THE VERIFICATION OF A COMPUTATIONAL MODEL OF ARC MOTION USING AN ARC IMAGING SYSTEM

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ABSTRACT

This paper considers the computational modelling of arc motion under short circuit conditions in low voltage circuit breakers with a focus on the verification using controlled experimental conditions. An optical fibre based arc imaging system (AIS) is used to provide the quantitative data on the arc motion. The paper shows that the arc root motion is linked to the arc voltage and that the simulation gives a good representation of the overall arc movement, but is unable to model the high frequency events associated with the arc entry into splitter plates. A modification to the arc model is shown to allow the determination of the exit voltage, prior to arc extinction.

1. INTRODUCTION

Low-voltage switching devices (LVSDs) are widely utilized in power distribution networks to turn on and off circuits and to extinguish the arc during overload or short circuit conditions. The quenching chamber consists of a movable and fixed contact, splitter plates and vents. During an opening event, an arc is established between the contacts and then forced by electro-magnetic forces into the quenching chamber, where it elongates, increasing the arc voltage before entering the splitter plates. In the splitter plates the arc is divided into smaller arc segments, resulting in multiple arc interactions with the metallic surfaces, and increasing the overall arc voltage as a function of the number of voltage drops associated with each anode and cathode roots. The increase in the arc voltage leads to a reduction in the arc current, and when compared to the prospective current, this is referred to as current limitation. A detailed review of the arcing phenomena associated with LVSD's is described in [1,2]. Enhanced switching performance is achieved by improved current limitation; when the arc quickly enters and stays within the splitter plate region with the arc remaining attached to the surface of the plates. In this paper a flexible test apparatus (FTA) is combined with an arc imaging system (AIS) to link experimentation and computational models, allowing an analysis of the robustness of the computational model. A key output parameter from the modelling process is the exit voltage, as this has been shown to be linked to the arc re-striking after current zero in AC systems, [3].

2. ARC IMAGING SYSTEM (AIS).

The first solid state optical fibre based arc imaging system was presented in [4]; and described in detail including an overview of the current limiting application and other related technological areas, in [5]. The system was used in a detailed study of parameters influencing arc motion in a flexible arc testing chamber (FTA). In [6] a commercial circuit breaker was used and the AIS used to determine the influence of the magnetic circuits on the arc motion. In [7], the first definition of parameters used in the FTA; where the arc root times were used to determine the influence of the contact velocity. In [8], it is shown that the delay in the anode root transfer from the moving contact, contributes to a delay in arc motion. Prior to this it was assumed that the cathode root motion was the dominate mechanism. In [9], important solutions were introduced to aid the arc commutation from a moving contact. The experimental results presented show the influence of arc chamber venting, current level, current polarity and contact velocity on arc motion, and a solution was proposed to reduce the influence of gas flow on the arc commutation from the moving contact. In [10], a pressure probe and spectral data measurement were incorporated into the FTA. These measurements were used to investigate gas flow characteristics in the arc chamber. The combination of optical and spectral data provided new insights into the nature of arc motion. The influences of arc chamber material, contact material, and contact opening speed, were investigated to improve arc control for a low contact opening velocity. In [11], a new approach to our understanding of the short circuit arcing process is presented by concentrating on the bulk thermal behaviour and energetics of the arcing and gas flow during contact opening. Data is presented on mass and volume flow rates as well as estimates of the gas velocity in the contact region. In [12], a new actuation methods was presented to remove the dependency on a solenoid actuated short circuit opening. The AIS system developed and used in all of these paper was re-designed in 2010 and the new upgraded AIS is detailed in [13,14]. The key features of the new AIS are detailed in table 1, where the parameters used in the experimental investigations presented in this paper are also shown. The system has been designed to improve the light transmission performance with specially designed connector blocks, such that users can station the AIS remotely from the arcing event, (up to 20m). The normalisation of the fibre array to provide consistent transmission levels for a known light level is a further innovation in the new design. In the experimental setup used in this paper, as shown in table 1, an optical filter (ND8) is used to reduce the light intensity recorded, as a consequence of the short optical fibre length (2 m).

