

Innovative Science and Technology Publications

International Journal of Future Innovative Science and Technology
ISSN: 2454- 194X **Volume - 2, Issue - 2**



Manuscript Title

SATURATION ANALYSIS ON CURRENT TRANSFORMER

Thilepa R¹, Yogaraj J², Vinoth kumar C S³, Santhosh P K⁴,

¹*Department of Electrical and Electronics Engineering, Priyadarshini Engineering College, Vaniyambadi, Tamilnadu, India*

²*Department of Electrical and Electronics Engineering, Rajagopal Polytechnic College, Gudiyattam, Tamilnadu, India*

³*Department of Electrical and Electronics Engineering, T J Institute of Technology, Chennai, Tamilnadu, India*

⁴*Department of Electrical and Electronics Engineering, Priyadarshini Engineering College, Vaniyambadi, Tamilnadu, India*

¹thilepa@gmail.com

²yogarajdj@gmail.com

³vinothkmr087@gmail.com

⁴santhoshbe2013@gmail.com

May – 2016

www.istpublications.com

Saturation Analysis on Current Transformer

Thilepa R¹, Yogaraj J², Vinoth kumar C S³, Santhosh P K⁴,

¹Department of Electrical and Electronics Engineering, Priyadarshini Engineering College, Vaniyambadi, Tamilnadu, India

²Department of Electrical and Electronics Engineering, Rajagopal Polytechnic College, Gudiyattam, Tamilnadu, India

³Department of Electrical and Electronics Engineering, T J Institute of Technology, Chennai, Tamilnadu, India

⁴Department of Electrical and Electronics Engineering, Priyadarshini Engineering College, Vaniyambadi, Tamilnadu, India

¹thilepa@gmail.com

²yogarajdj@gmail.com

³vinothkmr087@gmail.com

⁴santhoshbe2013@gmail.com

Abstract— Current transformer (CT) is one of the important element of power system protection. It is the main source of information and measuring organs of the devices of protection. The accuracy in transforming the primary currents by high voltage and intervening CT determines the reliability of the entire power system protection. This paper describes the saturation study of current transformer during transient fault. A measurement type CT of 2000/5 A, 25VA rating is used in this analysis and it is tested for normal and transient fault condition using MATLAB software. In simulation the secondary current waveforms are recorded for different values of fault current at the primary side. All the current waveforms are compared for analyzing the behavior of CT during transient fault.

Index Terms— Current Transformers, Transients, Hysteresis, Ferro resonance, Saturation.

I.INTRODUCTION

Current transformers are most commonly used integral component of the power system. The needs of current transformers are wide over secure operation of electric power generation, transmission and distribution systems. All types of protection and control devices need current transformers to measure the current. It is well known that current and voltage profiles may carry several transient features about the nature of fault. Some of these features are very high frequency components. The Electro-Magnetic Current Transformers (EMCT) are not capable to transform these transients perfectly [1]. The current advancement in the field of electronics and IC manufacturing technology lead to development of relays with miniature size. The conventional electromechanical relays use the signals on average basis but the present digital/numerical relays sample the signal many times in every cycle. So the potential susceptibility of protection and control devices are becoming very much dependent on the instantaneous current values. The EMCT have natural tendency of transient or permanent saturation due to ferroresonance [2]. The transient modeling of an EMCT includes the B-H curve into the mathematical model and it is expressed by function of magnetizing inductance versus magnetizing current [3].

During short circuit conditions in power network the primary current of CT is several times higher than under normal operation [4]. This causes non-linear behavior of the current transformer. As it is known, the DC

