Application of IEEE1588 in Time Synchronizing System of Smart Distribution Grid

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Abstract:

The application of IEEE1588 in time synchronizing system of smart distribution grid is researched in this paper. Topologic structure of communication system of distribution grid is analysed in the second instance. Redundancy configuration and auto-select technique of precise clock source are brought forward afterwards. Thirdly, clock mode selection scheme of backbone layer, access layer and distribution terminal are analysed with emphasis. Finally, IEEE1588 synchronization process in the redundant mechanism of backbone layer, access layer and distribution terminal is presented in detail.

1 Introduction

With the development of smart distribution grid[1-4], synchronous measurement, pilot protection based on communication system and other key technologies in smart distribution grid have proposed high time precision requirement. [5] As a result, time synchronization technology are more and more important in smart distribution grid.[6,7]

The existing popular synchronization technologies in power system are global positioning system (GPS), Inter Range Instrumentation Group-B (IRIG-B) code, Simple Network Time Protocol (SNTP) and IEEE1588.[8] The statistical error of GPS output is up to 1μs, which satisfies the demand in substation automation and SCADA. However, the scattered position, wide distribution, bad testing sites, and other feathers of distribution grid make the application of GPS in every distribution node unpractical. The general precision of IRIG-B code synchronization technology is less than 12μs, but it needs additional dedicated channel. This does not suitable for the actual situation in distribution grid stated above. By means of SNTP technology only 1ms accuracy can be gotten.

IEEE1588 is known as precision clock synchronization protocol for networked measurement and control systems (precise time protocol, PTP).[9-12] It is a precise time synchronization protocol, with sub-microsecond synchronization performance. The main principle is that, by using GPS as clock source, the distribution network transfers the precise time progressively through the existing communication system, which would lead to the synchronization of the entire distribution network. By applying IEEE1588 technique, it helps the time synchronizing system of smart distribution grid to reduce the dependency on GPS. Contrast to GPS and other technology, IEEE1588 offers more advantages such as higher bandwidth, stronger anti-jamming capability, lower cost, lower bit error rate, stronger security and better security. All of these outstanding feathers make IEEE1588 suitable for time synchronizing system of distribution grid.

In view of the high time precision requirement and the actual situation, this paper introduces IEEE1588 into time synchronizing system of smart distribution grid. Given that one of the biggest difficulties of the application of IEEE1588 in distribution grid is the isomerization of the communication system, this paper focuses on the solution to this problem.

2 Typical communication system of distribution grid

In structure, communication system of distribution grid could be divided in backbone layer and access layer. Backbone layer realizes the communication among substations, by using SDH/MSTP (synchronous digital hierarchy/multi-service transfer platform) technology, industrial Ethernet technology and so on. For its higher data transmission rate, more mature technology and operation experience, industrial Ethernet technology has been one of the most popular techniques in backbone layer communication construction. Access layer realizes the gather of data from FTUs to substations, by using industrial Ethernet technology and Ethernet passive optical network (EPON). For its lower construction cost, more suitable for multi-services, easier for extension and upgrading, EPON has been the most preferred access layer construction technique.

This paper takes a typical communication system of distribution grid as object. Its backbone layer applied industrial Ethernet technology, access layer applied EPON technology.[13] The topologic structure is shown in Figure 1.

In Figure 1, host station and substations in backbone layer compose ring network by using Gigabit Ethernet switches. To avoid broadcast storm, a block is set in the backbone ring. When the system is running normally, the block is disconnected. Data could not pass the block. If fault occurs, the block would be connected in 50ms automatically. It would provide a new link for data to pass.

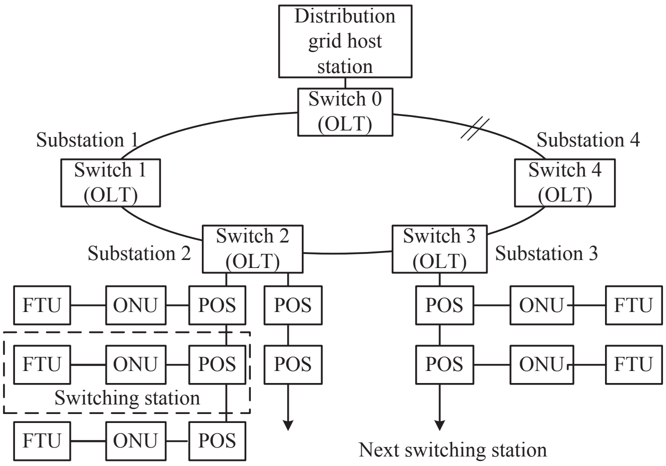

Figure 1 Construction of distribution grid communication system

Besides the normal bus topology shown in Figure 1, there are two other EPON topologies in access layer. They are hand-in-hand redundant network and OLT with double PON interfaces redundant network.[14] The topologic structures are shown in Figure 3 and Figure 4.

