Evaluation on Health Status of Microgrid Equipment in Tropical Islands Based on D-S Evidence Theory

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Abstract In order to improve the reliability of electrical equipment for isolated microgrids in tropical islands, it is necessary to accurately assess the health status of key equipment to carry out differentiated operation and maintenance. We propose a health status assessment model that comprehensively considers multi-dimensional information such as equipment operating parameters, meteorological environment, operation and maintenance history, and equipment resume. Based on D-S evidence theory, multi-source data is fused and analyzed, and the effectiveness of the assessment model is verified using a diesel generator as an example. The results show that the defects of diesel generators are mainly concentrated in five major functional systems, including fuel, startup, heat dissipation, electrical, and motive power systems. Among them, the number of defects involving power and electrical systems is relatively large and the severity of defects is higher. About 40% of the defects involving environmental impacts. According to the defect type and experience, the health status under different defects is given, and then the trust allocation function is preset. The credibility of the integrated assessment results of diesel generator's health status is significantly improved compared to using single assessment information. Our study can provide a reference for the differentiated operation and maintenance of microgrid equipment in tropical islands.

Keywords Isolated microgrid · Tropical island · Health status assessment · Reliability of equipment · Differentiated operation and maintenance

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1 Introduction

With the proposal and promotion of China's marine power strategy, the development and utilization of tropical island resources are gradually being valued. Since tropical islands are usually far away from the mainland, small in area and permanent population, considering the technical and economic efficiency, it is difficult to use submarine cables to provide power energy through the mainland. Therefore, these islands mainly use diesel generator, photovoltaic panels, wind turbines and other power sources to build isolated microgrids (hereinafter referred to as isolated grids) for power supply. In order to improve the reliability of isolated network systems, it is necessary to study the health status assessment of electrical equipment under the special geographical and climatic environment of tropical islands. Accurate evaluation and prediction on the health status of equipment is the basis for differentiated operation and maintenance strategies.

At present, researches on island isolated networks mostly focus on the stability and control of isolated network systems [1], energy optimization configuration and planning [2], and new energy generation prediction [3]. There are few researches on the operation and maintenance strategies of isolated network equipment. Tropical islands have special meteorological environments such as high temperature, high humidity, high salinity, strong sunlight, heavy rainfall, and strong typhoons, which can lead to serious corrosion of equipment on islands, thereby reducing equipment reliability. On the other hand, due to the island's distance from the mainland, the supply of spare parts required for maintenance is relatively lagging. This brings new challenges to the operation and maintenance of isolated network equipment on tropical islands. It is necessary to consider the impact of multiple factors such as the environment on the health status of equipment and establish an evaluation model in line with the actual operation of power equipment on tropical islands.

Researchers have focused on the status assessment of power equipment in tropical island environment [4]. By analyzing the types and causes of equipment defects in tropical islands, an environmental status assessment index for vacuum circuit breakers has been constructed. The combination of sequential relationship analysis and independence weight method is used to achieve comprehensive evaluation of the operating status of vacuum circuit breakers. In addition, a monitoring scheme for electrical equipment in tropical island environment is proposed to monitor the atmospheric environment, service microenvironment and typical equipment operation status, and provide effective data for equipment test correlated with environment. At the same time, the environmental adaptability and related standards of distribution automation terminals in tropical islands were analyzed, and it was pointed out that environmental effects such as corrosion and aging have reduced the reliability of equipment operation. There is still room for improvement in anti-corrosion treatment, moisture-proof structure, and environmental control technology. Due to the significant difference between the comprehensive environment of tropical islands and the conventional continental environment, it is particularly important to establish a new operational reliability assessment system [5]. In addition, the monitoring and protective measures for the “three high” environmental conditions of the island microgrid were studied, and it was found that the island’s high humidity and high salt environment has extremely strong corrosiveness to equipment metal materials and components, reaching G3 level. Experiments have found that selecting appropriate materials and coatings can effectively reduce or avoid corrosion [6]. The above research provides important references for the health status assessment of power equipment on tropical islands, but it is still in the preliminary exploration stage, involving only a few types of equipment, and the influencing factors considered are not comprehensive enough. Therefore, it is necessary to establish a multi-dimensional information fusion method for evaluating device health status.

