Component reliability parameters estimation considering weather factors

Yuan Wang
School of electronic engineering, Xi'an Aeronautical University Xi’an, China
E-mail:578101618@qq.com

Abstract. In order to study influence of power system reliability parameters under the complex weather, this paper presents a component reliability parameter estimation method based on the one directional S-rough law and F-decomposition law. The S-rough rule handles the failure rate and the uncertain weather conditions. According to this, it establishes reliable parameter estimation model. Then the power system reliability evaluation adds the F-decomposition law analysis to form the interfere metrics and analyzes influence of component reliability parameters under different weather combinations. In the numerical example verification, the results show that the proposed model can predict the transmission line failure rate, and reveals the influence regularity of component reliability parameter. Based on the objective data (climate in many years), the proposed method can eliminate the influence of subjective factor. Evaluation results are more objective, and provide important information for the power system reliability evaluation.

1. Introduction
In recent years, there are blackout accidents which caused huge economic loss and social influence at home and abroad, so it is very important to enhance the power system reliability evaluation. It is the most basic work to get original reliability parameters of reliability research. Usually, the original reliability parameters adopt average values. However, the parameters are dynamic randomness with the greatly influence of many factors: climate factors, human factors, geographical conditions, the quality of the product itself, load level, operating conditions, etc. [1-2].

Until now, many researches have studied the selection of original reliability parameters prediction. Literature [3] focused on prediction and correction of original reliability parameters, rarely on how to make use of the reliability of the existing original parameters to evaluate the launch of the new project. Literature [4] get the failure rate of the whole line by segment length weighted. Literature [5] analyzed impact factors of the transmission line by the empirical formula. It only mathematical pulsed the impact factors, because of complex reality, it can't reflect the comprehensive effect of meteorological factors.

Z. Pawlak professor, a polish mathematician professor, put forward rough sets theory in 1982. It is a mathematical tool to deal with fuzzy and uncertain information, to discover the implicit knowledge and reveal the potential regularity. The theory has been applied in power system: power system load forecasting [6], fault line selection [7], etc. According to the theory, Kaiquan Shi professor presented the one directional singular rough set (S-rough set), the bidirectional singular rough set, function S-rough set and the F-decomposition law theory(F is a given system)[8], with dynamic collection description. Component reliability parameters are uncertain. The one directional singular rough set theory can well solve such uncertain law problem with dynamic properties. So this paper adopts this theory.
Aiming at the shortcomings of the existing reliability parameter estimation methods, this paper adopts the following method to solve: Based on the historical statistical data, the article analyzes the characteristics of random change in the weather; Using the one-way S-rough law to analyze method, considering the weather factor of component reliability parameters estimation model is set up; Using F-decomposition rule to analyze the influence of climate on reliability parameters, this paper predicts transmission line failure rate. The model proposed in this paper provides a new way for the transmission line reliability parameters of reasonable evaluation of new production.

2. The One Directional Singular Rough Set Theory [9]

In the power system component reliability parameter estimation, when external factors that affect the reliability parameters don’t change, the impact factor is described by a set of attributes A, and the corresponding factor in attribute values is described by X. The one directional S-rough rule obtains component failure rate model, namely the relationship between the impact factor and the component failure rate. When the dynamic external factors change, the attribute set A becomes A’, and the attribute value X becomes X’. The F-decomposition rough law analyzes the relationship between the impact factor and the reliability parameters.

2.1. The One Directional S-Rough Law

It assumes that A is the attribute set of law p(t), and X is the attribute value vector of law p(t). In another word, X = {x₁, x₂, …, xₘ} is value of the attribute A = {a₁, a₂, …, aₘ}, where m is the number of attributes. It gets the the failure rate set [λ] = {λ₁, λ₂, …, λₙ}, where n is the number of lines, based on the component failure model. By rule generation model, it gets rough law p(t) of element failure rate.

