Dynamic analysis of a current transformer during electrical faults

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***Abstract*— Current-transformer saturation may lead to the false trip of a protection relay. In this paper, dynamic analysis of a current transformer during electrical faults is investigated. The ratio of current transformer is 1200/5A. The secondary current and flux response have been computed for difference values of load. To validate the results, the proposed model has been compared to IEEE power system relaying committee (IPSR model). In this paper, the current transformer transient model caused by fault current in primary windings is presented. In this model the inducted voltage in secondary is calculated using basic electromagnetic analytical equations in transient and it is analyzed in discrete space using digital signal processing algorithms. Then the current transformers saturation and its impact on the power system protection analyzed. Analytical equations corresponding to current transformers saturation are also described. Prevalent digital signal processing algorithms are assessed and their advantages and disadvantages are introduced. The proposed algorithm is simulated using MATLAB program.**

***Keywords*: current transformer, dynamic analysis, core saturation, electrical faults.**

I. INTRODUCTION

To accurate performance of the protection system, an accurate model for CT is needed. When fault current flows through the primary winding of the CT, the asymmetrical component causes a rise in the core flux. The increase in flux causes core saturation that lead to the secondary current distortion. Various models to the analysis of the transient behavior of CT were presented in the past which very complicate and very laborious [1-4].

In this paper, dynamic analysis of a current transformer during electrical faults is investigated. To solve the equations in the proposed algorithm, the fourth-order Runge-kutta method is used. The obtained results show the accuracy of this numerical integration method. To prove the obtained results, the proposed algorithm has been compared to ATP-EMTP program and IPSR model [5-6]. The ratio of a current transformer is 1200/5A and the secondary current and flux response have been computed for difference values of load. In this paper, a very simple and effective model is presented. The main advantages of this proposed model are following: 1) not require information of B-H curve for magnetic branch, 2) hysteresis effect doesn't taken into account and results can be compare to the IEEE model with considering hysteresis effect, and 3) It includes proper computing speed and accuracy. In this paper, the current transformer transient model caused by fault current in primary windings is presented. In this model the inducted voltage in secondary is calculated using basic electromagnetic analytical equations in transient and it is analyzed in discrete space using digital signal processing algorithms. Then the current transformers saturation and its impact on the power system protection analyzed. Analytical equations corresponding to current transformers saturation are also described. Prevalent digital signal processing algorithms are assessed and their advantages and disadvantages are introduced. The proposed algorithm is simulated using MATLAB program.

II. PROBLEM DESCRIPTION AND PROPOSED ALGORITHM

When a fault in a power system happens, the fault current is defined by [5, 7]:

$$i_P = \frac{U_p}{\sqrt{(R_1{}^2 + W^2 L_1{}^2)}}[\sin(wt + \alpha - \phi) + \sin(\phi - \alpha)e^{\frac{-t}{\tau_P}}] \quad (1)$$

Where U_p is voltage of the system peak, R_1 and L_1 are the primary resistive and inductive of power system, α is the angle of the initial phase at the instant fault, and $\phi = tg^{-1}\frac{wL_1}{R_1}$. The maximum offset in the fault current occurs when $\sin(\phi - \alpha) = 1$. Under this condition:

$$i_p = \sqrt{2}I[e^{-t/\tau_P} - \cos wt] \quad (2)$$

Where $I = \dfrac{U_p}{(R_1^2 + w^2 L_1^2)^{1/2}}$ is the primary effective steady state current. The equivalent circuit of the CT referred to the secondary side is shown in Fig. 1. In this circuit R_2, L_2 and R_b and L_b represent the resistance and inductance of the secondary side and load, respectively.

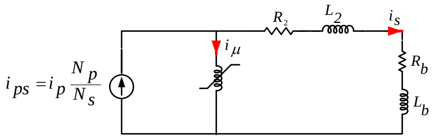

Fig. 1: CT model referred to secondary side.

The magnetization characteristic of the CT can be considered as a single-valued since the hysteresis characteristic does not considerably affect the CT transient behavior [8]. To present a new model which coincides to real situation, single-valued curve can be changed to magnetization curve shown in Fig. 2 and by using the Curve Fitting Toolbox, i_μ is defined as following:

$$i_\mu = 0.2(\psi_\mu + 0.8\psi_\mu{}^7) \tag{3}$$

Where ψ_μ and i_μ are the flux linkage and the magnetizing current.

