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Researches on Position Detection for Vacuum Switch Electrode

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Abstract. Form and transformation character of vacuum arc is important influencing factor on the vacuum switch performance, and the dynamic separations of electrode is the chief effecting factor on the transformation of vacuum arcs forms. Consequently, how to detect the position of electrode to calculate the separations in the arcs image is of great significance. However, gray level distribution of vacuum arcs image isn't even, the gray level of burning arcs is high, but the gray level of electrode is low, meanwhile, the forms of vacuum arcs changes sharply, the problems above restrict electrode position detection precisely. In this paper, algorithm of detecting electrode position base on vacuum arcs image was proposed. The digital image processing technology was used in vacuum switch arcs image analysis, the upper edge and lower edge were detected respectively, then linear fitting was done using the result of edge detection, the fitting result was the position of electrode, thus, accurate position detection of electrode was realized. From the experimental results, we can see that: algorithm described in this paper detected upper and lower edge of arcs successfully and the position of electrode was obtained through calculation.

1. Introduction

Along with the rapid development of national economy, industrial and agricultural electricity demand is growing, scale of power grid is increasing, and voltage level is gradually improving, more higher requirements is put forward to control and protection equipment of the power system. Vacuum switch is one of the important control and protection equipment in power system, then, research on its structure design optimization, reliability improvement and service life extension become a hot topic to scholars. In these hot topics, the key problem of reliability is how to control the arc form to make vacuum switch work effectively; an important problem to Service life is how to prevent the electrode surface from damaging by agglomeration arc. So the research on vacuum arc is important. At present, most of the arc form research is based on the arc burning sequence images shot by the high-speed framing camera, then some key information is extracted from sequence images using image processing techniques [1-3]. Fast advance of High-speed framing CMOS and CCD camera technology lay solid hardware foundation for the arc form research, also make the arc form studies based on arc image became a hot spot and achieve fruitful research results.

Burning process of vacuum arc is complicated, electrical parameters, mechanical parameters and magnetic parameters of vacuum switch impact on arc form [4]. Scholars have done lots of work on the influence of electric parameters, magnetic parameters on arc form[5-7], But study on the impact of mechanical parameters on the arc form is very lack. Wang Lijun[8-9]studied the influence of electrode

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gaps on arc form from the aspects of simulation and experiment respectively; Jiang Sheng[10] Analyzed the mechanical characteristics of vacuum switch from the respect of electrde gaps and separations. In these papers, the electrde separations was measured by Grating sensor，Accuracy of the measurement for accurate analysis of arc characteristics is not enough. Schulman M B[11] put forward that, in the breaking process of vacuum switch, the arc form change from constricted type to diffuse type along with the electrode separations changes, fully constricted vacuum arc lead to electrode ablation. Therefore, the research on how to detect dynamic electrode position in the arc image and calculate the separation is meaningful, we can analyse the relationship between the arc form and electrode separations quantitatively[12-14]. In the process of algorithm development, we found out that, the existing target detection algorithm is not effective on the electrode detection in the vacuum arc sequence images. This paper presents upper and lower arc edge detection algorithm in vacuum arc sequence images, and calculate the separation by fitting the edge into straight line, the result of this research lay a foundation for the relation research between electrode separation and arc form [15-17].

2. Object detection

The analysis techniques of image processing mainly includes the following: image preprocessing, automatic detection of moving object, moving object tracking, moving object classification and moving object positioning, etc. Object detection is at the lowest level of image processing, and it is the basis of following advanced processing, such as the object classification and activity understanding. Currently, the mainly moving target detection algorithms are the optical flow method, frame difference method, background difference method, template matching method and feature extraction method [18]. Comparing with the daily images, the vacuum switch arc image as shown in Figure1 has following characteristics.

