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Estimation of Voltage Sag Loss Based on Blind Number Theory

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Abstract

Serious power quality issues and huge economic loss can be caused by voltage sag. It's helpful for grid corporation to estimate voltage sag loss. Voltage sag and influence of sensitive equipment are analyzed in the paper. An estimation method of voltage sag loss based on blind number theory is proposed, which takes the sag magnitude and duration as its main characteristic parameters. First Euclid distance and relative close degree between the sag magnitude and duration of voltage sag samples and threshold values is calculated based on TOPSIS. According to relative similarity degree, probable value, credibility and mean value of voltage sag loss are then calculated and influence of uncertainty factor can be considered. Example analysis shows that loss estimation method is a feasible and applicable for most sensitive equipments.

Keywords: *voltage sag, loss estimation, blind number, credibility*

1. Introduction

With computer, electronic equipments and speed control device and so on are applied widely in both industry and daily life, the demand of power quality more and more concentrate voltage sag [1-2] etc transient power quality. On the basis of foreign research, voltage sag has been major power quality issues of impacting equipments safe operation. The impact of voltage sag on users and society is becoming more significant. Though the connection between power sources and power consumption equipments is not broken off by voltage sag, the times of voltage sag is far more than blackout. Therfore losses caused by voltage sag are more severe than by blackout in some cases. According to researchs of foreign agencies, 80 percent of the customer complaints are complaints caused by voltage sag in developed country. Economic loss [3] is attributable to voltage sag costs tens of billions of dollars every year in industrial and commercial fields.

Estimating reasonably losses of voltage sag will help for forming consensus about seriousness of voltage sag between power system and users, applying essential reference to deal with voltage sag and applying decision basis for power grid construction. Currently many methods of estimating losses of voltage sag are proposed by scholars at home and abroad. It includes three categories: losses estimation of voltage sag based on load sensitive curve [4-6], losses estimation of voltage sag based on probabilistic method [7-8], losses estimation of voltage sag based on quality loss [9].

Voltage sag can cause large economic loss and has been major power quality issues. It's important realistic meaning for studying voltage sag losses. An method of estimation voltage sag losses for almost sensitive equipments based on blind number theory [10] is presented in the paper on the basis of summarizing current researches. The method could effectively and easily assess the economic loss caused by voltage sag.

2. Causes of Voltage Sag and Voltage Sag Tolerance Ability Curve

Voltage sag is defined according to IEEE standard: power frequency voltage effective value dives to 0.9p.u.~0.1p.u. and recovers normal value after short duration of 10ms~1min at somewhere in power system. When short-circuit faults, transformers and capacitors switching, switches manipulating and large capacity induction motors starting happen, a branch current

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increases within a short term and then voltage sag happens. Thereinto short-circuit faults, lightning and induction motors starting are major causes of voltage sag. Generally the influences of voltage sag on equipments are related to sensitivity of equipments. The more sensitive the equipments for voltage sag are, the bigger the economic loss is. For different equipments the sensitivity of users is measured by selected most sensitive equipments during the manufacturing process according to experiential data. Then U_{max}、$U_{\min}$、T_{max}、$T_{\min}$ are defined and voltage tolerance area [3] of sensitive users is showed in Fig.1 according to voltage tolerance curve of sensitive equipments.

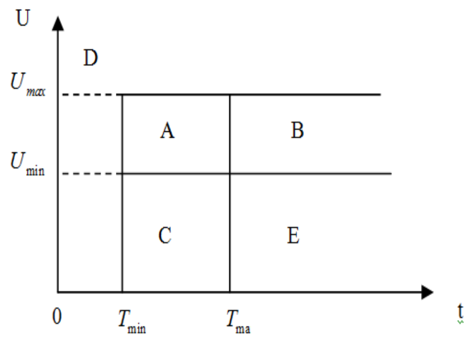

Figure 1. Voltage Sag Tolerance Areas of Sensitive Equipments

In Figure 1 D region represents that equipment faults are not certainly caused by voltage sag and E region represents that equipment faults are certainly caused by voltage sag. A, B, C regions represent uncertainty region. The influences of voltage sag on users and equipments are uncertainty in A, B, C region. Therefore equipment faults and production interruption could be caused by voltage sag and equipments could not be influenced obviously.

3. Loss Estimation Model of Voltage Sag Based on Blind Number Theory

3.1. The Meaning of Blind Number Theory

Uncertainty includes randomness, fuzziness, unascertainty and grayness. Blind information performs above two classification or more uncertain informations. Blind number can be considered credibility function [11-14] of interval distribution. If object performs uncertain, actual value of object is not always point value but interval value in the neighborhood of point value. If interval value can be represented by interval number x and $\alpha \in [0,1]$ is credibility of interval, blind number is composed by interval distribution from a number of interval number x_i and credibility α_i.

