Application of edge computing in fault diagnosis of 10kV ring net switch cabinet

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Abstract. To ensure the safe and reliable operation of the distribution network system, this paper analyzes the fault diagnosis of 10kV ring net switch cabinet, introduces the concept and advantages of edge computing, and then proposes a new fault diagnosis system of 10kV ring net switch cabinet based on edge computing. This paper also introduces the overall design of the system and the design of each part, and finally makes a contrastive analysis with the traditional fault diagnosis methods of the ring net switch cabinet.

1. Introduction

With the continuous development of the economy, the impact of electric energy on daily life is growing. At present, the urban power supply model has gradually changed from the overhead line power supply to the underground cable power supply. The outdoor ring net switch cabinet is generally used for power transmission and distribution. 10kV ring net switch cabinet has become an important node of urban distribution network. 10kV ring net switch cabinet has the advantages of good closure, high insulation, small size, low production cost, convenient maintenance and good economic benefits. The operational status of the distribution network is directly related to the stability of the whole power grid. Therefore, it is of great significance to detect the real-time fault of 10kV ring net switch cabinet.

To detect the real-time faults of the ring net switch cabinet, it is necessary to measure the parameters of the ring net switch cabinet by using multiple sensors. By processing and analyzing the variable data collected by the sensors, we can judge whether the ring net switch cabinet has faults. But the traditional methods mostly aim at the single variable of the ring network switch cabinet, such as temperature, humidity, partial discharge and so on, which can not reflect the operational status of the whole ring net switch cabinet. There is a certain correlation among the variables of the operational state of the ring net switch cabinet. Comprehensive monitoring and analyzing of the multiple variables can reflect the operational status of the ring net switch cabinet more comprehensively and accurately than the traditional fault diagnosis methods. In this paper, a fault diagnosis system for 10kV ring net switch cabinet based on edge computing is proposed. Various parameters collected by sensors are input into the edge gateway. Edge gateway is an intelligent gateway based on edge computing, which can store and synthetically analyze all kinds of variable data collected by sensors, and then judge the running state of the ring net switch cabinet.
2. Edge computing
With the rapid development of artificial intelligence, Internet of Things, big data and other technologies, profound changes have been brought to the Internet and industrial users, and new requirements have been put forward for computing models. The current computing model is mainly cloud computing. Cloud computing is a kind of computing model that pays for its usage. This mode provides available, convenient and on-demand network access, and this mode can access to the configurable computing resources sharing pool. These resources can be provided quickly. Users only need to invest a little management work or interact with service providers to make it possible to use. The cloud computing model is based on a data sharing center with powerful computing and storage capabilities. All data computing and storage are implemented in the data sharing center, and no other computing and storage resources are needed.

However, with the increasing intelligence of the Internet of Things devices and the increasing number of intelligent devices, the amount of data generated by them is also increasing. Simply relying on Cloud Computing Center for data processing can not meet the needs of the Internet of Things. The shortcomings of cloud computing in dealing with real-time data and unable to make rapid decisions are beginning to emerge. Aim at these problems, many enterprises and research centers began to seek a new computing model to solve these problems, and edge computing came into being.

Edge computing is a new computing model. Edge computing refers to a new kind of network architecture and open platform that integrates network, computing, storage and application core competence at the edge of the network where close to people, objects and data sources. Compared with the traditional cloud computing model, edge computing changes the way of centralized cloud computing processing to the way of moving storage and computing capabilities down to the edge of the network and providing intelligent services nearby. Edge computing can realize real-time processing of large data of industrial edge equipment, reduce the real-time and security problems caused by data transmission, reduce the bandwidth occupied by data transmission, reduce the power consumption of terminal equipment used for communicating with the cloud, and effectively improve the efficiency of data storage and processing.

3. Design and implementation of the system
As shown in figure 2, the proposed fault diagnosis system is mainly composed of a cloud computing center, an edge gateway, ring net switch cabinet monitoring devices and ring net switch cabinets.
The monitoring device of the ring net switch cabinet is equipped with various types of sensors to monitor the operating state parameters of the ring net switch cabinet, including temperature, humidity, partial discharge and other parameters. The state parameters collected by the sensors are transmitted to the edge gateway. The monitoring device of ring net switch cabinet uses RS485 bus to transmit data information, and the monitoring device accesses the industrial Ethernet and cloud computing center through the edge gateway. The edge gateway stores and synthesizes the collected parameters, and then compares them with the fault model data. If the collected parameters conform to the established fault model, it indicates that a fault has occurred, so as to realize the fault diagnosis and send the results to the cloud computing center. Users can understand the operational status of the ring net switch cabinet through the mobile communication equipments connected with the cloud computing center. Local users can query the operational status of the ring net switch cabinet through the interactive terminals based on Web Servers in the factory private LAN.

