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Research on Test of Key Parameters of On-Load Tap-Changer in Transformer

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Abstract. There are two main testing methods for the key parameters of the transformer on-load tap changer. One is the DC test method and the other is the AC test method. Based on the AC test method for on-load tap changer key parameters, a new test scheme was proposed. The on-load tap changer switching operation of the transformer can be simulated by establishing a model. The waveforms of the transitional AC current and the testing AC voltage are stored and preprocessed. Then the transitional AC current is equivalent to DC components through the Park transformation. By using the off-line identification algorithm, the transient stage of the transformer on-load tap changers can be determined and the transition resistance value can be accurately calculated.

1. Introduction

The power transformer is an important part of the power system and one of the main equipment of the power grid. The safe and stable operation of power transformers is closely related to the stable operation of the power grid. The on-load tap changer of transformers consists of operating mechanism, tap selector, changeover switch and drive part [1-4]. The use of the on-load tap changer enables the transformer to switch the number of windings of the transformer without cutting off the load, thereby changing the transformer ratio and changing the output voltage on the load side [1]. Therefore, the working status and operating characteristics of the on-load tap changer directly affect the safe and stable operation of the transformer. With the increasing complexity of power grid structure and the continuous expansion of power systems, more and more faults have occurred in transformer on-load tap changers [4-5]. Therefore, it is significance to use certain test methods testing the operating characteristics of the on-load tap changer when it is installed and inspected, which can ensure the safe operation of the power transformer and the stable operation of the power system.

There are two main methods for testing the key parameters of on-load tap changer: DC test method and AC test method [6-12]. There are many analyses of the technical methods used in the test process of the existing DC test methods and AC test methods in literature [6-12]. Due to the test principle, technical ability and other reasons, the DC test methods sometimes has a large difference between the measured operating characteristics and the operating characteristics given by the manufacturer. Therefore, using the DC test method cannot accurately determine the transition process, which may cause the on-load tap changer to repeatedly check out and affect the normal operation of the equipment. Because of the deficiencies of the DC test method, the AC test method was proposed. The experimental method using AC test is closer to the actual operating state of the transformer on-load tap changer. By



analyzing transitional current waveforms, the transitional stages of on-load tap changer can be judged. However, after adopting the alternating transition current waveform obtained by the AC test method, it is necessary to manually analyze the transition process. By doing this, it is not possible to accurately determine the transition phase and calculate the transition resistance.

Based on the AC test method, this paper proposes a new scheme to identify the transition time of the on-load tap changer switching transition and calculate the value of the transition resistance. First, acquire and store test AC voltage waveforms and transitional AC current waveforms and preprocess them. Second, obtain the equivalent DC component of the resulting AC transient current waveform by using Park transformation. Last, use offline identification algorithm to judge the transition process and calculate the transition resistance. For testing the proposed scheme, a simulation model was established to verify the feasibility of the design scheme.

2. The working principle of the on-load tap changer

The on-load tap changer basic operating principle [6]: bring many taps out in the transformer windings, then switch from one tap of transformer to another and change the effective number of turns in transformers, so the voltage of load can be regulated by changing the ratio of transformer. In this process, the load current is not interrupted. There are two conditions in the process of on-load tap changer switching: one is the load current is continuous during the switching process of on-load tap changer, the other is that the tap of transformer cannot occur short circuit fault. So it is necessary to add transition resistance between the taps [10]. Figure 1 shows the equivalent circuit diagram of the on-load tap changer for the transformer. In figure 1, “s” stands for the slide contact of on-load tap changer, “k1” “k2” “k3” “k4” respectively stands for point contact of on-load tap changer, “k1” and “k4” respectively stand for main contact of on-load tap changer, “k2” and “k3” are transition contacts of on-load tap changer, “N1” and “N2” are static contacts of on-load tap changer. Figure 2 shows the switching process of the double transition resistance on-load tap changer of transformer. In figure 2, (a), (b), (c), (d), (e), (f), and (g) respectively indicate the stages of the operation of the on-load tap changer. Stage (a) is the first steady state stage, stage (b) is the first bypass stage, stage (c) is the first half bridge stage, stage (d) is the bridge stage, stage (e) is the second half-bridge stage, stage (f) is the second bypass stage, and stage (g) is the second steady state stage.

