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IMPROVEMENT OF THE PROCEDURE OF INSTRUMENT TRANSFORMERS TESTING IN OPERATION CONDITIONS

The paper analyzes the methods of shading coils detecting in the windings of current transformers. Method of shading coils determination in the winding of current transformers is suggested. This method differs from already known methods by greater efficiency and reliability and may be recommended for application in practice.

Key words: current transformer, turn short circuit, transformation ratio, voltage, magnetizing current.

Introduction

In the process of operation turn short circuits rather frequently occur in secondary windings of current transformers, used for measurement of current in the circuits of electric energy account, relay protection and automation. This leads to considerable errors in the process of currents measurement and abnormal operation of relay protection and automatic devices. That is why, in the process of operation, in accordance with Rules of arrangement and operation, current transformers are annually tested on the subject of shading coils.

In accordance with the existing norms technical current transformers (CT), designed for supply of measuring instruments, relatively admissible errors are divided into the following classes of accuracy 0.2; 0.5; 1.0; 3.0 and 10. Accuracy class equals admissible current error at multiplicity of current ratio that equals one, on condition, that $\cos \varphi_l = 0.8$ and the value of load impedance is within the limits $(0.25 \div 1.0) \cdot Z_{l.nom}$ for current transformers of accuracy class 0.2; 0.5 and 1.0 and within the limits $(0.5 \div 1.0) \cdot Z_{l.nom}$ for current transformers of accuracy class 3.0 and 10, where $Z_{l.nom}$ – nominal load impedance [1, 6].

In relay protection circuits the possibility of considerable bend of magnetizing current and secondary current curve must be taken into account.

As it is known alternating current protective relays are calibrated and controlled, as a rule, at sinusoidal current, conditions of operation and non-operation are characterized by the values of sinusoidal current. If the form of the curve is violated, then the acting value of the bent current sufficiently characterizes the behavior only in those relays, for which the acting value of the current is the response parameter (for instance, electromagnetic relays). If the response parameter is, for instance, mean rectification value of the current I_{mr} , then the acting value of the current, bent by the form of current, does not characterize the behavior of the relay. In the given case relay operation is characterized by certain conventional current, that equals $1.11 \cdot I_{m.r}$, where 1.11 – is the coefficient of the form of sinusoidal current curve, used for relay testing. If the relay, that responds to mean rectified value of the current, operates at the acting value of sinusoidal current, that equals $I_{p.c}$ then, in case of the bent form of current curve it will operate at the acting value of the current:

$$I'_{p.c} = I_{p.c} \cdot K_f / 1.11,$$

where K_f – coefficient of the form of current curve bent.

Thus, depending on the character of current bent (on the value K_f) the relay may be more or less sensitive to acting value of the current.

Similarly if the relays responds to current amplitude, then its acting value of operation current is:

$$I'_{p.c} = \sqrt{2} \cdot I_{p.c} / K_a,$$

where K_a – coefficient of current amplitude.

Accuracy of current transformation in transient process of short-circuiting (SC) influences considerably the stability of operation of relay protection devices, especially in the networks of 220 kV and higher, when rapid disconnection of SC is needed.

It should be taken into account that at constant of the primary network time $T_a > 0.03 \div 0.05$ with (network of 110 kV and higher, sometimes lower voltages) current transformers (CT) with close magnetic circuit in transient processes are often saturated, that leads to considerable errors. As such CT are widely used, then measuring instruments of fast-acting relay protection devices must be realized in such a way that the bent form of the secondary current would not result in violation of protection system operation.

According to ICEE recommendations current transformers, intended for supply of fast-acting relay protection devices are divided into three classes and are denoted as:

- a) TPX – current transformer, that has ring-type magnetic circuit, enabling to supply accurately in secondary circuit both alternating and direct components, that are proportional to primary current;
- b) TPX – current transformer with small nonmagnetic gap for elimination of residual inductance;
- c) TPZ – current transformer with nonmagnetic gaps and linear characteristic along the whole range of currents change.

TPZ current transformers provide accurate transformation of only periodic component of SC current. In accordance with the designation of CT of the corresponding class, accuracy requirements are regulated in transient processes. Accuracy requirements at active loading, that creates the greatest errors, are regulated in the following manner [2]:

- For TPX class current transformers the error by the maximum of instant value of magnetizing current must not exceed 5 % of the amplitude of nominal secondary symmetrical current of SC and the error by the transition of the current across zero value – 3 % during any period of SC process, for which accuracy is regulated;
- for TPY class current transformers errors are defined as for TPX class transformers and are 7.5% and 4.5% correspondingly;
- for TPZ current transformers transformation error of periodic component of SC current is standardized, periodic component of magnetizing current must not exceed 10 % of periodic component of the secondary current.

