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Case study of factor affecting current transformer operation in saturation point of view using MATLAB

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ABSTRACT

Current transformers form an integral part of protective systems. Ideal Current Transformers (CTs) are expected to reproduce the primary current faithfully on the secondary side. Under conditions the CT saturates, and hence it cannot reproduce the primary current faithfully. This paper deals with simulation methods for determining CT performance under different factor. A Simulink model has been developed to observe CT response under steady-state w.r.t Burden, Turns ratio, Asymmetrical current, Hysteresis conditions. Thus, it is now possible to evaluate CT performance under these factors.

Keywords— *DC offset, FFT, Hysteresis, Burden*

1. INTRODUCTION

A "protection" CT must saturate sufficiently high to allow a relatively accurate measurement of the fault current by the protection whose operating threshold can be very high. Current transformers are thus expected to have to withstand high overcurrent.

2. CT EQUIVALENT CIRCUIT

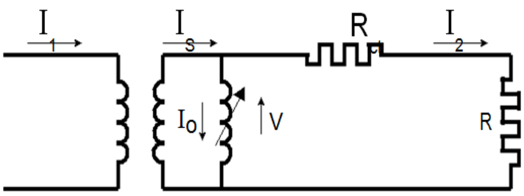


Fig. 1: CT equivalent circuit

Applied to this diagram,
Ohm's law lets us write: $V = I2\ (Rct + R)$, where:
Rct: CT secondary winding resistance
R: load resistance including wiring,

$$\text{v } if\ I2 = kn\ In \text{ and } R = Rn = Pn\ /\ In2\ ,$$

$$Vn = kn\ In\ (Rct + Rn)\ (1)$$

(kn = nominal ALF)

$$\text{v if } I2 = kn\ In\ and\ R = Rp = Pr\ /\ In2\ ,$$

$$Vr = kn\ In\ (Rct + Rp)$$

3. FACTOR AFFECTING CT OPERATION

There are various factors below which are considered during CT operation

3.1 Burden

(a) By varying resistance/burden on the secondary side we get this DC Offset values:

Switch	R or Burden	C.B.	DC offset
1	0.001	1	1.0316E-07
1	0.01	1	2.57E-06
1	0.1	1	0.000196
1	1	1	0.018
1	10	1	0.9951
1	100	1	1.5805
1	1000	1	0.3131
1	0.001	0	0.0263
1	0.01	0	0.1441
1	0.1	0	1.314
1	1	0	15.504
1	10	0	163.307
1	100	0	9.9001
1	1000	0	1.953
0	0.001	1	13.1079
0	0.01	1	13.1079
0	0.1	1	13.1079
0	1	1	13.1079
0	0.001	0	49.9413
0	0.01	0	49.9413
0	0.1	0	49.9413
0	1	0	49.9413
0	10	0	49.9413
0	100	0	49.9413
0	1000	0	49.9413
0	10	1	13.1079
0	100	1	13.1079
0	1000	1	13.1079

(b) BY using FFT analysis tool of Powergui, the analysis of dc offset for various burden and switching position for the given simulation in MATLAB for CT saturation.

Switch	C.B.	Burden	DC						
			Scope 1		Scope 2				
			Current	CT flux	I(pu/25VA)	2nd	4th	5th	
1	1	0.1	0.000149	2.593	0.2191	1010	362.8	271.2	Rated burden at rated current of 5A
0	1	0.1	0.01768	1.26E+05	25.98	868400	2.97E+05	2.17E+05	
1	0	0.1	0.08744	2123	128.5	1021	368.5	275.7	
1	1	1	0.1136	2.35E+04	166.9	8748	2995	2236	
0	1	1	0.1091	7.76E+05	161	8.68E+05	2.97E+05	2.17E+05	
1	0	1	0.08752	2.29E+05	128.6	8865	3054	128.6	
1	1	12	0.1136	2.65E+04	166.9	1.56E+05	1.18E+05	4.19E+05	
0	1	12	0.1095	7.79E+05	161	8.68E+05	2.97E+05	2.17E+05	
1	0	12	0.08751	6.91E+05	128.6	1.31E+05	6.94E+05	1.01E+05	
					h11/h7	8.66E+00	8.26E+00	8.24E+00	
					h15/h11	1.78E+01	3.94E+01	1.87E+02	

