Considerations Regarding the Short-Circuit Withstand Tests of Power Transformers

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***Abstract* – In the first part of paper are presented aspects related to tests methods and procedures of power transformers and technical conditions established by standards. In the second part are presented experiments on 161/34.5 kV 50/66 MVA oil-immersed power transformer through method of pre-established short-circuit together with acceptance criteria and diagnosis method by frequency response analysis for transformer behavior at test.**

***Index Terms*-Power transformer, diagnosis, shortcircuit**

I. INTRODUCTION

The ability to withstand the dynamic effects of short-circuit shall be demonstrated either by tests, or by calculation and design and manufacture considerations.

There is wide agreement with the statement that a short-circuit test on a fully assembled transformer is the only direct means of determining and checking its ability to withstand short-circuits. On the other hand, especially with large units rated higher than 100 MVA the tests can be performed at only very few powerful test stations. In some very special cases, short-circuit tests are performed at the actual power station like High Power Laboratory. These tests require very expensive costs of activities, such transportation from factory and to factory, local erection of test Laboratory and again to factory, and other operations like untanking, visual inspection, repetition of dielectric tests [1]. Therefore the short-circuit withstand tests is considered a Special test according to IEC standard, to be specified and agreed between purchaser and manufacturer.

Also IEC 60076-5 standard considers the ability to withstand and dynamic effect of short-circuit can be evaluated theoretically by calculus [2]. But the calculus is very difficult because the transformer consists of high complex and non-homogenous structure and its behaviour will be influenced by whole manufacturing process [1]. Consequently, transformers with power less than 100 MVA (category I and II) will be tested in high power stations and laboratories.

II. REQUIRMENTS OF STANDARDS FOR THE ABILITY TO WITHSTAND SHORT-CIRCUIT CURRENT

The tests shall be carried out in accordance with the requirements of the standard. Power transformers are tested according to IEC 60076-5 standard the ability to withstand short-circuit current. This standard establishes: test methods, technical procedure of test, test parameters (short-circuit current and duration, test voltage, acceptance criteria) [2]

A. Test methods

According to IEC 60076-5 there are two different techniques for carrying out a short-circuit withstand test, namely [1,2]: a) with pre-established short-circuit; b) with post-established short-circuit.

Test method a) involves closing of a breaker at the source terminal to energize the previously short-circuited transformer. This means that the secondary winding is short-circuited in advance and power is switched on to the primary. This method works fairly well if the secondary winding is inner winding of a concentric–winding, core-type transformer. The core flux will be very low, because the closest winding is short-circuited and no change in flux will occur. In the opposite case, when the primary winding is closest to the core and short-circuited winding outwards, the flux is forced to recluse inwards. There will be a significant amount of inrush current – needed to magnetize the core – flowing through the primary winding and superimposed on the short-circuit current. This situation leads to unbalance the magneto motive forces of two windings as well a s to an increase in the internal dynamic stresses. In addition, test repeatability is hardly possible, since the current flowing through in the primary winding depends on the amount of residual flux in the core and on the closing instant [1].

Test method b) involves closing a breaker at the faulted terminal to apply a short-circuit to the previously energized transformer. By adapting this test method, the difficulty of uncontrolled core magnetization disappears. The transformer is taken up at no-load to rated voltage and the secondary short-circuit is then closed (Fig. 1), at the predetermined phase angle, by means of a synchronous make-switch [1].

The method using a post-established short-circuit should be preferred as far as possible, since it represents more closely the typical condition during the faults. If the impedance of the power source is not negligible compared with that of the transformer, the no-load voltage applied to the transformer prior to the short-circuit needs to be increased by a certain amount in relation to the rated voltage. The aim is to attain the rated voltage at the winding terminals at the moment the short-circuit is performed in spite of the voltage drop occurring upstream in the supply system, and to establish the prescribed steady-state value of the short-circuit current [1].