components in the fault current flowing into core of current transformer can cause core material to saturate and produce a distorted secondary current [5]. The CTs are designed to operate at normal conditions, meaning that they are designed to be operates over the linear part of the B-H curve. Under normal (steady state) operation the difference between primary current i_1 and secondary current i_2 can be calculated by the turns-ratio of the CT and the magnetizing current can be neglected [6]. The transformation accuracy of measuring CT in steady state operation is very high, approximately 0.5. The Transients are instantaneous change in state, leading to burst of magnitude in shorter time period [7]. They can be classified as impulsive and oscillatory transients based on wave shape. Many events are being the reason for power system. (i) Intentional Transient (Bus Bar/Capacitor Bank switching), (ii) Unintentional Transient (An accident) like ground faults, short circuits, lightning stroke, break of conductors, and even erroneous operation of C.B & similar inadvertent processes [8]. Transients, especially the decaying DC waveform in primary current, cause the CT to go into saturation and produces distorted current waveform [9]. The methodology described in [4] is practical CT's tested in EPRI and simulation used EMTP for three different models are compared with practical CT test cases. The comparison found the model works satisfactorily as expected in many cases.

In this paper the simulation model of a 2000/5 A ratio rated CT is simulated in MATLAB; and the model is

validated for normal operation, and then subjected to transient fault. The transient performance of the CT is analyzed by giving short circuit current to the CT primary side. The simulation system is modeled for a 120KV constant voltage source supplying a RL load of 69.3MVA; a measuring CT of 25VA, 2000/5 A ratio rating used to measure the current. The saturation is analyzed by comparing the measurements: primary current, secondary current, flux-current curve.

II. MATHEMATICAL MODEL OF CT

The working principle of the current transformer is based on the principle of magnetic coupling. The mathematical model of a CT can be derived from the equivalent circuit diagram. The general equivalent circuit consists of primary winding resistance (R_p), primary winding leakage inductance (X_p), secondary winding connected to the burden (Z_b). The primary current (I_p) flowing in the core induces alternating flux ϕ . This flux is of just sufficient to buildup potential in secondary winding (E_s), which is due to the secondary current (I_s). Current Transformer has short-circuited secondary with burden. A modern CT can be represented with the simplified equivalent diagram according to fig. 1. The burden is considered to be entirely resistive. This is correct in most modern applications where the burden of the relay is very small and the secondary wires are the major part of the total burden.

In ideal condition the primary is reproduced in secondary in exact ratio and phase relationship [10].

Primary Ampere Turn = Secondary Ampere Turn

$$N_p I_p = N_s I_s \quad (1)$$

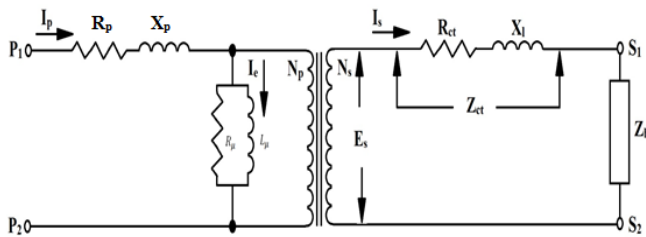


Fig. 1 Equivalent circuit diagram of current transformer

Secondary circuit side impedance Z_s can be given by

$$Z_s = (R_b + R_{sw}) + j(X_b + X_{sw}) \quad (2)$$

And the secondary circuit power factor is given by

$$\cos \delta = \frac{R_b + R_{sw}}{Z_s} \quad (3)$$

The secondary voltage can be derived from the induced flux

$$E_s = \frac{d\phi}{dt} \text{ Volts} \quad (4)$$

$$E_s = I_s (Z_b + Z_{sw} + Z_L) \quad (5)$$

If the core is saturated the flux practically cannot be increased and the secondary current will be practically zero. Equation (6) gives the differential equation for the magnetization of the magnetic core with cross section area and number of secondary turns in the CT.

$$E_s = N_s \cdot A \cdot \frac{dB}{dt} \quad (6)$$

Integration of equation (6) gives the expression of the flux density, equation (7) and it can be seen that the flux density is proportional to the time integral of the secondary EMF (E_s).

$$B(t) = \frac{1}{N_s \cdot A} \cdot \int_0^t E(t) dt \quad (7)$$

According to the above equation the secondary EMF will be sinusoidal if we apply sinusoidal current at the primary of CT and assume that it's not reached saturation level. Solving the above equation we can get the following relationship between induced EMF and magnetic flux density.

