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SHORT CIRCUIT ANALYSIS OF AIR CIRCUIT BREAKER

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ABSTRACT

In this paper, the overall effect of the different parameters which affect the circuit breaker at the time of short-circuiting is to be elaborated. The air circuit breaker is a switching device that is used to make and hold current under normal conditions and to break the current under abnormal conditions. Due to the short circuit current, a greater amount of detrimental energy is emitted in the form of heat and magnetic force. So it is vital to calculate and analyze the electro-dynamic repulsive forces appearing on the movable conductor. By the usage of the finite element analysis, current, magnetic field, repulsive forces have been simulated with the assist of the contact bridge model. With different configuration and model simulations and experiments been carried out for repulsion forces. The end result shows the tremendous use of no of contact system in the model to gain efficient force at the contact surface.

Key words: Short Circuit, FEM, Electrodynamic Forces, Parallel conductor, ACB

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1. INTRODUCTION

The circuit breaker is a device that is capable of making, carrying and breaking the current is a normal state and often consists of fault current for a specific duration, breaking the current for a certain fault state. ACB is a low voltage device with a most voltage of up to 1000 V AC and 1500 V DC with a high current level of up to 6300 A and a breaking capacity of 50 kA to 100 kA. The air circuit breaker is used as an arc-quenching device via air at ambient pressure. The air circuit breakers have replaced the oil circuit breakers. The operating theory of the Air

Circuit Breaker is very different from other types of circuit breakers. The main purpose of the circuit breaker is to avoid arcing from re-establishing after zero when the contact hole withstands the device recuperation voltage. It does the same thing, but in a different way. If the arc is disrupted, it produces an arc voltage instead of a supply voltage. The arc voltage is known as the minimum voltage needed to maintain the arc. Here, the basic of different parameters like magnetic forces, contact force, joule losses, arcing etc. , and mainly centered on the software evaluation of the electromagnetic forces not including the temperature effect, Which influences at the time of short circuit.

Usually, to reduce electromagnetic repulsion force, the configuration of parallel contacts is applied to ACB, so the Holm force included in electromagnetic repulsion force can’t be obtained directly by means of Holm formula because the current flowing through every parallel contact is unknown [2]. By 3D finite element method, the electromagnetic field transient analysis is executed for the prepared mathematical model. After every time step of solution, the cross-sectional areas of contact bridges are modified with the electromagnetic repulsion force by Holm formula [2]. To limit the unwanted operation of a circuit breaker like the fault current for a very short time or sudden change or reduce in loads, the circuit breaker should not trip and disconnect the circuit if the fault disappear automatically and cope with the electromagnetic force and temperature rise. If it exceeds the particular time in seconds or milliseconds, the breaker then will open the contacts to make sure the max possible protection to the connected component of loads and equipment.

2. FACTOR AFFECTING SHORT CIRCUIT PERFORMANCE

2.1. Electromagnetic Forces

When the short circuit occurs in a circuit breaker the higher current flows through the finger conductor path, this current generates electromagnetic forces between each finger conductor assembly. Electromagnetic forces are depended on the geometric arrangement. And additionally, it depends on the current density and magnetic flux density of the conductor. There are two kinds of forces repulsive force, attraction forces.

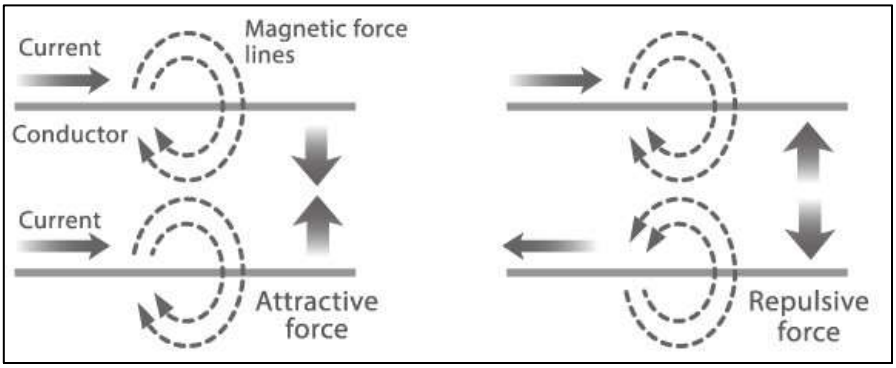

Figure 1 Electromagnetic force acting on parallel conductor

As proven in fig-1, the two conductors are positioned parallelly to each different with distance x and the current flowing via them is i1 and i2. When the current flowing through the conductor is in the same direction means i1=i2, than the pressure appearing on it, is stated to be an attractive force. Because the distance between the two conductors is increased, the force value is positive. As the same, when the current flowing via the conductor is opposite to each other means $i1 \neq i2$ than the force appearing on it is stated to be a repulsive force. To analyze electromagnetic forces FEM evaluation has to be carried out. When the current-carrying conductor positioned in a magnetic field, it experiences electromagnetic pressure between every current-carrying conductor.

