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Simulation Analysis of Transformer Short Circuit Fault

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Abstract: Power transformers are one of the main equipment in power production, with high cost and long manufacturing time. If a fault occurs during the power supply process, it will prevent the normal operation of the power system and result in no electricity available to power users. One of the main factors affecting the safe operation of transformers is short circuit fault, and short circuit faults at the outlet of substations or in close proximity can also pose a serious threat to transformers. This article simulates transformer short-circuit faults and establishes a simulation model using MATLAB/simulink to verify the harm caused by transformer short-circuit. Verification has shown that short circuit faults pose significant risks.

1. Introduction

Through statistical analysis of the operation and accidents of power transformers across the country over the years, it has been found that equipment damage accidents caused by external short circuit faults are increasing year by year. Controlling the upward trend of such accidents has become the key to improving the safe operation level of power transformers [1]. In transformer accidents, the probability of occurrence is high, and the transformer short circuit accident poses a greater threat to the equipment, especially the short circuit fault on the low-voltage side of the transformer [2]. This article elaborates on the cause analysis and handling methods after the short circuit faul [3].

With the rapid development of the power industry and the increasing requirements of society for the reliability of power supply, ensuring the quality of power supply is an obligation that every operation and maintenance personnel should fulfill [4]. Power transformers are important equipment for the safe operation of the power system and the heart of the transmission and transformation system [5]. Short circuit fault of power transformer is one of the more serious faults among all [6].

2. Analysis of Short Circuit Fault Factors in Transformers

The main reasons for transformer short circuit faults are as follows: 1) Local short circuit and overheating of the iron core and clamp (some with multiple grounding points), fastening the bolt clamp magnet core is a local short circuit of the iron core, insulation fracture or carbonization of the through core bolt causes local short circuit of the iron core, welding slag or other metal foreign objects cause local short circuit, and the through core nut seat sleeve is too long; The grounding strip is too long and tightly adheres to the iron core, causing local short circuits. The locking nuts at the ends of the upper and lower iron yoke pull rods are loose; 2) High voltage inter layer arc discharge, poor grounding, accumulation or operation of overvoltage, severe dampness of insulation, insufficient insulation margin (such as thin insulation), and short circuit accidents at the outlet of the voltage transformer; 3) Short circuit discharge of low-voltage turn layer box, low-voltage phase to phase short circuit discharge, insufficient insulation margin between turns or insulation aging, lightning stroke or overvoltage caused by operation, failure of joint welding, and outlet short circuit impact; 4) The protection system has a dead zone and malfunctions, resulting in the transformer being subjected to stable short-circuit current for a long time. During winding deformation, rough statistical results show that when subjected to external short-circuit, the transformer that cannot trip from time to time and is damaged accounts for 10% of short-circuit damage accidents; 5) When a transformer is subjected to a sudden short circuit, both the high and low voltage sides will be greatly impacted by short-circuit current [7]. In a short period of time before the circuit breaker can open, the short-circuit current will generate an electric force proportional to the square of the current, which will act on the transformer winding. This electric force can be divided into radial force and axial force [8]. During a short circuit, the radial force acting on the winding will cause tension on the high-voltage winding and pressure on the low-voltage winding, Due to the circular shape of the winding, circular objects are more likely to deform under pressure than under tension [9]. Therefore, low-voltage windings are more prone to deformation. The axial force generated during sudden short circuits causes compression, twisting, bulging, and inter turn short circuits in the winding [10]. Causes axial displacement of the high-voltage and low-voltage windings, and axial force also acts on the iron core and clamp [11].

The low-voltage winding and balance winding are the most susceptible to deformation when transformers are subjected to sudden short circuits, followed by the high and medium voltage windings, iron cores, and clamps. So, the main purpose of the transformer short-circuit accident is to check the windings, iron cores, clamps, and other components.