The standards in force for short-circuit tests prescribe that, with the post-established short-circuit procedure, the no-load voltage of the source shall not exceed 1.15 times the rated voltage of the winding supplied. This requirement accounts for the limited over excitations capability of power transformers and implies that the short-circuit power available on the supply system is at least nine times higher compared with the power absorbed by the transformer during the test [1].

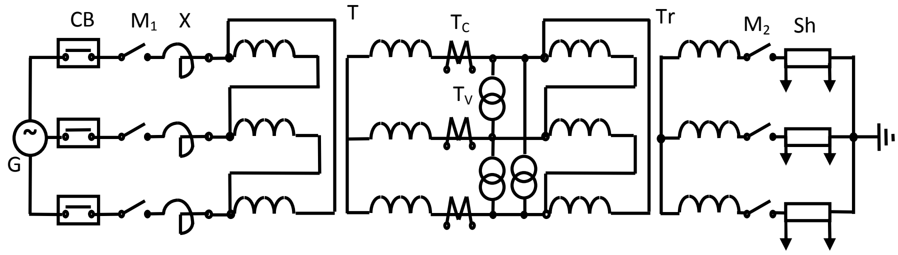

Fig. 1 Test diagram for post-established short-circuit

G – voltage supply	T_c – instrument current transformer
CB – circuit-breaker	T_V – instrument voltage transformer
M_1, M_2 – making switch	Tr – power transformer tested
X - reactor	Sh – shunt for current measuring
T – step-up transformer	

An essential disadvantage of post-established short-circuit method is that station short-circuit power will be greater than station power in the case of pre-established method.

B. Technical procedures regarding the tests of dynamic stability checking through pre-established short-circuit method

In order to reach the initial peak value of the current through the tested phase, the switch closing instant is chosen hereby for tests in three-phase circuits:

a) For windings with Y connection, maximum asymmetry is obtained when the moment of the connection is the voltage between phases passage through 0;

b) For windings with D connection maximum asymmetry is obtained when the moment of the connection is the voltage between phases passage through 0;

c) For the transformer with YZ connection of 1st category, having Ux/Ur≤3 (K√2≤1.95), all three phases are connected simultaneously;

d) For other transformers with YZ connection, the connection way is established through a technical document and it is part of an agreement between manufacturer and purchaser.

C. Technical procedures regarding the tests of dynamic stability checking through post-established short-circuit method

The test of short-circuit stability check is carried out according IEC 60076 recommendations. In order to achieve the symmetrical test current and the peak value of the current the connection instant is adjusted with the aid of a switch from the secondary circuit [2,3].

Switches connection at single-phase tests

In case of a single-phase test the procedure is:

- the switch from the power supply primary circuit is connected at the power supply voltage pass through the maximum value;
- the switch from the secondary circuit is connected at power supply voltage pass through 0, in order to achieve the peak value of the short-circuit current.

Switches connection at three-phase tests

Switches from the primary circuit shall be connected as function of the tested transformer connection type on its primary winding:

- for Y connection, the optimum connection case is obtained by connecting the first two phases in the instant of voltage pass through 0, and the third phase with 5 ms later;
- for D connection, the best case is obtained when one phase is connected at voltage pass through 0 and the other two phases with 5 ms later;

This way of connection eliminates the transient currents from the primary circuit of the transformers. Switches from the secondary circuit connect as follows:

- for Y connection on primary winding of tested transformers the maximum asymmetry is obtained by connecting when the phase voltage passes through 0, this being achieved by connecting the first phase before and the other two simultaneously at phase-voltage pass through 0;
- for D connection on primary winding of tested transformers the maximum asymmetry is obtained by connecting when the voltage between phase passes through 0, this being achieved by connecting the first phase before and the other two simultaneously at voltage between phases pass through 0.

D. Test parameters

In order to perform short-circuit tests, some parameters are determined by calculus, such as: symmetrical short-circuit current, peak value of short-circuit current and other are established by test standard, such as: duration of short-circuit, test voltage, number of tests. Short-circuit current is established for its two components (rms and peak value) depending of rated voltage of the system, short-circuit apparent power of the system, rated voltage of transformer, short-circuit impedance of the transformer. Peak value is determined in function of reactance and resistances of the transformer and of system.

