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| **ARTICLE TYPE** |  |

***A Study on the Evaluation Method for the Operating Status of Overhead Transmission Lines Based on Analytic Hierarchy Process (AHP)***

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| 1School Of Electric Power,  Shenyang Institute of Engineering ,  Liaoning, Shenyang 110136  2State Grid Liaoning Electric Power Co., LTD. UHV Branch,  Liaoning, Shenyang 110155  3Grid Liaoning Electric Power Co., Liaoyang Branch,  Liaoning,Shenyang 111000  **Correspondence**  \*WANG Liang,School Of Electric Power,Shenyang Engineering Institute, Shenyang 110136, Liaoning Province  Email: [2253755887@qq.com](mailto:authorone@gmail.com) | **Abstract**  To address the difficulty of dynamically assessing overhead transmission lines under varying meteorological conditions through manual inspections and drone monitoring, this study proposes an evaluation method for the operating status of overhead transmission lines based on the Analytic Hierarchy Process (AHP). A mathematical model based on AHP is first established to perform weighted processing of five meteorological factors, generating a comprehensive meteorological dataset. A simulation model for the LGJ-300/70 type conductor is then developed under the temperature field, where temperature distribution during operation is determined based on different meteorological data. Stress variations are observed, and evaluation criteria are established by calculating displacement deviations in the two-dimensional transmission line model. The transmission line is considered to be in a normal operating state when the maximum displacement deviation is ≤ ±0.63 mm. This demonstrates that the AHP-based evaluation method can effectively enable dynamic assessment of the operating status of overhead transmission lines.  **KEYWORDS**  dynamically assessing, Analytic Hierarchy Process ,temperature field,transmission lines |

# Introduction

As a crucial component of the power system, the operating status of transmission lines significantly affects the safety and stability of power system operations. In recent years, frequent natural disasters in China, particularly severe icing events, have had a serious impact on the safe operation of the power grid, affecting both southern and northern regions. Given that the power grid is a vital safeguard for the livelihoods of citizens, its safe and reliable operation is of utmost importance. Therefore, research on methods for assessing the operating status of transmission lines is critical for ensuring the continuous operation of the power grid and supporting the sustainable development of the national economy.

In recent years, several approaches have been proposed for assessing the operating status of transmission lines, primarily involving proportional risk models. Reference [1] constructed a system of key parameters for status assessment based on guidelines for status evaluation, taking into account the actual operating years of the transmission lines and the intervals between maintenance. This approach generates equivalent operating time input characteristics for status assessment; however, it relies on a relatively singular basis for evaluation, resulting in certain deviations in the assessment outcomes. Reference [2] utilized Bayesian network methods for the status assessment of multiple transmission lines, mining operational data to achieve effective evaluations, which facilitates the early understanding of transmission line operating conditions. However, the simplicity of Bayesian network calculations primarily focuses on the analysis and study of uncertain factors, making it unsuitable for evaluating the operating status of key parameters of transmission lines under different climatic and environmental conditions, thus leading to an overly simplistic assessment framework. Reference [3] employed big data analysis techniques for transmission lines, utilizing factor analysis to extract relevant parameters and construct a framework. By calculating the failure rate of key parameters using a relative degradation method and combining it with the Analytic Hierarchy Process (AHP) to determine the importance weights among different levels, this method addresses the impact of key parameters on failure rates. However, it does not provide specific evaluation indicators and lacks consideration of comprehensive metrics. Reference [4] conducted simulations of transmission lines using ANSYS, but the construction of the temperature field was limited, failing to comprehensively consider the effects of other meteorological factors on the operational status of transmission lines.

When assessing the operating status of transmission lines, it is essential to consider the timeliness of their operational state, specifically the real-time monitoring of transmission line operations. Currently, there are two primary methods for this purpose. The first method involves using aerial devices such as drones for real-time video monitoring. This approach transmits images captured by drones to an online platform for continuous monitoring. However, it has limitations in timeliness, as operational inspectors must constantly monitor the video feed for movements and changes. The second method utilizes electronic devices or sensor data collection, selecting various types of sensors to gather real-time data on the components of transmission lines for comprehensive evaluation. While this method offers a relatively complete assessment standard, it produces a large volume of data, resulting in poor operational feasibility. In addition to the Joule heating generated by the current flowing through overhead transmission lines, their operational status is also influenced by external meteorological conditions such as temperature, humidity, wind speed, air pressure, and precipitation. To perform a real-time operational status assessment, it is necessary to consider the different impacts of these various elements.

In conclusion, there is significant potential for improvement in the assessment of the operational status of overhead transmission lines.

1. Evaluating and making decisions based solely on a single meteorological factor, while disregarding the influence of other factors, may result in evaluation outcomes that are not applicable under complex weather conditions.
2. Although factor analysis proves effective in processing key parameters, its application in the comprehensive analysis of meteorological influences remains limited. Moreover, an overemphasis on key parameters can lead to the neglect of the effects of integrated conditions.
3. In engineering challenges characterized by numerous influencing factors, the difficulty in defining evaluation metrics often results in insufficient comprehensive consideration of individual indicators.

