High-Voltage Equipment Monitoring System Based on IOT

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Abstract. The key to achieve intelligent is to introduce frontal information communication technology and integrate high-voltage equipment monitoring with the information system . High-voltage equipment system based on Internet of Things (IOT), including radio frequency technology, wireless sensor network and WISP environment monitoring technology, makes high-voltage equipment system,computer system and the network work together. It can realize the immediate response,analysis and control of the high-voltage equipment. This paper will lauch the research from following parts. First, it brings up a structural frame of high-voltage monitoring system based on the concept of IOT and characteristics of the high voltage equipment monitoring. Then main functions and core technology of the frane are introduced. Finally, the author elaborates the research problems and challenges of high-voltage equipment monitoring based on IOT from the aspects of the pivotal parts of IOT、 simulation algorithms and security assessment.

Keywords: Internet of Things (IOT), radio frequency technology, WISP, high voltage equipment.

1 Introduction

There is a wide range of high voltage equipments which mainly includes transformers, various types of switchgear、 arrester, insulation casing, current transformers, voltage transformers and so on. We can measure the parameters which reflect their characteristics according to different structural principles of the above-mentioned equipments. At present, high-voltage equipment maintenance working in China is done under the requirements of "Preventive test code for electrical equipment"[1] with regular preventive tests. Preventive tests play a significant part on the detection and diagnostic of equipment defection in time. But with the longer downtime period, the traditional preventive tests and and maintenance mode are fell behind[1-12]. So, a new maintenance mode based on the real-time device status and its trends prediction is being taking into consideration. From the 1990s, PC online monitoring system taking digital waveform acquisition and processing as core technology appeared. With this

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P. Sénac, M. Ott, and A. Seneviratne (Eds.): ICWCA 2011, LNICST 72, pp. 44–57, 2012.

system, we use high-tech like advanced sensors and computers to get more online monitoring parameters' data. Literature [35-37] introduced the UV applications on temperature and insulation monitoring. By studying the graphs and the data in different fault condition, we can find the places where are easy to breakdown. And then we can provide basis for malfunction analysis and optimal control. Literature [38-42] proposed a new monitoring model, communication protocols and fault location algorithm based on network topology.

Rising voltage level requires higher standard of security and reliability. Online monitoring has to confront mass of information(Structural features、performance parameters and operating conditions are different among equipments. And components in the same kind of equipment are also different. As a result, there may be different macro signals for the same fault type. And vise verse, the same macro signal may reflect different fault types), which arise the need for new communication technology, sensor technology, network technology and optimal control methods. Thus, the existing theories, models, methods and algorithm system of high-voltage equipment monitoring system need a further development. And the key point for further development is to introduce new technology of computing、 communication and sensing [2-5].

As a new interconnected system, IOT integrates computing systems, large-scale communication networks, extensive sensor networks and control systems, by which it can achieve real-time monitoring, simulation, analysis and optimal control of large-scale physical system [10-20]. Internet of Things can improve the level of informationization and the efficiency of infrastructure utilization. Through IOT, we can achieve a high degree of cognitive and intelligentized decision-making control on high-voltage equipment. First, quick location of high-voltage equipment fault in transfomer substation is implemented. Then the information of high-voltage equipment identification and its attribute as well as the surrounding environment is obtained by automatic identification、collection and induction. All the information is aggregated into a unified information network through various kinds of information transmission technology. Utimately, analysis and fusion of the relevant data is conducted by using some intelligent computing technology such as cloud computing, image recognition, data mining and semantic analysis. IOT technology makes the communication among different objects a possible thing, which also realize the communication between different types of entity and virtual body [3-20]. So, IOT is to meet the requirements of monitoring r different equipment and different control volume with different approaches.

This paper puts forword the structural frame and main funtions of high-voltage equipment monitoring system based on IOT. It elabarates the application of IOT on high voltage equipment monitoring from two aspects—wireless sensors frequency technology and information processing & optimal control. Meanwhile, the new sensing devices, simulation algorithms and security as core technologies are new trend for high-voltage equipment monitoring system based on IOT.

