Modeling of Practical CT Based on Lucas Model and Study of CT Saturation

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***Abstract*— For a proper operation of the protection system during electromagnetic transients, proper representation and modeling of the current transformer (CT) and the potential transformer (PT) is necessary. The CT model should accurately represent the transient characteristics of the CT in practical use. In this paper, Lucas model of a CT is discussed, the model parameters of a practical CT is used to study the CT saturation characteristics for a fault with line reclosure conditions and for CT secondary burdens.**

***Index Terms*— burden; current transformer; dc offset; Lucas model; pscad; remanence; saturation; simulation**

I. INTRODUCTION

There has been huge development of power infrastructure with high-density AC/DC hybrid systems being integrated to already complex electric grid. To ensure a reliable and efficient operation of the grid, sensing devices which have nonlinear ferromagnetic components such as CT are to be modeled with saturation considerations [1].

Parameters such as DC offset, remnant flux, time decay constant, physical structure have impact on CT saturation.

In this paper, Lucas model for CT is discussed [2]. Lucas parameters of a P class CT[3] is used for the PSCAD simulation model. The modeled CT is used in a test system for the study of saturation due to DC offset in the primary fault current and the impact of reclosing the line while the fault is still present. Also, the effect of burden on CT saturation is studied.

II. ANALYSIS OF LUCAS MODEL

Many models developed for representing flux current variations in transformer cores have been based purely on magnetizing characteristic. Jiles-Atherton model (J-A model) [4] based on ferromagnetic material theory and the Lucas model based on non-linear equivalent circuit is widely used in transient analysis.

Lucas has shown that the field intensity H can be expressed by a power curve of flux density B [5] of the form shown by,

$$H=\sum K_a B^{n_a} \qquad (1)$$

Where $K_a>0$ and $n_a>0$ for all a. The magnetizing curve equation for Lucas model becomes,

$$H=K_1B + K_2B^{n_2} + K_3B^{n_3} \qquad (2)$$

From Ampere circuital law,

$$Hl=N_1i_1 - N_2i_2=N_2i_c \qquad (3)$$

Where, N_1, N_2, are the number of turns of the primary and secondary of CT, l is the path length of CT, i_1, i_2 are the primary and secondary current.

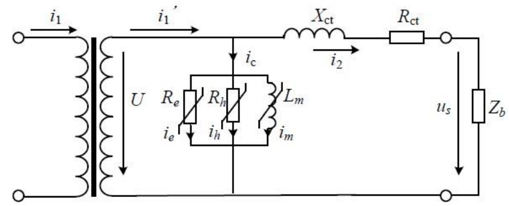


Fig. 1 Non-linear equivalent circuit of CT

As shown in Fig. 1, i_c is total core current refereed to secondary and according to the nonlinear equivalent circuit, i_c consists of three parts; Eddy loss current (i_e), Hysteresis loss current (i_h) Magnetizing current (i_m).

$$i_c = i_e + i_h + i_m \qquad (4)$$

U is the secondary induced voltage, Xct and Rct are secondary reactance and resistance, Zb is burden impedance.

In PSCAD, eddy loss current and hysteresis loss current are given as,

$$i_e = G_{ed} \,.\, U \qquad (5)$$

$$i_h = G_1.\, sign\,(U).\sqrt{|U|} + G_2.\,U.\,|B|^3 + G_2.\,U.\,|B|^{15}$$

Combining equations (2) and (3),

$$i_c = k_1B + k_2B^{n_2} + k_3B^{n_3} \qquad (7)$$

$$k_a = \frac{l.\,K_a}{N_2} \qquad (8)$$

(6)

From above discussion, the constants k_1, k_2, k_3, n_2, n_3 form the Lucas magnetizing characteristics parameters and G_{ed}, G_1, G_2, G_3 form the Lucas loss characteristics parameters.

III. MODELING RESULTS OF PRACTICAL PROTECTIVE CT

The Lucas model parameters of practical 22kV P class CT is shown in table 1. The simulated magnetizing curve is shown in Fig. 2. Whereas Fig. 2.1 shows the resultant magnetizing curve obtained by authors [3] for the parameters in table 1.

