, Substation_name, Occurrence_time, Defect_description, Defect_equipment |
4. Competitive neural network
The competitive neural network has only two layers, and its structure is shown in Figure 1. The output layer of competitive neural network is also called the core layer. \(x_1, x_2, \ldots, x_m\) are input neurons, \(y_1, y_2, \ldots, y_n\) are output neurons. In a calculation, only one output neuron wins, the winning neuron is marked as 1, and the other output neurons are marked as 0 [2]. At first, the weights from the input layer to the output layer are given randomly, and each output layer neuron has the same probability of winning, but at last, it will produce an output neuron with the strongest excitation. In the process of weight adjustment, the excitability of this neuron is further enhanced, while the excitability of other neurons remains unchanged. Competitive neural network obtains the distribution information of training samples in this way. Each training sample corresponds to a winning neuron.

![Fig. 1. Structure of competitive neural network](image)

The learning rule of competitive neural network is the Kohonen rule developed from the inner star rule [3]. Its basic principle is as follows: suppose that the input layer of the network contains \(m\) input neurons \(x_1, x_2, \ldots, x_m\), and the input vector is \(X = [x_1, x_2, \ldots, x_m]\), that is, each sample is an \(m\)-dimensional vector. The output layer contains \(n\) output neurons \(y_1, y_2, \ldots, y_n\), and the output vector is \(Y = [y_1, y_2, \ldots, y_n]\). The network weight \(\omega\) is an \(m \times n\) matrix. The relationship among them is as follows

\[
Y = X \omega
\]

One of the \(n\) output neurons must get the maximum value and become the winning neuron. Assuming that the winning neuron is \(y_k\), the corresponding weights are adjusted according to formula (2) [2]

\[
\Delta \omega_k = \eta (x_i - \omega_k) y_k
\]

\(\eta\) is the learning step. The network weight is close to the input sample value \(x_i\) as the learning step \(\eta\). In the next round of calculation, \(y_k\) becomes the winning neuron with a higher probability. When the appropriate value is taken, the network weight is equal to the input sample vector after gradual learning. The competitive neural network continues to receive other input samples, each sample corresponds to a winning neuron, and the corresponding weight vector is adjusted to the direction of the input vector. Similar input samples correspond to the same winning neuron, indicating that they are divided into the same class; The corresponding weights of the neuron are adjusted to the direction of each input vector, and finally stabilized to the average value of the input vector [2].

5. Comprehensive monitoring cycle classification method of centralized monitoring substation based on competitive neural network
It can be seen from the discussion in Section 2 that the influencing factors of comprehensive monitoring cycle of centralized monitoring in substation include voltage level of substation, frequency of centralized monitoring defects, equipment operation condition, importance of substation, operation environment of substation and average load of equipment. The comprehensive monitoring cycle of centralized monitoring substation can be classified according to the following steps.

The first step is to quantify the above six factors. In terms of voltage level, the voltage level indexes of 220kV, 110kV and 35kV substations are defined as 4, 2 and 1 respectively. In terms of the frequency of centralized monitoring defects, the frequency index of centralized monitoring defects is defined as the average number of centralized monitoring defects per year after the substation is put into operation. In terms of equipment operation, the initial value of equipment operation index of all
Substations are defined as 0. 1 and 0.5 will be added when there is a serious defect or a general defect but the defect is not eliminated. 0 ~ 1 will be added when there is potential operation hazard. 1 and 0.5 will be added when the operation period of main equipment such as transformer, bus and circuit breaker is more than 20 years, 10 ~ 20 years, 5 ~ 10 years and less than 5 years 0.25, 0.125. As for the importance of substations, the initial value of the importance index of all substations is defined as 0. The power supply level of the area is A+, A, B, C, D and E plus 1, 0.5, 0.25, 0.125, 0.1 and 0.075 respectively. For each important user and sensitive user, 0.5 and 0.25 are added, and for each electric heating user and flood control user, 0.1 is added, Add 0.1 ~ 0.5 for each other power guarantee user. In terms of substation operation environment, the initial value of operation environment index of all substations is defined as 0. For outdoor stations and indoor stations, 1 and 0.5 are added respectively. For outdoor stations, 0 ~ 1 is added depending on the severity of surrounding environment, and 0 ~ 1 is added depending on the local climate. For the average load of equipment, when the average load rate of transformer is above 0.75, 0.5 ~ 0.75, 0.25 ~ 0.5 and below 0.25, the average load index of equipment is 4, 2, 1 and 0.5 respectively. It should be noted that each power supply company can determine the scoring standard of each index according to its own characteristics and power supply requirements. Each substation can be represented by a six dimensional eigenvector through the above index quantization method