D-S evidence theory is mainly used for information fusion decision making, which can realize multi-source information synthesis and has been widely used in equipment diagnosis [7]. In this paper, we consider the special climatic environment of tropical islands, equipment operation data and O&M (operation and maintenance) data, equipment history and other factors to establish a multidimensional health status assessment model of isolated network equipment in tropical islands based on D-S evidence theory, and combine the actual data of typical equipment diesel generators to verify the validity of the model.

2 Health Status Assessment Model

The D-S evidence theory can simulate human thought processes for equipment health status assessment, the evaluation process is shown in Fig. 1, Firstly, the identification framework of health degree needs to be determined, which is finally used to evaluate the specific health status of the output. Information is then observed and collected, i.e. the evidence for the evaluation, which can come from different dimensions of evidence information. Then a trust allocation function is given for each piece of evaluative evidence, i.e. the trust value for each category of health status evaluated on the basis of that evidence. Finally, the multi-dimensional information is synthesized to make D-S fusion judgment, that is, evidence synthesis, so as to obtain the final evaluation result of the health status of the device. The key steps are determining the health status range (identification framework), the probability corresponding to the evidence set assignment (trust allocation function), and the synthesis of evidence probability data (D-S synthesis rules).

The modelling and solution method for equipment health state assessment using D-S evidence theory is as follows: let Θ be the identification frame and the trust allocation function m on the identification frame Θ satisfies the conditions shown in Eq. (1).

$$\begin{cases} m(\emptyset) = 0 \\ \sum_{A \subseteq \Theta} m(A) = 1 \end{cases} \tag{1}$$

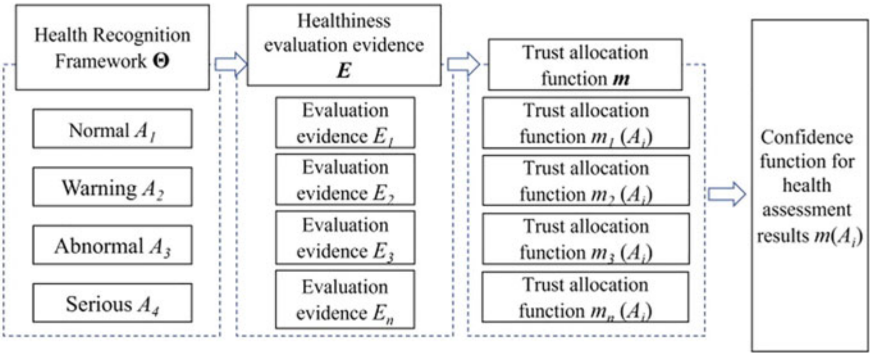

Fig. 1 Process of equipment health assessment using D-S evidence theory

$m(A)$ reflects the support of the evidence for health state A. Its value is the assigned value of trust for health state A. The null set has a trust value of zero and all other subsets have a trust value equal to 1. Assuming that there are n sets of evidence $E1$, $E2 \ldots En$ and $m1$, $m2 \ldots mn$ are the corresponding trust allocation functions under the same identification framework Θ, the D-S synthesis rule can be expressed in Eq. (2). K is called the conflict coefficient and can be calculated by Eq. (3), which reflects the degree of conflict between different evidences, with a larger K indicating a greater conflict between evidences.

$$m(A) = \begin{cases} \frac{1}{1-K} \sum_{\cap Ai=A} \prod_{0 \le i \le n} m_i(A_i) \\ 0, \end{cases} \tag{2}$$

$$K = \sum_{\cap Ai=\emptyset} \prod_{0 \le i \le n} m_i(A_i) \tag{3}$$

The evaluation evidence can be any quantity related to the health status of the equipment, such as the micro-environment of the equipment that may have a significant impact on the health status, the service life of the equipment, and the amount of operation and maintenance status. Each piece of evidence can be given an initial trust assignment function in conjunction with the equipment's operation and maintenance experience. As the operation and maintenance data accumulates, a trust assignment function will be derived that brings the evaluation results closer and closer to the true state of health.

