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DETECTION OF INTER TURN FAULT IN TRANSFORMER WINDINGS BY PARAMETERS OF THEIR TRANSITION PROCESSES

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Abstract: The proposed method of detection the inter turn fault of transformer windings relates to the area of defectoscopy and allows detecting inter turn faults in a wide range of damaged (closed) turns. Power and instrument transformers with iron-core are widely used in power networks. As the insulation ages or is damaged, the wires between various transformer sections short circuits occur, which inevitably leads to a complete damage of the transformer. Shortcircuited part of the transformer forms an additional winding, the outputs of which are shortcircuited. The transition process of current increasing when DC voltage is connected to the transformer outputs occurs in diverse ways in undamaged (cut-off) winding section and in the damaged (short-circuited) section. The current growth rate in the undamaged section of the winding is determined by high magnetization inductance. The inductance of the short-circuited part of the winding is much less, so, the current growth rate in the short-circuited part is significantly greater than the current growth rate in the undamaged part of the winding. The article presents observations from computer models and real measurements of the substation auxiliary power transformer, which show the possibility of determining the presence of a turn fault in regards to the transition process parameters, the rate of current increase and decay in the transformer winding. The device aimed to find the inter turn faults in the transformer windings, working according to the proposed method will be quite simple and have a high sensitivity.

Keywords: transformer, ferromagnetic core, inter turn fault, transition process.

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ОБНАРУЖЕНИЯ ВИТКОВЫХ ЗАМЫКАНИЙ ОБМОТОК ТРАНСФОРМАТОРОВ ПО ПАРАМЕТРАМ ПЕРЕХОДНОГО ПРОЦЕССА

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Резюме: Предлагаемая методика обнаружения витковых замыканий обмоток трансформаторов относится к области дефектоскопии и позволяет обнаруживать витковые замыкания в обмотках трансформатора в широком диапазоне поврежденных (замкнутых) витков. Силовые и измерительные трансформаторы с железным сердечником широко применяются в электроэнергетических сетях. При старении изоляции, при повреждении изоляции, в трансформаторах возникают замыкания между

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витками из разных частей обмотки, что неизбежно приводит к полному повреждению трансформатора. Короткозамкнутая часть обмотки трансформатора образует дополнительную обмотку, выводы которой замкнуты накоротко. Переходный процесс роста тока при подключении постоянного напряжения к выводам трансформатора поразному происходит в неповрежденной (разомкнутой) части обмотки, и в поврежденной (короткозамкнутой) части. Скорость роста тока в неповрежденной части обмотки определяется большой величиной индуктивности намагничения. Индуктивность короткозамкнутой части обмотки значительно меньше, соответственно скорость роста тока в короткозамкнутой части существенно больше скорости роста тока в неповрежденной части обмотки. В статье приводятся наблюдения в компьютерной модели и в реальных измерениях на трансформаторе собственных нужд подстанции возможность определения наличия витковых замыканий по параметрам переходного процесса, по скорости нарастания и спада тока в обмотке трансформатора. Прибор, предназначенный для поиска витковых замыканий в обмотках трансформатора, работающий по предлагаемой методике будет достаточно простым и иметь высокую чувствительность.

Ключевые слова: трансформатор, ферромагнитный сердечник, витковые замыкания, переходный процесс.

Introduction

One of the most frequently-occurring transformer defects is the inter turn fault, when some of the transformer winding turns is short-circuited [1]. Usually, the presence of inter turn faults is detected from the parameters of the transformer normal operation at industrial frequency of 50 Hz [2-6]. Increasing the frequency range during measurements of transformer parameters can increase the sensitivity of detection methods of inter turn faults [7, 8].

In case of inter turn faults, two parts of a winding are formed: the undamaged part (A in Fig. 1), which plays the role of the primary transformer winding, and short-circuited one (B in Fig. 1), which works as a secondary transformer winding.

To analyze the operation of the transformer winding with an inter turn fault, consider the T-shaped model [9] (Fig. 1), where the active resistance of the A turns is Ra; scattering inductance of the A turns is La; active resistance of B turns is Rb; scattering inductance of the B turns is Lb; inductance of saturation is L'o (which is less than the initial inductance Lo due to short-circuiting of B turns); E is the EMF connected to the winding. (All values are given for side A).



Fig. 1. T-shaped model of winding with inter turn fault (B turns)

Note that the scattering inductances of turns *La* and *Lb* are significantly less than the saturation inductance of *L'o*, so the time constant *Tab* (of the *Ra-La-Lb-Rb* circuit), equal to, $T_{ab} = (L_a + L_b)/(R_a + R_b)$, is significantly less than the time constant *T'o* (of the *Ra-La-L'o* chain), which is equal to. $T_o' = (L_a + L_o')/R_a$. Thus, the time constant *Tab* of the winding with inter turn fault is significantly less than the time constant of the saturation circui *T'o*: $T_{ab} \ll T_o'$. This difference governs the principle of detection the inter turn faults of transformer windings: the

time constant is measured in wide range, and the presence of transients with a small transition time clearly indicates the winding short circuits in the transformer winding.

Materials and methods

To illustrate the operating principle of method for detection the inter turn fault of transformed windings, the Matlab/Simulink software was used to build the model (Figure 2).



Fig. 2. The model of a transformer with a inter turn short-circuit, which is presented in the form of a short-circuited secondary transformer winding

Fig 3 presents the parameters of the three-phase transformer model.

