

Analysis, Modelling and Simulation of Current Transformer

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ABSTRACT: The aim of the paper is to study and analyse the current transformer and simulate it for various burdens. Current transformer is simulated in Ltspice software. Simulation of current transformer helps in analysing the transformer behaviour for various burdens. Current transformer converts high currents in the primary side into low current in the secondary side. It has applications in current measurement, current monitoring and protection etc. Simulating the current transformer in software helps in learning the behaviour of the transformer for different burdens.

KEYWORDS: Current transformer, Burden, CT principle, Core saturation, Equivalent circuit.

I. INTRODUCTION

Current transformer is a static device which transfers power from one circuit to the other circuit based on electromagnetic induction. It consists of two windings (primary and secondary) wound on a core. Current transformer basically converts high input current in primary winding into low current in secondary winding.

II. CURRENT TRANSFORMER

Current transformer works on the principle of electromagnetic induction. Electromagnetic induction principle states that an alternating magnetic flux induces a voltage across a closed loop [4]. Magnetic flux is the amount of magnetic field passing through a transformer core.

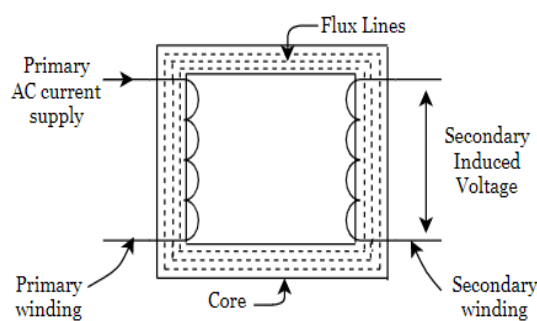


Fig. 1. Basic current transformer

When alternating current flows in the primary winding of a current transformer, it generates an alternating magnetic field (H), which corresponds to an alternating magnetic flux (ϕ), around the core. The secondary winding is connected to a burden. The alternating magnetic flux in the core induces an alternating voltage (Vs) across the secondary and corresponding alternating current (Is) flows in the secondary winding. The alternating current in the secondary creates its own alternating magnetic field and alternating magnetic flux that oppose those created by the primary winding, leaving a negligible amount of net flux in the core.

Ferromagnetic material is used for transformer core. Core is made up of a fixed number of magnetic dipoles (magnets) [3]. Ideally, these dipoles are randomly arranged in polarity throughout the core. When alternating current flows in the

primary winding and generates the magnetic field, the strength of the magnetic field affects the dipoles in the core and causes them to line up in the direction as the magnetic field. This produces the magnetic flux (ϕ). More dipoles are lined up as the primary current is increased. When all the dipoles are aligned in the same direction, the maximum magnetic flux density (B) of the core is attained. At this point when no further dipoles alignment is possible the core is said to be saturated [1]. The relationship between the H and B is given by the B - H curve of the core. Different types of core materials have different B - H curves depending on material properties.

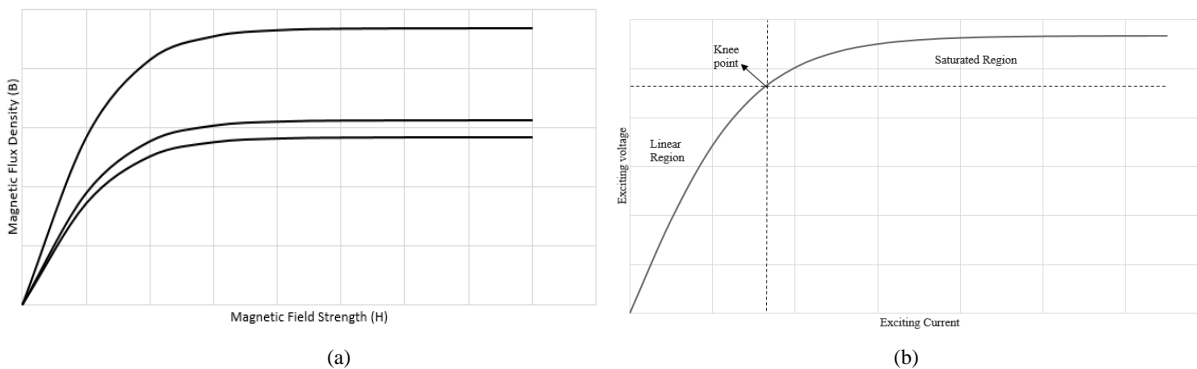


Fig. 2. (a) B-H curve for different materials (b) Excitation curve

The change in flux is caused by the dipoles changing direction. This induces voltage across the secondary winding. Voltage in turn generates current through the secondary winding. When the core reaches maximum flux density, it is fully saturated and there are no more dipoles(magnets) remaining to change direction. This causes voltage to drop to zero, and current ceases to flow.

