Research on the application of WIA industrial wireless technology in the substation auxiliary control system

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Abstract: This paper presents a new substation auxiliary control system communication scheme based on WIA industrial wireless technology. The structure and operation principle are introduced, and the technical difficulties and solutions of the WIA industrial wireless technology in substation auxiliary control system application are analyzed from the network protocol and hardware design. The validity of the schema has been verified through the practical application in the pilot project.

Key Words: WIA; auxiliary control system; substation wireless communication; network protocol; hardware design

1 Introduction

Substation is one of the core platform to realize the energy conversion and control in the construction of sturdy and smart grid, but also the key to link generation, transmission, transformation, distribution, consumption and scheduling in the smart grid[1]. Intelligent auxiliary control system is an important embodiment and necessary part of smart substation[2].

With the expanding construction scale of smart substation and the rapid development of the related technologies, unmanned substation is promoted and applied. On the basis of this, the auxiliary control system becomes more and more important. Currently, there are manufacturers can provide a relatively complete auxiliary control system, but the information transmission generally use wired, there are many disadvantages such as large amount of wiring construction, high cost, system flexibility and scalability is limited, hard maintenance and so on[3]. Therefore, the wireless sensor network with low cost, low power is an effective way to solve these problems.

WIA (Wireless Networks for Industrial Automation) technology is an ultra-low-power intelligent multi-hop wireless sensor network technology which is more suitable for industrial application of high reliability. In this paper, according to the substation operating environment and the structure of auxiliary control system, based on the analysis of application deployment and node hardware design for WIA wireless network in the auxiliary control systems, gives a new substation auxiliary control system communication scheme based on WIA industrial wireless technology.

2 Substation Auxiliary Control System Communication Architecture Based on WIA Industrial Wireless Technology

Substation auxiliary control system using sensor technology, visualization technology, modern communication technology and control technology, achieves the real-time intelligent monitoring for substation environment, power and equipment, intelligent data analysis, alarm linkage and integrated visual display, provides an important auxiliary support for substation operation, maintenance and information[4]. With the deepening of understanding to the smart substation, to build a highly integrative auxiliary control system platform is a new development trend of smart substation.

2.1 Substation Auxiliary Control System Overview

Substation auxiliary control system is generally divided into three layers: the first layer is the remote integrated application server, the second layer is the station auxiliary control system host, the third layer are various kinds of auxiliary subsystem, the system composition structure as shown in Fig. 1[5].
The remote integrated application server is responsible for receiving various kinds of auxiliary subsystem operation after station auxiliary control system host processed, including exception handling results, video and so on, and issuing control instruction to realize the remote control of auxiliary subsystem.

The main function of the station auxiliary control system host is to collect data for each subsystem and storage, processing, analysis and reporting exception handling process to the remote integrated application server, and executing the commands issued by remote server.

Substation auxiliary subsystem includes video monitoring subsystem, security subsystem, environmental monitoring subsystem, fire alarm subsystem. Using a variety of sensors (HD cameras, electronic fence, temperature and humidity sensors, waterlogging sensors, infrared detector, etc) to collect data for each subsystem and then upload to the station auxiliary control system host, and the intelligent terminals (sound and light alarm, air conditioning, etc) execute the results processed by station host.

2.2 Auxiliary Control System Communication Architecture Based on WIA Technology

According to the actual situation of substation, the sensors which have multiple nodes, wiring difficulty and using in high voltage electric equipment with insulation requirements are use wireless communication. For example, temperature and humidity sensors, waterlogging sensors, temperature measurement terminals of equipment temperature monitoring system and so on use wireless communication. Other auxiliary subsystems such as the intelligent access control system, a substation is generally only one to two sets, the number of intelligent access controller is less and most installed indoors, so still use the wired connection. Video monitoring subsystem with higher requirements on wireless communication bandwidth and real-time, is not suitable for the use of wireless communication. The communication architecture of auxiliary control system based on WIA Technology is shown in Fig.2.

As shown above, the auxiliary control system is divided into various independent wireless communication sub-networks, each sub-network forms a cluster, and the cluster head is an intelligent wireless communication gateway. The nodes in cluster take gateway as the center to form self organizational multi-hop WIA wireless network, and each sub-network has different network identification and communication channel, so there is no mutual interference. Each wireless gateway supports IEC-61850 protocol which is connected with the station auxiliary control system host.

The communication system scheme is neat layout and clear layers. Each subsystem communicates with station auxiliary control system host through wireless gateway based on IEC-61850 protocol format. It is conducive to realize the integration of full auxiliary control system information, and provide communication infrastructure for establishing integrated auxiliary control system platform.