Thus, there is an urgent need to adopt methodologies that enhance the comprehensiveness of influencing factors, approaching evaluation issues with a robust and integrated assessment framework.

To address these improvement areas, this study employs the Analytic Hierarchy Process (AHP) to analyze the weights of multiple influencing factors. The AHP leverages the strengths of both factor analysis and Bayesian networks, facilitating the uniform weighting of various factors under different coefficients for cohesive decision-making. As shown in Table 1, complex meteorological conditions are often associated with key influencing factors. Therefore, this study first gathers diverse meteorological data across different conditions, including external temperature, humidity, wind speed, air pressure, and precipitation. Through the AHP, the weights of these influencing factors are integrated to identify the most significant contributing factors.

**Table 1** Corresponding factors of complex weather

|  |  |
| --- | --- |
| **Complex weather** | **Main influencing factors** |
| **typhoon** | Wind speed, air pressure |
| **heavy snow** | Temperature, humidity, and wind speed |
| **hail** | Temperature, humidity |
| **ice rain** | Rainfall, temperature |

Subsequently, a two-dimensional finite element model of the overhead transmission line is developed using COMSOL, incorporating boundary conditions and temperature fields. Given that transmission lines are directly exposed to outdoor air, the flow of current generates Joule heating, while heat dissipation occurs, leading to energy exchange with the surrounding environment. The airflow contributes to heat loss through convective processes, enabling the determination of the radial temperature distribution of the overhead conductor under convective heat transfer conditions. The stress values of the overhead conductor at a specific current load are then calculated based on the real-time operating temperature. By comparing these calculated stress values with actual measurements, we can assess whether the stress variations remain within acceptable limits, thereby enabling real-time evaluation and early warning of the operational status of transmission lines.

# Analytic Hierarchy Process (AHP)

## Implementation Architecture of Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is essentially a decision-making approach that endows algorithms with the analytical, judgmental, and synthesizing characteristics of human thought. The implementation of AHP primarily consists of four steps.

In the first step, complex problems are hierarchically structured to establish a goal layer for the issues to be addressed. The goal layer represents the factor or element with the highest final weight and serves as the ultimate objective of the problem. Subsequently, the criterion and standard layers are refined, creating a hierarchical dominance relationship network from top to bottom. For overhead transmission lines, ice accumulation can be influenced by weather conditions such as hail, heavy snowfall, and freezing rain, with temperature being the primary meteorological factor. Therefore, temperature is designated as the final objective, and its dominance relationship network is illustrated in Figure 1.



**Figure 1** A dominant relationship network diagram

In the second step, a judgment matrix is constructed based on the relationship network. Comparative assessments are made between different indicators or influencing factors (Assuming there are 1,2,3,…,m influencing factors) to obtain relative importance data, thereby forming an m-order matrix:

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

Let denote the weight values in the judgment matrix, where （）The matrix A is an mm-order square matrix that represents the judgment matrix.

In the third step, the consistency of the judgment matrix is evaluated. If inconsistencies are detected, the maximum eigenvalue of matrix A is computed. The corresponding eigenvector  represents the ranking weights for each criterion layer.

In the fourth step, the judgment matrix is calculated row by row to obtain the weights of the corresponding factors. The factor with the highest weight is identified as the primary factor that has the greatest impact on the objective factor.

The Analytic Hierarchy Process (AHP) allows for the hierarchical structuring of complex problems, facilitating a comprehensive analysis of multiple influencing factors. It effectively addresses complex issues involving multiple criteria, various influencing factors, and multiple objectives in decision-making.

## Data Training

Before determining the weights of the temperature data, it is essential to configure the judgment matrix appropriately to ensure that the resulting temperature values closely align with actual conditions. The consistency of the judgment matrix reflects the coherence of human judgments throughout the decision-making process, and maintaining this consistency is crucial for making accurate decisions.However, due to the presence of various influencing factors within the judgment matrix, it is necessary to first rank the impact of these factors. When assigning values to multiple factors, different scaling methods are often employed. Common scaling methods include the triangular scale, the 1-9 scale, the 9/9-9/1 scale, and the 90/9-99/9 scale [11]. While the triangular scale ensures the order of elements, it lacks precision. The 9/9-9/1 scale and the 90/9-99/9 scale perform well in terms of weight fitting but exhibit poor scaling uniformity. In contrast, the 1-9 scale provides good scaling uniformity while maintaining order. This method involves pairwise comparisons among all elements in the current layer relative to a specific element in the previous layer, allowing for hierarchical ranking based on importance [6].Given that this study aims to evaluate the influence of various factors on overhead transmission lines, it is essential to consider these factors uniformly. Therefore, the 1-9 scale, which offers good scaling uniformity, was selected for the weight assignment of different factors, as outlined in the judgment matrix assignment standards shown in Table 2. This approach facilitates the construction of distinct judgment matrices.