3.1 Design of monitoring device for ring net switch cabinet

As shown in figure 3, the monitoring device of the ring net switch cabinet is composed of temperature sensors, humidity sensors, current sensors, data acquisition unit and RS485 bus. The temperature sensors include an environment temperature sensor, a bus room temperature sensor, a switch room temperature sensor, a cable room temperature sensor and a baffle temperature sensor, which are used to monitor the temperature of each compartment and external environment of the ring net switch cabinet. The humidity sensors include an environmental humidity sensor, a bus room humidity sensor, a switch room humidity sensor, a cable room humidity sensor and a partition humidity sensor, which are used to monitor the humidity of each compartment and external environment of the ring net switch cabinet. The current sensor is used to monitor bus current and partial discharge parameters of the ring net switch cabinet. The environmental temperature sensor, the bus room temperature sensor, the switch room temperature sensor, the cable room temperature sensor and the baffle temperature sensor are connected with the temperature acquisition module of data acquisition unit; the environmental humidity sensor, the bus room humidity sensor, the switch room humidity sensor, the cable room humidity sensor and the baffle humidity sensor are connected with the humidity acquisition module of data acquisition unit; the current sensor is connected with the current acquisition module of data acquisition unit. The data acquisition unit is responsible for the processing of temperature, humidity and current signals, and realizing the operation of amplification, A/D conversion, data storage and transmission.
sampling, signal conditioning and data processing of weak current signals. The data acquisition unit is connected with the edge gateway by RS485 bus.

![Fig 3. Structure diagram of the monitoring device for ring net switch cabinet.](image)

### 3.2 Edge gateway

To realize edge computing, the edge gateway is introduced near the terminal of the device. Edge gateway is an intelligent gateway based on edge computing. It is an industrial computer. Its function is to store and synthesize the operational data of the ring net switch cabinet collected by sensors, and to compare with the fault model established to evaluate the operation status of the device. In this paper, we use the neighborhood preservation embedding algorithm to construct the structural feature model of the ring net switch cabinet in the edge gateway and realize the on-line fault diagnosis of the ring net switch cabinet.

#### 3.2.1 Neighborhood-preserving embedding algorithm

NPE algorithm is based on the idea of local linearity of data, and its overall manifold structural features are obtained by describing the local features of data. The algorithm constructs the projection matrix by constructing the reconstruction weight between each sample point and its neighborhood points and maintaining the objective function of the weight vectors. Geometrically speaking, any surface manifold can be joined by local linear blocks of different sizes. Therefore, in every small neighborhood, the data can be approximated by a linear model. NPE uses the reconstructed weight vectors constructed between each sample point and its neighborhood points to find the hidden low-dimensional manifold information in the original variable space. NPE reduces the dimension of the data by maintaining the weight of each neighborhood in the low-dimensional space to obtain the irrelevant feature information about the original data.

Under the assumption of local linearity, NPE firstly uses the linear combined weight of each data sample point and its nearest neighbor points to represent its local geometric structure. Its optimization goal is that the data points after dimensionality reduction can still be reconstructed with the same weight. We set up \( n \) training data points set \( X(x_1, x_2, \ldots, x_n) \in \mathbb{R}^D \). Firstly, the K-nearest neighbors (K-NN) method is used to determine the nearest neighbor points \( \{x_j\}_{j=1}^{k} \) from near to far for each sample point \( x_i \). The reconstruction coefficients of each sample point are obtained by linear reconstruction of neighboring points. The reconstruction coefficient matrix \( W \) is obtained by minimizing the reconstruction error of formula (1):
\[ \phi(W) = \sum_{i} \left\| x_i - \sum_{j=1}^{n} W_{ij} x_j \right\|^2 \] (1)

In the formula: \( W_{ij} \) is the proportion of data point \( x_j \) when \( x_i \) is reconstructed in the \( k \) neighborhoods of \( x_j \), \( \sum_{j=1}^{n} W_{ij} = 1 \). Each data point is reconstructed only by its nearest neighbor point. When \( x_j \) is not in the neighborhood of \( x_i \), \( W_{ij} = 0 \).

The goal of the NPE algorithm is to find a set of projection vectors: \( a_1, a_2, \ldots, a_d \). The projected low-dimensional space \( Y(y_1, \ldots, y_n) \in R^d (d \leq D) \), which has a similar local structure to the original space. Mathematically, the target is transformed into each data point that can still be reconstructed by its corresponding adjacent points with the same weight. The projection matrix is obtained by the minimum value of formula (2):

\[ \phi(a) = \sum_{i,j} (y_i - \sum_j W_{ij} y_j)^2 = Y^\top (I - W)^\top (I - W) Y = a^\top XX^\top (I - W) (I - W)^\top Y = a^\top XX^\top a \] (2)

In the formula: Matrix \( M \) is \( (I - W)^\top (I - W) \), and the constraint is \( Y^\top y = a^\top XX^\top a^\top = 1 \). Based on this constraint condition, the new \( d \) low-dimensional feature variables are not correlated with each other after dimensionality reduction of multivariable data.