2 High-Voltage Equipment Monitoring System Based on IOT

2.1 Monitoring System Architecture

Specifically speaking, Internet of Things is a new technology which interrelates all kinds of sensors and the existing Internet. In IOT, all items will be linked with the network by installing information sensing equipments like RFID, infrared sensors, GPS, Laser scanner, which will facilitate the identification and management of the items [12-18]. Therefore, high-voltage equipment monitoring system based on LOT consists of three parts: 1. Perception of some high voltage equipment, to achieve "objects" identification with RFID and sensor; 2. Data transmission, data are transmitted and calculated through the new communication networks which is made up of the existing Internet, radio and TV networks, communication network; 3. Application, that is, the control terminal responsive for the input and output of signals.

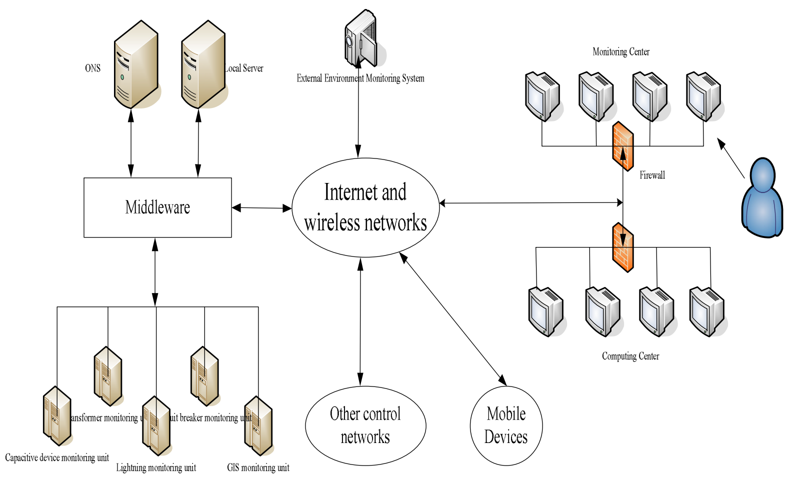

Fig. 1. architecture of high voltage equipment monitoring system based on IOT

High-voltage equipment monitoring system based on IOT should take the following characteristics into consideration:

1) The position of monitored equipment should be relatively fixed. The manifestation of macro-monitoring is different from communication.
2) There is a large number of wireless sensors and a large amount of information, what 's more, some sensors are in bad location. To ensure accurate communication among nodes, we need to consider problems with node topology, cluster and delay [5-8].
3) For external monitoring, we need to consider the location of equipment as well as the monitoring perspective to make sure we can clearly grasp external characteristics visually [33-36].
4) The monitored data can be divided into dynamic and static data. In order to achieve real-time monitoring and analysis with RFID, WISPS and wireless sensors, we need to consider power life and transmission distance.

2.2 System Function Analysis

1. Real-time monitoring and comprehensive simulation
As shown in Figure1, feedback information about the status of high-voltage equipment system is sent back to the monitoring center and computer center through wireless sensor networks and the wired network. With the acquired real-time information , the computer center constantly revises parameters so as to improve accuracy of simulation model. Then the simulation results conversely control the high-voltage equipment system via monitoring center. By this way, interaction and interoperability can be achieved. It seems that between the monitoring center and computer center we construct a virtual system co-existing with high-voltage equipment information collection. These two systems change synchronously and influence each other, which reflect the characteristics of actual condition of coexistence and interoperability of IOT [2-3].