The new design has enabled a number of innovations in the monitoring of the arc motion. The increased number of fibre has allowed a detailed investigation of the arc motion in splitter plates, as shown by the fibre positions in the FTA arrangements shown in Fig 1. The venting of the arc chamber is controlled, by the green block on the left of the image. The moving contact is triggered by a short circuit event from capacitive discharge system, [4-12]. The 120 optical fibre positions are shown with the white dots, and include 4 positions between each of 7 splitter plates. This allows for the monitoring of the arc in the splitter plates, for comparison with CFD models. The yellow fibre positions are used to allow the plotting of the arc root motion (X) along the fixed contact runner, with X=0 mm in the contact region to X= 50.7 mm, in the splitter plates. A correlation between the intensity of the light and the plasma temperature, has been investigated [15] and it has been shown that the intensity measured by the AIS has a near linear relationship with the plasma temperature.

Table 1. Arc Imaging System AIS specification.

	Max Value	Experiment Values
Sample Rate	6 MHz	1 MHz
Number of Optical Fibres	1024	120
Number of Frames	512,000	512,000
Capture time	0.09 sec	0.5 sec
Light Intensity Resolution	8 bit (0-255)	8 bit (0-255)
Signal Gain	1-32	1-4
Length of Optical Fibre	100 m	2 m
Light Intensity Filter	ND0-16	ND8

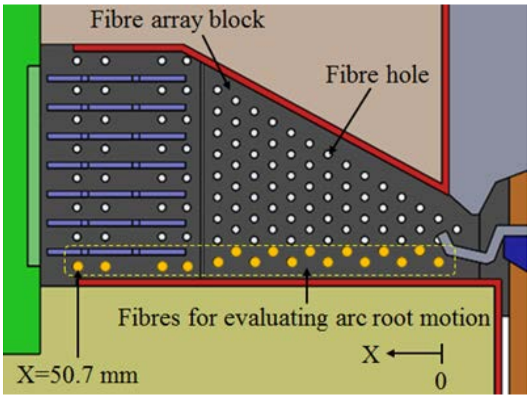

Fig.1 New FTA showing the optical fibre positions, used for evaluation of arc root motion and the position of optical fibres in the splitter plate region.

3. ARC ROOT MOTION.

The AIS has been used to investigate phenomena associated with arc extinction process, when compared to the previous studies reported here, which were mainly focused on the arc opening processes. A number of studies have been conducted, firstly around the venting condition for a simplified arc chamber FTA, [16,17]. In a related study an experimental investigation has been conducted of Re-ignition Evaluators, [3]; where it has been shown that a ratio between the exit voltage, (the arc voltage prior to the current zero) and the supply voltage is a critical factor governing the likelihood of a re-strike after current zero. The estimation of the exit voltage has been shown to be a critical output from CFD computational models and the AIS and FTA have been used in the evaluation of these parameters.

Fig 2 shows the link between the arc motion (X) and the arc voltage, over a 1.2 ms window, as the arc enters the splitter plates. A correlation is shown between the position of the arc root and the arc voltage. The evaluation of the arc root positon is based on an averaging of the light intensities along the fibre positions highlighted in yellow in Fig.1, [16]. Fig.2 shows the fluctuation of the voltage as arc enters the splitter plates. It is shown that while the root of the arc on the runner is in the splitter plates at 50mm, the main body of the arc plasma shows instability, reflected in the voltage fluctuations.

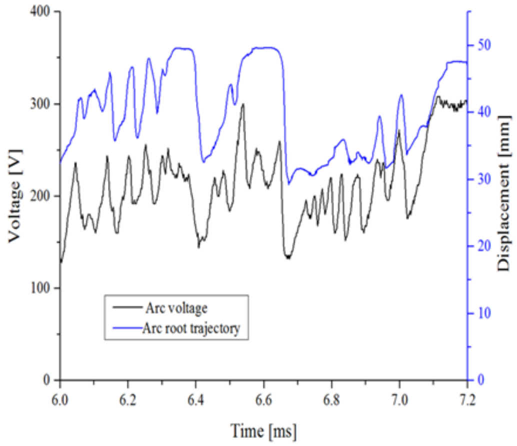

Fig.2 The arc root trajectory as the arc enters the splitter plates, (X) displacement and arc voltage, for a 200 V, short circuit event.