$$S_i = [s_{i1}, s_{i2}, s_{i3}, s_{i4}, s_{i5}, s_{i6}]$$ (3)

Where $S_i$ is the eigenvector of the $i$th substation; $s_{i1}, s_{i2}, s_{i3}, s_{i4}, s_{i5}, s_{i6}$ represents the voltage level index, centralized monitoring defect frequency index, equipment operation index, importance index, operation environment index and average load index.

The second step is to establish competitive neural network. According to the literature [4, 5], the inspection cycle of substation should be classified into 3 to 5 categories, and the comprehensive monitoring cycle of the corresponding on duty monitor should also be divided into 3 to 5 categories. In this paper, the comprehensive monitoring cycle of substation centralized monitoring is divided into four categories. Each power supply company can reasonably select the number of categories according to the actual situation and characteristics. Since the dimension of the input vector is 6, the number of input layer neurons is set to 6. Network competition layer selection 2×2 hexagon structure, that is, the final number of categories is 4. The competition layer of the network consists of four nodes. After training, each input vector, that is, each substation, belongs to a competition layer node.

The third step is to use MATLAB toolbox function competlayer to achieve competitive neural network clustering. The code is as follows:

```matlab
x0=[s_{11}, s_{12}, s_{13}, ..., s_{16};
    s_{21}, s_{22}, s_{23}, ..., s_{26};
    s_{31}, s_{32}, s_{33}, ..., s_{36};
    ...
    s_{16}, s_{26}, s_{36}, ..., s_{66}];
net=competlayer(4);
et.trainParam.epochs=400;
tic
net=train(net,x0);
Toc
y=net(x0);
classes=vec2ind(y)
```

The fourth step is to determine the comprehensive monitoring cycle of each substation according to the classification results given by the competitive neural network.

6. Conclusion
In this paper, aiming at the problem of differential determination of comprehensive monitoring cycle of centralized monitoring substations, the influencing factors of comprehensive monitoring cycle are analyzed firstly, which include voltage level of substation, frequency of centralized monitoring defects,
equipment operation condition, importance of substation, operation environment of substation and average load of equipment. The higher the voltage level is, the higher the frequency of centralized monitoring defects is, the worse the equipment operation is, the higher the importance of substation is, the worse the operation environment is, and the higher the average load rate of equipment is, the more monitoring efforts should be strengthened to shorten the comprehensive monitoring cycle.

By combing the key data information of EMS, OMS, monitoring big data, monitoring eventualization, control cloud, grid topology, fault recording and other systems, the knowledge map of centralized monitoring can be constructed to obtain the above influencing factors information.

A classification method of comprehensive monitoring cycle for centralized monitoring substation based on competitive neural network is proposed. The steps can be summarized as follows: quantifying the six influencing factors of comprehensive monitoring cycle, obtaining the eigenvectors representing the influencing factors of comprehensive monitoring cycle of each substation; a competitive neural network is established, the number of neurons in input layer is 6, and the number of neurons in output layer is the number of categories to be classified in the comprehensive monitoring cycle of substation; the competlayer function of MATLAB toolbox is used to realize the competitive neural network classification; according to the classification results given by the competitive neural network, the comprehensive monitoring cycle of each substation is determined.

This method can use the competitive neural network to realize the scientific and reasonable classification of the comprehensive monitoring cycle of centralized monitoring substations, and provide technical support for the power supply company to arrange the comprehensive monitoring cycle.

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