Research on a Fully Digital Simulation Training System for Power Communication EPON Equipment

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Abstract: With the continuous application of EPON (Ethernet Passive Optical Network) technology in the power communication network, communication operation and maintenance personnel urgently need to carry out equipment practical training and skill drills regularly. In response to the problems of high investment and maintenance costs, low training implementation efficiency, and difficulty in efficient practical exercises for equipment operation and fault handling in EPON training equipment, this article designs a solution for a fully digital EPON equipment simulation training system, and proposes simulation methods for software functions of EPON equipment such as OLT (Optical Line Terminal) and ONU (Optical Network Unit). It also proposes simulation methods for hardware appearance and interactive operation of the equipment, and further proposes a synchronization mechanism for software function and hardware feature simulation. The simulation training system developed based on this scheme not only comprehensively simulates the hardware interaction characteristics and communication logic characteristics of the equipment, but also has the ability to organize and implement large-scale, scenario based, and efficient skill training, fully supporting EPON equipment skill training and drills, and achieving rapid improvement of communication operation and maintenance personnel's skill level and work ability.

Keywords: EPON; OLT; ONU; Fully Digital Simulation Training System; Software Functional Simulation; Hardware Feature Simulation

1. Introduction

With the construction of new power systems and the advancement of digital transformation of power grids, power communication networks including EPON technology are playing an increasingly important role [1].

As a power communication infrastructure, EPON supports real-time data exchange between various intelligent terminal devices of the distribution automation system and the main station system, and can carry multiple services such as electricity information collection, distributed energy access, and monitoring of electric vehicle charging stations/piles [2, 3]. Meanwhile, with the large-scale integration of new energy, EPON supports remote monitoring and data collection of new energy power plants such as wind power and photovoltaics with its high-speed and bidirectional communication capabilities. Through the EPON network, new energy power stations can upload real-time power generation data, equipment status, and other information, which helps the power grid dispatch center to reasonably dispatch and consume new energy [4, 5]. EPON simplifies the structure of power communication networks and reduces the complexity and cost of network maintenance due to its passive optical network characteristics. EPON supports multiple service interfaces and flexible networking methods, making it easy to interconnect with other power communication systems. In summary, EPON provides strong communication support for the new power system with its efficient and reliable data transmission capability, achieving high-speed and real-time information exchange between various links of the power system. This not only improves the operational efficiency and stability of the power system, but also promotes the integration and consumption of new energy, laying a solid foundation for building a clean, low-carbon, safe and efficient new energy system.

With the continuous expansion of EPON

network scale, the number of equipments continues to increase, the types of equipments continue to enrich, the fault phenomena become more complex, and the difficulty of operation and maintenance work continues to increase. This poses new challenges to the knowledge and skills of communication operation and maintenance personnel. A large number of operation and maintenance personnel urgently need to carry out training on EPON related equipment cognition, equipment operation and maintenance, data configuration, and fault handling. Given the current lack of practical training support environment for EPON equipment in various power training centers and communication operation and maintenance departments, it is difficult to effectively carry out EPON equipment training, especially in terms of practical operational skills.

Due to the large number of EPON equipment models and high prices, purchasing multiple real equipments to build a training support environment has the following problems: 1) The equipment procurement price is expensive, the installation process takes a long time, and the daily maintenance cost is high, resulting in a significant increase in training costs; 2) Due to the fact that a physical equipment can only accommodate one trainee for practical operation, it is not possible for multiple people to participate in practical training and practice simultaneously, resulting in low training efficiency; 3) Based on real equipment, reproducing faults is not only technically difficult and costly, but also poses certain safety hazards and equipment damage risks, posing additional challenges and limitations to training work.

The existing EPON simulation software is mainly used for network planning and analysis scenarios, does not support communication equipment operation, cannot simulate equipment software and hardware failures, and cannot meet the needs of skill training and fault drills [6, 7]. The EPON simulation training system implemented based on the "software+hardware" method requires the introduction of special hardware such as interface circuits and signal processors, which is expensive and can only simulate faults of a single type of equipment, making it difficult to install and use anytime and anywhere. Therefore, the practical effect is unsatisfactory and difficult to promote and popularize [8, 9].

