Reliability Analysis of Smart Distribution Grid Communication System Based on EPON

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Abstract—**In order to work out an exact value of the EPON(Ethernet Passive Optical Network) reliability in the smart distribution grid communication system, this paper proposed a method from both the micro and macro perspectives to calculate the failure rate and the reliability in smart distribution grid. On the micro, the reliability of optical devices in OLT(Optical Line Terminal) and ONU(Optical Network Unit)has been evaluated in different temperature conditions which is based on GR-468-CORE standard. On the macro, the effect of different architectural protections of communication has also been estimated. Trunk and branch protection in the EPON architecture can effectively improve the total reliability of communication.**

Keywords-reliability; wear-out failure rate; EPON; smart distribution grid

I. INTRODUCTION

The Smart Grid highly combines modern communication technology, computer technology, sensor technology and control technology with physical power network, which can realize the bidirectional flows of energy and information. Compared to the traditional power grid, smart grid relies more on the communication networks which not only charge with electricity production dispatching but also is responsible for automation communication and wide area control tasks. As one important part of smart grid, smart distribution network manages to realize the bidirectional flows between the clients and vendors based on the communication network. The architecture model is "point to multi-points" [1], which is characterized by huge number of nodes, widely distribution and poor working conditions.

Optical fiber communication technology has been widely used in smart grid communication network construction, and the State Grid Corporation Based on MSTP/SDH transmission technology in optical fiber transmission network has been well developed. Optical fiber communication in electric network has already covered more than 95% of the 110/10kV substations, and 75% of 35/10kV substations[2] while 35kV and higher voltage level distribution network communication transmission medium has been the basic realization of optical fiber.

EPON(Ethernet Passive Optical Network) is one kind of passive optical network communication technologies，which has low comprehensive cost, quick construction, safety equipment etc.. Point to multipoint communication architecture, particularly suitable for the smart distribution grid communication needs, has become the current hot research. The communication reliability in electric power system is an important research direction in smart grid, [3] introduced a general failure rate prediction method for semiconductor optical devices, lacking of pertinence analysis. [4]Proposed temperature and humidity accelerated models for receivers, while its basic principle should be more valuable to apply to the lasers. [2] and[5] only released a relatively rough calculation for network structure reliability, not a source analysis on the microcosmic approach.

In this paper, based on the EPON technology, the reliabilities of optical devices and electrical chips have been carefully calculated under different working temperatures on the micro, and analysis of communication reliability and system availability have been scrupulously evaluated on the macroscopical architecture and protection methods.

II. THE EPON CHARACTERISTICS

A. EPON Fundamentals

A typical EPON communication system has following parts: OLT (Optical Line Terminal), ONU (Optical Network Unit) and POS (Passive Optical Splitter). In the application of smart distribution network, the OLT is placed in the central computer room of a substation while the ONUs are placed in some terminals such as FTU or TTU far away as figure1 shown. Bidirectional communication in a single fiber is used in EPON system.

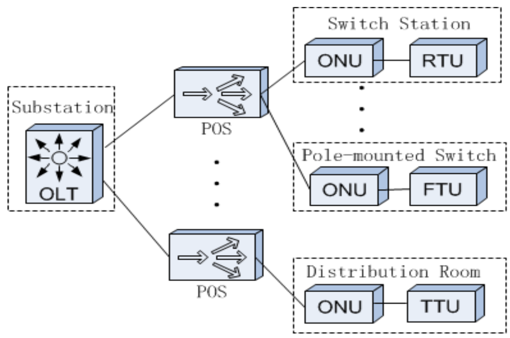

Figure 1. A Typical Application of EPON In Smart Distribution Grid.

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B. Advantages of EPON

EPON system is an all-optical network which has strong ability of anti-electromagnetic interference abiding by the trend of optical solutions for copper. Low maintenance cost, large bandwidth, high security and easy upgrade; EPON system can cover a vast area. The network topology has been testified that a small amount of OLTs can service a large number of terminal clients, which is very suitable for smart distribution grid ring, chain and tree topology.

III. FAILURE RATE OF OLT/ONU ON THE MICRO

The reliability of communication in the electric power system is very important. Analysis on the failure rate of OLT and ONU in the EPON system has been carried into execution on the micro.

