Research on Online Detection System for Electrical Wear of Vacuum Circuit Breaker Contacts (Postprint)

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Abstract

The development of smart grid technology has posed new requirements and challenges for the intelligentization of high-voltage switching equipment. Based on the intelligence requirements for high-voltage switches—namely self-monitoring, self-diagnosis, and self-control capabilities—this paper designs an online monitoring device for electrical wear of the contact system during the intelligentization process of vacuum circuit breakers. The wear calculation of the contact system in this device employs an improved cumulative weighted method for breaking current, where the selection of weights and calculation of total wear are obtained by fitting the electrical life curve using the least squares method; this approach is universal and can be applied to different types of vacuum circuit breakers. The weighted integral coefficient K is dynamically predicted using a trained LM-BP neural network, making the selection of K values more consistent with engineering practice. An arcing time sensor is utilized to collect arcing time, and the installation position of the arcing time sensor along with the adopted shielding measures are presented. The hardware processing core adopts the TMS320F2812 microprocessor chip, primarily responsible for algorithm processing, host computer communication, and CAN-BUS controller area network communication. Short-circuit current is collected using a Rogowski coil, with a current processing circuit designed and the 2812AD sampling correction method presented. Finally, the software flow for online monitoring of contact system wear and key technologies that should be noted during design are presented.

Full Text

Study on Online Monitoring System for Electrical Wear of Vacuum Circuit Breaker Contacts

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Abstract

The development of smart grid technologies has introduced new requirements and challenges for the intelligentization of high-voltage switching equipment. Based on the intelligentization requirements for high-voltage switches—namely self-monitoring, self-diagnosis, and self-control capabilities—this paper designs an online monitoring device for the electrical wear of contact systems in vacuum circuit breakers (VCBs) during their intelligentization process. The device employs an improved cumulative weighted method for calculating contact system wear, where the weight selection and total wear calculation are derived from electrical life curves using least squares fitting. This approach offers universality and can be applied to different VCB models. The weighted integral coefficient K is dynamically predicted using a trained LM-BP neural network, making the K value selection more consistent with engineering practice. An arcing time sensor collects arcing duration data, and the paper presents the sensor' s installation position and shielding measures. The hardware core adopts the TMS320F2812 microprocessor chip, which is primarily responsible for algorithm processing, host computer communication, and CAN-BUS controller area network communication. Short-circuit current is collected using a Rogowski coil, with a designed current processing circuit and a 2812 AD sampling correction method presented. Finally, the software flowchart for online monitoring of contact system wear and key technologies requiring attention during design are provided.

Keywords: Vacuum circuit breaker, electrical wear, online monitoring, contact system

1 Introduction

Circuit breakers serve critical protection and control functions in power grids, and their performance directly affects grid safety and stable operation. Vacuum circuit breakers, with their excellent interrupting performance and environmentally friendly characteristics, are widely used in medium- and low-voltage power systems and have achieved certain successes in expanding into high-voltage and ultra-high-voltage domains [1-2]. In high-voltage and ultra-high-voltage applications, SF gas has a global warming potential 24,900 times that of CO and a lifespan of 3,200 years [1]. According to the Kyoto Protocol, SF gas will be completely banned by 2030 [2], indicating that vacuum circuit breakers will see even broader application in the future.

The contact system is the core component of a vacuum circuit breaker, and its lifespan directly affects the overall breaker lifespan. With the development of smart grids and reliability-based power equipment monitoring, lifespan evaluation and online monitoring of contact systems have become increasingly important. The evaluation and online monitoring have evolved through three stages: First, using marks on the moving conducting rod to indicate wear degree. Second, assessment and monitoring through cumulative weighting of breaking current. Third, online monitoring and prediction using an improved cumulative weighting method for breaking current. Stage one provides only a rough estimate with low precision [3]. Stage two fails to consider actual operational differences in current magnitude and arcing time between phases, resulting in significant errors between fault and non-fault phases [3]. Stage three addresses the conditions ignored in stage two and can be applied to engineering practice for contact system electrical lifespan evaluation, though it lacks a systematic and unified method for determining required parameters, making parameter determination difficult [3-4].

