ISSN: 2414-1895 DOI: 10.6919/ICJE.202002_6(2).0023

Numerical Analysis of Electric Field of Insulation Structure at Winding End of Power Transformer Based on Contact Finite Element Method

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Abstract

Statistics of power equipment operation faults show that the damage of insulation structure is one of the main causes of transformer faults. Transformers are widely used in power plants, substations and entire transmission and distribution networks in power systems. During transportation, power transformers may suffer from collision or external short circuit fault, which may cause winding looseness and deformation fault. If we can focus on the characteristics of the fault state of disconnection and remove it in time when the distribution line is disconnected, the difficulty of fault detection can be reduced. For the insulation structure, because of the complexity of the electric field distribution between the coils, especially at the end of the coil, the numerical analysis of the electric field distribution is of great significance to the design and optimization of the insulation structure. Based on the contact finite element method, this paper analyzes and studies the electric field value of the winding end insulation structure of power transformer, and further explores and analyzes the influencing factors of the electric field distribution of the winding end insulation structure.

Keywords

Electric power equipment, Transformer, Insulation structure, Contact finite element.

1. Introduction

Power transformer is the main power equipment in the power network, which plays an important role in changing the voltage level in the power system. The transportation of electric energy is the simplest and most convenient form of transportation of energy. The electric power system provides powerful energy transportation guarantee for economic development [1]. Power transformers are widely used in power plants, power transmission and transformation networks, substations and entire transmission and distribution networks in power systems [2]. Power transformers will make energy transportation faster and more efficient. During transportation, the power transformer may suffer from collision or external short circuit fault, which may cause winding looseness and deformation fault. Long-term operation of the transformer in this state will bring great harm to the safe operation of the power grid [3]. Power transformer control based on contact finite element method can learn from traditional quality management tools and make appropriate improvements to adapt to the dynamic organization form of networked manufacturing. As a new type of numerical calculation method developed with the vigorous rise of high-speed electronic computers in modern times, finite element method is especially useful for calculating complex structures [4]. Only through accurate theoretical calculation, numerical analysis and reasonable test technology can a reasonable insulation structure be designed.

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The insulation problem of power transformers is a key factor that restricts the voltage level and capacity of the transformer. The quality of the insulation structure design not only limits the capacity of the transformer, but also has important significance for the safe and reliable operation and economics of the transformer [5].Statistics of power equipment operation faults indicate that damage to the insulation structure is one of the main causes of transformer failure. [6] Because the fault current is small, especially when a high-resistance ground fault occurs, the fault line selection is more difficult, so a completely reliable method of line selection has been lacking [7]. Relying on traditional zero-sequence protection or high-impedance detection methods is difficult. If you can focus on the characteristics of the fault state such as disconnection and cut off in time when the distribution line is disconnected, you can reduce the difficulty of fault detection. Power electronics technology has evolved with the development of power switching devices and converter topologies [8]. From the point of view of the power grid and the motor, it is high voltage, and there is a large current in the middle low voltage link. The step-up transformer must be specially designed. Both transformers have large losses. Every improvement and innovation of power electronics and power transmission technology can be immediately applied to practical industrial and civil applications [9]. Power transformers are important equipment in power systems. It is of great significance to research and design a reasonable dancing structure to reduce transformer manufacturing and operation costs and improve operation reliability [10]. Based on the contact finite element method, this paper analyzes and studies the electric field value of the insulation structure at the end of the power transformer winding, further explores and analyzes the influencing factors of the electric field distribution of the insulation structure at the end of the winding, so as to guide the optimization design of the insulation structure of the power transformer.

2. Numerical Analysis of Two-dimensional Electric Field at Winding End of Power Transformer

The topological structure of the main circuit of the three-level transformer was first proposed by German scholars. This early topological structure was only to improve the voltage quality and reduce the voltage harmonic components, while a zero level was added to the intermediate DC circuit based on the two-point method. The insulation structure at the winding end of power transformer is complex, including solid insulation materials such as corner ring, cushion block and paper cylinder and transformer oil liquid insulation materials. On the basis of considering the electric field to solve the boundary conditions of the field, the variational principle is used to transform the problem into the extremum problem of the equivalent energy functional. For the design of analog control circuit, its reliability and practicability should be considered comprehensively. For the input signal, the transmission distance should be reduced as much as possible in the process of processing, so that it is not affected by external interference. Each bridge arm of the topological structure consists of two fully controlled devices connected in series, and the two devices are anti-parallel connected with diodes. When the devices are used in series, static and dynamic voltage sharing problems exist because the dynamic resistance and polar capacitance of each device are different [11]. The thyristor of the transformer can realize natural commutation, and the capacity of the filter is basically equivalent to that of the frequency converter. The more levels, the less harmonic content of the output voltage. In step wave modulation, the device is switched on and off at the fundamental frequency, with low loss and high efficiency. The greater the capacity of variable frequency speed regulation, the more important the efficiency of the system. The analog processing circuit consists of filtering, DC bias superposition circuit, etc.

