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Improvement of AMF distribution in the inter-contact gap of VCB

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ABSTRACT

Nowadays, many manufacturers of vacuum circuit breakers (VCB) apply the axial magnetic field (AMF) to stabilise the electric arc diffusion during current breaking process. In many papers, various designs of contacts are proposed to improve the AMF distribution between circuit breaker's contacts. In the present paper, some methodological aspects of AMF investigations have been presented and discussed. In the beginning, a short explanation of AMF influence on arc behaviour has been presented. A simplified physical model of phenomena considered has been applied for this purpose. The above analysis indicates that special attention should be paid to reach possibly high value of the axial magnetic field density especially in the peripheral electrode region. An own laboratory stand for AMF measurements has been described. Measurement and computational results of AMF distribution have been compared. The computations have been done with a commercial software package Maxwell (Ansoft) based on the finite element method (FEM). Good convergence of the results compared indicates that AMF can be investigated in experimental as well as in theoretical way. The numerical analysis presented enabled to select the contact configuration which ensures more stable arc behaviour during the circuit breaking process. Images of arc behaviour registered with a high speed camera for a new contact construction as well as contacts known from industrial practice have been presented.

1. Introduction

Nowadays, many manufacturers apply the axial magnetic field (AMF) to stabilise the electric arc diffusion between contacts of medium voltage vacuum circuit breakers (VCB). Recently, AMF is also employed in prototypes of high voltage VCBs with a single break [1,2]. Due to AMF the vacuum arc constriction is reduced and the arc disperses more uniformly over the contact surface. It limits the contact erosion and enlarges the number of successful breaking operations. Application of AMF enables the VCB size reduction and increases its interrupting ability.

Therefore, the analysis of the AMF distribution between VCB contacts is of great practical importance for designers.

The literature concerning the problem in question is very extensive. There are numerous papers, e.g., [3–16], concerning experimental investigations of VCBs with AMF. Mainly, a demountable vacuum chamber has been applied in these articles. The wide review of these papers was presented in Ref. [14].

There are also articles, e.g., [17–25], devoted to the numerical estimation of physical processes in the inter-contact gap of VCBs. Some of these papers [17,22–24] concern the numerical modelling of arc behaviour (diffusion) between the contacts of VCBs. 2D axisymmetric magnetohydrodynamics (MHD) arc models are applied in the most of these papers, e.g., [17,22]. Unfortunately, the problem is typically 3D because of complex geometry of the contacts considered. The 2D approach mentioned needs simplifications of contact shapes and these simplifications cause inaccuracies in the AMF estimation. Recent advancement of computer technology and development of numerical techniques enable to solve this problem in 3D with a simplified MHD representation [23,24]. Such an analysis (after further development of numerical techniques and progress in computer technology) in near future will be probably a helpful tool for investigations of the arc phenomenon. Nevertheless, the AMF distribution can be investigated (for practical purpose) using much simpler methods, e.g., [20,25]. Such an approach is presented in this paper.

Own laboratory stands and the commercial software package Maxwell (Ansoft) for the analysis of 3D quasistationary eddy current problems are applied here. The finite element technique is employed in the software mentioned. The results of the numerical analysis have been compared to the measurements taken on the laboratory stand. The approach presented has been used to design the contact set which ensure more stable arc behaviour during the circuit breaking process. These new contacts have been tested in a demountable vacuum chamber.

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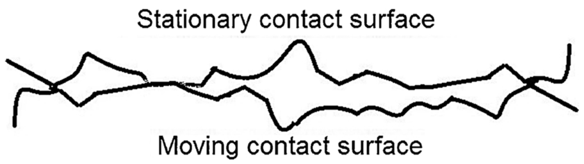

Fig. 1. Sketch of high-magnification picture of contact surfaces.

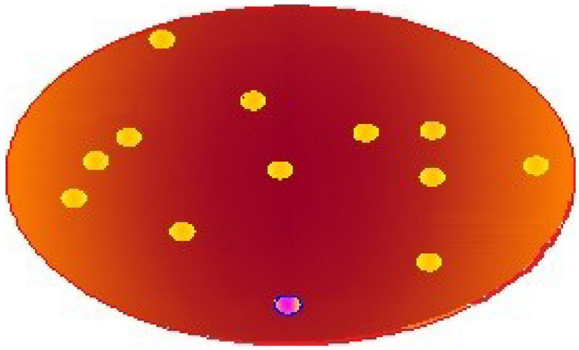

Fig. 2. Cathode spots randomly distributed on contact surface.