2. Massive information Processing
High-voltage equipment monitoring system based on IOT can solve the problem of "funnel effect" [8] in system information(the larger monitoring scale and the more data traffic is, the more bottleneck pressure the "funnel" feels. This can cause a greater possibility of information blocking and congestion, which will seriously affect the safety of transformer substation. The functions of high-voltage equipment monitoring system based on IOT are shown in Figure2. In this system, data integration is divided into preliminary data processing, feature processing and fusion according to the characteristics of monitored objects. In Preliminary data processing, the collected data can stored with distributed or centralized control style selectively. In the process, real-time processing results can be transmitted to the monitoring center. It can also be made into backup data as history record future inquiries. In feature data processing, collected data with different characteristics are classified according to different requirements as well as various rules like data attributes, data packet length and data content. Useful information is targeted extracted and unwanted one is shielded through sorting and filtering. Fusion processing refers to data associating, transformation and encryption in monitoring [6-7] to ensure the security of transformer substation.

3. Adaptive and self-organization to external environment
With the rising voltage degree and increasing substation capacity, a lot of monitoring equipment access to the system, such as smart dust [5]. High-voltage equipment monitoring system based on IOT possesses the self-organization feature [10]of IOT. Any new device is connected to the system, the monitoring center can get all the information of the device and control the device at any time. Meanwhile, high voltage equipment monitoring system based on IOT possesses the adaptive function of IOT. Through the perception from sensors and electronic tags management, the system can grasp the dynamic environmental information and take corresponding measures. That is to say, according to the real-time environment information, the system can automatically remove all kinds of system failures (including the physical failure and information failure), guaranteeing the normal operation of system.

4. Mobile equipment and operator management
As is shown in Figure 2, any device accessed to high-voltage system may affect the security status of substation. With IOT, we can achieve tracking management on

mobile devices (operators) that is to be registered at any location through IOT before entering the high voltage system. With the development of perception technology and the popularity of electronic tags, we can know all the things we concerned. Each mobile equipment (maintenance personnel) is given a temporary ID. IOT can get detailed information of the device (basic properties, running state, the services to face) through the identification of the device ID. After mobile device (operator) entering the high voltage system, all information is back to the monitoring center through the wireless network. Once abnormalitis are discovered, monitoring center can remove connection between mobile equipment and network, cancel the given ID or take corresponding management . Mobile equipment(operator) can log-out through IOT in any place if permitted.

5. Scalability features
As a new generation of networks, IOT has better capacity to integrate different network elements. In high voltage equipment monitoring, when add or remove a monitoring device, we just need to follow the re-definition the generated object according to the IOT semantics or delete the object directory service. Object can get in touch with other devices or be removed easily.

