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Proposal of Testing Procedure for Resonance and Ferroresonance Inception Possibility in Instrument Transformers

Bruno Jurišić, Marijan Perković, Ivan Novko, Luka Kovačić, Igor Žiger, Tomislav Župan

***Summary* — This paper deals with the possibility of ferroresonance occurence in the interaction between circuit breakers and inductive instrument transformers. Existing standards lack guidance on testing for ferroresonant behaviour. The paper proposes a standardized testing procedure and presents measurements on a full-scale system. EMTP simulations complement the measurements for a broader network topology analysis, i.e. circuit breaker capacitance combinations. EMTP simulations are validated for a 170 kV voltage transformer and a combined instrument transformer, showing accuracy within 10%. The paper also extends the EMTP modelling application to a 420 kV voltage power transformer during design phase, ensuring it doesn't experience ferroresonance. This study offers a practical approach for testing and simulating ferroresonance in inductive instrument transformers, contributing to the safe operation of power networks.**

***Keywords* — Circuit breaker, EMTP, ferroresonance, laboratory testing, resonance, voltage power transformer**

I. Introduction

Interaction between circuit breaker and inductive instrument transformer (i.e. voltage or voltage power transformer) can result in resonance which can be non-linear (ferroresonance) or linear [1]-[4]. In both cases it may lead to excessive temporary overvoltages causing failure of the primary power equipment. Therefore, it is necessary to dimension equipment properly and to check if there is a possibility for resonance inception in the particular network configuration. However, most of the relevant instrument transformer standards do not provide any guidance on how transformers should be tested to evaluate if they exhibit ferroresonant behavior for a certain combination of capacitances. Open-core type instrument transformers used in this paper, due to their magnetizing characteristics, are less susceptible to ferroresonance than closed-core instrument transformers [6].

This paper aims to propose a standard testing procedure for resonance inception possibility in instrument transformer. Therefore, the results of measurement done in high voltage laboratory, on the full-scale system, are presented. The goal of the measurements is to prove that no ferroresonance will occur and that the possible temporary overvoltage amplitudes, due to the resonant behavior, will not exceed permissible values.

Test results can be extended with an EMTP simulation results for the wider range of network topology. The simulation requires a T-scheme model of an instrument transformer, including saturation curve and grounding capacitance. In the paper, a comparison between EMTP simulation and laboratory measurements is shown, for the observed instrument transformer unit. Moreover, the application of EMTP modeling is done on the additional transformer unit.

II. Ferroresonance Measurements

The measurements set-up consists of test transformer, capacitor divider, full size circuit breaker, exchangeable grading capacitors, capacitors to the ground, and test object (instrument transformer). Test procedure includes changing the test network topology by exchanging the grading capacitors and capacitors to the ground in the ranges that can be found in the real power network. In addition to changing network topology, C_s ranges from 250 pF to 300 pF, C_g ranges from 0 to 700 pF and U ranges from 0.9 to 1.5 U_r (rated voltage). During the test, the current at the primary side of the instrument transformer is measured, using current shunt, as well as the voltages at source side of the circuit breaker and at the secondary side of instrument transformer. This can be seen from the scheme given in Figure 1. Test sequence begins with energized test object. Then the circuit breaker opens, which may trigger resonant behavior as the test object is energized through the grading capacitance. The last part of the test sequence is closing of the circuit breaker. The test is designed to represent switching of the inductive voltage transformer, using the circuit breaker with grading capacitors installed.

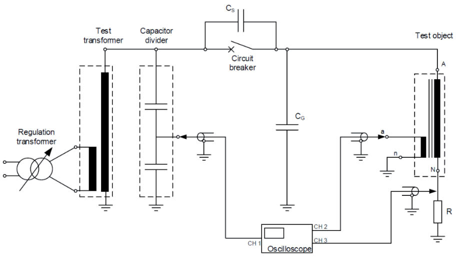

Fig. 1. Measurement circuit for interaction between inductive instrument transformer and circuit breaker.

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It is necessary to note that the voltages measured at the secondary side of the instrument transformer can be recalculated at primary voltages only for 50 Hz, as the voltage transfer characteristic of the instrument transformer may not be constant for the frequencies higher than 2500 Hz. To decide if the transformer has passed the test, it is necessary to check that the measured values do not exceed the long-term permissible value at which the transformer can be operated. In general, open core design instrument transformers are less prone to lead to ferroresonant behavior due to their BH characteristics, that tends to be more linear than the one of the transformers with closed core design.

