Construction of Dynamic Weights in State Degradation of AC Contactor

Jin Li¹, Ersheng Tian², Yanfeng Li³, Shuxin Liu³*, Lei Hou¹, Guodong Zhu², Yang Su¹

¹State Grid Xiong'an New Area Electric Power Supply Company, Baoding, Hebei, 71600, China
²Xuji Group Corporation, Xuchang, Henan, 461000, China
³Institute of Electrical Apparatus New Technology and Application, Shenyang University of Technology, Shenyang, Liaoning, 110870, China

*Corresponding author’s e-mail: liushuxin@sut.edu.cn

Abstract. AC contactor needs to break the main circuit and control circuit frequently in the process of operation. With the accumulation of electrical stress and other losses, AC contactor will fail, causing accidents and huge losses. The whole life model of AC contactor is designed to objectively reflect the state information during the operation of AC contactor and predict the end time of the electric life of the contactor, so as to ensure the safe and reliable operation of the power system. The whole life test of AC contactor was carried out under the test condition of AC-4, and the parameters of the whole life model were obtained from the test data. In order to accurately reflect the influence degree of each characteristic parameter on the life during the whole degradation process, the general constant weight evaluation model was optimized. The results show that the evaluation model with dynamic weight is better than that with constant weight.

1. Introduction
In recent years, combined with the introduction of smart grids, people have put forward higher requirements for the reliability of power system facilities. AC contactor is a representative low-voltage electrical appliance in power control, and its performance will directly affect the quality of power system operation [1]. As the number of contact breaks accumulates, the arc erosion and other factors gradually increase the electrical erosion of the contacts. When the overtravel, contact pressure and contact area are reduced to a critical value, the value of the contact resistance will continue to increase until the end of the contactor life.

At present, scholars focus on the following aspects of the dynamic performance analysis and evaluation of switchgear: Junfeng Li [2] analyzed the contact bounce phenomenon in the dynamic response process of the contactor, and studied the measures to reduce its bounce. Bingtao Qiu [3] and others found that it is necessary to introduce the parameters related to vibration signals and the evaluation of the life of the contactor. Zhiyuan Wei [4] verified the failure of the AC contactor of the high-speed motor car to meet the Weibull distribution law, and established the reliability evaluation model of the contactor of this model. Nan Jiang [5] obtained the functional relationship between the
second-order input tensor and the residual electrical life composed of cumulative arc energy and pull-in
time based on BP neural network.

This paper will take AC contactor as an example to study. By extracting the characteristic parameters
reflecting its running state, the relationship between many electrical characteristic parameters and life is
reasonably and accurately reflected, and a more real variable weight model is established to evaluate the
factors affecting the electrical life of contactors, so as to prepare for the establishment of a more
complete AC contactor life model.

2. Establishment process of dynamic weight model

2.1 Construction of AC contactor life test system

This test system combines NI data acquisition cards with Labview virtual instrumentation technology
with sample rates up to 1.25M/s per channel. This test uses AC-4 test conditions to conduct a full life
test on the CJX2-8011 AC contactor. The system monitors and stores the current and voltage signals of
the AC contactor coil and the current and voltage signals of the three-phase contacts in real time. A large
amount of waveform data is obtained by performing a life test on the AC contactor.

| Test condition category       | Specific test conditions | Test condition category       | Specific test conditions |
|-------------------------------|--------------------------|-------------------------------|--------------------------|
| Coil voltage (V)              | AC220                    | Work system                   | AC-4                     |
| Load voltage (V)              | 400(380)                 | Load current (A)              | 222                      |
| Load type                     | Resistor-inductive load  | Power factor                  | 0.35                     |
| Operating frequency (time / h)| 300                      | Sampling frequency (Hz)       | 1M                       |
2.2 Selection of characteristic parameters of AC contactor

The key to analyze the degradation law of contact material is to find the characteristic parameters that characterize the electrical life state of ac contactor. These characteristic parameters can reflect the important characteristics of the working state of ac contactor. With the extension of test time, there is a certain trend change, which is convenient for subsequent analysis. In this paper, contact resistance, release time, bounce time and response time are selected as characteristic parameters.