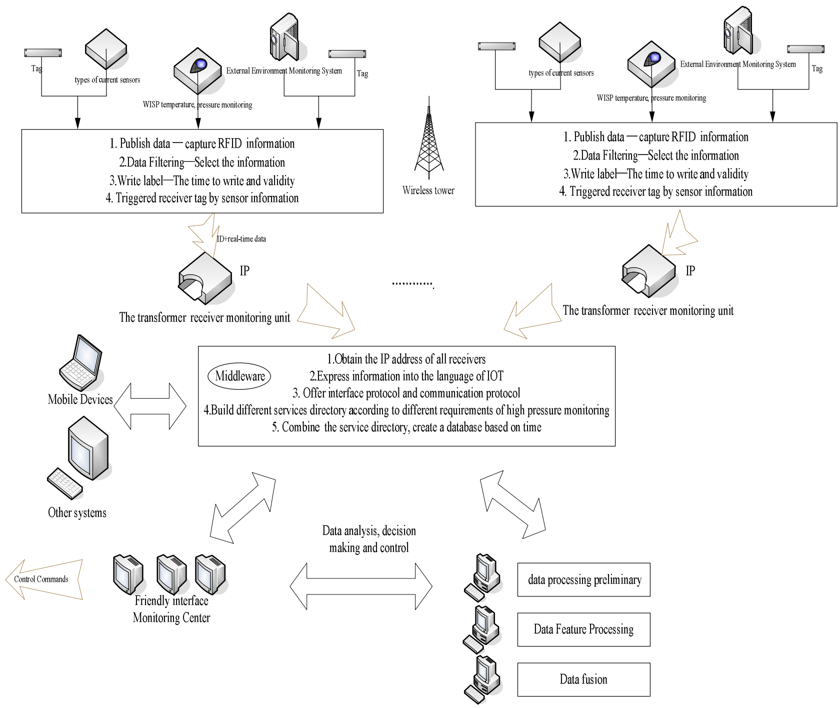

Fig. 2. Function of high voltage equipment monitoring system based on IOT

3 Key Technology

3.1 RFID Technology with Wireless Sensor

RFID, short for radio frequency identification,is often named as inductive electronic chips,proximity cards, non-contact card, electronic tags and electronic bar code, etc. The radio scanner transmits wireless electric wave energy in specific frequency to the receiver, driving the receiver circuit to send out its code which the scanner receives.

In IOT, RFID electronic tags store standard and interoperability-utilized information, which can be automatically collected into central information system through wireless communication network to achieve object identification. And through open computer networks for information exchange and sharing, we can achieve the "transparent" managemen of the objects.

1. RFID used in condition collection of high voltage equipment

In high-voltage equipment monitoring, each sensor is assigned a unique EPC (Electronic Product Code). This code is stored in the electronic tag attached to the wireless sensor. At the same time, the detailed information of the corresponding sensor is stored in the server of RFID information service system. Information and code collected through sensor is packed and flow to each link node along the communication path and eventually transmitted to receiving device of every monitoring unit. Through analysis of ONS(Object Naming Service),monitoring Center can acquire URI(Universal Resource Identifier) of information service system the very sensor belongs to. Put it in another way, it is to analyze the information carried by electronic tags, including the basic properties of the sensor (intrinsic information), location information (the location of the topology) and service information (the service directory for the next object) broken down. In this way, It can achieve automatic tracking of the status and quick positioning of device failure.

2. Wireless sensor

Wireless sensor network (WSN) is an comprehensive intelligent information system, which can collect, transmit and process information in one set. WSN possesses characteristics of low cost, low power consumption, low data rate and self-organizing network. WSN is a task-oriented wireless personal LA network consisting of a large number of distributed intelligent sensors nodes. It combines technologies in various fields, such as micro-motor technology, data acquisition technology, embedded computer technology, modern network and wireless communication technology, distributed information processing technology, the node energy-saving technology [15].

The deployment of wireless sensor based on high-voltage equipment monitoring should be closely related to its application. It involves network structure design, node selection and settings,etc. Researches on deployment strategies mainly focus on regional coverage and network connection problems. Figure 3 below is a typical WSN deployment which is frequently quoted[8]. Sensor nodes are arranged in the target area according to some strategic planning. And then all nodes are building the network in the form of self-organization. Each node has the same function, concluding information collection, RFID communication, routing from software and data processing. Each sensor node sends the useful information after preliminary processing and fusion. WSN data transmission is achieved by connecting the outside world with WSN through the Sink nodes. Information collected by nodes converge on Sink Nodes in multi-hop way. Then tne information is transmitted to the external world(the reader of the system).

