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Investigation of ferroresonance oscillations in the systems with electromagnetic potential transformers by experimental and calculation methods

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In order to assure reliable work of inductive voltage transformers (VT) designer of substation and exploiting organization should have common vision of installed voltage transformers characteristics, existing restrictions to their operations, conditions and operations of power grid under which ferroresonance processes occur.

Inductive voltage transformer represents the form of nonlinear inductivity since it contains a ferromagnetic core. Sometimes voltage oscillations (ferroresonance oscillations) occur, when VT is included into a circuit, containing such elements like high-voltage switch capacitive dividers, and circuit breaker is switched off. In some cases these oscillations are dangerous for installed equipment and current magnitude can be much higher than rated current through primary winding of VT. This current leads to overheating of primary winding, deterioration of its insulation, in the most critical operation mode the current exceeds thermal current of primary wire, which leads to burning of primary winding, ignition of the arc and destruction of VT.

Ferroresonance oscillation can occur after switching off the circuit breaker with capacitive divider on the substations higher than 110 kV with inductive VT. At the stage of designing and analyzing the schemes of substations the range of capacitances Cv (grading capacitance of circuit breaker) and Cz (equivalent capacitance on the ground) existing on the substations can be estimated. Ferroresonance oscillations depend on balance between Cv and Cz. For the prediction of the ferroresonance oscillation on the substation transient process can be calculated for all range of capacitances with appropriate computer model of inductive VT. There are presented real tests results and calculation methods for studying inductive VT ferroresonance oscillation in this report.

Existing methods to avoid ferroresonance oscillation can be divided into following three groups:

-exclusion of ferroresonance at the level of substation electric scheme;

-application of special damping devices inserted into VT secondary winding ;

-application of VT, where resonance is eliminated by ferromagnetic core construction.

In all cases the VT operation in electrical network modes as well as the exclusion or limitation of ferroresonant oscillations to an acceptable level require experimental confirmation. Even though many papers are devoted to studying of reliability of inductive VT, typically only theoretical and calculation aspects are represented, but the experimental aspect receives little attention. Another essential issue that there are no standards and standardized methods of testing and researching of ferroresonant oscillations for all the manufacturers of VT

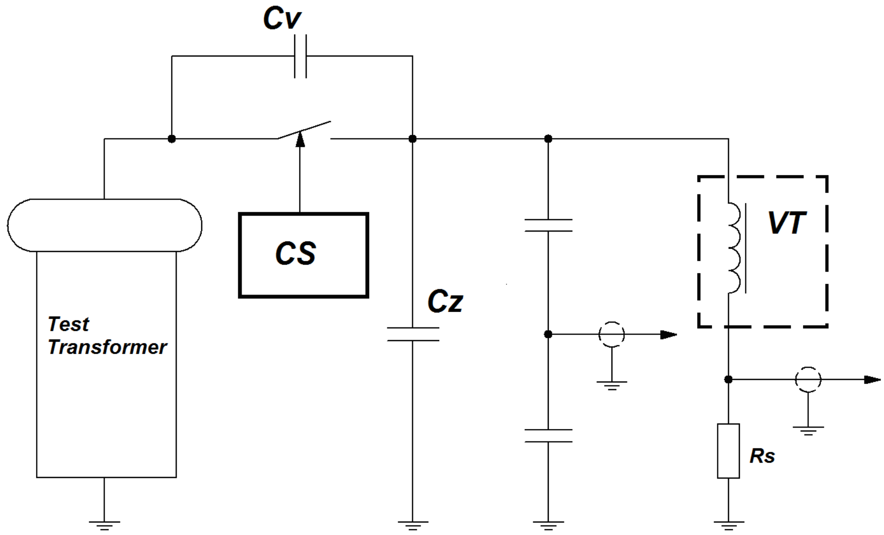

Fig. 1 Principle circuit for laboratory ferroresonance oscillations investigation