$$E_s = 4.44 f s A N_s B \quad (8)$$

CT has a definite capability to produce a secondary EMF depending on the core material, the frequency, the core cross section area and the number of secondary turns. The only way of changing the saturation level for a CT, with a specific core material, is to change the core area or the number of secondary turns. Equation (5) shows that the secondary EMF is equal to the voltage over the secondary winding resistance and the connected burden. Increasing the current or the burden can raise the secondary EMF to a level that will saturate the CT. The peak value of maximum flux density B_m can be easily calculated from the well popular transformer voltage induced equation at knee point given below

$$E_K = 4.44 f s A N_s B_m \quad (9)$$

As per the pictorial representation in fig. 2 the RMS value of the sinusoidal voltage at rated frequency applied to the secondary terminals of the transformer, all other terminals being open-circuited, which, when increased by 10%, causes the RMS value of the exciting current to increase by 50% [11].

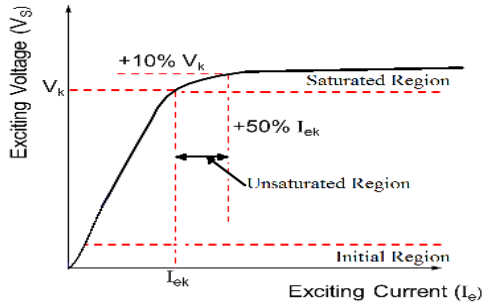


Fig. 2 Secondary excitation curve representing knee-point

The voltage at the secondary terminal can be given as

$$V_{O/P} = I_s Z_b = E_K - I_s Z_{sw} \quad (10)$$

Equation (6) can be rewritten as

$$E_s = K_v B \quad (11)$$

Where

$$K_v = 4.44 f_s A N_s \quad (12)$$

The primary current contains two components. These are the secondary current which is transformed in the inverse ratio of the turns-ratio and an exciting current (I_e), which supplies the eddy current and hysteresis losses and magnetises the core. This latter current flows in the primary winding only and therefore, is the cause of the transformer errors. The amount of exciting current drawn by a current transformer depends upon the core material and the amount of flux which must be developed in the core to satisfy the burden requirements of the current transformer. The excitation current can be related with magnetic field intensity as follows

$$I_e = H \cdot L / N_s \quad (13)$$

Equation (13) can be written as

$$I_e = K_i H \quad (14)$$

Where

L – Mean magnetic path = $2\pi r$

$$r = \frac{r_o - r_i}{2} + r_i$$

$$K_i = \frac{L}{N_s}$$

The excitation characteristic is differing for different ratio of current transformer. Fig. 3 shows the excitation characteristics of different ratio of CT's. The core starts to saturate after the knee point. In the case when the core saturates, a disproportionate amount of primary current is required to magnetise the core and, regardless of the value

of primary current, a secondary current will not be produced. In Matlab Simulink the hysteresis characteristics curve for the CT is modeled.

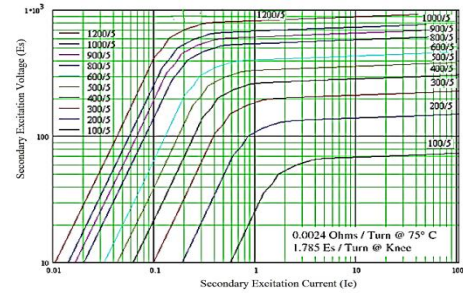


Fig. 3 Secondary Excitation Characteristics

III. SIMULATION

The simulation is done for continuous type with 50Hz fundamental frequency and base voltage of 120KV, using ode23tb (stiff/TR-BDF2) solver with default step size and relative tolerance in MATLAB/Simulink. A measurement current transformer of 2000/5A rating was modelled with the 25VA, 50HZ. The CT designed to have four connection terminals P₁, P₂, S₁, and S₂. The CT is modelled to saturate at 1.6pu flux as shown in fig. 4. To evaluate the performance of the current transformer the primary and secondary currents are measured; and compared with scope. The flux distribution is monitored as B-H curve by X-Y plotter.

