Research on Synchronous Acquisition and Processing Technology of Arc During Breaking Tests of Low-Voltage Electrical Devices

An Zu [1, 2, 3], Hongkui Zhang [1, 2, 3, *]

[1] CCTEG Shenyang Research Institute, Fushun, CO 110178, China

[2] State Key Laboratory of Coal Mine Safety Technology, Fushun, CO 110178, China

[3] Fushun CCTEG Inspection Center Co. Ltd, Fushun, CO 110178, China

* Corresponding Author Email: 18940021505@126.com

Abstract. Based on the analysis of the arc generation mechanism in low-voltage electrical devices, a synchronous acquisition system for arc during breaking tests of low-voltage electrical equipment has been designed. A wavelet analysis-based method for enhancing arc images has been proposed to improve the accuracy of arc image acquisition and recognition, providing a reference for the development of breaking test technology for low-voltage electrical devices.

Keywords: Low-voltage electrical devices, breaking test, arc, image enhancement.

1. Introduction

Low-voltage electrical devices refer to a general category that includes low-voltage circuit breakers, contactors, isolating switches, electromagnetic starters, buttons, and toggle switches, along with other electrical equipment that uses these components as core parts. It plays a dual role in controlling and protecting electrical systems. The breaking capacity test is an important inspection item for assessing whether low-voltage electrical devices can reliably interrupt fault currents under conditions such as overload and short circuits occurring in the circuit. During the breaking moment, the arc between mechanical contacts delays the interruption time of the circuit. Additionally, the high temperatures generated by the arc can potentially damage the contacts, resulting in increased contact resistance, material transfer and erosion of contacts, reduced dielectric strength, and even destruction of low-voltage electrical equipment. Therefore, researching the motion characteristics of arcs during breaking tests for low-voltage electrical devices can help improve arc-extinguishing structures and enhance safety performance. Existing methods for collecting arcs during breaking tests on low-voltage electrical devices use self-focusing lens arc motion fiber testing systems to achieve preliminary acquisition of arc images. However, these methods suffer from poor spatial resolution of arc images, inadequate synchronization between arcing and acquisition, a limited number of collected images, and a low success rate in image acquisition.

2. Mechanism of Arc Generation

The process or form of current flowing through a gas is referred to as gas discharge. In an ideal state, where there are no external influences and parameters such as air temperature and humidity are within normal ranges, the gas (air) can be considered an ideal insulating medium. When a voltage is applied to the electrodes for a certain period, no current flows through the gas in the insulation gap. However, gas insulation is affected by external factors such as ultraviolet rays and cosmic rays, and the gas typically contains a certain number of charged particles (electrons, positive ions, negative ions). When a certain voltage is applied to the electrodes, these charged particles will move in the direction of the electric field under its influence, thereby forming conductive current. When the electric field is weak, the number of charged particles in the gas is extremely low, resulting in a very small current. Once the voltage across the electrodes is increased to a certain level, the gas between the electrodes will lose its insulating properties, leading to a dramatic increase in current between the

electrodes. This transition of gas from an insulating state to a conductive state is known as gas breakdown. Depending on various factors such as gas pressure, power supply capacity, and electrode shape, different discharge processes may occur after gas breakdown. Arc discharge is one form of gas discharge.

If the power supply's capacity is sufficiently high, reducing circuit resistance will lead to an increase in discharge current. Once this discharge current reaches a certain value, the discharge channel will noticeably narrow and become increasingly bright. The voltage drops across the discharge gap will also decrease accordingly, indicating that the resistance of the discharge channel is becoming smaller while its conductivity increases. At this point, the discharge enters the arc discharge phase. The arc discharge form is commonly referred to simply as an arc. When a switch interrupts a current greater than 1A in air with a gap voltage exceeding 20V at the break point, an arc will be generated at that break point after contact separation. The primary task of low-voltage electrical devices is to connect and disconnect working circuit currents; their break point gap voltages and currents are significantly greater than the critical values required for arc generation. The presence of arcs will affect both the breaking characteristics and other performance indicators of low-voltage electrical devices.

