Optimal Design of Mechanical Fast Switch for DC Circuit Breaker Using Response Surface Method

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Abstract

This paper deals with the design optimization of a mechanical fast switch for DC circuit breaker (DCCB) using the response surface method (RSM). The dynamic characteristics such as transient current, electromagnetic force, velocity, and movement of repulsive plate are calculated using a coupled electric circuit, magnetic, and mechanical analysis based on the finite element method (FEM). In order to verify the validity of coupled analysis model, the calculated dynamic characteristics are compared with the experimental values. Subsequently, in order to improve the action completion time of the mechanical fast switch, an optimal thomson coil model(TCA) is designed using the RSM.

1 Introduction

In recent years, there has been increasing interest in the potential of DC transmission and distribution. To integrate a DC grid into the electric distribution system, the multi-terminal DC (MTDC) grid approach is required, and the use of DC circuit breakers (DCCBs) is essential for the operation of the MTDC grid [1].

Unlike AC fault current with frequencies of 50 or 60Hz, DC fault current exhibits a rapid increase in current without any current zero crossing. Therefore, it is essential for DCCB to have the capability to forcibly establish a current zero crossing within a few milliseconds. DC circuit breakers can be classified into mechanical, solid-state, and hybrid types based on the method used to achieve a current zero crossing. For DCCBs in the MV Class and above, utilizing hybrid type is advantageous. To enable the operation of hybrid type DCCBs within a few milliseconds, the use of a mechanical fast switch is obviously necessary [2].

This paper presents the design optimization of a mechanical fast switch for DCCB using the response surface method (RSM). The dynamic characteristics of the mechanical fast switch, which consists of a thomson coil actuator (TCA), are calculated by using coupled electric circuit, magnetic, and mechanical analysis based on the finite element method (FEM). The calculated dynamic characteristics of an initial TCA model are compared with experimental results to validate the numerical model. Finally, the optimal TCA model designed by using the RSM is compared with the initial TCA model to confirm the effectiveness of the design optimization.

2 Governing Equation

The transient current supplied to the TCA model can be determined using electric circuit equation which consists of resistance, inductance, and capacitance.

$$\frac{1}{C}\int i(t)dt = R \cdot i(t) + L(\phi)\frac{di(t)}{dt} \quad (1)$$

The transient current calculated from the electric circuit equation is utilized as the source term in the governing equation for the magnetic field problem. The transient magnetic field problem which is necessary for calculating the electromagnetic force can be solved using the following the governing equation as below.

$$\nabla \times \left(\frac{1}{\mu_0}\nabla \times \vec{A}\right) + \sigma\left(\frac{\partial \vec{A}}{\partial t} + \nabla V\right) = \vec{J} \quad (2)$$

The magnetic flux generated by the transient current supplied to the TC induces eddy current in the repulsive plate. The interaction between the induced eddy current and the magnetic flux generates the electromagnetic force, which causes the repulsive plate to move upward or downward. The acceleration, velocity, and position of the repulsive plate are calculated using the equation of motion.

$$F_{mag} = M\frac{d^2z}{dt^2} + B\frac{dz}{dt} + K \cdot z + F_g + F_f \quad (3)$$

This paper presents a design optimization process using the RSM to enhance the dynamic characteristics of the initial TCA model. The dynamic characteristics are calculated by using proposed coupling analysis as shown in Figure 1. In order to confirm the improved operating performance of the optimal TCA model using the RSM, the calculated action completion time of the optimal TCA model and that of the initial TCA model are compared as shown in Figure 2.

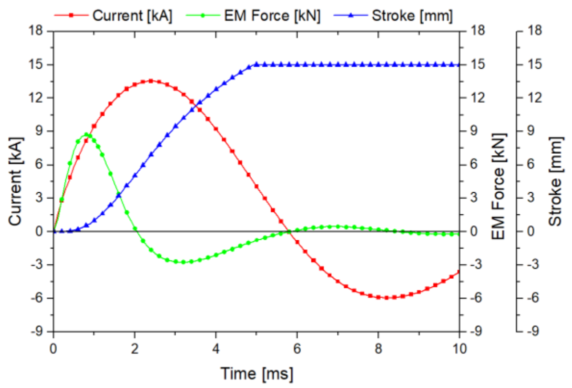

Figure 1: Dynamic characterictics

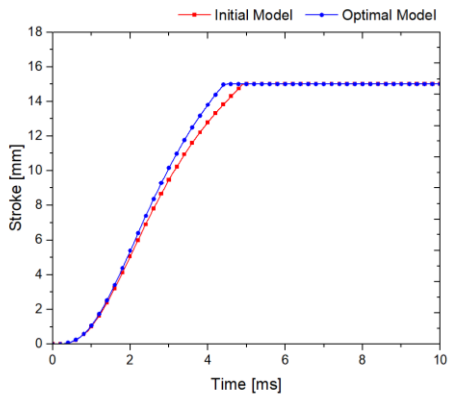

Figure 2: Strokes of initial and optimal TCA model

3 Conclusion

In this paper, we proposed a process for the design optimization of a mechanical fast switch for DCCB using the RSM. The dynamic characteristics including transient current, electromagnetic force, velocity, and movement of repulsive plate are calculated using a coupled analysis of electric circuit, magnetic, and mechanical behavior. In order to verify the validity of coupled analysis model, the calculated dynamic characteristics are compared with the experimental values. Subsequently, in order to improve the action completion time of the mechanical fast-switch, we designed an optimal TCA model using the RSM.

References

[1] M. Barnes, et. al, HVDC Circuit Breakers – A Review, *IEEE Acces* **8** (2020) 211829-211848.
[2] S. Coffey, et. al, Review of MVDC Applications, Technologies, and Future Prospects, *Energys* **14** (2021) 8294.