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Research on Turn-to-turn Insulation Test Method of Dry-type Air-core Reactor

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Abstract: The paper introduces the principle of pulse-voltage method. With the parameters of a real dry-type air-core reactor, the emulation analysis verifies that the pulse-voltage method is suitable to test its turn-to-turn insulation.

Keywords: dry-type air-core reactor, pulse-voltage method, turn-to-turn insulation test, emulation analysis

I. PREFACE

In contrast with a traditional oil immersed iron-core reactor, a dry-type air-core reactor has many advantages, such as simple structure, light weight, small volume, good linearity, low loss and its maintenance is convenient. So it is rapidly developed and used widely.

A typical dry-type air-core reactor may consist of multiple centered packages. All packages are electrically connected in parallel. In each package, there are a number of small diameter metallic conductors (Aluminum conductors most commonly) which individually insulated with a thin mylar film or glass fiber. Each package is reinforced with the aid of a filamentary fiberglass that is impregnated with epoxy resin. After curing, the whole winding forms a sturdily encapsulated ensemble.

The serving state and numerous data show that the turn-to-turn insulation failure is the most common one that occurred during service of air-core reactor. Such failure often leads to short circuit of turn-to-turn insulation, and further burns the reactor. The direct and indirect economic lost is huge. Therefore, the air-core reactor manufactories and operating departments both take it seriously. The reactor manufactories should make the quality of reactor's coils better, modify the insulation structure and improve the technology; In addition, it is necessary to research a suitable method and develop an apparatus to test its turn-to-turn insulation failure.

At present, the research on turn-to-turn insulation test set of a dry-type air-core reactor is little in China. Products have already been shown on markets overseas, but the price is high and up to hundreds of thousand dollars. It is too expensive to purchase it for most manufactories in China. Therefore, it is urgent to develop a turn-to-turn insulation test set with good performance and low cost.

It is normal practice to perform induced voltage tests on transformers. Such tests are performed by energizing on winding by high frequency voltage and inducing the test voltage in high voltage(medium voltage) winding in order to electrically stress the turn-to-turn insulation. In the case of reactors, however, there is only one winding and the magnetic path is open. It is therefore not possible to induce a test voltage in it. Although it is feasible to test reactors with sinusoidal voltage waveforms by using a separate transformer, the rating of transformer is large and therefore its cost would be high, particularly when testing low inductance rectors. In addition, such test circuits adapt substantial capacitive compensation, it would reduce the rating of transformer, but it further adds to the overall cost. The paper introduces the principle of pulse-voltage method, and presents this method to test the insulation condition of a dry-type air-core reactor. In addition, with the parameters of a real dry-type air-core reactor, the feasibility on a real dry-type air-core reactor is analyzed with computer-aided analysis method.

II. PRINCIPLE OF PULSE-VOLTAGE METHOD

The pulse-voltage method is a method of directly stresses pulse-voltage on test winding [1]. The simplified test circuit is shown in "Fig.1".

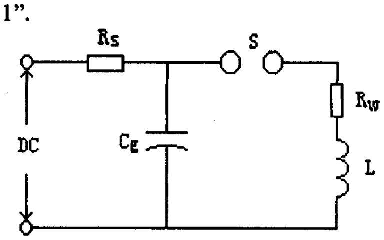


Fig.1. Basic operation figure of pulse-voltage method

Where,

L represents the resistance of the winding
Cg represents the main capacitor
Rw represents the resistance of the winding
S represents the discharge switch
Rs represents the current-limiting resistance

During testing, the capacitor Cg is charged up from a DC source to a voltage V0. The switch S is usually in the form of a spark gap that is caused to spark over when the capacitor has been charged to the desired voltage. At the instance of spark over, the capacitor Cg and test winging L forms a damped oscillatory circuit, the frequency of oscillation is given by: $f = 1/2\pi\sqrt{LC_g - R_w^2/4L^2}$. When the oscillatory discharge current has decayed to zero, the DC current from the supply is too low (since the resistance value of Rs is very high) to maintain the arc. The arc therefore extinguishes, and the capacitor Cg begins to charge up again. The charging continues until the voltage is high enough to cause another spark-over of the gap thereby applying another oscillatory pulse to the reactor. This process will repeat indefinitely or until the DC supply is switched off.

In this method, the frequency of oscillation is varies with the inductance value of the test winging, however, it can be limited in a certain range by choosing the right capacitor, and the high-voltage holding effect will not be changed. The advantage is that this method can raise high turn-to-turn test voltage, so, it is easy to find the turn-to-turn insulation default.