2.2. The F- Decomposition Law

In a dynamic system, a is the attribute set with dynamic characteristics, and f is the family of dynamic mobility. If A’ = A ∪ {a’} = {p₁, a₂, …, aₙ, a’}, where a’ is the new increase (decrease) the properties, A’ is attribute complement set of A. Similarly, X’ = {x₁, x₂, …, xₙ} is vector f - decomposition of the attribute value vector X, and then p(t)’ is the f - decomposition law of p(t). If p(t) is the F-decomposition up law of p(t), and p(t)’ is the F - decomposition under law of p(t), (p(t), p(t)’) is the F-decomposition rough law.

3. Component Reliability Parameter Model

Equipment working of the transmission system outdoor, especially the overhead line, is greatly affected by the weather such as thunderstorms, hail, and fog, therefore it is necessary to take into account element reliability parameters in polymorphic weather.

According to the characteristics of the reliability impact factor, the impact factors of overhead transmission line failure rate are due to the following categories: a₈ shows storm weather; a₂ shows heavy rain the weather; a₃ shows ice and snow; a₄ shows shows high temperatures; a₅ shows foundation reason and others; a₆ shows launch time; a₇ shows voltage grade, where a₁ - a₄ is the weather data and a₅ - a₇ is the non-weather data. It assumes that the attribute set of the impact factors is A = {a₁, a₂, a₃, a₄, a₅, a₆, a₇}, the attribute value vector of the impact factors is X = {x₁, x₂, x₃, x₄, x₅, x₆, x₇}. It assumes that the weight of each attribute is H = (h₁, h₂, h₃, h₄, h₅, h₆, h₇)', and \( \sum_{i=1}^{7} h_i = 1 \).

3.1. Component Failure Rate Model

If the power system transmission line number is n, the matrix [X] of attribute characteristic value are obtained by the attribute values vector X of every line.
The efficiency target optimization $\gamma_j$ of each eigenvalue $x_j$ in the matrix of attribute characteristic value is then calculated by:

$$\gamma_j = \frac{x_j}{\vee_j x_j + \wedge_j x_j}$$  \hspace{1cm} (1)

In Equation 1, $\vee$ is taking big operation, and $\wedge$ is taking small operation.

Target optimization matrix $\Gamma$ is obtained as follows:

$$\Gamma = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1n} \\ \gamma_{21} & \gamma_{22} & \cdots & \gamma_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{m1} & \gamma_{m2} & \cdots & \gamma_{mn} \end{bmatrix}$$  \hspace{1cm} (2)

In Equation (2), $\gamma_j$ is target optimization.

According to the ordering method approaching the ideal solution (TOPSIS), it constructs the ideal optimization (Excellent decision of target optimization) and the negative ideal optimization.

The ideal optimization is

$$G = (g_1, g_2, \ldots, g_m)^T = (\gamma_{11} \vee \gamma_{12} \vee \cdots \vee \gamma_{1n},$$

$$\gamma_{21} \vee \gamma_{22} \vee \cdots \vee \gamma_{2n}, \ldots, \gamma_{m1} \vee \gamma_{m2} \vee \cdots \vee \gamma_{mn})^T$$

the negative ideal optimization is

$$B = (b_1, b_2, \ldots, b_m)^T = (\gamma_{11} \wedge \gamma_{12} \wedge \cdots \wedge \gamma_{1n},$$

$$\gamma_{21} \wedge \gamma_{22} \wedge \cdots \wedge \gamma_{2n}, \ldots, \gamma_{m1} \wedge \gamma_{m2} \wedge \cdots \wedge \gamma_{mn})^T$$

The weight matrix gets $[H]$ from the attribute weights.

$$[H] = \begin{bmatrix} H_1^T, H_2^T, \ldots, H_n^T \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1n} \\ h_{21} & h_{22} & \cdots & h_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & \cdots & h_{mn} \end{bmatrix}$$

Each weight value in the weight matrix is put into the equation (3), and it can obtain the failure rate $\lambda_i$.

$$\lambda_i = \frac{1}{1 + \left( \frac{\sum_{j=1}^{n} (b_{ij} - \gamma_j)^2}{\sum_{j=1}^{n} (b_{ij} - b_j)^2} \right)^2}$$  \hspace{1cm} (3)

In Equation (3), the distance parameter is 2. Then component failure set $[\lambda] = \{\lambda_1, \lambda_2, \ldots, \lambda_n\}$ is obtained.
When the impact factor set \([A]\) is expanding dynamically, The impact factor value sequence set is formed, namely, \([X]=\{X_1, \ldots, X_n\}\). It gets a set of component failure rate sequence \(\{X_1, X_2, \ldots, X_n\}\) and \(\{X_1, X_2, \ldots, X_n\}\).  