This paper systematically investigates the parameter determination methods for stage three. Inspired by the SF contact wear equivalent law obtained by Électricité de France (EDF) and Italian engineering guidance companies (ENEL) [5-6] and referencing the VCB electrical lifespan conversion formula from literature [7], this paper employs extensive mathematical experiments and verification analysis. Based on electrical life curves, the least squares method is used to select and analyze the current exponent and theoretical wear total in the improved cumulative weighted method for breaking current.

[Figure 1: see original paper] shows a typical set of electrical life curves. Mathematical analysis yields the fitted curve shown in [Figure 2: see original paper], illustrating the relationship between breaking current magnitude and breaking times, with the corresponding fitting formula. Research results demonstrate that the curve exhibits certain smoothness, and breakers with higher rated current have greater breaking times at the same breaking current.

2.1 Selection of Current Exponent and Calculation of Wear Total

According to the method for calculating theoretical wear total presented in literature [3-4], the functional relationship between weight values and their corresponding parameters can be obtained. Taking the rated current I = 1,600 A shown in [Figure 1: see original paper] as an example, the relationship between wear total Q and weight value is:

$N(I) = N(I) = N(I) = N(I) = \ () \ () \ () \ ()$
1.93 1,600 A
2.07 2,000 A
2.33 2,500 A
2.46 3,150 A

By substituting a certain amount of breaking current values into the above equation, the relationship diagram between theoretical wear total Q and weight value shown in [Figure 3: see original paper] can be obtained. Analysis of [Figure 3: see original paper] reveals that after determining contact material, structure, and arc extinguishing method, the theoretical wear total and weight value are unique. In the figure, Q = 50,500 and = 1.93. Using the method proposed in this paper, the relationship between theoretical wear total Q and weight value for the electrical life curve in literature [4] can be calculated, as shown in [Figure 3: see original paper].

In literature [4], = 1.91 and Q = 87,300 were selected. From the curve in [Figure 3: see original paper], = 1.918 and Q = 89,979. Comparative analysis shows Δ = 0.418% and ΔQ = 3.07%. These results demonstrate that the design method proposed in this paper is effective.

2.2 Characteristics and Selection Method of Integral Current Coefficient

Literature [4] proposes an improved cumulative weighted method for breaking current based on electrical contact theory and provides a calculation method for the integral current coefficient K. The K value calculation method is based on ideal breaking assessment according to electrical life curves. The calculation assumes uniform distribution of arcing time within the arcing interval, whereas actual breaking operations exhibit three-phase non-uniformity, making the calculated K value conservative [4]. Building upon the research in literature [4], this paper considers the influence of arcing time differences and breaking times, analyzes the distribution characteristics of K values, and performs dynamic analysis.

Theoretical calculations and experimental verification yield the K value distribution pattern shown in [Figure 4: see original paper]. The curves represent the relationship between arcing time of the first breaking phase and K value at different breaking currents, where t represents the minimum arcing time,

i represents breaking times, and N represents allowable breaking times. Point A represents the K value corresponding to average arcing time, consistent with the selection result in literature [4]. Research shows that after determining contact material and structure, the K value is a physical quantity that dynamically changes with three-phase breaking current, three-phase arcing time, and three-phase breaking times. Its variation pattern forms an envelope band that cannot be predicted or determined using conventional numerical equations. Therefore, the LM-BP neural network algorithm is introduced to dynamically predict and analyze the integral current coefficient K based on actual arcing time variations during the breaking process. The specific process of constructing the neural network model is analyzed and discussed in depth elsewhere by the authors and will not be elaborated here.

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3 Design and Simulation of Arcing Time Initial Moment Detection Device

Applying the improved cumulative weighted method for breaking current to evaluate contact remaining lifespan requires determination of the key parameters discussed above, as well as arcing time t . The arc extinguishing time can be determined based on the breaking current waveform, while the arcing initiation time is determined by the designed detection device. The design principle of the arcing initiation time detection device is based on the fact that when a vacuum breaker interrupts short-circuit current, an arc occurs between contacts, generating strong electromagnetic radiation signals in space. The arcing initiation moment is determined based on electromagnetic signal variation characteristics.

