Maintenance Decision Based on Risk Assessment of Electric Transmission and Distribution Equipment

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Abstract. Given the current maintenance technology of electric transmission equipment, the risk assessment is introduced into the maintenance decision of electric transmission equipment, and a basic technical framework which is based on the maintenance method of risk assessment applying to the power transmission equipment is built. From two aspects of economic risk and systemic risk, each quantitative risk indicator of the equipment is gotten. By quantifying the systemic risk economically, the system consequence of electric transmission equipment outage can be presented by the corresponding system severity. This method has been proved to be more scientifically to assess risk and more quickly and effectively to make maintenance decisions by the final example analysis.

1. Introduction
In recent years, with the rapid expansion of the power grid scale, large-scale power failure accidents in the system occur from time to time. The influence of single equipment failure is not only limited to itself, but may be extended to the regional power grid or even the whole system. Therefore, if the maintenance decision-making only considers the influence of the equipment itself and does not take into account its impact on the system, it cannot meet the requirements of the safe operation of the system [1].

Risk Based Maintenance (RBM) is an effective maintenance decision-making method, which takes full account of the different locations of equipment in the system and the difference of the magnitude of failure consequences, and introduces risk indicators, in which risk indicators can take into account both safety and economy. The risk-based condition-based maintenance technology can well measure the state of equipment itself and the impact of equipment failure [2].

At present, the application of RBM in the power industry is still in its infancy, mainly in the petrochemical industry [3]. Sun et al. [4] and Dong et al. [5] focused on the research object of risk analysis on the electrical equipment itself, with less consideration of the factors affecting the power grid. Mccalley et al. [6], Dai et al. [7], and Ni et al. [8] used severity index to assess system risk, and used self-defined severity function to calculate the risk indicators of line overload, low voltage, voltage instability and cascading failure respectively. Zhao et al. [9] revised and expanded the existing maintenance technology based on risk assessment, but mostly focused on the theoretical analysis of risk assessment, with less experience in complete engineering application.

In this paper, risk assessment is introduced into the maintenance decision-making of power transmission and distribution equipment. Considering the economic risk and system risk separately, the system risk is quantified economically, which makes the maintenance decision-making more scientific and reasonable. Finally, an example is given to verify the rationality and effectiveness of the proposed algorithm.
2. Maintenance Based on Risk Assessment

Maintenance based on risk assessment is a method of optimizing inspection strategy established on the basis of pursuing the unification of system safety and economy. Its essence is to assess and diagnose the risk indicators of equipment status, after obtaining the possibility and loss of a certain type of equipment failure, it synthesizes the results of various risk factors to get the total risk value [10]. Finally, combined with different maintenance schemes, the risk decision-making of condition-based maintenance of the whole equipment is completed. The specific process is shown in Fig.1.

![Flow chart of equipment condition-based maintenance decision-making](image)

**Figure 1.** Flow chart of equipment condition-based maintenance decision-making

Considering the economic risk and system risk, this paper divides economic risk into equipment risk, personal and environmental risk and social risk, and its risk value is the superposition of these three items. The system risk is assessed by severity index, which is divided into power flow out-of-limit severity, voltage out-of-limit severity, voltage instability severity and cascading failure severity. Then, the sum of them is quantified economically and used as the final system risk value. Finally, the total risk value of the equipment is shown in the equation (1):

$$R(t) = P(t) \sum W_i C_i(t)$$  \hspace{1cm} (1)

Among them, $R(t)$ is the total risk of equipment caused by failure; $P(t)$ is the possibility of equipment failure; $W_i$ is the weight coefficient of economic risk and system risk respectively; $C_i(t)$ is the different consequences of equipment failure, which means economic risk and system risk, and $t$ is a certain time.

3. Economic Risk Assessment

3.1. Equipment Risk

The equipment itself will be damaged because of the failure. The corresponding equipment risk is the cost needed to restore the equipment to normal level, which is measured by the maintenance cost. The maintenance level of equipment failure is divided into four levels: A, B, C and D. According to the historical data of enterprise maintenance, the corresponding maintenance cost can be obtained. Among them, maintenance level A refers to the highest maintenance cost and the greatest risk after failure.

3.2. Personal and Environmental Risk

If explosion happens after equipment failure, it may endanger personal safety, and may also be accompanied by environmental pollution, such as insulation oil and SF₆ gas leakage. These losses are often difficult to quantify economically. If we want to consider their economic costs, we can divide the level of personal loss and environmental loss of equipment failure by analyzing the past cases and the provisions of relevant laws and regulations. Finally, the corresponding personal loss and environmental loss of equipment failure can be obtained.

3.3. Social Risk

Social risk is the loss caused by the loss of load after equipment failure. Based on previous research methods, an economical and effective ratio of output value to unit electric energy consumption(ROVTUE) method is used to calculate the social risk, as shown in equation (2):

$$R_s = P_G \times W_L \times T$$  \hspace{1cm} (2)

Among them, $R_s$ refers to the social loss caused by equipment failure, $P_G$ refers to the power generation ratio of a certain region, that is, the ratio of gross domestic product(GDP) to electricity consumption, $W_L$ refers to the amount of load loss, and $T$ refers to the time of power failure.

