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A Monitoring System Design in Transmission Lines based on Wireless Sensor Networks

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Abstract

A smart grid application in monitoring the condition of transmission line with wireless sensor networks was described in this paper. ZigBee and GPRS (General Packet Radio Service) technology were adopted in this system to ensure normal transmission of signals, even in remote areas where there is no telecommunication service, and data could be transmitted over a long distance. In addition, the system provided warnings before the damage caused by meteorological disasters to ensure the line security.

Keywords: GPRS, smart grid, wireless sensor networks, ZigBee

1. Introduction

In the smart grid system, power transmission is related to the security, so it is essential and important. In the domestic electric industry, the management of the transmission line is still in the stage of patrol on foot, which is a relatively initial state. So it is difficult to meet the increasing reliability requirements and the need of smart grid's development. High voltage transmission lines, especially for a long distance, often need to cross mountains. The whole line may be in different meteorological areas, which brings certain difficulties for the management of the line. In recent years, the occurrences of severe weather become more frequent, which caused severe collapse of power towers and broken of the power lines. The research on the monitoring of the transmission lines is one of the directions for the smart grid technologies. The device is designed to offer the meteorological data, which can help to make forecast and alarm of the accident, so as to lessen the loss of the power grid [1].

Therefore, a smart system for the meteorological monitoring of transmission line based on ZigBee and

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General Packet Radio Service (GPRS) technology was developed in order to overcome the shortcomings of the present system, such as the totally dependence on the limited coverage of communication network, the single monitoring parameters and the poor extensibility, etc. The system in this paper has the advantages of low power consumption, low node cost, large network capacity, long cycle life and strong extensibility.

ZigBee, developed on the basis of IEEE 802.15.4 standard, is a latest wireless communication technology. The standard provides the Physical layer (PHY) and Medium Access Control layer (MAC) for the wireless communication.

The Zigbee protocol working on the topper performs as the Network layer (NWK) and Application layer (APL). The PHY, MAC and NWK layers handle the data transmission and the APL layer handles the tasks of each device [2].

GPRS is a GSM-based wireless packet technology. It provides wide-area wireless IP connection by a kind of point to point way. GPRS is a high-speed data-processing technology, for which data are transmitted in the form of "group"[3]. It has the following characteristics: first, it will remain online as long as GPRS is applied; second, GPRS only charges when it generates communication flow; third, the current GPRS can support the peak rate of 53.6Kbps while theoretical transferring peak reaches more than 100 Kbps; fourth, it can cover the most areas of China.

The research of the smart grid is important and necessary, and the research focuses are different in different countries. Because of the lack of uniform standards in the smart grid, most of the research of the transmission monitoring still remain in the theoretic step, and lags behind the practical application. Reference [4]-[6] provide some schemes in power transmission monitoring, and reference [7]-[10] provide some approaches of measuring parameters. However, these approaches were complicated, bringing difficulties to install the devices. There were also difficulties in the signal acquisition and transmission. Besides, because of the bad extensibility, they were unable to meet with the comprehensive and unified collection requirements in the smart grid. According to the development of the smart grid in China, a wireless transmission-monitoring system was designed in this paper, and some results were obtained.

2. System Description

The data such as the temperature, humidity, wind speed and wind direction were collected and analyzed in the system, so that the meteorological environment was monitored and the transmission state was assessed. When the data are abnormal, the warnings of the severe weather were achieved through a particular algorithm, which helps staffs to make decisions accurately and take effective measures to protect the transmission lines. Fig.1 is the work flow chart of the system.

The main feature of this system is the combination of ZigBee and GPRS technology. It contains a two-stage wireless network. The first level uses IEEE 802.15.4/ZigBee technology widely called "wireless sensor networks ". It has the features of large network capacity, low node cost, low node power and etc. Besides, the first level covers at least 500 meters in diameter. The second level uses GPRS technology. GPRS module supports TCP / IP protocol, and can send data directly in the way of point to point to a specified IP address on the specified port device of the Internet. As a result of high data transmission rate, even if there are lots of sensor nodes within the first level, GPRS module is still capable of processing and sending data.