The negative sequence current mostly flows from the fault point to the power supply through the fault line, while the negative sequence current of the non-fault line is relatively small. The disconnection fault discrimination requires that the phase current is less than a certain threshold value, which can be determined according to the maximum load current. The current limit condition is as follows:

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$$W = \chi \frac{QL^3}{EI_\infty} + \Delta\kappa \frac{Q}{EI_\infty} \tag{1}$$

In general, the load current is much larger than the capacitance current to the ground, and the capacitance current to the ground is ignored, thus obtaining the proportional characteristics of negative sequence positive sequence current during disconnection fault:

$$\min_x \sum_{(i,j)\in Lreal} \int_0^{x_{ij}} t_{ij}(\omega)d\omega \tag{2}$$

Since the high voltage output is not realized by adopting the traditional device series connection mode, the whole power unit is connected in series. Therefore, there is no voltage equalization problem caused by series connection of devices. In the dynamic analysis of complex structures, it is necessary to use discretization methods to establish discretization models of structures [12]. The vibration of transformer body mainly comes from the vibration of iron core caused by magnetostriction and magnetic flux leakage and the vibration of winding caused by electromagnetic force, while the vibration of iron core caused by magnetic flux leakage is weaker than other vibrations. The finite element method is to divide the structure into finite elements, and then the mass matrix and stiffness matrix of each element are assembled into a total mass matrix and stiffness matrix, thus obtaining the finite element model of the total system [13]. From the perspective of mechanical structure, the vibration on the surface of power transformer body is closely related to the compaction of transformer windings and iron cores. Stator current vector can be regarded as a combination of orthogonal excitation current and torque current vector, so the distribution ratio of excitation current and torque current will not only affect the amplitude of stator current, but also affect the phase angle of stator current.

3. Three-dimensional Finite Element Analysis of Electric Field at End of Transformer Winding

The multi-level high-voltage converter with units connected in series adopts a mode of connecting a plurality of independent low-voltage power units in series to realize high-voltage output. For the closed-loop control system of variable frequency speed regulation, the operating speed is an extremely important parameter. The propagation path of harmonic wave is conduction and radiation. The solution to conduction interference is to filter or isolate the conducted high frequency current in the circuit. The signal transmitted from the control cabinet shall be transmitted to the digital control system on the basis of ensuring accuracy and reliability as much as possible. It is necessary to design linear optocoupler isolation circuit in analog control circuit. The full digitalization of the control means makes use of the powerful information processing capability of the microcomputer, so that the software functions are continuously strengthened, and the flexibility and adaptability of the frequency converter are continuously enhanced. Considering that the linear velocity difference of the product will first cause tension fluctuation in the product and then cause displacement of the elastic frame. The series devices shall be turned on and off at the same time as far as possible, otherwise, the devices will bear uneven voltage due to different switching times. For the output calculation modules of the current regulator and speed regulator of the system, each redundant calculation unit can adopt different algorithms and make each algorithm as different as possible. For the same output voltage, it can be obtained by combining different switching states. The selectivity of the switch state combination provides reliability and flexibility for voltage balance of flying capacitor.

The sample is sent to the hidden layer unit through the connection weight to generate a new activation value of the hidden layer unit:

$$E(x,y,z) = \frac{xL_{LED}A_{LED}}{\left[(x-x_0)^2+(y-y_0)^2+(z-z_0)^2\right]^{3/2}} \tag{3}$$

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The selection of parameters in the finite element layout system is crucial to the convergence of the algorithm. According to the initial conditions of the finite element layout, it can be concluded that:

$$e_j = -k\sum_{i=1}^{m}(p_{ij}\ln p_{ij}) \tag{4}$$

The finite element information model is extracted and converted based on specific information format to realize docking and sharing of different professional software data. The comparison sequence and the reference sequence are nondimensionalized. In this paper, the averaging method is used to deal with:

$$w_j = g_i / \sum_{j=1}^{n} g_i \tag{5}$$

Under the interference of new factors, there may be new deviations, which need to be controlled according to the above methods:

$$T = \frac{M}{R} = \frac{i\eta_e M_e}{r} \tag{6}$$

The controller uses the corresponding control algorithm to control the turn-off timing of the power devices in the transformer according to the given rotational speed and feedback amount. When phase-controlled rectifier is used for voltage regulation, the power factor on the net side will decrease with the increase of the regulation depth. Although the inverter has an additional intermediate DC link, the frequency of the output AC power can be higher than that of the power grid. When necessary, the route from the source node to the destination node is found by using the known route to the destination node or by re-initiating the route discovery process. The output loop current signal can also be decomposed into the fundamental wave containing only sine wave and other harmonics, while the higher harmonic current directly interferes with the load. In the vector control system, the stator current is controlled, so the relationship between the two components of the stator current and other physical quantities must be found from the mathematical model the excitation circuit and armature circuit of DC motor are separated and can be controlled separately. However, the excitation current and torque current of AC asynchronous motor synthesize the stator current vector. The inverter module is connected in parallel, and the output current of the inverter is the sum of the two inverter modules. Therefore, the output mode is used to solve the problem of high current drive when the load starts or runs at low speed.

4. Summary

In this paper, the winding looseness defect of transformer is studied through finite element modeling analysis and experiment from the perspective of mechanical dynamics. According to the finite element calculation results and experimental results, the following conclusions are obtained. In the electric field simulation, the dielectric constant of the insulating material is idealized, because the insulating material is dispersive. Looseness of transformer winding essentially affects its own dynamic performance. Therefore, whether the winding loosens can be judged by calculating the vibration response characteristics of transformer under different pre-tightening forces and comparing with historical data. Because the finite element model is based on the mechanical structure of the transformer, this method can be applied to all transformers with the same structure, which has certain universality. According to the given speed and feedback, the controller uses the corresponding control algorithm to control the turn off time sequence of power devices in the transformer. However, the excitation current and torque current of AC asynchronous motor synthesize the stator current vector. Through the establishment of the transformer finite element model, not only can we judge whether the winding is loose, but also can preliminarily locate the fault according to the signal changes of different measuring points, which has certain significance for the research and diagnosis of transformer fault.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202002_6(2).0023

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