III. EMTP Simulation

Detailed model of the test circuit has been made in EMTP. Instrument transformers are modelled using the PI-equivalent model with nonlinear magnetizing inductance Lnonl1, grounding capacitance C3, primary winding resistance R2, magnetizing resistance R3, secondary winding resistance R4 and secondary leakage inductance L2 [5]. Nonlinear inductance is characterized using the magnetization curve obtained from measurements. Grounding capacitance is calculated in EMTP using current measurements through N and tgδ terminals during no load test. Due to open core design, end segments of transformer windings can be represented with series of equivalent parallels of capacitances and reactances, as shown in figure 3.

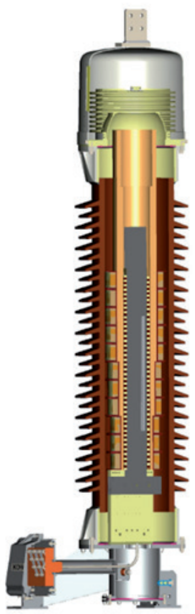

Fig. 2. Cross-section drawing of a open-core voltage transformer.

Measurement through N terminal represents current through winding segment that is closest to grounding point. Current through tgδ represents capacitance of the electrode closest to the grounding point. Nevertheless, the measured current values do not represent the exact capacitance and inductance of the transformer. It is possible to build up a "black box" model that acts as the observed transformer at its terminal, using parallel connection of equivalent capacitance and equivalent inductance. It is not necessary that the model parameters physically correspond to the real values, in this approach they are rather just mathematical representations. Therefore, the model might be considered a "black box" model. It is assumed that the initial magnetic flux of the instrument transformer is 0 Wb. During testing, the transformers are connected to source voltage for a significant time prior to circuit breaker switching off, so remanent flux can be neglected. Since there is no burden connected to the secondary winding during tests, the primary leakage inductance is neglected. The magnetizing resistance of the open-core transformer is set to value of 100 MΩ [6]. This value is a question of future research and will be studied in more detail. The model with non-linear core magnetizing characteristics is shown in figures 3 and 4 below.

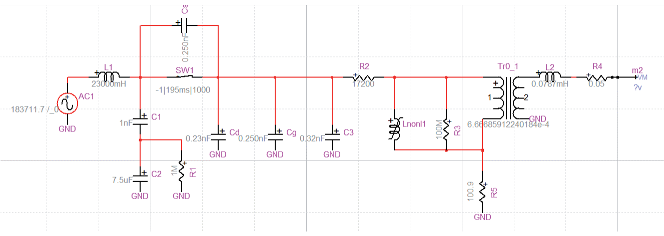

Fig. 3. EMTP model of the test circuit with circuit breaker and inductive instrument transformer models.

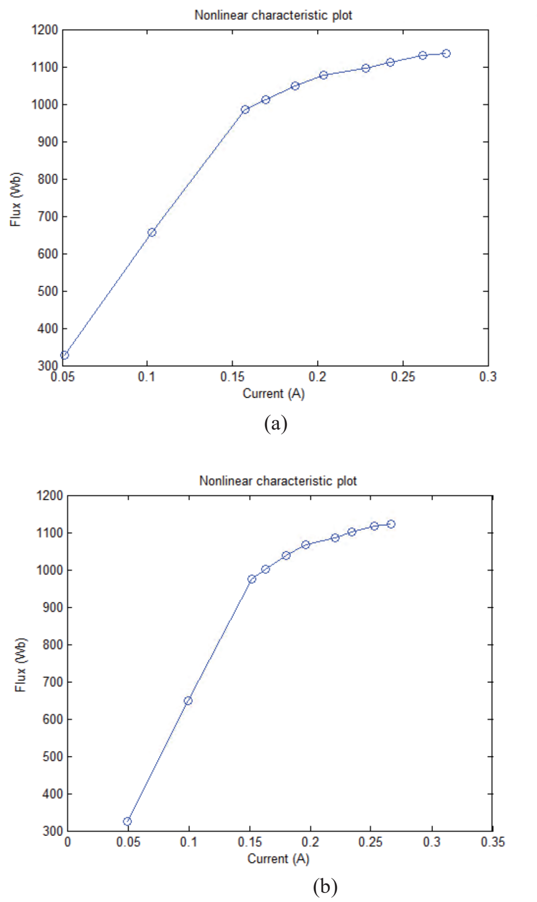

Fig. 4. EMTP model of the test circuit with circuit breaker and inductive instrument transformer models. (a) 170 kV voltage transformer and (b) 170 kV combined instrument

