A Box Transformer Substation Fault Diagnosis Based on IoT

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Abstract—**In order to change the traditional fault diagnosis form and realize on-line fault diagnosis, a fault diagnosis architecture of box transformer substation based on Internet of Things(IoT) technology is proposed. This architecture is a three-layer fault diagnosis framework of box transformer substation including the perception layer, the transport layer and the application layer. This paper analyzes the online fault diagnosis process of box transformer substation under the IoT architecture and its key technologies. Through the IoT technology to realize the collection of information data and online fault diagnosis of box transformer substation operation, the box transformer substation can be processed quickly, in real time and accurately when it fails, to prevent system fluctuations and catastrophic accidents, and provide necessary basis for planned maintenance, so as to extend the service life of box transformer substation and improve the operation efficiency.**

Keywords-Component; Box Transformer Substation; Internet of Things Architecture; Fault Diagnosis

I. INTRODUCTION

The power system is mainly composed of five links: power generation, power transmission and transformation, power distribution, power consumption, and power dispatch. Among them, the power distribution link is closely related to the operation of urban power grid, the power consumption of industrial enterprises and ordinary users, and is the "first line of defense" for production and life. The safe operation of powistribution directly affects the stability and reliability of power supply. It is imperative to improve the informationization and automation level of the power distribution and realize the real-time perception of the operation status of the power distribution. At present, domestic and foreign scholars have studied the application of the IoT in power distribution, data mining in distribution automation and fault diagnosis of power distribution equipment. Marco[1] et al. smart metering infrastructure for distribution grid services and automation, and realized the automation of distribution systems under the IoT architecture; Wang Lei[2] et al proposed a framework of fault trace for smart substation based on big data mining technology, find faulty components and give the cause of the fault; Malik[3] et al. evaluated the four state conditions of transformer logic paper with fuzzy-logic, estimated the deterioration of transformer insulation paper of 20 or more transformers, and proposed an appropriate maintenance scheme.

From the existing research, the IoT technology is basically mature at present, and the fault diagnosis research of the distribution link has achieved certain results, but the research is mainly concentrated on the 220kv large-scale substation. For the boxtransformer substations located near urban building, there are few studies. This paper analyzes the general process of traditional box transformer substation fault diagnosis. Aiming at the shortcomings of the traditional manual inspection fault diagnosis mode, a box transformer substation fault diagnosis system architecture based on the IoT technology is proposed, and the box transformer substation fault diagnosis process and key technologies in the IoT architecture are analyzed.

II. BOX TRANSFORMER SUBSTATION STRUCTURE AND FAULT ANALYSIS

A. Box Transformer Substation Structure and Function

Box transformer substation is a device used to transfer electrical energy from a high-voltage system to a low-voltage system. It is mainly used in outdoor places such as road lighting, residential quarters, construction sites, airports, terminals, stations, plazas, industrial and mining enterprises, and temporary power supply for sports venues. It consists of high-voltage switchgear, power transformer, low-voltage switchgear, electric energy metering equipment, reactive power compensation equipment, auxiliary equipment and coupling parts. These complete sets of equipment are placed in the high-voltage room, transformer room, low-voltage room and capacitor cabinet inside the cabinet, and the power

of the high voltage system is delivered to the low voltage system[4], as shown in Figure 1.

Figure 1.   Structure of Box Transformer Substation

B.   Box Transformer Substation Common Fault

The box transformer substation has a complicated structure, a complicated operating environment, and various types of faults. According to the location of the fault, common faults can be classified into low-voltage equipment faults, transformer faults, and high-voltage equipment faults. Among them, the low-voltage equipment failure mainly manifests as over-temperature of the low-voltage busbar and the equipment connection point, overheating of the electrical contacts, damage or disconnection of the ground wire, and step-by-step operation of the circuit breaker. These faults will cause the wires to overheat even a fire, or cause poor contact of the feeder, ablation of the circuit breaker contacts and other adverse consequences. The transformer fault mainly include multi-point grounding and partial short-circuit of the core, winding fault, core fault, magnetic flux leakage or magnetic screen discharge overheating, insulation system fault and so on. If the transformer fails, it will cause the operation of the whole box transformer substation to fail, resulting in serious consequences. The failure of high-voltage equipment is characterized by abnormal closing of the circuit breaker, tripping of the mechanism, and energy storage of the energy storage mechanism. The failure of the high-voltage equipment will lead to the box transformer substation to become overloaded, over-temperature, and equipment burned due to abnormal circuit breakers.