4. COMPUTATION MODELLING OF ARC MOTION IN LVSD'S.

The FTA geometry shown in Fig.2 has been used as the control volume for the computational modelling. Details of the simulation approach are provided in [15,18]. Fig.3 shows the arc event starting at 0ms, (to synchronise with the arc model) while the short circuit current is close to the peak value (1750A). The arc images shown that the arc moves rapidly to 1.5ms where it starts to enter the plates. It then re-strikes at 2ms before re-entering the plates at 2.3ms. The corresponding arc voltage increases to 150V before reducing to 80V during the re-strike. After 2.3ms there are a number of fluctuations in the arc voltage before stabilising in the plates at 3.7ms. The exit voltage is shown to be 390V. The simulated voltage is shown to follow the trend. The drop in the voltage at 1.7ms, rather than linked to a re-strike, as in the real event, is linked to a stationary arc with reducing current flow. The simulated arc fully enters the plates at before 3ms, showing a backwards motion, before stabilising in the plates at 3.3ms. The exit voltage is lower than the real voltage and occurs before the real event. The reduced duration of the event is a consequence of the current limiting effect, as the arc remain longer in the plates in the simulated data.

The CFD model, [15,18], in Fig.4 shows the plasma temperature, in a half section of the arc chamber. Thus the splitter plates appear to be smaller, because of the cross section geometry of the plates. The AIS, arc intensity image on the right, is superimposed on a photo of the arc chamber, where the contact is shown in the default closed position. In the simulation the temperature is higher close to the arc root. The corresponding arc image shows the arc roots at a similar locations but with the higher temperature (intensity) away from the arc roots. It is noted that some fibres close to the runner are likely to be obscured by the arc runner, leading to a lower intensity. The arc model provides a reasonably good simulation of the real event in both position and voltage, but that there are inconsistencies around the temperature distribution and the arc position during high frequency events.

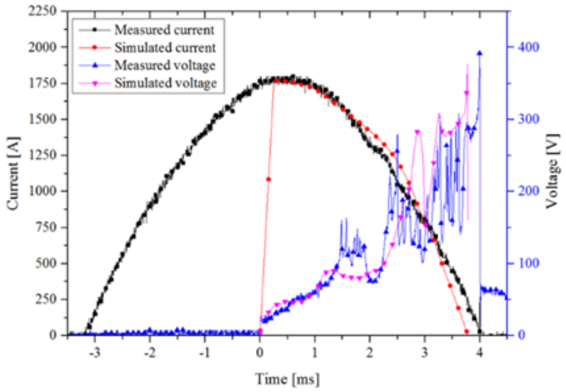

Fig.3 Measured and Simulated V,I for a 200V supply,1750 A peak.

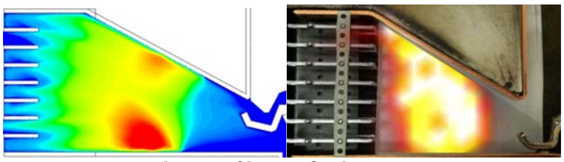

Fig.4 200V supply, ND8 filter, Left, plasma temperature at 2ms, (blue below 5,000 K, and red above 19,000 K). Right, the corresponding arc image at frame 5210.

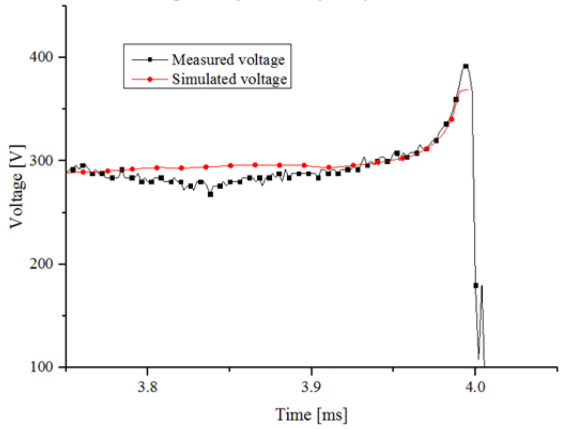

Fig. 5. Measured and simulated arc voltage near the current zero point.

To improve the prediction of the exit voltage, the simulations shown in Fig 3 and Fig. 5, have implemented a modification to the V-J curve, [19,20], (relationship between the arc root voltage and current density). Fig 5, shows details of the arc voltage prior to extinction for both measured and simulated data. In this case (Fig.5) using the experiment current as an input to the model to improve the synchronisation with the experiment. The arc model shows an exit arc voltage of 327V at 3.98ms, while the measured value is 332V, where the exit arc voltage is defined as the arc voltage 20µs prior to the current zero point [20].

6. CONCLUSIONS

The paper summarises the verification process for CFD based computational models of arc motion in LVSD's. It shows that high frequency events are not replicated however the overall trends are predicted. A new approach on calculating the arc exit voltage has been discussed and is shown to improve the prediction capability.

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