The two-stage structure combines the merits of two wireless networks, which can ensure the normal operation in remote areas without telecommunication service. In addition, it can finish the data collection and long-distance transmission with large network capacity, low power consumption and low cost. It is much more advanced than the present wireless network which uses only one level [11].

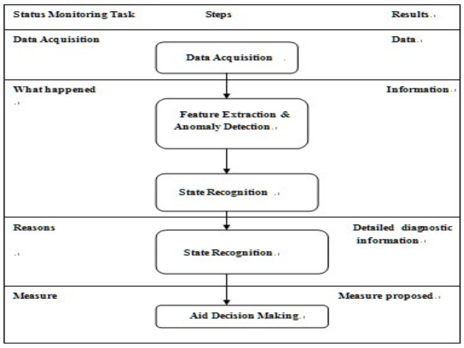

Fig. 1.The illustration of smart condition monitoring for power line

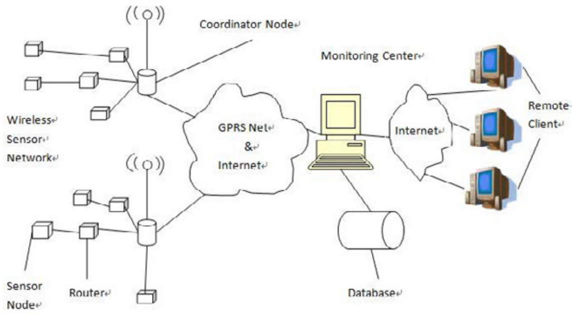

Fig. 2.The structure of the system

3. Hardware Design

The system (as shown in Fig.2) is a distributed network composed of three parts: the sensor nodes, the coordinator nodes and the monitoring center. After power up, the coordinator sets up the network and other devices join the network. The newly joined child devices to the network can either work as end devices or routers where the coordinator is the parent. Routers can permit other devices to join it whereas end devices can't; i.e. they are leaf nodes of the network. In our system the sensor node is end device and the coordinator node is coordinator device, while the routers only used to increase the transport distance. All the nodes should be installed on towers of the transmission line.

The sensor nodes detect the meteorological parameters and send them to ZigBee wireless network. The coordinator nodes which are in the same network receive the data, and then send them to the GPRS module. The data finally are transferred to the monitoring center and stored in a database of the server. The information could be read and processed in database through the server and client software, and then data evaluation could be achieved through an algorithm. Furthermore, it provides warnings when the data received are abnormal.

3.1. Sensor nodes

Sensor nodes are composed of sensor module, MCU&RF (Micro Control Unit & Radio Frequency) module and power supply module. Sensor module collects the information in the monitoring area. MCU&RF module controls the operation of all the sensor nodes, including storing and processing data; meanwhile, it is responsible for wireless communication with other nodes, mainly exchanging control information, sending and receiving data. Fig. 3 shows the structure of the sensor node.

The sensor module contains some sensors for parameter acquisition. Data-collection ports are reserved which can be extended when additional sensors are needed. The SHT10 digital temperature and humidity sensor made by Sensirion, TF-M1 wind speed sensor and TX-V1 wind direction sensor made by Beijing DIY sensing center were used.

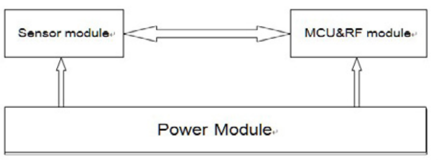

Fig. 3.The structure of the sensor node

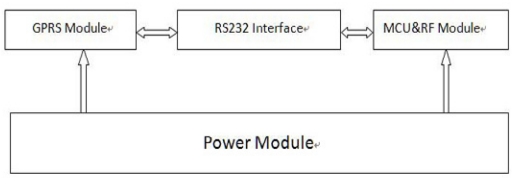

Fig. 4.Structure of the coordinator node

SHT10 integrates the sensing element and signal processing circuit in a micro-circuit board. It has output of standardized digital signal, small size and low power consumption. This sensor can run in the range of -40-123.8 °C. Under the conditions of 25 °C and 3.3V, the relative humidity accuracy can reach ± 4.5% R.H., while temperature accuracy ± 0.5 °C. TF-M1 wind speed sensor and TX-V1 wind direction sensor, which are light and easy to assemble, can detect the external environment information effectively. Their shells, made of high quality aluminum alloy, have good anti-corrosion and anti-erosion. Besides, they are unlikely to rust and keep the accuracy of information collection for a long time [12].

