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Credibility Measure and Its Assessment of Customer Equipment Failure Probability Due to Voltage Sag

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Abstract

In order to accurately describe the equipment' severity caused by voltage sag, the credibility measure which meets the conditions of non-additive is proposed based on their physical properties of responses. This assessment measure can avoid the deficiencies that classical probability measure needs a large number of samples and the non-duality of fuzzy measure. The membership functions of sensitive equipment voltage tolerance capability that corresponding to the characteristic quantities in the status uncertain area was determined by fuzzy statistical method and polynomial fitting method. Then the joint credibility distribution function was deduced based on uncertainty theory. Hence, the assessment model of severity of equipment failure is constructed. Based on practical samples, the PCs were simulated using the proposed method. Comparing the simulation results with methods using classical probability measure and possibility measure prove that the proposed method is proper and credible and can reflect practical condition more objectively.

Keywords: voltage sag, non-duality, non-additive, credibility measure, joint credibility distribution function, uncertainty theory.

1. Introduction

Voltage sag is the worst power quality problem which always causes sensitive equipments huge financial losses [1-3]. And therefore a variety of assessment methods proposed by domestic and foreign scholars keep voltage sag severity as one of the satisfaction degree indexes of power customers. Unfortunately the

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deficiencies exist in the present assessment measures. Under the different operation states, the sensitive equipment of different types or the same one have various voltage sag severity. Consequently, the scientific evaluation measure and methods should research from measure theory and its' existence condition.

The voltage sag severity on equipment can be attributed to electromagnetic compatibility between the power supply disturbances and the voltage tolerance level of equipment, affected by operation state, fault level and location, equipments' types, working conditions and other uncertainties. The existing assessment method includes statistical method [4], probabilistic assessment method [5], and fuzzy assessment method [6]. Based on CBEMA and ITIC curve, scholars put forward relevant assessment method from with different angles. The team of Milanovic [2-3] considers the event of equipments affected by sag as random event, proposing probabilistic assessment method. Professor Xiao [7] brings measure theory and uncertainty theory into the assessment of equipment sensitivity, getting maximum entropy estimation method [8] which has the least dependent on subjective assumptions. According to fuzziness of sag event, Taiwan scholars Lu Chan-Nan [6] presents fuzzy assessment method based on fuzzy inference rules. Fuzzy-random assessment method, interval assessment method [9] and multi-uncertainty assessment method [10] are achieved surrounding the uncertainty of equipment immunity and sample characteristics. However, a classical axiomatization condition is used in the above methods. In fact, existence conditions of classic measure are difficult to be contented. The problem include that equipment voltage sag severity don't meet countable additivity and self-duality. Therefore, based on modern measure theory, the credibility measure is developed by Liu, which is used in many fields of power system.

From the physical mechanism of voltage sag's influence to equipment, this credibility assessment measure meets the conditions of subadditivity and self-duality, which is based on uncertainty theory. This proposed uncertainty measure and model are verified by simulation and practical test, which is more effective than the other assessment methods with classic measure.

2. Theoretical basis of credibility measure

Uncertainty refers to the property of connection and development between events, including randomness, possibility, fuzziness and roughness. The credibility measure [11] is developed by Liu in 2002, and it is the most appropriate measure to quantify the fuzzy event. The credibility measure has the equal status in fuzzy field as the probability measure in probability theory.

The credibility of event A is expressed as:

$$Cr(A) = \frac{1}{2}(Pos(A) + Nec(A)) \tag{1}$$

Where: $Pos(A)$ and $Nec(A)$ are the possibility measure and necessity measure, and have:

$$Nec(A) = 1 - Pos(A^c) \tag{2}$$

Where: A^c is the complement of A.

If A can be influenced by a variety of uncertainties, the combined credibility distribution function of A is expressed as:

$$\Phi(x_1, x_2, ..., x_n)$$
$$= Cr\{\theta \in \Theta \mid \xi_1(\theta) \le x_1, \xi_2(\theta) \le x_2, ..., \xi_n(\theta) \le x_n\} \tag{3}$$

Where: $(\xi_1, \xi_2, ..., \xi_n)$ are fuzzy vector and the range of Φ belongs to $[-\infty, +\infty]^n \to [0,1]$.

3. Attribute of Equipment Voltage Sag Severity

In order to ensure the accuracy and credibility of assessment, a reasonable measure should be selected. The defect of past assessment based on classic measure contain that a mass of sample, subjectivity, harsh condition. Therefore, the more appropriate assessment should start from the physical attribute.

