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Reliability Analysis of Power Optical Transmission Network Based on Evidence Cloud Droplets Model

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***Abstract*—In order to solve the problem that the qualitative indicators in reliability analysis of the power optical transmission network can not be accurately measured, this paper proposes a reliability evaluation method based on the evidence cloud droplets model. The model uses the cloud model to achieve the conversion between qualitative concept and quantitative value. Considering the correlation between the cloud droplets, it deeply excavates the interaction between cloud droplets combined with the evidence theory, and obtains the support of qualitative indicators to each reliability level. Finally, all indicators are used to give the analysis results of the reliability of the power optical transmission network in the form of ranks. By comparing with the traditional cloud model similarity algorithm, the proposed method has the advantages of objective science and high sensitivity, and can provide reliable decision-making basis for reliability evaluation of power optical transmission network.**

Keywords—Power optical transmission network; reliability analysis; cloud model; evidence theory

I. INTRODUCTION

With the development of smart grid, fiber optic communication is increasingly applied to the power communication transmission network due to its large load capacity, small signal attenuation and strong anti-interference ability. Power optical transmission network has a very important guarantee role in power production and scheduling. Therefore, many scholars have used different methods to evaluate the evaluation of power optical transmission networks in different dimensions [1-3]. However, most studies now use quantitative indicators to evaluate and analyze power optical transmission networks, but some qualitative indicators are also of great significance for reliability analysis.

Cloud model is a good method to analyze qualitative indicators. Professor Li Deyi proposed and improved the formation of cloud model. This theory has been successfully applied in the fields of intelligent control and data mining. In recent years, the field of system evaluation has also begun to pay attention to the cloud model and conducted in-depth research. The reference [5] combined the advantages of the cloud model and the TOPSIS method, and used the cloud model to overcome the ambiguity and randomness of the evaluation language set in the decision process. The reference [6] used the cloud model to achieve a conversion of qualitative concepts to quantitative representations, and also combined with the gray system theory and the vector projection principle to calculate the superiority of the evaluation object . It can be seen from the above analysis that most of the current research on cloud model focuses on its ambiguity and randomness , but does not deeply analyze and mine the relationship between cloud droplets.

Therefore, this paper proposes a analysis mechanism based on evidence cloud droplets model for qualitative indicators. Firstly, the cloud model is used to realize the conversion between qualitative indicators and quantitative value. Then, the cloud droplets generator is used to generate the representative cloud droplets and the evidence theory is combined to analyze the interaction between them, and the level support of the indicators for each level is obtained. Finally, the analysis conclusions of the reliability of the power optical transmission network are obtained by synthesizing the level support of each indicator, and the existing or potential problems of the power optical transmission network at a specific development stage are pointed out to clarify the future investment focus and improve the development quality and development capability.

II. EVIDENCE CLOUD DROPLETS MODEL

A. Problem Description

At present, the problem of reliability analysis is mainly reflected in the fact that most of the selected indicators can be quantified by a specific algorithm, and the introduction of qualitative indicators is reduced , reducing the weakness of the influence of qualitative factors. This is because the evaluation of qualitative indicators often needs to be indirectly converted by the evaluation experts into quantitative values that can be used for evaluation work based on relevant data and comparison criteria. The traditional method is greatly influenced by human factors, and the simple weighted average processing is easy to cover the true attribute of the index value, thus it will reduce the reliability of the evaluation conclusion. Therefore, this paper uses the randomness and ambiguity of cloud model to achieve the conversion between qualitative concept and quantitative value, reduce the subjectivity of man-made, and deeply analyze the reliability in combination with evidence theory.

B. Model definition

The essence of the evidence cloud droplets model is to integrate the evidence theory with the cloud model theory, and to analyze and evaluate the things to be diagnosed by means of the reasoning analysis method of evidence theory. This paper defines the concept of the hierarchical cloud model and the indicator cloud model. For the indicator cloud model, the cloud generator is used to generate the cloud droplets. The cloud is composed of numerous cloud droplets, and each cloud droplets can be regarded as a representative of the cloud. . From the perspective of cloud droplets, the evidence theory is used to make the consistency and conflict of multiple evidences of evidence source into the characteristics of uncertainty reasoning, and the distance of different clouds generated by the same indicator cloud to the hierarchical cloud is regarded as evidence theory. Multiple sets of evidence, and then use the evidence theory method to deeply explore the interaction between cloud droplets, and obtain the final reliability level diagnosis result.

