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Design of On-line Monitoring System for Intelligent Package Substation based on WSN and GPRS

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Abstract

An idea of applying wireless sensor network and GPRS to intelligent package substation on-line monitoring system is brought to light in this paper. Network schemes of intelligent package substation are given based on wireless sensor network and GPRS. The detailed analysis has also been made on some key technologies. At the same time, the combination of special CT and accumulators is adopted to solve the power supply shortage of sensor nodes effectively. To reduce the routing hops and improve the transmission efficiency, the two-layer and three-cluster of network structure is used. Finally, the on-line monitoring system of transformer room is taken as an example, it is discussed how to obtained optimal layout of sensor nodes. The paper also points out which can be taken as the research focus in the future such as intellectualized reconstruction of package substation, network security and clock synchronization.

Keywords: *wireless sensor network; GPRS; intelligent package substation; on-line monitoring system*

1. Introduction

With the development of smart grid, wireless sensor network (WSN) plays an important role in implement state supervisory and condition-based maintenance of the power system [1]. And now it is applied in such numerous aspects as equipment maintenance [2], safety monitoring [3] and temperature monitoring [4] in the field of intelligent substation. The successful application of WSN in intelligent substation provides reference for exploring a new means of communication in intelligent package substation.

WSN can choose different sensors according to different needs, it also can select different radio frequency communication technologies with the actual communication latency or bandwidth requirements [5], such as ZigBee, WiFi and PLC. It is very suitable for obtaining status parameters in the intelligent package substation. Now, there was a primary research in overall scheme about applying WSN and GPRS to intelligent package substation. But for the online monitoring programs to specific devices, the design of WSN nodes and the transport communication between the gateway node and station level, it is not covered. This paper will go into details of these technologies, and hope to provide certain reference for applying WSN and GPRS to intelligent package substation.

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2. The Network Architecture and Its Characteristics of WSN

WSN consists of three network components: sensor node, sink node and management node. Figure 1 is a typical architecture diagram of WSN [6].

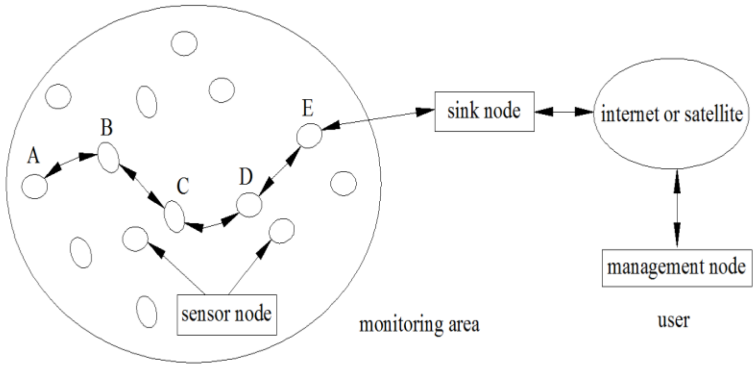

Figure 1. Typical WSN Architecture

Compared with traditional wireless network, WSN is more suitable for intelligent package substation with the following advantages:

(1) Application relativity. According to the practical application requirements of intelligent package substation, its networking scheme, sensor node, gateway node, software system and network protocol can be designed differently. According different applications to select different WSN technologies, it is the most significant feature of WSN different from traditional wireless network [7].

(2) Broad-scale. It needs to arrange a large number of sensor nodes to obtain accurate physical quantities from high-pressure chamber, transformer room and low-pressure chamber of intelligent package substation. On one hand, it reduces the monitoring blind area in each chamber, on the other hand, the existence of redundant nodes reduces the dependence on the accuracy of a single node.

(3) Self-organized. Topologies will be changed dynamically with the increasing or decreasing of sensor nodes in intelligent package substation. Sensor nodes can be automatically configured and managed for the self-organizing capacity of WSN.

(4) Multi-hop routing. There is limited communication distance between WSN nodes. Expanding the scope of the transport is completed by common sensor nodes, each node has the function of receiving and forwarding information.

