Study on Life Model of MOV Based on Multiple Parameters and Surge History

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Research Article

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Study on Life Model of MOV Based on Multiple Parameters and Surge History

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Abstract: With the advance of intelligent operation and maintenance in china railways, the requirement of condition monitoring and remaining life prediction for lightning protection equipment has become increasingly urgent. MOV(Metal Oxide Varistor) is the key component of railway surge protector, and it is necessary to study the description model of its degradation process. The output of the model that uses a single parameter to characterize degradation is more prone to contingency, and cannot truly and fully reflect the life state of the MOV. The degradation of MOV is a cumulative effect, and its life model should consider the surge history information. In view of the above problems, a prediction model of the residual life value of MOV is given by combining various degradation related parameters and surge history. Firstly, nine degradation related parameters are fused to construct degradation core. Then, the degradation core and surge history are fused through Markov chain to build a life model of MOV. Then, the model is calibrated with experimental data. Finally, the model is validated and analyzed by experiments. The model can describe the degradation process of MOV more comprehensively and accurately, and can predict the residual life value at the same time, and it has potential application in the life assessment of surge protective devices.

Key words: Metal Oxide Varistor(MOV); Multiple parameters; Surge history; Markov Chain

1. Preamble

Surge protector is a widely used equipment in lightning protection for communication signals of railways,which is equipped with a thermal trip device inside, and when enough surge flows through, a large amount of heat energy can be generated, so that the thermal trip device will fuse.The sign in the surge protector display window turns from green to red, indicating its failure.There are still a large number of instances where the surge protector has failed before the replacement time or the "turning red" is reached.When the surge invasion, the failure of the protection device can not play a protective role, and even cause fire.The sign in the surge protector display window turns from green to red, indicating its failure.There are still a large number of instances where the surge protector has failed before the replacement time or the "turning red" is reached.When the surge intrudes, the collapsed protective device fails to play a protective role, and even cause fire.On the other hand, the operation and maintenance of the surge protector in the railway system has been in the state of periodic repair which requires the staff to inspect in a regular manner with low efficiency.Inspection is mainly conducted to observe whether the appearance is damaged and tripped.As a consequence, it failed to effectively and timely check out the failure or the failure of the surge protector.There are a large number of applications of surge protectors and if effective monitoring for the operation sate and life evaluation, many accidents may occur, resulting in huge economic losses[1,2].With the advancement of intelligent railway, it is very necessary to carry out effective and accurate online life assessment of surge protection device to prevent the disaster caused by surge protection device and improve the level of lightning protection operation and maintenance.With the development of electronic technology, monitoring means become more and more mature and advanced, and it is feasible to carry out online life prediction for surge protectors under existing technology conditions [3-5].

The MOV is the core device of the surge protector. Its failure can cause complex chain reaction, resulting in the damage of the surge protector. The life description of the MOV is the core of the state monitoring of the surge protector[6].

Kazuo Eda et al from the Wireless Research Laboratory of Matsushita Electric Industry Co., LTD., studied the degradation caused by DC and AC bias in ZnO ceramics, indicating that the degradation caused by DC and AC bias was caused by the asymmetric and symmetric deformation of Schottky barrier respectively[7].Yin Guilai of Xi 'an Jiaotong University studied the electron trap process of shock aging of MOV[8].Li Huifeng et al from Huazhong University of Science and Technology analyzed the relationship between the impact aging mechanism of nonlinear resistance of zinc oxide and the dielectric response of the material from a microscopic point of view[9].Zhang Shugao and Ji Youzhang from Central South University studied the aging phenomenon of ZnO MOV and proposed the aging mechanism based on linear chain theory[10].The above characterization methods give emphasis on microphysics theory, which are not suitable for practical engineering application.

Varistor voltage and leakage current are two traditional degradation characterization parameters, which can reflect the health state of MOV[11].It is generally believed that when the measured value of the varistor voltage is less than 90% of the initial value, the MOV shows degradation fault[12].Yang Zhongjiang et al from Nanjing University of Information Science and Technology showed through experiments that the nonlinear coefficient [13], capacitance [14], dynamic resistance [15] and residual voltage ratio [16] all have certain variation rules in the process of MOV degradation.Zhang Youguo studied the variation trend of temperature change rate in the degradation process of zinc oxide varistor[17].The above parameters can be used as a reference for the characterization of MOV degradation.However, it is one-sided to adopt a single parameter to characterize degradation with uncertainty,which is prone to generate misjudgment and poor prediction.