Table 1. Lucas model parameters of P class CT

Magnetizing Characteristics Parameter		Loss Characteristics Parameter	
k_1	2.111×10^{-3}	G_{ed}	0.6
k_2	2.099×10^{-3}	G_1	0.6
k_3	6.296×10^{-11}	G_2	0.45
n_2	6.575	G_3	4.0×10^{-5}
n_3	35.48		

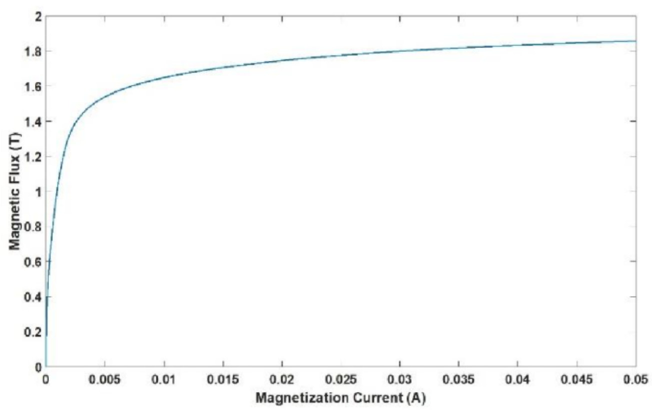


Fig. 2 The P class CT magnetizing curve of the identified parameters

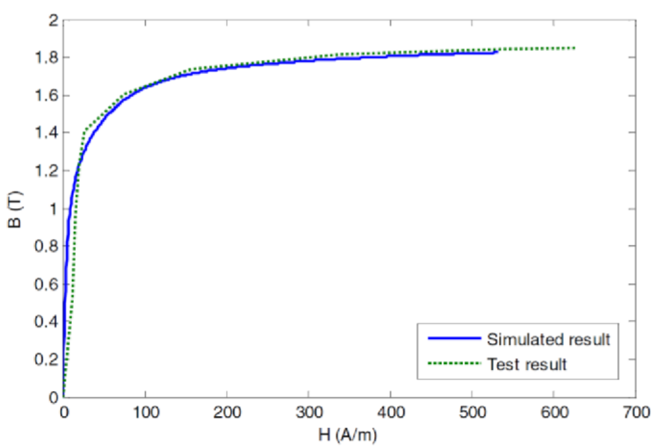


Fig. 2.1 The P class CT magnetizing curve (Paper results [3])

IV. Study of CT Saturation

In this section, we use the modelled CT for studying the impact of fault current and the reclosure of line on CT saturation. This study helps in understanding the importance of the saturation characteristics which are elegantly modelled using Lucas model.

A. System Overview

The AC system shown in Fig. 3 consists of two 230 kV, 60 Hz Thevenin's voltage sources, a 25 MVA load and three 230 kV transmission lines (125 km, 75 km and 75 km). A single phase (Phase A) to ground fault is applied between the first two transmission lines.

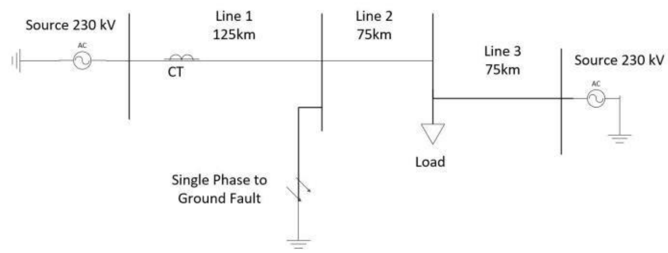


Fig. 3 AC system of study

B. Impact of DC offset in the Primary Fault Current

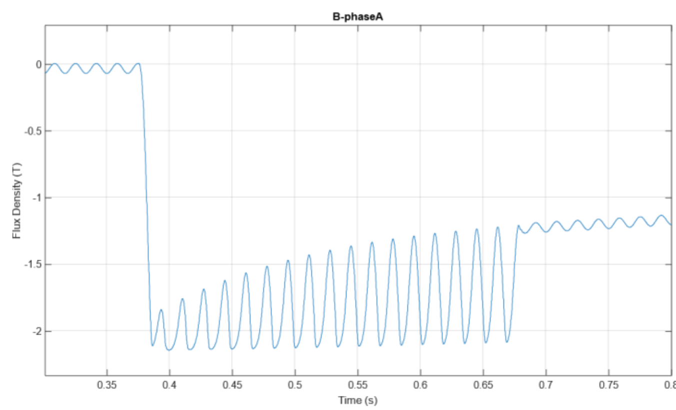
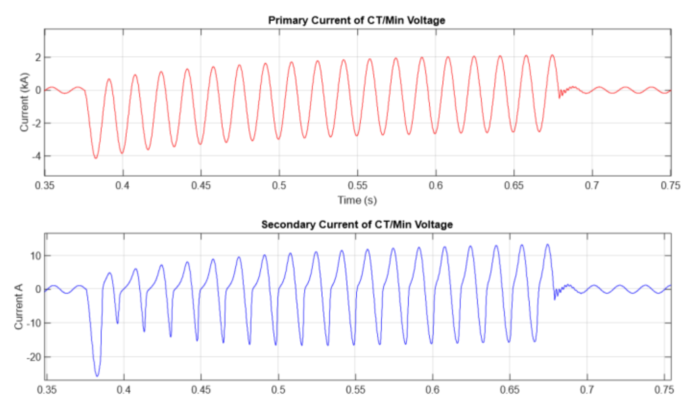


Fig. 4 CT core Flux (Min voltage switching)



From the theory of inrush current, instant of energization/fault determines the level of DC offset, thus maximum peak of the inrush current. In this case, maximum DC offset will occur when the fault is applied at a voltage minimum, at t=0.375s. The CT currents are shown in Fig. 5

Fig. 5 CT primary and secondary currents (Min voltage switching)

The DC offset causes the CT flux to go into saturation. It can be observed that the saturation occurs within a cycle (Fig. 4). This causes the secondary current to reduce as shown in Fig. 5. After the fault is cleared, CT core still has some remnant flux. This effects the CT operation which is studied in next section. Fig. 5.1 shows a similar type of saturation results for a different case used by the authors [3].

Other simulation is run with fault being applied at t= 0.3876, when the voltage is maximum. In this case, there is no DC offset and the CT does not saturate (Fig. 6). Secondary current of CT is a faithful scaled down version of the primary. This can be seen in Fig. 7.

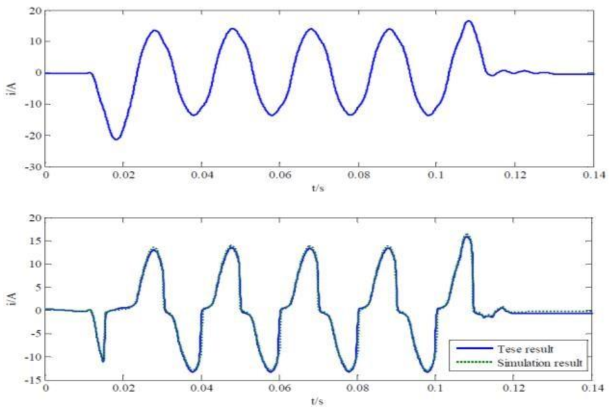


Fig. 5.1 CT primary and secondary currents (Paper results [3])

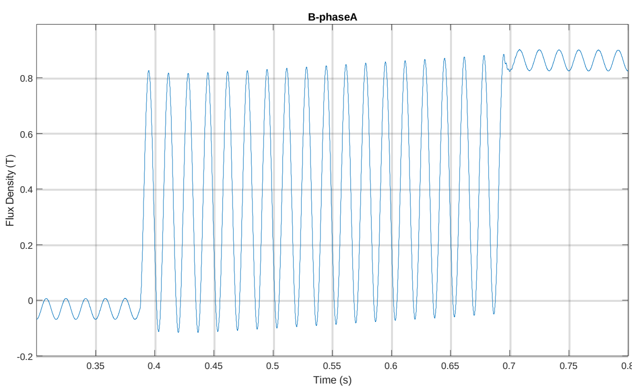


Fig. 6 CT core Flux (Max voltage switching)

C. *Impact of Remanence*

In the previous case, CT core saturated within a cycle. If the line is reclosed when the fault is present, CT may saturate much faster due to the remnant flux in the core. This is shown in Fig. 8. The line is reclosed at t=0.99105s, due to remnant flux in the core due to previous operation, the CT saturates even faster.

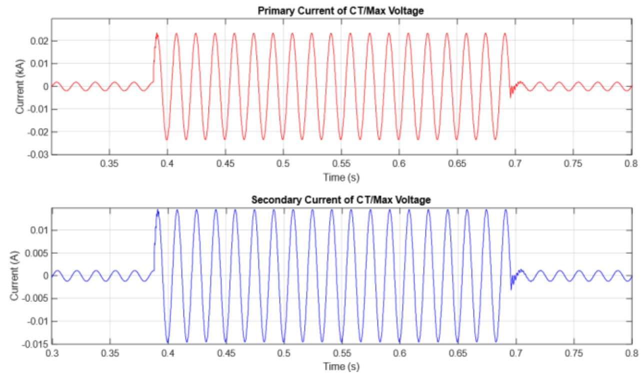


Fig. 7 CT primary and secondary currents (Max voltage switching)

D. *Impact of CT Burden*

Burden is the load connected at the secondary of a CT. When the voltage induced across the CT burden is low, the exciting current is low.

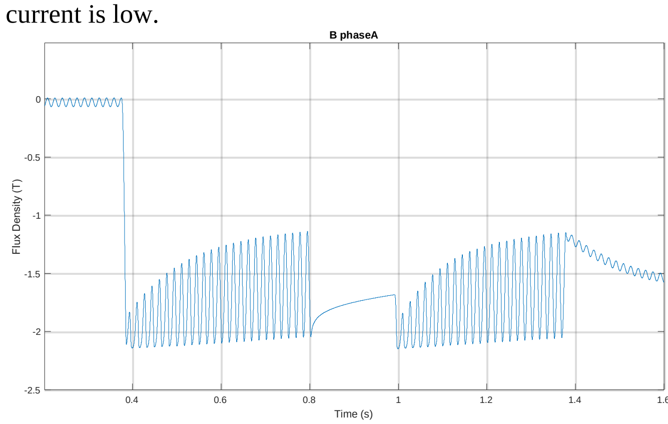


Fig. 8 CT core Flux (Remanence)

The secondary current waveform does not contain considerable distortion. As the either the burden or current increase, the voltage across the CT secondary winding increases so, the flux in the CT core will also increase. Due to the voltage increases, finally the CT core will entering the magnetically saturated region; operation beyond saturation region will cause in a distorted secondary current waveform an increasing the ratio error [6].

In Fig. 9, it can be seen that the CT takes 2 cycles to enter into saturation when the burden on its secondary is 0.5. Also, as shown in Fig. 10, as the burden on the CT increases, the CT secondary current has more distortions due to saturation.

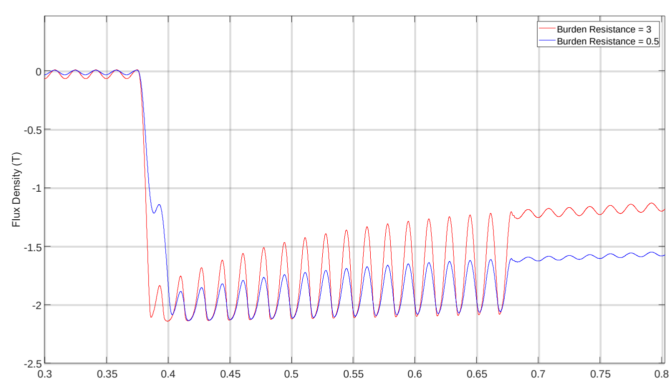


Fig. 9 Effect of CT burden on saturation

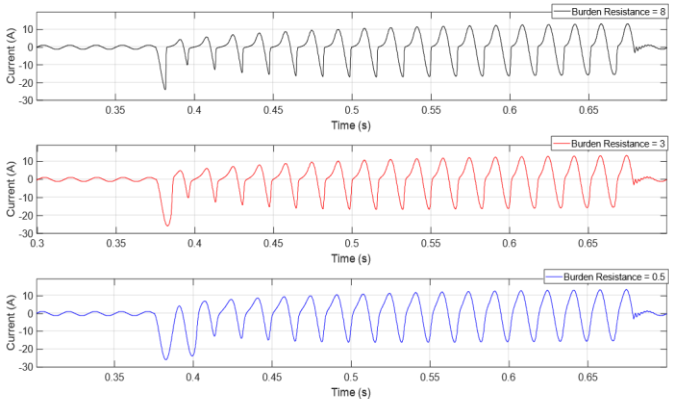


Fig. 10 Secondary current distortion for various CT burdens

V. Conclusion

The study of transient characteristics of CT and its impact in the protection scheme is important. Lucas model techniques and its parameters are studied. A CT model based on Lucas parameters is considered and studied for saturation characteristics and the observations are noted. Effects of Remanance and burden on saturation are studied. This study can be extended with use of relay protection scheme simulations. This will further help the study of CT saturation on system protection.

VI. References

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