(5) Data-centric. When the main monitoring system needs to look up an event, it can inform the event to network directly instead of finding the certain sensor node in one certain intelligent package substation. After obtaining the information, network will report to the main monitor system.

3. Overall Scheme Design of On-Line Monitoring System

The intelligent package substation comprises field devices layer, communication layer and station level. There is no specified communication topology or limited physical communication interface between the three layers. Wireless sensor network is adopted inside the intelligent package substation. GPRS and Internet are adopted between the intelligent package substation and the network communication control facility. Internet is used for connection between network communication control facility and the main monitoring system in the station level. Figure 2 is a complete network scheme about the on-line monitoring system in intelligent package substation.

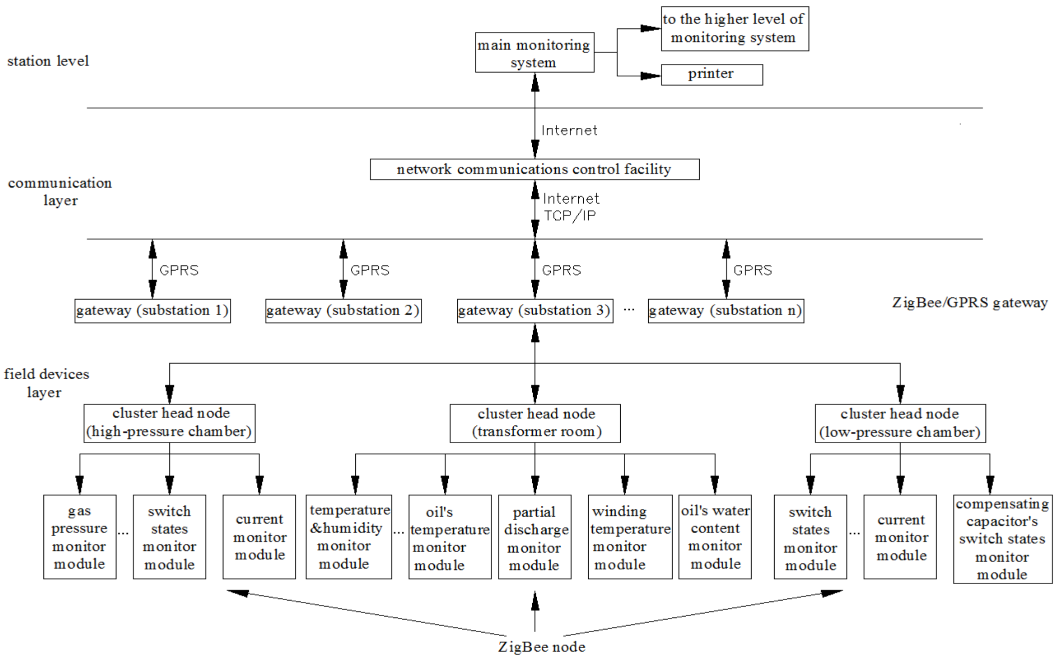

Figure 2. The Overall Scheme of Intelligent Package Substation On-Line Monitoring System

3.1. Design of WSN Node

(1) Design of sensor node

All the equipments which need to transmit data in the intelligent package substation can be designed into sensor nodes. Not only can they be short circuit indicators or cable fault indicators with the function of wireless router, but also they can be the temperature, humidity and pressure sensors attached to primary electric equipments, and they also can be other measuring instruments or monitor modules.

The designing scheme of sensor node is usually based on MCU+RF [8], but which need to be consider the problems about the matching between MCU and RF, the size of the Packaging volume, etc. System-on-a-Chip (SOC) integrates the critical components to one chip, in which case the problems can be solved well. The MCU kernel processor chip adopts CC2530. CC2530 chips have a high performance of sending and receiving, 256 KB flash memory and 20 KB erase cycle, which can support wireless updates and large applications. Extension interface can mount other sensors as required, also can connect the LED circuit status indicators, it is convenient to find which nodes are good-working and which nodes are bad-working.