In the model, capacitors C1 and C2 represent capacitor divider. SW1 is an ideal switch, which is initially closed and opens at 195 ms of simulation (approximately equal to opening time in the laboratory). Capacitor Cd is added to the simulation model to simulate the grounding capacitance of the circuit breaker. R5 is a current shunt resistor for measuring the primary current, with a resistance value of 100.9 Ω. Instrument transformer parameters used in the modeling are shown in the table below.

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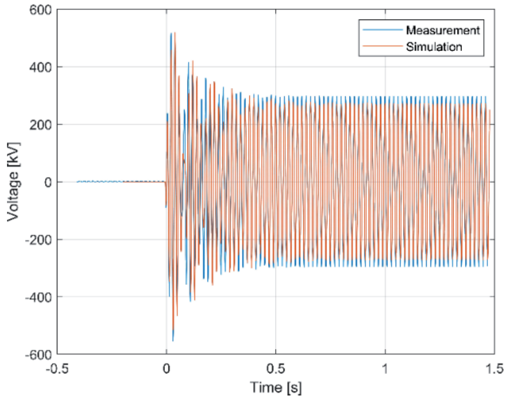
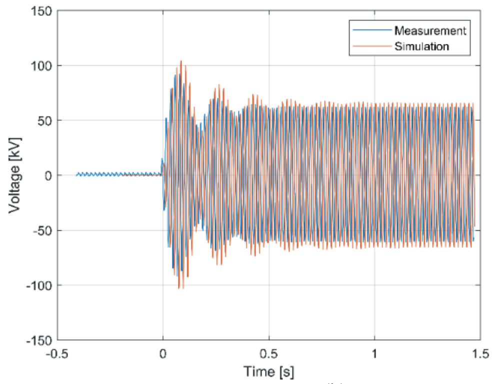
TABLE I.
MANUFACTURER TRANSFORMER DESIGN DETAILS

	Voltage instrument transformer	Combined instrument transformer
R2 [Ω]	17200	25200
R4 [Ω]	0.05	0.05
C3 [nF]	0.32	1.09
L2 [mH]	0.0787	52300
R0 [MΩ]	100	100

Figures 5 – 7 show the comparison of simulated and measured response for a 170 kV inductive voltage and combined transformer. While multiple combinations of C_s and C_g were tested, to keep the paper length within reasonable limits, only a single combination was included for model verification purposes. Three values are compared versus the simulation results: voltage across circuit breaker contacts, secondary voltage of instrument transformer and primary current. Voltage across circuit breaker contacts is calculated from measured voltage at source side and voltage at primary side of the instrument transformer (calculated from measured secondary side voltage).

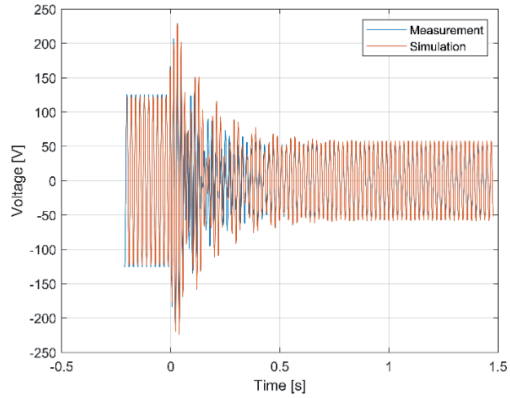


(a)



(b)

Fig. 5. Comparison of simulation and measurement results for case Cs=250 pF, Cg=250 pF, U=1.5 Ur (voltage across the circuit breaker contacts) for (a) 170 kV voltage transformer and (b) 170 kV combined instrument transformer