Based on the analysis of the functions and characteristics of power communication equipment, this article proposes a fully digital simulation training system solution for power communication EPON equipment that fully meets the requirements of skill practical training scenarios, using computer simulation, 3D modeling, and natural interaction technology.

2. Functions and Characteristics of Power Communication EPON Equipment

The power communication EPON network uses a point-to-point network structure, passive fiber optic transmission, and Ethernet protocol to provide high-speed and efficient data transmission services. Its main equipment is OLT (Optical Line Terminal), ONU (Optical Network Unit), and POS (Passive Optical Splitter).

OLT is the core component of the entire EPON system, serving as both a switch or router and a multi service provider platform. Its main functions include: Connect multiple ONUs through optical fibers to achieve data aggregation and transmission; Manage and control the entire EPON network, including registration, authentication, ranging, time synchronization, etc. of ONU equipments; Provide users with multiple service interfaces and support multiple service models; Dynamically allocate bandwidth resources to ONUs based on user needs and network conditions, control the starting time and sending window size of data sent by ONUs.

ONU is a user side equipment in the EPON network, connected to OLT via fiber optic to achieve high-speed and efficient data transmission and exchange, providing users with stable and reliable network services. Its main functions include: selecting to receive broadcast data sent by OLT; Respond to the ranging and power control commands issued by OLT and make corresponding adjustments; Cache the user's Ethernet data and send it in the upstream direction within the sending window allocated by OLT; Provide user interfaces and other related Ethernet functions.

POS is a passive equipment that links OLT and ONU, and its function is to distribute downlink data and concentrate uplink data.

3. Overall Design of EPON Equipment

Simulation Training System

Due to the relatively simple POS function, which generally does not require operation by maintenance personnel and is rarely involved in practical training, the simulation training system designed in this article mainly realizes the simulation functions of OLT and ONU. From the perspective of equipment training, it is necessary to simulate both the software functions of OLT and ONU equipments, as well as the hardware characteristics of the simulated equipments, while also simulating the abnormal state of the equipments when different types of faults occur.

The software functions of EPON equipments are mainly reflected in two aspects: communication signal processing and equipment management. In terms of communication signal processing, EPON equipments have the ability to receive, send, and process various communication signals, such as EPON frames, Ethernet frames, etc. In terms of equipment management, it provides a series of functions such as parameter configuration, alarm generation and reporting, and performance management. The hardware characteristics of EPON equipments cover multiple aspects of the equipment and its constituent elements, including physical, state, and operational characteristics. The physical characteristics mainly involve the visual effects, size, and placement position of the equipment and its components; The state characteristics are reflected through the color changes of the state indicator lights and the alarm sounds emitted; The operational characteristics refer to the various operations supported by the equipment and its components, such as component replacement, button pressing, cable insertion and removal, etc. The EPON abnormal state includes both the abnormal processing logic of the equipment when a fault occurs, as well as the abnormal state indication and alarm information of the simulation equipment.

In order to replace real equipments and economically and efficiently support the practical training of EPON equipments, the EPON equipment simulation training system realizes the software function simulation and hardware feature simulation of OLT and ONU respectively, and uses special real-time synchronization technology to achieve real-time and complete EPON equipment simulation function.

4. Key Technologies of EPON Equipment Simulation Training System

4.1. Simulation Method for EPON Equipment Software Functionality

The EPON equipment simulation training system constructs a equipment mechanism model for OLT and ONU based on the actual software functions of OLT and ONU equipments and combined with skill training needs.

The EPON equipment mechanism model is a model used to describe and simulate the software behavior of equipments such as OLT and ONU. It can accurately reflect the detailed process of receiving data, processing data, status changes, and sending data of the equipment. In terms of data reception, mechanism models can describe how equipments accurately capture and recognize data from the network, including data format, transmission protocols, and any related error detection mechanisms. In terms of data processing, the model can demonstrate in detail how the equipment parses, converts, and stores the received data, as well as how to analyze and process data based on specific service logic. At the same time, the mechanism model can accurately simulate the internal state changes of the equipment. Equipments exhibit different states under different operating conditions, and the model can describe the transition conditions and processes between these states, as well as the impact of state changes on equipment behavior. In addition, the mechanism model can also simulate how to handle abnormal states detected by equipments. In terms of data transmission, the mechanism model can describe how the equipment sends processed data in a specific format and protocol, as well as the timing and frequency of data transmission. The EPON equipment mechanism model can also reflect the changes in equipment operation mechanism caused by data configuration changes or hardware operations. When the configuration parameters of the equipment change or hardware operations are performed, these changes directly affect the operation mode and data processing flow of the equipment. The mechanism model can accurately simulate the impact of these changes, thereby comprehensively simulating the behavior of EPON equipments under different configurations and hardware operations.