The current transformers are designed to operate at over the linear part of the BH curve. Under steady state operation the difference between primary and secondary currents can be calculated by the turns-ratio neglecting the magnetizing current.

Under steady state, Current transformer operates in linear or saturation region depending upon the level of excitation applied to the core. The core starts to saturate after the knee point. The various reasons for saturation of current transformer are high primary current, high secondary burden, low turns ratio, small cross-sectional area of core, DC offset.

Current transformer is a static device and hence only electrical losses in the transformer are to be considered. Electrical losses mainly include core losses and copper loss. Copper losses occur in the primary and secondary windings of the transformer when heat is dissipated due to internal resistance offered by the windings when the current passes through the windings. Core losses are caused by the alternating flux in the core. It is further divided into hysteresis loss and eddy current loss. Core losses are fixed and are independent of the load while copper losses vary with the current.

III. EQUIVALENT CIRCUIT

A current transformer can be represented by an equivalent circuit diagram as shown in figure. Resistive burden is considered as it relates to most of the applications. For ideal current transformer, primary is reproduced in the secondary in exact ratio. Magnetic field created by primary current is used by current transformer to induce current in the secondary winding.

Consider simplified equivalent circuit neglecting the leakage losses. The magnetizing current is part of primary current that satisfies the eddy loss and hysteresis losses. Magnetizing inductance and burden are in parallel and hence current divides between them. The magnetizing inductance depends on core parameters.

Primary ampere-turn (N_p) equals Secondary ampere-turn (N_s) The equivalent circuit consists of primary winding resistance (R_p), primary winding leakage inductance (X_p), core resistance (R_c), magnetizing reactance (X_m), secondary winding resistance (R_s), secondary winding leakage inductance (X_s). Besides the loss components (i.e. R_c and X_m), there are distributed capacitances (very small) in the windings but they are usually neglected for low frequencies (below several tens of kilohertz). The total secondary current (I_s) is the sum of magnetizing current, core loss current and the load current.

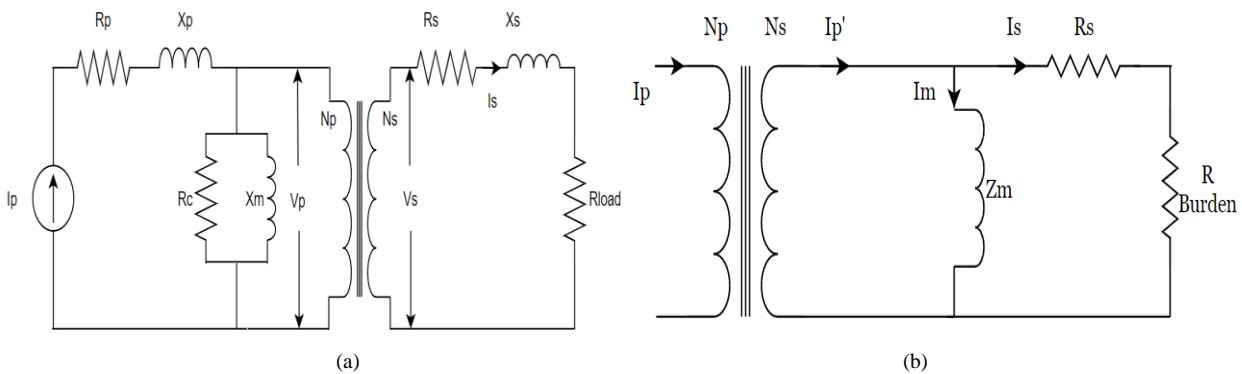


Fig.3. (a) Equivalent circuit of current transformer (b)Simplified equivalent circuit

Output voltage is determined primarily by load resistance. The current transformer should never be operated with secondary open circuited. If secondary is open circuited, then all the input current will be supplied as magnetizing and core loss current resulting in very high flux density further leading to high secondary voltage.

IV. THEORETICAL ANALYSIS

Current Transformer has a definite capability to produce a secondary voltage(V_s) depending on the core material, frequency(f), core cross section area and the number of secondary turns. The only way of changing the saturation level for a current transformer, with a specific core material, is to change the core area or the number of secondary turns. Alternating flux(ϕ) developed by primary winding in linked to secondary winding through core. Alternating flux produces electromotive force (emf) which can be given by Faradays laws of electromagnetic induction.

$$V = -N (d\phi/dt)$$

$$V_p = -N_p (d\phi/dt)$$

Solving above equation, maximum induced emf can be obtained as

$$V_p(max) = N_p \omega \phi_{max}$$

ω is angular frequency in radians per second.