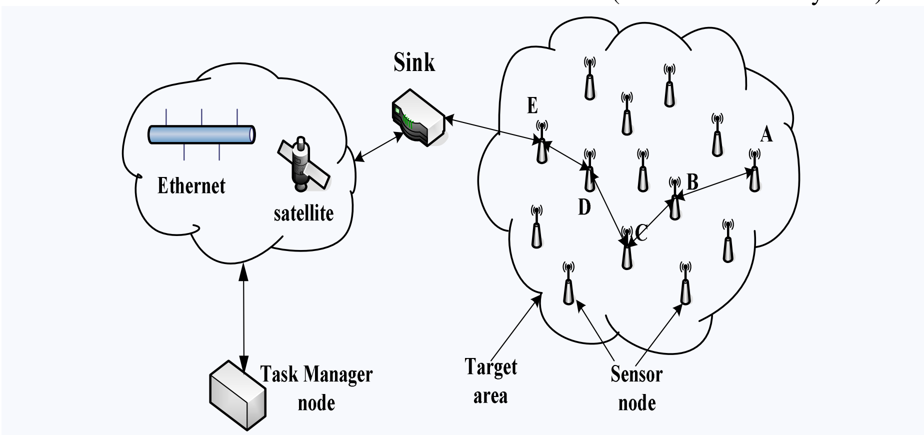

Fig. 3. a typical deployment of wireless sensor networks

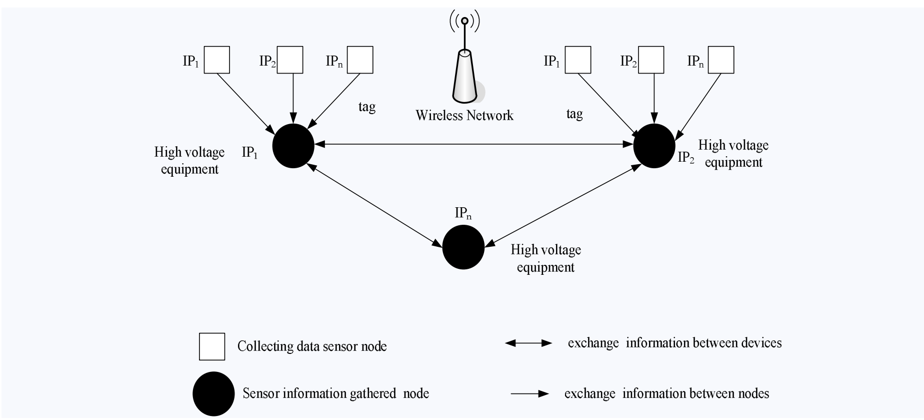

Fig. 4. The function of RFID with wireless sensor technology

3. Middleware

Middleware is to link the virtual network with the physical world。 It in essence is a software layer integrating different services and simplifying them. Therefore, it is the basis of IOT application. In the high-voltage equipment monitoring system based on IOT, all the data get in touch with monitoring center, computer center and other systems through the middleware in network to achieve commucation among “things”. Information in middleware is processed in three layers: 1. Information abstract. Each monitoring unit is given a receiver IP, at the same time, through communication protocol, the gathered information are represented in the middleware language so as to communicate with the virtual world. Therefore, the redundancy of IP addresses and semantic standards are the difficult problems in IOT development. 2. Information management. Based on the computational simulation requirements, information management directory is made chronologically in the primary and secondary order according to specific rules. 3. Portfolio service. According to different requirements and the information management directory, we define a particular logical combination by specific semantics [39] and create a real-time database. In this layer, any complex process can be presented with a simple act. It is crucial for optimal control based on IOT.

4. WISP(wireless identification and sensing platforms)

WISP(Wireless Identification and Sensing Platform) bears the capabilities of RFID tags, supporting remote sensing and computing. Like any passive RFID tag, WISP is powered and read by a standard off-the-shelf RFID reader, harvesting the power it uses from the reader's emitted radio signals. WISPs have been used to sense quantities such as light, temperature, acceleration, strain and liquid level. Most of the work on WISP so far has involved single WISPs performing sensing or computing functions. We think the next phase of WISP work will involve the interaction of many WISPs based on LOT, and thus allow an exciting exploration of a new battery-free form of wireless sensor networking.

WISPs are powered by harvested energy from off-the-shelf UHF RFID readers. A WISP is just a normal EPC tag,but inside the WISP, the harvested energy is operating a 16-bit general purpose microcontroller[10-11]. The microcontroller can perform a variety of computing tasks, including sampling sensors, and reporting that sensor data back to the RFID reader. WISPs can write to flash and perform cryptographic computations. Furthermore, WISPs have these features: up to 10 feet range with harvested RF power, Ultra-low power microcontroller and Real-time clock.

WISP combined the advantages of wireless sensors and RFID. It can make the RFID static tags processing to dynamic data processing, connecting real-time data with electronic tags. The block diagram of the WISP platform just as Figure5[26-28].In this way, it can reduce the use of monitoring equipments and equipment investment. Therefore, using WISP widely in the future is the trend of combining wireless sensor technology and RFID technology.

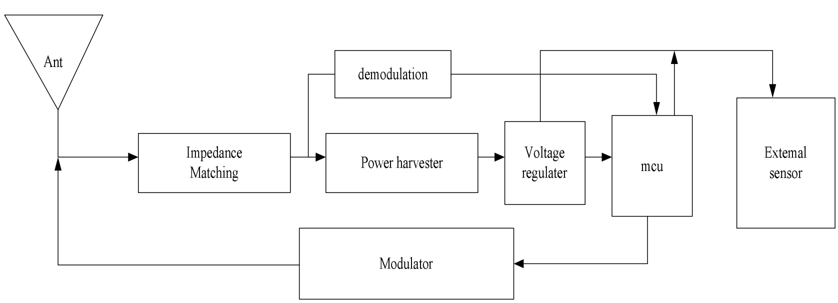

Fig. 5. block diagram of the WISP platform

3.2 Information Processing and Optimal Control

High-voltage equipment monitoring center is based on the technology of computer, communication, networks. Operators in monitoring center can get information of device operating conditions and parameters through the computer interface and achiece monitoring and controlling of high voltage equipments. With the application of IOT, high-voltage equipment monitoring system can achieve optimal coordination and remote control on "the distribution and concentration" of IOT.

High-voltage equipment monitoring system based on IOT will enhance ability to control the high-voltage system. Computer center process all the data from the whole region. The large variety and amount of data calls for high demanding of real-time analysis and simulation. So the computer center must have a high capacity of computing simulation. As a result, the large-scale distributed computing framework based on cloud computing is introduce to build a computing platform [18]. We need to build all the resources of high-voltage equipment monitoring into a huge resource library. Based on the requirements of simulation, cloud computing take real-time data、 images and temperature needed from the resource pool. It also matches the requirement of combining centralized control and decentralized control in IOT [3].

Based on IOT, high voltage equipment data simulations need a large number of experimental studies and field tests. By analyzing which parts of various types of equipment are easily to fall abnormal or adverse phenomenon as well as the mechanism of its occurrence, we obtain a large number of typical patterns, samples and data model. Then develop a corresponding database and corresponding evaluation rules. With the information aggregation technology of IOT, the mass of information can be processed, transmitted and integrated when it is transmitted [19]. We need to analyze and process the high-voltage equipment information from its the nature features. All the collected information high-voltage equipment includes large number of discrete redundancy data. Through the primary processing, feature processing and fusion, and compared to the corresponding evaluation rules, no concrete data and images but only the simple results are sent to monitoring center if the equipment is normal. otherwise, analysis results and alarm signal are displayed, and at the same time, detailed data and images will be sent to the monitoring center. Computer center record the change of important information with time scale information, which provides evidence for high-voltage equipment failure analysis. When abnomalites occurs, mass of information is generated ,recording data and images in chronological order. Then we conduct failure analysis according to specific algorithms to investigate causes and eliminate potential danger.

Electrical signals of high-voltage equipment can be acquired through various types of sensors and WISP environmental monitoring. Some operating status which are very difficult to detect by electrical signals, such as oil spill in transformer, crack of high voltage bushing, fire and theft,etc. we can use other technology, such as camera, infrared, ultraviolet, to achieve monitoring of these external circumstances[25-26].