To determine the resistance to ferroresonance oscillations it is proposed to test the VT included into a circuit with a circuit breaker, containing capacitance connected in parallel to contacts Cv and capacitance connected to earth Cz (Fig. 1). Capacitance range Cv and Cz are varied in a wide range limited by test laboratory abilities. The procedure of test is following. Circuit breaker disconnection is performed simultaneously with ability to control switching-off phase as well as in a critical moment of time when the current through the VT is equal to zero (the moment of voltage maximum). Voltage and primary current are recorded during tests. The VT is tested with measuring its main parameters on the basis of which mathematical model is made. Exciting current and core losses are measured to determine the parameters of the VT equivalent circuit. Based on the tests results of the circuit breaker disconnection containing a capacitive divider and measurements of the transformer equivalent circuit parameters the mathematical model is made and verified (Fig. 2). Additional calculations are carried out by means of the mathematical model at modes which aren't verified during laboratory testing. The stability criterion is RMS value of the current through the VT primary winding which should not exceed the value defined during temperature-rise test.

In this report modeling of VT is considered in detail and more precisely. Real test results are presented in comparison with calculation method results. Mathematical model is composed, validated and corrected with taking into account test results. Tests are performed in the wide range of capacitances with different switching angle and voltage level of VT. Test transformer model is included in equivalent mathematical model of test scheme. Mathematical model with test transformer describes process in scheme Fig.1 more precisely. VT equivalent circuit parameters can be corrected after the comparison of calculations with tests.

On the first step of modeling all parameters of VT and test transformer are measured during no-load current and short circuit impedance tests. Measuring of current-voltage characteristic is the most important and difficult part of test. Part of the current that depends on leakage inductance and self capacitance of primary winding can be more than no-load current of the magnetic core itself.

Test results are compared with modeling results and shown in the Fig. 4, 5, 6, 7. After the comparison equivalent circuit parameters can be changed for improving mathematical model.