A. Compositions of OLT and ONU Failure Rate

The key part of ONU is the optical transceiver which contains a laser device, a receiver device and other electrical chips. The failure rates of optical devices are much higher than electrical chips under the same operating condition because of totally different production process. The failure rates of semiconductor chips contains two parts, one part is random failure rate while the other is wear-out failure rate. The wear-out failures of ordinary electrical chips are usually so low that they would be ignored. Laser devices' wear-out failure rate would be under estimation because of the gradually reduced emitter power as operating year by year. Optical receivers' process is so mature that wear-out failure rate could be ignored.

The compositions of ONU failure rates are presented as follows: laser wear-out failure rate, laser random failure rate, receiver random failure rate and other electrical chips random failure rates including the chips inside and outside of the optical transceiver. The analysis of OLT failure rate is much the same, however the exact failure rate number is different because of different mounts and kinds of chips.

B. Failure Rate Under Different Temperature Conditions

The median life (ML) of a laser is the time for which 50% of the population has failed. Typical failure data always exhibits a lognormal distribution which would not have given a perfect straight line. The standard deviation (σ) of the distribution can be easily calculated using (1), which indicates the width of the distribution.

$$\sigma = \frac{\ln(t_{84}) - \ln(t_{16})}{2} \tag{1}$$

Where t_{84} and t_{16} are the times to 84% and 16% failures, respectively, as taken from the lognormal plot. On some probability paper,. σ can be obtained directly from a special scale [6]. Note that ML and σ are not constant, and they may vary in different operating conditions such as different temperatures. (2) Shows the different values of ML under different temperatures based on Arrhenius equation [7].

$$\frac{ML(T_2)}{ML(T_1)} = \exp[\frac{E_a}{k}(\frac{1}{T_2} - \frac{1}{T_1})] \tag{2}$$

$ML(T_2)$ and $ML(T_1)$ are ML under the temperature T_2 and T_1, Ea is the activation energy, k is Boltzmann's constant. The laser wear-out failure rate λ (t) represents the probability of failure occurring in the next unit time for devices which have not yet failed when the specific time t has elapsed and can be expressed as the following (3) and (4). Erfc(A) is the complementary error function and A can be express as (5)

$$\lambda(t) = \frac{\sqrt{2} * \exp[-\frac{1}{2\sigma^2}(\ln\frac{t}{ML})^2]}{\sqrt{\pi} * t * \sigma * Erfc(A)} \tag{3}$$

$$Erfc(A) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-t^2} dt \tag{4}$$

$$A = \frac{1}{\sqrt{\sigma}} \ln\frac{t}{ML} \tag{5}$$

Based on the datasheet of laser vendor, Ea=0.35eV and Erfc(A)=2.00 approximatively under 0-85℃ working condition. The wear-out failure rates of ONU laser device working for 5 years, 10 years and 20 years under different temperature conditions were calculated as table 1 shown.

TABLE 1 ONU LASER WEAR-OUT FAILURE RATE IN DIFFERENT CONDITIONS

Wear-out Failure rate (FIT)	40℃	55℃	70℃	85℃
failure rate@5yr	11	234	1860	12809
failure rate@10yr	124	1140	4484	18842
failure rate@20yr	593	2552	6046	18782

ONUs may be placed outside computer rooms under the air temperature 40 degrees centigrade while inside the ONU the laser operating temperature is less than 55 degrees centigrade. Equipments of telecommunication should properly work more than 20 years, so the ONU laser wear-out failure rate for 20 years less than 55 degrees centigrade is 2552 FIT. OLT laser wear-out failure rate could be calculated in the same way while the result should be a little higher because the optical device is more complicated. Then the random failure rates of ONU receiver and other electrical chips could be calculated under the same temperature condition according to the Arrhenius equation and the datasheets of the vendors. The total failure rates of the whole ONU were shown in table 2. The total failure rates of the whole OLT could be calculated in the same way, and the total failure rate is 3568 FIT working for 20 years under the condition of 55 degrees centigrade.