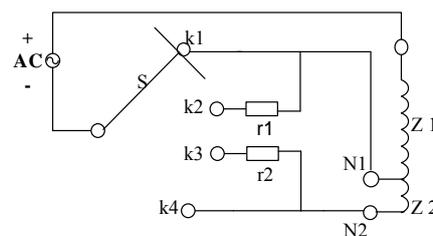


Figure 1. The equivalent circuit diagram of the on-load tap changer for the transformer

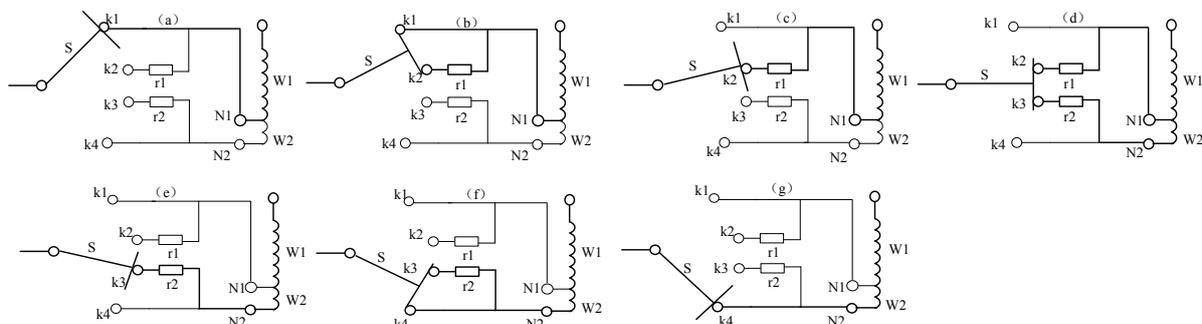


Figure 2. The switching process of the double transition resistance on-load tap changer

3. On-load tap changer action process simulation model establishment

Figure 2 shows the complete acting process of the transformer on-load tap changer. Establish simulation models to simulate the on-load tap changer action process. Figure 3 shows the transformer on-load tap changer simulation module. Figure 4 shows the timing diagram of each tap contact action signal of the on-load tap changer. In figure 4, the on-load tap changer starts to operate at the rising edge of the Step signal, the rising edge of the tap control signal indicates that the tap contact is closed and the falling edge indicates that the tap contact is open. The on-load tap changer specific action logic can be implemented by programming a program. According to the timing shown in Figure 4, the on-load tap changer switching transition can be completely simulated.

