

The Study of Overhead Line Fault Probability Model Based on Fuzzy Theory

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ABSTRACT

In the background of the design and construction of Smart Grid Operation Supporting System for District Power Networks, this paper established the weighted fault probability model of the overhead line which is based on equipment operating status, utility theory and fuzzy theory. In this model, the proper membership function is adopted to describe the influence of lightning, wind speed, line ice and temperature, and the outage rate of overhead line, derived from historical statistics, is amended. Based on this model, the power supply risk analysis software is developed to calculate the online risk indicators of district grid, and provide real-time decision support information based on risk theory for scheduling operations personnel.

Keywords: Power System; Fault Probability Mode; the Overhead Line; Risk Assessment

1. Introduction

Regional power grid plays an important role in transportation and distribution of electric energy between high-voltage transmission grid and power consumer. It is closely linked with the country's economic development and people's living standards. With the development of social economics and power technology, the regional power grid is appearing the characteristic of more complex structures, more random load and more complex operational condition[1,3,5]. So, it is of great significance to study how to assess the security of district power grid.

In this paper, the overhead line fault probability model is established based on power system risk assessment theory and combined with the knowledge of fuzzy theory, and the forced outage rate of the lines is more in line with the actual operating conditions.

2. Overhead Line Fault Probability Model Based on Fuzzy Theory

During the operation of the power system, overhead lines operation conditions are more complex and most severely affected by uncertain factors such as climate environmental and so on, which have different influence characteristics to the overhead lines[2,4]. In this paper, a method of dealing with uncertainty information based on the fuzzy theory was adopted of appointment, and combined with the actual operation conditions of the power

system, the overhead line fault probability model is established.

2.1. Main Uncertain Factors

The overhead line unplanned outage causes in 2010(table C-3), released by the Electricity Reliability Management Center of the State Electricity Regulatory Commission, presented that the unplanned outage times caused by natural disasters and climate factors is 632, accounting for 59.7% of the total number of the unplanned outage times; the unplanned downtime caused by natural disasters and climate factors is 6758.02 hours, accounting for 70.97% of the total time of non-planned outage. Therefore, the study of climate environmental factors for the impact of overhead lines and the prevention and control measures has far-reaching significance to ensure the safe and stable operation of the power system.

External environmental factors have greater impacts to overhead line fault, The main reason is that: on the one hand, the long distance of most of overhead lines, and across different climate regions, increase the difficulty of planning and research; on the other hand, most overhead lines are direct contact with the external environment, the impact of climatic and environmental conditions around is the larger, and frequent lightning, line Icing, the higher wind speed will caused the line outage rate rising. However, it is still a problem to known the influence to the line reliability integrating various factors. This paper

main study the Uncertainties factors affecting line outage rate as follows:

1) Temperature: The temperature changes will cause expansion and contraction of the line, and thus cause the lines sag and stress changes, and will affect the electrical parameters of the line. Higher temperatures, due to thermal expansion factors, the lines sag increase and the length elongate, which impact the safe distance of the wire-to-ground and cross across, and make the line resistance increases, and thus increasing the power loss in the line transfer power; When the temperature decreases, due to the cold shrink effect, the line length becomes shorter, the stress is increased, affecting the mechanical strength of the wire.

2) Wind: effects of wind on the overhead line are mainly in three aspects: Firstly, it will increase the load of wires and towers when the wind blows on the towers, conductors and its accessories; Secondly, with the action of the wind, the wire will deviate from the vertical plane, which will change the ground distance of the live wire, cross arm, towers, etc; Thirdly, the wire will vibrate and dancing in the wind, and the vibration will cause the wire fatigue, in severe condition it will cause broken stocks or short line, dancing makes chaos between the upper and lower rows of wire .

3) Lightning: line tripping caused by lightning can reach 70% of the total number of line tripping. And it can trigger a chain of reactions after being struck by lightning, such as wires blown, insulator broken, switch trip, etc. Being struck by lightning, over-voltage of overhead lines will result in flashover accident of insulation breakdown.