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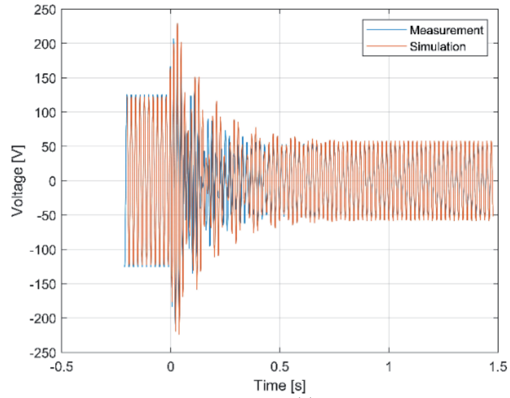
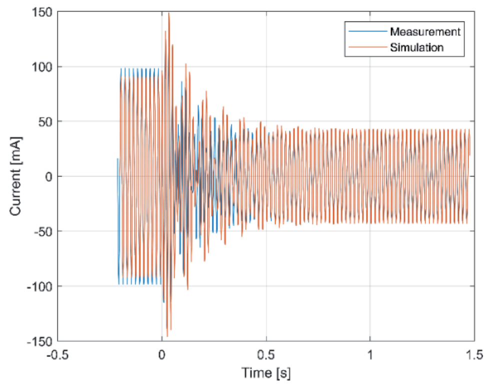


(a)

Fig. 6. Comparison of simulation and measurement results for case Cs=250 pF, Cg=250 pF, U=1.5 Ur (voltage across the secondary winding) for (a) 170 kV voltage transformer and (b) 170 kV combined instrument transformer



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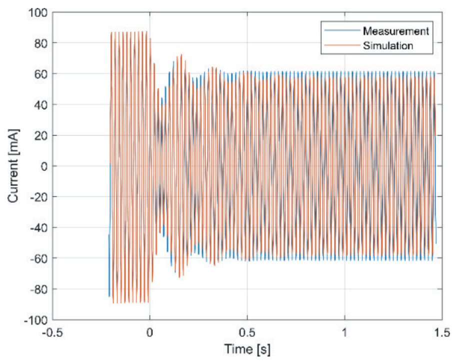

(b)

Fig. 7. Comparison of simulation and measurement results for case Cs=250 pF, Cg=250 pF, U=1.5 Ur (primary winding current) for (a) 170 kV voltage transformer and (b) 170 kV combined instrument transformer

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From the comparison it can be seen that the results of the simulation yielded similar values and waveshapes to the measured ones. Therefore, it is possible to use such modelling to determine the possibility of resonant behavior of the observed electrical configuration. Furthermore, the singular values obtained from waveshapes in figures 5-7 are summarized in table 2. It can be clearly seen that the proposed model provided results accurate enough for engineering practices and use in further analyses. Typical errors in the observed values were under 10%.

TABLE II.
COMPARISON OF SIMULATION AND MEASUREMENT RESULTS, CS=250 PF, CG=250 PF, U=1.5 UR

(a)

	170 kV voltage transformer			
	Transient measured	Transient simulated	Steady state measured	Steady state simulated
Voltage across CB [kV]	554.8	519.5	296.5	267.0
Primary current [mA]	138.4	149.0	41.5	43.3
Secondary voltage [V]	219.0	229.4	53.7	57.4

(b)

	170 kV combined instrument transformer			
	Transient measured	Transient simulated	Steady state measured	Steady state simulated
Voltage across CB [kV]]	92.4	104.6	62.0	65.4
Primary current [mA]	70.8	72.7	61.5	58.2
Secondary voltage [V]	102.0	104.1	90.4	86.2

IV. APPLICATION ON 420 KV VOLTAGE POWER TRANSFORMER MODEL

During design phase of 420 kV voltage power transformer (VPT), proposed EMTP modelling method is used as one of the ways to confirm that power voltage transformer will not experience ferroresonance for given parameters Cs and Cg.

Figure above shows that model transformer did not experience any resonance nor ferroresonance in three EMTP simulations with different set of capacitances Cg and Cs. Primary voltage was set to 150% Un and switching time was set to 195 ms, as it corresponds to breaker closing at zero voltage crossing that results with highest secondary transformer transient overvoltage.