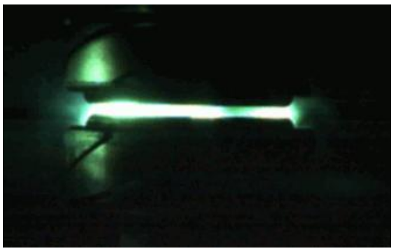

Figure 1 Colorized vacuum arcs image

Figure 2 Binary image vacuum arcs image

In the Figure1, the top electrode is anode, and the other is cathode. Normally, anode is fixed, and cathode moves, we have to detect the cathode to track the cathode and calculate the displacement. When burning: uneven distribution of arc image grayscale, part of the arc has high gray value and high brightness, while the other part has low gray value and low brightness. And the gray value between frames of the same pixel will change dramatically with the morphological change of burning arc; Droplet will splash during the arc burning process which makes the arc image also appears in the area of electrode image; The morphological changes are irregular and the characteristic corner is vague, so it is difficult to finish the feature points matching between frames; The quality of arc image largely depends on the resolution of high-speed framing camera. Base on the statement above, the background and electrode cannot be segmented due to the low gray value of electrode in the image. At the same time, the electrode characteristics matching or the electrode pattern-matching between frames also cannot be finished.

In conclusion, the electrode position cannot be detected directly with the existing target detection algorithm due to the particularity of arc images. Through the analysis of arc images we find out that, edge of electrode and edge of vacuum arc are overlap, and the position of anode and cathode are the upper edge and lower edge respectively, then we can avoid the problem of detecting the contact position directly by detecting the upper and lower edge of vacuum arc.

3. Detection algorithm

Through gray processing, binarization processing and image denoising, the binarization image as Figure.2 was abtained.

The techniques of edge detection have been very mature，there are a lot of Edge detection operator such as Roberts, Sobel and Prewitt [19]. But operators above can't be used to detect the upper and the lower edge respectively, and the computation of operators above is large. Analyzing the pixel of arc edge, we find out that the pixel of the upper edge is the first pixel which value is equal to 1 from top row to the bottom row in its column, and the pixel of the lower edge is the first pixel which value is equal to 1 from bottom row to top row in its column. Assume that there are M rows and N columns in arc image, then the process of upper edge pixel detection is: detecting the pixels from row 1 to row i(1≤i<M)in column j(1≤j<N)until the pixel value is equal to 1, which is the pixel of upper edge; in the same way, the process of lower edge pixel detection is: detecting the pixels from row M to row i(1≤i<M)in column j(1≤j<N)until the pixel value is equal to 1, which is the pixel of lower edge. Program is designed based on above idea, program flowchart is shown in Figure 3 and Figure4.