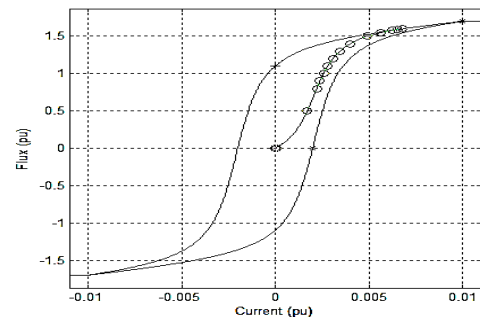


Fig. 4 Hysteresis model of CT

The overall simulation is having two set of diagrams as shown in fig. 5 and fig. 6.

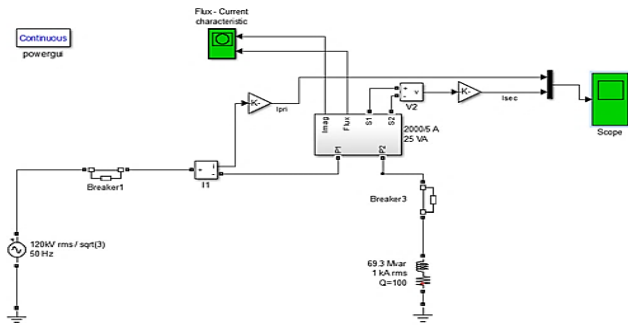


Fig. 5 Simulation model of CT during normal operation

Fig. 5 shows the primary terminal P_1 is connected with constant voltage source via breaker1; P_2 is connected to a load through breaker3. Here the measurements are primary current, secondary current, flux (pu), Magnetizing current and voltage across the breaker 2. Fig. 6 shows P_1 is connected with short circuit current source via breaker 2. Another terminal of primary winding P_2 is connected to ground. In both these models secondary terminals are shorted with rated burden value as per precautions.

The simulation model can be validated by testing the model in to the system operation; and to analyze the transient behavior of the CT; short circuit current given to the CT primary side.

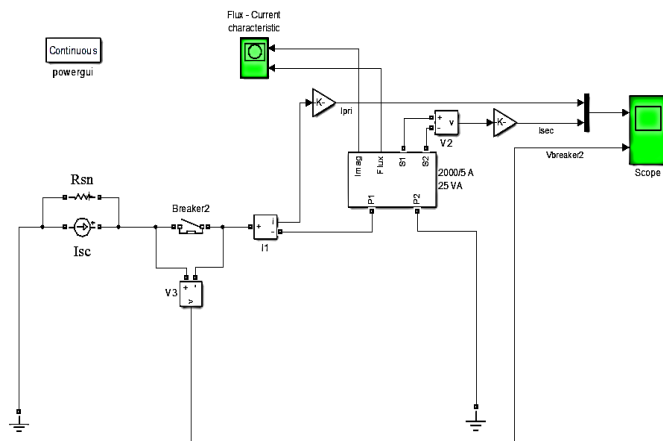


Fig. 6 Simulation diagram of CT for short time current test

IV RESULTS AND DISCUSSIONS

Testing the current transformer is can be done for two cases (i) Normal operation (ii) Transient fault analysis

a) Normal operation:

Simulation model can be tested to validate its designed hysteresis, under normal operation. Hysteresis

shown in fig. 4 is used in the simulation. As shown in fig. 5 the 120KV constant voltage source supplying RL load of 69.3MVA, 1KA rms. In this CT is connected in series between source and load to measure the load current.

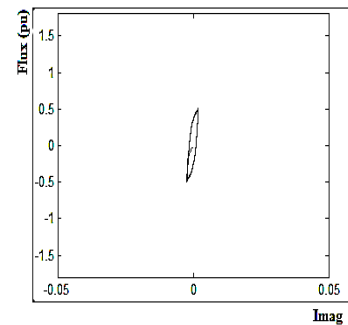


Fig. 7 Hysteresis curve during normal operation

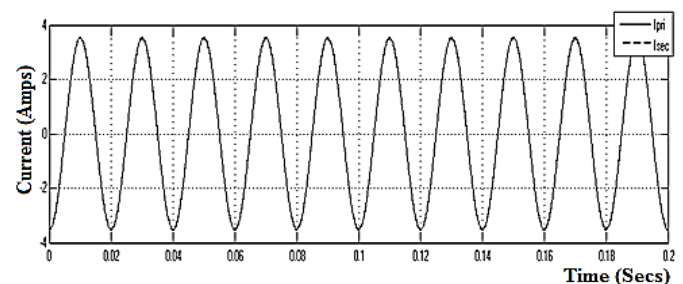


Fig. 8 Comparison of primary and secondary currents for normal operation with 69.3MVA load

