Simulation study on transformer inrush current and its suppression

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Abstract: When no-load closing or the voltage recovers after external fault removal of transformer, the inrush current will be caused due to the saturation of iron core, which may lead to misoperation of relay protection device, overvoltage and damage of equipment insulation. It is necessary to find a method to restrain the inrush current harm of transformer. In this paper, Matlab / PSB is used to simulate the inrush current of three-phase transformer under the conditions of no-load switching on and external fault removal, and the simulation research is carried out by changing the switching angle method and changing the transformer connection group method to suppress the inrush current of transformer. The simulation results show that the simulation of inrush current and its suppression can be realized effectively by using Matlab / PSB, which provides the basis for the research of transformer protection algorithm.

1. Introduction
Inrush current of transformer means that when the voltage of transformer increases suddenly, such as no-load input or voltage recovery after external fault removal, the transformer may be seriously saturated and produce large transient excitation current [1,2]. It can reach 4-8 times of the rated current at the primary side and contains a large number of high-order harmonics, which is easy to cause misoperation of transformer relay protection device [3,4]. Therefore, it is very important to study the characteristics of inrush current and find out the measures to restrain the influence of inrush current on transformer differential protection.

In this paper, the inrush current of transformer under no-load closing and voltage recovery after short-circuit fault removal is simulated. The inrush current of three-phase transformer is simulated by Matlab / PSB, and the measures of restraining inrush current by changing the closing angle and the connection group of transformer are studied.

2. Causes of inrush current
When the transformer is in normal operation, the maximum excitation current is only 2% - 5% of the rated current. When external fault occurs, the excitation current will decrease with the decrease of voltage. Therefore, the inrush current will not appear when the transformer is in normal operation or external fault occurs. However, when the transformer is put into no-load operation or put into operation again after the external fault is removed, the magnetic field increases sharply due to the
sudden change of voltage, which leads to the saturation of the inner core of the transformer. The saturation flux depends on the permeability of the core material, the length of the magnetic circuit and the cross section of the core material. The saturation flux of the core leads to the decrease of the excitation inductance and the surge of the excitation current to the inrush current.

3. Suppression method of transformer inrush current
Various suppression methods of inrush current can be divided into external method and internal control [5]. External methods, that is, by taking certain measures on the structure of the transformer and the connecting line to reduce and restrain part of the inrush current, in order to reduce the damage of the inrush, the commonly used methods are [6-8]: series resistance method, parallel capacitance method, series inductance method, interpolation resistance method, eliminating residual magnetism method and changing the connection group, etc. Internal control, that is, from the principle of inrush current generation, by changing the transformer closing time and other aspects of control, fundamentally eliminate the inrush current [9,10], there are virtual gas method and phase selection switching technology.

4. Modeling and Simulation of transformer inrush current

4.1. The inrush current of transformer when no-load closing
A 35 kV substation is established, and the high voltage side of the transformer is connected to the power grid through 300 km overhead line, as shown in Figure 1. When the closing angle of three-phase circuit breaker is 0 degrees, the waveform is shown in Figure 2.

It can be seen from Fig. 2 that the characteristics of three-phase inrush current are as follows:
(1) The inrush current is asymmetric and contains a large number of aperiodic components, and its waveform is closer to the side of the time axis than the normal excitation current.
(2) The waveform of inrush current has discontinuity and obvious discontinuity angle.
(3) With the increase of time axis, inrush current decreases slowly.
(4) The different degree of inrush current is due to the phase difference of 120 degrees between three-phase voltages.

4.2. Inrush current of transformer after short circuit fault removal

The short circuit simulation model and waveform of three-phase transformer are shown in Fig. 3 and Fig. 4 respectively. The simulation time is 0.6s and the fault operation time is 0.2s to 0.4s.

![Fig. 3](image1)

Simulation model of three phase transformer in case of short circuit

![Fig. 4](image2)

Simulation waveform of three-phase transformer in case of short circuit

It can be seen from Fig. 4 that the short-circuit current is very large during the operation of the short-circuit fault, and the inrush current will be generated after the short-circuit fault is removed.

4.3. The research on inrush current suppression of three phase transformer

4.3.1 Suppressing inrush current by changing closing angle

![Fig. 5](image3)

Simulation waveform of A phase closing at 30 degrees
It can be seen from Fig. 5 to Fig. 8 that when the A-phase closing is 90 degrees, the suppression effect on inrush current is the best.

4.3.2 Changing the connection group of transformer to suppress inrush current

The suppression waveform of transformer Yd and Yy connection is shown in Fig. 9 and Fig. 10 respectively.
Fig. 9 the suppression waveform of transformer Yd connection

Fig. 10 the suppression waveform of transformer Yy connection

It can be seen from Fig. 9 and Fig. 10 that changing the connection group of transformer can also effectively suppress inrush current, and the effect of Yy connection is slightly better than that of Yd connection.

5. Conclusion
In this paper, the inrush current of transformer under no-load closing and voltage recovery after short-circuit fault removal is simulated. The inrush current of three-phase transformer is simulated by Matlab / PSB, and the measures of restraining inrush current by changing the closing angle and the connection group of transformer are studied. The simulation results show that the simulation of inrush current and its suppression can be realized effectively by using Matlab / PSB, which provides the basis for the research of transformer protection algorithm.

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