The specific design structure and shielding measures are shown in [Figure 5: see original paper]. In the figure: 1 provides insulation support; 2 is the electromagnetic shielding layer, which shields interference from other phases’ electromagnetic signals when two or more phases interrupt breaking current, ensuring each phase’ s arcing time sensor can accurately collect the corresponding arcing initiation time and arcing duration; 3 is the induction coil for receiving and identifying electromagnetic signals during the breaking process; 4 is induction coil output terminal I, connected to the BNC metal shell (ground output); 5 is the standard BNC interface output terminal, ensuring universality and good anti-interference performance of the arcing time sensor; 6 is induction coil output terminal II, the arcing time signal output terminal connected to subsequent processing and sampling circuits; 7 is the magnetic core frame material for increasing inductance; 8 is the epoxy resin casting area for fixing the induction coil and providing protection [9].

The arcing time initiation signal output from the BNC terminal is sent to the microprocessor for algorithmic operation after subsequent filtering and multi-stage amplification. The wear amount for each breaking operation is calculated using the improved cumulative weighted algorithm for breaking current. [Figure

6: see original paper] shows the simulation results of the detection device' s post-stage processing circuit, demonstrating the device' s response sensitivity and response time.

4 Overall System Architecture and Software Design

The monitoring device uses three-phase breaking current, output from three-phase breaker arcing time sensors, and three-phase switching status signals as inputs. The system control and algorithm chip adopts the TMS320F2812 produced by Texas Instruments, a 32-bit fixed-point digital signal processor integrating a 16-channel × 12-bit ADC that can complete 32-bit × 32-bit multiplication in a single cycle, offering powerful digital signal processing and control capabilities. The monitoring device system architecture is shown in [Figure 7: see original paper], where CT represents current transformers for collecting breaking current.

The arcing time detection devices are installed in groups of three near the three-phase arc extinguishing chambers using insulation supports. Detected three-phase arcing moment variations are processed and sent to the DSP for processing and calculation. Multiple online electrical lifespan monitoring devices are connected to the CAN bus to achieve information and data sharing. Monitored data is uploaded to the host computer via Ethernet to enable data storage and support improvements to online monitoring methods.

The main flowchart of the TMS320F2812 electrical wear online monitoring system is shown in [Figure 8: see original paper]. The system begins by determining whether there is a switching-off signal or reclosing signal in the grid system. When no breaking signal exists, data transmission occurs via Ethernet. When a breaking signal is detected, information collection proceeds: current signals, arcing time signals, and switching status are captured for all three phases. The collected information is then processed and sent to the LM-BP algorithm for core algorithmic processing [10] to dynamically calculate the K value based on field information. Finally, the K value and value are called upon for weighted cumulative integration to obtain the monitored wear amount Q , which is compared with the theoretical wear total Q to evaluate the electrical lifespan of the VCB contact system.

6 Conclusion

This paper focuses on researching the characteristics of vacuum circuit breaker electrical life curves and designs an online monitoring system for VCB contact electrical lifespan using the improved cumulative weighted method for breaking current. The research establishes selection methods and specific implementations for key parameters in the improved algorithm. Based on theoretical analysis, the implementation method of the VCB contact electrical lifespan online monitoring system is designed, with comprehensive hardware and software design and core parameter selection methods presented to form a practical engineering application method. The paper emphasizes research on calculating current exponents, wear totals, and current coefficients to ensure universality and simplicity for practical engineering application. Based on electromagnetic field variations around the arc extinguishing chamber at the breaking moment, an arcing time initial moment detection device is designed, with its working principle and electromagnetic shielding measures presented. This research provides beneficial exploration and reference for online monitoring of electrical lifespan in high-voltage vacuum switch contacts.

To verify the response characteristics of the online monitoring device, particularly the designed arcing time detection device, the authors simulated high-frequency electromagnetic signals generated during breaker switching in the laboratory and measured the device output. The field test results are shown in [Figure 9: see original paper], where figure 9a shows the detection device output waveform (curve 1) and the induction coil terminal waveform (curve 2), and figure 9b shows a detailed view of the detection device’ s rising jump process (curve 1), representing the time from trigger to step jump and reflecting device sensitivity.

Analysis reveals that when high-frequency signals are generated during switching, the detection device produces a pulse signal with a rising jump time of approximately 40 s, consistent with the simulation results shown in [Figure 6: see original paper]. Compared with arcing durations lasting several to tens of milliseconds, this clearly enables rapid and sensitive detection of arcing initiation moments with higher precision than conventional auxiliary contacts.

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