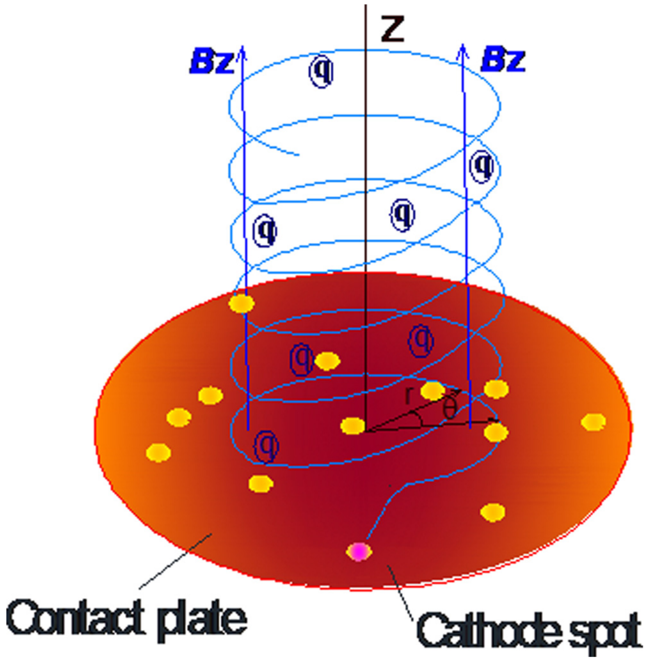

Fig. 3. Electron (emitted from cathode spot) travelling between contacts in presence of AMF.

However the beneficial influence of AMF on arc behaviour is well known for VCB designers, the explanation of this phenomenon is described (in the literature) rather seldom and very cursorily, e.g., in Ref. [26]. Therefore, a simplified model accounting for the role of AMF in vacuum arc diffusion is shortly presented in the next section of this paper.

2. Simplified physical model accounting for the AMF influence on arc behaviour

The contact surfaces are never perfectly flat. A high-magnification picture (Fig. 1) shows a number of microscopic peaks and valleys on the contact surface. Therefore, the current is conducted only through a number of microscopic contact spots of the closed contacts. These contact spots are randomly distributed (Fig. 2). During the contact opening, the cathode surface has a number of bright regions named cathode spots. The electrons emitted by cathode spots (Fig. 3) create the vacuum arc (conducting a short circuit current).

Precise mathematical simulation of arc behaviour in the VCB's inter-contact space is a very complicated task that requires to solve the 3D coupled partial differential equations of plasma magnetohydrodynamics (MHD) with consideration of cathode spots' theory [26]. Fortunately for VCB's designers, a detailed quantitative knowledge about the arc behaviour is not necessary, however, is very useful. To account for the influence of AMF on arc behaviour, the simplified physical model of the phenomena can be applied. In this model, a single charged particle (electron) emitted from the cathode spot is considered.

The basic formula describing the force acting on a electric charge, q, in the magnetic field, $\boldsymbol{B}$, and the electric field, $\boldsymbol{E}$, is:

$$\boldsymbol{F} = \boldsymbol{F}_{el} + \boldsymbol{F}_m = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}) \tag{1}$$

The above formula contains Coulomb's ($\boldsymbol{F}_{el} = q\boldsymbol{E}$) and Lorentz's ($\boldsymbol{F}_m = q\boldsymbol{v} \times \boldsymbol{B}$)forces, where $\boldsymbol{v}$ is the particle velocity.

The axial charge movement with a velocity, v_z, due to the force $F_z = qE_z$ is caused by the voltage between the contacts. The total short-circuit current, I_z, consists of all these charges moving with velocity v_z. The above short-circuit current produces a tangential magnetic field, B_Θ, accordingly to Ampère's law. Applying a simplification that j_z is of constant value:

$$j_z(r) = I_z/S_c \tag{2}$$

(where S_c is the contact surface area) the circumferential magnetic field mentioned can be estimated as follows:

$$B_\Theta(r) = \mu_0 I_z \frac{r}{2\pi R^2} \tag{3}$$

This circumferential magnetic field, B_Θ, in conjunction with the axial charge velocity, v_z, produces the radial Lorentz force:

$$F_{mr}(r) = -q\mu_0 I_z \frac{r}{2\pi R^2} v_z \tag{4}$$

where R is the radius of contact's surface. The minus sign denotes that the force is directed toward the contact axis. This force causes an adverse arc constriction (columnar arc). The above arc constriction is hampered by the Hall force (5) which is opposite to Lorentz's force under consideration.

$$F_{hr}(r) = qE_{hr} \tag{5}$$

In absence of an additional magnetic field, the columnar arc radius, r_c, is stabilised when Lorentz's and Hall's forces are balanced:

$$F_{mr}(r) + F_{hr}(r) = 0 \tag{6}$$

As it was mentioned, the columnar arc causes considerable erosion of the contact plate's surface which shorten the apparatus lifetime. Therefore, an auxiliary magnetic field should be produced to disperse the columnar arc making it more diffusive. Such a magnetic field is obtained by appropriate contact design.

In the AMF type contacts because of their geometry, the circumferential current appears. This current excites the axial magnetic flux density, B_z, in the inter-contact gap The mentioned magnetic flux density component in conjunction with the radial charge velocity, v_r, produces circumferential magnetic force, $F_{m\Theta}$:

$$F_{m\Theta}(r) = qB_z v_r \tag{7}$$

The above circumferential force causes the circumferential velocity, v_Θ. Therefore, a centrifugal force appears: