

Effect of DC and Transient Current Components on Instrument Current Transformer Function

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Abstract - The paper is focused on instrument current transformer (CT) function during non-standard operating state that is caused by DC transient current component. There is described a way, how to build a numerical model, when CT material parameters are known. The numerical model allows behaviour simulation of the real CT, so it is possible to solve the output current time behaviour if there is defined any transient current waveform at its input terminal. Results enumerated by the numerical model were compared with results measured at the real CT. Comparison between enumerated and measured waveforms confirmed the correct design of the numerical model.

I. Introduction

The paper describes a way, how to build a CT numerical model, when its material parameters are known (magnetization characteristic, winding resistance). The numerical model allows behaviour simulation of the real CT. It is possible to solve the output current time behaviour if there is defined any transient current waveform at its input terminal.

It was necessary to measure magnetic circuit hysteresis loop and both primary and secondary winding resistance to build up the numerical model. There was measured a CT with magnetic core material Trafoker, that is commonly used. Results enumerated by numerical model were compared with results measured at the real CT. Comparison between enumerated and measured values confirmed the correct proposition of the numerical model. It is possible and suitable to solve occurrences, where measured currents, including transients, reach very high values, since these effects are not realisable in reality.

I. Experimental circuit

A. Measurement of characteristics of the CT

It is necessary to know characteristic properties of the CT to know its behaviour in an electric circuit. Any transformer is exactly enough described by the transformer substitution diagram, see Figure 1.

There are R_1 , L_{r1} elements, characterizing primary winding in the CT substitution diagram. The element R_1 is resistance and L_{r1} leakage inductance of that primary winding. The element R_2 is resistance and L_{r2} leakage inductance of the secondary winding. The element R_m represents loss of energy caused by eddy currents and hysteresis losses in the magnetic circuit of the transformer. The main (magnetization) inductance L_m is non-linear and its characteristic is described by hysteresis loop that may be expressed as dependence of magnetic flux Φ on magnetizing current I . This type of characteristic was chosen because the transformer numerical model used that dependence.

The time course of magnetic flux $\varphi(t)$ is possible to obtain by integration of induced voltage on the main (magnetization) inductance L_m . Putting it together with the time course of the current $i(t)$ gives the required dependence $\Phi = f(I)$.

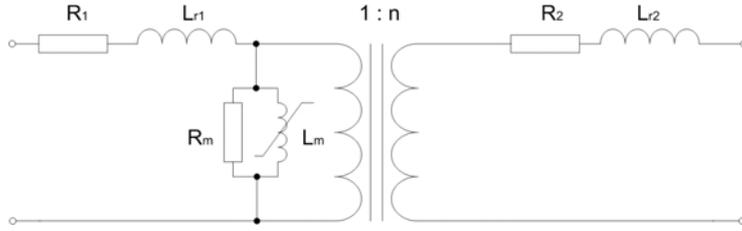


Figure 1: Transformer substitution diagram

The measurement was realized with sine wave supply voltage at 50 Hz frequency. There was used a CT with a toroidal core, consisting of the material Trafoker. The CT ratio was 50 A/1 A and the load was 1.5 VA real. There were two identical secondary windings on the toroidal core, 50-turns each, and nominal current $I_{(2)n} = 1$ A. Primary winding with nominal current $I_{1n} = 50$ A was realized by one pass of the wire through the toroidal core – along the toroidal axis practically, but it was not used in our experiment, because there was no supply powerful enough to feed the 50 A primary winding. There was used one of these 1 A windings to excite the circuit as primary winding.

The calculation of induced voltage $u_i(t)$ was simplified – the leakage inductance L_{r1} was neglected because almost all the magnetic flux passed through the primary winding. That is the reason why there was subtracted the voltage drop $u_{R1}(t)$ from the measured voltage $u_1(t)$ only. The value of R_1 was 0.08Ω in case of our experimental CT 50 A/1 A. The induced voltage $u_i(t)$ may be expressed as

$$u_i(t) = u_1(t) - R_1 \cdot i_1(t) \quad (1)$$

The time course of induced voltage was numerically integrated and the result was time course of the magnetic flux $\varphi(t)$

$$\varphi(t) = \int u_i(t) dt \quad (2)$$

The time course of measured current $i(t)$ was put together with the time course of magnetic flux $\varphi(t)$ into the required magnetization characteristic $\Phi = f(I)$.

B. The experimental circuit with the CT

The experimental circuit substitution diagram, as shown in the Figure 2, was designed to simulate the real conditions in a power system as well as possible. The feeding of the CT 50 A/1 A was realized by controlled current source with required current time course. The situation in that experimental circuit is similar to a power system, where almost ideal voltage sources (power supplies like generators, transformers, etc.) works into relative high impedance of the load (consumers like transformers, electric motors, semiconductor converters, etc.), where the current is measured by means of CT included in the power system.