The problem about power shortage of sensor nodes can be solved through the combination of special CT with accumulator [9]. The special CT utilizes the electromagnetic induction principle to take electricity from the substation line, which can supply for sensor nodes after the rectifier, filter and regulator. When the special CT supplies power normally, its working voltage is higher than the battery voltage, then, the diode is cut off. When the package substation situates in a power failure, the small CT won't supply and the diode will be in a conducting state in order to keep monitoring systems working normally. The structure of sensor node is shown in Figure 3.

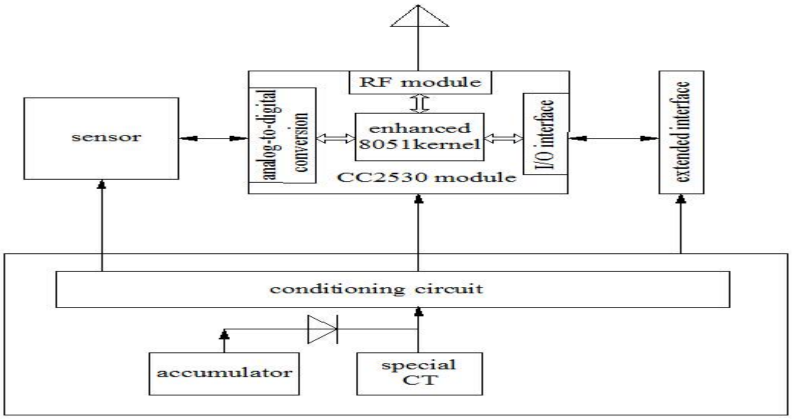

Figure 3. The Design Block Diagram of Sensor Node

(2) The design of gateway node

Gateway node also called sink node, is crucial to the wireless sensor network. It is the 'bridge' between the intranet and extranet, can be designed as a special gateway device, also can be designed with an extra monitoring function. The gateway node in this paper is a special ZigBee/GPRS gateway device, without the function of monitoring, based on ZigBee protocol and TCP/IP protocol.

The hardware of the gateway node is composed by special CT, GPRS module, microprocessor and coordinator [10]. The chip of the coordinator is CC2530, the chip of GRPS is SIM300 and the chip of microprocessor is C8051F120.The communication between the three devices above is cross-linked via serial lines of RS232. There are 64 digital I/O pins, 128KB flash memory, 8448B RAM and two serial communications interfaces called UART0 and UART1 in C8051F120. The two interfaces are very important for executing of control commands and transmission of database directives, UATR0 is responsible for communicating with GPRS and UART1 is responsible for communicating with coordinator. SIM300 is embedded with TCP/IP protocol and builds network with computers by AT instructions, This makes them very adept for communicating between intelligent package substation and network communicating control facility on the Communication Layer, the structure of gateway node is shown in Figure 4.