3. The Manifestation and Harm of Transformer Short Circuit Fault

3.1 Main Forms of Transformer Winding Short-Circuit Fault

Under the action of transformer short-circuit electromagnetic force, winding damage and lead displacement are the most likely consequences of transformer short-circuit faults. Both experimental research and operational practice have shown that the damage modes of transformer windings under short-circuit electromagnetic force mainly have the following forms:

(1) Winding deformation leads to the rupture of turn insulation, resulting in inter turn short circuits. This type of fault is the main form of damage to small distribution transformers with smaller diameters under the action of amplitude tensile electromagnetic force in short circuit accidents.

(2) The deformation of the winding leads to a decrease in the strength of the main insulation, resulting in the breakdown of the main insulation. The deformation of the winding leads to a decrease in the strength of the main insulation, resulting in a breakdown accident of the main insulation. This is the main damage mode of medium-sized and above power transformer windings subjected to amplitude tensile short circuit forces. Therefore, when designing the short-circuit strength of transformer windings, it is necessary to consider the accumulation effect of residual deformation of the winding under the action of short-circuit electromagnetic force.

(3) The amplitude instability of the winding may be caused by the circumferential compression caused by the electromagnetic force of the amplitude short circuit in the short circuit condition of the inner winding of the transformer placed next to the iron core or the intermediate winding of the

multi winding transformer. The amplitude instability of the internal windings of medium-sized and above transformers is the main manifestation of transformer damage under the action of amplitude short circuit electromagnetic force.

(4) The axial instability of the winding is the main form of winding damage caused by the combined action of short-circuit axial electrodynamic force and short-circuit amplitude electrodynamic force.

(5) The overall displacement and tilt of the three-phase transformer winding occur in the case of a three-phase symmetrical short circuit fault.

3.2 Hazards of Transformer Winding Short Circuit Fault

Short circuit damage to transformers is calculated based on the degree of equipment damage. Mild damage refers to the deformation of the winding of the equipment, the burning of the leads, but the insulation is not damaged; Moderate damage refers to significant deformation of the winding, burning of the winding or lead wire, and certain degree of insulation damage; Severe damage refers to severe deformation of the winding, breaking of the pressure plate, burning of the winding, breakdown or burning of the insulation, and in severe cases, explosion and fire, resulting in the burning of the transformer.

The internal fault of the transformer leads to accelerated oil flow, which may cause heavy gas action, circuit breaker tripping, and the transformer exiting the power grid operation.

4. Testing and Inspection of Transformers after Short Circuit Fault

Due to the fact that when a transformer is short circuited, the winding is subjected to various forces such as compression, tension, and bending under the action of electric force. The faults caused by these forces are sometimes hidden and difficult to inspect and repair. Therefore, after a short circuit fault, the condition of the winding should be carefully inspected.

4.1 Measurement of Transformer DC Resistance

Checking the DC resistance imbalance rate of the winding based on the measured value of the transformer's DC resistance can effectively investigate the damage situation of the transformer winding compared to previous measurements. For example, after a short circuit accident of a certain transformer, the DC resistance of phase A on the low-voltage side increased by about 10%. Therefore, it was determined that there may be a broken strand in the winding. After the winding was lifted out for inspection, it was found that the A-phase winding had a broken strand.

4.2 Measurement of Insulation Resistance of Transformer Winding

Before and after transformer maintenance, as well as during drying, a 2500V megger should be used to measure the insulation resistance absorption ratio of each winding to ground and between windings. The insulation resistance of the winding should usually be greater than 500M Ω and not less than 70% of the initial measured value. According to the requirements of the operating regulations for power transformers, the allowable values for the insulation resistance of oil-immersed power transformer windings are shown in Table 1. Whether they are qualified or not should be based on the values measured when immersed in oil. After oil injection, it should be allowed to stand for 5-6 hours before measurement.

Table 1: Allowable Insulation Resistance Values of Oil Immersed Power Transformer Windings
Unit: M Ω

Voltage level of high-voltage winding	Temperature ℃							
	10	20	30	40	50	60	70	80
3~10KV	450	300	200	130	90	60	40	25
20~35KV	600	400	270	180	120	80	50	35
60~220KV	1200	800	540	360	240	160	100	710

4.3 Measurement of Transformer Winding Capacitance

The capacitance of a winding is composed of inter turn, inter layer, and inter cake capacitance of the winding, as well as the capacitance generated by the winding. The specific capacitance is related to the gap between the winding and the iron core and the ground, the gap between the winding and the iron core, and the gap between turns, layers, and cakes of the winding. When the winding deforms, it is generally an S-shaped bend, which causes the gap distance between the winding and the iron core to decrease, and the capacitance of the winding to the ground will increase. Moreover, the smaller the gap, the greater the change in capacitance. Therefore, the capacitance of the winding can indirectly reflect the degree of deformation of the winding.

4.4 Inspection after Lifting the Cover

After hanging the transformer cover, if molten copper or aluminum slag or fragments of high-density cable paper are detected inside the transformer, it can be determined that the winding has undergone significant deformation and strand breakage. In addition, the degree of damage to the winding can also be determined by the displacement or detachment of the winding pad, the positioning of the pressing plate, and the displacement of the pressing pin.

4.5 Inspection of Iron Cores and Clamps

The iron core of a transformer should have sufficient mechanical strength, which is ensured by the strength of all clamping components and connectors on the iron core. When the winding generates electrical force, the axial force of the winding will be offset by the reaction force of the clamp. If the strength of the clamp, pull plate is less than the axial force, the clamp, pull plate, and winding will be damaged. Therefore, the condition of the iron core, clamps, pull plates, and their connections should be carefully inspected.

5. Transformer Fault Simulation Analysis

5.1 Simulation Model Establishment

Establish a transformer simulation model using MATLAB/simulink to establish a simple power system with dual side power supply and dual winding transformers. The schematic diagram is shown in Figure 1:

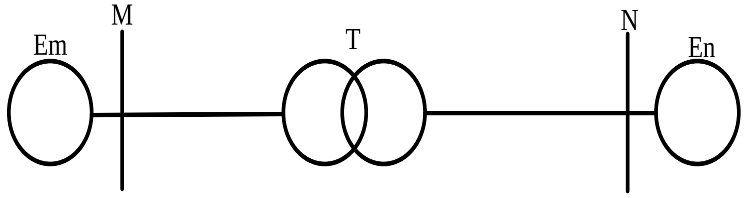

Figure 1: Power system diagram of a dual winding transformer with dual current sources

In Figure 1, Em and En are the power supplies on both sides of the system, and T is the double-winding transformer.

The simulation model is shown in Figure2:

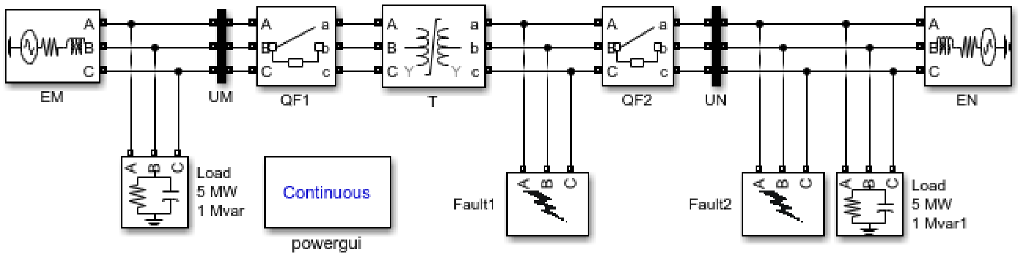

Figure 2: Simulation diagram of a dual winding transformer with dual current sources

In order to simulate the current situation of longitudinal differential protection during ratio braking when faults occur inside and outside the transformer area, an operation module has been added. The calculation module is shown in Figure 3. The simulation parameters are shown in Table 2.