In measurement side the primary current is divided by the turns-ratio; so that primary wave will coincide with secondary wave with same equivalent value. It will more useful to compare both the waveforms. Fig. 7 shows the hysteresis of CT core while measuring the current through the load; the load takes 1414A which is measured by secondary as 3.535A. So primary and secondary waves in fig. 8 coincide together, the simulation of CT under normal condition is working well.

b) Transient fault analysis:

Transient can cause by many events. Short circuit is one of the events among them. During this test the CT is subjected to short circuit current at its primary terminal P_1 , and P_2 is grounded as shown in fig. 6.

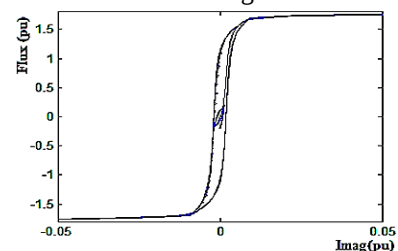


Fig. 9 Hysteresis curve during transient test

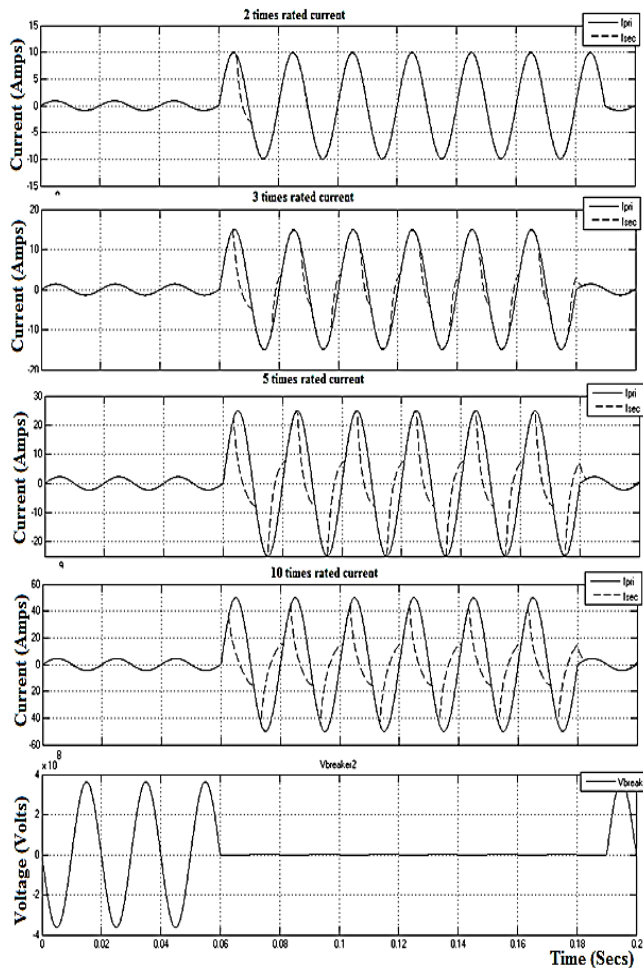


Fig. 10 Current waveforms comparison for various SC currents

In simulation as shown in fig. 6 by making breaker2 ON we can supply the short circuit current to the CT primary. This test is performed for different multiples of rated current as short circuit current; and the response is analyzed by comparing primary and secondary current waveforms. The duration of this fault is 0.12sec i.e., from 3rd cycle to 9th cycle.