Test voltage is established depending on rated voltage of transformer according to IEC recommendations. Test duration and number of tests are established by IEC standard for transformers with power less than 100 MVA and for power larger than 100 MVA it is given by agreement between purchaser and manufacturer.

III. EXPERIMENTS ON POWER TRANSFORMERS

A. Test of ability to withstand of dynamic effects of short-circuit on oil-immersed power transformer

In High Power Laboratory was performed three-phase tests of ability to withstand of dynamic effects of short-circuit on 15.8/0.4 kV 400 kVA oil-immersed distribution transformer [4] and single-phased tests on 161/34.5 kV 50/66 MVA oil-immersed power transformer [5] according to IEC 60076-5/2006 subclause 4.2 [2] by pre-established short-circuit method. Before short-circuit tests the transformer is supposed to individual tests. According to tests program were determined: tapping voltage, current rms value, current peak value. After that were measured reactances for tappings where short-circuit tests were performed.

Using a digital data acquisition system, there were recorded: terminal voltages on supply side, short-circuit currents. Data obtained at tests are synthetised in Table I by processing the oscillograms. Testing and measuring diagram is presented in Fig. 2 [5]. An example of oscillogram from test is presented in Fig. 3 [5].

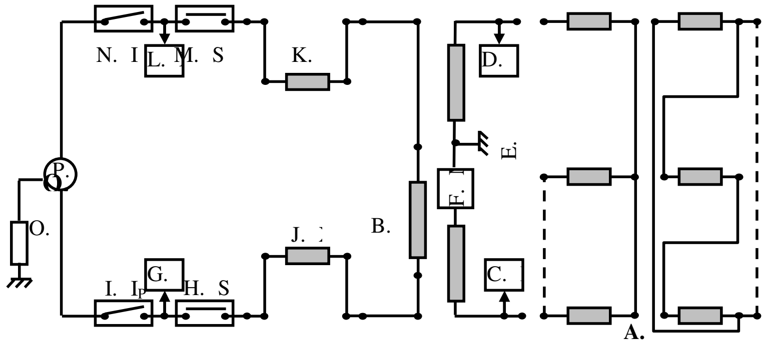

Fig. 2 Testing and measuring diagram

G - Shortcircuit generator
I_P - 12 kV protection circuit breaker
S_K - 12 kV making switch
X - Reactor
R - Resistance
TR - Shock step up transformer
M1-M5 - Measuring points
K - Earthing point
T - Tested power transformer

TABLE I. DATA OBTAINED AT TESTS

Test no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Tapping no.	17	9	1	1	9	17	9	17	1
Oscillogram no.	69946	69947	69948	69949	69950	69951	69952	69953	69954
T [s]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Supply terminals	A-BC	A-BC	A-BC	B-AC	B-AC	B-AC	C-AB	C-AB	C-AB
Short - circuited terminals	ac	ac	ac	ab	ab	ab	bc	bc	bc
U[kV]	113	124	138	137	123.5	111	124	111	139
î [A]	6087	5300	4600	4540	5276	5953	5360	5932	4650
I [A]	2380	2180	1900	1930	2066	2240	2101	2277	1799

SYMBOLS USED IN TABLES AND IN OSCILLOGRAMS

U = applied voltage
î = peak of asymmetrical current
I = symmetrical current
t = duration of circuit
U_{S1}, U_{S2} = generator voltage
B1, B2 = Bucholtz contact

