Application Research of Fault Tree Analysis in Grid Communication System Corrective Maintenance

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Application Research of Fault Tree Analysis in Grid Communication System Corrective Maintenance

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Abstract. This paper attempts to apply the fault tree analysis method to the corrective maintenance field of grid communication system. Through the establishment of the fault tree model of typical system and the engineering experience, the fault tree analysis theory is used to analyze the fault tree model, which contains the field of structural function, probability importance and so on. The results show that the fault tree analysis can realize fast positioning and well repairing of the system. Meanwhile, it finds that the analysis method of fault tree has some guiding significance to the reliability researching and upgrading the system.

1. Introduction
In recent years, with the further development of smart grid, communication equipment will be more and more, and the grid communication system will become more and more complex. From the current situation, how to get fast position when the system failure, and how to reduce the possibility of similar failure again and other issues, have become the core of the operation and maintenance of the system.

Fault Tree Analysis (FTA) [1] is a kind of analytical method which is refined from the result to the reason and then quickly repair the failure, and through follow-up measures to reduce the probability of similar failures. Recently, the diagnosis theories and methods based on fault tree have been applied in power system, such as fault diagnosis of boiler in power plant[2] fault research of large power transformer [3], reliability analysis of power system and so on [4].

2. Grid Communication System
After several years of upgrading the grid technology, although it has established a relatively complete grid communication system, but there are still two serious problems stated in follows. Firstly, grid communication system management is complex, the system reliability is not high. Secondly, grid communication system structure is complex, poor quality of data transmission.

The grid communication system is responsible for the safety and stability of grid system. Once the communication system failure, which requires the communication operation and maintenance personnel to quickly determine the feature and location of the fault, and to take effective measures to deal with failure in time to restore the normal work of the system. Based on the experience of the operation and maintenance of the system over several years of the author, the two serious problems of the current grid communication system analyzed above need to find the corresponding technical measures deeply. See Table 1.
Table 1. Grid Communication System Problems Analysis

| NO. | Problems                     | Reasons                                | Constructive Measures                                              |
|-----|------------------------------|----------------------------------------|---------------------------------------------------------------------|
| 1   | System Structure Complex     | Lack of unifying planning SDH nodes increase | Design, optimization and upgrading of grid communication system    |
| 2   | System Reliability Low       | Sys Monitoring is incomplete Poor maintenance of equipment | Establishment of fault monitoring and warning system Development operation, maintenance and replacement plan. |
| 3   | Low Quality of Transmission  | Poor quality media equipment Unbalanced allocation of resources | Improve the quality of optic cable and node equipment and allocation of network resources reasonable combined with fault experience. |
| 4   | Poor System Management       | Management system is unscientific Lock of advanced tools | Improve scientific level of operation and management system and creation of advanced grid communication navigation system. |

3. The Principle of Fault Tree Analysis
Fault tree analysis method is based on the inherent level and causal relationship between the cause of the failure and the results, and to synthesizes the correlation of the fault event, such as a reason leads to multiple results, one result is caused by multiple reasons.

3.1. Establishment Process and Method of Fault Tree
When the fault tree analysis method is used to carry out the failure research, the most undesired failure condition of the system is taken as the target of failure analysis, and the corresponding failure event is defined as the top event, and then the causal relationship is found that leads to the direct cause of the top event (full or necessary). The sub events that trigger the top event are defined as secondary event, and all the sub-events that cause the secondary events to occur directly are found in the same way as the three sub-events, followed by the basic event that cannot be found again or no longer need to be found. Finally, the appropriate logical relationship is used to link the events, and the causal logical structure of the event is the required fault tree. The basic process is shown in Figure.1.

![Figure 1. Analysis Process of Fault Tree](image1)

![Figure 2. And Logical Fault Tree](image2)
3.2. Mathematical Description and Analysis of Fault Tree

Considering a fault tree consists of n different independent bottom events, and the state of the fault tree event $\emptyset$ is simplified by the logical relationship. The state of the event $\emptyset$ is given by the state of the bottom event $X_i$ ($i=1,2,...,n$) value of the decision (a total of $2^n$ state), that is

$$\emptyset = \emptyset(X) = \emptyset(X_1, X_2, ..., X_n)$$ (1)

Equation (1), which is the mathematical description of the fault tree. The structural functions of the two basic fault trees that are common in engineering are:

$$\emptyset = \emptyset(X) = \bigcap_{i=1}^{n} X_i = \min(X_1, X_2, ..., X_n)$$ (2)

The engineering significance of the equation (2) means the top event occurs when all the bottom events occur, and the corresponding fault tree corresponding to it is shown in Figure 2.

$$\emptyset = \emptyset(X) = \bigcup_{i=1}^{n} X_i = \max(X_1, X_2, ..., X_n)$$ (3)

The engineering significance of the equation (3) means the bottom event occurs can lead the top event occurs, and the corresponding fault tree corresponding to it is shown in Figure 3.

![Or Logical Fault Tree](image1)

![Fault Tree of A 220KV Substation to the City Dispatch Center Communication System](image2)

Figure 3. Or Logical Fault Tree

Figure 4. Fault Tree of A 220KV Substation to the City Dispatch Center Communication System

The main purpose of qualitative analysis the fault tree is to find all the combinations and paths that may cause the top event to occur from the bottom of the tree. The set of fault events for all bottom events:

$$E = \{e_1, e_2, ..., e_n\}$$ (4)

Its corresponding state vector X is:

$$X = \{x_1, x_2, ..., x_n\}$$ (5)

For a fault tree with n independent bottom events, the number of state vectors is $2^n$. When there is a subset of the corresponding state vectors:

$$X_k = \{x_{k1}, x_{k2}, ..., x_{kl}\}$$ (6)
When $x_{k1} = x_{k2} = x_{kl} = 1$, the top event occurs, then the corresponding subset of the bottom events are called the minimum cut sets, which directly indicates the possibility of the top event, all the smallest cut sets of the fault tree that gives a complete description of the system failure. Through the analysis of the minimum cut set, we can find the weakest part of the system or system failure point.

In this paper, the fault tree analysis method is mainly used for the analysis and processing of faults. Therefore, the parameters related to the failure rate of the equipment will be emphasized. When the minimum cut set of the equipment fault tree is established, the bottom events will be estimated according to the historical data and the probability of occurrence, and to develop the best maintenance strategy to carry out and specific technical improvements.

4. Fault Tree Analysis of Optic Fiber Communication System Between Site(Substation) and Dispatch Center

Once failure appear in optic fiber communication system, firstly to locate the fault and fault type accurately, and then take the fault handling measures. In the event of fault location of the grid communication system, it is common to follow the four basic principles shown in Table 2.

| Sequence NO. | Principle Description | Principle Analysis |
|--------------|-----------------------|--------------------|
| 1            | From external examination to transmission | Remove the external possible factors, such as fiber optic cable disconnected, power failure and so on. |
| 2            | From single station to single disk | Failure location as accurate as possible to the communication station. |
| 3            | From group to branch road | Group road disk failure often cause abnormal alarm. |
| 4            | From advance to normal | Follow the level of failure to reduce the level of analysis. |

4.1. Fault Tree Construction of Optical Fiber Communication System between Substation and Dispatch Center

In this paper, we take the 220KV substation to the city dispatch center communication system as an example, and select the communication system failure for the top event, use deductive method to establish the corresponding fault tree shown in Figure4, and the fault tree name and fault probability shown in Table 3.

| Code | Name             | Probability $\times 10^{-6}$ | Code | Name             | Probability $\times 10^{-6}$ |
|------|------------------|-------------------------------|------|------------------|-------------------------------|
| X1   | Power failure    | And event                     | X7   | #1 Power failure | $P_7=7.5$                    |
| X2   | Server failure   | $P_2=0.72$                   | X8   | #2 Power failure | $P_2=7.5$                    |
| X3   | Line failure     | And event                     | X9   | #1 Line failure  | $P_2=8.2$                    |
| X4   | Switch failure   | $P_4=0.81$                   | X10  | #2 Line failure  | $P_2=8.2$                    |
| X5   | Router failure   | $P_5=0.38$                   | X11  | Program Failure  | $P_2=4.5$                    |
| X6   | Protection failure | And event                  | X12  | Interface failure| $P_2=5.6$                    |

4.2. Mathematical Description and Technical Analysis of the Fault Tree

The minimum cut set is the basis of the fault tree. This article uses the uplink method to analyze, from the last level step up to the last level, using the logic between the rules of operations. According to this principle, we can see the bottom-up relationship between the last level, intermediate level and top event, respectively describe as follows:
\[ X_1 = X_7 \cdot X_8 \]  \hspace{1cm} (8)

\[ X_3 = X_9 \cdot X_{10} \]  \hspace{1cm} (9)

\[ X_6 = X_{11} \cdot X_{12} \]  \hspace{1cm} (10)

\[ X_0 = X_1 + X_2 + X_3 + X_4 + X_5 + X_6 \]  \hspace{1cm} (11)

\[ X_0 = X_7 \cdot X_8 + X_2 + X_9 \cdot X_{10} + X_4 + X_5 + X_{11} \cdot X_{12} \]  \hspace{1cm} (12)

There are six minimum cut sets for the fault tree, respectively \( \{X_2\}, \{X_4\}, \{X_5\}, \{X_7, X_8\}, \{X_9, X_{10}\}, \{X_{11}, X_{12}\} \).

So, we can learn from the structure of the end of the events on the impact of the incident, to strengthen control by the importance of the order of protection measures, can also be prepared in this order security check procedures. For this fault tree, it is clear that the minimum cut set and its probabilistic analysis can be used to quickly know the weakest links of the system, such as for the power supply system, lines and protection equipment, the corresponding redundant fault-tolerant design to improve the system reliability.

The probability of occurrence of the top event is the core index of the system reliability analysis. According to the structural function relation of the fault tree, the probability event of the top event is as follows:

\[ P(X_0) = P(X_7 \cdot X_8) + P(X_2) + P(X_9 \cdot X_{10}) + P(X_4) + P(X_5) + P(X_{11} \cdot X_{12}) \]  \hspace{1cm} (13)

\[ P(X_0) = P_7 \cdot P_8 + P_2 + P_9 \cdot P_{10} + P_4 + P_5 + P_{11} \cdot P_{12} \approx P_2 + P_4 + P_5 = 1.91 \times 10^{-6} \]  \hspace{1cm} (14)

As the communication system has designed a redundant structure for events \( X_1, X_3, X_6 \), the probability of occurrence is greatly reduced. Therefore, the probability of occurrence of the final top event is basically determined by events \( X_2, X_4, X_5 \). In addition, from the point of view of probability importance, the probability of redundancy design is also greatly reduced, which can effectively reduce the probability of occurrence of top event due to the event failure, and to improve the safety and reliability of the whole system.

Therefore, in the design process of the system, the parallel redundant structure can greatly improve the reliability of the system for the components with low security failure rate. Similarly, when the system fails, we should combine with experience, and all the bottom events in accordance with the importance of probability sorting, to set the fault monitoring point, to achieve as little as possible, to achieve the highest monitoring points to determine the fault ability to reduce troubleshooting time.

With the fault tree analysis method applied in the field of fault diagnosis practice of the system, it can not only enrich the application of fault tree analysis method, but also can rationalize and program the maintenance experience of the system, and quickly locate according to the known data failure to ensure the safe production of grid to enhance the economic benefits of power.

5. Conclusion

In this paper, the practical application of fault tree analysis method in fault diagnosis of grid communication system is studied. Through the establishment of fault tree model of typical communication system, the structural function and event probability and probability importance are analyzed, and the fault tree is used to analyze the system. Different levels of analysis and research, which can better guide the operation and maintenance personnel of the system to carry out troubleshooting. Of course, for complex systems, fault tree analysis is more difficult, which need to use computer analysis. Therefore, we suggest that only the failure mode with large probability of probability can be analyzed when the complex system is analyzed by fault tree. Then, combined with the engineering experience, it
can judge the faulty parts quickly and improve the fault repair efficiency. In addition, the fault tree analysis can intuitively understand the failure mode of the whole system, master the weak link of system design and operation, and finally we can propose the improvement scheme according to the structural function and probability importance information.

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