3 Typical Equipment Health Condition Assessment

As shown in Fig. 2, the defects of diesel generators found in the operation and maintenance of isolated microgrids on a tropical island are classified, which are obtained from the actual operation and maintenance data of seven diesel engines over the past 2 years. It can be seen that the defects are mainly concentrated in five major systems, including fuel, startup, heat dissipation, electrical and motive power systems. The defects are classified into three categories: major, emergency and general according to the severity of their impact, while environment-related defects are considered according to the unique environment of tropical islands, mainly corrosion-related contact point rust, oxidation and leakage of sealed containers such as fuel tanks and water tanks. Those marked with a number in the chart are the number of times the defect has been repeated, for example, a water tank leakage defect due to corrosion is 3 times. All other defects not marked with a number have a number of 1 occurrence.

It can be seen that, in terms of defect types, the number of defects involving electrical and motive power systems is the highest, and the severity is higher. This is because the electrical and motive power systems operate in a more complex environment and are subjected to strong electromagnetic, high temperature and high pressure for a long period of time, which accelerates the ageing of materials. At the same time, the electrical and motive power systems are the core of the diesel engine and defects involving these two systems usually develop directly into downtime failures, hence the higher severity of the defects. In addition, environment-related

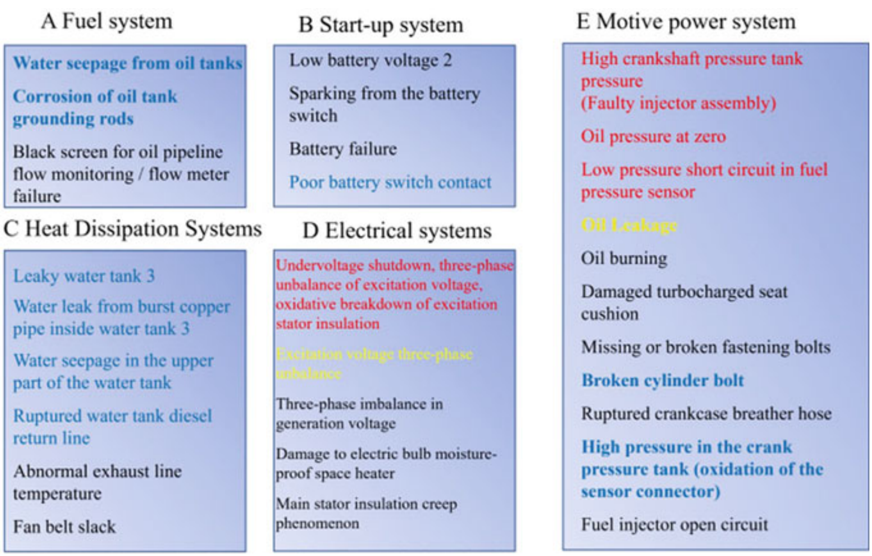

Fig. 2 Defect types of different functional systems of diesel generators (Red represents major defects, yellow represents abnormal defects, black represents attention defects and blue represents environmental related defects)

defects reached 13 times, accounting for about 40% of the total number of defects, but such defects usually take longer to develop into failures and can generally be detected and eliminated in time.

The possible subset categories in the health status identification framework for diesel generators derived from the above analysis are shown in Table 1. For equipment corrosion caused by the environment, it is often difficult to determine its health status as normal or warning, and there are fuzzy intervals between these two states. There are also fuzzy intervals for inspection items where multiple states are difficult to identify.

Using a typical case illustration of a water tank leakage defect found during an inspection, the results of a fusion assessment using D-S evidence theory are shown in Table 2. The figures in the table indicate the probability of assessment using different information, or the confidence level of the corresponding state. The defect occurs in the heat sink and is a corrosion-related problem at the ambient weather information level, and since it has not been long since the tank was last shut down for cleaning, the assessment from the ambient weather information is more likely to be that the equipment is currently in a 'normal' state, but there are other states that are possible with a lower degree of confidence. From an operations and maintenance inspection perspective, the inspection found water leaking from the tank is more inclined to consider the equipment to be in the 'warning' state, but due to the low rate of leakage, there is a certain probability that it is in the 'normal' or 'normal and warning' status. From the perspective of the equipment ledger, because the equipment has just been put into operation, its reliability should be in the stable section at the bottom of the 'bathtub curve', so the probability of a 'warning' or 'abnormal' state is not high, and it is even considered unlikely that a 'serious' condition will occur at this time. After fusing the information from the three different dimensions using D-S evidence theory, it was found that the reliability of the 'normal' state was still the highest, followed by the 'warning' state, and the 'between normal and warning' state. The reliability of the "between normal and warning" dimension is significantly lower