4) Line Icing: Line Icing cause wire and towers forming a vertical load, line load increasing, may cause the disconnection and connection fittings destruction even down rod accident; Otherwise, ice-shedding difference or uneven may cause overhead lines jump, easily leading to flashover between parallels or between the wire and the lightning conductor, then burn wires or lightning conductor.

2.2. The Method of Fuzzy Theory to Deal with Uncertain Factors

The fuzzy uncertain factors are different from random factors, there is no exact probability distribution, and classical probability statistical methods can not be used to describe it. The fuzzy set theory introduced by Zadeh Professor is a powerful tool to deal with and descript the fuzzy uncertain factors. The fuzzy set allows for the description of concepts in which the boundary is not sharp. Besides, a fuzzy set concerns whether an element belongs to the set and to what degree it belongs. It does not consider the situations where elements do not belong to. As a result, the range of fuzzy set is in [0,1]. A fuzzy set is mathematically defined by Zadeh as:

$$A = \{(x, \mu_A(x)) | x \in X\} \tag{1}$$

where is the membership function of in A , and X is the universe of objects with elements x . In the case of the classical “crisp” set A , membership of x in A can be viewed as a characteristic function that can obtain two discrete values:

$$\mu_A(x) = \begin{cases} 1; & \text{if } x \in A \\ 0; & \text{if } x \notin A \end{cases} \tag{2}$$

For the fuzzy set A , the value of the membership function can be anywhere between 0 and 1, making it different from a crisp set. Membership function of a fuzzy set expresses to what degree the value of x is compatible with the concept of A .

There is a wide variety of forms for fuzzy numbers, and triangular fuzzy numbers and trapezoidal fuzzy numbers are the most widely used in practical applications. Trapezoidal fuzzy number is function based on left expand function $L(x)$ and right expand function $R(x)$. As shown in **Figure 1**, it is a L-R fuzzy numbers described by the real parameters in (a, b, c, d) , and the representation of its membership function as:

$$\mu_L(x) = \begin{cases} L(x), & a \leq x < b \\ 1.0, & b \leq x < c \\ R(x), & c \leq x < d \\ 0, & \text{others} \end{cases} \tag{3}$$

where $L(x) = (x-a) / (b-a)$ for $[a, b]$ single increasing function; $R(x) = (d-x)/(d-c)$ of $[c,d]$ within a single reduction function; the trapezoidal fuzzy numbers center value is $(b + c) / 2$; a, d , respectively, is the left and right borders of the fuzzy numbers.

Trapezoidal fuzzy numbers to characterize fuzzy features of the value have better usability. In power systems, the generator, load, and component failure status parameters can be described by the trapezoidal fuzzy number. For example, predict the maximum load of a system within a year, the fuzzy predictive method may conclude that: “the highest load will not be greater than 900 MW or less than 750 MW, more possibly from 800 MW to 850 MW”, then it is more appropriate to indicates it adopting the trapezoidal fuzzy number, as **Figure 1** shows.

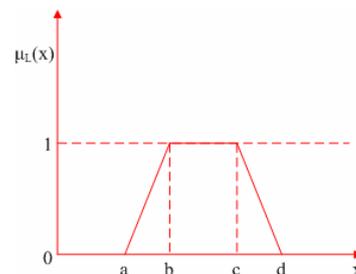


Figure 1. Trapezoidal fuzzy function.

2.3. Modeling Overhead Line Fault Probability Considering Fuzzy Uncertain Factors

1) Uncertainties membership function choice

The method of establishing the membership function include weighted method, fuzzy statistics, expert scoring method, interpolation ,standard function method and so on. There is strong uncertainty to the impact of climate change for overhead lines running. In this paper, based on the long-term experience of dispatcher to judge for these types of environmental factors and determine the membership function.

a) The membership function of lightning impact

The density of lightning is an important indicator to determine the lightning degree of a region. Lightning Location System (LLS) can automatically measure and record the density of lightning. Lightning protection design standards also adopt lightning density as a reference. The membership function of the lightning effects identified here as shown in **Figure 2**:

The membership function of lightning disasters impact on overhead lines running as:

$$\mu_1(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \leq x < b \\ 1, & x \geq b \end{cases} \quad (4)$$

where in (4) a and b is the lightning density threshold determined according to the experiences of the dispatching personnel, In other words, it does not affect while the lightning density is less than the lower limit threshold value a , and the influence coefficient is 0, otherwise, higher than the high limit threshold value b is considered a greater impact, influence coefficient is 1.

b) the membership function of wind speed and line Icing

Wind speed can be obtained by the meteorological department forecast; while ice thickness for the line, air humidity, temperature and wind size the extent of ice damage has a larger impact, not yet theoretical or empirical model to predict the extent of ice cover based on meteorological conditions, we use the actual ice thickness measurement indicators to assess the severity of the ice storm. Wind speed and line of ice thickness with the fall line health density similar to lightning, the same form of the membership function $\mu_2(x)$, $\mu_3(x)$, shown in **Figure 3**:

For the wind speed, in $\mu_2(x)$, A is the impact threshold value determined according to the experiences of the dispatching personnel, b is the critical value determined catastrophe occur; Line Icing $\mu_3(x)$, a and b are respectively the upper and lower critical value of ice thickness impact.

c) the membership function of temperature impact on

overhead lines

The temperature forecast information can be obtained by contact with the meteorological department. Within the normal temperature range, the temperature did not affect the line running, so the value is set at 0; when the temperature is too low or too high, its influence is large, and the function value is set to 1. The membership function shown in **Figure 4** below:

The membership function of temperature impact on overhead lines as:

$$\mu_4(x) = \begin{cases} 1, & x < c \\ \frac{a-x}{a-c}, & c \leq x < a \\ 0, & a \leq x < b \\ \frac{x-b}{d-b}, & b \leq x < d \\ 1, & x \geq b \end{cases} \quad (5)$$

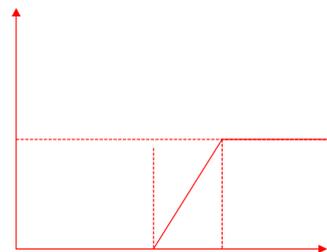


Figure 2. The membership function of the lightning effects.

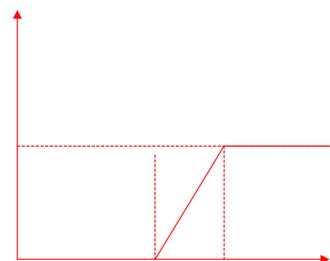


Figure 3. The membership function of the wind speed and line Icing.

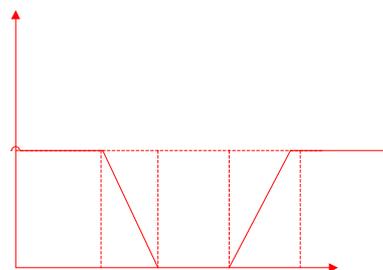


Figure 4. The membership function of air temperature.

where in formula 5, a, b, c and d determined according to the experiences of the dispatching personnel are the impact threshold value that air temperature impact on overhead lines running.

2) *overhead line fault possibility model*

For any transmission lines, Generally, the span of overhead lines is larger, and different segments of the line in different climatic and environmental conditions. So first according to geographic information system (GIS) information, with the most complex of climatic factors that lines through as criteria for overhead line segment description, assume that the cross-regional temperature distribution of the most complex and divided into n stages, the definition:

$$L = [l_1, l_2, l_3, \dots, l_n] \tag{6}$$

where $l_1, l_2, l_3, \dots, l_n$ is segmented vector.

Any overhead line segmentation, the fuzzy number vector composed by the membership function of various impact factors is determined as follows

$$r = [r_{i1}, r_{i2}, r_{i3}, r_{i4}] \tag{7}$$

where r_{i1}, r_{i2}, r_{i3} and r_{i4} successively corresponds the fuzzy numbers that lightning, wind speed, line icing and temperature affect the segment i line outage probability, then the fuzzy number matrix as:

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & r_{n3} & r_{n4} \end{bmatrix} \tag{8}$$

where, r_{ij} represents the fuzzy number of the j -th impact factors impact on the i -th segment line. Definition $B = [B1, B2, B3, B4]$ as the weight coefficients of line fault outage rate considering four influence factors, then:

$$A = R \times B = [a_1, a_2, \dots, a_n] \tag{9}$$

where, a_i is the impact factor of the i -th overhead lines considering the four influential factors, thus four factors for the average impact factor of the whole of the line as:

$$\mu = \left(\sum_{i=1}^n a_i l_i \right) / \left(\sum_{i=1}^n l_i \right) \tag{10}$$

Set the outage rate of overhead lines acquired from historical statistics is λ' , and after correction by the influencing factors of overhead line outage rate is λ , then:

$$\lambda = \begin{cases} (1 + \mu)\lambda', & (1 + \mu)\lambda' < 1 \\ 1, & (1 + \mu)\lambda' \geq 1 \end{cases} \tag{11}$$

3. Analysis of Examples

According existing research results as defined in Section

2, this section defines the membership function coefficient and the critical value of the influencing factors for a hypothetical transmission lines to create a its outages model. Line forced outage rate under normal operating conditions adopted “220 kV transmission line in 2010 forced outage rate”, released by the State Electricity Regulatory Commission, and it is 0.247. This section assumes the line running condition to correct its forced outage rate.

3.1. The Membership Function

The critical value of the membership function of lightning, wind speed, line Icing and air temperature impact on overhead lines is shown in **Table 1**.

3.2. Line Segmentation

It is assumed that the total length of an overhead line is 100 km, and the wind speed change are maximum in its span area. The line is divided into four sections, namely $l_1 = 20$ km, $l_2 = 30$ km, $l_3 = 30$ km, $l_4 = 20$ km, its weather experienced can be shown as **Table 2**, this line can be seen mainly effected by wind during the running.

3.3. The Correction Overhead Lines Forced Outage rate

The fuzzy numbers of various influencing factors obtained are shown in **Table 3**: that:

Table 1. The critical value of the membership function.

The Influencing Factors	The Critical Value Of The Membership Function
Lightning (number/(km ² •a))	$a_1 = 1.05; b_1 = 6.30$
wind speed (m/s)	$a_2 = 6; b_2 = 15$
line Icing (mm)	$a_3 = 5 \text{ mm}; b_3 = 20 \text{ mm}$
Temperature (°C)	$a_4 = -20; b_4 = 40; c_4 = -40; d_4 = 60$

Table 2. The specific values of the overhead lines each segment external factors.

Segment Influencing Factors	Lightning (number/(km ² •a))	Wind Speed (m/s)	Line Icing (mm)	Temperature (°C)
l_1	0	4	0	16
l_2	0	8	0	18
l_3	1.80	12	0	20
l_4	1.80	13	0	20

Table 3. The fuzzy numbers of various influencing factors.

The Fuzzy Numbers	Lightning	Wind Speed	Line Icing	Temperature
11	0	0	0	0
12	0	0.222	0	0
13	0.143	0.333	0	0
14	0.143	0.444	0	0

$$R = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0.222 & 0 & 0 \\ 0.143 & 0.333 & 0 & 0 \\ 0.143 & 0.444 & 0 & 0 \end{bmatrix} \quad (12)$$

Define the weight coefficient vector of four impact factors for line fault outage rate is: $B = [0.2, 0.4, 0.2, 0.2]$ T, then:

$$A = R \times B = [0, 0.0888, 0.1618, 0.2062] \quad (13)$$

By (10), four factors for the average impact factor of the whole line is $\mu = 0.1164$.

By the formula (11) can be obtained the line forced outage rate after the correction:

$$\lambda = (1 + 0.1164) \times 0.247 = 0.276 \quad (14)$$

As can be seen the line running is affected by external environmental factors, the forced outage rates is significantly increased compared to normal circumstances statistics value, so the in overhead lines outage modeling process can not overlooked the impact of environmental factors.

4. Conclusions

Based on power system risk assessment theory and combined with the knowledge of fuzzy theory, the overhead line fault probability model is established, by selecting the proper membership function to describe the influence of lightning, wind speed, line ice and temperature. In this model, the outage rate of overhead line, derived from historical statistics, is amended, and the forced outage rate of the lines is more in line with the actual operating conditions.

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