2.2. Holm's Force

The current-carrying contact region has the form of a round contact spot. The magnetic traces of force produced by the current are moreover circular [1]. Constriction is a current-density vector field with a radial dimension that has an impact on the round magnetic field and produces a repulsive force. This states the Holm's low.

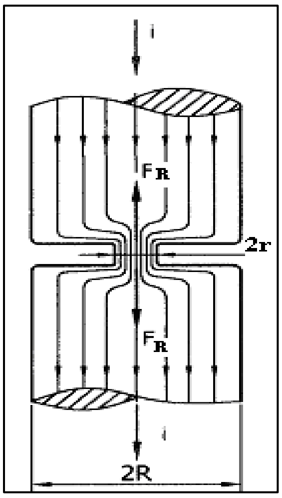

Figure 2 Holm's force distribution

2.3. Contact Spring Force

After S.C., The contact force is the most essential element which does not allow the contact separation. It has to be capable to withstand that much amount of S.C. force. Mainly, the parameter which affects the spring is the mean coil diameter of spring (D), the free length of spring Lf, Wire diameter, No of Turns.

2.4. Arc

The arc is an electrical spark between constant contact and movable contact when they are separated for the duration of a fault. During the breaking operation of the air circuit breaker, high arching creates material to switch from one contact to another. When this procedure takes place, the point at which the breaker contact consistently in contact may additionally erode. Arc length is moreover one of the factors which create erosion in electrical contact. One of the significant results from these statistics was that current density extended and erosion dramatically improved as the arc root area approached the contact surface region dimensions [3]. There is also a review of the initial arcing stages at contact section included along with new data, taken from the erosion studies, that provides statistical data on high-current contact bridge time, ignition voltage, minimum fall potential, and metallic-to-gaseous phase transition times [4-5].

3. CALCULATION

3.1. Framework of Contact System

The contact system structure of low voltage Air Circuit Breaker is demonstrated in figure-3. It mainly includes a top terminal, bottom terminal, moving contact, fixed contact, and movable copper wire. The short-time withstand current increases as the electrodynamic force being compensated with the aid of Lorentz force on moving contact rod and copper braids. Its structure is shown in fig-3.

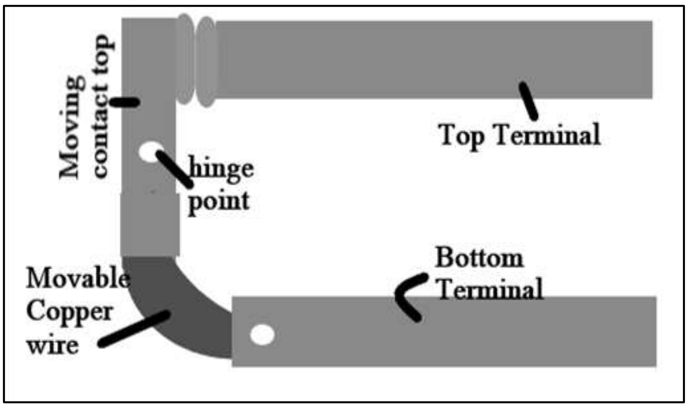

Figure 3 Structure of contact system

3.2. Calculation

The repulsion force of the contact system includes the Lorentz force and the Holm force. The Lorentz force of contact rod is calculated according to Ampere's law. Fist for the given structure of the contact system, the current density of the overall current pass can be written as the equation (1).

$$\vec{J} = -\sigma(T)[\nabla V + \frac{\partial \vec{A}}{\partial t}] \quad (1)$$