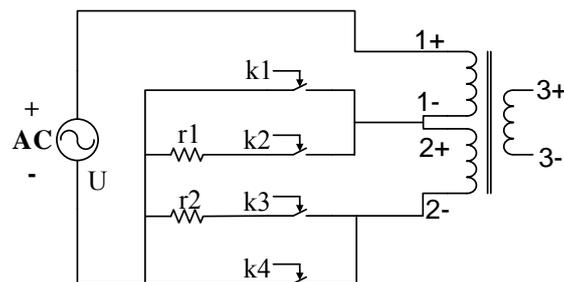


Figure 3. The transformer on-load tap changer simulation module

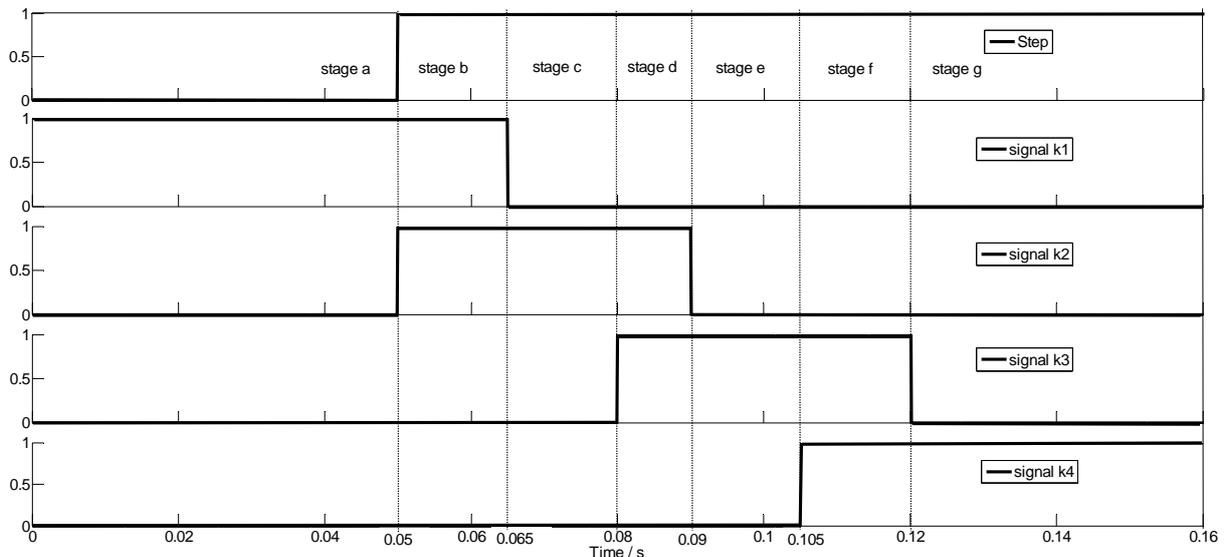


Figure 4. The timing diagram of each tap contact action signal of the on-load tap changer

4. Offline identification algorithm

The so-called offline identification algorithm is to store the AC test voltage waveform and the AC transient current waveform used in the AC test method, then design algorithms to analyze the stored waveforms off line. Last, determine the transition period of transformer on-load tap changer and calculate the transition resistance value. Figure 5 is the flowchart of offline identification algorithm.

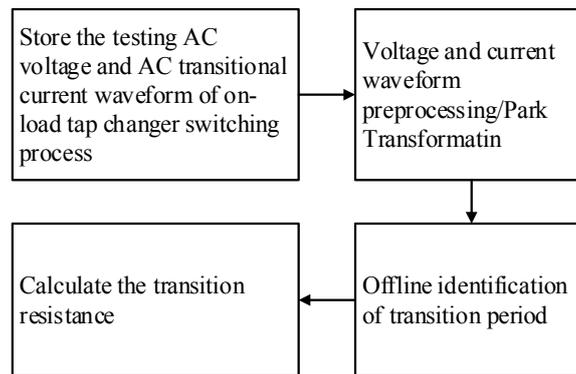


Figure 5. The flowchart of offline identification algorithm

Set up transformer on-load tap changer AC testing simulation model and then use simulation model to simulate an acting process of the on-load tap changer. The testing AC voltage and AC transient current waveforms are stored. First, find positive zero-crossings for testing AC voltage waveforms and choose this point for phase reference. Second, obtain the direct and axial components of the AC transition current by using Park Transformation. Then the transition period can be identified through the equivalent DC value of the AC transient current. So we can accurately determine the exact moments that occur at each transitional stage. And the stage includes steady state before switching, first half-bridging start stage, first half-bridging steady stage, bridging start stage, bridging steady stage, second half-bridging start stage, second half-bridging steady stage and post-switching steady stage. Furthermore, the transition resistance value is calculated based on the transition time and the equivalent direct current component of the AC transient current.

The acquired voltage and current waveforms are preprocessed and then obtain the AC transient current d component I_{dn} and current q component I_{qn} by using Park Transformation. Figure 6 shows the testing AC voltage waveform and the transitional AC current waveform. Figure 7 shows the AC transient current equivalent d and q component waveforms. According to the AC transient current d component I_{dn} and current q component I_{qn} , and then calculate the current amplitude I_{dq} . The calculation formula of I_{dq} is:

$$I_{dq} = \sqrt{I_{dn}^2 + I_{qn}^2} \quad (1)$$

Then use the current amplitude corresponding to the two adjacent sampling times to subtract to obtain the law of current amplitude variation. According to the law of current amplitude variation, we can find out the moment of action of the on-load tap changer, and then identify the transition period of the transformer on-load tap changer. In order to distinguish the transitional process stages, set the parameters at each current change time point in the algorithm and set the identification criteria of different states at the same time. The time of each phase of the transition process is set:

- t11 - The time to start switching of the on-load tap changer;
- t12 - The time to start entering first half-bridge of the on-load tap changer;
- t13 - First half-bridge steady time of the on-load tap changer;
- t14 - Bridge starting time of the on-load tap changer;
- t15 - Bridging into the steady state moment of the on-load tap changer;
- t16 - The second half-bridge starting time of the on-load tap changer;
- t17 - The second half-bridge steady state moment of the on-load tap changer;

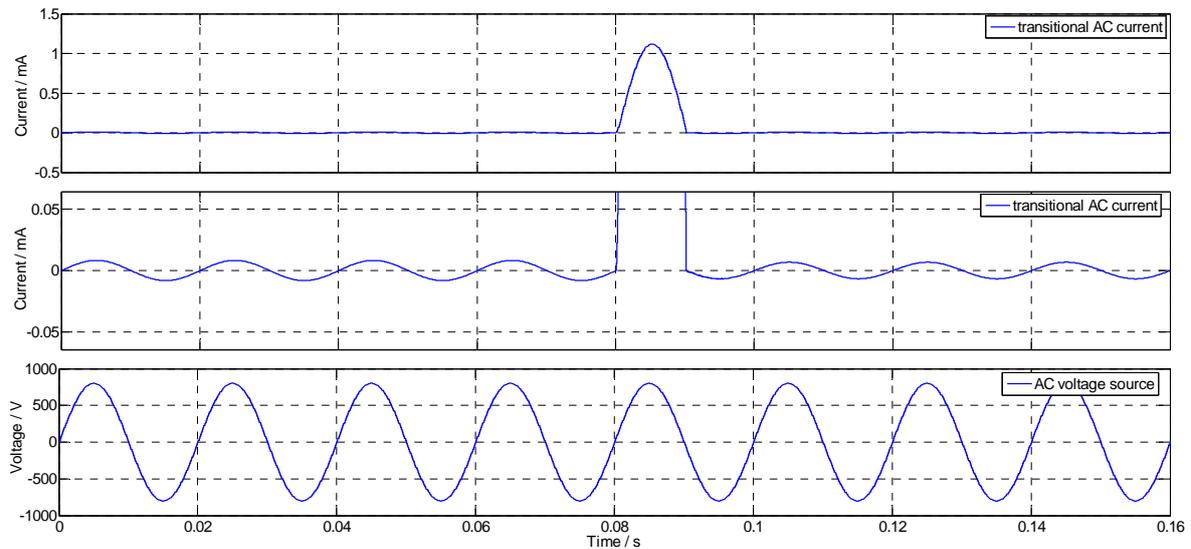


Figure 6. The testing AC voltage waveform and the transitional AC current waveform