TABLE 2 ONU TOTAL FAILURE RATE

Failure Rate （FIT）	40℃	55℃	70℃	85℃
LD wear-out @5yr	11	234	1860	12809
LD wear-out @10yr	124	1140	4484	18842
LD wear-out @20yr	593	2552	6046	18782
LD random	248	448	770	1264
PD random	38	69	118	194
ONU other ICs	49	153	451	1208
ONU total @20yr	928	3222	7385	21448

IV. THE RELIABILITY OF EPON ARCHITECTURE

The total failure rates of OLT and ONU were a little high, however the actual reliability of EPON system should be evaluated under certain architecture and protection methods.

A. EPON Architecture

The architecture of EPON system is very flexible; a tree structure was shown in figure2 and a bus structure was shown in figure 3. The bus structure could also be regarded as a special kind of tree structures with different power distribution in the splitters.

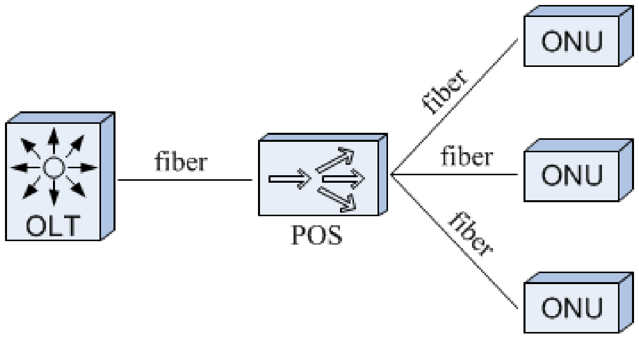

Figure 2. Tree Structure.

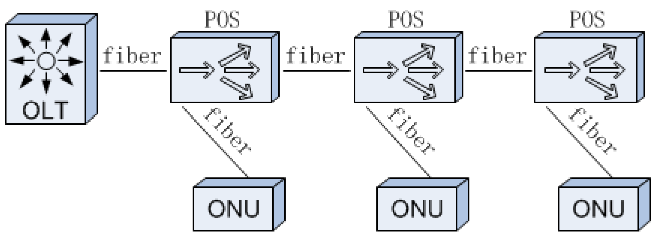

Figure 3. . Bus structure

B. Reliability Analysis of Different Protections

The failure rates of OLT and ONU in EPON systems were a little high from the evaluation above while the protection architectures could improve the reliability by the mean of adding redundancies. The unavailability rate can be described to evaluate the reliability of a communication system, as (6) shown.

$$U = \lambda * MTTR * 10^{-9} \quad (6)$$

U means unavailability rate, λ presents the failure rate(FIT) and the unit of MTTR(Mean Time To Repair) is hour. The unavailability rates of EPON system suffering from different kinds of failures has been worked out based on the table 2 and (6), as the table 3 shown.

TABLE 3 DIFFERENT FAILURES IN EPON SYSTEM

Items	Failure Rate/FIT	MTTR/h	U
OLT Fails	3568	2	7.14×10^{-6}
ONU Fails	3222	6	1.93×10^{-5}
Trunk Fiber Fails	1141	12	1.37×10^{-5}
Branch Fiber Fails	1712	12	2.05×10^{-5}
POS Fails	114	12	1.03×10^{-6}

There are three main kinds of protections as following: trunk protection (figure 4), branch protection (figure 5) and trunk with branch protection (figure 6).

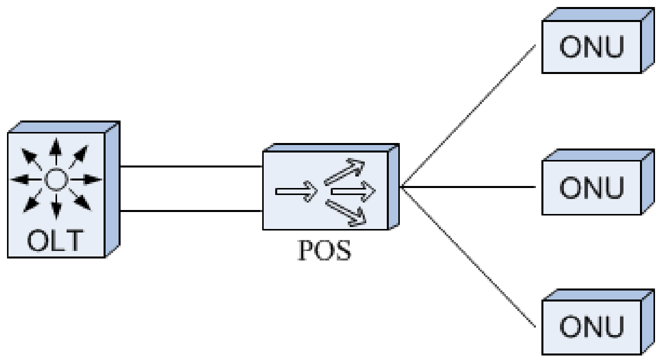

Figure 4. Trunk Protection.