CC2430 made by TI (Texas Instruments) was used as MCU and RF module. The chip is chosen to implement the chip system on embedded ZigBee applications. They support 2.4GHz IEEE802.15.4 / ZigBee agreement. The chip is integration of industry-standard enhanced 8051 MCU, CC2420RF transceiver, 128KB Flash and 8KB SRAM. Its power consumption is low and its current is only 0.9μA in power-down mode.

Seeing that the sensor node has to be located on the top of the tower, they were always in an unattended state, which brought out a protrusive problem of the power supply. The isolation and electromagnetic interference of high voltage made it hard to get power supply from the transmission line directly. Hence the power supply module uses the management strategy of solar panels and battery hybrid power [13], so that the sensor nodes can not only run for a very long time, but also can be extended easily for more sensors.

3.2. Coordinator nodes

The coordinator node is composed of the MCU&RF module, the power module, the GPRS module and the serial module. Fig. 4 shows the structure of the coordinator node.

Coordinator nodes send and receive data using the same kind of MCU&RF module as the sensor nodes. An embedded system was composed of the MCU&RF module, the RS232 interface and the GPRS module, in which the GPRS module was directly used to support the transparent data communication. Through a simple set, the data were sent to the port of the server we have set up. The power module here is the same with that in the sensor node, which ensures that the coordinator node is online all the time.

3.3. Monitoring center

The monitoring center includes database, server and client. The server is a sever host that connects with the Internet. The database is installed in the server host. The client is a PC installed the client software and connected with Internet.

3.4. Software design

Software installed in the sensor nodes and the coordinator nodes is developed by the IAR Embedded workbench. The software includes an embedded operating system and applications. Software of the monitoring center is installed in the server and the client. Fig.5 shows flow charts of the software.

3.5. Sensor nodes

The process of software in the sensor nodes can be described as follows. Initialize the system, and then check if there is a network. If there is, just join in. The microprocessor controls data measurement of the sensor modules and receives data from the sensors. The data are sent out by the RF module. The sensor nodes automatically turn into the sleep mode after completing the sending data. The microprocessor turns off the sensing module function first, and then the internal clock to enter "sleep", only maintaining weak current to monitor external interrupt signal. The external real-time clock device called RTC controls the time of the nodes. RTC is of low power consumption, which can be neglected. At this time, the whole sensor nodes maintain in a low power state. When the data transmission cycle arrives, RTC sends an interrupt signal to the microprocessor to wake it up from sleep mode. The microprocessor restores functions of the clock and turns on the sensor modules, leading the entire nodes into the working state.

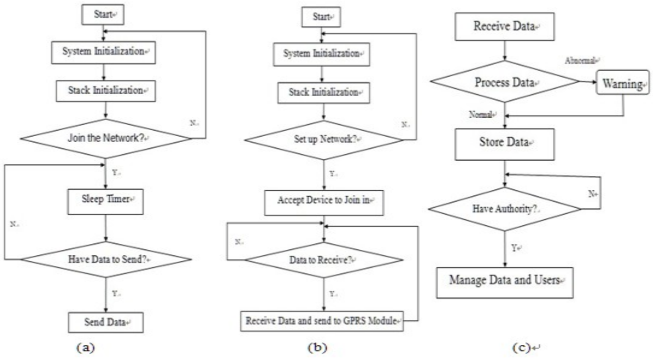

Fig. 5.(a) Flow chart of sensor node, (b) flow chart of coordinator node, (c) flow chart of monitor center

3.6. Coordinator nodes

The process of data-processing software in the coordinator nodes can be described as follows. First, initialize after the system is powered. Next, the coordinator node sets up ZigBee network and receives data collected by sensor nodes. Then the data are sent to GPRS module through RS232 interface. At last, GPRS module sends the received data to a specified IP address of the Internet. The coordinator nodes will always be online [14].

3.7. Monitoring center

The server is connected with the Internet. It has a static IP address and a particular port to receive GPRS data. To obtain the data of sensor network, the management software is connected with the distant coordinator node by socket (Windows Sockets). Through a series of data processing, the server stores the data into a database.