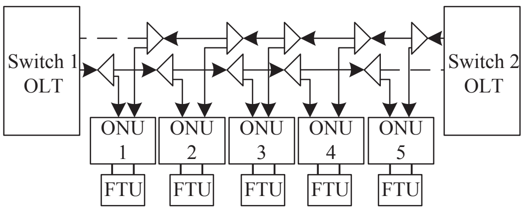

Figure 2 Hand-in-hand redundant network

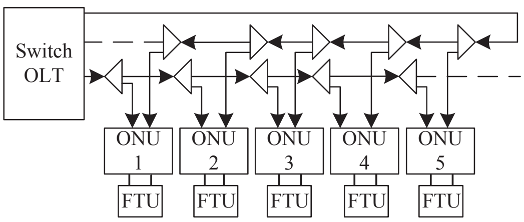

Figure 3 OLT with double PON interfaces redundant network

The difference between these two types is where the OLTs are placed. In hand-in-hand redundant network, the main and backup OLTs are placed in different substations. This topology is suitable for the devices located between two substations geographically. In OLT with double PON interfaces redundant network, both the main and standby OLTs are placed in the same substation. They could be two different switches or two PON interfaces on one switch. This topology is generally suitable for most distribution devices. Presently, hand-in-hand redundant network is the most popular networking mode.

Besides, feeder terminal units (FTU) are also equipped with two redundant interfaces. Each interface links to different substation.

The above is typical communication system of distribution grid, which applied industrial Ethernet in backbone layer, and EPON in access layer. The primary research of this paper concentrates on clock source configuration, selection of clock modes for each node and IEEE1588 synchronization process in redundant network.

3 Clock source configuration

The clock source of the entire time synchronizing system of distribution grid could be equipped in distribution host station and some qualified substations.

The grandmaster clock of the whole time synchronizing system of distribution grid is commonly set in distribution host station. The clock source of the system is GPS/Beidou system. The local clock is oven controlled crystal oscillator (OCXO) which is synchronized by GPS/Beidou system. If GPS/Beidou system runs abnormally, OCXO would automatically enter the hold mode, output high-precision frequency and time signal, in order to maintain system working normally continually. The structure of GPS/Beidou system precise clock source in grandmaster clock is shown in Figure 4.

In addition, some qualified substations could also be equipped with the GPS/Beidou system. When substations lose contact with host station or the precision of the grandmaster clock source declines, according to the result of Best Master Clock (BMC) algorithm, backbone layer switch take the time signal from the GPS/Beidou system in substation as the clock source, to synchronize the whole or divided distribution grid.

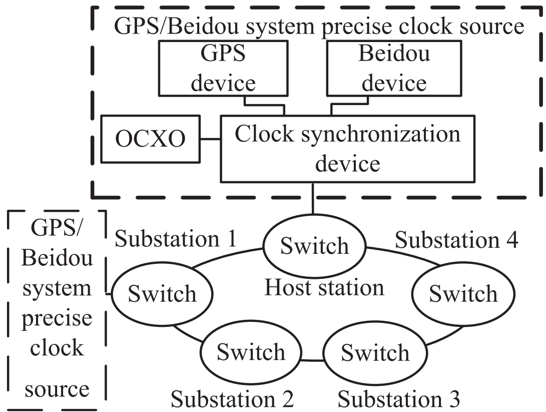

Figure 4 GPS/Beidou system precise clock source

When there are two or more clock sources in a system, it is necessary to find out the best one and set it as the grandmaster clock of the entire time synchronizing system. This could be realized by using BMC algorithm of IEEE1588. BMC algorithm is a key algorithm in IEEE1558, composed by

Dataset Comparison algorithm and State Decision algorithm. Dataset comparison algorithm could find a better one from two clock data by comparing characteristics of grandmaster clock (such as clock level, clock variance and clock identifier, etc.) and the path length from grandmaster clock to local clock. Based on the result of Dataset Comparison algorithm, State Decision algorithm sets the better qualified one as the master clock. If external clock is better than local clock, the algorithm sets local clock as slave clock and modify the local dataset to synchronize master clock. If local clock is better, it sets local clock as master clock and send time synchronization message to slave clock. From the network perspective, BMC algorithm could build a time synchronization tree with the grandmaster clock being the root. From each node perspective, BMC algorithm can determine the master-slave relationship between each and other nodes.