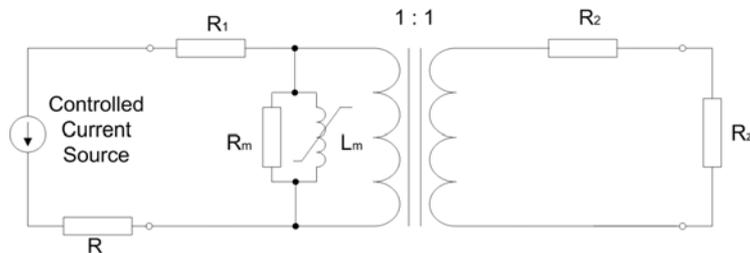


Figure 2: Experimental circuit substitution diagram

The experimental circuit scheme for the transient measurement with the CT 50 A/1 A is shown at the Figure 3 and that scheme is equivalent to the experimental circuit substitution diagram at the Figure 2. As mentioned above, the 50 A primary winding, consisting of one pass of a wire through the toroidal core, was not used, but substituted by one of two identical 1 A 50-turn windings.

There were also neglected leakage inductances L_{r1} and L_{r2} because all turns of both CT windings were wound close together. That is the reason why the leakage inductances were neglected. The value of the primary winding resistance R_1 is the same as the secondary winding resistance R_2 and it is equal

to 0.08Ω . The element R_m , representing the loss of energy caused by eddy currents and hysteresis losses in the magnetic circuit, was neglected in this case also because the hysteresis loop area is very small, especially in the DC super-saturated state. The element L_m represents the main (magnetization) inductance that is non-linear and it is characterized by the dependence $\Phi = f(I)$ which was described in the previous chapter. The sensing resistor R with a resistance 1Ω was used for the current measurement. The resistance $R_z = 1,5 \Omega$ is equal to CT nominal load at the 1 A secondary winding, that is 1.5 VA.

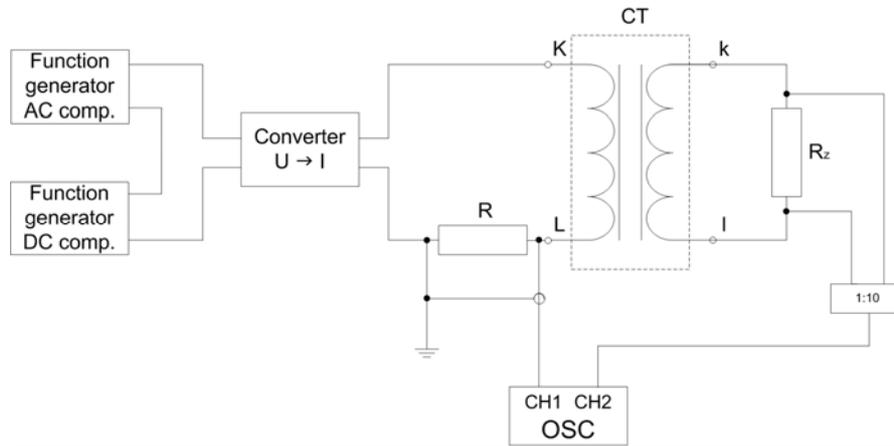


Figure 3: Experimental circuit with CT 50 A/1 A

II. Numerical model

There was used the program MatLab 6.5 [1] and its subsystem Simulink for the solution of whole the circuit with the CT numerical model. Complete scheme of the model, designed in the Simulink, is shown at the Figure 4. The area “Current source” consists of Simulink blocks that generates required current time course. The area “Current Transformer” consists of the CT numerical model and the transformer rated load. Other blocks include data measured in the experimental circuit.

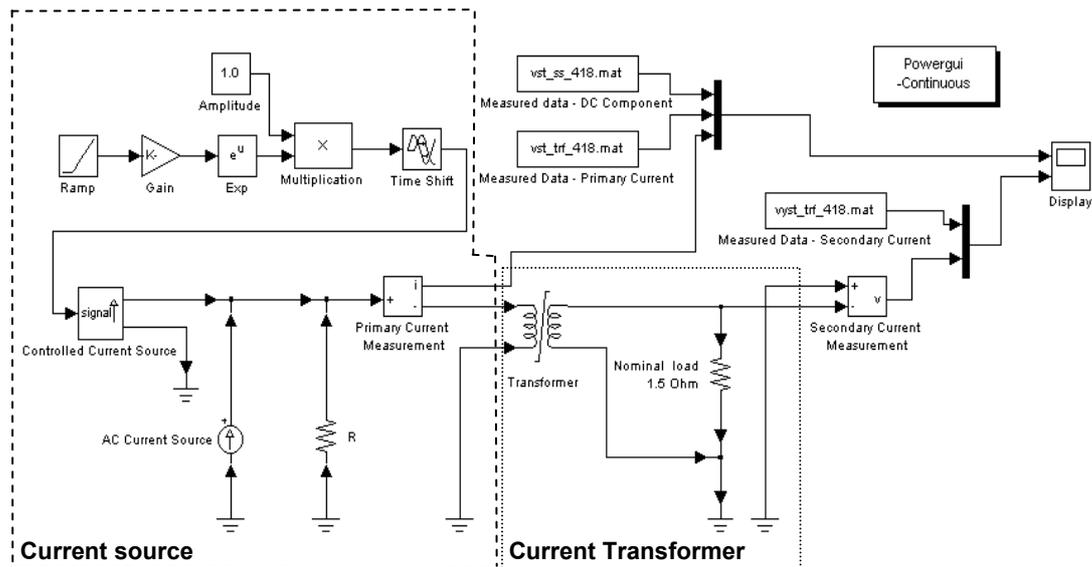


Figure 4: Numerical model of the experimental circuit with CT 50 A/1 A

The numerical model of the CT is substituted by the block Saturable Transformer [2], that is a component of the toolbox SimPowerSystems. This model made possible include a non-linear characteristic with hysteresis loop of the CT ferromagnetic toroidal core.