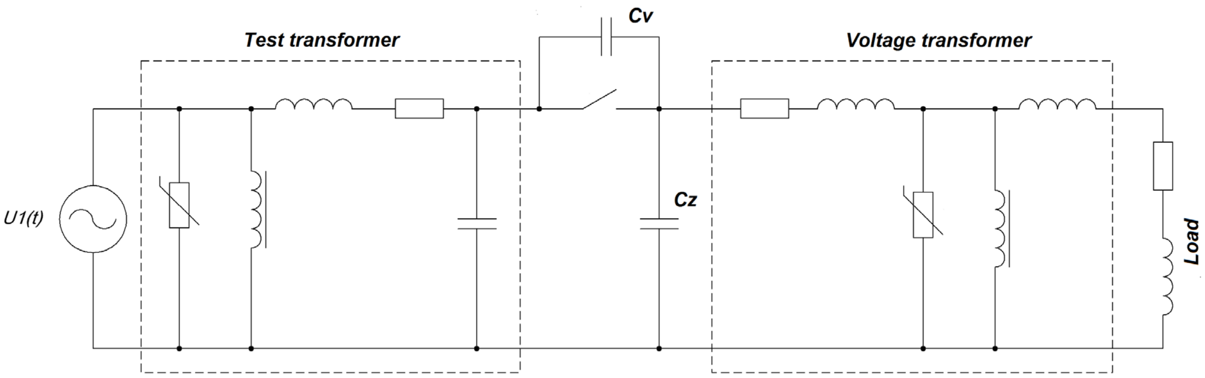

Fig. 2 Equivalent circuit of the test arrangement

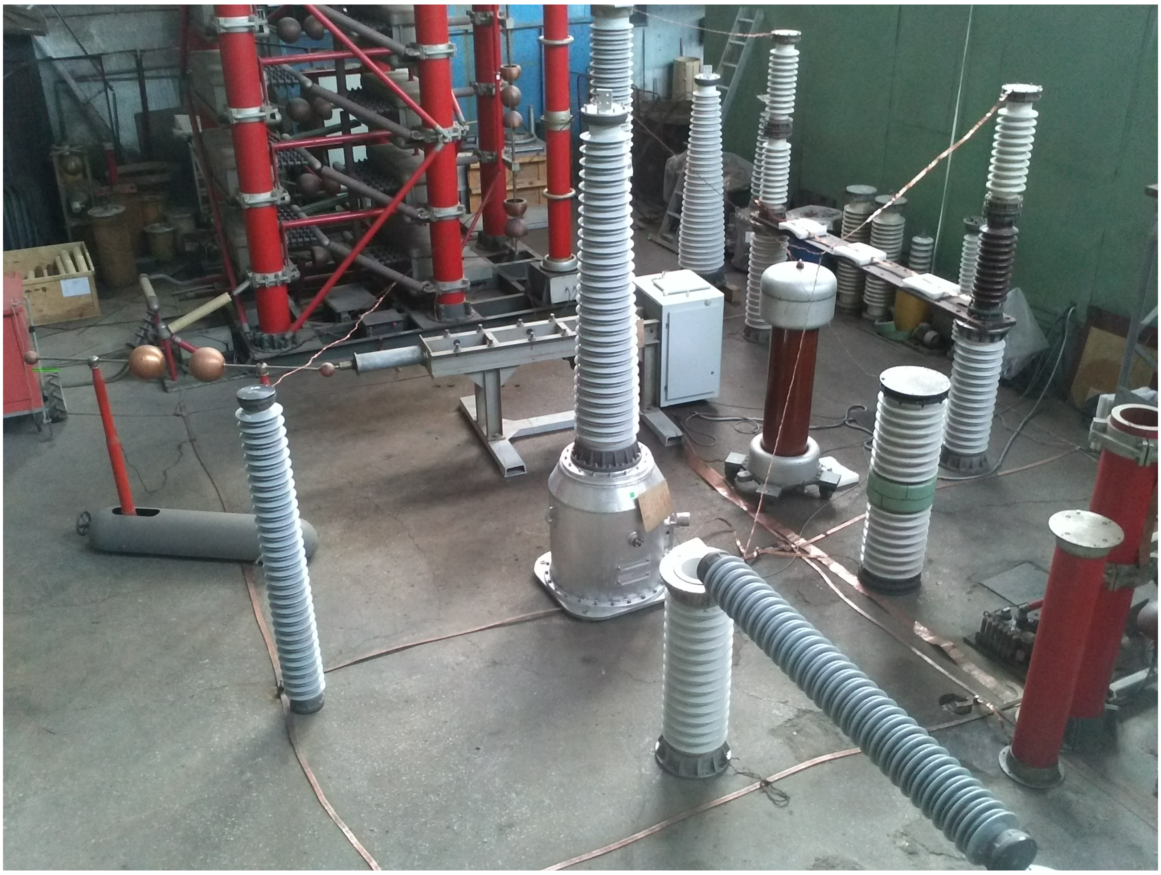

Fig 3 Test arrangement

Test arrangement with VT 220 kV, set of capacitors connected between ground and high voltage electrode of VT and set of grading capacitors are shown on the Fig.3.