Suppose $A(I)$ is interval grey number set: $\alpha_i \in A(I)$ and $\alpha_i \in [0,1]$, $i = 1, 2, \cdots, n$. $f(x)$ is grey function of $A(I)$:

$$f(x) = \begin{cases} \alpha_i, x = x_i, i = 1, 2, \cdots, n \\ 0, 其他 \end{cases} \quad (1)$$

Where $x_i \neq x_{i+1}$, $\sum_{i=1}^{n} \alpha_i = \alpha \leq 1$. Function $f(x)$ is a blind number. α_i is credibility of x_i. α is total credibility of $f(x)$. n is degree of $f(x)$.

3.2. Algorithm of Blind Number

Suppose blind number $A = f(x) = \begin{cases} \alpha_i, x = x_i, i = 1, 2, \cdots, m \\ 0, 其他 \end{cases}$ and $B = g(y) = \begin{cases} \alpha_i, y = y_j, j = 1, 2, \cdots, n \\ 0, 其他 \end{cases}$, * is algorithm arithmetic operators that represent ＋, 一, ×, ÷.

A new $m \times n$ degree blind number is formed by algorithm of A and B and presented by probable value matrix X and credibility matrix Y .

$$X = \begin{bmatrix} x_1 & x_1 * y_1 & \cdots & x_1 * y_j & \cdots & x_1 * y_n \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_i & x_i * y_1 & \cdots & x_i * y_j & \cdots & x_i * y_n \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_m & x_m * y_1 & \cdots & x_m * y_j & \cdots & x_m * y_n \\ * & y_1 & \cdots & y_j & \cdots & y_n \end{bmatrix}$$

$$Y = \begin{bmatrix} \alpha_1 & \alpha_1 * \beta_1 & \cdots & \alpha_1 * \beta_j & \cdots & \alpha_1 * \beta_n \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ \alpha_i & \alpha_i * \beta_1 & \cdots & \alpha_i * \beta_j & \cdots & \alpha_i * \beta_n \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ \alpha_m & \alpha_m * \beta_1 & \cdots & \alpha_m * \beta_j & \cdots & \alpha_m * \beta_n \\ * & \beta_1 & \cdots & \beta_j & \cdots & \beta_n \end{bmatrix} \quad (2)$$

The same elements are regarded as a value and probable value are arranged in sequence in probable value matrix X . If $\overline{x_i}$ has S_i difference positions in sequence in probable value matrix X , the sum of the elements of S_i corresponding positions is regarded as $\overline{r_i}$ in credibility matrix Y and sequence $\overline{r_1}, \overline{r_2}, \cdots, \overline{r_k}$ is obtained. The * of blind number A and blind number B can be represented as:

$$\varphi(x) = A^* B = \begin{cases} \overline{r_i}, x = \overline{x_i}, i = 1, 2, \cdots, k \\ 0, 其他 \end{cases} \quad (3)$$

3.3. Algorithm of Blind Number

Suppose a and b are real numbers and $a \leq b$. $\theta(a,b)$ is signed by $(a+b)/2$ course. Mean value of blind number A and blind number B are calculated as follows.

$$E(A) = E(f(x)) = \begin{cases} \alpha, x = \sum_{i=1}^{m} \alpha_i = \alpha_i \times \theta(x_i, x_{i+1}) \\ 0, 其他 \end{cases} \quad (4)$$

$$E(B) = E(g(y)) = \begin{cases} \beta, x = \sum_{j=1}^{n} \beta_j = \beta_j \times \theta(y_j, y_{j+1}) \\ 0, 其他 \end{cases} \quad (5)$$

$$E(A+B) = E(A) + E(B) = \begin{cases} \alpha \times \beta, z = \sum_{i=1}^{m} \alpha_i \times \theta(x_i, x_{i+1}) + \sum_{j=1}^{n} \beta_j \times \theta(y_j, y_{j+1}) \\ 0, 其他 \end{cases} \quad (6)$$

3.4. Loss Estimation Model

Sensitivity of equipments is influenced lots of elements that include mounting locations, structure characteristics, operating environments, running states, load level and supply side in the circumstance of voltage sag. These uncertain informations that perform randomness, fuzziness, unascertainty and grayness show characteristic of blind informations. Therefore voltage sag tolerance curves of sensitive equipments appear uncertainty. On the other hand the influences of voltage sag on sensitive equipments appear uncertainty. Uncertain condition of equipment faults or production interruption could be indicated by blind number theory. Therefore the severity of voltage sag could be reflected by blind number. Voltage sag loss could be estimated by calculating mean value of blind number.