The construction process of EPON equipment mechanism model is: Study EPON specifications and EPON equipment manuals from various manufacturers, analyze their specified protocol models, communication processes, data formats, and interaction methods; Divide the equipment into several basic logical functional modules based on the working principles and functions of different types of equipments (OLT and ONU); Further subdivide each functional module into sub functional modules, each responsible for completing specific tasks or processing flows; Perform state analysis on each submodule, clarify the internal data processing flow of each word module, including data reception, parsing, storage, processing, and sending, further define the data interaction methods between modules, including communication interfaces, data formats, and synchronization mechanisms; Design simulation implementation plans for each sub functional module and develop corresponding software modules; Integrate the software of various logical functional modules together to form a complete equipment mechanism model

By analyzing the EPON technical specifications and the physical structure and functional characteristics of OLT equipments, the logical functional unit model is classified into three functional modules: EPON service module, main control module, and uplink service module. Through the interaction of data (service data and management data) between modules, three modules organically form an OLT equipment logic mechanism model, which simulates the EPON signal reception, Ethernet signal reception, data forwarding, ONU registration, VLAN processing, frame overhead analysis, alarm generation and other mechanisms of real equipments in a panoramic manner. The overall architecture of the OLT equipment mechanism model is shown in Figure 1.

Using a similar method, by analyzing the EPON technical specifications and the physical structure and functional characteristics of ONU equipments, the logical functional unit model is classified into three functional modules: EPON interface module, forwarding processing module, and Ethernet interface module.

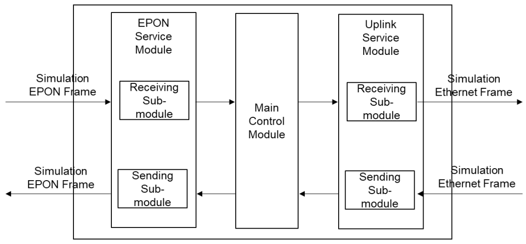

Figure 1. Overall Architecture of OLT Equipment Mechanism Model

4.2 Simulation Method for Hardware Characteristics of EPON Equipments

The EPON simulation training system is modeled based on the 1:1 hardware characteristics of the actual OLT and ONU equipment in the power communication network of State Grid Corporation of China. It simulates the hardware appearance, status indication, and operational characteristics of different types of equipment in various states.

The implementation process of equipment hardware feature simulation is divided into 8 steps, and ultimately forms a three-dimensional model of the equipment. The specific implementation method for each step name is as follows:

4.2.1 Equipment data collection and organization

Use high-precision measurement tools, such as laser scanners or photogrammetric systems, to comprehensively measure the physical characteristics of the equipment and obtain accurate data on size, shape, color, and texture.

The operation action information of the collection equipment, including motion trajectory, operation process, etc., can be achieved through sensor technology or video capture technology.

Organize and analyze the collected data to ensure its accuracy and completeness.

4.2.2 Component design

Use professional 3D modeling software such as 3ds Max, Maya, etc. to create 3D components of the equipment based on the collected data.

Based on the hierarchical structure of equipment, boards, and components, gradually construct components from details to the whole, ensuring complete consistency with the physical appearance characteristics of the equipment.

Fine texture mapping, material adjustments, and lighting settings are applied to each component to make it visually more realistic.

4.2.3 Animation production

Add animation effects to the model based on the actual workflow and action information of the equipment.

Create keyframe animations to enable the model to display equipment actions and motion trajectories.

Adjust the rhythm and smoothness of the animation to ensure that the animation effect matches the actual equipment's movements.

4.2.4 Model assembly

In a 3D development engine, various components are assembled together based on the structural characteristics and assembly rules of the equipment.

Ensure the structural integrity and rationality of the model, following the actual assembly sequence and connection method of the equipment.

Perform structural checks and adjustments on the assembled model to ensure that there are no misalignments or omissions.

4.2.5 Rendering and Effect Processing

Use renderers such as V-Ray, Mental Ray, etc. to render the assembled model, increasing realism and texture.