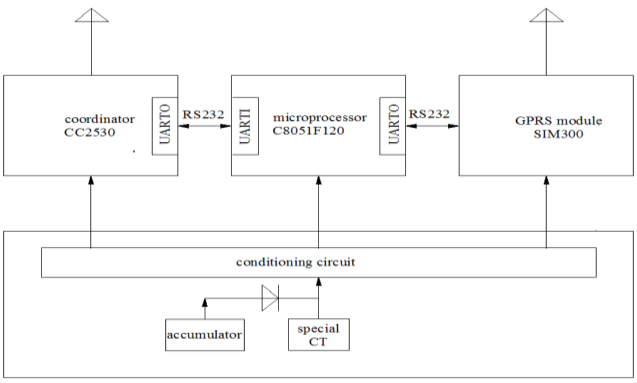

Figure 4. The Design Block Diagram of Gateway Node

3.2. The Architecture Design of the Field Devices Layer Network Based on WSN

Wireless sensor network in the intelligent package substation can be divided into a 2-layer and 3-cluster networking architecture. It is divided into three clusters in terms of high-pressure chamber, transformer room and low-pressure chamber. Each cluster generates a cluster head node, and each cluster head node is responsible for distributing time slots to sensor nodes in its clusters. Cluster node can be selected through algorithm, can also choose a specialized sensor node with good communications and data handling capabilities. On one hand, it collects communication data from child nodes and sends to gateway node, on the other hand, it receives the orders from the gateway node and sends them to the child nodes, performing a function rather like a junction or relay station. In which case, the top network was constituted of cluster head nodes, and the bottom network was constituted of head node and child nodes. The network structure can effectively reduce the unnecessary data transmission between child nodes, improve the efficiency of transmission through the ways to reduce the routing hops, the structure of field devices layer network is shown in Figure 5.

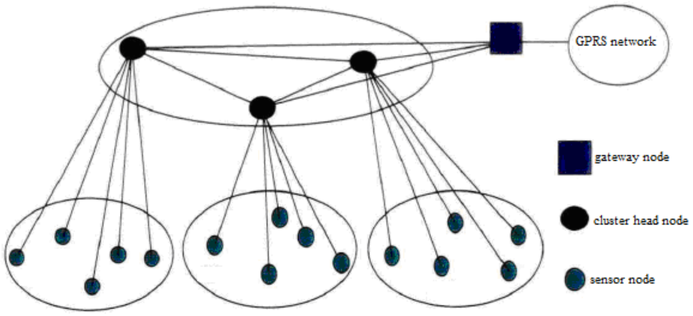

Figure 5. The 2-Layer and 3-Cluster Networking Architecture of Field Devices Layer

3.3. The Design of the Communication Layer Network Architecture Based on GPRS

The communication layer is mainly composed of communication network and Network communication control facility, which is the ‘bridge’ between the field devices layer and station level. The network communication control facility has lots of downlink communication interfaces and uplink network interfaces. On one hand, it is used for collecting communication data from intelligent package substations and sending them to the main monitoring system in the station layer, realizing the function of remote sign and remote measure. On the other hand, it receives the orders from the main monitoring system and sends them to the intelligent package substations, realizing the function of remote control and remote adjustment.

Lots of intelligent package substations need to be monitorred by the control center on the station layer at the same time. It is very difficult and also costs too much to set up the networks if a wired net is used, and it has a large initial investment. So GPRS is put into use for connecting gateway nodes to internet junction center. The internet junction center is linked with network communication control facility after protocol transform, realizing the remote sign to the control center through internet. In return network communication control facility also can realize the remote control to the wireless sensor network through internet and GPRS. The internet will assign an IP address to every ZigBee/GPRS gateway, in which case each of the gateway equipment will become a ‘computer’ in the internet, the structure of communication layer network is shown in Figure 6.

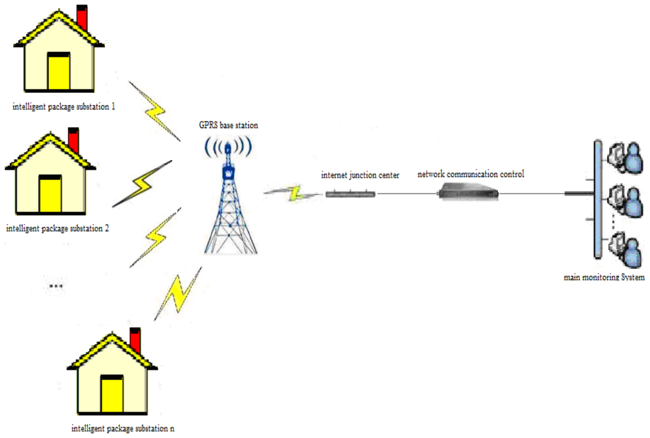

Figure 6. The Networking Architecture of Communication Layer

4. Design of Online Monitoring System of Power Transformer Room

In the construction process of the intelligent package substation, the intellectualized reconstruction of transformer is also an important segment. There is no essential difference between intelligent transformer and ordinary transformer, but in the design phase of the transformer, the idea that implanting necessary intelligent sensors and actuators into the interior of the transformer or welding them to the exterior of the transformer should be considered.

