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AC short-circuit control mechanism and short-time discharge technology

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ABSTRACT
The purpose of this study is to present a technique for quick vacuum breaking that is controlled by an AC short-circuit current and carried out by a fast vacuum circuit breaker (FVCB) in a brief arcing period. The technology consists of calculating the lowest opening velocity, quickly estimating the zero point of the short-circuit current, and optimizing the Thomson coil actuator. When a few cup-type axial magnetic field contacts are employed to break a short-circuit current of 40 kA, the minimum opening velocity of 3.2 m/s is discovered. The required time is 4.0 $\pm$0.4 ms for the forecast of the short-circuit current zero.
The actuator's optimization aims to reduce both the moving mass of the FVCB's gearbox components and the stored energy of its opening and closing capacitors. In order to confirm the controlled breaking performance, terminal fault test responsibilities of T100s and T100a were executed on a prototype of 363 kV/5000 A-63 kA FVCB. The regulated short-arcing time of the prototype was 2.5 ms, as shown by the successful termination of an 80.6 kA short circuit current at a 4.5 m/s opening velocity.
Keywords-controlled switching; electromagnetic repulsion actuator; fast vacuum circuitbreaker; short-circuit current

I.INTRODUCTION

When compared to a traditional mechanical circuit breaker, a fast circuit breaker powered by a Thomson coil actuator can open quickly as soon as the opening coil is activated[1]. By using controlled switching technology, it enables the fast circuit breaker (FVCB) to eliminate an AC short-circuit problem in the first current loop.Devices like the switch-type fault current limiter, the hybrid DC breaker, and the AC fast vacuum circuit breaker, which use Thomson coil actuators, are of great interest. A 126 kV doublebreaks FVCB with the intention of controlled switching was created by Bojian Zhang[2] in order to control switching and reduce the inrush current of the capacitor banks, Jinnchang Wu[3] suggested a hybrid fast switch. There are no present technologies that are pertinent to a technology of short-circuit current controlled quick vacuum breaking in a brief arcing period.

The FVCB's high opening velocity helps it perform well at breaking current. In a prior study[4], we discovered that when the initial opening velocity increased, the minimum arcing time of the FVCB reduced. In this study, a method for quick vacuum breaking under control of an AC short-circuit current in a brief arcing time is proposed.

II. TECHNOLOGY OF THE AC SHORT-CIRCUIT CURRENT CONTROLLED FAST VACUUM BREAKIN

A. Determination of the Minimum Opening Velocity

During the AC short-circuit current breaking process, there exists a threshold opening velocity υ_{th} corresponding to a peak critical arcing contact gap dcri_intense, for an axial magnetic field (AMF) contact. The dcri_intenseindicates a transition of the vacuum arc anode discharging mode from an intense mode into a diffuse arc mode, which is benefit for a successful breaking of the short-circuit current. Fig. 1 shows a dependence of the dcri_intenseon the opening velocity v of the FVCB, during a 40 kA short-circuit current breaking process. The transition of the diffuse arc mode was characterized by the cathode spots on contact surface dispersing from the constricted intense arc. When the FVCB opens, its velocity should be more than 3.2 m/s. The arcing contact gap for the change from the intense to the diffuse arc mode was 2.09 mm, and the required arcing duration was 0.47 ms, while the opening velocity of the 40.5 kV FVCB was 4.5 m/s. The terminal fault test duty of T100s(b) indicates that the minimum arcing time in a synthetic test circuit was shown to be 0.5 ms.