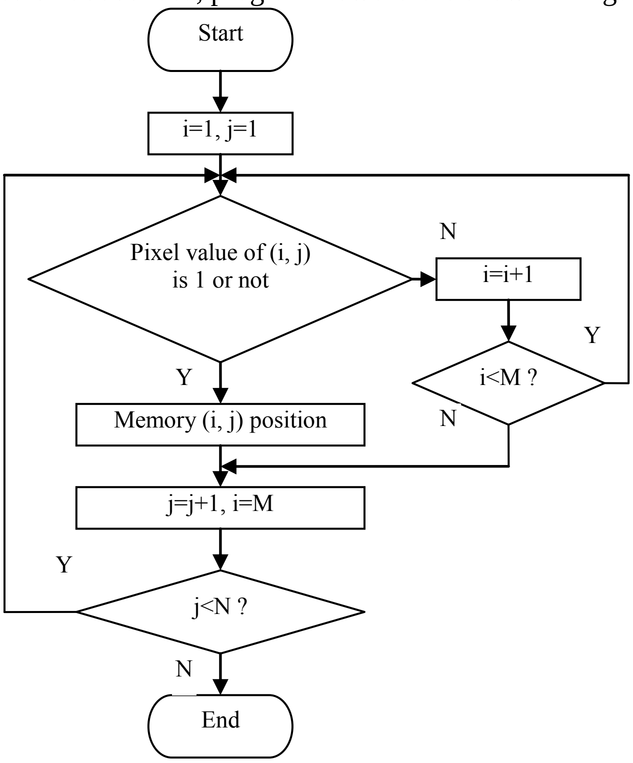

Figure 3 Program flowchart of upper edge detection

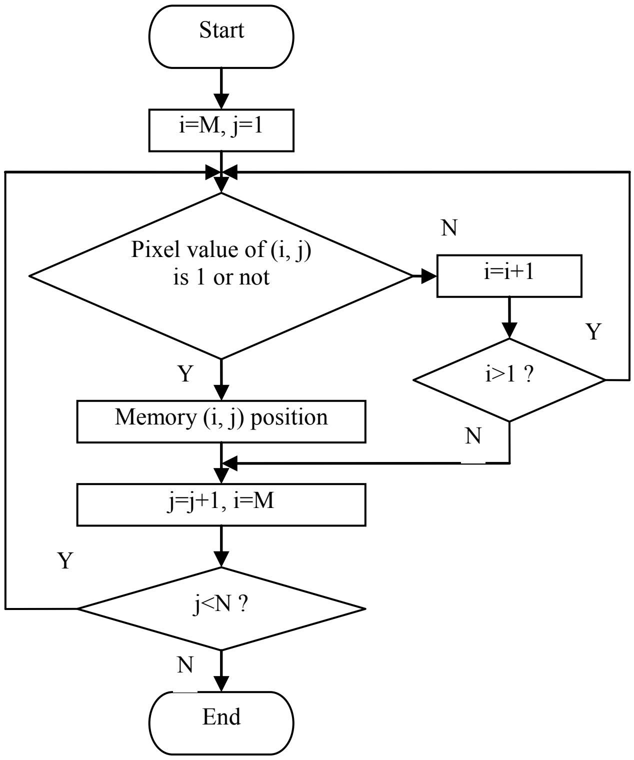

Figure 4 Program flowchart of lower edge detection

The detection result of upper and lower edge is sequence pixels (Yi, Xi), i [1, n], Yi is the raw coordinates, Xi is the column coordinates. On the macro, the upper and lower edge is the positon of electrode, the problem is that some of these sequence pixels are the edge pixels of splashing arc, and the upper and lower edge are not straight line, therefore, the mathematical method is necessary. We can calculate the position of electrode by Yi, i [1, n]. The formula (1) is applied to calculate the mean value of Yi, i [1,n]. The formula(2)is used to calculate the deviation degree of every pixel， formula(3)is applied to eliminate the pixels which deviation is larger than T.

$$b = \frac{\sum_{i=1}^{n} Y_i}{n} \tag{1}$$

$$D_i = [Y_i - b]^2 \tag{2}$$

$$I(Y_i, X_i) = \begin{cases} 0 & D_i > T^2 \\ 1 & D_i \leq T^2 \end{cases} \tag{3}$$

The upper edge and lower edge is not an ideal straight, to describe the position of electrode accurately, calculating the contact position by using linear fitting is necessary. Using least square method shown in formula (4) to formula (8) [20] to do a linear fitting for the electrode edge sequence pixels (Yi, Xi), i [1,n]. Supposing is the linear equation of electrode surface, and it can be simplified into . The reason is that usually the high-speed framing camera is placed horizontally to make the electrode parallel with the X axis all the time. The sequence pixels of upper edge (or the lower edge) after removing the larger deviation pixels is (Yi, Xi), i [1,n1], n1<n. The deviation of detected pixels and the pixels on the fitting line is:

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$$\begin{cases} d_1 = Y_1 - b \\ d_2 = Y_2 - b \\ d_3 = Y_3 - b \\ \cdots \\ d_{n1} = Y_{n1} - b \end{cases} \quad (4)$$

Assigning a suitable value for b to make the value of is the minimal. The calculating method of b is as follows:

$$D = \sum_{i=1}^{n1} d_i^{\,2} = \sum_{i=1}^{n1} [Y_i - b]^2 \quad (5)$$

The first derivative of D to b is:

$$\frac{\partial D}{\partial b} = -2[\sum_{i=1}^{n1} Y_i - n1 \cdot b] \quad (6)$$

