Reliability Analysis of Optical Path Automatic Protection Switching in Ubiquitous Power Communication Network

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Abstract. The reliability of power communication network plays an important role in the safe operation of ubiquitous power communication network. In this paper, the reliability model of power communication system is established by adopting the idea of hierarchical modeling. To begin with, the top-down decomposition method is used, the typical distribution network communication system is decomposed into terminal layer subsystem, access layer subsystem, substation communication layer subsystem and master station control layer subsystem. Next, the parameters such as mean time to failures, mean time between failures, mean time to repair and other parameters are used to evaluate the reliability of basic communication products. The reliability of each subsystem is evaluated by non-redundant system, complete redundancy system, partial redundancy system and by-pass system; Finally, The bottom-up synthesis method is used to evaluate the reliability of the whole network according to the topological structure of the system. The reliability analysis method proposed in this paper provides a theoretical basis for the reliability evaluation method of power communication network.

Keywords: Ubiquitous Power Communication Network, Automatic Protection Switching of Optical Path, Reliability Analysis, Hierarchical Modeling

1. Introduction

Optical transport network (OTN) has the technical advantages of large optical transmission capacity, long transmission distance and diversified services. OTN devices have more wavenumbers, and most OTN devices have spare wavelengths. With the large-scale application of OTN technology in power communication network, taking the OTN surplus wave as a backup channel can effectively solve the problem of shortage of optical cable resources.

The reliability of distribution network communication system needs a certain mathematical model for quantitative evaluation. At present, the academic community for Ethernet passive optical network (EPON), OTN, synchronous digital hierarchy (SDH) self-healing loop reliability evaluation has been widely studied [1-3]. However, the scene of SDH standby fiber automatic switching based on OTN surplus wave has not been sufficiently studied. In addition, the existing power system reliability...
research focuses on qualitative research, mainly using the analytic hierarchy process model to establish [4, 5]. Analytic hierarchy process (AHP) is a qualitative and quantitative analysis method. Through the establishment of three-level model of target level, criterion level and scheme level, the problem is finally reduced to the determination of relative important weight of scheme level relative to target level. However, the hierarchical evaluation model introduces subjective evaluation factors, so it is unable to objectively evaluate the reliability of power communication system.

In this paper, the quantitative analysis method is used to evaluate the reliability of the ubiquitous power communication system in the scenario of realizing SDH optical fiber automatic protection switching with OTN surplus wave. Based on the established reliability model, the reliability of automatic protection switching of SDH standby optical fiber realized by OTN surplus wave is evaluated. The reliability evaluation method proposed in this paper is of great significance to the quantitative research on the reliability of ubiquitous power communication network.

2. Ubiquitous internet of things in power systems
Ubiquitous Internet of Things in Power Systems is the "second network" of State Grid, which covers all aspects of energy, production and consumption, and co-exist with smart grid.

2.1. General architecture of ubiquitous internet of things in power systems
As shown in Figure 1, the overall architecture of ubiquitous Internet of Things in Power Systems includes perception layer, network layer, platform layer, and application layer.

The perception layer mainly realizes the whole link of Internet of things, that is to create a ubiquitous Internet of Things in Power Systems covering all aspects of the power system, so as to realize the comprehensive online collection of power production site, operation and control data. Popularizing intelligent terminals and mobile applications, building a mobile collaboration environment to support the new generation of power system to provide support for terminal diversified energy services.

The network layer mainly realizes the entire space-time communication coverage, that is, under the support of the new security system, it connects the Internet, public communication network, integrated energy users and other external networks, application of information, integrates to form an integrated communication network with space-time interconnection, open integration and wide coverage, providing ubiquitous Internet services for the construction of energy interconnection.

The platform layer focuses on realizing unified IOT management of super large-scale terminals, deepening the construction of unified data center for the full-services, promoting the construction and application of "State Grid cloud" platform, and improving the ability of data efficient processing and cloud collaboration. The platform layer mainly realizes all data unified management, full-service cloud operation, and all-round data application.

The application layer focuses on supporting intelligent operation of core business, comprehensively serving energy Internet Ecology, and promoting management improvement and business transformation.
2.2. Power communication network in ubiquitous internet of things in power systems

In order to realize state holographic perception and efficient data processing, ubiquitous Internet of Things in Power Systems requires ubiquitous intelligent connection at the terminal layer; it has the connection ability of all things; at the network layer, it requires the realization of entire space-time coverage; it has the ability of real-time connection and ubiquitous communication; at the platform layer, it is required to realize open sharing, which has the processing ability of data analysis and equipment control. In this section, analysing the network layer in the ubiquitous Internet of Things in Power Systems - the main architecture of power communication network and present weak links are the key points.

The structure of the power communication network in ubiquitous Internet of Things in Power Systems is shown in Figure 2. The power communication network consists of three levels from top to bottom: backbone transmission network, distribution network transmission network, and terminal access network.

The backbone transmission network covers 220kV/110kV and above substations in the province. The main goal is to build a 100-400G optical transport network (OTN) system to achieve ultra long station distance optical communication of more than 3000 km.

Distribution network transmission network covers 110kV/35kV and below substation, switching station, pole switch, ring main unit, distribution room, distribution transformer, distributed energy station, electric vehicle charging station and 10kV communication lines and equipment.

Terminal access network covers distribution network terminal equipment (DTU), feeder terminal equipment (FTU) and distribution transformer terminal equipment (TTU). The main design objective is to achieve a "safe and reliable, one network multi-functional, high-quality and efficient" power wireless private network to solve the last mile problem of communication.
3. Reliability model of ubiquitous power communication network

Reliability $R(t)$ of communication system refers to the probability that the system can work normally in the specified time under the condition of non maintenance. Reliability $R(t)$ is a function of time and its value range is $[0,1]$.