**Table 2** 1-9 Scaling method determines the matrix assignment criteria

|  |  |
| --- | --- |
|  | **explain** |
| **1** | Both are equally important |
| **3** | The former is more important than the latter |
| **5** | The former is significantly more important than the latter |
| **7** | The former is strongly more important than the latter |
| **9** | The former is far more important than the latter |
| **2,4,6,8,** | The median of the judgment adjacent as described above |
| **Countdown to 1-9** | Represents the importance of the exchange order comparison of the corresponding quantity elements |

In the context of the complex meteorological conditions affecting transmission lines, the main influencing factors include temperature, wind speed, humidity, air pressure, and precipitation (arranged according to the five essential meteorological elements). Among these, temperature is recognized as the most significant factor, and its weight should be maximized. Based on the judgment matrix assignment standards, the resulting judgment matrix is as follows:

|  |  |  |
| --- | --- | --- |
|  |  | (2) |

Based on this judgment matrix, the five meteorological data factors were arranged in a matrix format, with pairwise comparisons conducted for each layer and each row. The resulting judgment matrix is presented in Table 3.

**Table 3** Judgment matrix assignment table

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **temperature** | **wind speed** | **humidity** | **pressure** | **precipitation** |
| **temperature** | 1 | 3 | 5 | 7 | 9 |
| **wind speed** | 1/3 | 1 | 3 | 5 | 7 |
| **humidity** | 1/5 | 1/3 | 1 | 3 | 5 |
| **pressure** | 1/7 | 1/5 | 1/3 | 1 | 3 |
| **precipitation** | 1/9 | 1/7 | 1/5 | 1/3 | 1 |

In the process of calculating weight values, the computation involves both row and column operations. Therefore, the axis function is utilized to define the coordinate axes, allowing for the resolution of different functions along the specified axis. The axis values vary based on the dimensions of the data: for one-dimensional data, the value is set to 0; for two-dimensional data, it can be either 0 or 1; and for three-dimensional data, the possible values are 0, 1, or 2. In this study, given that the data encompasses both temporal and spatial dimensions, the axis can take values of 0, 1, or 2. However, since the specific computations in this analysis only involve two-dimensional data, axis is set to 1.

## Weight Calculation

The weight calculation of the Analytic Hierarchy Process (AHP) requires the computation of the maximum eigenvalue of the judgment matrix. This study employs the 1-9 scale method. During the eigenvalue calculation process, the geometric mean method is utilized to determine the weight of each factor. This involves performing a product operation on the elements of the judgment matrix and then taking the m-th root，resulting in Equation (3):

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

The weights derived from Equation (3) are then sorted. The formula for calculating the sorting values is given by Equation (4):

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

Thus, the weights corresponding to different meteorological factors are obtained. The various meteorological factors are then combined based on these weights to calculate the weighted temperature required for this study.

# Construction of a Two-Dimensional Model for Transmission Lines in COMSOL

## Heat Conduction in Transmission Line Conductors

Heat Effects in Steel-Core Aluminum Stranded Conductors Due to Current Carrying Capacity,Steel-core aluminum stranded conductors generate thermal effects due to their own current carrying capacity. Under both natural and forced convection conditions, temperature variations occur. Additionally, there are varying gaps between the strands, which, when subjected to thermal effects, lead to thermal expansion and stress generation. However, since the thermal conductivity coefficients of steel and aluminum in the steel-core aluminum stranded conductors remain constant with temperature changes, we can assume that the gap between the steel core and the aluminum layer is negligible. Consequently, the two-dimensional heat conduction equation for steel-core aluminum stranded conductors can be established as Equation (5):

|  |  |  |
| --- | --- | --- |
|  |  | (5) |

Note:

is the thermal conductivity of the material;;

 is the temperature of the steel core;;

 represents the unit heat generation rate of the steel core and aluminum layer;

 is the position of the conductor at this time;

 is the material density;;

 is the specific heat capacity of the material;.

Overhead transmission lines consume a certain amount of energy while transmitting electrical power, resulting in thermal effects. The heat generated in the steel-core aluminum stranded conductors primarily consists of the heat produced under a specific current carrying capacity, as well as the heat generated due to external environmental influences.