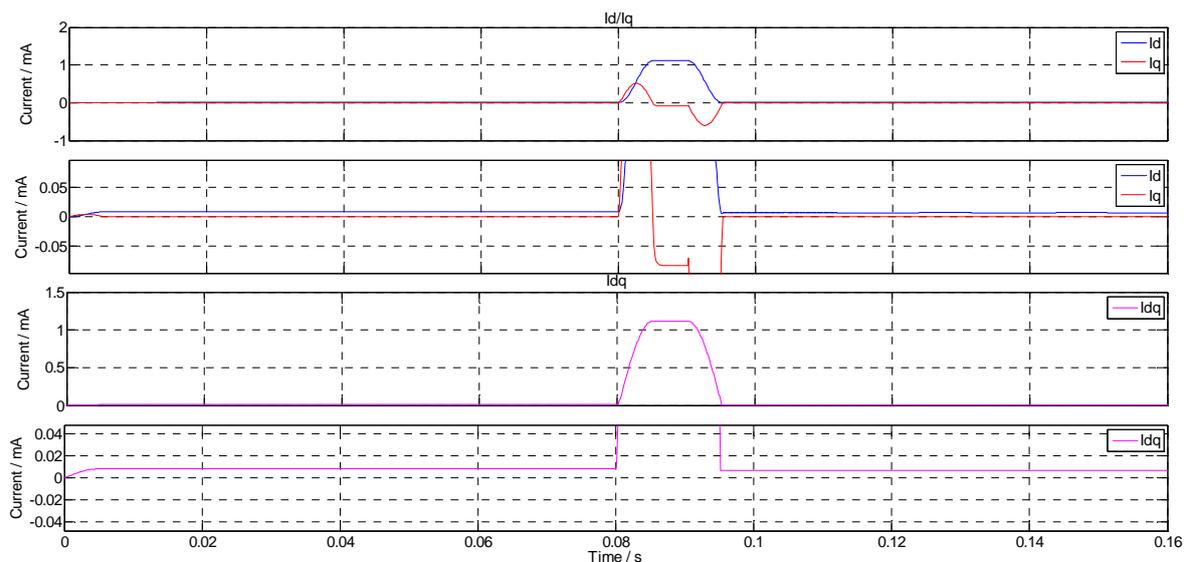


Figure 7. The AC transient current equivalent d and q component waveforms

t18 - The second bypass starting time of the on-load tap changer;

t19 - The second bypass steady time of the on-load tap changer;

After each period of the transition process is identified, use the pre-switching steady state current value, the half-bridged steady state current value and the post-switching steady state current value, then calculate the transition resistance value by designing an algorithm. After acquiring of on-load tap changer working process through the identification algorithm, select the sampling points in the middle of each phase and extract the corresponding value from the stored data for filtering. Then calculate the average value of the corresponding current component at each third of the acquisition time and calculate transitional resistance by using the algorithm program. The formula (2)-(14) shows the calculation process of the algorithm.

AC test power supply voltage (V):

$$U = 800 + 0 * 1j \quad (2)$$

The real part of the steady state impedance Z_1 before the on-load tap changer switching is equivalent resistance R_1 , which can be calculated by formula (3)-(5).

$$I_1 = I_{d1} + I_{q1} * 1j \quad (3)$$

$$Z_1 = U/I_1 \quad (4)$$

$$R_1 = \text{real}(Z_1) \quad (5)$$

On-load tap changer first transition resistance r'_1 can be calculated by formula (6)-(8).

$$I_2 = I_{d2} + I_{q2} * 1j \quad (6)$$

$$Z_{x1} = U/I_2 \quad (7)$$

$$r'_1 = \text{real}(Z_{x1}) - R_1 \quad (8)$$

After the transformer switching is completed, the real part of the steady state impedance Z'_2 is equivalent resistance R'_2 , which can be calculated by formula (9)-(11).

$$I_4 = I_{d4} + I_{q4} * 1j \quad (9)$$

$$Z'_2 = U/I_4 \quad (10)$$

$$R'_2 = \text{real}(Z'_2) \quad (11)$$

On-load tap changer first transition resistance r'_2 can be calculated by formula (12)-(14).

$$I_3 = I_{d3} + I_{q3} * 1j \quad (12)$$

$$Z_{x2} = U/I_3 \quad (13)$$

$$r'_2 = \text{real}(Z_{x2}) - R'_2 \quad (14)$$

This paper verifies the feasibility and accuracy of the proposed offline identification algorithm by presetting parameters. The conditions of pre-set parameters: AC measurement voltage source output remains stable, AC voltage peaks at 800 v, initial phase is 0 degree, no lag, and frequency is 50 Hz. Take the on-load tap changer starting switch time as the reference value, the moment of action of each tap contact in the transformer on-load tap changer is [0 15 30 40 55 70] ms, the transition resistance of on-load tap changer is: $r_1=3\Omega$, $r_2=3\Omega$. Table 1 shows the data obtained by the offline identification algorithm.

Table 1. The data obtained by the offline identification algorithm

t11 (ms)	t12 (ms)	t13 (ms)	t14 (ms)	t15 (ms)	t16 (ms)	t17 (ms)	t18 (ms)	t19 (ms)	r'_1 (Ω)	r'_2 (Ω)
50	65	70.1	80.1	84.9	90.1	95.2	105.1	110.2	2.9963	2.9959

5. Conclusion

Traditional AC test method can reflect the transition phase of on-load tap changer. The existing analyzing method is based on the analysis of the transitional current waveform. Then artificially analyze the transitional process phase. And this method is prone to misjudgment. So far, there is no set of practical judgments. This paper is based on the AC test method for on-load tap changers in transformers, and judges the transient stage of on-load tap changer by designing algorithms and using offline identification method. Finally, the transient resistance can be accurately calculated. This solution simulates by building models and presetting parameters. The results of simulation have small errors and meet the relevant standards of the national power industry.

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