3. Arc Acquisition System

The synchronous arc acquisition system for breaking tests of low-voltage electrical devices mainly consists of a high-voltage distribution cabinet, an impulse test transformer, a low-voltage distribution cabinet, a test parameter adjustment module, a companion switch, low-voltage electrical devices, a grounding cabinet, driver relay A, driver relay B, driver relay C, a clock unit, a crystal oscillator unit, a power supply unit, a control panel, a display unit, a DSP (Digital Signal Processor), a synchronous control circuit, a data processing card, a voltage and current transformer set, an image acquisition module, an image processing unit, a communication unit, and an industrial computer. The schematic structure of the system is shown in Figure 1. The high-voltage distribution cabinet, impulse test transformer, low-voltage distribution cabinet, test parameter adjustment module, companion switch, low-voltage electrical devices, and grounding cabinet form the experimental circuit for the synchronous acquisition system during breaking tests of low-voltage electrical devices. This circuit provides the necessary test voltage and current for the breaking process.

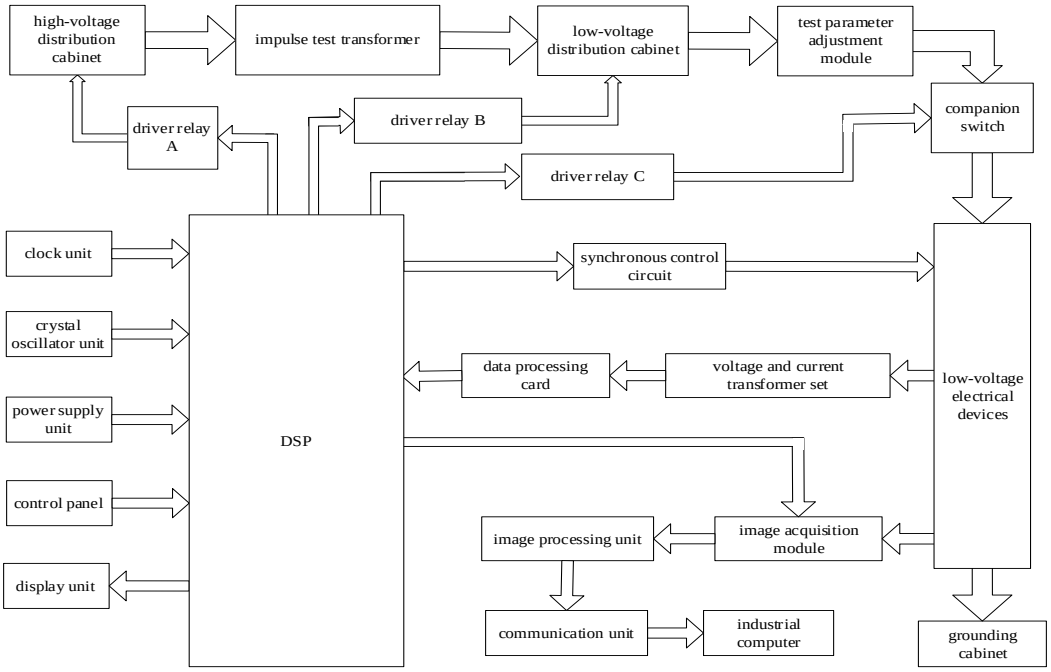


Figure 1. Structure diagram of arc synchronous acquisition and image processing system for low-voltage electrical apparatus breaking test

The working process of the synchronous arc acquisition system for breaking tests of low-voltage electrical devices (as shown in Figure 2) is described as follows:

1. The operator should check whether the wiring connections are correct and whether the equipment is intact. The line current and power factor should be adjusted through the test parameter adjustment module according to the requirements of the low-voltage electrical device breaking test.
2. The operator should power on the system and perform self-checks on the high-voltage distribution cabinet, low-voltage distribution cabinet, companion switch, DSP, industrial computer, image acquisition module, and image processing unit.
3. The control panel sends control signals to the DSP; the DSP then sends control commands to close the high-voltage distribution cabinet, low-voltage distribution cabinet, companion switch, and low-voltage electrical device.
4. The DSP sends synchronization control commands and image acquisition instructions; the synchronous control circuit drives the low-voltage electrical device to trip while the image acquisition module captures images of the arc during tripping. The voltage and current transformer set collects voltage and current signals from the low-voltage electrical device during interruption and feeds them back to the DSP through the data processing card.
5. The DSP calculates system voltage and current data and displays this information along with operational status updates for the high-voltage distribution cabinet, low-voltage distribution cabinet, companion switch, and low-voltage electrical device on the display unit.
6. The image processing unit performs initial processing on images of arcs during tripping from the low-voltage electrical device before sending these images to the industrial computer via the communication unit.
7. The industrial computer enhances images of arcs during tripping using wavelet transform methods.
8. The control panel sends control signals to the DSP; subsequently, the DSP issues control commands to trip the high-voltage distribution cabinet, low-voltage distribution cabinet, and companion switch.
9. The operator should power down the system; this concludes both arc synchronization acquisition and image enhancement processing.

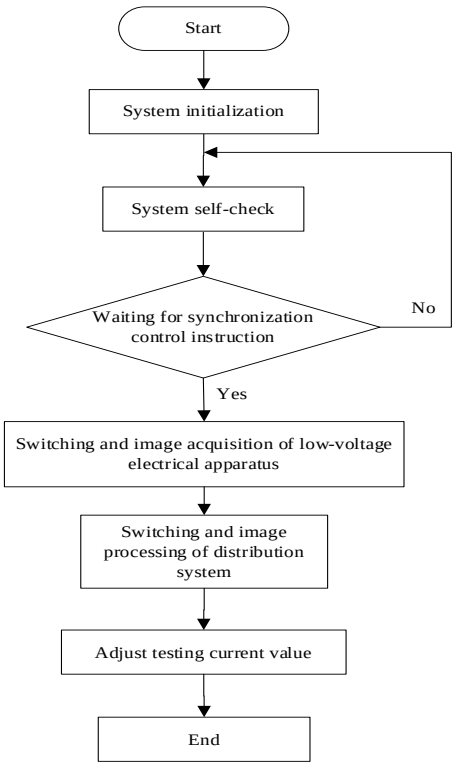


Figure 2. Arc synchronous acquisition process of low-voltage electrical apparatus breaking test

4. Image Processing End

Image enhancement is an important preprocessing step in image analysis and processing that can improve the visual quality of images and increase their clarity. By utilizing wavelet transform for multi-scale decomposition, low-frequency smooth sub-images and high-frequency detail sub-images of the image can be obtained at different scales. The magnitude of the wavelet coefficients corresponds to the differences in image grayscale. The reversible nature of wavelet transform allows for the reconstruction of contrast-enhanced arc images, preserving the arc shape while highlighting contact characteristics. The enhancement processing of arc images during breaking tests of low-voltage electrical devices is achieved through scaling and translation of the mother wavelet function, which is represented as follows:

$$\varphi_{j,k}(t) = 2^{-\frac{j}{2}} \varphi(2^{-j}t - k) \tag{1}$$

In the formula, j is the scaling parameter, where j belongs to the set of integers; k is the translation parameter, where k also belongs to the set of integers. The $\varphi(t)$ represents the mother wavelet of the arc images from low-voltage electrical device breaking tests.

The family of discrete wavelet functions obtained from the function $\varphi(t)$ through scaling and translation forms a standard orthogonal basis for the space of square-integrable functions $L^2(R)$. This allows any function $f(t)$ in space $L^2(R)$ to be represented by a wavelet series:

$$f(t) = \sum_{j,k \in Z} d_{j,k} \varphi_{j,k}(t) \tag{2}$$

In this equation, $d_{j,k}$ can be viewed as the projection of function $f(t)$ onto the wavelet function system, referred to as wavelet transform coefficients. Let $\phi(x,y)$ and $\varphi(x,y)$ represent the two-dimensional scaling function and wavelet function, respectively, and let J denote the level of image decomposition. Then, the expression corresponding to the wavelet decomposition of arc images during breaking tests of low-voltage electrical devices is given by:

$$f(x,y) = \sum_{n} C_{J,n} \phi_{J,n}(x,y) + \sum_{k=1}^{J} \sum_{n} d_{k,n} \varphi_{k,n}(x,y) \tag{3}$$

In this equation, the first term represents a low-resolution image, while the second term consists of sub-images from different frequency bands.