3 WIA Industrial Wireless Technology Applied in the Substation Auxiliary Control System

Substation is different from the general industrial applications, the work site has complex structure and high voltage, large current and strong electromagnetic field, the environment is very bad. So the application of wireless sensor network technology into the substation is also facing with many practical problems, and needing to take the necessary measures to effectively reduce application difficult.

3.1 The Main Application Difficulties

3.1.1 Effects of Environmental Conditions on Communication Performance

Substation has a complex electromagnetic environment, including power frequency electromagnetic field, corona discharge, electrostatic discharge, partial discharge, SF6 gap breakdown arcing, etc. Which the transient
electromagnetic interference such as SF6 gap breakdown arcing is rich in high frequency components, easy to form the interference of wireless communication[6].

Also the presence of multipath interference can not be ignored in substation, the substation construction structure is complex, and a large number of metal equipments and columns easy to reflect RF signals, resulting in multiple path interference. Multipath interference will lead to signal fading, phase shift and decomposition, have a great influence on the wireless communication system.

In addition, the installation location of wireless sensor node is generally in the outdoor, the environment is very harsh, thunder and lightning storms and other natural factors may make the communication performance change frequently, and resulting in network topology is not controllable[7].

All of these will bring many problems for wireless communication, such as node frequently dropped, the channel loss and abnormal data transmission, seriously affecting the real-time, stability and reliability of wireless communication network[8].

3.1.2 The Requirement of Hardware Design for Network Node in High Voltage and Electromagnetic Environment Is High

There are a variety of discharge conditions in substation environment. General circuit design is difficult to withstand the impact of high voltage pulse, resulting in damage to the circuit board. Substation complex electromagnetic environment will also have a great impact on the circuit, such as the power ripple increase, clock frequency offset and the signal level disturbance and so on.

So in the substation, the hardware design of wireless sensor node should fully consider high voltage protection and electromagnetic compatibility.

3.2 Adopted Measures

In order to make wireless sensor networks play a good communication performance in substation auxiliary control system, this paper analyzes the measures from two aspects of hardware and network protocol design.

3.2.1 The Characteristics of WIA Technology

WIA has several advantages compared with other wireless networks including rapid deployment and easy installation, low power consumption, robustness and flexible structure. This system uses the WIA wireless technology, make full use of the characteristics of WIA network can well adapt to the substation environment.

1. Adaptive frequency hopping

WIA technology uses the adaptive frequency hopping technology, can effectively inhibit various kinds of electromagnetic interference and multipath interference in substation environment. The method based on traditional frequency hopping has blindness which is ineffectiveness in most grid applications. Adaptive frequency hopping method by evaluating the link quality of the current channel can be performed on non-interference frequency point to improve the quality of the received signal in frequency hopping communication and avoid the influence of interference with high quality[9].

As shown in Fig.3, the WIA network communication is according to the time slot with the TDMA method based on time synchronization. In each time slot, the network devices communicate in adaptive channel selection way based on the quality of the current channel. When the channel quality is poor, that is the packet loss rate is bigger than the threshold value, the communication channel is changed in the next time slot.

Fig. 3: Schematic diagram of adaptive frequency hopping

2. Multi paths routing

WIA technology uses the intelligent mesh network in the network layer. Each node has at least two available communication paths. After joining the network, the node can choose the data transmission path automatically. When a path is interrupted due to interference, the network device can automatically switch to the path of other communication quality better. This feature can effectively solve the communication link state unstable between nodes caused by the factors of natural environment[10].

The neighbor relationship between nodes in the WIA network is not fixed. Each node has network self-organization and self-maintenance capabilities to automate network configuration and management, a typical network topology shown in Fig.4.

Fig. 4: The network topologic structure of WIA

3. Automatic retransmission mechanism

WIA technology uses automatic retransmission mechanism in the data link layer to ensure that the success rate of the packet transmission. As shown in Fig.5, when a network node sends a packet, it immediately switches to the receive state and waiting for the ACK. If received ACK, then the message is successfully sent, if fail to receive ACK, and then resends the packet[11].

Fig. 5: The network topologic structure of WIA
Fig. 5: The schematic diagram of packet retransmission

- **Low power**
  WIA network uses the global synchronized sleep mode based on TDMA, reducing interception and standby time, so the duty cycle of the node up to 99%, as shown in Fig. 6. In order to reduce the communication overhead, WIA network supports the message combination, increasing the proportion of valid data in the packets. So the power consumption is effectively reduced, the average current of node is microampere level[12].

Fig. 6: The power consumption of WIA network node

### 3.2.1 Hardware Design Optimization

In the face of substation specific application environment, this paper takes two aspects from the circuit protection and electromagnetic compatibility to optimize the hardware design of wireless communication devices.