C.   General Procedure for Fault Diagnosis of Box Transformer Substation

The box transformer substation fault diagnosis process generally occurs after the fault occurs. The maintenance personnel rush to the site for maintenance after getting the operation fault message of box transformer substation, and make fault judgment according to the condition of field equipment with the help of expert experience value. Mainly for low-voltage equipment, transformers, high-voltage equipment, capacitor equipment inspection, as shown in Figure 2.

Check low voltage equipment	Check the transformer	Check high voltage equipment	Check capacitor equipment
Voltage and current	Shell rupture	Three-phase voltage indication	Capacitor contactor
Air switch in the cabinet	Transformer fire situation	Protection device operation	Compensator operation
Ground wire condition	Casing burst	Cable connector fastening	Shell damage
DC screen charging	Casing discharge	heating circumstance	Grounding condition
Aappearance damage	Equipment explosion	Redness	heating circumstance

Figure 2.   General Fault Diagnosis Process of Box Transformer Substation

III.   FAULT DIAGNOSIS OF BOX TRANSFORMER SUBSTATION BASED ON IOT ARCHITECTURE

The power IoT is generally divided into three layers: the perception layer, the transport layer, and the application layer. The perception layer is the core infrastructure, which mainly solves the problem of information perception and collection. The transport layer mainly transmits information reliably over long distances; The application layer is used to support platform and application services, mainly supporting information collaboration, sharing and interworking. The online fault diagnosis framework of box transformer substation is based on the power IoT architecture. According to the power IoT architecture and the box transformer substation structure, the IoT three-layer fault diagnosis architecture conforming to its actual use situation is constructed, as shown in Figure 3.

A.   Perception Layer

In the sensing layer, the intelligent monitoring unit/smart sensor is selected as the device for collecting the operation data of the box transformer substation, and collecting different types of data including temperature and humidity, phase voltage, phase current, active power, reactive power, harmonic factor and insulation factor. These data are horizontally aggregated into different indicators such as environment, electrical, power quality, energy efficiency, and faults. These intelligent monitoring units / smart sensors are connected to the corresponding collection parts of the box transformer substation by the combination of wired RS485 and wireless. After the data is converted by Modbus protocol, it is uploaded to the transport layer.

B.   Transport Layer

In the transport layer, intelligent acquisition terminals such as data collectors and environmental parameter collectors are designed using embedded technology and automation technology. According to the data collected and analyzed by Modbus protocol, ZigBee, WiFi, RS485 and other single or combined networking forms are used to transmit the data to the intelligent acquisition terminal for further analysis and processing. The data transmission to the server is selected by the GPRS public network transmission, and the collected data is converted into a TCP/IP protocol in the intelligent collection terminal, and the data is transmitted to a database in the data center server for storage.