Calculation of current transformers errors is carried out, applying the method of magnetization characteristic for CT with rated active load from 2.5 to 15 W.

To detect short-circuited turns in secondary windings of current transformers (CT) the following methods are used [3]:

- taking of voltage – current characteristic of current transformer;
- measuring of magnetizing current at plant control point;
- measuring of transformation ratio of CT while connecting with the resistance secondary winding;
- usage of BAΦ-85M type device.

A. Taking of voltage – current characteristic of current transformer

Voltage current characteristic of CT is the dependence of secondary winding voltage U_2 on

magnetizing current I'_{2mag} , i.e., $U_2 = f(I'_{2mag})$. Drop of voltage – current characteristic and change of its slope shows widely spread and the most dangerous damage – turn short circuit in the secondary winding.

When voltage current characteristic is taken, variable regulated voltage is supplied to the secondary winding, being tested, at disconnected primary winding, and current, passing across the winding is measured (Fig 1).

When one of the secondary windings is tested, all other secondary windings of the given CT must be closed. In the process control the test circuit with voltage regulation by means of autotransformer (AT), that provides the least bending of voltage curve form must be used.

The circuit, using one autotransformer of ЛАТП-2 type provides regulation range from 0 to 250 V, and the circuits with two ЛАТП-2 allows to obtain regulation voltage up to 450 V. In accordance with the norms [4], while VAC testing the voltage at the secondary windings must not exceed 1800 V.

Voltage U_2 measurement must be carried out by the voltmeter, that measures mean value, in this case, readings of the voltmeter must be multiplied by 1.11 factor. The voltmeter, readings of which are proportional to mean value of the voltage and the scale is calibrated in acting values of sinusoidal curve is accepted for usage. In this case, multiplication of voltmeter readings by the coefficient 1.11 is not needed. Measurement of magnetization current must be performed by the ammeter of acting value.

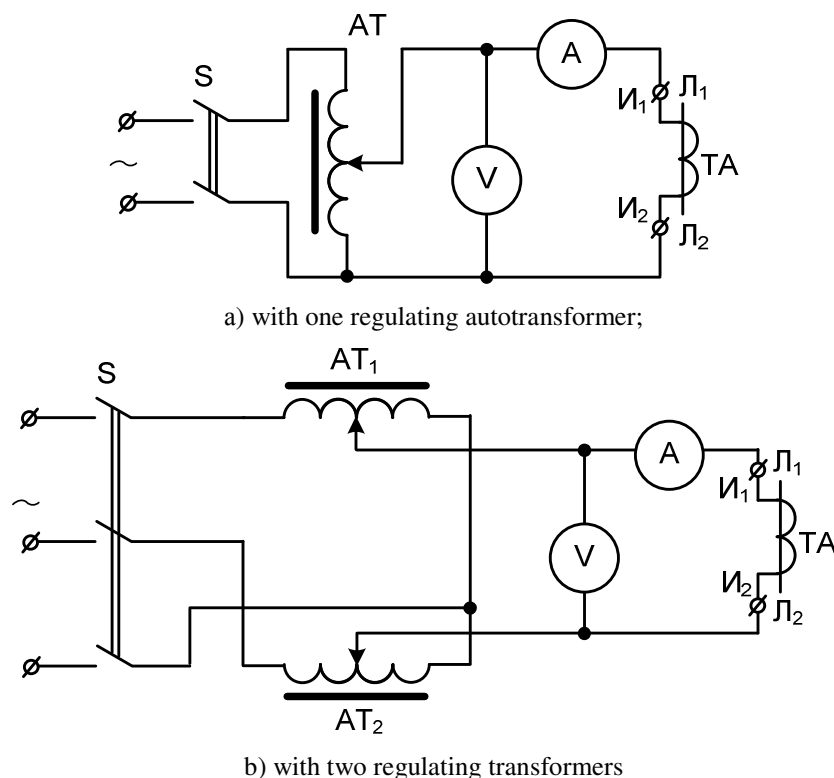


Fig. 1. Scheme of taking voltage – current characteristics of current transformer

For CT, that have their own primary winding it is accepted to measure U_1 voltage at the terminals of the first winding and recalculate it into the voltage of the secondary winding U_2 by the formula:

$$U_2 = 1.11 \cdot U_1 \cdot \omega_1 / \omega_2,$$

where ω_1 , ω_2 – number of turns in the primary and secondary windings of CT.

For cascade current transformers measurement of magnetizing current is carried out separately for each stage.