### 3.2. The Rough Law Generation Model of Component Failure Rate

In the sample of the components failure rate, the weather data is the changing factor and the non-weather data is the relatively stable factor. It forms a new sample set \((X', \lambda')\) because of the weather data as unilateral dynamic data.

The data \([X']\) is put into the Lagrange interpolation formula, it gets a law generation \(p(t)\) as follow:

\[
p(t) = \sum_{j=1}^{n} \lambda_j \prod_{i, j \neq j} \frac{t-i}{j-i}
\]

In Equation (4), \(t\) is line number.

If considered the weather data and the non-weather data, it can obtain \(\bar{\lambda}_t\) from Eq. (3). Then it can obtain law \(\bar{p}(t)\) from the rough law generation model Eq. (4). It is called the upper law \(\bar{p}(t)\). Similarly, if considered the non-weather data, it is gotten law \(\hat{p}(t)\) and then the lower law \(\hat{p}(t)\) by employing Eq. (3) and Eq. (4). Thus, the one directional S-rough law \((\bar{p}(t), \hat{p}(t))\) can be formed.

### 3.3. Component Failure Rate Prediction

The weather data can be forecast next year. With weather sample values which are known over the years and normal sampling method, \(x_{n+1}\) can be obtained, because the relatively stable non-weather data is set the average value. It can predict component failure rate \(\hat{\lambda}_{n+1}\) the next year, according to the component failure rate model which is proposed from 3.1.

### 4. Rough Law Index

The law energy is a reflection of the device performance, and can be used as the basis for choosing components. The law interference degree reflects the influence of different weather conditions on the transmission system.

The law energy \(W\): supposing that \(p(t)\) is the law on the interval \([a, b]\), \(W\) is the law energy of \(p(t)\) as follow

\[
W = \int_a^b p(t)dx
\]

The interference degree \(\rho\): supposing that \(p(t)^f\) is \(f\)-decomposition law generated by \(p(t)\), \(\rho\) is the interference degree \(p(t)^f\) of \(p(t)\) as follow:

\[
\rho = \frac{\|X^f\|_2^2}{\|X\|_2^2} - 1
\]

In Equation (6), \(X\) is the corresponding attribute value vector \(p(t)\), and \(\|X\|_2\) is the norm of the vector \(X\).

### 5. Illustrative Example

The line failure sample data’s are listed in Table I. The weather data are showed in Figure 2 from 2009 to 2014.
Table 1. The failure rate of each line and its influence factors

|    | The annual average storm days/d | The annual average rainstorm days/d | The annual average days of snow and ice/d | The high temperature days(≥35°C)/d | The foundation and other reasons/(km·a) | The average production time/a | Volta ge grade/kV | Line failure rate |
|----|---------------------------------|-----------------------------------|------------------------------------------|-----------------------------------|----------------------------------------|----------------------------|-----------------|------------------|
| 1  | 24                              | 22                                | 0                                        | 27                                | 8                                      | 14                        | 220             | 0.083            |
| 2  | 21                              | 23                                | 2                                        | 20                                | 5                                      | 10                        | 35              | 0.078            |
| 3  | 7                               | 10                                | 9                                        | 10                                | 4                                      | 6                         | 115             | 0.063            |
| 4  | 13                              | 2                                 | 28                                       | 2                                 | 2                                      | 6                         | 35              | 0.059            |
| 5  | 22                              | 21                                | 1                                        | 24                                | 6                                      | 12                        | 220             | 0.081            |
| 6  | 14                              | 6                                 | 18                                       | 7                                 | 2                                      | 2                         | 115             | 0.073            |

5.1. Test of the Rationality of the Prediction of Unidirectional S- Rough Sets

First of all, by using the rough law generation model of component failure rate, the failure rate of fluctuation range value, as shown in Figure 1, can be forecasted by the failure rate law \( p(t) \) per line in Table I, which is compared with the actual values in Table 1 of transmission line.