- **Circuit protection**
  In order to prevent the high voltage pulse damage to the circuit board, the main protection circuit is applied to the circuit board of the power supply circuit and a communication interface circuit. As shown in Fig. 7, this is the triple protection circuit is composed of a gas discharge tube, varistors and TVS diode. Gas discharge tubes G1, G2, G3 on the front line compose the first-level protection circuit for amplifying leakage current. The second-level protection circuit is composed of varistors Rv1, Rv2, Rv3, used to further reduce the residual voltage. The third-level protection circuit is composed of TVS diode T1, T2, T3 to control of the residual voltage at a certain level. The inductance L between the first and second level protection circuit, and resistor R between the second and third level protection circuit are used for coordinating two levels protection elements in the action on the characteristics to avoid damage to the device.

Fig. 7: The triple protection circuit

- **EMC**
  Aiming at the complex electromagnetic environment in substation, this paper take three measures form filtering, grounding and shielding to ensure that the electromagnetic compatibility design of hardware circuit. Filtering technology is mainly reflected in the equipment and the external connection port, used to filter the interference signal by external conduction. This paper presents a dual filter circuit shown in Fig. 8. C1, C2, C6, C7 are common mode filtering capacitors, C3, C4, C5 are differential mode filter capacitors, L1, L2 are common mode inductors, this circuit can filter out differential mode and common mode interference on the line simultaneously.

Fig. 8: Dual filter circuit

Grounding technology is an important means to restrain electromagnetic interference and improve the electromagnetic compatibility of electronic equipment[13]. The device ground is divided into the power ground, the signal ground and the shield ground from the electromagnetic compatibility consideration in this paper. The power ground uses bonding copper technology to reduce the loop area, and connected with the shell by the fixed screw. The device shell is the shield ground, and connected with the earth directly. Signal ground is connected to the power ground via a capacitor.

Shielding technology is the use of shield to block or reduce the electromagnetic energy transmission, is one of the important means to restrain electromagnetic interference. Considering the cost, volume, weight and insulating property, this paper uses the insulated shell enclosing the metal net as the device shield[14].

### 4 Application of the Wireless Auxiliary Control System in the 220KV Smart Substation

The auxiliary control system based on WIA industrial wireless technology designed above has been put into operation in a 220kV smart substation. The validity of the system has been verified.

The 220kV smart substation is a pilot substation of the state grid. The devices using wireless communication by the
auxiliary control system are including environmental temperature and humidity sensors, equipment temperature sensors, waterlogging sensors, wind sensor, infrared detector, electronic fence and air conditioning remote control according to the design of the substation. Details of devices are listed in TABLE 1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental temperature and humidity sensors</td>
<td>Monitoring of environmental temperature and humidity</td>
<td>11</td>
</tr>
<tr>
<td>Equipment temperature sensors</td>
<td>Equipment temperature monitoring</td>
<td>22</td>
</tr>
<tr>
<td>Waterlogging sensors</td>
<td>Waterlogging alarm</td>
<td>12</td>
</tr>
<tr>
<td>Wind sensor</td>
<td>Environmental wind monitoring</td>
<td>1</td>
</tr>
<tr>
<td>Infrared detector</td>
<td>Intrusion alarm</td>
<td>1</td>
</tr>
<tr>
<td>Electronic fence</td>
<td>Intrusion alarm</td>
<td>1</td>
</tr>
<tr>
<td>Air conditioning remote control</td>
<td>Air conditioning control</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 9 shows the physical structure of the system. The integrated application server is located in the province grid, responsible for management and controlling monitoring device at all levels. The station auxiliary control system host is a station level device in the smart substation, it is mainly used for getting all monitoring data within the smart substation, analyzing based on these data, and sending alarm information to the integrated application server and downloading control commands from it. The access control and video monitoring use wired communication, the others use wireless communication. The wireless gateway which supported the IEC61850 is using for management network and exchanging of data and control information between the station auxiliary control system host and monitoring equipment based on IEC61850 standard.

The system has been running for about six months in the 220kV smart substation, Fig.10-12 are the pictures of station auxiliary control system host, wireless gateway and wireless monitoring devices installed in the substation.

Fig. 10: Picture of station auxiliary control system host

Fig. 11: Picture of wireless gateway

Fig. 12: Picture of the wireless monitoring devices

5 Conclusion

Aiming at the substation complex application environment, we propose a new communication scheme for auxiliary control system based on WIA industrial wireless technology. In the application of 220kV smart substation shows that this scheme can be well overcome the high cost of wiring, limited system extendibility and flexibility and so on. The system can reduce construction costs about 200,000 Yuan and promotes the integration of on-line monitoring system and auxiliary control system, to provide ideas for integration platform. It will be the first substation auxiliary control system that is almost fully using wireless communication, and will guide the application of wireless
in the follow-up projects. However, there are still many challenges including video signals wireless transmission and energy supply and so on. So we still need further study on the application of wireless auxiliary control system in the smart substation.

References