C. Application Layer

In the application layer, the data is mined and the box fault diagnosis analysis is performed. According to the IoT architecture, the online monitoring of the box is completed, and the collected data is used as the original accumulation of the box transformer substation fault diagnosis process. Based on the data, the online fault diagnosis process is completed.
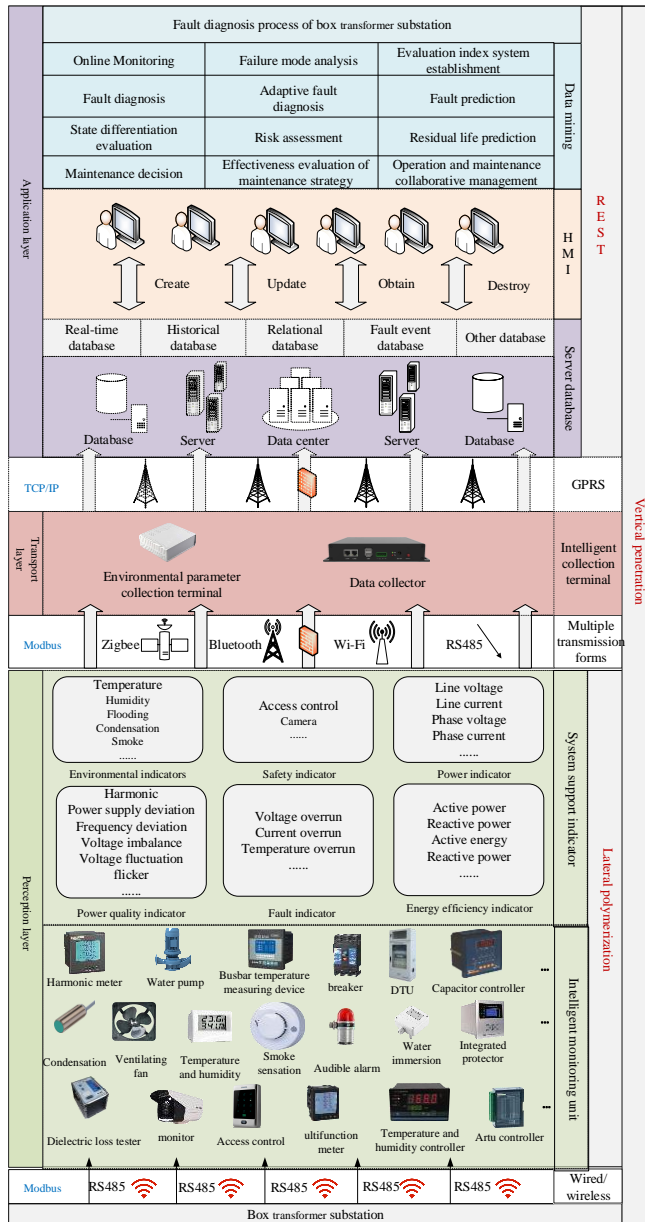

Figure 3.   IoT Fault Diagnosis Structure of Box Transformer Substation

IV. PROCESS ANALYSIS OF FAULT DIAGNOSIS OF BOX TRANSFORMER SUBSTATION BASED ON IOT

According to the above analysis, for the box transformer substation based on the IoT architecture, the research process of fault diagnosis is: failure mode analysis, evaluation index system establishment, fault diagnosis, adaptive fault

diagnosis, fault prediction, state differentiation evaluation, risk assessment, residual life prediction, maintenance decision and maintenance strategy performance evaluation, as shown in Figure 4.
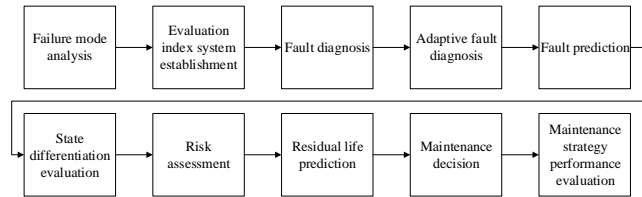

Figure 4.   Fault Diagnosis Process of Box Transformer Substation under IoT

1) Failure mode analysis

As an integrated device, considering the complexity of its overall structure and the uncertainty of the failure mode, before the fault diagnosis, the fault mode analysis of the whole equipment should be carried out first, that is, the main fault location of the equipment, the fault mode and the fault characteristic parameters, and the correspondence between them, which provides the research basis for the next fault diagnosis. Commonly used failure mode analysis methods include Reliability Block Diagrams (RBD), State Analysis (SA), Failure Mode and Effect Analysis (FMEA), and Fault Tree Analysis (FTA).