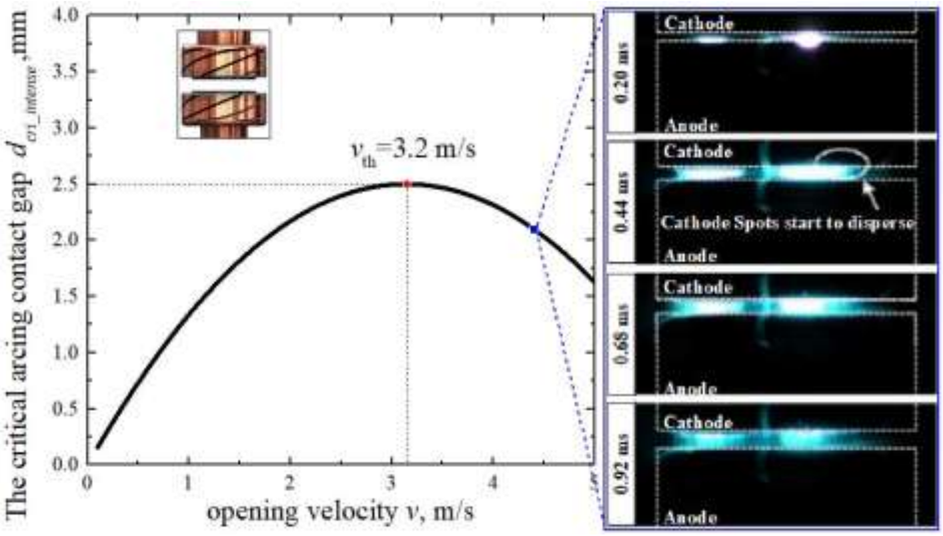

Figure 1. Dependence of the critical arcing contact gap dc intense on theopening velocityv of the FVCB, indicting a transition of the anode dischargemodes from the intense arc mode into the diffuse arc mode.

B. Fast prediction of the short-circuit current zero

For the FVCB to eliminate the AC short-circuit fault in one current cycle, a fast relay protection system was required. In this paper, a fast current zero predicting algorithm based on the method of the least square was also used. Both algorithms worked together to predict the current zero once the curvature of the current waveform was higher than a threshold value, usually 0.01; in this case, the 40.5 kV FVCB was informed to open with an arcing time higher than the minimum arcing time of 0.5 ms for a reliable breaking of the short-circuit current.An STM32 processor was used to run the algorithms, and an RTDS (real-time digital simulation system) was used to confirm them. It was confirmed that the amount of timerequired to estimate the present zero point was4.0 $\pm$0.4 ms.

C. Optimization of the Thomson coil actuator

Based on a multi-physics coupled simulation, an optimization of the Thomson coil actuator integrated with a gas buffer was carried out. The optimization sought to minimise the moving mass of the transmission components as well as the stored energy in the opening and closing capacitors. The relevance of each impact factor on opening and closing features was ascertained using the Plackett-Burman factorial designing method.The optimized parameters of the actuator, which powers the 40.5 kV FVCB, are displayed in Table I. The structure of the optimized actuator integrated with the gas buffer is depicted in Fig. 2. The FVCB's gearbox components' combined moving mass dropped from 7.5 kg to 4.5 kg. Half of the 20 mm stroke had average opening and closing velocities of 4.5 m/s and 2.5 m/s, respectively.

TABLE I. OPTIMIZED PARAMETERS OF THE THOMSON COIL ACTUATOR

Items	**Symbol**	**Units**	**Quantity**
Turns of the opening & closing coils	N	———	15
Hight of the opening & closing coils	H	mm	15
Inner diameter of the coils	r	mm	60
Outer diameter of the coils	R	mm	200
Thickness of the repulsion disk	T	mm	15
Diameter of the repulsion disk	D	mm	200

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Air gap between the disk with the coils	δ	mm	1.0
Opening & Closing capacitor	C	mf	15
Charged voltage of the opening capacitor	Uop	KV	0.65
Charged voltage of the closing capacitor	Uclo	KV	0.65
Moving mass of the FVCB	m	Kg	4.5