4 clock mode selection for each node

PTP defined three clock modes. They are ordinary clock (OC), boundary clock (BC), transparent clock (TC). Generally, there is only one IEEE1588 interface on an ordinary clock, used as the beginning or end of the time synchronizing system. Its task is to send or receive time data to synchronize the local clock, by acting as master or slave clock. Boundary clock is the time device in middle node. There are several interfaces on it. One of them acts as a slave one, and adjusts local clock to synchronize the superior clock. Others act as master, sending time data to subordinate clocks. In this way, the time data could be transmitted step by step. Transparent clock could calculate the time IEEE1588 packet cost in going through the device. The time would be provided to the receiver with the packet. After the calculation in subordinate clock, IEEE1588 packet could pass through the device transparently.

4.1Clock mode selection for backbone layer nodes

Substations communicate through industrial Ethernet. The delays in upstream and downstream are equal, which satisfies the demand of IEEE1588. Moreover, if switches in backbone layer were set as TC, they would lose the ability to end and generate PTP packet, and to act as BC in the access layer, which means that every FTU would communicate with host station directly. This would cause the CPU in host station overload, which would hold back the system expanding and upgrading. Above all, switches in backbone layer should be set as BC. Take substation 2 in Figure 1 for example, synchronization progress is as follow. Switch 2 receives PTP packet from switch 1. After updating local clock, switch 2 generates new PTP packet with local time stamp in substation 2, then sends it to substation 3.

4.2 Clock mode selection for access layer nodes

Nodes in access layer communicate through EPON. Downstream adopts broadcasting communication technique, upstream adopts TDMA technique. Delays are not equal, which cannot satisfy IEEE1588 demand. For this reason, PTP packet cannot be transferred transparently. Thus, it is necessary to synchronize OLT and ONU (optical network unit) in EPON system firstly, then set them connectively as BC or TC.

4.2.1 OLT and ONU set as TC

In downstream, ONU calculates the time PTP packet cost in going through OLT and ONU, then add it into time adjusting domain. In upstream, OLT does the above work. Eventually, by calculating data in time stamp and time adjusting domain, subordinate clock would obtain precise time.

4.2.2 OLT and ONU set as BC

In downstream, OLT in substation receives PTP packet from superior clock. At the same time, the packet would be ended. Through the EPON synchronizing system, ONU would update local clock. As master of subordinate clock, ONU would generate new PTP packet, then send it to FTUs. On the contrary, in upstream ONU receives and ends PTP packet, then OLT actualizes the communication with master clock.

The technique setting OLT and ONU connectively as BC has been widely applied, and the synchronization accuracy could achieve 100ns, which satisfies smart distribution grid requirement.

4.3 Clock mode selection for FTU node

FTU node could only act as slave clock, and it just need one PTP interface to receive packet, so all FTU nodes should be set as OC.

5 IEEE1588 synchronization process in redundant mechanism

5.1 IEEE1588 synchronization process in backbone layer

When the system is running normally, the block is open, data packet could not pass the block. When fault occurs, the block would be connected in 50ms automatically. Then data packet could pass the block. The disconnected substation would communicate with host station through the new link. By BMC algorithm, the backbone layer node would get the information that the time data received by the interface connected with the new link is the best. Switch would set that interface as slave, and other interfaces would still act as master to send synchronization information. In this way, the backbone layer would complete fault self-recovery.

5.2 Synchronization process in access layer

In access layer redundant mechanism, main and backup OLTs send synchronization data to each optical cable in the same time. There are two main and backup PON interfaces on every ONU, receiving data from each optical cable respectively. When the system is running normally, ONU receives data from the main PON interface. When fault happens, the main interface could not receive data from OLT, ONU would switch to backup interface automatically. In this way, it would guarantee reliability of the communication system of access layer.

5.3 IEEE1588 synchronization process in FTU with two PON interfaces

In this redundant mechanism, every FTU would receive packets from two systems with different clock sources. It is necessary for FTU to compare and select a better one. Because FTU could only act as slave clock and receive synchronization packet, it just need to calculate Dataset Comparison algorithm. According to the result, FTU would choose the better time data to update local clock.

6 Conclusion

Industrial Ethernet and EPON technology are commonly used in the communication system of distribution grid. Application of IEEE1588 technology would help to improve the precision of the synchronizing system, and reduce the dependence on GPS. At present, the domestic research on this field is not sufficient, this paper proposed solutions to problems such as clock source configuration, clock mode selection for each node and IEEE1588 synchronization process in redundant mechanism.

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