The management software of the system is developed by C + + Builder, while the database is set by SQL server. The management software includes data reception, data processing, data storage, user management, data management, data reporting and other modules. Data reception, data processing and data storage modules are used to receive the data from the remote coordinator node, and determine whether the data are normal or not. The users can be added or deleted and user permissions are set in the user management module. To prevent the misuse and malicious damage, only users who have authorities can use the software's specific functions. The data management module includes query of database, data deletion, data modification and so on.

3.8. Results and discussion

The experimental device is shown in Fig. 6. Three sensor nodes and one coordinator node are used for our test. Temperature is measured in an ESPEC series environmental chamber. Humidity is measured in the standard humidity generator. Wind velocity and wind direction are measured in the open air on different days. The server in our lab received the test results which are showed in Table 1, 2, 3 and 4.

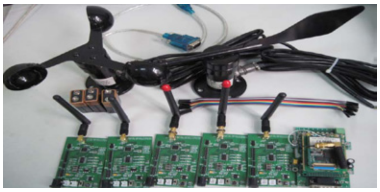

Fig. 6. Part of the experimental device

3.9. Sensor accuracy test

Table 1.Temperature measuring results

Environment	node1	node 2	Node3
-10	-10	-10	-10
0	0	1	0
10	10	10	9
20	18	19	19
30	28	31	30

(Temperature unit ℃)

Table 2.Humidity measuring results

Environment	node1	node 2	Node3
5.5	7	7	6
10.5	11	12	12
20.9	20	21	22
31.1	28	29	30
41.3	35	36	36
50.5	49	48	45
59.5	54	58	58
70.3	65	66	65
80.2	76	75	76
90.1	85	86	87
95.2	93	92	93

(Humidity unit %RH)

Table 3.Wind velocity measuring results

Environment	node1	node 2	Node3
≤0.2	0	0	0
1.6-3.3	2.0	2.3	2.5
3.4-5.4	3.5	3.8	3.7
8.0-10.7	7.6	7.8	7.5
8.0-10.7	10.0	10.5	10.4

(Wind velocity unit is m/s)

Table 4.Wind direction measuring results

Environment	node1	node 2	Node3
NW	NNW	NNW	NW
SE	SSE	SSE	SSE
NE	NNE	NNE	NE
SW	SSW	SW	SSW
E	E	NSE	E

(N=North, NW=Northwest, NNW=North by Northwest, similar to the others)

The data show that the maximum error of the temperature is 2℃, while the maximum error of the relative humidity 5.5% RH. They are consistent with the accuracy of SHT10 described in [12]. According to the weather forecast, we got the wind information of the environment in different days. From Table 3 and Table 4 we can see that the output of wind direction sensor is accurate and the wind velocity sensor is in line with weather forecast in a broad range.

3.10. Communication distance test

The communication distance of sensor nodes and coordinator nodes reaches up to 100 meters indoor and 200 meters outdoor. With the method in ref. [15], the communication distance can be increased by increasing the power amplifier, so that it can meet the actual requirement.

3.11. Power consumption test

Sensors and RF modules are the main parts which use power. According to the ref. [16], we tested the power with Packet Sniffer which is provided by TI in sleep mode. The power consumption of microcontroller in sleep mode is very low. It has been calculated that 9V battery can last 200 hours.

3.12. Warning test

According to the statistical analysis, the basic meteorological conditions that the transmission lines are covered with ice are as follows. The temperature of equipment surface reaches -8-0 ℃; The air humidity reaches more than 85% RH; the most suitable wind speed for generating ice is usually 2-7m / s. Data processing software in the server is programmed with a particular algorithm. In the algorithm, when meeting the conditions above, the monitoring center will warn. Tests showed that the monitoring center's host alarmed accurately when data meet the conditions.

4. Conclusion

This paper introduces a smart monitoring system on transmission lines. The most significant feature of the system is the wireless transmission with ZigBee and GPRS technology. The results showed that it could meet the basic requirements in the aspects of sensor accuracy, communication distance, power management and warning. In addition, the system has good extensibility and compatibility. The data acquisition is modular. Each kind of the equipment has the separate measurement module, so it is very easy for the unified transferring management of large amounts of data. The system can be applied to all aspects of power generation, distribution, transmission and so on. The cost of the system is relatively low. What's more, it is easy to install and implement long-distance monitoring.