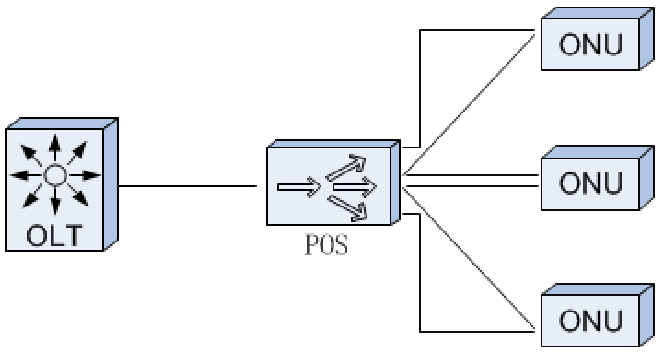

Figure 5. Branch Protection

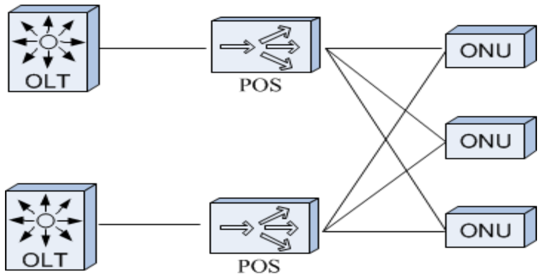

Figure 6. Trunk With Branch Protection.

After the introduction of protections in the EPON, the communication system could be regarded as a parallel system so that there would not be only one communication channel from OLT to a certain ONU. The unavailability of a parallel system could be calculated as (7), where A_i represents the availability of a certain component. And the availability of the total system could be evaluated as (8).

$$U_s = \prod_{i=1}^{n} U_i = \prod_{i=1}^{n} (1 - A_i) \tag{7}$$

$$A_s = 1 - U_s \tag{8}$$

The reliability of the EPON system could be expressed by the unavailability and the values could be calculated in table 4 under different kinds of protections.

TABLE 4 DIFFERENT UNAVAILABILITIES IN DIFFERENT PROTECTIONS

Protection Type	Unavailability	Failure Time In Prediction（min/yr）	Availability（%）
No Protection	3.12E-05	16.41	99.99687703%
Trunk	2.99E-05	15.69	99.99701402%
Branch	2.92E-05	15.33	99.99708202%
Trunk with Branch	4.31E-10	0.00022	99.99999996%

The failure time in prediction mean how long the failure of communication might last. Obviously, the trunk protection and branch protection could only improve the reliability of the whole system a little while the trunk with branch protection could improve the availability of the EPON system substantially.

V. CONCLUSION

The reliability of EPON system in the communication system of the smart distribution grid is so important that it deserves to be calculated carefully. In this paper, it proposed a method that could evaluate the reliability from both micro and macro perspectives as follows:

(1) calculating the failure rates of optical devices in the OLT and ONU based on the GR-468-CORE;

(2) calculating the failure rates of the whole OLT and ONU under a certain temperature;

(3) using the failure rates mentioned above to calculate the availability of the whole EPON system under a certain protection.

Moreover, the truck with branch protection could improve the reliability of the whole EPON system despite of the high failure rates of OLT and ONU.

REFERENCES

[1] YU XiaoDong, and YU Fang, “Application of passive optical network technology in communication system of power distribution and utilization network,” Telecommunications for Electric Power System, vol. 31 No.211, pp. 28-31, May 2010.

[2] ZHANG Jiazhu, and ZHANG Zhenliang, “Study on reliability of the communication structure system in smart grid,” Electric Power IT, vol .8, pp. 26-29, May 2010.

[3] H. Sudo, and Y. Nakano, “Failure rate prediction of optical semiconductor devices,” Microelectronics Reliability, vol. 25, no. 3, pp. 525-540, 1985.

[4] J. W. Osenbach and T. L. Evanosk, “Temperature humidity bias behavior and acceleration model for InP planar PIN photodiodes,” Journal of Lightwave Technology, vol.14, no.8, August 1996.

[5] Xue Mei, “A novel protection mechanism for EPON,” Telecommunications Science, no. 8, pp. 71-75, August 2010.

[6] H. Nagadomi, “Reliability report for MITSUBISHI semiconductor device,” datesheet of MITSUBISHI Electric Corporation, January 2008.

[7] GR-468-Core Standard, “Generic reliability assurance requirements for optoelectronic devices used in telecommunications equipment,” Issue1, December 1998.