2) Evaluation index system establishment

The evaluation index is established to help the researcher establish the failure level of the internal equipment of the box transformer substation after the failure mode analysis is completed, describe the frequency of the failure of the component, quantify the degree of failure of the components in the system, and the severity of the failure. so as to select the component that most affects the normal operation of the box transformer substation, that is, the critical fault component. Commonly used evaluation methods include analytic hierarchy process, principal component analysis, failure mode and risk sequence index determination method in impact analysis.

3) Fault diagnosis

The model of box transformer substation fault diagnosis is established between the fault data obtained based on the IoT architecture and the key fault components of box transformer substation. Through the correlation analysis of the fault data and key components, the fault location is carried out, the fault mechanism is clarified, and the judgment of fault type is realized. The fault diagnosis method of power distribution equipment usually uses artificial intelligence diagnosis methods, such as expert system diagnosis method, neural network diagnosis method and so on[5].

4) Adaptive fault diagnosis

The establishment of adaptive fault diagnosis model for box transformer substation is to supplement and improve its fault diagnosis model. According to the data boundary

conditions, the adaptive model judges whether the fault type of the box transformer substation belongs to a known fault or an unknown fault, updates the established fault diagnosis model according to the judgment result, and obtains the optimal fault diagnosis model through continuous updating. The key to the establishment of the adaptive fault diagnosis model is the establishment of the boundary condition judgment mechanism, usually using the support vector machine method.

5) Fault prediction

The failure prediction of the box transformer substation predicts the form of failure that may occur in the future through the established fault model and condition monitoring data. Through the massive historical data obtained by online monitoring, a fault model for time change is established, and factor analysis, cluster analysis, correlation analysis, or time series analysis method are used to obtain the fault early warning result.

6) State differentiation evaluation

The box transformer substation selects the feature quantity of its own equipment and environment, analyzes the characteristic quantity, conducts multi-parameter fusion evaluation, and obtains its gridded state evaluation model from the fault history knowledge base by horizontally matching the similar equipment status. Combined with the multi-parameter evaluation results, the state trajectory of the device itself is obtained, and the differentiated evaluation result is obtained.

7) Risk assessment

According to the operation data, asset data, experimental data, average failure rate of the box transformer substation, the risk quantification result obtained by the diagnostic model, the operational reliability of the box transformer substation is evaluated.

8) Residual life prediction

The residual life prediction of box transformer substation is based on the expected operation life model. The expected operation life model is affected by load factor, design life, environmental factor and other parameters. Through the evaluation results of operation environment and equipment defects, the health index of box transformer substation is obtained, so as to obtain its remaining life and failure probability.

9) Maintenance decision and maintenance strategy performance evaluation

The selection of the maintenance mode of the box transformer substation is judged based on the results of various factors such as fault diagnosis results, state differentiation decision, risk assessment and remaining life prediction results, and multi-factor evaluation and program optimization are performed to determine the maintenance sequence. The quality of the maintenance plan needs to be evaluated by the effectiveness evaluation of the maintenance strategy. Therefore, before the implementation of a certain maintenance strategy, the reliability of the maintenance plan needs to be judged, and the effectiveness of the plan needs to be evaluated by scoring the box transformer substation status before and after the maintenance.

V. CONCLUSION

In order to realize the online fault diagnosis of box transformer substation, a fault diagnosis architecture based on power IoT is established. The composition and function of the perception layer, transport layer and application layer in the architecture are analyzed respectively. On this basis, the online fault diagnosis process based on the IoT and its key technologies are analyzed. The realization of online real-time fault diagnosis of box transformer substation based on IoT technology, to improve the management level of power distribution operation, improve the intelligence and information level of power distribution equipment, meet the requirements of power distribution state maintenance, reduce the labor intensity of maintenance personnel, reduce the failure rate of equipment, reduce the cost of fault maintenance, and ensure the stable and reliable operation of the urban power supply system, has great significance.

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