III. THE FEASIBILITY OF PULSE-VOLTAGE METHOD ON A DRY-TYPE AIR-CORE REACTOR

Replace the test winding with a reactor, if a short-circuited turn exists in the reactor, the following incidents will happen because of the mutual inductance between coils.

1. The decrease of the number of reactor's turns will reduce the overall inductance of the reactor, and it leads to a change of ring frequency of the circuit;
2. The coils except the short-circuited one will genèrate induced voltage on the short-circuited turn. This induced voltage will cause very large circumfluence, which form demagnetization field. So the total magnetic field intensity decreases and the inductance of the reactor decreases, thereby, the ring frequency of the circuit changes;
3. The circumfluence of the short-circuited turn will increase the loss of reactor, thus quicken the speed of voltage and current attenuation;
4. The existing short-circuited turn will break magnetometive balance of the reactor, and this will change the current distribution in each layer, generate circumfluence which run through the whole winding. Also, the circumfluence will increase the loss of the reactor, and speed up the voltage and current attenuation of the oscillatory circuit.

To sum up, with pulse-voltage method, a short-circuited turn of a reactor will change the speed of voltage and current attenuation and ring frequency in the test circuit Thereby, the insulation state can be judged by observing the change of voltage and current waveforms or by frequency.

Apparently, it is related to the number of turns that which is more obvious of the change of frequency and attenuation speed. If a reactor has a lot of turns (such as high-voltage shunt reactors) of a reactor, the influence of one or several shorted turns is small in frequency, in the opposite, if the number is relatively little (such as series reactors), the influence is large.

In order to research on the feasibility of pulse-voltage method that apply to a dry-type air-core reactor, and choosing a suitable method to judge if a default is existing, the paper does emulation analysis with Pspice[2], and observes the difference of voltage and current waveforms when a short-circuited turn exists and not exists. So we can judge whether the method is suitable and determine parameters of the circuit elements.

For emulation analysis with computer, the parameters of air-core reactor must be known, so the inductance of each layer、the mutual-inductance between two layers and the equivalent resistance should be calculated according to the size (such as height、inside radius etc.)、the number of layers and turns. Account for the demand of turn-to-turn test on a model reactor, the mutual inductance between short-circuited turn and other turn and the inductance of short-circuited turn should be calculated. With Bartky method[3] and programming with Fortran language, the paper calculates the inductance、mutual inductance between two layers and equivalent resistance of a real dry-type air-core reactor with 5 packages and 20 layers. The circuit of emulation analysis is shown in "Fig.2":

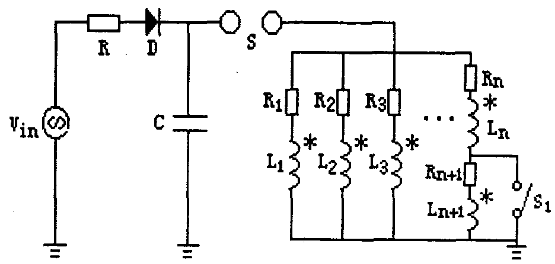


Fig.2. Emulation circuit

Where,

L1~Ln represents the inductance of the 1st layer to the 20th layer

R1~Rn represents the resistance of the 1st layer to the 20th layer

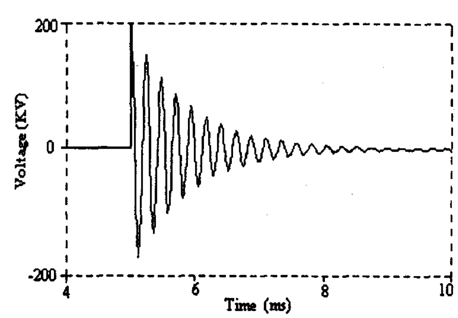
Ln+1 represents the inductance of the short-circuited turn

Rn+1 represents the resistance of the short-circuited turn

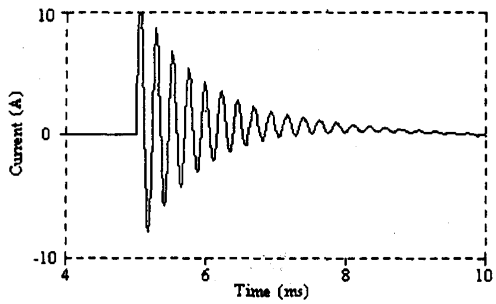
After the circuit model of an air-core reactor is established, the emulation analysis with Pspice can be proceeded. A lot of works have been done according to different types of turn-to-turn insulation.