Surges can degrade the MOV, and the MOV actually fails after many surges.The degradation process of the MOV is directly related to the magnitude of the impulse current and the number of the impulse. It is a cumulative effect and is determined by the history of the impulse experienced by the MOV[18].

The remaining life of a MOV is related to its surge history and various parameters.A method to accurately describe the life of MOV is needed in the actual project of state monitoring of surge protector.In view of the defects of the method of representing the deterioration of the varistor with a single parameter, such as large chance and poor prediction effect, and the fact that the deterioration of the varistor is a cumulative effect, this paper studies a life prediction model combining the history of surge impact and various related parameters of the varistor deterioration.

2. Fusion of multiple degradation related parameters

The degradation process of MOV is related to many parameters.In order to avoid the misjudgment of the output result caused by the accidental disturbance, the accurate life model can be made with many factors to be taken into account comprehensively.In this paper, 9 kinds of degradation related parameters were fused [19] to construct the concept of deterioration kernel.The construction method is as follows.

2.1 Vector representation for degradation

In order to be able to express and use it in a unified way, 9 kinds of degradation related parameters of MOV are composed of degradation vector, which is represented by X.Each parameter is a component vector.These parameters can be summarized into three types:

1) State parameters of the MOV: The measured VImA U_{1mA}, leakage current $I_{Leakage}$, nonlinear coefficient *Alpha*;

2) Surge related historical parameters: The shape of the surge $w(t)$, the amplitude of the surge I_{Pulse};

3) The characteristic parameters of the MOV: The initial VImA U_{1mA_Rated}, the initial leakage flow $I_{Leakage\_Rated}$, the nominal impact tolerance value I_n, the maximum nominal impact tolerance value I_{Max}.

Where, 1) and 2) are variable parameters, and 3) are constant parameters.The vector can be expressed as:

$$X = [U_{1mA}, U_{1mA\_Rated}, I_{Leakage}, I_{Leakage\_Rated}, Alpha, w(t), I_{Pulse}, I_n, I_{Max}] \tag{1}$$

2.2 Construction of degradation core

In order to integrate various degradation related parameters, the concept of degradation core representing the health degree of MOV was defined in the form of fraction, which was represented by K(X).The parameters positively related to MOV degradation are placed in the denominator, and the parameters negatively related to MOV degradation are placed in the molecule.The degradation core is input as the degradation vector and outputs the value representing the health of the MOV.The value is in the range of (0,+∞).The larger the value, the healthier the MOV.

According to the actual experience in engineering and experimental results, the expression of K(X) is determined as follows.

$$A = Alpha \cdot I_n \cdot I_{Max} \tag{2}$$

$$B = \frac{U_{1mA}}{U_{1mA\_Rated}} \tag{3}$$

$$C = I_{Leakage} - I_{Leakage\_Rated} \tag{4}$$

$$D = I_{pulse} \cdot \int_0^t w(\tau)d\tau \tag{5}$$

$$K(X) = \eta \cdot \frac{A \cdot B}{C \cdot D} \tag{6}$$

Where, A and B represent the positive correlation parameters that maintain a healthy state with the MOV, while C and D are negative correlation parameters.η represents a constant, which is used to distinguish different types of MOV to adjust the applicability of the model.

3. Fusion of degradation core and surge histories through the Markov chain

The health of a MOV depends on the total cumulative value over time of the surge current flowed through, which is a cumulative result.The degradation process of MOV is closely related to the surge history. The more the surge times it experiences, the more easily it will be damaged.In this paper, the degradation core is combined with the surge history, and the Markov chain is used to construct the life model [20,21].

3.1 Selection of state space

Markov chain state space adopts 2 - dimensional structure to describe good and bad states, which is expressed by [F D].The state space after the shock can be expressed as [F_n D_n]. The initial value of the state space specified is [1 0].

3.2 Determination of transition matrix

There is a transition matrix $A_{n\,AS\,T}$he Markov chain goes from the Nth state to the N^{th+1} state, which makes a sense as $P(n+1)=P(n)\cdot A_n$. A_n is the conversion probability corresponding to the transformation of each component vector in state n into state $n+1$.The degradation core is introduced into the transition matrix to control the degree and quantity of the state change.

