Dynamic Simulation and Optimization of High Voltage Circuit Breaker Structure Based on Finite Element

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Abstract. the Main Cause of Substation Circuit Breaker Break Accidents Mainly in Post Insulator Accidents is That the Flexural Strength of the Insulators Does Not Meet the Design Requirements. At the Same Time, There Are Problems Such as Eccentricity of the Porcelain Column, Large Difference in the Thickness of the Cement Casting, No Asphalt Buffer Layer in the Pouring Part, and No Waterproof Silicone Rubber. as the Temperature Changes, a Break Occurs under the Mechanical Force of the Switch. This Paper is Based on the Dynamic Simulation and Optimization of the Structure of High Voltage Circuit Breaker Based on the Finite Element Partial Dynamic Characteristics of Mechanical Structure. through Experiments by Ansys, the Optimized Solution Helps Manufacturers to Improve the Manufacturing Process of Insulators. the Operating Unit Strengthens the Equipment Acceptance, Operation, and Maintenance, and Carries out Visual Inspection and Ultrasonic Flaw Detection in Strict Accordance with the Requirements of the Regulations, Which Can Prevent the Occurrence of Insulator Breakage Accidents.

1. INTRODUCTION
High Voltage Circuit Breakers Are the Most Important Control and Protection Devices in Power Systems. It Has Two Functions: First, the Control Function, That is, According to the Requirements of the Grid Operation, a Part of the Electrical Equipment and Lines Are Put into or out of the Operating State, and Turned into Standby or Maintenance State. the Second is the Protection Function, That is, the Electrical Equipment or the Line is Faulty. When the Circuit Breaker Operated by the Relay Protection Device and the Automatic Device, the Fault Portion is Quickly Removed from the Power Grid to Prevent the Accident from Expanding, and the Fault-Free Portion of the Power Grid is Ensured to Operate Normally. the Pillar Porcelain Insulator Plays an Important Role in the Electrical Insulation and Mechanical Support of the Circuit Breaker. under the Combined Effects of Strong Electromagnetic Environment, Long-Term Mechanical Load, and Severe Meteorological Conditions, the Electromechanical Performance of the Pillar Porcelain Insulator Will Have Significantly Reduced, and the Quality Problems That May Exist in the Product May Easily Lead to Fracture Accidents [1, 2]. for Different Types of Circuit Breakers, the Force Forms of the Post Insulators Are Different, But Mainly the Bending and Torsion Loads Are Encountered, and It is Easy to Cause a Fracture Accident under the Action Stress. Therefore, It is Necessary to Check the Strength of the Bending and Torsion of the High-Voltage Pillar Porcelain Insulator.

With the Rapid Development of the National Power Grid and the Widespread Use of High-Voltage Switchgear, High-Voltage Switchgear Accidents Are Common. Accidents Mainly Caused by Insulation Accidents, Current-Carrying Faults, Mechanical Accidents, Accidents, and Refusal Accidents. among Them, Insulation Accidents Are Particularly Prominent. Because the Gas Insulated Switchgear is Made
of Metal-Enclosed Structure, the Circuit Breakers, Switches and Other Components Are Sealed in the Sf6 Gas Chamber, Because the Sf6 Gas Insulation is Much More Sensitive to Electric Field Uniformity Than Air [3]. When Setting Up the Switchgear, the Uniformity of the Electric Field Must Have Fully Considered. in Addition, the Electric Field Distribution of the Entire Field is as Uniform as Possible. Ansys Software is a Large-Scale General Finite Element Analysis Software Developed by Ansys in the United States. It Can Interface with Most Computer-Aided Design Software to Realize Data Sharing and Exchange, Such as Ansys, Autocad. This Part Uses Its Powerful Functions to Scientifically Analyze the Causes of Equipment Problems, Quantify the Problems, and Guide the Design Work through Data, Which Will Play an Active Role in Optimizing the Product Design [4]. This Paper Adopts the Parameter Analysis and Target Optimization Design Function of the Finite Element Analysis Software Ansys Which is Relatively Simple and Practical. Using Its Powerful Electric Field Analysis Function, Qualitative Analysis is Made on the Diameter of the High and Low Pressure End of the Insulator, the Radial Installation Panel of the Inner Wall of the Insulating Sleeve of the Wall Bushing and the Diameter of the Countersunk Head of the Inner Hexagonal Screw. in Turn, the Optimal Design of the Internal Structure of the Switchgear is Realized, Aiming to Make the Internal Electric Field Distribution as Uniform as Possible [5].