3.1.Fuzziness of the Intermediate State

Under the influence of voltage sag, the physical attribute of the device response performances as: the border of equipment's state between normal and fault is undefined, which is called intermediate state, such as system halted. The sum of equipment's normal possibility and failure possibility is not 1 due to this fuzziness, which is against the additivity. This superimposed phenomenon can be described by the subadditivity of credibility measure. For any event A and B: $Cr(A_1 \bigcup A_2) \le Cr(A_1) + Cr(A_2)$

3.2.Uncertainty of Non-probability

According to the size of information, uncertainty can be divided into probability and non- probability. There is a recognized probable value for the event can be test repeatedly, which is named probability. While the equipment voltage sag severity has many influence factors, which lead it difficult to repeat. So the severity assessment belongs to non- probability. For this question, membership function of fuzzy variables has the superiority that relaxed requirements of information and the same result under different membership functions. Above all, credibility measure is appropriate choice for that.

3.3.Self-duality

The possibility measure has been widely used in equipment reliability assessment. However, it has no self-duality property in theory. It means that, the event with the possibility of 1 will not absolutely occur, while the event with the possibility of 0 may occur. This phenomenon isn't allowed to happened in the engineering field.

Based on possibility measure, credibility measure has self-duality same to probability measure, as: $Cr(A) + Cr(A^c) = 1$

It can be seen from that event A is certainly present if $Cr\{A\}$ is 1, and absolutely impossible if Cr{A} is 0.

3.4.Non-independence of Factors

Classical probability assessment method assumes that the equipment's response to the magnitude U and duration T are independent random events. The criterion is the severity($s(U，T)$) exceed immunity($x(U，T)$). In practice, equipment may fail when each event happened. Therefore, the failure probability union model of sensitive equipment is:

$$P(A_1 \cup A_2) = P(A_1) + P(A_2) - P(A_1A_2) \qquad (4)$$

where, event A_1 is s (U)>x (U), event A_2 is s (T)>x (T), but i $P(A_1A_2)$ is difficult to obtain.

To overcome this problem, the union model based on uncertainty theory is:

$$Pos(\bigcup_i A_i) = \sup_i Pos(A_i) \qquad (5)$$

Where, sup means the supremum. It's obviously that had and owe estimated can both be avoided.

4. Assessment system of credibility measure

4.1.Uncertain State of Equipment.

Voltage tolerance of equipment can be depicted by voltage tolerance curve (VTC). Due to experimental evidence, the VTC of various equipments is rectangle on the magnitude-duration plane. U_{min}, U_{max} and T_{min} ,T_{max} are maximum and minimum of magnitude and duration respectively. External area of curve one express normal state; inner region of curve one express faulted state; the middle shows the uncertain state, containing sub-region of *A,B,C*.
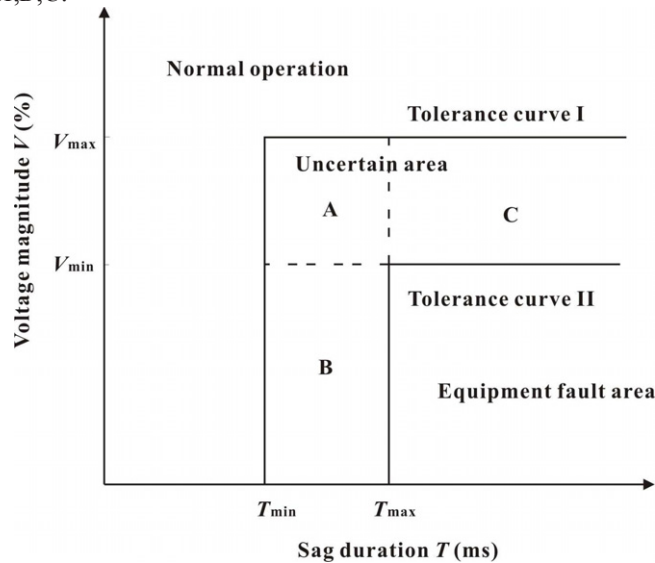

Fig.1. Region of uncertainty of the equipment state

4.2.Characterization Function of Equipment Tolerance Uncertain.

The boundary between safety and fault is fuzzy. This multivalued state can be depicted by the membership function. The intermediate state corresponds to the uncertain region of VTC. According to fuzzy statistical and polynomial fitting method, membership function of equipment $\mu(x)$ can be constructed with measured samples.

$$\mu(x) = k_1 x^n + k_2 x^{n-1} + ... + k_n x + k_{n+1} \tag{6}$$

Where, k_i (*i*=1, 2... *n*+1) is the polynomial coefficients, *x* is the disturbance tolerance characteristic, *n* is the polynomial orders which relate to sample capacity.