Table 2: Simulation Parameter Settings

Parameter settings			Parameter settings	
Power supply voltage and flat frequency	35kV, 50Hz		Transformer 1 and 2 secondary side voltage	35kV
Load1, Load2	5MW, 1Mvar		Transformer capacity and frequency	50MVA, 50Hz
Transformer connection method	Y-Yconnect		Short-circuit	Single phase ground short circuit

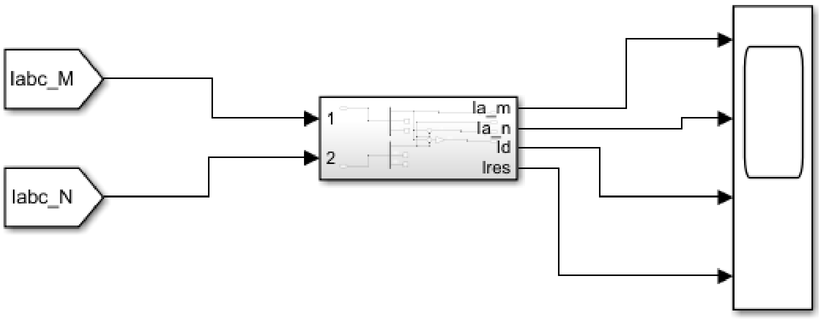

Figure 3: Calculation module

5.2 Simulation Waveform Analysis

The A phase difference dynamic current and braking current of the system during the longitudinal differential protection within the transformer fault protection zone are shown in Figure

4, while the A phase difference dynamic current and braking current of the system during the longitudinal differential protection outside the transformer fault protection zone are shown in Figure 5.

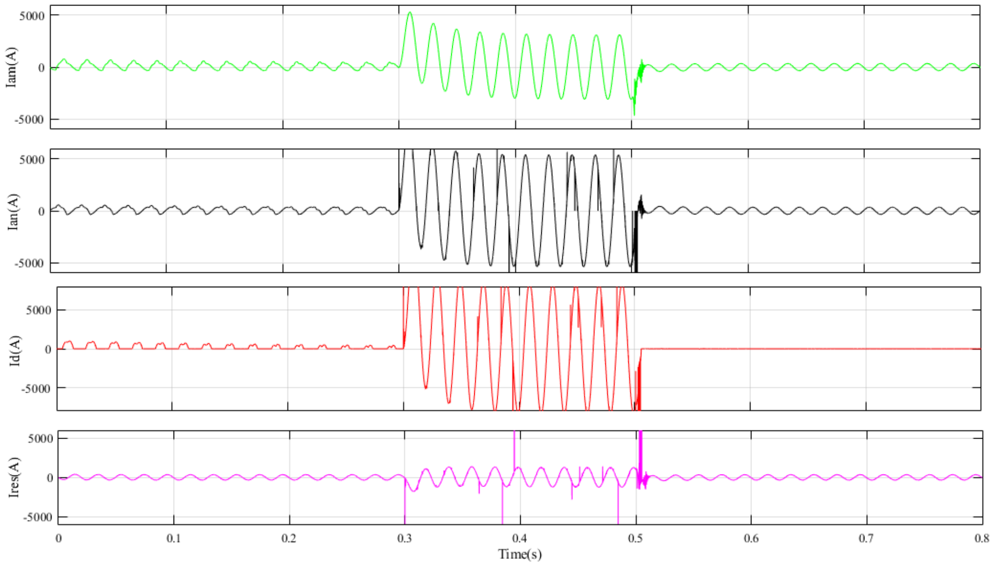

Figure 4: Simulation Waveform of Short Circuit Fault in Transformer Protection Zone.