Making the value of first derivative zero:

$$-2[\sum_{i=1}^{n1} Y_i - n1 \cdot b] \quad (7)$$

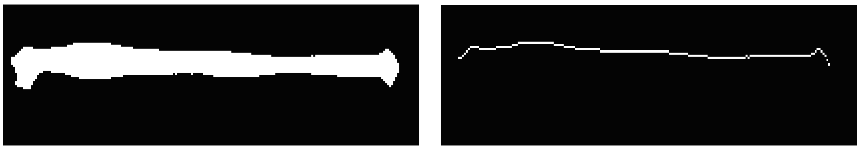
Then, we can get:

$$b = \frac{\sum_{i=1}^{n1} Y_i}{n1} \quad (8)$$

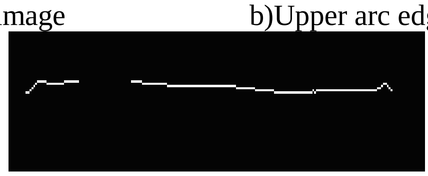
The result, Y=b is the electrode position.

4. Experimental results

To validate the algorithm above, we programmed with MATLAB, selected single frame arc image with 220*340 pixels and running the program on a computer with INTEL i5-2400 CPU 3.10GHz, 3.23GB memory. The result is shown in Figure 5.

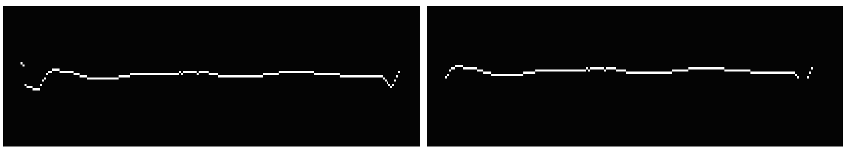


a)Binary arc image b)Upper arc edge detection result



c) Eliminated larger deviation pixels

(1) Detection result of upper edge in arc image



a) Lower arc edge detection result b) Eliminated larger deviation pixels

(2) Detection result of lower edge in arc image

Figure 5. Detection result of lower and upper edge in arcs image

After calculation above, we can find out that the upper edge position of Figure5 is Y=90.1031, and the lower edge position is Y=101.6134. The detection result indicates that the lower and upper edge of arc can be detected effectively by using the edge detection algorithm described in this paper.

The algorithm above can be also applied to the sequence images. The dynamic electrode position tracking will be realized by detecting the lower edge of arc in each frame image. Select 8 frames in sequence vacuum arc images which are shown in Figure6, and select an image every 5 frames to distinguish the change of dynamic electrode position more clearly. The detection result of dynamic electrode position of each image is shown in Figure7. In the result, the white line is the detection results of arc edge and the red straight line is fitting results. The fitting result of lower edge is Y100=100.0495,Y105=100.5784,Y110=101.0591,Y115=101.8474,Y120=102.4158,Y125=102.6578, Y130=103.8474,Y135=104.6839. The results shown in Figure 5 to Figure7 are the selection of the results which are more representative to illustrate the effect of the algorithm. It is true that, we can identify the displacement of electrode by the experimental data Y more obviously than by eyes. The curve of electrode displacement over time shown in Figure8 is used to indicate the electrode movement in sequence images more intuitively. In the experimental process, 41 frames images were selected from 400 sequence images which were the images appear in the arcing process during 10ms. That means we detected the dynamic electrode position in every 10 frames images. The difference value of upper edge fitting result and lower edge fitting result is the displacement of cathode.