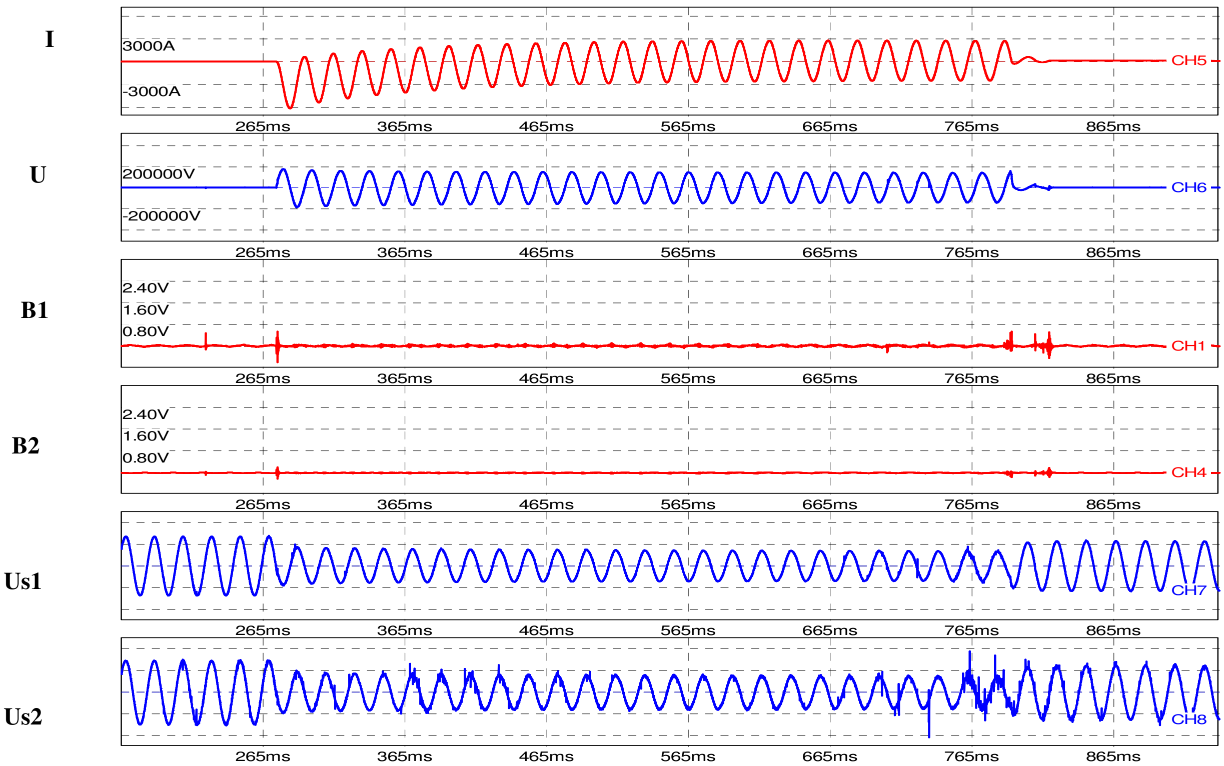

Fig. 3 Oscillogram from tests

B. Diagnosis of behavior at short-circuit by method of frequency response analysis

Behavior of power transformers at short-circuit withstand test it is a complex problem requiring utilization of some methods and devices for diagnosis [7, 8]. One of diagnosis method consists of frequency response analysis with low voltage impulses [3].

The method consists in applying successive impulses at low voltage and high voltage input terminals and response recording on output terminals on each phase. Using FFT algorithm are obtained frequency characteristics Y (F) (Y – admittance, F - frequency), recorded before and after short-circuit withstand test. By superimposing these two characteristics, they are compared and observed if there are significant changes (Fig. 4.1 and Fig. 4.2).

This method allows the detection of winding mechanical defects.

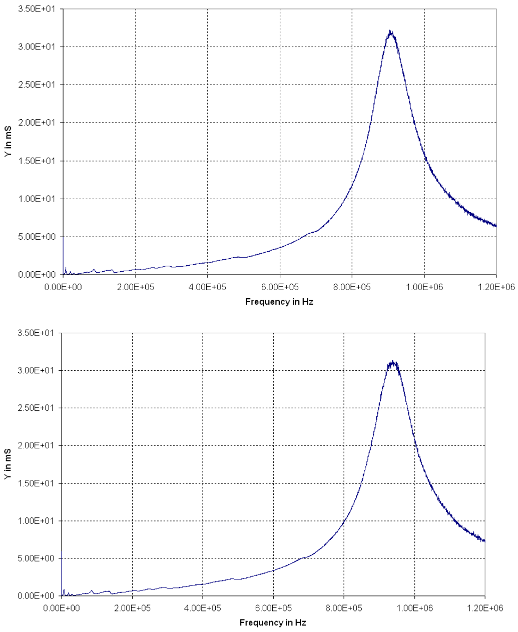

Fig. 4.1 Frequency characteristics on phase A, before and after short-circuit withstand test