For the Reasons Above, We Propose an Improved Method by Ansys for the Pillar Porcelain Insulator is Subjected to Bending Moment and Torque. Stress Concentration Will Occur on the Umbrella Root of the Shed.

2. THE STRUCTURE AND PARAMETERS OF CIRCUIT BREAKER
The structure is described by many structural parameters, and there are certain relationships and laws between these structural parameters. In the case of an engine circuit breaker, some of the structural parameters are independent and some of the structural parameters are not independent [5]. Some are common to all types of circuit breakers, and some are proprietary to specific construction types. Summarizing the various structural types and structural parameters of the circuit breaker is the premise of using the circuit breaker [4].
The circuit breaker is mainly composed of a small head of a circuit breaker, a shaft, a big head, a bolt, etc., and the structure type of the circuit breaker is embodied in these components [8]. (1) Structure of the circuit breaker. The small head of the circuit breaker is usually formed into a circular, integrally closed lug shape, which has a smooth connection with the circuit breaker shaft and is symmetrical with respect to the longitudinal axis of the shaft. (2) Structure type of the large circuit breaker. The large size of the circuit breaker has characterized by its extremely diverse shape. There are flat-cut circuit breakers and oblique-cut circuit breakers from the large-head split type. The separation surface of the circuit breaker head and the circuit breaker cover is perpendicular to the circuit breaker axis, which is called a flat-cut circuit breaker; otherwise, it is called a diagonal-cut circuit breaker. (3) The circuit breaker is subjected to alternating load, which may cause fatigue damage and deformation. The lateral inertia force will also bend and deform the circuit breaker, when the circuit breaker swings at high speed. Therefore, the circuit breaker must have enough breakage and eliminate the stress concentration. In order to obtain a large rigidity under a small weight, except for the elliptical shaft on some low-stroke two-stroke engines, the circuit breaker shaft section is “work” shaped, and its long axis should be in the circuit breaker. Swing in the plane [6]. The development of vacuum circuit breakers tends to be high voltage, large capacity, miniaturization, intelligence, low overvoltage, maintenance free, specialization, and multi-function.

With the continuous improvement of vacuum switch manufacturing technology and theoretical research, the development of vacuum switches has not been completely limited to medium voltage and has developed toward high voltage and large capacity [7]. The first is 72.5kV ~ 126kV, Japan has
developed a 126kV40kA vacuum circuit breaker. At present, SF6 circuit breakers and GIS dominate the world at voltage levels of 126kV and above. Since SF6 gas has designated as a restricted gas in the Kyoto Protocol, how to reduce the use of SF6 gas has become a concern of power workers in various countries. Vacuum circuit breakers have the advantages of large breaking capacity and no pollution. The development of high voltage vacuum circuit breakers is a powerful way to solve this problem and has become an important direction for the development of various countries.

The 120KV porcelain column type of circuit breakers is listed. The main structural parameters of the circuit breakers summarized are shown in Table 1.

### Table 1 Circuit Breaker Structural and Technical Data

| Circuit breaker part                        | Size (mm) |
|---------------------------------------------|-----------|
| Circuit breaker head inner diameter         | 74        |
| Circuit breaker head outer diameter         | 90        |
| Circuit breaker small head inner diameter   | 42        |
| Circuit breaker small head outer diameter   | 54        |
| Circuit breaker technical data              |           |
| Terminal block static load                  | 1000N     |
| Gas pressure in the casing                  | 38        |

3. TEST BED AND MEASUREMENTS

3.1 Parameter Optimization Based on Ansys

The optimization design of Analysis consists of two parts: parameterization analysis and optimization analysis [9]. Using the optimizer, users can find an optimal solution from a wide range of possible solutions.

1) Parametric analysis defines one or more scan variables. In addition, define a range of values for each scan variable. The optimizer will calculate at all variable take points. Get a series of calculation results. This allows the user to compare the results. This determines the impact of each design variable on the final design performance. The process is shown in Figure 2.