Our next task is to improve the performance of system: increase communication distance based on low power consumption, improve the algorithm to process the data for providing more warning programs and add more sensor modules to increase the scope of monitoring, i.e., the monitoring of the forest fire and transmission line breakage can be achieved by using of image sensors and improving the algorithm.

Acknowledgements

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References

[1] Hubert Zangl, Thomas Bretterklieber, and Georg Brasseur, "A Feasibility Study on Autonomous Online Condition Monitoring of High-Voltage Overhead Power Lines," IEEE Transactions on Instrumentation and Measurement, Vol. 58, No. 5, MAY 2009

[2] Zhang Gang, "Study on Electrical Switching Device Junction Temperature Monitoring System Based on ZigBee Technology," 2010 International Conference on Computer Application and System Modeling (ICCASM 2010)

[3] Christos Xenakis, Danae Apostolopoulou, Angeliki Panou, Ioannis Stavrakakis, "A Qualitative Risk Analysis for the GPRS Technology," 2008 IEEE/IFIP International Conference on Embedded and Ubiquitous Computing

[4] Aryadevi Remanidevi Devidas, Maneesha Vinodini Ramesh, "Wireless Smart Grid Design for Monitoring and Optimizing Electric Transmission in India," 2010 Fourth International Conference on Sensor Technologies and Applications

[5] Degang Gan, Fan Liu, Lin Du, Yuming Liu, "Research and Implementation of On-line Monitoring Techniques for High Voltage Equipments in Smart Grid," High Voltage Engineering and Application (ICHVE), 2010 International Conference on 11-14 Oct. 2010

[6] Qinyou Wang Ming Zhong Yumei Liu, "Remote Monitoring and Intelligent Diagnosis for Power Transmission Lines," Control and Automation, 2003. ICCA '03. Proceedings. 4th International Conference on 12-12 June 2003

[7] Xiao Tian and Yangchun Cheng, "The Investigation of FBG sensor system for the transmission line icing measurement," 2008 International Conference on High Voltage Engineering and Application, Chongqing, China, November 9-13, 2008

[8] Xiaopeng Wang, Jianlin Hu, Bin Wu, Lin Du, Caixin Sun, "Study on Edge Extraction Methods for Image-based Icing On-line Monitoring on Overhead Transmission Lines," 2008 International Conference on High Voltage Engineering and Application, Chongqing, China, November 9-13, 2008

[9] P.L. Lewin, L. Hao, D.J. Swaffield and S.G. Swingler, "Condition Monitoring Of Power Cables," IET Power Convention, 2007

[10] F. V. B. de Nazaré, M. M. Werneck, "Temperature and Current Monitoring System for Transmission Lines Using Power-over-Fiber Technology," Instrumentation and Measurement Technology Conference (I2MTC), 2010 IEEE

[11] Yu Chen, Haijun Zhang, "Research and Design of High-Voltage Electronic Power Equipment Monitor System Based on Wireless Communication Technology," Power and Energy Engineering Conference, 2009. APPEEC 2009. Asia-Pacific

[12] Datasheet SHT1x (SHT10, SHT11, SHT15) Humidity and Temperature Sensor

[13] Yin Ting, Chen Xuanshu, Du Yan, He Yejun, "Research on Power Supply Employed in Ices Real-Time Monitoring System of High-Voltage Transmission Lines," 2008 International Conference on High Voltage Engineering and Application, Chongqing, China, November 9-13, 2008

[14] Jian Huang, Peilei Rao, Xiaoguang Hu, Jin Xiao, "Research of On-line Monitoring System of the Condition of Circuit Breaker Based on ARM and FPGA," 2009 IEEE International Conference on Control and Automation Christchurch, New Zealand, December 9-11, 2009

[15] Mingzhi Chen, "The design and scheme of dynamically increasing ZigBee's distance of communication," Automation & Instrumentation,CNKI:SUN:ZDYY.0.2007-04-011

[16] SELVIG B., "Measuring power consumption with CC2430 &Z-Stack application note AN053," TI lit