(1) No default in the turn-to-turn insulation of the reactor

When there is no default in the turn-to-turn insulation in the reactor, the overall voltage and current waveforms are shown in "Fig.3". As we saw, the voltage and current are both attenuate and oscillatory.



(a) The voltage waveform

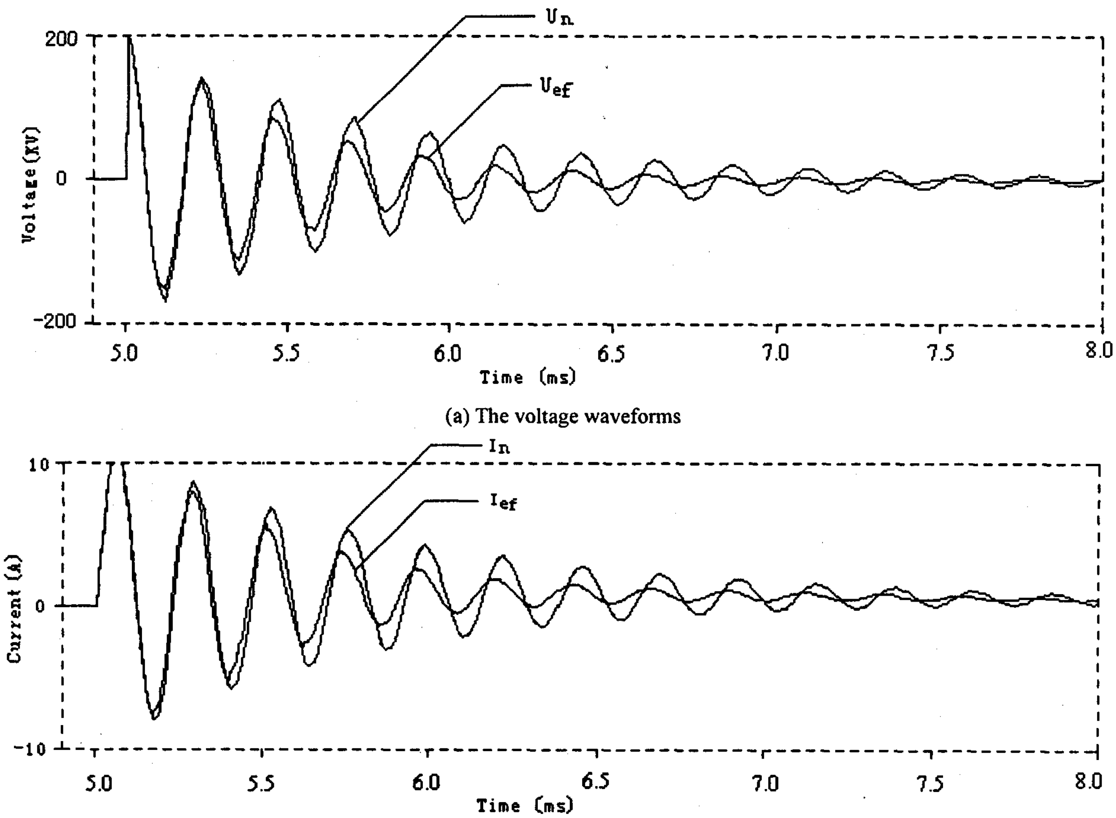


(b) The current waveform

Fig.3. The voltage and current waveforms without default

(2) the default occurred at the end of the winding

In this case, the mutual inductance between short-circuited turn and other turns of the reactor is low, the voltage and current waveforms gotten by emulation analysis are shown at "Fig.4". In order to contrast conveniently, the fig gives the overall voltage and current waveforms when there is no default in the reactor. Where: $U_n(I_n)$ represents the overall voltage (current) when there is no default in the reactor, $U_{ef}(I_{ef})$ represents the overall voltage (current) when the default occurred at the end of reactor's winding. "Fig.4" shows the attenuation is more rapidly when the default occurred at the end of the winding than the one when the insulation condition is good, moreover, the ring frequency is higher.