2.3 Determination of dynamic weight

In this paper, analytic hierarchy process (AHP) and extension theory are used to calculate the dynamic weight coefficients of each characteristic parameter.

2.3.1 Determination of weight set

Assume that there are 4 influencing factors, the set of factors is \( P = \{p_1, p_2, p_3, p_4\} \). All possible outcomes constitute a judging set \( J = \{j_1, j_2, \ldots, j_m\} \). The weight of each feature parameter is different. It is necessary to adopt an appropriate weight determination method, and the weight set of the evaluation object factor is recorded as

\[
W = \{w_1, w_2, w_3, w_4\}, \quad \text{and} \quad w_i \in [0,1], \sum_{i=1}^{n} w_i = 1
\]  

(1)

In the above formula, \( w_1 \) is the weight value of the contact resistance, \( w_2 \) is the weight value of the release time, \( w_3 \) is the weight value of the bounce time, and \( w_4 \) is the weight value of the response time. For the fuzzy relation matrix \( R \), the corresponding membership function needs to be established to establish the fuzzy relation matrix. According to the weight set \( W \) and the fuzzy relation matrix \( R \) determined above, the comprehensive evaluation result of the evaluation object is finally obtained.

2.3.2 Determine the subjective weight by analytic hierarchy process

The AHP is used to calculate the subjective weights, and the importance of the characteristic parameters and the impact on the degradation process are compared.

Using the principle of analytic hierarchy process, each level of indicators affects the importance of an indicator in the upper layer. Let \( n \) indicators under a certain indicator be expressed as \( A_1, A_2, \ldots, A_n \), \( a_j \) is the ratio of the importance of \( A_i \) and \( A_j \) to the secondary indicator.

Assuming that the weights of the factors in factor \( W = \{w_1, w_2, \ldots, w_n\} \) are studied, the comparison matrix \( C \) needs to be constructed by a pairwise comparison method. Where \( C = (w_{ij})_{n \times n} \), \( w_{ij} \) represents the importance of the ith factor compared to the jth factor, using integers 1 through 9 and its reciprocal as the scale. The scale value table is not listed due to space limitations.

The eigenvectors and eigenvalues of the judgment matrix \( C \) are calculated, and the eigenvector \( W \) corresponding to the maximum \( \lambda_{max} \) of the eigenvalues is obtained.

When constructing the judgment matrix, it is necessary to relatively objectively judge the relative importance of each feature parameter and the consistency of the entire matrix. The consistency agreement \( RI \) is calculated using the consistency indicators \( CI \) and \( RI \) for consistency analysis.

\[
CI = \frac{\lambda_{max} - n}{n - 1}
\]  

(2)

\[
CR = \frac{CI}{RI}
\]  

(3)

If the matrix \( C \) satisfies the consistency test, then each element of the matrix eigenvector is the weight of each factor indicator.

2.3.3 Determine the objective weight by extension theory

In order to make the weight value more realistic, this part introduces a dynamic weight algorithm based on extenics to perform weighting on feature parameters.
The matter element is the basic element describing the thing in extenics. It is expressed by $R=[T, q, V]$, where $T$ is the life condition, $q$ is the characteristic parameter of the contactor that affects the life, and $V$ is the value of $T$ about $q$.

The evaluation object is divided into $I$ levels, and there are $m$ to be weighted feature parameters. The matter of the $j$th grade $T_j$ is as follows:

$$R_j = (T_j, q, V) = \begin{bmatrix} T_j & U_1 & v_{1j} \\ U_2 & v_{2j} \\ \vdots & \vdots \\ U_m & v_{mj} \end{bmatrix}$$

(4)

Combining the two-two comparison judgment matrix, where $v$ represents the range of values of the $i$-th evaluation factor in $T_j$, and the classical domain $R$ including four evaluation levels (good, normal, caution, warning) should be:

$$R_i = (v_i)_{i=1}^4 = \begin{bmatrix} \frac{95.100}{<95.100> <55.95> <20.55> <0.20> \\ \vdots \\ \frac{95.100}{<95.100> <55.95> <20.55> <0.20> \end{bmatrix}$$

(5)