The CT is subjected to short circuit (SC) fault for the specified time period. For all the tests the hysteresis is same as shown in fig. 9. Fig. 10 shows that when two times of rated current (4000A) is supplied to the CT; it goes for small amount of distortion in secondary current only at the first cycle; this is because the saturation limit is fixed as 1.6pu value. When the SC current is of three times entire cycles throughout the duration of fault is distorted; but the distortion reduces for consequent wave forms. This is because the CT core tries to build more flux in secondary. For SC current of 5 times and 10 times shows that the entire secondary current distorted. Comparing the 5 times and 10 times wave forms; it's clearly shown that the secondary current magnitude decreases.

This is because the high magnitude AC current in primary increases the magnitude of the flux. When it goes beyond the limit of flux, it makes the core to saturate. Under severe CT saturation the secondary currents is not behave in the same manner as the ratio (scaled primary) current. That is CT accuracy becomes poor, the secondary side output waveform becomes distorted; also the magnitude of secondary wave reduces as shown in fig. 9.

V CONCLUSION

The simulation model for 2000/5 A ratio rated CT is works properly as per the designed range. When subjecting the CT to short circuit current test; by supplying the SC current to the CT primary. The primary and secondary current waveforms are observed to analyze the transient fault behaviour. Test results clears that the CT core goes saturation during transients, but the saturation is based on the magnitude of the fault current. As the CT is modeled to saturate for 1.6 pu flux, the CT core goes partial saturation (only one or two cycles of secondary wave forms distorted) for fault current equivalent to two times of the rated primary current. Furthermore increase in SC fault current magnitude results in complete secondary current waveforms to distortion. Furthermore SC currents (5 times of rated primary current) the CT secondary current waveform becomes heavily distorted due to large saturation. More increase in fault current value results the reduction in secondary current magnitude. It results to lose its proportionality and accuracy of transformation. This is due to core saturation for larger magnitude primary current.

REFERENCES

- [1] Rafajdus P, Bracinik P, Hrabovcova V, Saitz J, Kankula L. "Current transformer analysis under transient conditions", *XIX International Conference on Electrical Machines - ICEM 2010, Rome*, 2010.
- [2] Longfei Ren, Zhiguo Hao, Baohui Zhang. "A novel algorithm applied in the transient saturation of current transformer", *TENCON 2013 - 2013 IEEE Region 10 Conference (31194)*, pp. 1-4, 2013.
- [3] Davarpanah M, Sanaye-Pasand M, Iravani R. "A saturation suppression approach for the current transformer—Part I: fundamental concepts and design", *IEEE Transactions on Power Delivery*, Vol. 28, No. 3, pp.1928-1935, 2013.
- [4] Kezunovic M, fromen C.W, Phillips F. "Experimental evaluation of EMTP-based current transformer models for protective relay transient study", *IEEE*

- Transactions on Power Delivery*, Vol. 9, No. 1, pp.405-413, 2011.
- [5] Brain D Jenkins, "Introduction to Instrument-Transformers" George Newnes Limited, London, 2013.
 - [6] Chi-Shan Yu. "Detection and correction of saturated current transformer measurements using decaying dc components", *IEEE Transactions on Power Delivery*, Vol. 25, No. 3, pp.1340-1347, 2010.
 - [7] Shirkovets A.I. "Modeling of transient processes at ground faults in the electrical network with a high content of harmonics", *2nd International Conference on Electric Power Equipment - Switching Technology (ICEPE-ST)*, 2013, pp.1-5, 2013.
 - [8] Juan A. Martinez-Velasco, "Power System Transients Parameter Determination" CRC Press, New York, 2010
 - [9] Davarpanah M, Sanaye-Pasand M, Iravani R. "A saturation suppression approach for the current transformer—Part II: fundamental concepts and design", *IEEE Transactions on Power Delivery*, Vol. 28, No. 3, pp.1936-1942, 2013.
 - [10] Bahram Noshad, Babak Fakhar, Mina Goodarzi." A new model for current transformer", *Journal of Basic and Applied Scientific Research*, Vol. 3, No.2, pp.738-744, 2013.
 - [11] Pandey R. P, Patel R. N. "An efficient detection algorithm for ct saturation using linear predictive coding", *International Journal of Engineering Development and Research*, Vol. 2, No. 2, pp.1648-1652, 2014.