After applying wavelet transform to arc images during breaking tests on low-voltage electrical devices, appropriate decomposition coefficients should be utilized for transformation. The transformation function is expressed as follows:

$$C_{out}(j,k) = sign(c_i(j,k)) * (A + In(abs(c_i(j,k)) + 1) / InB) \tag{4}$$

In this equation, “sign ()” denotes the sign function, ensuring that the signs remain consistent before and after the wavelet transformation of arc images during breaking tests on low-voltage electrical devices. The A and B are positive real numbers. By varying the magnification factors, A and B, different image enhancement effects can be achieved.

5. Conclusion

By employing a wavelet transform-based method for synchronous acquisition and image enhancement processing of arcs during breaking tests on low-voltage electrical devices, we have improved both the success rate and stability of arc acquisition during these tests. Additionally, this method has enhanced image processing accuracy while conserving electrical resources. It also

provides technical support for research into arcs during breaking tests on low-voltage electrical devices, ensuring their safety performance and preventing potential safety production accidents caused by failures in low-voltage electrical equipment.

References

[1] C. Li, D. Wei, B. Zhang, J. Li and W. Zhang, "On Novel Methods for Characterizing the Arc/Contact Movement and Its Relation with the Current/Voltage in Low-Voltage Circuit Breaker," in IEEE Transactions on Plasma Science, vol. 45, no. 5, pp. 882-888

[2] X. Bing, "Welding Arc Signal Acquisition and Analysis System Based on VC++ and MATLAB Mixed Programming," 2011 Third International Conference on Measuring Technology and Mechatronics Automation, Shanghai, China, 2011, pp. 1150-1153

[3] M. Chen and Z. Xu, "Design of series fault arc waveform generating device," 2019 4th International Conference on Intelligent Green Building and Smart Grid (IGBSG), Hubei, China, 2019, pp. 10-13

[4] D. A. Asfani, D. Fahmi, I. M. Yulistya Negara, A. Brastama, F. F. Kurniawan and I. F. Ramadhan, "Web-based Online Monitoring of Low Voltage Series Arcing with Line Impedance Analysis," 2018 International Seminar on Intelligent Technology and Its Applications (ISITIA), Bali, Indonesia, 2018, pp. 123-128

[5] Jing-Hong Wang, Li-Na Liu, Da-Wei Yue and Jiao-Min Liu, "Image de-noise research on switching arc acquisition system," 2008 International Conference on Machine Learning and Cybernetics, Kunming, 2008, pp. 2894-2898

[6] B. S. Galani Pernambuco, C. Rafael Steffens, A. V. Werhli and S. Silva da Costa Botelho, "Data Analysis Tool and Image Acquisition System for Linear Arc Weld Deposition Evaluation," 2019 IEEE 17th International Conference on Industrial Informatics (INDIN), Helsinki, Finland, 2019, pp. 1177-1184

[7] Y. Wang, L. Hou, K. C. Paul, Y. Ban, C. Chen and T. Zhao, "ArcNet: Series AC Arc Fault Detection Based on Raw Current and Convolutional Neural Network," in IEEE Transactions on Industrial Informatics, vol. 18, no. 1, pp. 77-86

[8] H. Chen, X. Liu, L. Li, P. Li, Y. Huang and Y. Liu, "Analyse of Vacuum Arc Characteristics under Short-Circuit Breaking," 2018 28th International Symposium on Discharges and Electrical Insulation in Vacuum (ISDEIV), Greifswald, Germany, 2018, pp. 411-414