III. Comparison of the experimental circuit and numerical model

The numerical model of the CT 50 A/1 A (see Figure 4) was fed from controlled current source with 0.5 A constant amplitude 50 Hz alternating component and superposed 1 A exponential falling DC component, see Figure 5. There is also compared the waveform simulated at the numerical model in Matlab with the waveform measured at the experimental circuit.

Resultant transient may be divided in time into two parts. In the first part, the magnetic circuit got into full saturation state, in the time interval from 0.025 s to 0.04 s. During this interval there was great CT output current overshoot caused by rapid decrease of the main (magnetization) inductance. In the second part, the magnetic circuit got into initial steady state from full saturation state, in the time longer than 0.04 s. There is evident high saturation of the magnetic circuit at the beginning of the transient second part, that is shown at the low output current value, i.e. low voltage on the load resistor R_z . This amplitude would stay non-zero also if there is arbitrary high over-saturation because the main (magnetization) inductance would never decrease to zero (relative permeability would stay nearby one).

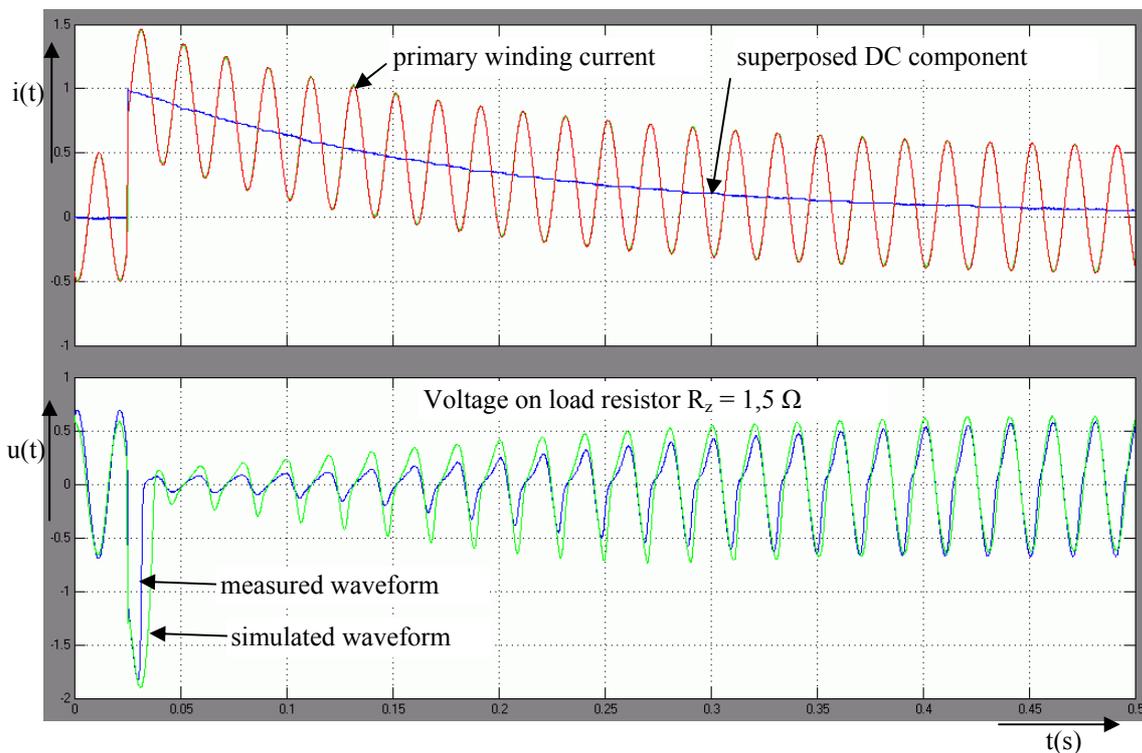


Figure 5: Comparison of simulated and measured waveforms

IV. Conclusions

The main reason for solution of problems described in this paper is the faulty function of electric protections in power systems during transients with slowly changing current DC component. This phenomenon occurs for example during switching-on of power transformers. The transient current in these devices reaches usually values of hundreds or thousands Amperes. So it is impossible to prove behaviour of the CT connected to such a device experimentally. That was the reason why this paper was focused on the problem of the numerical model desing, that made possible numerical solution of the transient transfer through the CT, when its ferromagnetic core material parameters and other electric parameters were known. The CT model was compared with the real experimental circuit which included the CT 50 A/1 A. Simulated values corresponded quite well to measured values, especially at the beginning of the transient where the current pulse reached the maximum and should cause faulty function of electric protections in power systems.

Acknowledgements

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