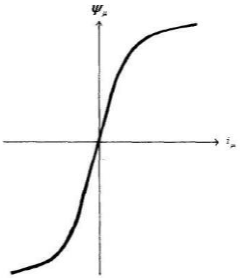

Fig. 2: Magnetization characteristic of CT.

To present a new model, the CT model shown in Fig. 1 is taken into account. First, we defined:

$$R = R_2 + R_b,\ \ L = L_2 + L_b \tag{4}$$

According to Fig. 1:

$$i_{ps} = i_\mu + i_s \tag{5}$$

$$e_s = Ri_s + L\frac{di_s}{dt} \tag{6}$$

$$i_{ps} = \frac{N_p}{N_s} i_p \tag{7}$$

Where i_{ps} represents the primary current referred to secondary side, i_s represents the secondary current, N_p and N_s represent the number of primary and secondary turns and e_s represents the induced voltage in the secondary winding. From (2), (5) and (7):

$$i_s = \frac{N_p}{N_s}\sqrt{2}I(e^{-t/\tau_p} - \cos wt) - i_\mu \tag{8}$$

According to (3) and (8):

$$i_s = p(e^{-t/\tau_p} - \cos\omega t) - 0.2(\psi_\mu + 0.8\psi_\mu^7) \tag{9}$$

Where $p = \frac{N_p}{N_s}\sqrt{2}I$. Differentiating of (9):

$$\frac{di_s}{dt} = \frac{-p}{\tau_p}e^{-t/\tau_p} + p_1\omega\sin\omega t - 0.2\frac{d\psi_\mu}{dt} - 0.16(\frac{d\psi_\mu^7}{dt}) \tag{10}$$

Since $\frac{d\psi_\mu}{dt} = e_s$ and according to (6), (9) and (10):

$$\frac{d\psi_\mu}{dt} = \frac{Rp}{1+0.2L}(e^{-t/\tau_p} - \cos\omega t) - \frac{0.2R}{1+0.2L}(\psi_\mu + 0.8\psi_\mu^7) \tag{11}$$
$$-\frac{Lp}{\tau_p(1+0.2L)}e^{-t/\tau_p} + \left(\frac{Lp\omega}{(1+0.2L)}\right)\sin\omega t - \frac{0.16L}{(1+0.2L)}\frac{d(\psi_\mu^7)}{dt}$$

Where τ_p represents the time constant of the power system. ψ_μ can be calculated from (11) by using the forth-order Runge-Kutta method with a 10µs time step. The secondary current has been calculated from (9) using the computed ψ_μ. The flowchart of the program is shown in Fig. 3.

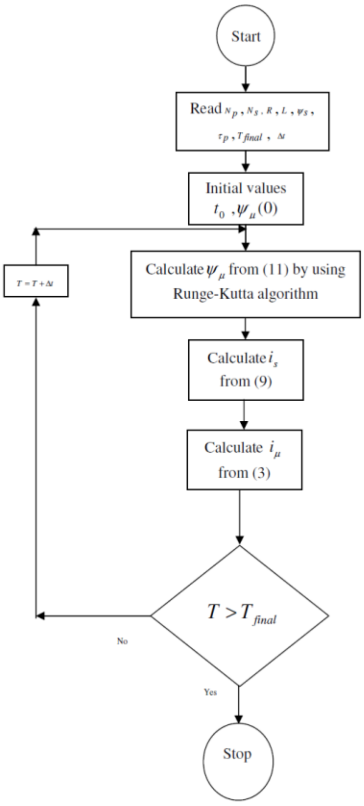

Fig. 3: Flowchart of the proposed algorithm.

III. SIMULATION RESULTS

In this paper, a typical 1200/5A CT with the parameter given in table 1 has been used. The characteristic of power system in the simulation is also given in table 1.

Table I
Characteristics of the CT and power system

Ratio of CT	1200/5
N_P	1
N_S	240
B_S (Tesla)	1.8
Number of core turns	240
L_S (mH)	0.7
A (m^2)	3.472e-3
Time constant (s)	0.027
Frequency (Hz)	50
Fault current amplitude (KA)	12

IV. ANALYSIS OF THE SECONDARY CURRENT

If the resistance component dominates in the impedance, the distortion of the secondary current of current transformer increases. In this paper, to study the secondary current, various simulations are presented. By using the proposed algorithm, the waveforms of the primary and secondary currents for various values of load impedance are shown in Figs. 4-7.