Evaluation of CT serviceability in case of complete connection is realized as a rule, by means of comparison of VAC of all transformers of the given type with the same transformation ratio (n_c). If one of the characteristics is located lower than the others (50 % and more), it shows that there is turn short circuiting in current transformer; if the difference is 25 – 40%, in this case, it is necessary to compare VAC of CT with typical characteristic and perform certain additional checking, that will allow with great probability to reveal the availability to short-circuited turns.

Additional inspections for CT with the lowest VAC, if there are suspicions regarding turn short-circuiting, must be done, comparing with the results of analog testing at serviceable current transformer (CT). Fig 2 shows VAC of current transformers of ТПШФ and ТВ types [5].

B. Measurement of magnetizing current in plant control point

Manufacturing plants in CT certificate indicate the values of U_2 and I'_{2mag} for control measurements at complete connection, but for the time being there is no sufficient experience, that allows to evaluate the efficiency of detecting turn short-circuiting by measuring magnetizing current at plant control point (Table 1) [1].

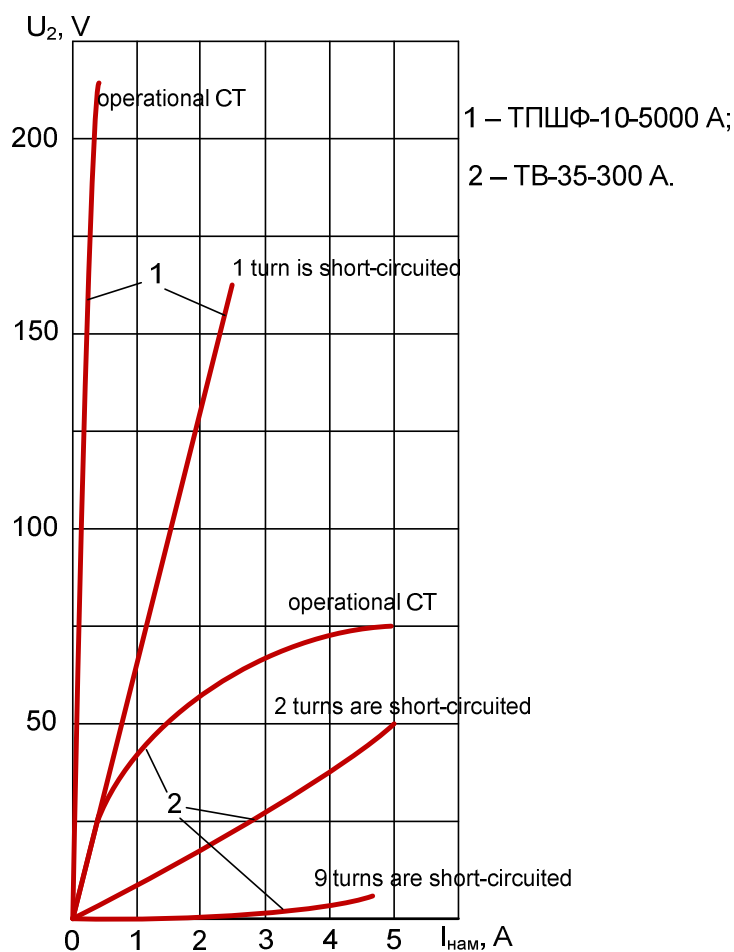


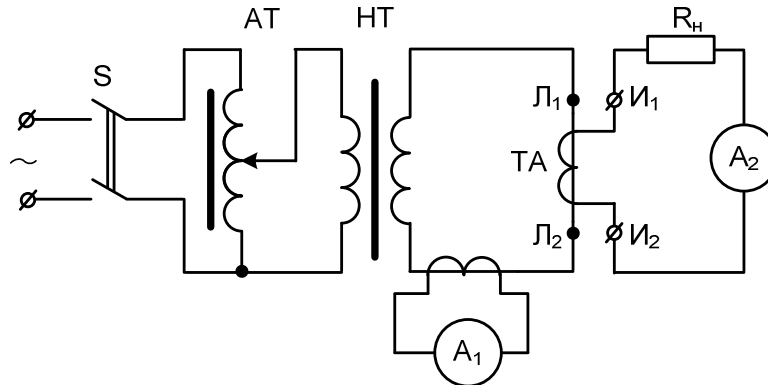
Fig. 2. Characteristic of current transformers magnetizing at turn short-circuiting in secondary windings

Table 1 – Data for current transformer checking according to plant control points