2) Target Optimization: Determine the optimization target and cost function first. The optimizer satisfies the optimization goal by optimizing the design parameter values. Continuous non-linear planning is used to optimize.
3.2 Partial Dynamic Analysis
An analytical method for the dynamic characteristics of modern research structures is partial dynamic analysis. The partial dynamics refers to the inherent vibration characteristics of the mechanical structure. The partial dynamic analysis refers to the process of decomposing the complex vibration of a structure into a plurality of simple and independent vibrations and using a series of partial dynamic parameters. In general, for a multi-degree-of-freedom structural system, any motion synthesized by a free-vibrating modality. According to the vibration theory, the uninterrupted circuit breaker structure is discretized into a mesh model composed of s units and n nodes. Thereby the dynamic differential equation (1) of the circuit breaker system can be obtained.

\[ M\ddot{x} + C\dot{x} + Kx = f(t) \]  

In the above formula: 
- \( M \) - the quality of the circuit breaker, Kg;
- \( C \)--damage coefficient, N/(m/s);
- \( K \)--stiffness coefficient, N/m;
- \( X \)--the vibration displacement of the circuit breaker, m;
- \( f(t) \) - external load function, N;

When performing the modal calculation of the circuit breaker, the damping has minimal effect on the natural frequency and mode shape of the mechanical structure. Let \( C = 0 \), \( f(t) = 0 \), so that the undamped free vibration equation (2) of the engine breaker structure can be obtained.

\[ M\ddot{x} + Kx = 0 \]  

For linear systems, this is a linear homogeneous differential equation with second order constant coefficients. Thus, the characteristic equation (3) of the natural frequency and vibration mode of the circuit breaker structure can be obtained.

\[ \omega^2 = \frac{K}{M} \]  

Where \( \omega \) is the natural frequency of the circuit breaker and \( \Phi \) is the corresponding eigenvector, which is the regularization model of the structure.

3.3 Constraints and Loads
The constraints and loads of the boundary conditions in the partial dynamic analysis should be consistent with the engineering practice. This paper mainly analyzes the mode of the mode under Free State. When the corresponding load is applied, other alternating loads are ignored, only the effect of own gravity is considered, and the constraint is imposed according to the actual situation. Because the main load, position of the circuit breaker during the movement is the surface of the contact area between the small head of the circuit breaker and the post insulator [10]. Therefore, when the constraint is applied, in the contact area between the small head of the circuit breaker and the post insulator, only the degree of freedom of movement along the centerline of the cylinder and the degree of freedom of rotation around the centerline of the small hole are retained, and other degrees of freedom are constrained. In the circuit breaker head and post insulators, only the rotational freedom of the centerline around the hole is retained, and other parts of the degree of freedom are constrained. Perform the necessary modal analysis according to the above boundary condition constraints. The frequency of the first 8 modes is extracted, as shown in Table 2.

| Order | \( f \) (Hz) | Order | \( f \) (Hz) |
|-------|---------------|-------|---------------|
| 1     | 312.6         | 5     | 4099.4        |
| 2     | 773.1         | 6     | 5030.8        |
| 3     | 1026.9        | 7     | 7303.3        |
| 4     | 2435.2        | 8     | 7559.5        |
34 Simulation and experiment

The analysis results of the supporting insulators are shown in the figure below, wherein the maximum stress is 4.4 MPa, which is more evenly distributed on the upper plate and far below the yield stress of the material. The maximum deformation is 0.22mm, which is concentrated on the upper plate and meets the requirements for use.

![Figure 3 Test Results Of Circuit Breaker Base](image)
It can be seen from Figure 3 and Figure 4 that the vibration form of the circuit breaker is various. The first-order mode is a first-order bend, which is mainly bent along the X-axis direction. The second-order mode is mainly to bend the breaker shaft along the Y-axis direction. The third-order deformation is relatively large, so that the shaft of the circuit breaker twisted at the same time. Since the latter five stages are all above 1500 Hz, it is extremely easy to generate modal coupled vibration, which has a great influence on the dynamic characteristics of the circuit breaker. It can be seen from the vibration pattern that the circuit breaker has a second-order bending along the X-axis direction. The circuit breaker has a second-order bend along the Y direction. There is a certain compression and tensile deformation along the Z direction [10].

4. CONCLUSIONS
Circuit breakers play an important role in controlling and protecting the power grid. In operation, it is often necessary to perform normal opening and closing operations. In the course of operation, surges in voltage and current in the power grid are often accompanied, resulting in operating overvoltage and overcurrent, which seriously affect the safe operation of the power grid. Theoretical analysis and practice prove that the transient phenomenon occurring in the operation has not only related to the circuit parameters controlled, but also related to the actual phase and closing phase of the circuit breaker. Due to the limitations of the technical level at the time, the correctness and reliability of the final control of the circuit breaker are difficult to guarantee and cannot be promoted. This paper is based on the dynamic simulation and optimization of the structure of high voltage circuit breaker based on the finite element partial dynamic characteristics of mechanical structure. Simulation experiments are
carried out by ANSYS to change the working mode of the current exploratory auto-reclosing, and become adaptive auto-reclosing, which effectively avoids the breakage of the breaker post insulators.

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