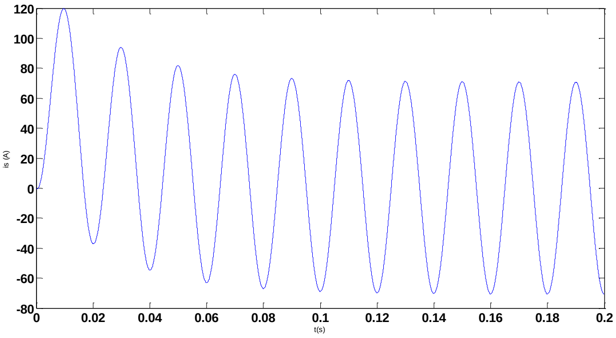

Fig. 4: the secondary current of current transformer with load impedance 0+j.1

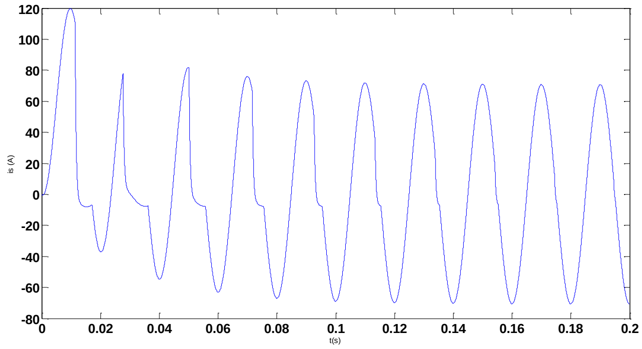

Fig. 5: the secondary current of current transformer with load impedance 2+j.1

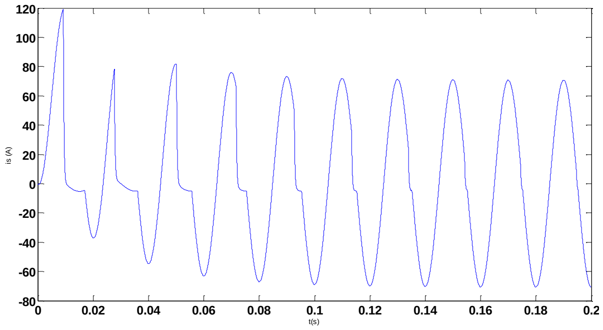

Fig. 6: the secondary current of current transformer with load impedance 2+j.08

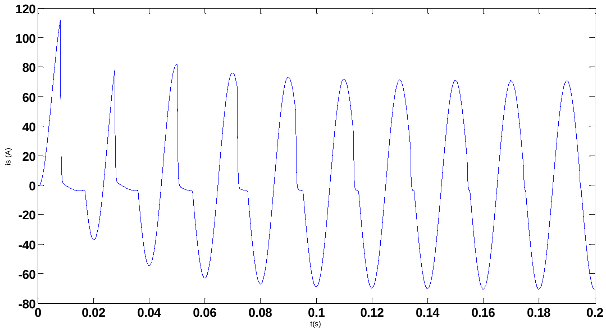

Fig. 7: the secondary current of current transformer with load impedance 3+j.1

According to these Figs, the obtained results showed the accuracy of the proposed algorithm. In this paper, the results of the proposed algorithm can be compared to IPSR model [5-8], considering the effect of hysteresis that show the accuracy of the proposed model. So, the hysteresis characteristic does not significantly affect the behavior of the CT and can be ignored [8]. The waveforms of the secondary current for various values of load impedance at various cases are shown in Figs. 4-7 and the results can be compared to [8] which in [8] results have been compared to IPSR model. Results show if the resistance component dominates in the impedance, the distortion of the secondary current of CT increases.

V. CONCLUSIONS

In this paper, dynamic analysis of a current transformer during electrical faults was investigated. To prove the obtained results, the proposed model was compared to IPSR model. Obtained results showed if the resistance component dominated in the impedance, the distortion increased in the flux and the secondary current of CT. therefore, obtained results showed accuracy of the proposed model. To solve the equations in the proposed algorithm, the fourth-order Runge-kutta method was used. The obtained results also showed the accuracy of this numerical integration method.

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