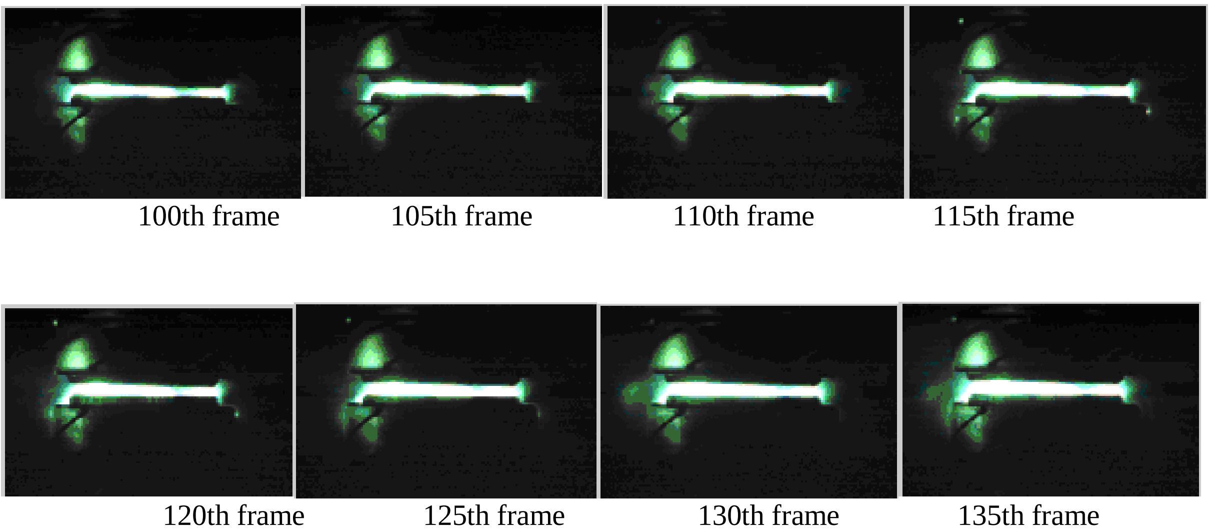


Figure 6. Sequence arcs images

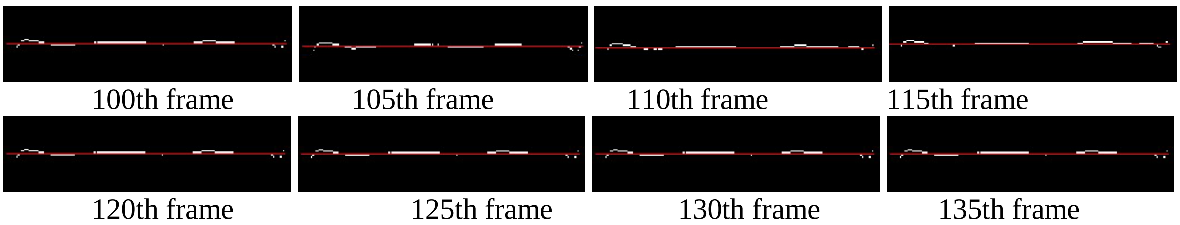


Figure 7. Lower edge detection in sequence arc images and the result of linear fit

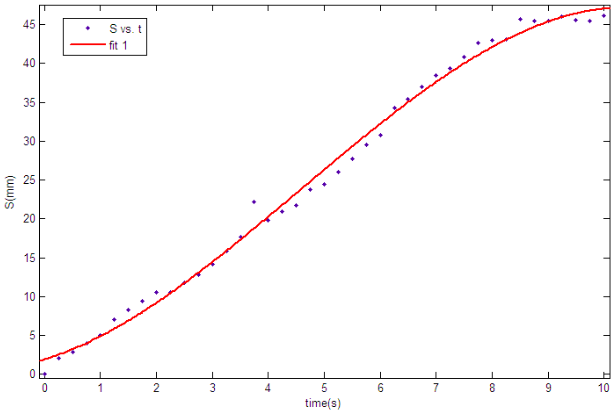


Figure 8. Curve of cathode displacement over time

5. Conclusion

The algorithm presented in this paper can be used to detect electrode position in the single frame arc image or in sequence arc images. By many experiments we have found that:

(1) In the vacuum switching arc image, the lower and upper edge of arc are the position of the anode and cathode respectively.

(2) The lower and upper edge of arc are not an ideal straight line, there are two main reasons: first, the violent combustion of arc splash out electrode gap, as a result, the edge image of electrode is no longer a straight line. Second, the melting phenomenon will appears on the local electrode caused by the arc erosion, which also makes the lower edge of the arc image not a straight line.

(3) The lower and upper edge of arc can be fitting into a straight line with the usage of linear fitting method. And the fitting straight line can mark the contact position more accurately.

(4) In vacuum arc image, the anode position will be detected by the detection of upper arc edge, and we just detect the anode position once for the anode is fixed, the cathode position will be detected by the detection of lower arc edge. The difference value of upper edge fitting result and lower edge fitting result is the displacement of cathode.

Acknowledgments

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