Communication system availability $A$ refers to the probability that the system can work normally in the specified time under the condition of maintainability. The effectiveness index $A$ is determined by the following three parameters. Mean time to failure (MTTF) refers to the average service time of equipment from the beginning of use to failure. Mean time to restore (MTTR) refers to the average value of repair time obtained after multiple fault repairs. Mean time between failures (MTBF) refers to the average time between two adjacent failures of repairable system, i.e. $A = \frac{MTBF}{MTBF + MTTR}$.

In this paper, the reliability $R$ is used as the measurement index of the reliability of the distribution network communication system, and the effectiveness $A$ is the reliability $R$, which can be calculated according to the results derived in this paper.

3.1. Terminal layer reliability model

TL subsystem can be regarded as a partial redundant system composed of $N$ independent DTU, FTU and TTU. Only when no less than $M (M \leq N)$ terminal devices collect monitoring data normally, the whole TL subsystem can work normally.

Assuming that the life of the $i$th DTU follows exponential distribution and the reliability of the $i$th
The reliability of TL subsystem is

\[ R_{TL}(t) = \sum_{i=0}^{N} C_i R_{DTU}^i(t) \left( 1 - R_{DTH}^i(t) \right)^{N-i} \]

Access layer reliability model

The reliability of AL subsystem based on wired network has been widely studied. In this paper, the reliability of AL subsystem based on wireless networking is studied. In the wireless networking mode, the DTU, FTU and TTU of TL subsystem are connected with the customer premise equipment (CPE) through the fast Ethernet (FE) interface. They are connected to the cellular base station (ENB) and the packet gateway (PGW) of the mobile core network in a wireless way, and finally converge to the backbone communication network. Mesh networking (mesh) is used among several ENBS, and one ENB is interconnected with three neighbor ENBS at most.

Al subsystem can be regarded as a non redundant system composed of wireless terminal PCE, wireless access network element ENB and wireless core network element PGW. The wireless access network consists of several ENBS in parallel. Assuming that the lifetime of eNB follows exponential distribution, the reliability of eNB is

\[ R_{eNB}(t) = \exp\left(-\lambda_{eNB} t\right) \]

3.3 Reliability model of communication layer of substation

Under the working principle of realizing SDH optical path automatic detour based on OTN residual wave: when the OLP device is installed, the protected equipment side is connected to the SDH terminal, the optical signal of the main line is connected to the original optical cable line, and the optical signal of the spare line is connected to the optical wavelength conversion device, and converted into the space residual wave length that can be recognized by the OTN combiner, then it enters the combiner for processing, the service optical signal after combining is transmitted by the spare optical cable To the splitter, after separation, it enters into the receiver of the opposite end OLP. Finally, the protection switching function of SDH is realized by using the spare wavelength channel of OTN.

SCL subsystem can be regarded as a side link system composed of SDH and OTN. assuming the reliability of SDH equipment in the main channel is

\[ R_{ONT}(t) = \int_{0}^{\infty} \exp\left(-\lambda_{ONT} t\right) dt \]

and the reliability of OTN equipment in the standby channel is

\[ R_{SDH}(t) = \int_{0}^{\infty} \exp\left(-\lambda_{SDH} t\right) dt \]

4. Quantitative analysis of reliability

Table 1 shows the data hypothesis combined with the actual situation.
Table 1. Reliability statistics of normal operation ($10^4$ hour) of equipment.

| Device | Reliability R | Device | Reliability R | Device | Reliability R |
|--------|---------------|--------|---------------|--------|---------------|
| DTU    | 0.950         | PCE    | 0.965         | SDH    | 0.999         |
| FTU    | 0.950         | eNB    | 0.985         | ONT    | 0.999         |
| TTU    | 0.950         | PGW    | 0.990         | ---    | ---           |

Table 1 shows the reliability statistics of normal operation for different devices. The reliability of these devices is calculated based on the data provided. The reliability of each device is represented by $R$.

Table 2 is the reliability model of each subsystem (terminal layer subsystem, access layer subsystem, substation communication layer subsystem and master station control layer subsystem) of the distribution network communication system derived in Section 2 of this paper according to the data in Table 1. The reliability of the subsystems and the reliability of the whole distribution network communication system are calculated.

Table 2. Subsystem and system reliability of distribution communication network.

| Subsystem                                      | Reliability R |
|------------------------------------------------|---------------|
| Terminal layer subsystem                        | 0.936         |
| Access layer subsystem                          | 0.9974        |
| Substation communication layer subsystem        | 0.9975        |
| Master station control layer subsystem          | 0.9986        |
| Distribution network communication system        | 0.9498        |

From the structure and calculation results of the distribution network communication system, it can be seen that the weak link of the distribution network communication system is the non-redundant system (for example, the access layer subsystem composed of wireless access network and wireless core network). The reliability of single equipment will directly affect the reliability of the whole system. Therefore, the reliability of single equipment in the non-redundant system should be strengthened. The reliability of the distribution network communication system is not only related to the reliability of single equipment in the above subsystems, but also related to the network topology of each subsystem. The more robust network topology structure can also improve the reliability of the whole distribution network communication system.

5. Summary
In this paper, hierarchical modeling is used to model and analyze the reliability of the distribution network communication system based on OTN residual wave to realize SDH main and spare optical fiber automatic detour. The research results of this paper can play a guiding role in the actual construction of the distribution communication network.

Acknowledgement
Science and technology project of State Grid Corporation of China (5204xa180049).

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