3. STUDY OF FACTOR AFFECTING CURRENT TRANSFORMER OPERATION IN SATURATION POINT OF VIEW

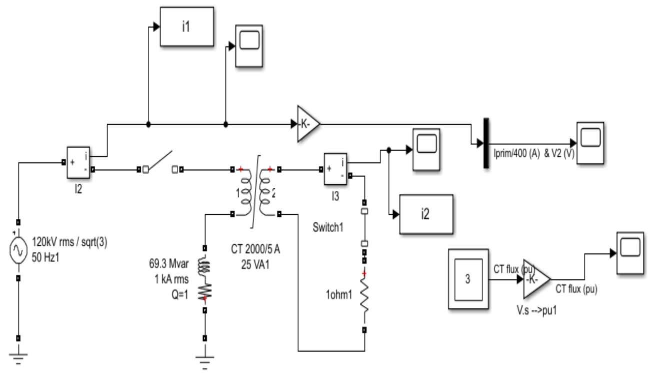


Fig. 1: Current transformer saturation

3.1 Effect of turns ratio

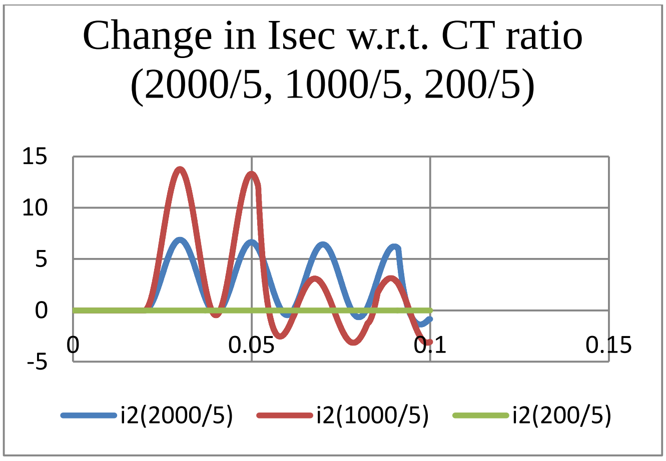


Fig. 2: Change in Isec w.r.t. CT ratio (2000/5, 1000/5, 200/5)

The primary and secondary currents are stated as a ratio such as 200/5. With a 200/5 ratio CT, 200A flowing in the primary winding will outcome in 5A flowing in the secondary winding, delivered the correct rated burden is connected to the secondary winding. Increasing the turn's ratio with the secondary will increase the accuracy and

Burden rating. However, decreasing the turn's ratio with the secondary will degrade the accuracy and burden rating from the simulation outputs illustrated in Fig, It is clear that at 2000:5 turns ratio time to saturation is approximately 0.09S while at 1000:5 turns ratio time to saturation decreases to approximately 0.05mS.

3.2 Effect on Burden

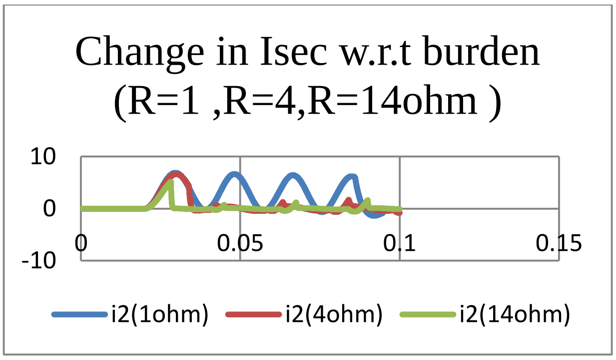


Fig. 3: Change in Isec w.r.t burden(R=1, R=4, R=14ohm)

From the simulation results shown in Figure. It is clear that at 4-ohm burden resistance the time to saturation is approximately 0.04S. While at 14-ohm burden, the time to saturation decreases to approximately 0.022S.

3.3 Effect of Hysteresis

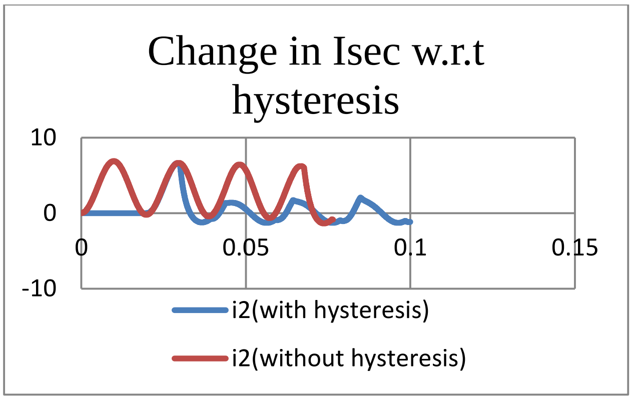


Fig. 4: Change in Isec w.r.t hysteresis

3.4 Effect of Hysteresis for different burden:

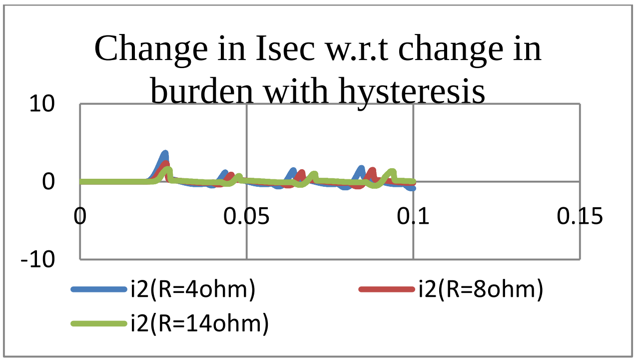


Fig. 5: Change in Isec w.r.t change in burden with hysteresis

From the simulation results shown in Figure, It was found that the Time to saturation for secondary current without hysteresis is approximately 0.07S. However with hysteresis only is approximately 0.03S and for Figure, the time to saturation is approximately 0.02s.