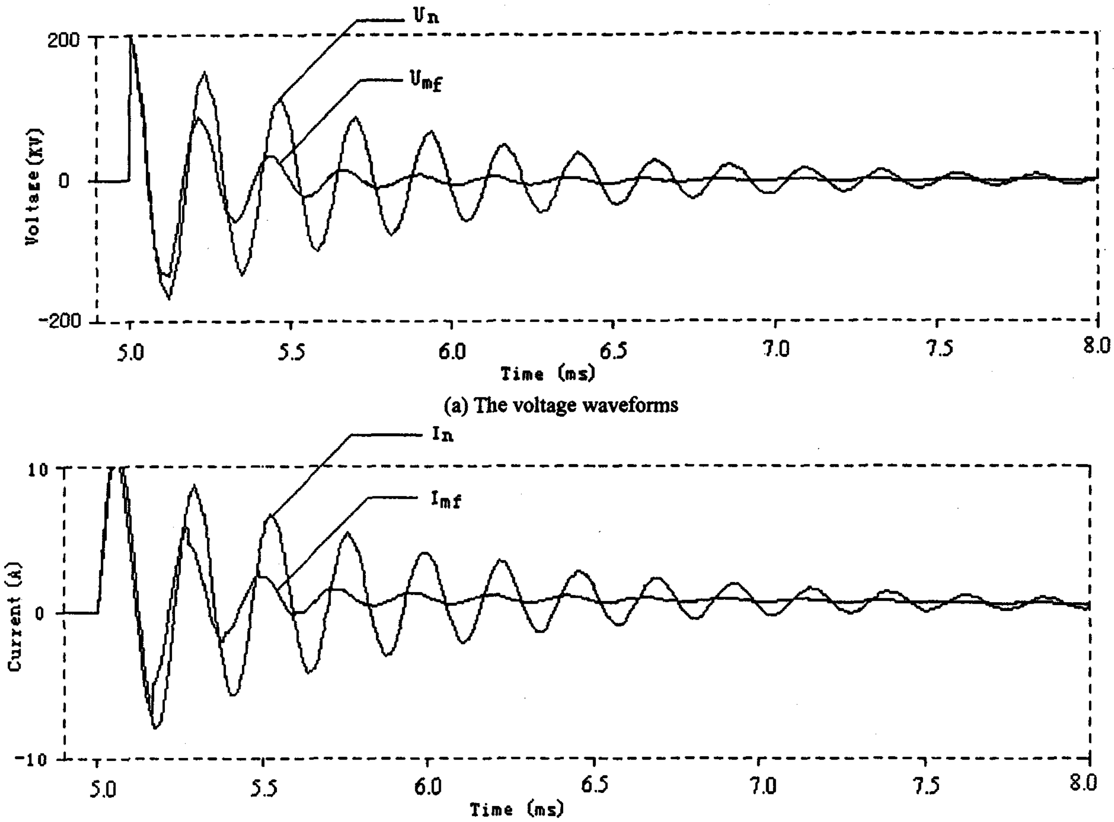
(a) The voltage waveforms

(b) The current waveforms

Fig.4. The voltage and current waveforms when the default occurred at the end of the winding

(3) the default occurred in the middle of the winding

In this case, the mutual inductance between short-circuited turn and other turns is high, the overall voltage and current waveforms gotten by emulation analysis are shown in "Fig.5". Where, $U_n(I_n)$ represents the overall voltage (current) in the reactor when there is no default in the reactor and $U_{mf}(I_{mf})$ represents overall voltage (current) waveform when the default occurred in the middle of the winding. "Fig.5" shows that the attenuation of the overall voltage and current is more rapidly when the default occurred in the middle of the winding than the one that when no default exists, moreover, the ring frequency is higher. In contrast with "Fig.4", the attenuation speed of overall voltage and current is higher in this circumstance, and the ring frequency is also higher.



(b) The current waveforms

Fig.5. The voltage and current waveforms when the default occurred in the middle of the windings

From analysis above, conclusions can be drawn as:

- If a turn-to-turn insulation failure occurred, the attenuation speed of the voltage and current waveforms is higher than the one when the reactor is in good state, And the frequency of the voltage and current waveforms is also higher.
- The attenuation of the voltage and current waveforms is less obvious if a turn-to-turn insulation failure occurred at the end of test winding than in the middle. In other words, it is much easier to judge whether default is existing if the turn-to-turn insulation failure occurred in the middle of the test winding.

According to emulation analysis with computer above, the pulse-voltage method is suitable to test turn-to-turn insulation of a dry-type air-core reactor, and the default can be judged by contrasting with the attenuation degree of the voltage energized on the winding and the current flow through the winding. To be sure, the change of ring frequency of voltage (current) can also judge the state of insulation. In addition, if the turn-to-turn insulation default exists when testing the reactor with pulse-voltage method, there may be accompany with such phenomena like noise、smoke and fog、spark etc. These all can be proofs of default judging.

IV. CONCLUSIONS

The paper presents pulse-voltage method to test turn-to-turn insulation of a dry-type air-core reactor, and verifies the feasibility of the method by emulation analysis with the parameters of a real dry-type air-core reactor.

V. PREFERENCE

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