F_n and D_n represent the values of "good" and "bad" after n shocks, respectively.As n increases, F_n approaches 0, D_n approaches 1.Markov chain is expressed as:

$$\begin{gathered}\left[F_{n+1} \quad D_{n+1}\right]=\left[F_n \quad D_n\right]\cdot A_n = \\ \left[F_n \quad D_n\right]\cdot\begin{bmatrix}\alpha_n & \beta_n \\ \gamma_n & \delta_n\end{bmatrix}\end{gathered} \tag{7}$$

α_n represents the probability that the state is "good" this time and "good" state will be demonstrated for the next time after n shocks, and the value is determined by the degradation core.β_n represents the probability that, after n shocks, the state is "good" this time and is "bad" next time. This value is also determined by the degradation core.γ_n displays the probability that, after n shocks, the state is "bad" this time and the next time is "good". It is an impossible event and the value is 0.N represents the probability that after n shocks, the state is "bad" this time and it is still "bad" next time. It is a certain event and the value is 1.The transition matrix can be further expressed as:

$$A_n=\begin{bmatrix}\alpha_n(X) & \beta_n(X) \\ 0 & 1\end{bmatrix} \tag{8}$$

According to the probability propertyα_n□X□□β_n□X□□□ of the transition matrix, A_n can be simplified as:

$$A_n=\begin{bmatrix}\alpha_n(X) & 1-\alpha_n(X) \\ 0 & 1\end{bmatrix} \tag{9}$$

The degree and quantity of state transition are controlled by the degradation core, as a result, α_n□X□ can be expressed as follows:

$$\alpha_n\left(X\right)=f\left(\mathrm{K}(X)\right) \tag{10}$$

Since the value of α_n□X□ must be limited between the range of (0, 1), as a result, the limiting function f□x□=1-e^{-x} is introduced, and its function graph is shown in Figure 1.In this case, the calculation expression of α_n□X□can be obtained as follows:

$$\alpha_n\left(X\right)=1-e^{-K(X)},\in\left(0,1\right) \tag{11}$$

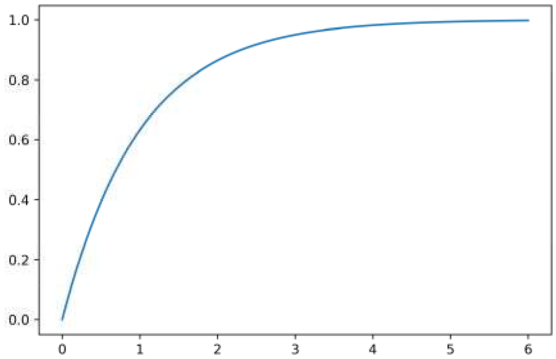

Fig. 1 Graph of restriction function for the value of transfer matrix elements

3.3 Construction of life mode

α_n□X, can be input to obtain the Markov chain model.Every time the MOV experiences a surge, its life value is considered to change, then the state value in the model transfers for one time, and a new life value is generated after calculation.The life probability value of the varistor after each surge is the result of multiplying the last state value by the transition matrix.The calculation expression is as follows:

$$
\begin{aligned}
&\left[F_{n+1} \quad D_{n+1}\right]= \\
&\quad \left[F_n \quad D_n\right] \cdot \begin{bmatrix} \alpha_n(X) & 1-\alpha_n(X) \\ 0 & 1 \end{bmatrix} = \\
&\quad [1 \quad 0] \cdot \prod_{i=1}^{n} \begin{bmatrix} \alpha_i(X) & 1-\alpha_i(X) \\ 0 & 1 \end{bmatrix}
\end{aligned} \tag{12}
$$

In the mode process of transition of model state, the surge history of the MOV is integrated with the degradation core.This model represents the relationship between the life value of the MOV and the degradation related parameters and the the number of impacts.

4. Model calibration

In order to calibrate the parameters in the degradation core, the degradation calibration based experiment of the MOV was carried out.The sample of the experiment is a certain brand of ZnO MOV with U_{1mA_Rated} standing at 180V, I_n 12kA, I_{Max} reaching 25kA.In the experiment, 8/20μs waveform with amplitude of 15kA was used for impact.A total of 52 experiments were carried out, and the time interval of each impact was 5min.At the 48th time, the green epoxy resin layer on the corner of the MOV burst and granular black powder appeared. The test sample and scene are shown in FIG. 2.

Fig. 2 Picture of experimental sample and laboratory

According to the calibration experiment, as the 8/20μs waveform of 15kA was used for shock, the experiment was executed until 48 times to produce burst, and the corresponding life value of the MOV showed 0,The data of the above calibration experiment were input into the model to calibrate the unknown parameters in the model.After calculation, the value of the parameter η in the degradation core is determined to be 209.8.