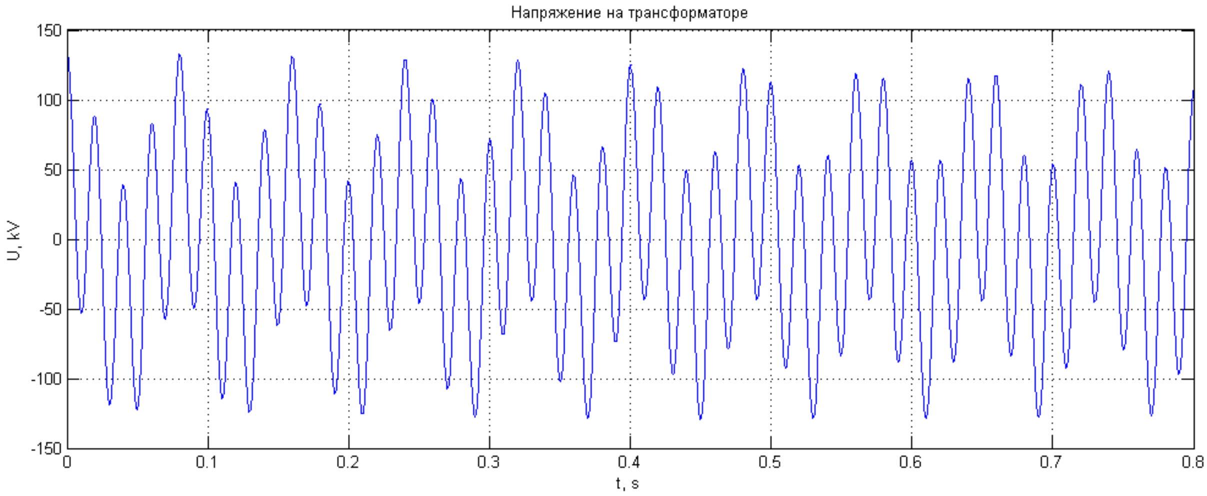

Fig. 4 Results of modeling. Voltage on the primary of VT

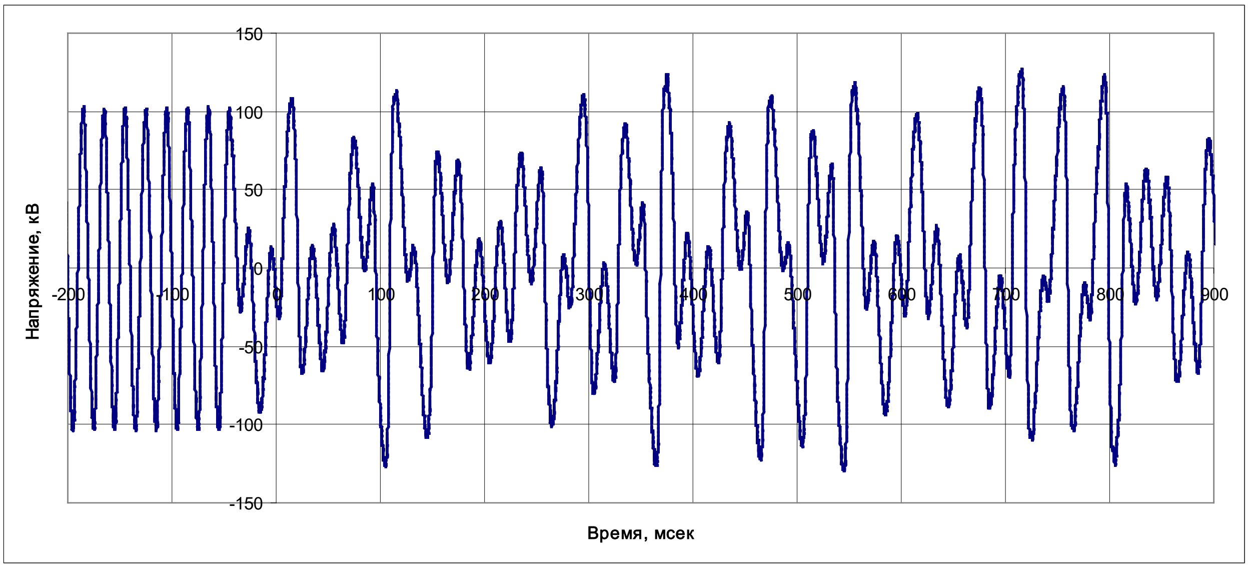

Fig. 5 Test results. Voltage on the primary of VT

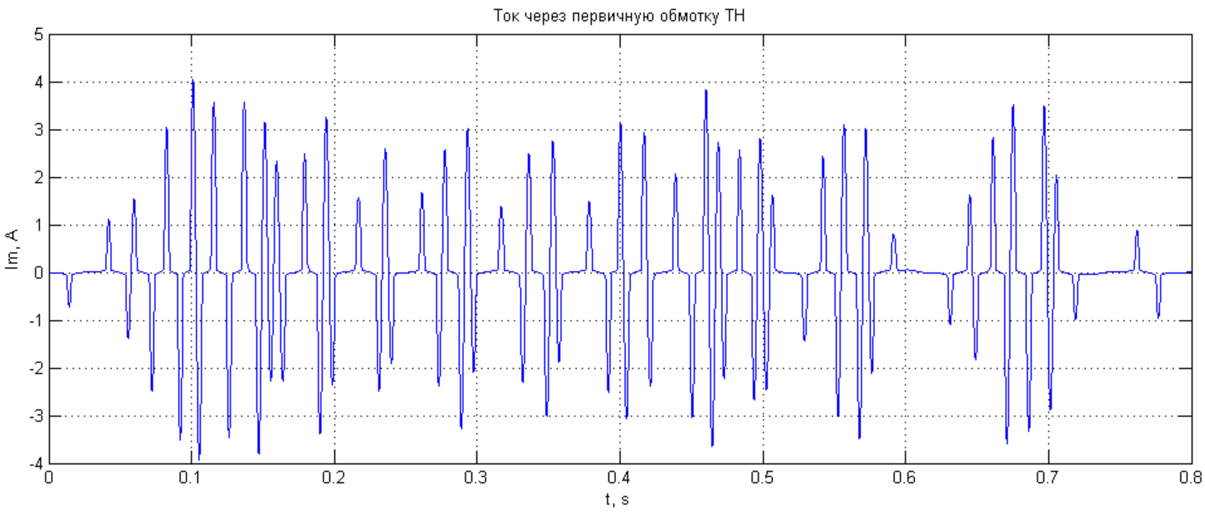

Fig. 6 Modeling results. Primary current of VT

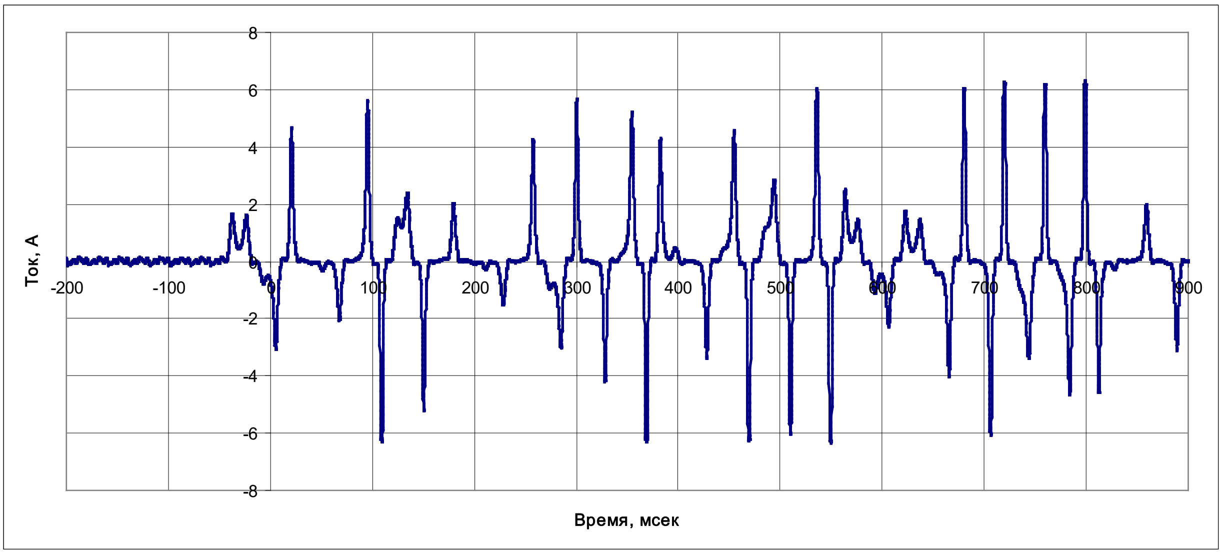

Fig. 7 Test results. Primary current of VT

Summary:

In this report test results performed on the test arrangement (fig.1) are presented for electromagnetic VT 110-330 kV. Test results, current and voltage oscillograms, calculation models and equivalent circuit are described.

Proposed methodology of experimental and calculation tests are suitable for newly developed and laboratory tests as well as for testing operation of VT.