Add lighting and reflection effects to enhance the visual effect of the model.

Adjust rendering parameters as needed, such as lighting intensity, shadow effects, etc., to achieve the best visual effect.

4.2.6 Interaction and Logic Development

Develop operation programs and interaction logic corresponding to various actions for the model. This includes various actions and state changes of the equipment.

Realize the function of users simulating the actual operation status of equipments through operating models.

The development status indicates the presentation logic of three-dimensional components, such as the working status and fault status of equipments.

4.2.7 Testing and debugging

Conduct comprehensive testing and debugging of the 3D model to check its accuracy, performance, and stability.

Fix and optimize the problems and errors in the model to ensure its accuracy and reliability.

Test the animation effect and interaction function of the model to ensure it works properly and matches the actual equipment.

4.2.8 Publishing and Storage

Publish the optimized 3D model after debugging to the model library for users to query and use.

The model library should have a good management and maintenance mechanism to ensure the integrity and security of the model.

Provide friendly query and retrieval functions, making it convenient for users to quickly find the desired model.

The 3D model of an ONU equipment (ISCOM5104P-4R-EA) constructed using the above method is shown in Figure 2.

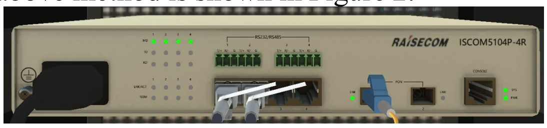

Figure 2. 3D model of ONU equipment

4.3. Synchronization Mechanism for Software Functionality and Hardware Feature Simulation

In real EPON equipments, software functions and hardware characteristics coexist and are closely connected, and the state changes between the two exhibit real-time synchronization. When a certain characteristic changes (for example, when the receiving submodule in the EPON service module of OLT detects an abnormal EPON frame signal and triggers an alarm), this change will immediately be reflected on another characteristic (for example, the status indicator light of the corresponding board in the OLT 3D model changes from a normal state to a red warning state). Given the close interdependence between software functionality and hardware characteristics in EPON equipments, ensuring real-time interaction and state synchronization updates between 3D models and logical mechanism models has become crucial. This synchronization is not only reflected in the display of the equipment's normal operation status, but more importantly, it can be quickly and accurately reflected in the corresponding model when the equipment experiences abnormalities or failures.

To achieve this synchronization, it is first necessary to accurately define the state attribute parameters of each hardware component in the 3D model. These parameters may include the color of the indicator light, flashing frequency, board temperature, voltage value, etc., which can intuitively reflect the hardware status of the equipment. Meanwhile, in the logical mechanism model, it is also necessary to define corresponding logical state parameters for each logical functional module and submodule. These parameters may involve the operational status of the module, the amount of data processed, error counts, etc. They describe the internal logical state and behavior of the module. Establishing the correspondence between the state attribute parameters in the 3D model and the logical state parameters in the logical mechanism model is a key step in achieving synchronization. This correspondence is achieved through mapping tables, associative arrays, databases, and other methods, ensuring that when the state parameters in one model change, the corresponding parameters in another model can be quickly found and updated.

In addition, during the simulation process, it is necessary to monitor the real-time changes in the state parameters of the two models. This can be achieved by setting timers, event listeners, or polling mechanisms in the simulation environment. Once a change in state parameters is detected, a synchronous update operation is triggered to synchronize the changed parameter values to another model. This can ensure that the states of the two models remain consistent, improving the accuracy and credibility of the simulation.

Through the above synchronization mechanism, it is possible to simulate the complete characteristics of EPON equipments more comprehensively, enhancing the realism of equipment simulation training.

5. Summary

The research on fully digital simulation training system for power communication EPON equipment has been successfully deployed and applied in multiple training centers. This system efficiently supports various training contents related to EPON, such as equipment inspection, equipment cognition, hardware maintenance, equipment management, and fault handling, providing large-scale and scenario based skill training capabilities. By using this system, communication professional operation and maintenance personnel can quickly improve their skills, possess the necessary abilities and experience to efficiently complete operation and maintenance work, and be able to cope with various network anomalies and faults. The application of this system provides a solid and powerful personnel capability guarantee for the construction of new power systems and the safe, stable, and efficient operation of the power grid.

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