Visualization of Arc Energy Distribution Based on CCD Image Sensor

Yunkun Deng¹, Yingping Chen², Jisheng Huang², Ke Wang¹, Xianping Zhao¹, Shuyu Gao³, Shuxin Liu³,⁴, Yong Cheng⁴

¹Yunnan Institute of Electrical Science, 650000, China
²Lincang Power Supply Bureau of Yunnan Power Grid Co. LTD, 677000, China
³Shenyang University of Technology, Shenyang, Liaoning, 110870, China
⁴Xi’an XD Switch Electrical Co. LTD, 710000, China

Abstract. With the advancement of computer and sensor technology, visualization research has been more and more widely used in the industrial field, especially for arc plasma research of high energy fields. During the electrical breaking process, the DC arc energy distribution directly affects the working performance of the switchgear. A single voltage and current monitoring method is difficult to characterize the complex energy evolution process of the arc. Therefore, the visualization of the arc energy distribution is particularly important. In this paper, the arc energy distribution of the arc combustion process is visualized as the main research content. The arc characteristic detection platform is built, and the voltage, current, contact displacement value and arc image between the contacts are synchronously collected. According to the spectral characteristics of the color CCD image sensor, the colorimetric temperature measurement formula with calibration coefficient is derived to establish the relationship between the pixel and the arc temperature. The acquired arc image is processed by matlab image processing technology to visualize the two-dimensional energy distribution characteristics of the arc in the horizontal projection direction during the breaking process.

1. Construction of test equipment

The kinetic energy of the operating mechanism of the prototype is provided by a DC servo motor. The pull-rod structure is used to conduct the kinetic energy, and the rotational kinetic energy of the servo motor end is transferred to the moving contact end for horizontal sliding, thus realizing the the opening and closing operation between the prototype contacts, as shown in Fig.1.

The complete experimental prototype model is shown in Fig.1. The moving contact of the arc generating device is rigidly connected with the displacement sensor with a screw rod to collect the change value of the distance between the contacts during the breaking process[1-2]. The current sensor and voltage sensor are installed in the main circuit to monitor the change process of the current and voltage between the contacts during the breaking process of the electric appliance.
Fig. 1 Experimental prototype model

Fig. 2 respectively show the contact displacement waveform, the current and voltage waveform between contacts.

Fig. 2 Waveform acquisition

2. The image processing

2.1. Image preprocessing

The image taken by CCD image sensor cannot be calculated directly, so spatial enhancement technology should be used to preprocess the image. Wiener filter and median filter are used to pre-process the arc image to reduce noise, which can not only remove the noise point, but also protect the real pixel value of the image[3-4]. Fig. 3 shows the contour distribution of the arc before pretreatment and the contour distribution after filtering, respectively. In contrast, the contour distribution after filtering is smoother.

Fig. 3 Comparison of contour distribution

2.2. Energy distribution processing

After the preprocessing operation, the images of red and green mono-primary color components at the moment of 23ms arc burning are obtained as shown in Fig. 4.

Fig. 4 Red and green component images

As shown in Fig. 5, it can be seen that during the entire arcing process, the arc energy distribution has undergone a change process from stable concentration in the center of the plasma in the high-temperature region to gradually transitioning to both sides.
3. Image edge detection

The edge detection process simplifies the arc image. Edge detection uses methods such as differentiation to locate the edge of the arc image by analyzing the degree of gray value transition, simplifying the arc image feature information and highlighting the effective information of arc contour[5].

In order to detect the arc motion trajectory in the two-dimensional image, the idea of calculating arc centroid was put forward, the density value is regarded as the gray value of the arc pixel, the detection threshold is set, the gray pixel matrix is double-cycled, and the centroid coordinates of the arc image are finally determined by calculation, which can be expressed as

\[
x = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} j \times x_{i,j}}{\sum_{i=1}^{m} \sum_{j=1}^{n} x_{i,j}}, \quad y = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} i \times x_{i,j}}{\sum_{i=1}^{m} \sum_{j=1}^{n} x_{i,j}}
\]

Where, *i* is the number of rows of the gray matrix, *j* is the number of columns of the gray matrix, *x_i* and *j* are the gray values of each point, and the centroid detection results are shown in Fig.6.

During edge detection, a custom threshold is used to realize binarization processing of arc image. The edge detection operator is used to determine the peripheral information of the connected domain, and then the pixels in the connected domain are filled, and the arc circumference and area information are calculated by progressive scanning, as shown in Fig.7. Finally, the curve of arc circumference and area change in the whole breaking process was fitted, and analyze the arc shape characteristics during the breaking process, as shown in Fig.8.
Fig. 8 shows that the evolution of arc area has gone through 4 stages.

In the image collected by the high-speed camera, the centroid coordinates are calculated every 5ms, and the recorded centroid position data. Fitting the arc centroid coordinate curve during the whole breaking process, the result is shown in Fig. 9. The moving contact moves to the negative direction of the abscissa. The curve shows that the arc movement process can be divided into two stages. In the first stage of 0~68ms, the contact is always in motion, and the arc column is under the action of the axial airflow field. The zone is continuously stretched, and the arc transfers smoothly to the moving contact. The lateral displacement of the arc centroid gradually expands, and the longitudinal displacement changes slowly. The axial airflow field has obvious effects, and the natural heat convection has a weaker longitudinal lift until 68ms, the contact reaches the maximum distance, the curve of the center of mass has an inflection point, and the arc motion state begins to transition to the second stage. In the second stage, the contact is in a static state. From the centroid displacement image, it can be seen that the longitudinal displacement of the arc centroid increases rapidly. The plasma between the contacts is severely pulled longitudinally under the lift of natural thermal convection and its own magnetic blowing. The arc energy distribution at the moment of 141ms is shown in Fig. 5, the arc temperature gradient increases sharply, and the arc energy decays rapidly until the arc is extinguished in 184ms.

4. Conclusion

The mathematical model of colorimetric temperature measurement with calibration coefficient is derived by using the spectral characteristics of color CCD image sensor, and the relation between arc temperature and pixel is established. When only focusing on the arc energy distribution trend in the breaking process, it is proposed to directly assign the calibration coefficients. With the help of image processing technology to measure and reconstruct the plasma arc energy distribution field online. The acquired arc image is processed by matlab image processing technology to visualize the two-dimensional energy distribution characteristics of the arc in the horizontal projection direction during the breaking process.

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References

[1] Guofu Zhai, Kai Bo, Xue Zhou, et al. Research summary of dc high power relay arc[J]. Journal of Electrical Technology, 2017(22):257-269(in Chinese).
[2] Shunxin Liu. Design and characteristic analysis of vacuum arc image acquisition system[D]. Dalian University of Technology, 2006(in Chinese).
[3] Jiaomin Liu, Xinfu Li. Research on switching arc Image Enhancement Algorithm[J]. Journal of Electrical Technology, 2005, 20(5):20-23(in Chinese).
[4] Zhenzhou Wan, Jiaomin Liu, Mu Li, et al. Histogram algorithm of arc image enhancement for low voltage switch[J]. Journal of Electrical Technology, 2008, 23(6):50-53(in Chinese).
[5] Strzecha K,pabijanska A Factors Restricting Accuracy of CCD Camera Images Founded High Temperature Measurements[C].2006.