(1) Standardizing decision matrix

Firstly, standardizing decision matrix $X = (x_{ij})_{m\times n}$ and achieving a standardized matrix $Y = (y_{ij})_{m\times n}$,

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} (i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n) \tag{7}$$

(2) Calculating weighted standardized matrix

$$U = (u_{ij})_{m\times n} = (\omega_j y_{ij})_{m\times n} \tag{8}$$

(3) Determining Ideal Solution and Negative Ideal Solution

$$U_0^+ = \left\{ \left(\max_{1\le i\le m} u_i(j) \right) j \in J^+, \left(\min_{1\le i\le m} u_i(j) \right) j \in J^- \right\} = \left(u_0^+(1), u_0^+(2), \cdots, u_0^+(j), \cdots u_0^+(n) \right) \tag{9}$$

$$U_0^- = \left\{ \left(\min_{1\le i\le m} u_i(j) \right) j \in J^+, \left(\max_{1\le i\le m} u_i(j) \right) j \in J^- \right\} = \left(u_0^-(1), u_0^-(2), \cdots, u_0^-(j), \cdots u_0^-(n) \right) \tag{10}$$

(4) Calculating Distance

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left[u_i(j) - u_0^+(j) \right]^2}, (i = 1, 2, \cdots, m) \tag{11}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left[u_i(j) - u_0^-(j) \right]^2}, (i = 1, 2, \cdots, m) \tag{12}$$

(5) Calculating relative similarity degree of samples

$$C_i^* = \frac{D_i^-}{D_i^+ + D_i^-}, (i = 1, 2, \cdots, m) \tag{13}$$

(6) Estimating probable value and credibility of voltage sag losses by production interruption cost.

$$L_i = C_{AV} \times (1 - C^*) \tag{14}$$

Where L_i is probable value of voltage sag losses, C_{AV} is average value of production interruption cost, C^* is relative similarity degree of voltage sag.

(7) Calculating mean value of blind number and Estimating losses of voltage sag cases.

$$L = L_i \times \alpha \quad (15)$$

Where L is mean value of blind number of voltage sag losses, α is credibility corresponding to probable value of voltage sag losses.

4. Case Study

A sensitive user is analyzes as case study in the paper. The sensitive user is subjected to many voltage sag during a statistics period. Threshold value of characteristic parameter of voltage tolerance curve of the sensitive users are achieved according to historical data of voltage sag: $U_{max} = 0.8 p.u.$, $U_{\min} = 0.3 p.u.$, $T_{max} = 30s$, $T_{\min} = 0.1s$, $C_{AV} = 5.262 \text{ten} - \text{thousand} - \text{yuan}$. The weight of sag magnitude and duration is respectively $\omega = [0.8 \quad 0.2]$, $\omega = [0.5 \quad 0.5]$ and $\omega = [0.2 \quad 0.8]$.

Supposing that the user is subjected to four times voltage sag but not production interruption. Characteristic parameters of four times voltage sag are shown as Table 1.

Table 1. Users' Characteristic Parameter of Voltage Sag

Case	sag magnitude	duration /s
	0.60	8
	0.45	25
	0.28	0.2
	0.80	30

Probable value, credibility and mean value of blind number of voltage sag losses are estimated and showed as Table 2.

Table 2. The Possible Value, Credibility and Mean Value of Blind Number of Voltage Sag Losses

case	probable value	credibility	mean value of blind number
	2.005	0.3	
1	1.589	0.5	1.676
	1.400	0.2	
	3.789	0.3	
2	4.173	0.5	4.096
	4.362	0.2	
	3.731	0.3	
3	2.000	0.5	2.260
	0.705	0.2	
	1.573	0.3	
4	3.315	0.5	3.046
	4.583	0.2	

According to results of Table 2, probable value of blind number of the first time and the second time vary slightly, but probable value of blind number of the third time and the fourth time vary obviously. Above result illustrate when characteristic parameter of voltage sag are close to or reach lower limit of threshold value in voltage sag case, it contributes to voltage sag losses bigger. Meanwhile the influence of the second time voltage sag on users is most serious. The influence of the third and fourth time voltage sag on users is less serious. The influence of the first time voltage sag on users is most slight. Though users' production interruption are not caused by four times voltage sag, accumulative economic losses are huge and reach to 11.078

ten-thousand-yuan and larger than losses of two times interruption. Therefore benefits of improve power quality for users are obvious.

5. Conclusion

The method of estimation of voltage sag loss based on blind number theory is proposed in the paper. Sag magnitude and duration are considered as main characteristic parameters by using the voltage sag tolerance ability of sensitive equipment. The idea of blind number is introduced in voltage sag case to calculate voltage sag loss. According to probable value, credibility of blind number, mean value of blind number representing economic losses of voltage sag are calculated. Example result shows that the estimation method is feasible and universal.

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