Optimization Design of a Permanent Magnet Actuator for 126kV Vacuum Circuit Breaker
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Introduction

- Background
  - Vacuum circuit breaker (VCB)
    - VCBs have been widely used in the distribution voltage levels of 3.6~40.5 kV due to their characteristics of environmentally friendly, maintenance-free and high breaking performance.
    - Their applications are extending to higher transmission voltage levels such as 126kV level in order to gradually replace SF6 circuit breakers whose insulation and arc extinguishing is harmful to the environment.
  - Permanent magnet actuator (PMA)
    - PMAs have advantages of high controllability and high reliability, which makes them widely used as the operating mechanism of medium-voltage VCBs.
    - Unlike the applications in medium-voltage situations, the PMA used in high-voltage power system has a much longer stroke and requires a much higher velocity, which limits the application of traditional PMA in high-voltage field.
- Contribution of this paper
  - A novel mono-stable PMA
  - A multi-step optimization method

Optimization Flowchart

1) Optimization of Breaking Spring Mechanism
   \[ \min v_{\text{av}}(a,b), \quad s.t. \begin{align*}
   3.2m/s \leq v_{\text{av}}(a,b) \leq 3.8m/s, \\
   a \geq 1200N, \quad b \geq 50000N/m
   \end{align*} \]

2) Optimization of PM Holding Mechanism
   \[ \min V_{\text{el}}(L_h, h_0, r), \quad s.t. \begin{align*}
   F_{\text{ed}}(L_h, h_0, r) \geq 17837N, \\
   2m \leq L_h \leq 20mm, 10mm \leq h_0 \leq 60mm, 55mm \leq r \leq 200mm
   \end{align*} \]

3) Optimization of Closing Mechanism
   \[ v_{\text{av}}(\hat{z}) = 0.183 + 0.021z_1 + 0.0103z_2 - 0.0083z_3 - 9.572 \times 10^{-7}z_4, \]
   \[ = 3.895 \times 10^{-7}z_5 - 1.744 \times 10^{-7}z_6 - 2.03 \times 10^{-7}z_7, \]
   \[ = -2.459 \times 10^{-7}z_8 + 2.622 \times 10^{-7}z_9, \]
   \[ v_{\text{av}}(\hat{z}) = -16.895 + 0.0844z_1 + 0.2153z_2 - 0.024z_3, \]
   \[ = -5.118 \times 10^{-7}z_4 + 5.21 \times 10^{-7}z_5 + 2.616 \times 10^{-7}z_6, \]
   \[ = -6.844 \times 10^{-7}z_7 - 2.112 \times 10^{-7}z_8 - 7.304 \times 10^{-7}z_9, \]
   \[ \min v_{\text{av}}(\hat{z}), \quad s.t. \begin{align*}
   1.7m/s \leq v_{\text{av}}(\hat{z}) \leq 2.3m/s, \\
   350V \leq z_1 \leq 400V, 60mF \leq z_2 \leq 100mF, 400 \leq z_3 \leq 650
   \end{align*} \]

Conclusion

The proposed PMA can satisfy the high velocity requirement for opening operation driven by disc spring and auxiliary breaking coil. A multi-step optimization method was adopted and the whole optimization for the PMA was divided into three parts, namely the optimizations of breaking spring mechanism, PM holding mechanism and closing driving mechanism. This method reduces the optimization time. The velocity characteristics of the optimized PMA meet the requirements of a 126kV VCB. The usage amount of the PM and the terminal velocities of opening and closing operations were reduced compared to the initial model, which verifies the validity of the proposed PMA and the effectiveness of the optimization method.

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