4. System Risk Assessment

4.1. Power Flow Out-of-Limit Severity

Line (transformer) load ratio $P_L$ is used to measure whether the power flow is beyond the limit. $P_L$ is the ratio of actual transmission power to power limit. The following is the calculation equation of severity.
4.2. Voltage Out-of-Limit Severity

Line (transformer) voltage ratio $P_V$ is used to measure whether the voltage is beyond the limit. According to the Chinese Voltage Standard, $P_V$ is the ratio of the actual voltage of the equipment to the rated voltage. The calculation equation of severity is as follows:

$$S_{\text{load}} = \begin{cases} 
0 & P_L < 0.7 \\
7(P_L - 0.7) & 0.7 \leq P_L < 1.2 \\
3.5 & P_L \geq 1.2 
\end{cases}$$

(3)

4.3. Voltage Instability Severity

The load power margin $P_M$ is used to measure the voltage stability. The calculation equation of $P_M$ is defined as (5):

$$P_M = \frac{L_A - L_P}{L_P}$$

(5)

Among them, $L_A$ is the maximum load of the system, which is calculated by continuous power flow, and $L_P$ is the predicted load of the system.

The probability of voltage instability $P_{\text{col}}$ has a linear relationship with load power margin $P_M$. The equation is as follows:

$$P_{\text{col}} = \begin{cases} 
1 & P_M < 0 \\
1 - 15P_M & 0 \leq P_M < 8\% \\
3.5 & P_M \geq 8\% 
\end{cases}$$

(6)

When the voltage collapses, the system loses its full load, and the consequence of voltage instability is the same as that of system collapse. Assuming this happens, the voltage instability severity $S_{\text{col}}$ can be calculated, as shown in equation (7):

$$S_{\text{col}} = P_{\text{col}} \times L_{to} \times K_{1-s}$$

(7)

Among them, $L_{to}$ is the total load lost by the system; $K_{1-s}$ is the conversion coefficient of the system load-severity.

4.4. Severity of Cascading Failures

If there is no cascading failure, the severity of the cascading failure is 0. If there are cascading failures, the severity of power flow exceeding the limit at the time of outage should be analyzed step by step. When the power flow of all lines (transformers) does not overload, the severity of the system cascading failure is the sum of the cumulative severity of the power flow exceeding the limit when removing elements in the cascading failure. When the cascading failure series exceeds the set maximum value or when the power flow calculation does not converge, the severity of the system cascading failure is proportional to the total load lost when the system crashes, as shown in equation (8).

$$S_{\text{chain}} = L_{to} \times K_{1-s}$$

(8)

Among them, $S_{\text{chain}}$ is the severity of the system cascading failure; $L_{to}$ is the total load lost by the system; $K_{1-s}$ is the conversion coefficient of the system load severity.
4.5. Calculation of System Risk Loss

By analyzing the severity of the four types of system risks above, it can be concluded that the total severity of system risks is shown in equation (9).

\[ S_{\text{system}} = S_{\text{load}} + S_{\text{vol}} + S_{\text{col}} + S_{\text{chain}} \]  

(9)

Among them, \( S_{\text{system}} \) is the total severity of the system; \( S_{\text{load}} \) is the power flow out-of-limit severity; \( S_{\text{vol}} \) is the voltage out-of-limit severity, \( S_{\text{col}} \) is the voltage instability severity; \( S_{\text{chain}} \) is the cascading failure severity.

The system risk loss includes system safety loss and outage loss, in which system safety loss can be converted into system severity, and outage loss can be calculated by load loss after fault. The calculation equation is shown in (10):

\[ R_{\text{system}} = K \times \left( S_{\text{after}} + S_{\text{before}} \right) \times p \times T \times P_{\text{price}} \times C_{\text{loss}} \]  

(10)

Among them, \( R_{\text{system}} \) is the economic quantified system risk value; \( K \) is the economic conversion coefficient of severity; \( S_{\text{after}} \) is the system severity after the failure; \( S_{\text{before}} \) is the system severity before the failure; \( p \) is the probability of equipment failure; \( T \) is the duration of risk; \( P_{\text{price}} \) is the local electricity price; \( C_{\text{loss}} \) is the lost load caused by the failure.

5. Conclusions

This paper introduces risk assessment into the maintenance decision-making of power transmission and distribution equipment, establishes the maintenance method based on risk assessment, and applies it to the basic technical framework of power transmission and distribution equipment. Compared with the previous blindly planned maintenance method, the risk-based maintenance method gives priority to the equipment with the greatest maintenance risk, and minimizes the maintenance cost as much as possible, which greatly reduces the waste of maintenance resources and provides scientific guidance for the decision-making process. For the weight definition of economic and system risks, this method takes into account the decision preferences of decision makers, so that the decision results can be more in line with the actual needs.

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