Based on the objective function and constraints, the ultimate goal of NPE algorithm is converted to the problem of solving matrix \( A \) in formula (3):

\[ XX^\top a = \lambda XX^\top a \] (3)

\( XX^\top \) and \( XX^\top \) are positive definite matrices. For solving the generalized eigenvalue problem of formula (3), \( d \) eigenvalues \( (\lambda_1 \leq \lambda_2 \leq \ldots \leq \lambda_d) \) are obtained. The eigenvectors corresponding to \( d \) eigenvalues form a projection matrix \( A = (a_1, a_2, \ldots, a_d) \).

The goal of the NPE algorithm is to remove the correlation of the original data and obtain independent variables after dimensionality reduction, and at the same time, to preserve the local spatial information of the original data to the greatest extent. Neighborhood preservation of the NPE algorithm shows that the position relationship of the nearest point in the original space is still close after it being projected to the low-dimensional space, and the data point far from the space is still far after it being projected. As a linear dimension reduction algorithm based on local data structure, NPE can effectively mine the local feature geometry structure between adjacent points, and obtain the changing relationship of the global structure of complex data by overlapping the neighborhood data.

3.2.2 Model implementation. To realize data modeling, the system firstly collects multi-variable measurement data of the ring net switch cabinet under normal conditions, such as environmental temperature, humidity, cable joint temperature, cable core temperature, CO gas volume, cable current and other information obtained by the sensors, as well as the public air temperature, humidity, wind speed, wind direction, sunshine intensity, user power load and other information. The collected data form a data set matrix \( X(x_1, x_2, \ldots, x_n) \in R^{n \times D} \). Among them, \( D \) is the dimension of measurement data, it is the number of process variables. The data are stored in the historical database and transmitted to the data monitoring center. The data monitoring center stores, backs up and preprocesses the data of the ring net switch cabinet and the public meteorological information. The processed data form a new training data set \( \tilde{X} \in R^{n \times D} \). The neighborhood preservation embedding algorithm is used to model data \( \tilde{X} \). Based on the objective function of formula (1), the following local optimal weight matrix \( W \in R^{n \times n} \) is constructed for training data \( \tilde{X} \).
\[ W'_{ij} = \frac{\sum_{m=1}^{k} (Q')_{jm}}{\sum_{q=1}^{r} \sum_{j=1}^{k} (Q')_{pq}} \]  

(4)

In the formula: \( Q'_{jm} = (x_i - x_j)^T (x_i - x_m) \), \( x_j \) \((j = 1, 2, \ldots, k)\) are the \( k \) nearest neighbors of \( x_i \), \( W'_{ij} \) are the weights between \( x_i \) and \( x_j \), and \( \sum_{i=1}^{k} W'_{ij} = 1 \).

Based on the local weight construction matrix \( W \) of modeling data and the dimension reduction target of the NPE algorithm, the low dimension projection of data \( \hat{X} \) is obtained. The low-dimensional projection \( Y(y_1, \ldots, y_n) \in R^{nd \times d} \) \((d \leq D)\). The data relationship is as follows:

\[ \hat{X} = \hat{X} + X = YB^T + E = \overline{XB} (B^T B)^{-1} B^T + E = \overline{XB} (B^T B)^{-1} B^T + (\overline{X} - YB^T) \]  

(5)

In the formula: \( A = \overline{XB} (B^T B)^{-1} \in R^{D \times d} \), \( d \) is the number of dimensionality reduction, \( X \) is the residual space of data, \( E \) is the residual matrix. Based on the data relationship, the original data are divided into model space and residual space. The projection matrix of residual space is as follows: \( A = [a_{d+1}, a_{d+2}, \ldots, a_D] \).

For the real-time measurement data \( x_{new} \) of the ring net switch cabinet, firstly, it is preprocessed and then projected into model space and residual space based on the projection matrix.

\[ x_{new} = \hat{x}_{new} + x_{new} = y_{new} B^T + (x_{new} - y_{new} B^T) = y_{new} B^T + x_{new} \left[ I - B (B^T B)^{-1} B^T \right] \]  

(6)

In the formula: \( y_{new} = x_{new} B (B^T B)^{-1} = x_{new} A \), \( \hat{x}_{new} = y_{new}^T B^T \) is the reconstructed vector of \( x_{new} \).