4.1. Monitoring Content and the Choice of Sensors

The online monitoring of transformer room mainly includes the monitoring of the running state of transformer and the environment of transformer room. The monitoring of the environment of transformer room is mainly about the measurement of temperature and humidity. The measurement of quantity of state is mainly detected through the corresponding intelligent sensor. The sensor names and their functions are shown in Table 1.

Table 1. The Sensors and Its Function of Monitoring System of Power Transformer

Sensor's name	Sensor's function
Humidity & Temperature Sensor	Measure transformer room's humidity and temperature
Windings fiber optical temperature probe sensor	Measure the temperature of winding
PT100 Platinum resistance temperature sensor	Measure the oil temperature
Wireless vibration sensor	Measure the vibration of transformer body or certain devices
High polymer film sensor MMT162	Measure water content in transformer oils
Gas sensor	Measure concentration of oil-dissolved gases
High-frequency acoustics sensor	Measure transient sound signals by its partial discharge
HFCT sensor	Measure the partial discharge current of transformer body or transformer bushing
Micro-current sensor	Measure the grounded current of transformer core or the grounded current of transformer bushing end screen

4.2. Layout of the Sensor Nodes

The whole monitoring network is composed of many sensor nodes, a good layout of sensor nodes is the premise of monitoring equipment running status exactly. Three principles should be followed in the layout of sensor nodes: first, sensor nodes do not affect the normal operation of the transformer; second, there is no monitoring blind area of WSN, a certain degree of redundancy configuration is also required; third, problems of economy should be considered, reducing the nodes that have similar functions to avoid unnecessary waste.

Micro-current sensor and High frequency current transformer (HFCT) are always encapsulated in the adapter of transformer bushing [7]. Micro-current sensor is used for gathering the grounded current f transformer core or transformer bushing end screen. Thus, whether there exist transformer core multiple grounding can be reflected through the grounded current of transformer core. HFCT is using the principle of pulse current method to measure the partial discharge current of transformer body or transformer bushing.

Wireless vibration sensor is installed on the surface of the transformer [11]. It used for obtaining the vibration signals of transformer or certain equipment. Equipment running status can be reaction after the analysis of vibration signals. High-frequency acoustics sensor is installed on the outside of the transformer to detect the transient acoustic signals produced by its partial discharge. The advantage is that it can be installed when the transformer is running.

Windings fiber optical temperature probe sensor has been implanted into the winding when the intelligent transformer is produced [12], using for measuring the temperature of winding. PT100 platinum resistance temperature sensor and gas sensors are installed into the oil tank, using for detecting the oil temperature and the concentration of dissolved gas in transformer oil. Moisture content in transformer oil is very low, generally less than 100ppm, so the traditional humidity sensor is not competent for this, high polymer film sensor MMT162 should be selected instead [13], which has a high sensitivity even in low humidity conditions (0%~ 30% RH). The insulation condition of transformer bushing can be reflected by the magnitude of the dielectric loss. The dielectric loss will increase when the bushing insulation faults, and the magnitude of the dielectric loss can be calculated through the bus voltage and the grounded current of transformer bushing end screen.

Temperature & Humidity Sensor should be installed in the transformer room, using for detecting the temperature and humidity of transformer’s running environment. Fan in transformer room can be automatically open at the time of high temperature, and it can be automatically shut down at the time of low temperature. At the same time, considering the intelligent sensors have been implanted into the oil tank in the process of transformer’s intellectualized design or reconstruction. So, on one hand, the life of the sensor nodes should exceed the service life of the transformer or has the nature of exemption from inspection; on the other hand, two sets of sensor nodes should be arranged in each monitoring area, in order to realize redundant configuration.