Table 1 Possible subsets in the health status identification framework of diesel generator

Serial number	Status	Remarks
1	Normal	/
2	Warning	/
3	Abnormal	/
4	Serious	/
5	Normal, Warning	Judgement between normal and warning
6	Warning, Abnormal	Judgement between warning and abnormal
7	Abnormal, Serious	Judgement between abnormal and serious
8	Warning, Abnormal, Serious	Judgement between warning, abnormal and serious

than that of the single information evaluation. Based on the fusion results, the device status can be evaluated as healthy.

The above case study shows that when using D-S evidence theory for multidimensional information fusion assessment, the consistency between different evidence has a greater impact on the fusion results. For example, in Table 2 the results evaluated using environmental meteorological information and equipment ledger information have a good consistency, which leads to both overwhelming the operations and maintenance inspection information. The assessment of environmental meteorological information in practical testing varies with increasing equipment operating time, as determined by the corrosion rate of the equipment. Table 3 shows the effect on the D-S fusion results of changes in the assessment of the ambient weather information. For the purpose of this analysis, the sum of the confidence levels for the normal and warning states is kept constant, while only the confidence level for normal or warning is changed. The results show that when the confidence level of 'normal' is reduced to 0.3, the D-S fusion result will be assessed as 'warning', which also illustrates the advantages of using the D-S evidence fusion approach for assessing the health status of electrical equipment on tropical islands, i.e. it allows for more accurate assessment results by fully considering the multidimensional information that affects complexity. Theoretically, the more evidence is obtained and the more consistent the different evidence is, the more accurate the assessment result will be.

Table 2 Multidimensional fusion result for health status evaluation of diesel generator

Serial number	Environmental Weather	Operations and maintenance	Equipment ledger	D-S Fusion
1	0.5	0.2	0.6	0.7040
2	0.2	0.6	0.2	0.2816
3	0.1	0.04	0.05	0.0023
4	0.025	0.01	0	0
5	0.1	0.1	0.1	0.0117
6	0.025	0.02	0.05	0
7	0.025	0.02	0	0
8	0.025	0.01	0	0

Table 3 Impact of changes in environmental information on fusion evaluation results

Normal in environmental weather	Warning in environmental weather	Normal in D-S fusion	Warning in D-S fusion
0.5	0.2	0.7040	0.2816
0.4	0.3	0.5632	0.4224
0.3	0.4	0.4224	0.5632
0.2	0.5	0.2816	0.7040
0.1	0.6	0.1408	0.8448

On the other hand, it is also evident that where there is a single piece of evidence that conflicts with other evidence, fusion assessment using D-S evidence theory often results in a minority of evidence being submerged in the majority. However, these few pieces of evidence are likely to be key pieces of evidence as well, and therefore the weighting of the different pieces of evidence needs to be considered when fusing, which is a direction that needs further research when using D-S evidence theory for equipment health status assessment.

4 Conclusions

(1) A multidimensional assessment model of the health status of isolated microgrid equipment on tropical islands considering environmental impacts, operation and maintenance inspection data, and ledger data is proposed, and the D-S evidence theory is used to fuse and assess the multidimensional information. The model is illustrated with diesel generators as a typical case to achieve an intelligent assessment of the health status of equipment that simulates human thought processes.

(2) The characteristics of diesel-fired defects in isolated microgrids in tropical islands were analysed. It was found that the number and severity of defects in electrical and motive power systems are high, and the number of defects brought about by corrosion due to environmental meteorology accounts for more than 40%, but the defects develop slowly and can usually be eliminated in time, so the severity of defects is not high. The defect characteristics analysis can provide an important reference for equipment health status assessment.

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