1. The thermal effects of overhead transmission lines are as follows:

|  |  |  |
| --- | --- | --- |
|  |  | (6) |

1. Temperature changes under the influence of external environmental factors.

When external meteorological factors affect the transmission lines, considering variables such as temperature, humidity, atmospheric pressure, precipitation, and wind speed, the Analytic Hierarchy Process (AHP) is employed to rank the weight of each factor. After this ranking, the weighted values are recalculated to obtain a final weighted temperature, measured in degrees, which represents the external environmental temperature.For the heat dissipation of the conductor, both convective and radiative heat transfer effects are taken into account. The heating rate of the steel core is designated as, and the heating rate of the aluminum layer is designated as. The expression for this is:

|  |  |  |
| --- | --- | --- |
|  |  | (7) |

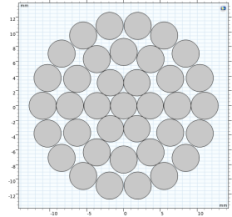
Whereis the amount of heat generated per unit time by the current passing through the material,;is the cross-sectional area of each material, andis a variable used in the analysis. Since the aluminum layer of the steel-core aluminum stranded conductor is exposed to the outside environment, the effects of solar radiation must be considered. Under normal circumstances, the solar radiation intensity is denoted as, typically around 1000 W/m². Therefore, the heating rate of the aluminum layer needs to be recalculated as follows:

|  |  |  |
| --- | --- | --- |
|  |  | (8) |

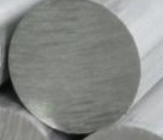
In the equation, is the amount of heat generated per unit time in the aluminum material due to the current,; is the outer diameter of the conductor, (which is the overall diameter of the wire), and is the absorption rate of the conductor when exposed to solar radiation;

## Simulation of Temperature Field in Overhead Transmission Lines Using COMSOL

Taking the overhead transmission line LGJ-150/35 as an example, the geometric parameters of the conductor are presented in the table. A two-dimensional geometry is created in COMSOL. When drawing a single cross-section, the circular cross-section is divided into four boundaries using a 90° span as the unit. Each node generates a temperature degree of freedom. The cross-section of the steel-core aluminum stranded wire is meshed according to a rotational geometric arrangement centered on the steel core, as shown in Figure 2, which serves as a reference for the actual cross-section of the overhead transmission line.



Cross-section geometry is equivalent



Steel materials

Aluminum materials

**Figure 2** Actual and geometric drawings of steel core aluminum stranded wire

Based on the operational control technology standards of the national power grid, as shown in Table 4, a two-dimensional geometric model is constructed.

**Table 4**  Geometric parameters of steel-core aluminum stranded wire

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **nominal cross** | **structure** | | **Calculate the section** | | |
| **Aluminum layer/mm** | **steel core /mm** | **Aluminum layer/** | **steel core /** | **amount to/** |
| 150/35 | 30/2.50 | 7/2.50 | 147.26 | 34.36 | 181.62 |

### Material Selection and Coupled Field Addition in COMSOL

According to the specifications of GB/T 17048-1997 "Hard Aluminum Wire for Overhead Stranded Conductors" and GB 3428-2002 "Galvanized Steel Wire for Overhead Stranded Conductors," the materials for the steel-core aluminum stranded wire are selected. The seven internal steel cores are chosen from the built-in galvanized steel material in COMSOL, while the outer layer consisting of thirty aluminum strands is selected from the built-in aluminum material. The detailed properties of the two materials are presented in Table 5:

**Table 5** Material parameter settings

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **attribute** | **thermal expansivity** | | **thermal conductivity W/(m)** | | **conductivity；** | | **relative dielectric constant** | |
| **material** | **steel** | **aluminum** | **steel** | **aluminum** | **steel** | **aluminum** | **steel** | **aluminum** |
| price |  |  | 45 | 228 |  | 35.4 | 10 | 1.5 |

After defining the materials for the two-dimensional cross-section of the overhead transmission line, temperature fields are applied based on the boundary conditions. The scope of the temperature field applies to all domains within which the transmission line is located. In a steady-state solving environment, the computational conditions for the temperature field acting on the transmission line are as follows:

|  |  |  |
| --- | --- | --- |
|  |  | (9) |

In the equation, represents the density of the medium,;  denotes the specific heat capacity of the medium, ;is the flow velocity of the medium in the two-dimensional coordinates,;is the heat source density load,;andis the temperature function within the two-dimensional coordinates,;

For each strand of the steel-core aluminum stranded wire, thermal insulation is set at the boundaries between the twisted materials. Considering that different materials may undergo deformation during the twisting process, a hypothetical equation is established for the boundary conditions to prevent heat conduction between the conductor materials. Thus, the heat equation is formulated as shown in Equation (10):