A short-term DC voltage of 100 V (from *DC Voltage Source* in Fig. 2), is supplied to the primary winding of transformer (*Three-Phase Transformer*) through the current limiting resistance (*Parallel RLC Branch*) of 60 Ohms active resistance. Three-phase breaker (*Three-Phase Breaker*) connects DC voltage to the primary winding of the transformer (to the BC winding) in 0.02 seconds after the model start-up. The second three-phase switch (*Three-Phase Breaker1*) closes the primary winding of the transformer (BC winding) in 0.5 seconds after the model start-up. Thus, magnetization of the transformer core occurs in the range of 0.02 - 0.5 seconds (current increase in the primary winding), after 0.5 seconds, the demagnetization of the transformer core occurs (current drop in the primary winding).



Fig. 3. Characteristics of transformer used in the model

In the absence of inter turn short circuits (secondary turns of the transformer bc are not closed), the transformer magnetization inductance is high (*Magnetization Inductance Lm* (H) in Fig. 3), consequently, the rate of magnetization current change is small (Fig. 4).

When a turn short circuit occurs (transformer secondary turns bc are closed), the model has two magnetization inductances: the primary circuit BC and the short circuit of bc turns. Moreover, the number of turns in the primary winding is much larger than the number of turns in the turn faults (as it can be seen in Fig. 3, from *Winding 1 parameters V1* and *Winding 2 parameters V2*). Therefore, the magnetization inductance of the primary BC circuit is much greater than the magnetization inductance of the inter turn short circuit bc. This is reflected in the rate of increase and decrease of the magnetization current (Fig. 5): first (up to a time of the order of 0.1 s), a rapid increase in current occurs in the inter turn short circuit bc.



Fig. 4. Current in the primary winding BC in the absence of inter turn short circuits. Horizontal axis is time, s; vertical axis is current, A



Fig. 5. Current in the primary winding BC in the presence of inter turn short circuits (the secondary transformer turns *bc* are closed). Horizontal axis is time, s; vertical axis is current, A

After current saturation in inter turn short circuit (as shown in Fig. 6), only the slow growth of the magnetization current component in the primary winding BC remains (at times from about 0.2 to 0.5 s). After the primary winding BC closes, a similar process occurs: a rapid decrease in the inter turn short circuit current (Fig. 6) (approximately in the range from 0.5 to 0.7 s), then a slow decrease in the current in the primary BC circuit (see Fig. 5).



Fig. 6. Current in inter turn short circuits bc. Horizontal axis is time, s; vertical axis is current, A

Results

From the presented model of inter turn failures in transformers (Figs. 2 - 6), it can be seen that, based on the large difference in the rates of current change in the primary winding BC and in the inter turn short circuit bc, it becomes possible to create a device for detecting coil faults in transformer windings [10], using which the search for coil damage is significantly facilitated.

To verify and test the proposed methodology, transients were measured using an auxiliary transformer TSKS-40/145/10-UZ of Askold Electrotechnical Plant LLC (TU 3411-002-65653492-2010, the transformer idle run current is not more than 12%, power is 38 kVA, number of phases is 3, frequency is 50 Hz, degree of protection is IP 00, rated voltage of HV winding is 10 kV, rated voltage of HV winding is 0.4 kV, rated current of HV winding is 2.19 A, rated current of LV winding is 54.9 A, short circuit voltage is 1.48%, insulation class F, circuit and group connection is Y/Yn-O).

To record transients, the digital oscilloscope 6501 was used; the current in the transformer windings was measured by recording the voltage drop across the active resistance, connected in series with the measured transformer winding. Initially, a constant voltage of 8 V (through an active resistance of 47 Ohms) was applied to the primary HV winding of the transformer (BC pins). The current through the winding was measured by the voltage drop at a resistance of 10 Ohms, while the behavior of the transformer windings) was similar to the picture observed in the Matlab/Simulink program (see Figs. 4, 5).

There are several ways for increasing the sensitivity of the proposed method:

1. By increasing DC voltage supplied to the transformer windings, while reducing the measurement time interval (to maintain the same current in the transformer winding).

2. By applying a constant voltage (measuring transient) in the windings of the lower voltage (LV).

3. By obtaining the reference measurements of the transient process in all windings of the undamaged (without winding short circuits) transformer. Further, during periodic measurements, the current transient measurements in the transformer windings should be compared with the saved reference measurements.





(current measurement in the HV primary winding)



Fig. 8. The transient process in the primary HV winding (BC pins), the secondary LV winding (BC pins) are closed. At a time of 33.5 s, a DC voltage of 8 V was applied to the HV through a resistance of 47 Ohms; at a time of 39.5 s, the HV winding was closed. The X axis is time, s; the Y axis is voltage amplitude, mV, at a resistance of 10 Ohms (current measurement in the HV primary winding)

Further DC voltage of 8 V (through an active resistance of 10 Ohms) was applied to the secondary LV transformer winding (bc pins), the current through the winding was measured by the voltage drop at a resistance of 1 Ohm. A clear difference between the transient process in the absence (Fig. 9) and in the presence (Fig. 10) of inter turn fault (additionally wound one short-circuited turn on the B phase core) was observed.









At time of 0.02 s a constant voltage of 8 V through a resistance of 10 Ohms was applied to the LV; at time of 0.10 s, the LV winding was closed. The X axis is time, s; the Y axis is voltage amplitude, mV, at a resistance of 1 Ohms (current measurement in the LV secondary winding)

Conclusions

Thus, in the proposed method for detection the inter turn faults of transformed windings, the transients are measured in wide ranges of times, which allows tuning away from transformer magnetization currents, by measuring the transient in the fault itself, namely in the short-circuited turns of the transformer winding. This solves the task of detecting the inter turn faults in the transformer windings in a wide range of damaged (closed) turns.

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