Where, J is current density of the short circuit current, σ is Conductivity of current-caring conductor, *T:* temperature, t: time and A is magnetic vector potential. With the electric-field intensity distribution of short current, the magnetic flux density equation can be written as

$$\vec{B} = \nabla \times \vec{A} \quad (2)$$

Consequently, the heat generation and electromagnetic repulsion force due to short-circuit current can be obtained by

$$Q = \frac{1}{\sigma(T)}\overrightarrow{J^2} \quad (3)$$

$$\vec{F} = \int \vec{J} \times \overrightarrow{B}\, dv \quad (4)$$

Q: heat generation of short circuit current

F: Electromagnetic repulsion force acting on the contact system

After contact bridges built between contacts, the electromagnetic repulsion force include the Holm force, it can be calculate as per the electrical contact theory [6]….

$$F_H = \frac{\mu I}{4\pi} \ln\frac{A}{a} \quad (5)$$

Where, A: actual contact radius, a: contact spot radius. Here the contact spring force is also important to make sure the making and caring contact pressure. The contact spring force can be calculated from the Hooke's law as $F_s = -kx$, where, k is spring constant, Fs is restoring force of spring, x is a displacement of spring from the equilibrium position. Summarily, the calculation process of electromagnetic forces under short-circuit current is concluded in Fig.4.

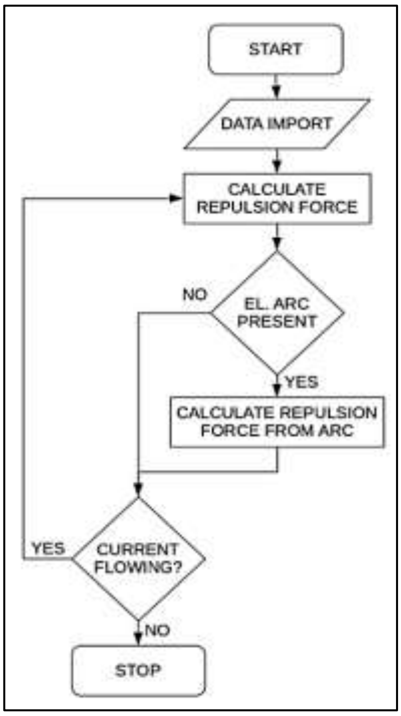

Figure 4 Process of electromagnetic force calculation under short circuit

4. SIMULATIONS AND RESULTS ANALYSIS

For the simulation of the repulsive forces, different model with different configuration is analyzed. Here, this paper will discuss one of the configuration models developed for analysis. In Fig.5, a simulation model whose configuration associated with the contact system of ACB is built. Due to its symmetrical structure, only a quarter of the model is built with x-Z and y-z being the symmetric planes. The contact system of this model is in a closed position as proven in Fig.5, the movable contact is fixed by using the operation mechanism, and the contact springs are put on the fixed contacts, which can be separated by means of electromagnetic repulsion force. The fixed contact consists of a whole of six pieces in parallel, No.6, and No. 1 represents the most internal and the most outer moving contact respectively.

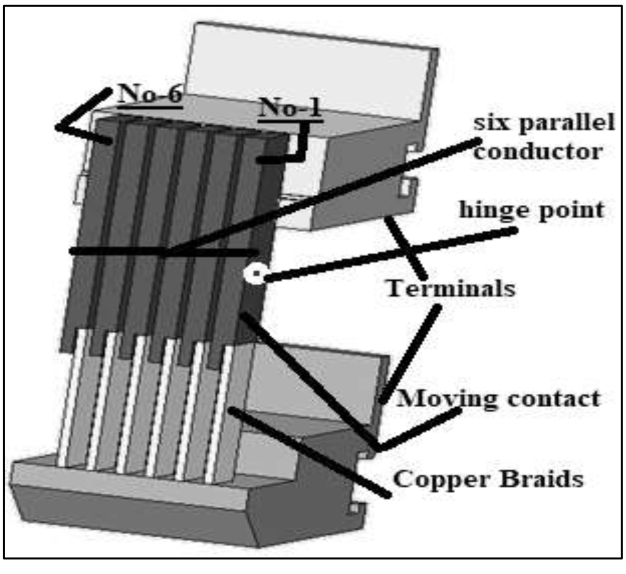

Figure 5 Simulation model of the ACB contact system.