|  |  |  |
| --- | --- | --- |
|  |  | (10) |

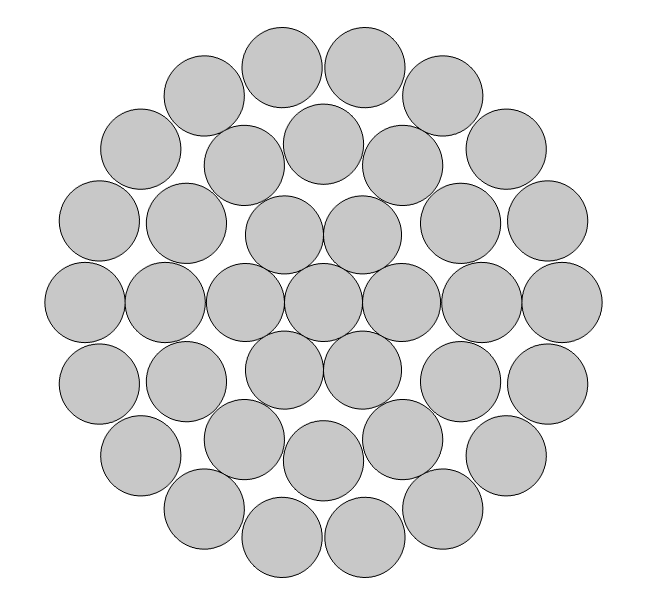
Combining Equation (10), the out-of-plane heat flux for the domain is hypothesized and calculated. The overall out-of-plane heat flux is defined as the algebraic sum of the inward heat flux on the upper side and the inward heat flux on the lower side. Let the inward heat flux on the upper side be denoted as and the inward heat flux on the lower side as  . The total out-of-plane heat flux is expressed in Equation (11):

|  |  |  |
| --- | --- | --- |
|  |  | (11) |

represents the heat exchanged between the solid surfaces (upper and lower sides) and the fluid per unit area over a unit time (heat flux density),; and  are the fluid temperatures at the solid surfaces,;specifically the upper and lower sides, respectively.  and denote the convective heat transfer coefficients for the upper and lower sides,.

Assuming the medium surrounding the outdoor transmission line is air, which generates natural convection, the above equation can be computed in COMSOL to obtain the overall temperature distribution in the two-dimensional temperature field. The two-dimensional temperature distribution diagram is shown in Figure 3. Since the steel-core aluminum stranded wire experiences energy flow under exposed conditions, it is necessary to additionally incorporate a solid heat transfer field.

**Heat of the wire itself**



**heat convection**

**natural convection**

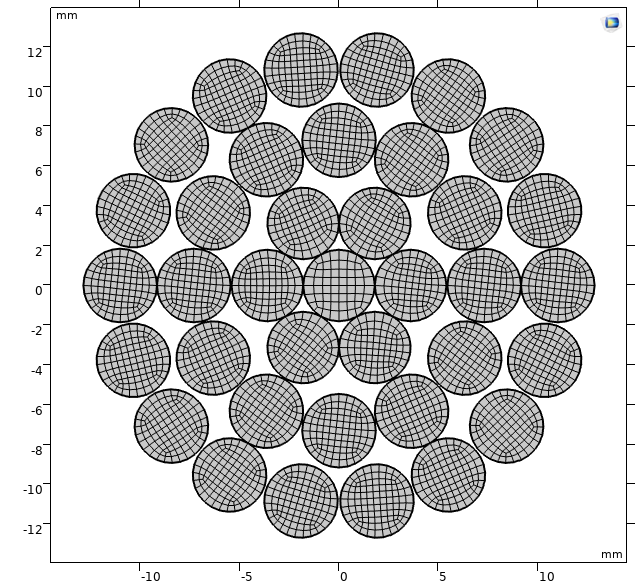
**Figure 3** 2-dimensional temperature guide diagram

### Mesh Generation and Study Configuration

Mesh generation is a crucial step in the multiphysics simulation process. Overall mesh generation primarily includes default settings for partitioning (triangular mesh generation) and mesh size function partitioning. The number of mesh elements significantly affects the computation time; as the number of elements increases, the computation time and the number of iterations also increase. Mesh density is related to the features of the structure being partitioned, with different mesh densities required for areas of significant curvature compared to flat, smooth regions.

A fundamental principle of mesh generation is that the physical field within an individual element should not experience drastic changes or large disturbances. Commonly used mesh generation methods include triangular and quadrilateral mesh partitioning. Triangular meshes are often employed for long stress and constant strain elements in the meshing of three-dimensional geometries, while quadrilateral meshes are typically used for highly stressed and strained elements, particularly in two-dimensional plane divisions. Therefore, a quadrilateral mesh is utilized for the two-dimensional plane of the steel-core aluminum stranded wire in this study.

When performing quadrilateral mesh generation for the transmission line plane, the mesh is divided using millimeters as the unit. The maximum cell size is set to 0.514 mm, while the minimum cell size is set to 0.00193 mm. The growth rate within the range of maximum and minimum cell sizes is set to 1.2, and the curvature factor is set to 0.25. The resulting two-dimensional mesh partitioning diagram of the steel-core aluminum stranded wire is shown in Figure 4.



**Figure 4** Grid division of steel-core aluminum strands

When solving the temperature field of overhead transmission lines, the model obtained does not represent a sudden change at a specific moment; rather, it is a steady-state model under stable conditions. In the research process, a steady-state approach is selected, incorporating electrical current, solid mechanics, and solid and fluid heat transfer as the physical field interfaces.

