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Analysis and improvement in repulsive force of 630 A frame Moulded Case Circuit Breaker (MCCB)☆

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Summary Moulded Case Circuit Breaker (MCCB) is a protective device used for low voltage protection in the range of 12–1250 A. It is having fast breaking and making ability due to special contact structure. In case of transformer it is generally placed in secondary side and in case of motor protection it is used as backup protection. The existing design is suffering from chattering of contact tip which lead to erosion and in turn affect electrical life. It also reduces interrupting/breaking capacity of MCCB. In this paper, detailed study of the factors and constraints related to repulsion threshold current (I_{rp}) and consistency of magnetic release for 630 A MCCB is carried out using Finite Element tool JMAG to find out limitations and scope of design improvements in existing design. The proposed suggestion is validated by testing.

Introduction

When two current carrying elements, carrying current in opposite direction, are placed in vicinity to each other, they have an experience of repulsion force, Moulded Case Circuit Breaker (MCCB) works on this basic principle. The contactors in MCCB are not straight through but blow apart. When the current flows through contactors magnetic field develops around them. Under the abnormal condition the effect of magnetic field on straight through contact arrangement is little. During a fault, the contacts are opened by mechanical operation of spring. In straight through contact system after sensing abnormal condition it takes more time to give trip signal. The blow apart contactors carry current in opposite direction so they are having force of repulsion in between. The amount of force between them is a function of current so it is clear that in case of blow apart contactors more is the fault current, more is the repulsive force between them and fast is the responding time. This ensures

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that the protective device is having inverse time characteristic which is necessary as protection point of view. The separation of the contacts is followed by an arc which is required to be quenched quickly for this purpose arc chute is provided. In addition to this breaking mechanism thermal as well as magnetic breaking mechanism are also there. It is observed that 630 A MCCB repel at 10 I_n where I_n is rated current and thermal magnetic release also gives short circuit protection for 6—10 I_n, if these two current limits are near or overlaps it may lead to chattering of contact tip which cause erosion of button and affect the electrical life of MCCB and also decrease interrupting/breaking capacity of MCCB. Hence, it is necessary to improve repulsive force in order to solve the above problems.

Electrodynamic repulsion force

Electrodynamic repulsion force contains Holm force and Lorentz force.

$$F_{ed} = F_H + F_L \quad (1)$$

Holms force

Repulsion force is exert between two contact buttons, there is a point of contact which is a very small area. Therefore a current between upper contact and lower contact flows through a very small area, which is the point of contact, due to current concentration in these contact tips, magnetic flux density between contact tips produces the electromagnetic repulsion force. This force is known as a Holms force (Ragnar, 1967). Holms force is given by Eq. (2)

$$F_H = \frac{\mu_0 I^2}{8\pi} \times \ln \frac{8\pi HA}{\mu_0 I^2} \quad (2)$$

where I is current, μ_0 is permeability constant, H is hardness of material and A is area of contact tip.

Material used in upper and lower contact is different, hence value of Modulus of Elasticity (E) and Poisson ratio (ν) is also different. As compare to this force, force between two parallel contacts affects more. Hence it is necessary to study Lorentz force. Lorentz force exert between two parallel conductor i.e. Contact system, now current flows through fixed and moving contact is in opposite direction. Hence magnetic field produce in both contact is also in opposite direction. Due to this between contacts electro-magnetic repulsion force takes place (Yu-Min et al., 2011).

When upper and lower contact has unequal finite length and same area of cross section. When current flow through them, force will be produced between contacts, this force is known as Lorentz force and can be find out by Eq. (4) (William Hayt et al., 2014).

$$F_L = 2 \times 10^{-7} \times I^2 \times \frac{l}{D}(C_1 + C_2) \quad (4)$$

where l is overlap length and C_1, C_2 is excess length of fix and moving contact and D is ratio of k and d. Where d is distance between two contacts and k is the corrective factor. k can be derived from Dwight's chart and C_1 and C_2 derived from Eqs. (5) and (6)

$$C_1 = \sqrt{\left(1 + \frac{c_1}{l}\right)^2 + \frac{d^2}{l^2}} - \sqrt{\frac{c_1^2}{l^2} - \frac{d^2}{l^2}} \quad (5)$$

$$C_2 = \sqrt{\left(1 + \frac{c_2}{l}\right)^2 + \frac{d^2}{l^2}} - \sqrt{\frac{c_2^2}{l^2} - \frac{d^2}{l^2}} \quad (6)$$

where C_2 is taken 0 because excess length before contactor is zero.

FEM analysis of contact system

Finite Element Analysis (FEA) is a computerized method used to check current density, magnetic flux density, magnetic strength density and a force exert between two non-magnetic materials i.e. Lorentz force in contact system (parallel conductor) and contact tip (Xingwen and Chen, 2005; Goran and Johansson, 2014).

As shown in vector plot (Fig. 1a) current flows from fix and moving contact is in opposite direction, hence magnetic field produce is in opposite direction of each other hence there is a repulsive force between fix and moving contact.

