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A new model for current transformer

Bahram Noshad[1], Babak Fakhar[2], Mina Goodarzi[3]
[1]Department of Electrical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran
[2]Department of Computer Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran
[3]Department of Mathematics, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran

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ABSTRACT

In this paper, a new mathematical model is developed for a current transformer to predict the transient performance with a complex burden consisting of inductance and resistance, taking core saturation into account. A typical 1200/5 A current transformer will be considered to simulation with various maximum offset fault currents. The flux response and secondary current have been computed for various values of load impedance. To validate the results, the proposed model has been compared to ATP-EMTP program.

KEYWORD*:* ATP-EMTP program, current transformer, transient analysis, core saturation, electrical faults.

I. INTRODUCTION

To accurate performance of the protection system, an accurate model for current transformer is needed. When a short circuit fault in the power system occurs, the current transformer approaches saturation region and this may lead to the secondary current distortion. Hence, it affects the protective relays operation and as a result, mal-operation will occur for the protective relays. Thus, this requires an accurate model of current transformer under short circuit in order to analyze the protective relays operation [1-4].

In this paper, an appropriate model is developed to predict the transient behavior of a current transformer with a burden consisting of inductance and resistance, taking saturation into account. First, the transient behavior of current transformer under fault conditions is analyzed by the proposed algorithm. In the proposed algorithm to solve the equations the fourth-order runge-kutta method is used. The results show the accuracy of this numerical integration method. Then, to validate the method a comparison is made with ATP-EMTP time domain simulation program. A typical 1200/5 A current transformer will be considered to simulation with various maximum offset fault currents. The flux response and secondary current have been computed for various values of load impedance. So, 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, simulation is done by MATLAB and ATP-EMTP programs.

II. PROPOSED ALGORITHM

When a fault in a power system occurs, 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:

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

Where $I = \frac{U_p}{(R_1^2 + w^2 L_1^2)^{1/2}}$ is the primary effective steady state current. The equivalent circuit of the current transformer 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 winding and load, respectively.

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[*] **Corresponding Author:** Bahram Noshad, Department of Electrical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran

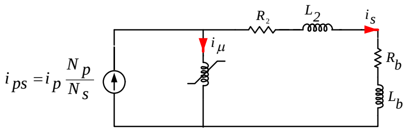


Fig. 1: current transformer model referred to secondary side

The magnetization characteristic of the current transformer can be considered as a single-valued since the hysteresis characteristic does not considerably affect the current transformer 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:

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

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

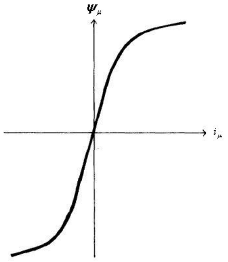


Fig. 2: Magnetization characteristic of current transformer

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

$$R = R_2 + R_b,\ \ L = L_2 + L_b \qquad (4)$$

According to Fig. 1:

$$i_{ps} = i_\mu + i_s \qquad (5)$$

$$e_s = Ri_s + L\frac{di_s}{dt} \qquad (6)$$

$$i_{ps} = \frac{N_p}{N_s} i_p \qquad (7)$$

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):

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

According to (3) and (8):

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

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

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

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

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

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.

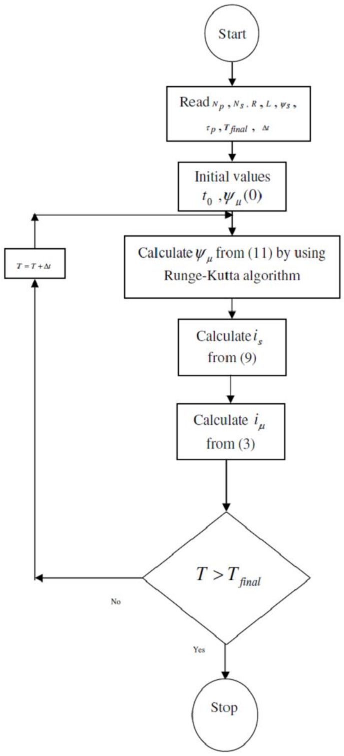


Fig. 3: Flowchart of the proposed algorithm

III. ANALYSIS BY USING ATP-EMTP PROGRAM

In this paper, to validity of the proposed algorithm, results will be compared to ATP-EMTP program (Fig. 4). If the switch in Fig. 4 is changed fault happens and transient behavior of CT has been studied.

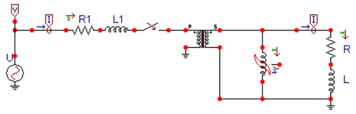


Fig. 4: Simulation of the current transformer model in ATP-EMTP program

IV. SIMULATION RESULTS

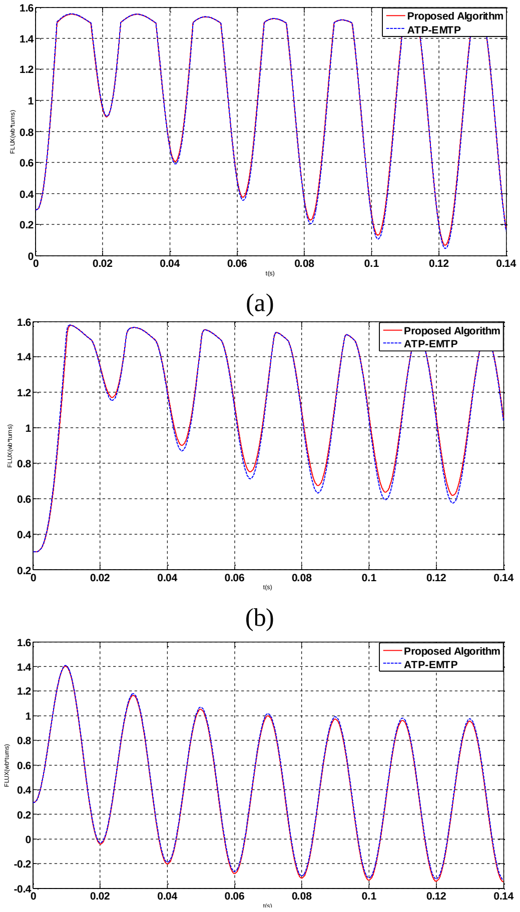
In this paper, a typical 1200/5A current transformer with the parameter given in table 1 has been used. The characteristic of power system in the simulation is also given in table 1.

Table 1: Characteristics of the current transformer 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

V. ANALYSIS OF THE FLUX

To analysis of the flux, the value of the initial flux is taken into account as 20% of the flux at the knee point of the magnetization curve. In current transformer against the power transformer, if the flux is farther than the knee point, it takes more time to reach saturated region when a fault happens and hence the core saturation of the current transformer causes the distortion of the secondary current. Three cases are considered for simulation according to standard values for inductance and resistance [5]. By using the proposed algorithm and ATP-EMTP programs, the waveforms of the flux in transient cases for various values of load impedance are shown in Fig. 5.



(a)

(b)

(c)

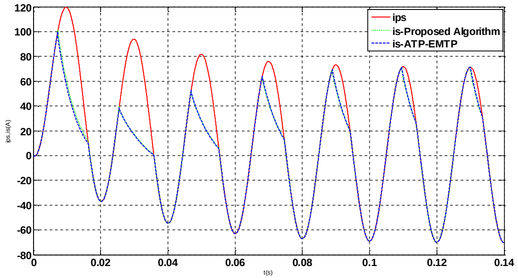
Fig. 5: The waveforms of the flux with load impedance

a) 2 + j 0.0092 Ω , b) 2+ j 0 Ω , c) 0 + j 0.0092 Ω

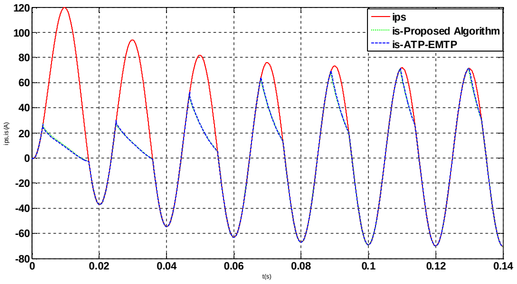
According to these Figs, if the resistance component dominates the impedance, the distortion increases in the flux and hence the current transformer is approached to a high saturation.

VI. ANALYSIS OF THE SECONDARY CURRENT

In this paper, to study the secondary current, three cases are taken into account. Three cases are the magnitude of the remnant flux 0%, +80% and -80% of the saturation point flux. When the current transformer is subjected to a short circuit fault with the AC component amplitude of 12KA, DC offset of 100% at remnant flux magnitudes of 0%, +80% and -80%. By using the proposed algorithm and ATP-EMTP program, the waveforms of the primary and secondary currents for various values of load impedance are shown in Fig. 6.



(a_1)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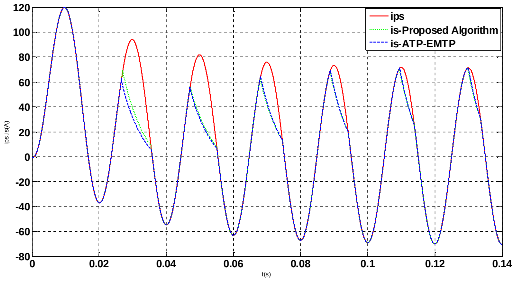
(b$_1$)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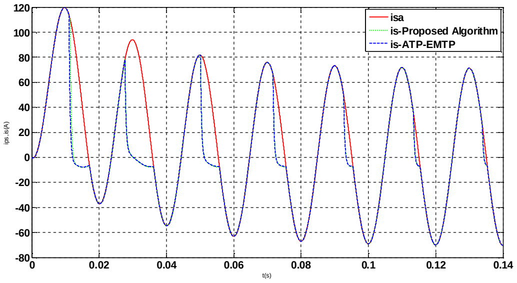
(c$_1$)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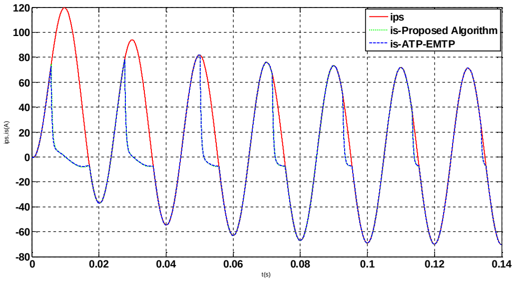
(a$_2$)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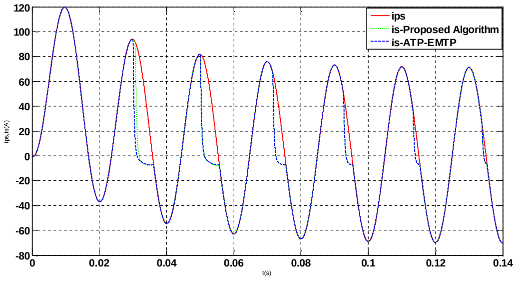
(b$_2$)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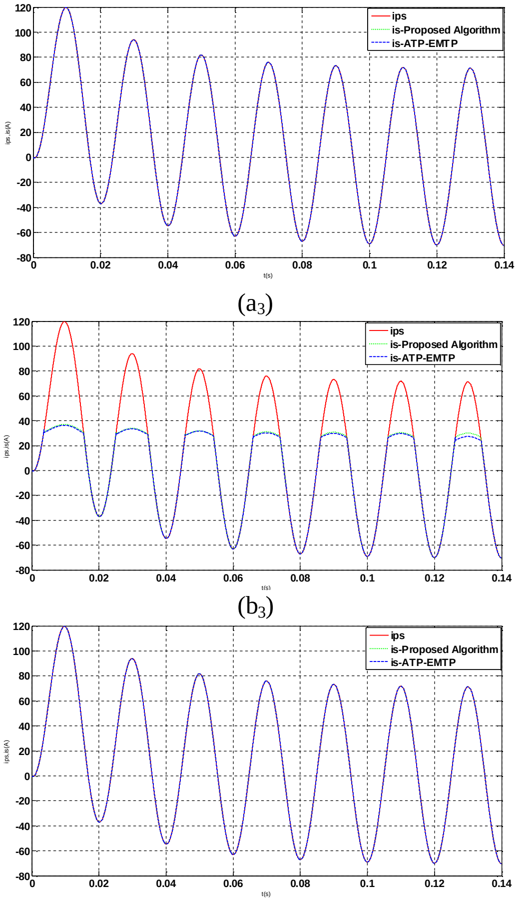
(c$_2$)



(a_3)

(b_3)

(c_3)

Fig. 6: The primary and secondary currents from different cases at remnant flux magnitude of (a_1) 0%, (b_1) +80%, (c_1) -80% with load impedance 2 + j0.0092Ω, (a_2) 0%, (b_2) +80%, (c_2) -80% with load impedance 2 + j0Ω, (a_3) 0%, (b_3) +80%, (c_3) -80% with load impedance 0 + j0.0092Ω

According to these Figs, the results of the proposed algorithm are compatible to ATP-EMTP program. In this paper, the results of the proposed algorithm and ATP-EMTP program 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 current transformer and can be ignored [8]. The waveforms of the secondary current for various values of load impedance at various cases are shown in Fig. 6 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 current transformer increases.

VII. CONCLUSIONS

In this paper, a new mathematical model was developed for a current transformer to predict the transient performance with a complex burden consisting of inductance and resistance, taking core saturation into account. A typical 1200/5 A current transformer was considered to simulation with various maximum offset fault currents. The flux response and secondary current have been computed for various values of load impedance. To validate the results, the proposed model has been compared to ATP-EMTP program. In the proposed algorithm to solve the equations the fourth-order Runge-kutta method was used. The results also showed the accuracy of this numerical integration method.

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