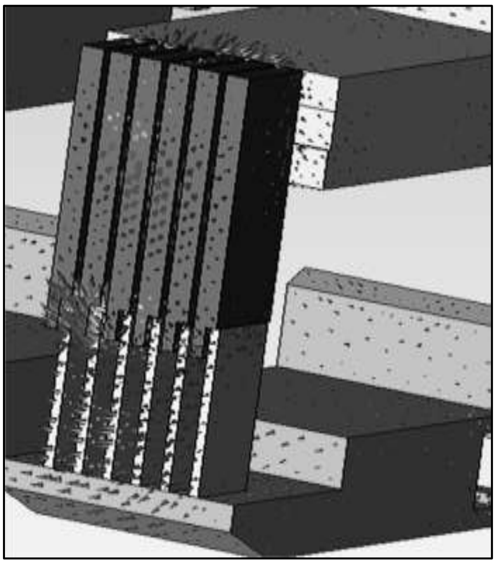

Figure 6 Vector Plot of magnetic flux density distribution

According to this model finite element evaluation for electromagnetic forces is executed using J-MAG software. For this every parallel part is divided into two components each like, top section and bottom part. And the time step is taken as 21 steps with 0.001s (complete 1 cycle). Because the current divided into 6 parallel parts, the electromagnetic pressure appearing on each contact has a exclusive peak value. And the current level is examined at the 150kA rating of ACB. Figure-6 indicates the vector plot of magnetic flux density distribution with each concentric part.

Figure-7 suggests the electromagnetic force variations with I appearing on contacts and at terminals, respectively. It demonstrates that the repulsive force appearing on top-terminal is higher than the force of the other parts. And also, it can be seen that forces are more at each bottom part of the parallel contact which is movable copper braid than the upper element of the parallel contact. It demonstrates that the current flowing through No.6 contact and the corresponding electromagnetic force performing on the No.6 contact are for sure greater than the force of the other contacts.

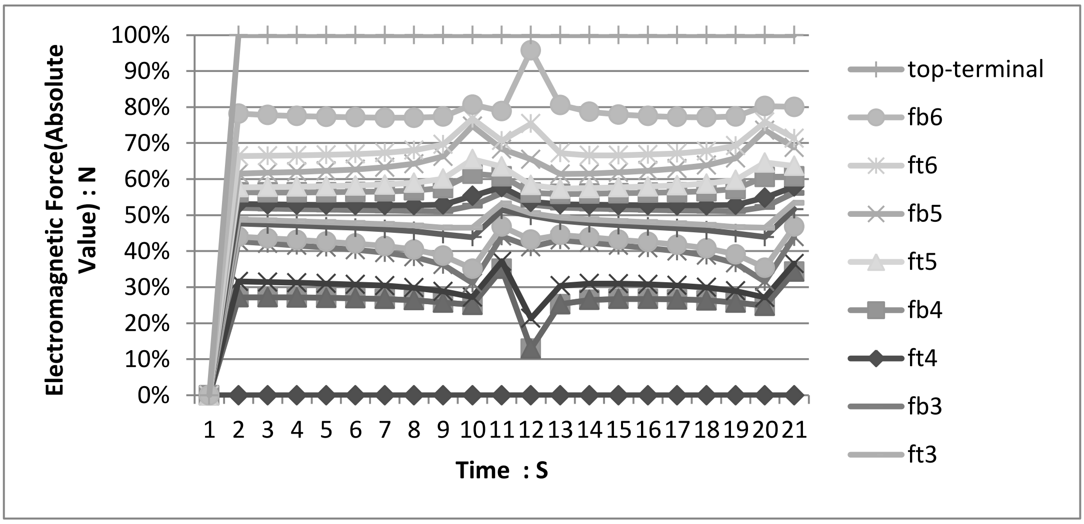

Figure 7 Force VS time Graph

For the maximum value of the current (150kA) the repulsive force with the maximum tip value is 7.5*10^12 N within the overall single-pole model. As a end result the magnetic flux density distribution is irregular and large to the contact nearer to the sub pole contact. From the outcomes of simulation, it can be additionally elaborate; the inner contact forces are influenced with the aid of the magnetic flux of nearer contacts. With the same process, the overall 3-pole or 4-pole ACB model can simulate further.

5. CONCLUSION

With the specific models and simulations, the electrodynamic repulsive force is analyzed. It can be viewed that the repulsive forces are greater than the other force; it means that the Lorentz force produced by the conductor makes overcompensation to Holm force. By simulation, the main influence factors and their influences on the electrodynamic force are obtained. And mainly the no of parallel contact with the flexible copper braid in each pole plays an essential role. It controls the temperature rise at the contact point and additionally enlarges the withstand capacity of the model.

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