C. Reliability Analysis Step

This section proposes the concept of cloud droplets support for each level of cloud model for qualitative indicators. Firstly, the cloud model is used to realize the conversion between qualitative linguistic values and quantitative digital features of cloud models, then from the perspective of cloud droplets ,the evidence theory is used to reason the analysis of the interaction between cloud droplets, and obtain the support of the indicator cloud model for each level of cloud model, the specific operations are as follows:

First, determine the indicator reliability level cloud model. For the qualitative indicator i, divide it into N (j = 1, 2, ..., N) reliability levels, and define $C_{ij}=(Ex_{ij},En_{ij},He_{ij})$ to be the reliability level cloud model of the level j corresponding to the indicator i. Where, C_{i1} , C_{iN} and C_{ij}, j = 2, 3, ..., N-1 corresponding to the reliable level cloud model are semi-falling clouds, half Ascending clouds and normal clouds. If the value of the level j of the index i is set to $[a_{ij},b_{ij}]$, j = 1, 2, ..., N, the numerical characteristics of the reliability level clouds can be calculated from Table I. Where, ε_{ij}, j=1, 2, ⋯, N is constant, which can be specifically adjusted according to the randomness and ambiguity of the actual situation. Fig. 1 shows a schematic diagram of hierarchical cloud partitioning.

TABLE I. RELATIONSHIP BETWEEN OF CLOUD MODELS DIGITAL FEATURES AND VALUE DOMAINS

Cloud	C_{i1}	$C_{ij}(j=2,3,\dots,N-1)$	C_{iN}
Ex_{ij}	a_{i1}	$(b_{ij}+a_{ij})/2$	b_{iN}
En_{ij}	$(b_{i1}-a_{i1})/3$	$(b_{ij}-a_{ij})/6$	$(b_{iN}-a_{iN})/3$
He_{ij}	ε_{i1}	ε_{ij}	ε_{iN}

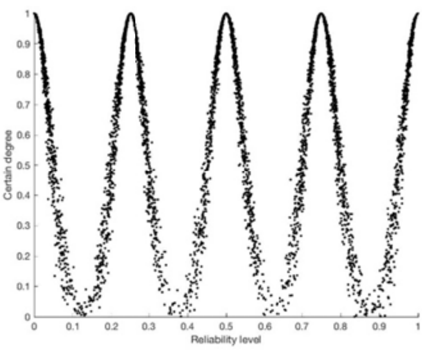


Fig. 1. Schematic diagram of hierarchical cloud model division.

Second, determine the indicator cloud model. According to the evaluation of the grade language value of the qualitative index i, the experts obtain the corresponding cloud model C_{ik}, and calculate the qualitative cloud model of the qualitative index $C_{ij}=(Ex_{ij},En_{ij},He_{ij})$ by the following (1)~(3).

$$Ex_i=\sum_{k=1}^{t}\lambda_k Ex_{ik} \tag{1}$$

$$En_i=\frac{\sum_{k=1}^{t}\lambda_k Ex_{ik}En_{ik}}{\sum_{k=1}^{t}\lambda_k Ex_{ik}} \tag{2}$$

$$He_i=\sqrt{\sum_{k=1}^{t}He_{ik}^{2}} \tag{3}$$

Where, Ex_i,En_i, He_i are the expectations of the integrated cloud model C_{ij}, entropy, super Entropy; λ_k is the weight of the expert k (k=1,2,3,...,t); Ex_{ik},En_{ik},He_{ik} is the expert k on the index i level language value evaluation corresponding to the expectation, entropy and super entropy of the level cloud model .

Finally, determine the indicator level support. The distance from the cloud droplets of the indicator cloud model to each level cloud model is regarded as evidence of a set of level support. This set of evidence is combined with the evidence theory to obtain the support of the qualitative index. α_{ij}. Specific steps are as follows:

1) Determine the distance from the indicator integrated cloud model to the N hierarchical cloud models. First, through the forward cloud generator, generate T evidence cloud droplets of the indicator integrated cloud model cloud C_i, then use (4) to calculate the European geometric distance from the evidence cloud droplets m (m = 1, 2, 3, ..., T) to the hierarchical cloud model C_j center (Ex_j, 0):

$$d_{mj}=\sqrt{(x_m-Ex_j)^2+\mu(x_m)^2} \tag{4}$$

2) According to the distance between each evidence cloud droplets and each level cloud model C_j, then use (5) to calculate the basic probability distribution function to each level corresponding of the evidence cloud droplets:

$$m_{im}(A_j)=\frac{1/d_{mj}}{\sum_{j=1}^{N}1/d_{mj}} \tag{5}$$

Where, $m_{im}(A_j)$ is the basic probability distribution function of the evidence cloud droplets m to the index cloud model C_i , d_{mj} is the distance from the evidence cloud droplets m to the level cloud j.

3) According to the basic probability distribution function of the evidence cloud droplets to each level, used (6) to calculate the divergence of evidence cloud droplets:

$$KL(m_{im}||m_{il})=\sum_{j=1}^{5}m_{im}(A_j)log\frac{m_{im}(A_j)}{m_{il}(A_j)} \tag{6}$$

Where, $KL(m_{im}||m_{il})$ is the divergence of the evidence cloud droplets, indicates the closeness for each level of support of the evidence cloud droplets m and l, the smaller the value, the closer it is..

4) Calculate the credibility of evidence cloud droplets using (7):

$$\rho_{im}=\sum_{\lambda=1}^{T}\left(1-\frac{KA(\mu_{i\kappa}\|\mu_{i\lambda})+KA(\mu_{i\lambda}\|\mu_{i\kappa})}{\sum_{\lambda,\mu=1,2,\ldots,T}KA(\mu_{i\kappa}\|\mu_{i\lambda})+KA(\mu_{i\lambda}\|\mu_{i\kappa})}\right) \quad (7)$$

And normalize the credibility of evidence cloud droplets:

$$\omega_{im}=\frac{\rho_{im}}{\sum_{m=1}^{T}\rho_{im}} \quad (8)$$

Equation (9) gives the normalized credibility of evidence cloud droplets:

$$\omega_{im}=[\omega_{i1},\omega_{i2},\ldots,\omega_{iT}]^{T} \quad (9)$$

5) Determine the comprehensive probability distribution function of the evidence cloud droplets m for the grade A_j according to (10):

$$m'_{im}(A_j)=\frac{\omega_{im}m_{im}(A_j)}{\sum_{m=1}^{T}\omega_{im}m_{im}(A_j)} \quad (10)$$

6) According to the evidence theory synthesis rule, use (11) to calculate the support of the index i for the grade A_j:

$$\alpha_{ij}=m_{i1}(A_j)\oplus\ldots\oplus m_{iT}(A_j)=\frac{1}{K}\prod_{m=1}^{T}m_{im}(A_j) \quad (11)$$

Where $K=1-\sum_{j=1}^{5}\prod_{m=1}^{T}m'_{im}(A_j)$ is the conflict factor in the evidence theory synthesis rule.

The fuzzy analytic hierarchy process [10] is used to obtain the index weights, and the final level of support is obtained by combining the support levels of each indicator.

III. Simulation Analysis

A. Algorithm Simulation

This paper takes a typical regional power optical transmission network as an example to verify the feasibility and rationality of the model proposed in this paper. Four qualitative indicators are selected: quality of network service (QoNS), completeness of spare parts (CoSP), scalability of network management system (SoNMS), and operation management system (OMS). Five levels (1~5) are selected to represent the difference from poor to excellent.

First, according to the historical data, the five-level domain division of each index is obtained, as shown in Table II, secondly, the index value of each indicator expert evaluation language is collected to obtain the indicator cloud model, and the results are shown in Table III; The relationship between the indicator integrated cloud model and the reliability level cloud model is shown in Figure 2.

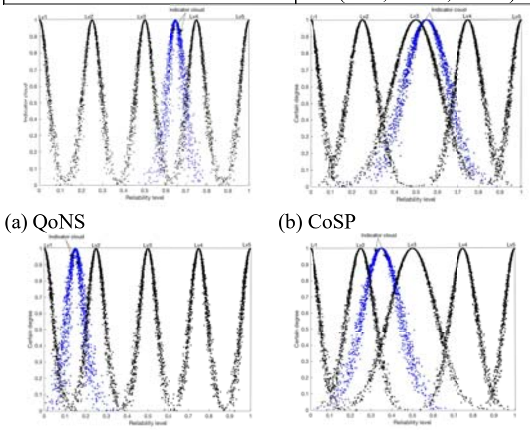
Then, the level support of each indicator is calculated, and combined with the index weights, the comprehensive support degree and final evaluation level of the power optical transmission network for five reliability levels are obtained.

TABLE II. Reliability Level Domain Division

Level	Lv1	Lv2	Lv3	Lv4	Lv5
QoNS	[0,0.125]	[0.125,0.375]	[0.375,0625]	[0.625,0.875]	[0.875,1]
CoSP	[0,0.15]	[0.15,0.35]	[0.35,0.65]	[0.65,0.85]	[0.85,1]
SoNMS	[0,0.125]	[0.125,0.375]	[0.375,0625]	[0.625,0.875]	[0.875,1]
OMS	[0,0.15]	[0.15,0.35]	[0.35,0.65]	[0.65,0.85]	[0.85,1]

TABLE III. Indicator Cloud Model

Indicator	QoNS	CoSP	SoNMS	OMS
Indicator cloud model	(0.65,0.0416,0.0112)	(0.55,0.1005,0.0112)	(0.15,0.0416,0.0112)	(0.25,0.0845,0.0112)



(a) QoNS (b) CoSP

(c) SoNMS (d) OMS

Fig. 2. Comparison of indicator cloud model and level cloud model.

The results of each indicator level support degree are shown in Figure 3. The final network reliability level diagnosis results are shown in Table IV.

It can be seen from Table IV that the reliability level of the power optical transmission network in the region is level 3, indicating that the level of the power optical transmission network in the region is good. It can be seen from Fig. 3 that the SoNMS and OMS corresponding level of the power optical transmission network in the region is level 2, indicating that the above two indicators still need to be improved.

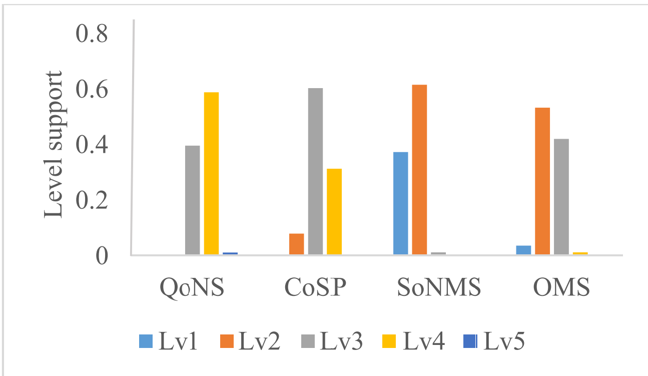


Fig. 3. Level support for indicators.

TABLE IV. Level Comprehensive Support

Level	Lv1	Lv2	Lv3	Lv4	Lv5
Level Support	0.1190	0.2955	0.3476	0.2138	0.0031

B. Comparative Analysis

The final support for each reliability level is defined as a judgment factor. Through the analysis, the support of the power optical transmission network for each reliability level is obtained. If the level with the highest degree of support has a greater degree of discrimination with other levels of judgment factors, then the decision model has higher sensitivity.

Define the sensitivity as:

$$\zeta = \frac{\alpha_{ijmax} - \alpha_{ijsec}}{\alpha_{ijmax}} \tag{12}$$

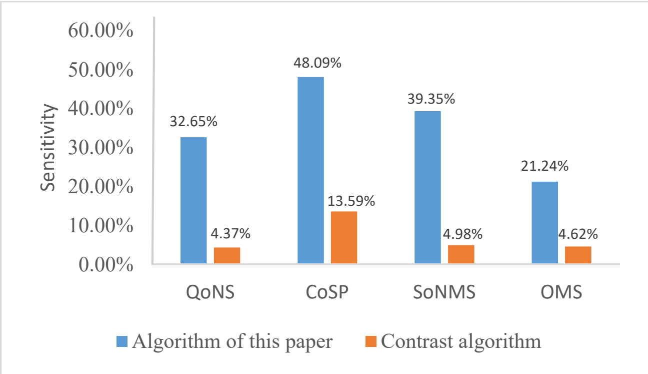


Fig. 4. Sensitivity comparison.

Where α_{ijmax} represents the maximum value of the indicator cloud model's support for all hierarchical cloud models, and α_{ijsec} represents the second largest support value. It can be seen from (12) that the sensitivity indicates the degree of differentiation of the same qualitative index to the support of different levels. Obviously, the greater the sensitivity is, the greater the discrimination of the corresponding decision model is, and the better the evaluation effect can be got.

The traditional cloud model similarity algorithm generates a certain number (of course a large number) of cloud droplets through two clouds, measured based on the distance between the cloud droplets. The traditional method is used to analyze the four indicators of the example, and the corresponding level support results are obtained and the sensitivity of the two algorithms is calculated. The results are shown in Fig 4.

It can be seen from Fig. 4 that the sensitivity of the proposed algorithm is higher than that of the traditional algorithm. This is because this paper utilizes the different contributions of each cloud droplets in a normal cloud model to a specific concept, and the use of evidence theory can make the advantages of uncertainty and conflict between multiple sets of evidence sources and highlight the role of cloud droplets with large cloud contribution, making the algorithm more accurate and reliable.

IV. Conclusion

With a view to the qualitative indicators in reliability analysis, this paper proposes a analysis mechanism based on evidence cloud droplets. The cloud model is used to realize the conversion from qualitative concept to quantitative value. Combined with cloud model theory and evidence theory, the interaction between cloud droplets is deeply explored. The support of the indicator cloud model for each level of cloud model, then get the support of the indicator cloud model for each level of cloud model. Finally, combined with the level support results of each indicator, the comprehensive support degree of each level of the whole network is obtained, and the analysis of the power optical transmission network is realized. It can accurately find the weak links in the development of power optical transmission network, and provide solutions for the construction and development of subsequent networks.

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