Considering the economical efficiency of sensor nodes, there are two main aspects. One is the hardware costs of the wireless sensor nodes, and the other is the amount of data waiting to be delivered [9]. Based on above-mentioned, the layout of the sensor nodes is determined by the structure characteristics of the transformer and transformer room. So, the hardware costs of the wireless sensor nodes are fixed. Nevertheless, it can depend on optimizing routing protocol and planning network topology structure, to achieve the result of reducing the unnecessary data transmission.

5. The Urgent Problems of On-Line Monitoring System

5.1. The Intellectualized Reconstruction of Package Substation Equipment

The first condition of applying WSN and GPRS to intelligent package substation is to finish the intellectualized reconstruction of package substation equipment itself. All data transmission equipment can be designed as sensor nodes of WSN, the can be both the sensors of measuring the electric parameters such as electronic current transformer or electronic voltage transformer, and the sensors of measuring the non-electric parameter. It can also be other intelligent instruments [6]. Sensor nodes with wireless routing function can send signals to the cluster header node directly, nodes without wireless routing function can be solved through the expansion of wireless routing equipment. For the sensor nodes which must be installed inside the device, the design of the implantation should be finished before the device produced.

5.2. The Network Security

The potential safety hazard of wireless sensor network is mainly comes from two aspects. One is from electromagnetic interference, another is from human interference. No matter in the process of data collection and transmission, the wireless sensor network applied to the intelligent package substation are likely to failure because of the electromagnetic interference. So, the problem of electromagnetic compatibility should be considered when products are designing. At the same time, due to the self-organizing of the wireless sensor network node and the intelligent package substation itself drafty of structure, makes artificial tentacles extended into intelligent package substation. These tentacles can attack sensor network or pose as sensor nodes to eavesdrop and send data.

5.3. Clock Synchronization

In the intelligent package substation, the completion of a task often requires the cooperation from several sensor nodes. Data fusion is an instance of this cooperation, its main purpose is to collect data from different sensor nodes to merge into a meaningful result. It requires the sensor nodes transmitting the physical parameters to the gateway node at the same time. And then, the control center evaluates the running status of intelligent package substation according to these data. If the clock is out of sync, the evaluation is not accurate. And the implementation of sensor nodes energy saving is also need the synchronous matching between the sensor nodes.

6. Conclusion

(1) The paper provides the overall scheme of intelligent package substation on-line monitoring system based on WSN and GPRS. In the scheme, the design of sensor node, gateway node and communication layer network architecture are completed.

(2) In view of the power shortage of sensor nodes and gateway nodes, it is dissolved by combining special CT taking power from substation line with accumulator. when the substation line has electricity, powered by special CT; when the substation line faults, powered by accumulators. The combination of both methods can provide reliable data support for safety monitoring and equipment maintenance perfectly, it makes the monitoring system of the intelligent package substation play its due role.

(3) In order to improve the efficiency of data transmission between the nodes in the substation, the two-layer and three-cluster of network structure has been proposed. Three clusters were divided according to the high voltage room, transformer room and low voltage room. Each cluster generates a cluster head node fixedly or automatically. The top network was constituted of cluster head nodes, and the bottom network was constituted of head node and child nodes of the sensor networks. The network structure can effectively

reduce the unnecessary data transmission between child nodes, improve the efficiency of transmission through the ways to reduce the routing hops.

(4) Taking the monitoring system of transformer room as an example, the selection of sensors, optimal layout of the sensor nodes are discussed. At the same time, two sets of sensor nodes are arranged in each monitoring area, it means to improve the reliability of monitoring through using the method of the appropriate redundancy configuration. This way also has important significance for the monitoring system of the low voltage room and the high voltage room in the intelligent package substation.

(5) Considering the current construction situation of intelligent package substation and technical level of wireless sensor network, there are still technical issues need to be studied about applying WSN and GPRS to intelligent package substation. It mainly includes intellectualized reconstruction of the package substation, network security and clock synchronization.

Acknowledgements

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