Using the monitoring statistic Hotelling \( T^2 \) and the square predicted error (SPE), we measure the fluctuation of the model space and the residual space respectively, so as to realize on-line monitoring. Statistical quantities and statistical limits associated with data point \( y \) are given by the following formula:

\[ T^2 = yA^T y \leq T^2_{lim} = \frac{d(n^2 - 1)}{n(n - d)} F(d, n - d; \alpha) \]  

(7)

\[ SPE = \|x_{new} - x_{new}\|^2 = \left\|x_{new}\left[I - B(B^T B)^{-1} B^T\right]\right\|^2 \leq g \times x_{new}^2 \]  

(8)

In the formula: \( A^T = \left[Y^T Y / (n - 1)\right]^{-1} ; F(d, n - d; \alpha) \) means the \( F \) distribution with significant level is \( \alpha \), degrees of freedom are \( d \) and \( n - d \); \( g \) and \( h \) are parameters of \( x^2 \) distribution, satisfying the conditions \( g = \frac{v}{2m} \) and \( h = \frac{2m^2}{v} \), \( m \) and \( v \) are the mean and variance of \( SPE \) statistics estimated by training samples, respectively.

The monitoring statistics of each real-time data are calculated, and whether the statistics exceed the corresponding statistical limit of modeling is judged. Based on this method, we can judge whether the data at this time are normal. If the fault is prompted, the corresponding troubleshooting should be carried out immediately. If the data statistics are less than the statistical limit, the process data are normal.

3.2.3 Model analysis. This paper proposes a fault diagnosis method for the ring net switch cabinets based on the neighborhood preservation embedding. Based on the actual data feature information, this method excavates the internal structural characteristics of the ring net switch cabinet. It does not
depend on the precise mathematical model and prior knowledge of the process, and it does not need to construct the complex mechanical model of the process. It uses process data to obtain real-time state, which makes the model more accurate and reduces the difficulty of modeling. Therefore, for complex processes that are difficult to obtain accurate data models and comprehensive process knowledge, the data-driven fault detection method for the ring net switch cabinets has great advantages.

The traditional single variable monitoring algorithms have the shortcomings of the single feature of data variables, neglecting the correlation among fault data variables and lacking of variable information fusion. The method proposed in this paper solves the above problems in the process of fault detection of the ring net switch cabinet. Based on the multi-variable process data information, the process information can be obtained more comprehensively. By establishing the monitoring statistics of the multi-variable data information, the fault detection effect of the ring net switch cabinet process can be improved.

Based on the idea of extracting local feature information from manifold learning, the local feature structure of process data sets is obtained by using the neighborhood preservation embedding algorithm. Because of the physical limitation of the ring net switch cabinet data and the complex variable relationship of high-dimensional data, the overall distribution characteristics of many data are not obvious. System faults are mainly reflected in a few variables closely related to the source of faults, which have the characteristics of locality. The traditional statistical learning methods based on the global structure of data are not clear about the local description and the methods lose the details of data. The method proposed in this paper can effectively maintain the local structural characteristics of the data while removing the coupling correlation of the original data, describe the internal structure of the data, make the model change with the change of the spatial structure of the data samples, and improve the expressive ability of the data features.

4. Concluding remarks
Industrial Internet of Things (IOT) is the trend of industrial development. In the face of the integration of a large number of edge devices in the Internet of Things, edge computing is an effective computing model, and its collaboration with cloud computing can better realize the data processing of IOT devices.

Aiming at the problem of fault diagnosis of 10kV ring net switch cabinet, this paper proposes a new on-line fault diagnosis system. Based on the operational data collected by the monitoring device of the ring net switch cabinet, the data structure characteristic model of the ring net switch cabinet is constructed in the edge gateway by using the neighborhood preservation embedding algorithm. The edge gateway stores and comprehensively analyzes the running data and compares them with the modeling data to determine whether the ring net switch cabinet is faulty and pushes the analysis result to the cloud computing center. Compared with the traditional fault diagnosis methods of the ring net switch cabinet, the proposed fault diagnosis system based on multi-variable data and local relationship algorithm can effectively acquire the data change characteristics of the ring net switch cabinet, and has more reliable monitoring performance. At the same time, the system can greatly reduce the upload data of edge devices, reduce the load of cloud center computing, and better meet the local and remote needs of users.

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References
[1] Lei, J.X., Zhang, H., Peng, D.G. (2016) Research on ground fault and line selection of distribution cable neutral point with small resistance. Automation Instrument., 37 (09): 48-51.
[2] Zhao, Z.M., Liu, F., Cai, Z.P. (2018) Edge Computing: Platform, Application and Challenge. Computer Research and Development., 55 (02): 327-337.
[3] Liu, J.Q., Fan, M.X., Li, X. (2017) Edge Computing, a new computing model in the era of big data. Computer Knowledge and Technology., 13 (19): 182-183.

[4] Shi, W.S., Zhang, X.Z., Wang, Y.F., Zhang, Q.Y. (2019) Edge Computing: Present Situation and Prospect. Computer Research and Development., 56 (01): 69-89.