5. Experimental verification and analysis

In circumstances that the environmental factors in the calibration experiment are consistent, the same type of MOV is impacted by the current waveform of 8/20μs with the amplitude of 25kA until it is completely damaged.In this process, the parameters of each element in the degradation vector are collected and the surge history is recorded respectively.The time for impact interval lasts 5min.The experiment was carried out for 25 times, and the MOV burst at the 25th shock.

The variation trend of varistor voltage, leakage current and nonlinear coefficient with the number of shocks is shown in Figure. 3.In order to compare the trend conveniently, the above data were normalized by Min-max.The three state parameters demonstrated their own variation trend in the process of impact degradation of the MOV, all of them proved to have non-monotonic defects.If a single parameter is used to judge the life, the life curve with non-monotonous changes is prone to cause misjudgment.The life curve of the MOV represented by the varistor voltage and leakage current presents mutation state.In the whole degradation process of the MOV, the above two parameters have little change in the initial and middle stage, but drastic change occurred in the later stage with poor performance in life prediction.

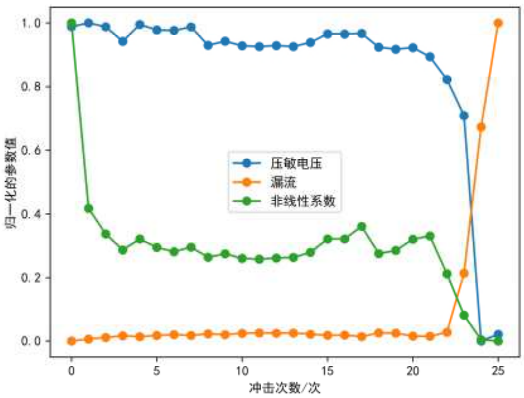

Fig 3 Trend of degradation related parameters with impact times

Each parameter was input into the constructed MOV based life model in turn to obtain the life curve, as shown in FIG. 4.According to the changing trend of the curve, the life value of the MOV drops to 0 at the 25th impact, which corresponds to the times of impact when the there was a burst in MOV.The results of the model is exactly consistent with the experimental data.The model effectively inhibits the uncertainty and mutation of single parameter.The life curve characterized with a monotonous decline with smooth downward trend.On the one hand, the addition of various degradation related parameters and surge history enhances the ability of the model to resist accidental interference and accuracy is improved accordingly.On the other hand, the model was enabled to describe the life of the MOV in a more meticulous and comprehensive manner.The output results of this model can be used to predict the life of the MOV

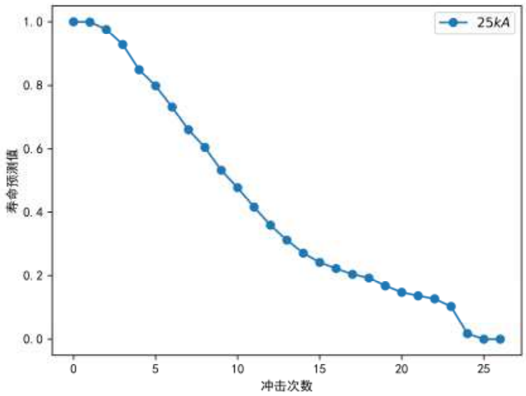

Fig 4 Life curve of model output

6. Conclusion

1) The life model of MOV integrating various degradation parameters and surge history is capable of describing the degradation process of the MOV.It is verified by experiments that the life evaluation curve of the model output can be used to predict the life of the MOV.

2) With the addition of multiple parameters and surge history, the model is endowed with the capability in describing the life of MOV in a more detailed and comprehensive way.Compared with the life evaluation by adoption of a single parameter, this method effectively reduces the contingency of the discriminant results and the results will be more accurate.

3) The model is endowed with the characteristics of clear calculation with simple steps, and easy calculation, which is convenient for the transplant and application of field equipment. As a result, it has potential application in the real-time monitoring and life evaluation of surge protectors in railway lightning protection.

Author Contributions RUAN Xiaofei and JIN Shaoyun made contributions as regards the conception of the work, the experimental work,the data analysis, and writing the paper; WEN Weigang and CHENG Weidong made contributions as regards the direction of the experiment and the modification of the manuscript.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Code availability Not applicable

Ethical approval This paper contains no cases of studies with human participants performed by any of the authors.

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