Magnetic field strength in contact structure is produced as shown in Fig. 1b. Magnetic field produced is in opposite direction in contact tip which is also produced in opposite direction and produces electromagnetic force. Magnetic flux density in movable contact is higher than magnetic flux density of fixed contact. Hence, force produced from movable contact is higher than fixed contact.

Modification in design

The problem of chattering is due to the narrow band between magnetic limit and repulsion limit. This band is called safety margin. The problem can be solved by increasing the band, which can be achieved by bringing repulsion limit away from magnetic limit. This can be achieve by reducing Lorentz force and increase the force of attraction between contactors. Therefore in the suggested modification in the contact system of MCCB, the overlap length of contactors is reduced and next to lower contactor piece of U-shape magnetic material is placed. The Reduced overlap length of contactors reduces Lorentz force and by converting leakage flux between fixed and movable contactors in to linkage flux, piece of U-shape magnetic material applies force of attraction. To avoid eddy current lose plate of 0.5 mm are placed one by one, as shown in Fig. 1c.

Magnetic flux density with slot motor is as shown in Fig. 1d, it can be easily concluded that in slot motor magnetic field produced is in opposite direction of magnetic field produced in upper contact, which helps to attract upper contact towards slot motor and helps it out in delayed separation of contact. Value of magnetic flux density at lower contact is 0:1474 T and in slot motor 0:5156 T.

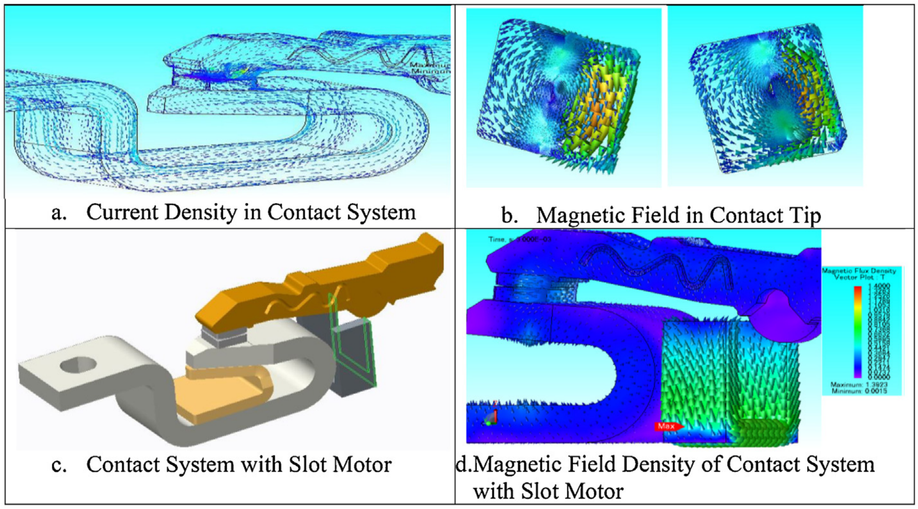

Figure 1 FEM analysis.

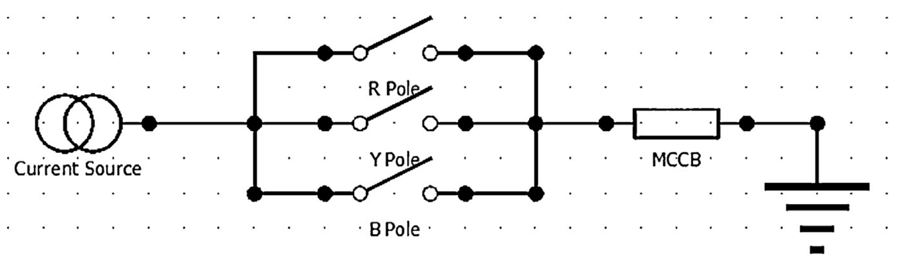

Figure 2 Repulsion test bench circuit.

Table 1 Test result in present design.

Phase	Absolute reading	Result
R	5127	No repulsion
	5680	Repulsion
Y	4853	No repulsion
	5164	Repulsion
B	5201	No repulsion
	5489	Repulsion

Table 2 Test result with slot motor.

Phase	Absolute reading	Result
R	5872	No repulsion
	6113	Repulsion
Y	5835	No repulsion
	6189	Repulsion
B	5719	No repulsion
	6284	Repulsion

Testing

Circuit diagram of repulsion test bench is as shown in Fig. 2. Sequentially R, Y and B Pole of MCCB are connected through copper probe and current is given in step-wise manner. To monitor repulsion force CRO/monitor is also connected with Test Setup. When distortion occurs in current wave form, repulsion current and time is noted (STANDARD, n.a.).

Repulsive and non-repulsive current of present and modified design is as listed in Tables 1 and 2.

Conclusion

In this paper, at a time of short circuit calculation and FEM analysis of electro dynamic force in contact system of 630 A MCCB is done. At a time of short circuit it is observed that contact are repelled earlier and because of repulsion force only, rather than thermal magnetic release and chattering between fixed and moving contact tip also observed. Because of these problems of single phasing take place. With the help of U-shape slot motor repulsion force as well as repulsion current is improved by attracting movable contact towards fix contact. Final testing is done with U-shape slot motor behind movable contact of MCCB and from test data it is proved that repulsion should be improved with the help of slot motor.

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