# Case Study Simulation Analysis

This study employs the Analytic Hierarchy Process (AHP) to rank the weights of the five meteorological elements and perform weighted calculations. Ultimately, the weights of the meteorological conditions—temperature, wind speed, humidity, atmospheric pressure, and precipitation—are determined, resulting in a weighted temperature based on temperature as the reference. This weighted temperature is then used as the input for the environmental temperature in the COMSOL simulation. By observing the stress variation contour maps of the transmission line under different temperature inputs and utilizing the state assessment criteria provided in this paper, the operational status of the transmission line can be evaluated, leading to a more accurate assessment result.

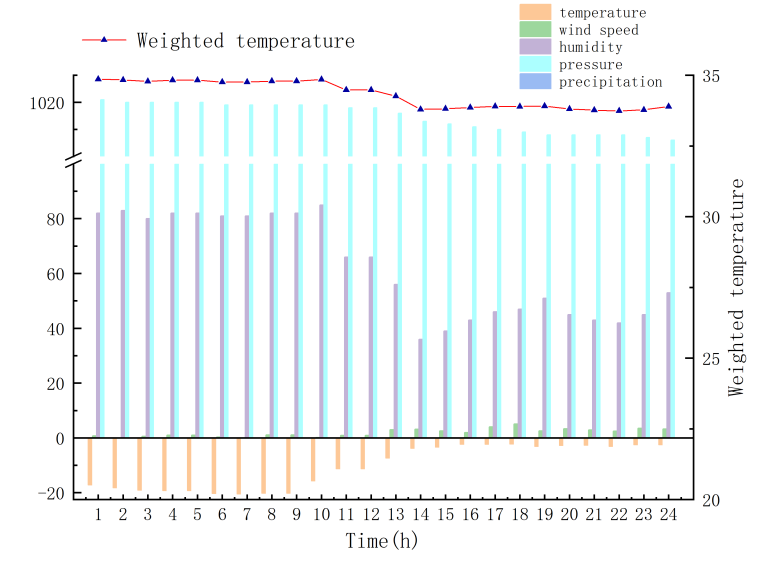
## Input Data Computational Model

The previous section has established a suitably matched judgment matrix through data training. Based on this judgment matrix, a computational model has been developed as illustrated in the figure 5.



**Figure 5** Computational Model

By integrating meteorological data, hourly weather data from February 10 in Shenbei New District, Shenyang, Liaoning Province, was selected. This dataset includes five meteorological factors: temperature, wind speed, humidity, atmospheric pressure, and precipitation. A judgment matrix was constructed through weighting, consolidating the meteorological characteristics of these five factors into a temperature-based metric for data output. The weighted data values are presented in Figure 6.

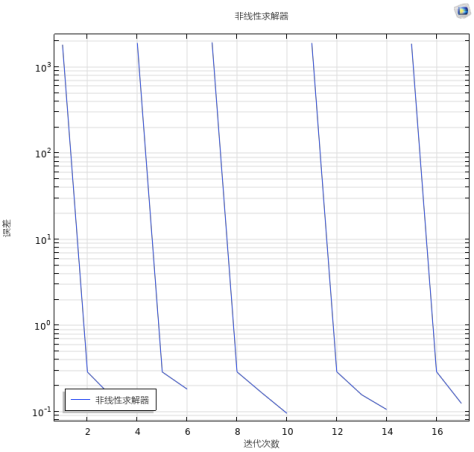


**Figure 6** Weighted processing of meteorological data

The difference between the weighted temperature and the actual temperature at this point lies in the fact that the weighted temperature serves merely as a dimensional input into the COMSOL 2D model, allowing for the observation of variations in stress.

## Stress and temperature changes at different input temperatures

Different weighted temperatures were input into COMSOL for computation to determine the stress variation corresponding to each weighted temperature. Based on the stress variation diagrams, the operational status of the transmission line can be assessed. During the calculation process, since a nonlinear solver was selected, there were jumps in the starting position of each iteration in the convergence graph. However, each iteration ultimately returned to the normal accuracy range (1-0.1). The convergence graph for the calculations is shown in Figure 7.



**Figure 7** calculates the convergence and scatter plot

Based on the image comparison, the weighted temperature data was input into COMSOL to calculate the temperature field, resulting in the stress distribution diagram for the two-dimensional cross-section of the overhead transmission line, as shown in Figure 8. The stress cross-section diagrams for Group 1 and Group 2 showed no changes. Under the given weighted temperature, the corresponding temperature, wind speed, and atmospheric pressure remained relatively stable, indicating a stable operational state for the transmission line.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **number** | **Weighted temperature** | **variation of stresses** | **number** | **Weighted temperature** | **variation of stresses** |
| 1 | 34.86213206 |  | 13 | 34.25867175 |  |
| 2 | 34.83747556 |  | 14 | 33.79407746 |  |
| 3 | 34.78266984 |  | 15 | 33.81442921 |  |
| 4 | 34.82382921 |  | 16 | 33.85599238 |  |
| 5 | 34.82382921 |  | 17 | 33.90016571 |  |
| 6 | 34.7619746 |  | 18 | 33.89627556 |  |
| 7 | 34.75845397 |  | 19 | 33.91363492 |  |
| 8 | 34.78888063 |  | 20 | 33.80778921 |  |
| 9 | 34.78888063 |  | 21 | 33.76533714 |  |
| 10 | 34.85374921 |  | 22 | 33.74109968 |  |
| 11 | 34.48109079 |  | 23 | 33.77713016 |  |
| 12 | 34.48109079 |  | 24 | 33.89512635 |  |

**Figure 8** Stress change diagram at different temperatures

In the stress cross-section diagrams for Groups 3 to 9, deviations in stress were observed in certain aluminum layers, showing some discrepancies from the original stress positions. Notably, Groups 4, 5, and 8 exhibited significant stress variations under changing wind speeds. Groups 10, 13, 15, and 18 displayed more pronounced stress changes; however, no abnormal phenomena were observed. The main reason for this was the significant fluctuations in wind speed due to temperature variations, which caused the stranded conductors to sway and undergo slight deformation.

According to the Operating Code for Overhead Transmission Lines of the People's Republic of China Electrical Industry Standard, when calculating the damage cross-section of aluminum stranded conductors, the total cross-sectional area of the conductors is used as the base for the calculations. For transmission lines at 220 kV and above, the phase-to-phase relative distance is 300 mm. When calculating the sag, the operational temperature data obtained through weighted temperatures is utilized; during this calculation, the effects of current and solar radiation can be disregarded.

Considering the above factors, the operational status of the transmission line is classified into three levels—Good, Normal, and Dangerous—based on the number of different materials showing changes in the stress variation diagrams. When one conductor within a closed cross-section experiences a change, it will exert pressure on the surrounding conductors, causing stress changes that may be absorbed by the gaps. However, if two conductors undergo stress changes, they will reach a critical state, inevitably leading to stress changes in a third conductor. If stress changes occur in the steel core, the transmission line will certainly be in a dangerous state.

The evaluation criteria are shown in Table 6. Groups 10, 13, 15, and 18 were selected for temperature calculations to derive the temperature distribution diagram, resulting in Table 8 as shown below:

**Table 6**  Status assessment criteria

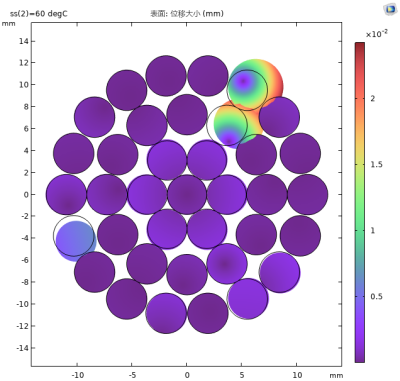
|  |  |  |
| --- | --- | --- |
| **order number** | **assessment criteria** | **Run status level** |
| 1 | In the stress change chart, the number of aluminum layer stress changes is less than or equal to 2 shares, in harmony with the temperature distribution chart | good |
| 2 | The number of aluminum layer stress changes is between 3 and 5, and is consistent with the temperature distribution diagram. | normal |
| 3 | The aluminum layer experiences significant stress changes, the steel core shows stress displacement, and this is inconsistent with the temperature distribution diagram. | danger |

**Table 7** Table corresponding to temperature distribution and stress changes

|  |  |  |  |
| --- | --- | --- | --- |
| **group number** | **Weighted temperature** | **Stress change diagram** | **Temperature distribution diagram** |
| 10 | 34.85374921 |  |  |
| 13 | 34.25867175 |  |  |
| 15 | 33.81442921 |  |  |
| 18 | 33.89627556 |  |  |

According to the data presented in the table, significant temperature variations are indicated by an orange color, which correspond to observable stress changes in the aluminum layer. These changes manifest as deformed circles, larger displacement circles, or overlapping circles. In real-world applications, this group reflects a stable operational state of the transmission line, indicating no faults present. Consequently, this model can serve as an effective evaluation tool for assessing the operational status of transmission lines.

To improve the authenticity of the results, stress displacement data were derived from the aluminum stranded conductor when stress changes occurred. This process yielded displacement change data for each coordinate in the two-dimensional cross-section of the transmission line. Using Origin software, a three-dimensional representation of these data was created, allowing for a clear visualization of the degree and location of stress changes. As an illustration, displacement data corresponding to a weighted temperature of 34.85374921 is presented in Figure 9 below:



**Figure 9** shift plot at weighted temperature 34.85374921

Based on the derived displacement change data, displacement values for each point in the two-dimensional cross-section were obtained. These data were then imported into Origin for three-dimensional data visualization. The resulting three-dimensional image, shown in Figure 10, illustrates the displacement behavior of each conductor in the transmission line.