4.3. Assessment Model of Equipment Voltage Sag Severity.

When the sag intensity $s(U_0, T_0)$ is greater than the tolerance $x(U, T)$, equipment may be malfunctioning. There is a fault set codetermined by fuzzy vectors U_0 and T_0. Combined with multi-factor joint credibility distribution function, the assessment model of equipment voltage sag severity is:

$$\Phi(U,T) = Cr\{U,T \in \Theta \mid U \le U_0, T \le T_0\} = \frac{1}{2}[Pos(U \le U_0, T \le T_0) + 1 - Pos(U > U_0, T > T_0)] \tag{7}$$

5. Voltage sag severity assessment process

- According to the sample data from the actual measurement or the historical records, the boundary of VTC's uncertain region is determined.
- Based on interval samples of equipment tolerance, membership function $\mu(x)$ is calculated by (6).
- The credibility measure of equipment voltage sag severity is evaluated by equation (7).

6. Practical comparison

6.1. Practical Test and Results

Voltage sag source is made up of a Fluke 6100A disturbance generator and a linear power amplifier. One PC is tested 5000 times with 5% step of magnitude and 20ms step of duration under the range of 0-1p.u. Under hundreds of independent tests for PC with various states, Uncertainty range of PC voltage tolerance capability is obtained in Table 1.
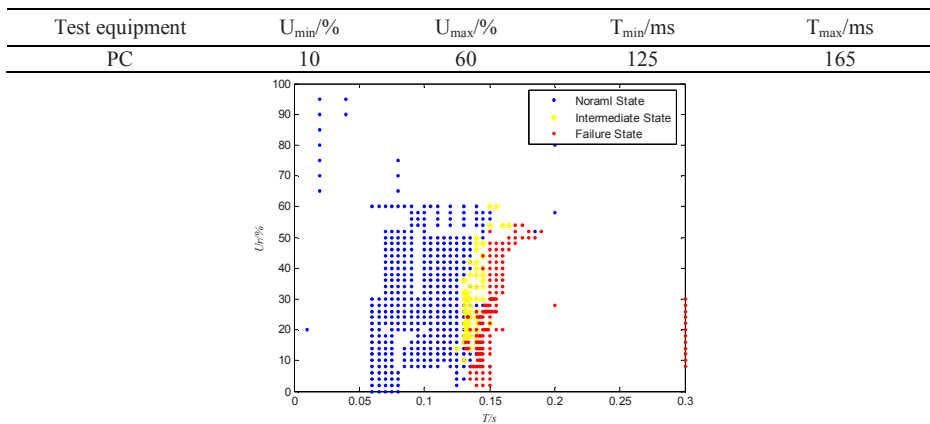
Table 1. Uncertain area of equipments' VTC

Test equipment	U_{min}/%	U_{max}/%	T_{min}/ms	T_{max}/ms
PC	10	60	125	165

Fig.2.Testing results of PC

6.2. Assessment and Results Comparison

To verify the correctness of the proposed method, the classic probability measure, possibility measure and credibility measure are used for evaluate. And the union model is used in the classic probability measure. The results of comparison are shown in Table 2. The relative errors are calculated as follows:

$$\varepsilon\% = \frac{|a_1 - a_0|}{a_0} \times 100\% \qquad (8)$$

Where, a_0 is the test results; a_1 is the assessment results.

From the assessment result as shown in Table 2, it can be found that the probability of failure is greater with increased voltage sag intensity. This phenomenon indicates that the proposed can correctly reflect the trend of severity. Because of the axiomatic assumptions of the classical probability measure is too harsh, the different measures have significant influence on results. The maximum errors of assessment method with credibility measure, possibility measure and probabilistic measure are 9.85%, 30.34% and 52.92%, respectively. The results have proved that the assessment method with credibility measure is more accurate and dependable.

Table 2.Comparison on the assessment results and test result

Voltage sag severity (U_r/%,T/ms)		a_0	Proposed method		Probabilistic measure		Possibility measure	
			a_1	e%	a_1	e%	a_1	e%
1	39, *	0.3109	0.3088	0.68	0.3156	1.511	0.2595	16.35
2	37, *	0.3455	0.3382	2.11	0.4052	17.28	0.3112	9.93
3	*, 144	0.4076	0.3958	2.89	0.4404	8.05	0.3860	5.30
4	*, 150	0.5897	0.5316	9.85	0.7734	31.15	0.6484	9.95
5	42, 140	0.3333	0.3125	6.24	0.3817	14.52	0.2344	29.67
6	30, 145	0.5666	0.5588	1.38	0.8026	43.63	0.5294	6.56
7	23, 128	0.6052	0.5938	1.88	0.9255	52.92	0.7888	30.34
8	16, 128	0.8571	0.8125	5.20	0.9888	15.37	0.9550	11.42

7. Conclusions

Form the physical properties, this paper proposes a credibility measure assessment method which can solve various issues with the lack of samples, non-additive and non-duality condition. The assessment results and comparison the credibility measure is more accurate, effective than the past methods. And the proposed method can be easily used for the assessment of the PLC, ASD, ACC and other equipment.

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