CT type	Secondary winding, being tested	Nominal primary current, A	Control voltage, V		Magnetizing current, mA	
			$I_{2nom} = 1 \text{ A}$	$I_{2nom} = 5 \text{ A}$	$I_{2nom} = 1 \text{ A}$	$I_{2nom} = 5 \text{ A}$
ТФ3М 35Б-ІІУ1	All	500	–	195	–	524
		1000	–	195	–	524
		2000	961	225	110	136
		3000	1100	245	44	134
ТФ3М 110Б-ІІУ1	All	1500	838	180	84	464
		2000	879	218	54	324
ТФ3М 150Б-ІІУ1	2И ₁ –2И ₂	1000, 2000	1635	378	89	980
	3И ₁ –3И ₂ ; 4И ₁ –4И ₂	–	1362	315	52	360
ТФ3М 220Б-ІІІУ1	2И ₁ –2И ₂ ; 3И ₁ –3И ₂	300–1200	900	173	112	548
	4И ₁ –4И ₂	–	319	76	44	266
ТФ3М 500Б-ІVУ1: low stage upper stage	All					
		5	1347	–	132	–
		1000, 2000	–	2303	–	368

C. Measurement of current transformer transformation ratio at connection of the resistance into the secondary winding

Measurement of transformation ratio n_c by primary current is realized, when the resistor $R_n = (10 \div 30) \cdot Z_{nom}$ of CT is connected into the secondary circuit (Fig 3). In operational current transformers value of n_c changes insignificantly and in case of turn short-circuiting the value of secondary current decreases and the value of n_c increases. In the process of testing of built-in CT with transformation ratios 2000/5, 1500/5 and 750/5 at taps И₁–И₂ at $R_N = 1, 0; 10; 20; 30 \text{ Ohm}$ ($Z_{nom} = 1 \text{ Ohm}$) at one short-circuited turn, corresponding values of $n_c = 150; 172; 220$ and 250 were obtained; in operational CT transformation ratio increased insignificantly.

Fig. 3. Checking of transformation ratio n_c at different values of Z_{nom} resistance

D. Usage of БАФ-85М – type device

БАФ-85М device is used for measurement of the angle between voltage U_2 and magnetizing current I'_{2mag} ; in operational current transformers in linear section of VAC voltage U_2 leaves behind magnetizing current I'_{2mag} by the angle of $30 \div 50^\circ$, and with saturation the angle reaches 90° . In case of turn short circuiting the angle of lead at the same values of current is far smaller, and its increase is observed at greater values of magnetizing current.

Analysis of the method of short-circuited turns in CT detection proves that all they are labor

consuming, require performing numerous experiments and long processing of the results, that is, they are not convenient in operation conditions. That is why, it is desirable to have simpler methods of short-circuited turns detection in the windings of CT. One of them may be the method that does not require great efforts from operation staff of energy enterprises and provides reliable results, regarding the detection of faulty CT.

The essence of the method is that current is applied to primary winding, and voltage is measured at the secondary winding, that proportional to magnetic flux (Fig 4). If there are short-circuited turns current, that passes across these turns creates opposite magnetic flux, as a result the voltage at open terminals of secondary winding drastically drops as compared with operational CT. Table 2 contains the experimental data for current transformers of ТПЛ-10У3 type.

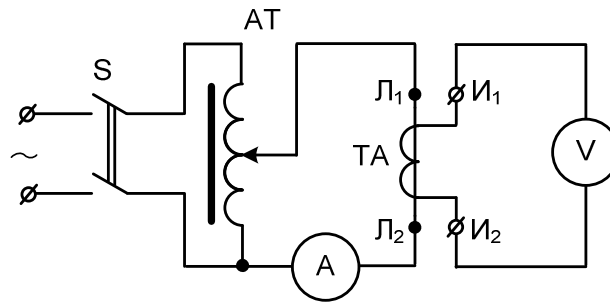


Fig. 4. Circuit for determining of short-circuited turns in CT

Table 2 – Experimental data regarding detection of short-circuited turns in secondary winding of ТПЛ-10У3 type current transformer

Current transformer	Transformation ratio	Accuracy class of the winding	I , A	U , B	Availability of short-circuited turns
ТПЛ-10У3	150/5	P	2,5	16	no
			2,5	2,5	1
			2,5	1,3	2
		0,5	2,5	10	no
			2,5	2,5	1
	50/5	P	2,5	18	no
			2,5	5,8	1
		0,5	2,5	12	no
			2,5	5,6	1

The analysis of experimental data for CT being tested, shows that in case of short-circuited turns in secondary windings of CT the voltage at its open terminals drastically drops.

Conclusions

The suggested method of short-circuited turns determination in the windings of CT differs from the known methods by higher efficiency and reliability and may be recommended for usage in the process of operation.

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