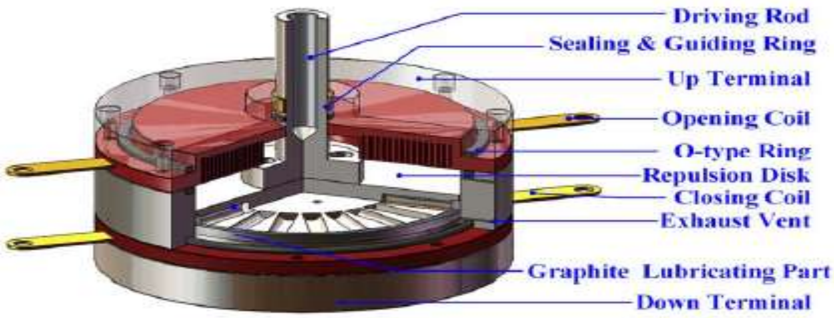

Figure 2. Optimized prototype of the Thomson coil actuator integrated witha gas buffer, which is used in a 40.5 kV FVCB.

III. TYPE TEST VERFICATION

Ultimately, a controlled quick vacuum breaking of the high short-circuit current was assigned to a short arcing time of 2.5 ms. To validate the technology of short circuit current controlled fast vacuum breaking performance in a short-arcing time of 2.5 ms, a prototype of a 363 kV/5000A-63 kA multi-breaks FVCB was used.The prototype was made up of two branches, each branch made up of six series-connected 40.5 kV FVCB units. In accordance with the national standard GB/T 1984-2014, test duties for T100s and T100a were completed. A typical T100s test record of the 363 kV FVCB prototype is displayed in Fig. 3. The test findings demonstrated the technology's confidence in its ability to successfully clear an 80.6 kA terminal fault short-circuit current.

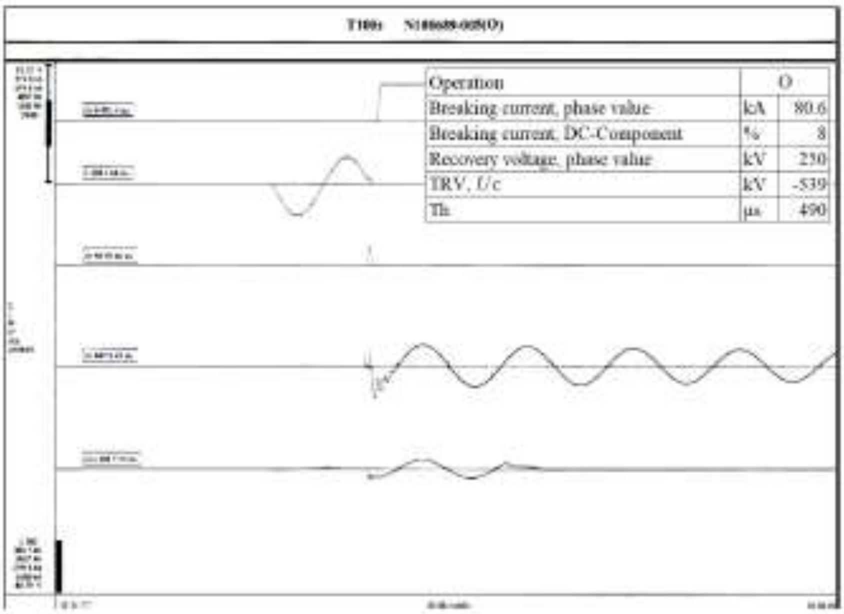

Figure 3. Typical T100s test record of the 363 kV FVCB prototype.

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IV. CONCLUSION

This work suggested and proved the technique of quick vacuum breaking with AC short-circuit current control in a short arcing time. The technique included the Thomson coil actuator optimization, the quick prediction of the short-circuit current zero in 4.0~<0.4 ms, and the minimum opening velocity of 3.2 m/s. The 363 kV/5000 A-63 kA FVCB was ultimately given a short arcing time of 2.5 ms and an opening velocity of 4.5 m/s for each 40.5 kV breaking unit. The prototype's controlled fast breaking ability was confirmed through the T100s and T100a terminal fault test duties, wherein the test short-circuit current was 80.6 kA.

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