Different sets of capacitances Cg and Cs lead to different stationary voltage values with open circuit breaker. With an open circuit breaker, equivalent circuit corresponds to capacitor divider with Cs as capacitance of upper branch. The lower branch of equivalent circuit capacitor divider is made from parallels of following capacitances: Cg, circuit breaker to earth capacitance and equivalent capacitance to earth of instrument transformer. In the divider lower branch has non-linear inductor of transformer open core connected to parallel with capacitance. Therefore, it is reasonable to assume that for increasing values of Cs in equivalent circuit, stationary voltage after opening the circuit breaker contacts will also increase, if no resonance nor ferroresonance occur.

V. CONCLUSION

The paper presents a laboratory setup designed to measure the interaction between an inductive instrument transformer and a circuit breaker. In addition to the measurements, a comprehensive EMTP model is developed to simulate the test circuit. Both the measurement and simulation results indicate that, for the specific instrument transformer units and capacitance configurations under consideration, ferroresonant behavior does not occur. The presented EMTP model proves to be effective for the analysis during the transformer's design phase. This paper offers essential guidance on testing and simulating the ferroresonant characteristics of different instrument transformers.

REFERENCES

[1] Cigré WG C4.307, Resonance and Ferroresonance in Power Networks, no. February. 2014.

[2] Valverde, V & Mazon, A.J. & Zamora, I & Buigues, G. Ferroresonance in Voltage Transformers: Analysis and Simulations. Renewable Energy and Power Quality Journal., 2011.

[3] Jacobson, D. & Menzies, R.W. Investigation of Station Service Transformer Ferroresonance in Manitoba Hydro's 230kV Dorsey Converter Station. Proceedings of International Conference Power Systems Transients, 2001.

[4] W. Piasecki, M. Stosur, M. Florkowski, M. Fulczyk, and B. Lewandowski, "Mitigating ferroresonance in HV inductive transformers," Int. Conf. Power Syst. Transients, IPST, vol. 9, 2009.

[5] M. Stosur, W. PiaSecki, M. Florkowski, and M. Fulczyk, "ATP/EMTP Study of Ferroresonance Involving HV Inductive VT and Circuit Breaker Capacitance," Electr. Power Qual. Util., vol. 14, no. 2, pp. 49–52, 2008.

[6] D. Krajtner and I. Žiger, "Influence of HV inductive voltage transformers core design to the ferroresonance occurrence probability," Int. Conf. Power Syst. Transients, pp. 1–7, 2015.

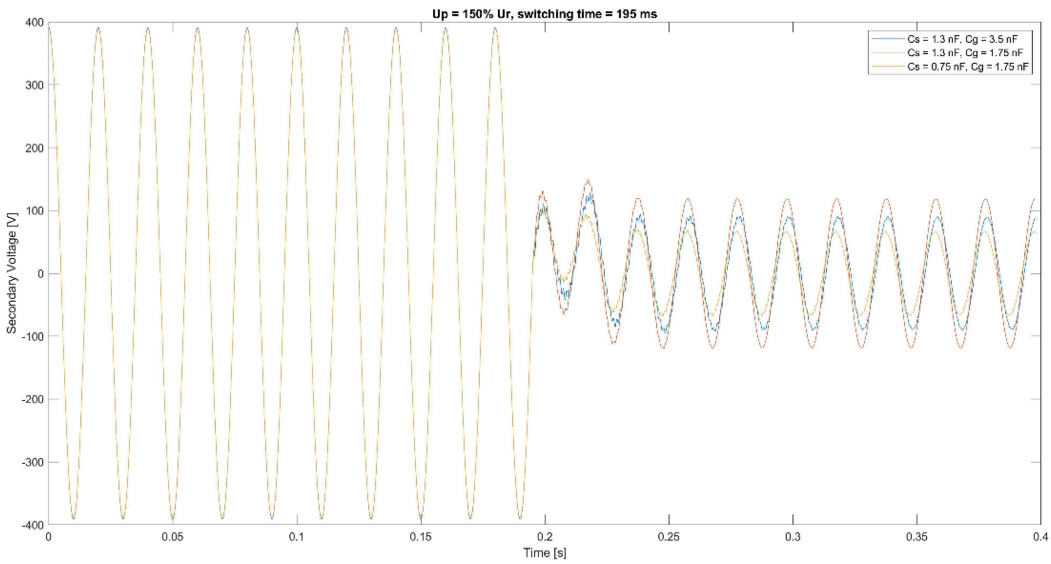

Fig. 8. Transient response of secondary voltage in ferroresonance test for different set of Cs and Cg.

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