In the table, $q_1$ is the contact resistance, $q_2$ is the release time, $q_3$ is the bounce time, and $q_4$ is the response time. The evaluation of the life rating, the evaluation interval, and the median value of the interval are shown in the table below.

| Evaluation mark | $T_1$ | $T_2$ | $T_3$ | $T_4$ |
|-----------------|-------|-------|-------|-------|
| Evaluation interval | [95, 100) | [55, 95) | [20, 55) | [0, 20) |
| Intermediate value of the interval | 98 | 75 | 38 | 10 |
| Evaluation levels | Warning | Caution | Normal | Good |

The intermediate value vector $M$ is:

$$M = (98 \ 75 \ 38 \ 10)^T$$

(6)

Multiplying the evaluation set $R$, by the vector $M$ to obtain a quantized result $v_i$.

3. Analysis of weight calculation results

In this paper, the subjective weight coefficient calculated by AHP based on the expert survey method is $W$, and the objective dynamic weight coefficient obtained by the extenics theory is $V$. Then the empirical factor $\rho$ is used to combine the two to construct the comprehensive weight:

$$AW = \rho W + (1-\rho)V$$

(7)

The value of the empirical factor $\rho$ depends on the level of experience of the expert. If the expert’s credibility is higher, the value can be larger. At this time, the weight coefficient is affected by subjective factors, otherwise, vice versa. The empirical factor $\rho$ in this paper is 0.5.

Calculate the subjective weight of each indicator as $W = (0.5312, 0.1856, 0.1856, 0.0976)$, and $CR=0.0018$ is calculated, so the judgment matrix passes the consistency test. The objective weight of each indicator as $V = (0.2902, 0.2408, 0.2410, 0.2280)$. The weight set $AW$ and the fuzzy relation matrix $F$ are combined by the fuzzy operator to obtain the final evaluation result, and $DW = AW \circ F$ is obtained.

In this paper, the model $M(\bullet, \Theta)$ is chosen as the fuzzy operator. This model not only retains the original evaluation information of each factor, but also objectively and truly considers the evaluation results of each factor.
Figure 2. Variable value of each index.

Table 3. Evaluation results.

| Breaking times | \(AW\) (The comprehensive weight) | Evaluation mark | \(DW\) (The dynamic weights) | Evaluation mark |
|----------------|----------------------------------|-----------------|-------------------------------|-----------------|
| 2000           | [0.6483, 0.2981, 0.0536, 0] \(T_4\) | [0.7359, 0.2198, 0.0443, 0] \(T_4\) |
| 6000           | [0.7760, 0.2240, 0, 0] \(T_4\)    | [0.8107, 0.1893, 0, 0] \(T_4\) |
| 12000          | [0.2183, 0.5686, 0, 0.2131] \(T_3\) | [0.2100, 0.6749, 0, 0.1151] \(T_3\) |
| 16000          | [0.2085, 0.5784, 0.0734, 0.1397] \(T_3\) | [0.1586, 0.6244, 0.0748, 0.1422] \(T_3\) |
| 22000          | [0, 0.3055, 0.5184, 0.1761] \(T_2\) | [0, 0.1184, 0.5412, 0.3424] \(T_2\) |
| 26000          | [0, 0.0864, 0.5246, 0.3890] \(T_2\) | [0, 0.0760, 0.4966, 0.4274] \(T_2\) |
| 32000          | [0, 0.2580, 0.4095, 0.3325] \(T_2\) | [0, 0.0842, 0.1477, 0.7681] \(T_1\) |
| 36000          | [0, 0.2126, 0.2924, 0.4950] \(T_1\) | [0, 0.1358, 0.1978, 0.6664] \(T_1\) |

4. Conclusion
Combined with the experimental data of the AC contactor life test system, the dynamic weights combined with the subjective and objective weights are calculated, and the weights of the feature parameters with higher membership are obtained during the degradation process of the AC contactor.

The variable weight coefficient method is adopted to increase the weight coefficient, so that the evaluation result is closer to the real running state of the AC contactor, and the accuracy of the state evaluation is improved. In future research, it is necessary to have a deeper understanding of the contact degradation mechanism of AC contactors and to establish a more accurate life model.

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