Table 1. principal monitoring of high-voltage equipment

Equipment	**principal monitoring**
Transformer	Dissolved gas partial discharge Core ground current Pipe insulation Vibration spectrum
Capacitive Equipment	insulation Capacitive current value of capacitance $\tan\delta$
Lightning rod	Full current Resistive current Capacitive current Leakage current Action times
Breaker	Gas density of SF_6 Partial discharge monitoring circuit breakers feature
GIS	Gas density of SF_6 Partial discharge monitoring circuit breakers feature

4 Main Research Difficulties and Challenges

Based on IOT, developing a high-voltage equipment monitoring system is a new study. There are large number of problems both on theories of IOT and monitoring technology.

Challenges can be summarized as follows:
1. RFID tag management for high-voltage equipment monitoring
RFID technology is the backbone of IOT, which is used radio waves to identify objects. Combine the RFID technology with new two-dimensional code and other software technologies, just like WISPs, RFID can track and analyze data automatically. And it can widely used in high voltage equipment monitoring. RFID is an advanced non-contact automatic identification technology. It is transparent through the two-dimensional codes. It is urgent to establish a standard to develop RFID technology with the increased requires. EPC system is the most typical solution in the world now[32-33].But it is not completing. Hence, we need a scalable standard specification and protocol to regulate the standards of coding tag and the corresponding identification technology

We can use completely wireless sensor network with the application of UHF radio frequency technology. Extending UHF RFID tag technology agreement to extend range of reader and the receiver. The purpose is to analyze real-time data tag while long-distance wireless transmission.

2. Wireless Sensor Networks Topology
Based on IOT, A typical feature of wireless sensor networks in high-voltage equipment monitoring system is coverage of a large area. Therefore, redundant nodes and complex communication links are problems. Due to the radio frequency interference, humidity, vibration, dust and dirt, wireless link will change. At the same time the changing of wireless sensor nodes lead to wireless connection failure. Some sensor nodes can not collect information or its misuse void, it will also affect the accuracy of electronic tags.

Second, energy of high side sensor node has a strict limit . The energy need to supply sensor nodes and the launch of electronic tags. Especially some sensor node in bad location. The agreement on self-organizing wireless network now(Ad Hoc wire-less networks) is difficult to adapt to the needs of sensor network technology based on IOT. Therefore, we need to be design a balanced and reliable data transmission protocol to accommodate the new features of wireless sensor networks

3. Simulation platform
High-voltage equipment monitoring system and control system constantly transfer data to the computer center while collecting huge data. Computer center needs to establish a dynamic real-time data model and information model. Computer center needs to recursive use and verify the correctness simulation model. And then continue to modify the simulation model and give the relationship between environmental change and simulation model. Take measures when environment model changes and get the risk of switching model. With assessment of switching model, the result provides the basis for dynamic adjustment of the model. Especially for the "smart dust", data acquisition network transfer a huge data, computer center requires a suitable algorithm for large-scale simulation. Ultimate goal are to enhance capacity of controlling high-voltage equipment and provide the theoretical basis of optimal control strategy for the monitoring center.

4. Security and reliability
As technology advances, RFID tag in high-voltage equipment monitoring holds detail information. When the wireless network is in a random attack or failure, information reliability is the issue to be examined. At the same time, LOT links high-voltage equipment monitoring system and network information systems. Therefore, information system security and safety of high-voltage monitoring system is not an isolated problem. Attacks on information systems may also lead to large-scale monitoring system failure, failure of information systems will lead to loss control of physical systems, which led to failure of the monitoring system.

5 Conclusion

High-voltage equipment monitoring based on IOT will promote the development of intelligence of transformer substations. Taking advantage of information aggregation technology of IOT to process massive terminal information that can be collected、sensed and identified, we can eliminate data redundancy and provide more accurate and comprehensive information through a series of key technologies such as data fusion. From the angle of IOT, this paper mainly describes modeling and failure analysis, equipment monitoring and equipment maintenance, network security and risk assessment, stand-alone computing and optimal control of distributed computing integration. This paper also discusses the still unsolved issues of high voltage equipment monitoring based on IOT from the aspects of the theoretical basis、 the simulation algorithm、 safety and reliability.

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