3.5 Effect of asymmetry current

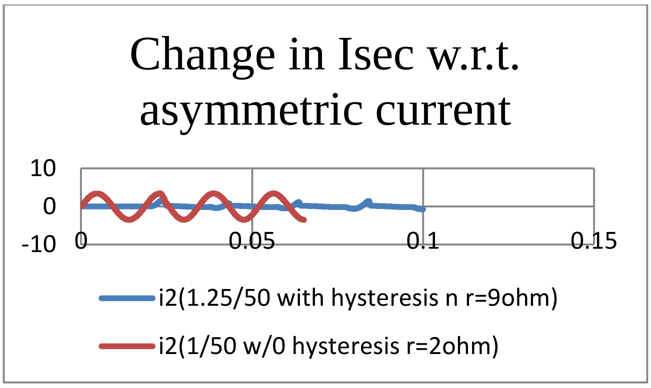


Fig. 6: Change in Isec w.r.t. asymmetric current

The dc component of an asymmetrical current greatly increases the flux in the CT. When the dc offset is at a maximum, the CT flux can potentially increase to 1 + X/R times the flux resulting from the sinusoidal, or non-offset component, where X and R are the primary system reactance and resistance to the point of the fault.

3.6 Symmetrical fault

Maximum allowable fault current for a given burden or maximum allowable burden for given fault current

$$Ifault/Ipri*(ZB+RS)/ZBSTD+RS) \leq 20$$

Ifault=Maximum fault current in primary for a given fault
Ipri=Primary current rating of CT
ZB=Actual burden
RS=Internal resistance of CT secondary
The zbstd=standard burden of CT (8ohm)

As microprocessor-based relay have less burden, ZB is approx. Equal to CT burden mostly.

Example, C800, 2000/5 CT tapped as 1200/5
ZBSTD=800/(20*5)*(1200/2000) =4.8
The resulting C-rating for tap would be 4.8*100=C480

3.7 Unsymmetrical fault

Selecting CT based only on symmetrical fault current is not advised because it ignores the risk of heavy CT saturation when the fault current includes the dc offset.

X/R ratio taken into account in case unsymmetrical fault current.

$$Ifault/Ipri*(ZB+RS)/ZBSTD+RS)*((X/R)+1) \leq 20$$

Ifault=Maximum fault current in primary for a given fault
Ipri=Primary current rating of CT
ZB=Actual burden
RS=Internal resistance of CT secondary
The zbstd=standard burden of CT (8ohm)
Example, C800,2000/5 CT with RS=0.5ohm is connected to 1ohm burden.(X/R=12)

Maximum 3-Ph fault current can be applied to CT without exceeding maximum flux density
Ifault/20*((1+0.5)/(8+0.5))*(12+1)≤20
Ifault≤174.35

4. CASE STUDY

Simulation for c400 CT with the burden of 4ohm and 100VA (2000/5)

CT saturation as per the simplified model gave:

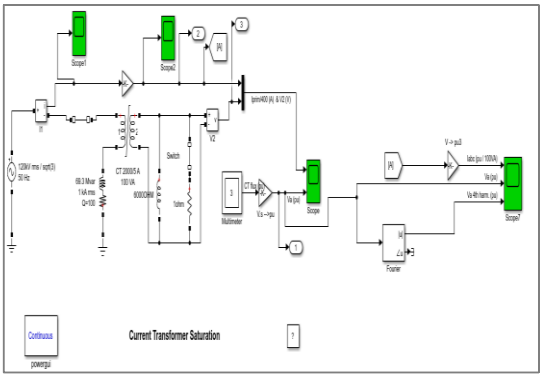
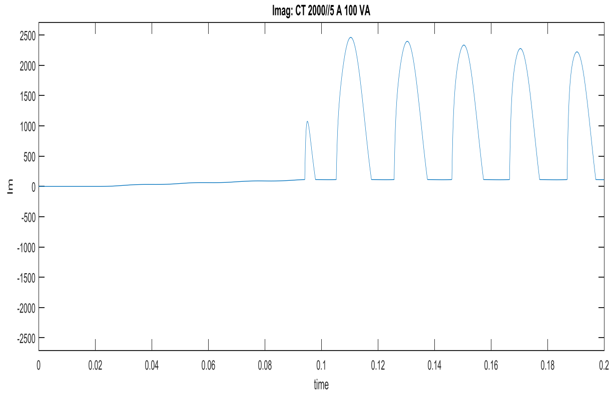
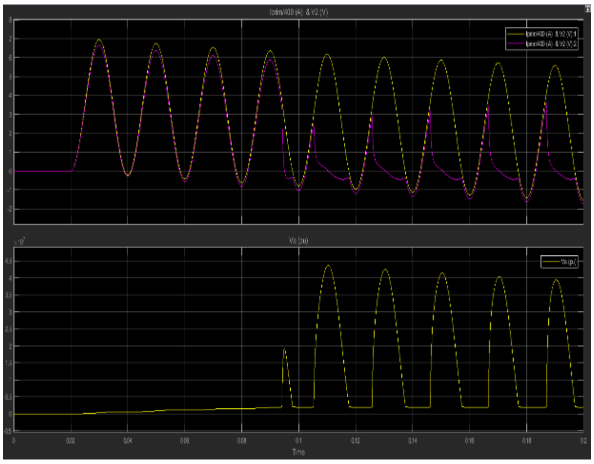
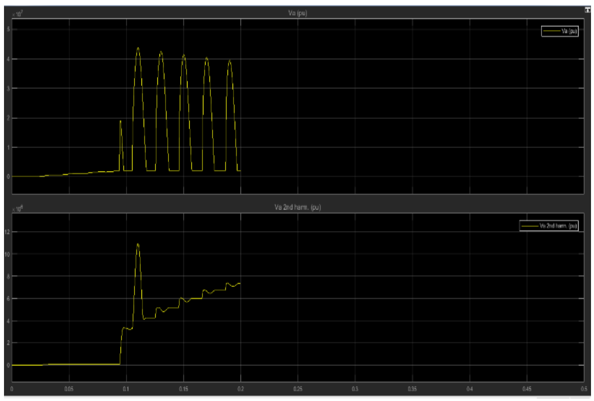


Fig. 7: CT saturation

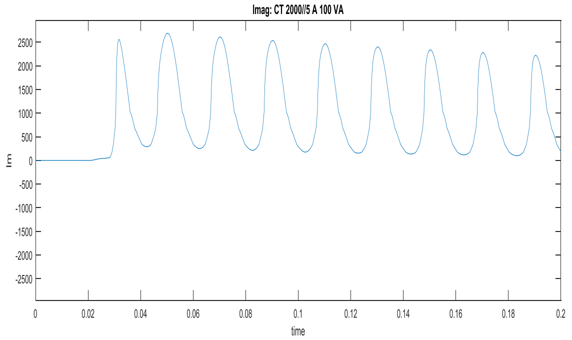
For Normal conditions the current shows following response:

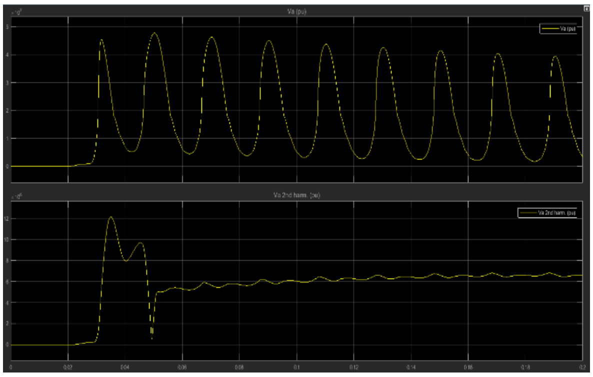






For hysteresis conditions the current shows following response:





For without saturation, the current through the core that is magnetizing current flow is much smaller compared to the magnetizing current considering hysteresis. For without saturation, the 2nd harmonic current is existing for lesser time compare to considering hysteresis.

5. CONCLUSION

- By investigating the effect of flux on the CT, where it was found that the increase of flux above a certain limit leads to saturation.
- When the remnant flux is extremely high, the core will reach the saturation almost immediately, especial when the burden is high.
- CTs that have the lowest ratio, they are the fastest to saturation.
- The maximum DC component of a fault occurs when the instantaneous voltage is zero, which is making the primary current unsymmetrical and then results in shorter CTs saturation.
- The maximum DC component of a fault occurs when the instantaneous voltage is zero. Then the dc component starts decaying according to the time constant of the primary power system. The larger time constant will result in the longer decaying process, and then longer CT saturation period.
- The CTs have the lowest burden and Rct show the best performance and they have large time to saturation.
- 2nd harmonic component measurement will give us the condition of CT saturation, by using FFT analysis

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