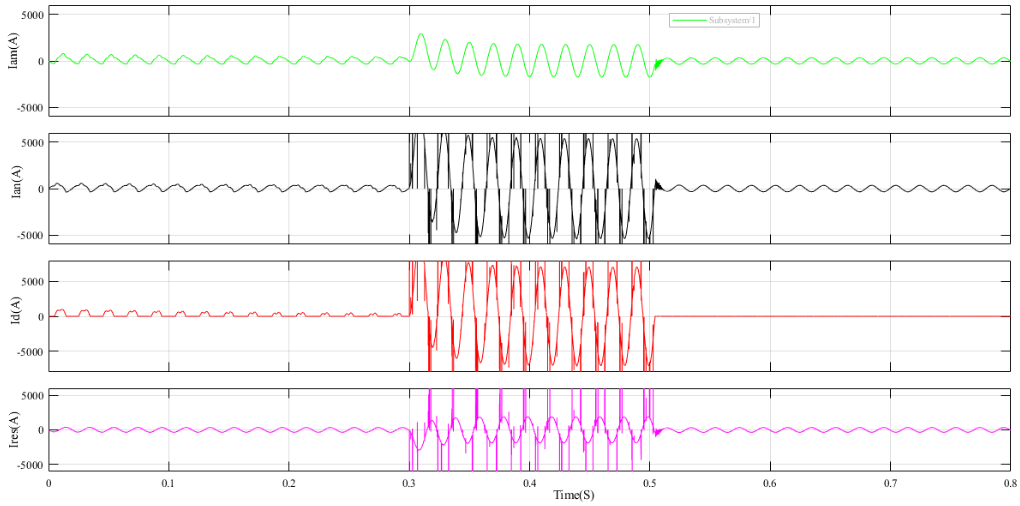

Figure 5: Simulation Waveform of Short Circuit Fault Outside the Transformer Protection Zone.

From the simulation waveforms inside and outside the transformer protection zone mentioned above, it can be seen that when an A short circuit to ground fault occurs at the output end of the transformer, the A-phase current at the transformer end increases, the differential current is the sum of the output currents of the two power sources, and the braking current is 1/2 times the difference between the output currents of the two power sources, and the harmonic content in the output current is relatively high. Therefore, dealing with it when it is not urgent will cause excessive input current of the transformer and cause transformer damage. Through simulation, it can be concluded that transformer short-circuit fault handling is very important for the safe and stable operation of the power system.

6. Conclusion

This article provides in-depth analysis of transformer faults, elaborates on the causes and hazards of transformer short circuit faults, and establishes a simulation model using MATLAB/Simulink. Through the simulation waveform, it can be concluded that when a transformer experiences a short circuit fault, the transformer terminal current will increase, with a current of 2-3 times the original value. If not handled in a timely manner, it will cause transformer damage.

References

[1] GE X. D. (2023). Fault location and cause analysis of short circuit in transformer operation. Electronic Technology (01), 272-273.

[2] Cui J. C. (2022). Simulation research on strength of winding and support structure of power transformer under short-circuit condition (master's thesis, Shenyang University of Technology).

[3] Gu K & Zheng X. D. (2022). Simulation test of transformer short-circuit impedance based on equivalent model at different frequencies. Journal of Vibroengineering (6).

[4] Huerta-Rosales R., Granados Lieberman D., Garcia Perez A., Camarena Martinez D., Amezquita Sanchez J. & Valtierra Rodriguez M. (2021). Short-Circuited Turn Fault Diagnosis in Transformers by Using Vibration Signals, Statistical Time Features, and Support Vector Machines on FPGA. Sensors (Basel, Switzerland) (11).

[5] He S. (2022). Selection of short-circuit impedance of rectifier transformers in electrical transmission systems Metallurgical Automation (S1), 462-465.

[6] Luo X. X, Xiao Q. B., Wang Q. & Sheng Z. P. (2021). A Novel Method for Distribution Transformer Short-circuit Test. Journal of Physics: Conference Series (4).

[7] Wang L. (2022). Diagnosis and maintenance of 6 kV transformer short circuit fault in power system. Equipment Management and maintenance (20), 149-150.

[8] Wang L. L., Huang S., Zhao C. & Jiang Z. H. (2017). Simulation and test of field-circuit coupling method for on-line monitoring of transformer short-circuit impedance. Guangdong Electric Power (06), 120-125.

[9] Wang W. T., Lu J. F. & Lu Z. C. (2022). Simulation of network-side current balance control of power supply device for transformer short-circuit test. Manufacturing Automation (02), 213-216.

[10] Xie W., Zhao M. M., Chen S. & Li W. B. (2020). Analysis of a 220kV transformer short circuit accident. Henan Science and Technology (22), 120-122.

[11] Zhao M. Y. and Li Y. B. (2021). Analysis and preventive measures for short-circuit resistance of transformers under short-circuit impact. Equipment Management and Maintenance (23), 38-40.