|  |  |
| --- | --- |
|  |  |
| 1. 3 D scatter plot | (b) 3D surface diagram |

**Figure 10** shows the 3 D images of the shifted data

At this point, the three aluminum conductors exhibited displacement changes, with the maximum recorded displacement reaching 0.09265 mm. The operational status of the transmission line is considered normal under these conditions. For steel-core aluminum stranded wires operating at voltage levels of 220 kV and above, the allowable stress deviation is ±2.5%. The nominal outer diameter deviation for the LGJ-300/70 conductor is ±0.63 mm. Therefore, as long as the maximum displacement deviation does not exceed ±0.63 mm, the line is deemed to be in a normal operational state. The evaluation criteria for this status have been detailed in Table 8 below:

**Table 8** Improvement criteria for status assessment

|  |  |  |  |
| --- | --- | --- | --- |
| **order number** | **assessment criteria** | **The displacement deviation amount** | **Run status level** |
| 1 | In the stress variation diagram, the number of aluminum layers exhibiting stress changes is limited to a maximum of two strands, which aligns harmoniously with the temperature distribution map. | ≤±0.63mm | good |
| 2 | In the stress variation diagram, the number of aluminum strands exhibiting stress changes is between three and five, which is consistent with the temperature distribution map. | ≤±0.63mm | normal |
| 3 | The aluminum layer exhibits significant stress variation, and the steel core shows stress displacement, which is inconsistent with the temperature distribution map. | ＞±0.63mm | danger |

## Case Status Assessment

Based on the stress variation and temperature distribution maps of 24 model groups in Shenbei New District, Shenyang, Liaoning Province, on February 10, 2023, an overall assessment of the operating status of the transmission line was conducted. The evaluation results are categorized into three levels: Good, Normal, and Dangerous, as summarized in the table 9:

**Table 9**  Operation status assessment of 24 transmission line in Shenbei New Area on February 10th

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **group number** | **variation of stresses** | **The displacement change amount(mm)** | **State assessment** | **group number** | **variation of stresses** | **The displacement change amount(mm)** | **State assessment** |
| **1** | / | 0.01121 | good | **13** | aluminium steel \*2 | 0.00738 | normal |
| **2** | / | 0.00531 | good | **14** | aluminium steel \*1 | 0.00662 | normal |
| **3** | aluminium steel \*1 | 0.01186 | normal | **15** | aluminium steel \*2 | 0.07507 | normal |
| **4** | aluminium steel \*1 | 0.00731 | normal | **16** | aluminium steel \*1 | 0.04541 | normal |
| **5** | aluminium steel \*1 | 0.00731 | normal | **17** | aluminium steel \*1 | 0.00649 | normal |
| **6** | aluminium steel \*1 | 0.03292 | normal | **18** | aluminium steel \*2 | 0.18569 | normal |
| **7** | aluminium steel \*1 | 0.00531 | normal | **19** | / | 0.08698 | good |
| **8** | aluminium steel \*1 | 0.01233 | normal | **20** | aluminium steel \*2 | 0.05016 | normal |
| **9** | aluminium steel \*1 | 0.03990 | normal | **21** | aluminium steel \*2 | 0.00809 | normal |
| **10** | aluminium steel \*3 | 0.09265 | normal | **22** | aluminium steel \*2 | 0.05436 | normal |
| **11** | / | 0.00439 | good | **23** | aluminium steel \*1 | 0.01046 | normal |
| **12** | / | 0.00439 | good | **24** | aluminium steel \*1 | 0.02739 | normal |

On February 10, 2024, there were no operational faults detected in the transmission lines in Shenbei New District, Shenyang, Liaoning Province, which aligns with the simulation results. Therefore, the assessment results of this model are deemed valid.

# Conclusion

1. In terms of algorithm application, the Analytic Hierarchy Process (AHP) employed in this study allows for the weighted recombination of five meteorological factors to generate a new parameter based on temperature, which serves as the input temperature for the simulation model. In the horizontal weighting calculation, the weighted value of temperature is 0.357. The weighted temperature value may deviate slightly from the actual temperature. However, as wind speed and precipitation vary, the output of the temperature parameter will exhibit minor fluctuations, which do not affect the usability of the weighted temperature value.
2. Regarding the modeling of the simulation, this paper conducts a simulation model for the overhead transmission line using LGJ-300/70 aluminum conductor with steel core. The grid division employs quadrilateral elements with an ultra-fine precision, resulting in a computation time of 17 seconds. As the grid becomes coarser, the computation time decreases, but the accuracy of the calculations also diminishes.
3. In the comparison of results, this study effectively addresses the five factors influencing the operational status of transmission lines (temperature, wind speed, humidity, atmospheric pressure, and precipitation) using the Analytic Hierarchy Process. Through COMSOL simulations, an evaluation method is constructed to compare and analyze stress variations. When compared with the actual operational status, the results are found to be quite accurate, indicating that the evaluation method is valid.

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