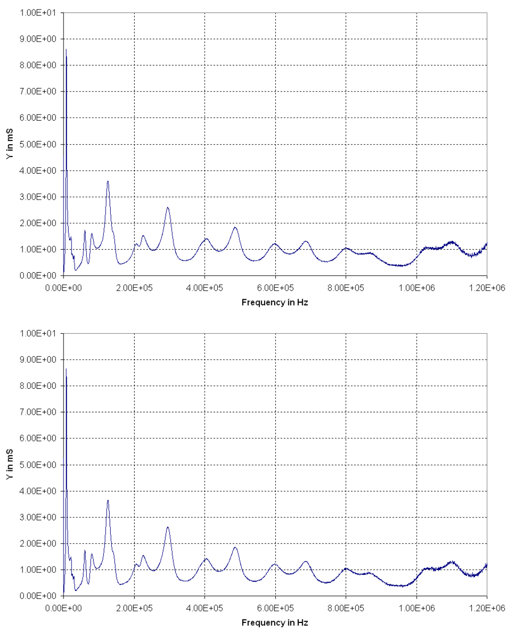

Fig. 4.2 Frequency characteristics on LV terminals a-b, before and after short-circuit withstand test

C. Acceptance criteria

After short-circuit tests is determined again the reactances and are compared with initial ones if there are within limits specified by IEC standard. After that transformer are supposed to dielectric tests and then is untanked for visual inspection.

The acceptance criteria are the following;

- The results of the short-circuit tests and the measurements and the checks performed during tests do not reveal any condition of faults
- The dielectric tests and other routine tests when applicable, have been successfully repeated and the lightning impulse test, if specified, successfully performed
- The out-of-tank inspection does not reveal any defects such as displacements, shift of laminations, deformation of windings, connections or supporting structures, so significant that they might endanger the safe operation of the transformer
- No traces of internal electrical discharge are found
- The short-circuit reactance values, in ohms, evaluated for each phases at the end of the tests do not differ from the original values by more than 1%

All acceptance criteria were fulfilled.

IV. CONCLUSION

- The behavior at short-circuit withstand test of 161/34.5 kV 50/66 MVA power transformer was diagnosed through frequency response analysis method which allows detection of mechanical defects without out-of-tank inspection of the transformer.
- Through comparative analyse of tests by pre-established and post-established short-circuit it resulted that first method is agreed by laboratories due to its simplicity in achieving test circuit and less power of station.
- Tests performed by pre-established short-circuit method on a 400 kVA power transformer shown this transformer fulfill acceptance criteria required by standard.

ACKNOWLEDGEMENT

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REFERENCES

[1] Giorgio Bertagnolli. Short-circuit duty of power transformers, Golinelli Editore, 1998.

[2] *** - IEC 60076-5/2006 – Power transformers – Part 5: Ability to withstand short-circuit

[3] George Curcanu. Test and diagnose of equipment and electric apparatus at high currents, Ed. Sitech, Craiova, 1999.

[4] *** - Test Report on 15.8/0.4 kV 400 kVA oil immersed distribution transformer

[5] *** - Test Report on 161/34.5 kV 50/66 MVA oil immersed power transformer

[6] A. Marinescu, I. Dumbravă, ŢSome aspects about the influence of the windings axial clamping forces on the frequency response of the power transformers", 15th International Symposium on High Voltage Engineering, Ljubljana, Slovenia, 27-31 August 2007.

[7] R. Wimmer, S. Tenbohlen, K. Feser, "Online Monitoring of a transformer by means of FRA", 15th International Symposium on High Voltage Engineering, Ljubljana, Slovenia, 27-31 August 2007.