Figure 1. Line failure rate forecast by the S-rough law range

As can be seen from Figure 1 and Table 1, the actual values of transmission line failure rate are within the range of the upper and lower failure rate, which is calculated by the one directional S-rough law. It confirms the rationality of transmission line failure rate.

5.2. Prediction of Line Failure Rate in 2015

The weather data is forecast in 2015, according to the normal sampling method and the historical weather samples as shown in figure 2. Thus, it can get the attribute values \( X = (3.8762, 2.7338, 10.5329, 28.386, 5, 10, 220) \), where the non-weather data sets the average value.
5.3. Impact Analysis of the Reliability Parameters under Different Weather

It can get the energy law $w$ and interference value $\rho$, because of influence of dynamic climate factors, considering the role of a combination of factors, selecting four kinds climatic factors tested, and using F-decomposition law to analyze transmission line failure rate under different weather. Analysis of the impact of weather on the transmission line failure rate is listed in Table II, according to the $w$ and $\rho$. In order to analyze the influence degree of various factors, it sets the following 6 kinds of situation reliability assessment.

Where:

$a = \{a_1, \text{The storm weather}, a_2, \text{The heavy rain weather}, a_3, \text{The ice and snow}, a_4, \text{The high temperature weather}, a_5, \text{The foundation}, a_6, \text{The production time}, a_7, \text{The voltage grade}\}$

case1: $a_{case1} = \{a_1, a_2, a_3, a_4, a_5, a_6, a_7\}$
case2: $a_{case2} = \{a_1, a_2, a_6, a_7\}$
case3: $a_{case3} = \{a_1, a_3, a_6, a_7\}$
case4: $a_{case4} = \{a_2, a_3, a_6, a_7\}$
case5: $a_{case5} = \{a_1, a_2, a_6, a_7\}$
case6: $a_{case6} = \{a_2, a_3, a_6, a_7\}$

| Case | Line failure rate | The law energy | The interference degree |
|------|------------------|----------------|------------------------|
| Case1| [0.0612, 0.0731] | 0.15913        | 0.1953                 |
| Case2| [0.0515, 0.0568] | 0.03733        | 0.1857                 |
| Case3| [0.0624, 0.0674] | 0.03356        | 0.1922                 |
| Case4| [0.0598, 0.0546] | 0.03754        | 0.1874                 |
| Case5| [0.0576, 0.0524] | 0.03657        | 0.1859                 |
| Case6| [0.0456, 0.0507] | 0.03549        | --                     |

As shown in Table 2, the influence of Frost factor is the most important for reliability parameters. The second is Heavy rains factor, and the third is High temperature factor and the Storm factor. As shown from the interference degree, it is a result of the combined action of many kinds of weather factors, not the sum total of the single factors, when four kinds of climate factors are working together. As shown from the law energy, the less important the influence factors and the smaller the energy laws.
Then performance of transmission line is better. The smaller reliability parameter estimation range, the more accurate reliability parameters.

6. Conclusion

The proposed method is applied to analysis example to do reliability parameter estimation. The following conclusions are obtained: (1) the one directional singular rough set can reasonably predict transmission line failure rate based on weather uncertainty. (2) The law energy and the interference degree reflect the influence of the component reliability parameters under the weather factors. So taking corresponding measures, it improve system reliability and the ability to cope with adverse weather.

This paper presents reliability parameter estimation method based on the one directional singular rough set theory in different weather. The one directional S-rough law analyzes line failure rate and weather uncertainty. The F- decomposition law analyzes impact of weather on reliability parameter. So reliability parameter uncertainty has the certainty measurement. When the one directional singular rough set theory dealing with the uncertainty of transmission system reliability parameters, it just needs simple weather days. Thus, it obtains reliability parameter based on objective data, eradicating the effect of subjective factor. The evaluation results are more objective.

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7. References

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