$$\omega = 2\pi f$$

$$V_p(max) = 2\pi f N_p \phi_{max}$$

RMS value is given as, $V_p = V_p(max) / \sqrt{2}$

$$V_p = \sqrt{2} \pi f N_p \phi_{max}$$

$$V_p = 4.44 f N_p \phi_{max}$$

Similarly, $V_s = 4.44 f N_s \phi_{max}$

Taking ratio of the above equations, $(V_p / V_s) = (N_p / N_s)$

If efficiency of transformer is 100%, input power equals output power that is, primary side power equals secondary side power, $V_p I_p \cos\phi_p = V_s I_s \cos\phi_s$

Where, $\cos\phi_p$ = power factor of primary side and $\cos\phi_s$ = power factor of secondary side

Practically, $\cos\phi_p = \cos\phi_s$

$$(V_p / V_s) = (I_s / I_p) = (N_p / N_s)$$

V. SIMULATION AND RESULTS

Ltspice software is used to simulate the current transformer model based on the equivalent circuit. Ltspice is free and high performance circuit simulation software. Current transformer is modelled using a non-linear inductor which represents nonlinearity of core. Non-linear inductance is function of number of turns, flux developed in core and current. The coupling coefficient is assumed to be 0.8. current transformer is simulated for various burdens(R_b) to view the saturation effect.

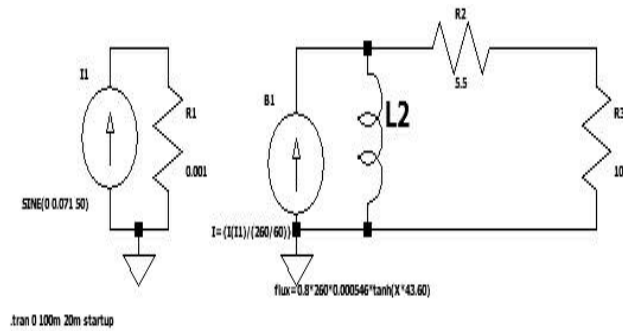


Fig. 4. Simplified equivalent circuit

Simulated Current transformer has following specification: Turn ratio= 60:260, Burden=100 ohms, 1000 ohms ,2000 ohms, primary current was varied from 0.02 to 0.2 amperes.

Current transformer was given input current from 0.02 amperes to 0.2 amperes for various resistive burdens 100 ohms, 1000 ohms and 2000 ohms. Voltage across burden, current through burden and magnetizing current was noted.

Ip (mA)	Rb =100 ohms			Rb =1000 ohms			Rb=2000 ohms		
	Im(mA)	Vb(V)	Ib(mA)	Im(mA)	Vb(V)	Ib(mA)	Im(mA)	Vb(V)	Ib(mA)
0	0	0	0	0	0	0	0	0	0
20	0.3	0.45	4.5	2.5	3.83	3.8	3.6	5.53	2.8
30	0.5	0.67	6.7	3.8	5.73	5.7	5.5	8.21	4.1
40	0.7	0.91	9.1	5.1	7.75	7.7	7.5	10.9	5.5
50	0.9	1.14	11.4	6.5	9.66	9.6	9.5	13.4	6.7
60	1.1	1.36	13.6	7.8	11.44	11.4	11.4	15.6	7.8
70	1.2	1.59	15.9	9.3	13.31	13.2	13.5	17.7	8.9
80	1.4	1.81	18.1	10.7	15.06	15.0	15.6	19.6	9.8
90	1.6	2.04	20.4	12.3	16.66	16.7	17.7	21.3	10.7
100	1.8	2.26	22.6	14.0	18.26	18.3	19.9	22.8	11.4
110	1.9	2.50	25.0	15.9	19.97	19.9	22.3	24.2	12.1
120	2.1	2.72	27.2	17.8	21.25	21.2	24.5	25.4	12.7
130	2.3	2.95	29.5	19.9	22.61	22.5	26.7	26.5	13.2
140	2.5	3.17	31.7	22.0	23.60	23.6	29.0	27.5	13.8
150	2.7	3.40	34.0	24.3	24.72	24.6	31.3	28.4	14.2
160	2.8	3.62	36.2	26.6	25.47	25.5	33.5	29.3	14.7
170	3.0	3.85	38.5	29.0	26.43	26.3	35.8	30.1	15.1
180	3.2	4.31	43.1	31.5	27.09	27.1	38.2	30.9	15.5
190	3.4	4.55	45.5	33.9	27.95	27.8	40.5	31.7	15.9
200	3.6	4.79	47.9	36.3	28.45	28.5	42.8	32.5	16.2

VI. OBSERVATIONS

It was observed that with 100 ohms burden the output of the current transformer was clean and sinusoidal for entire input current range. With 1000 ohms as burden the same current transformer starts to saturate at input current of 0.1 amperes producing output voltage of 18.25 volts. With 200 ohms as burden current transformer starts to saturate at input current of 0.07 amperes producing output voltage of 17.77 volts.

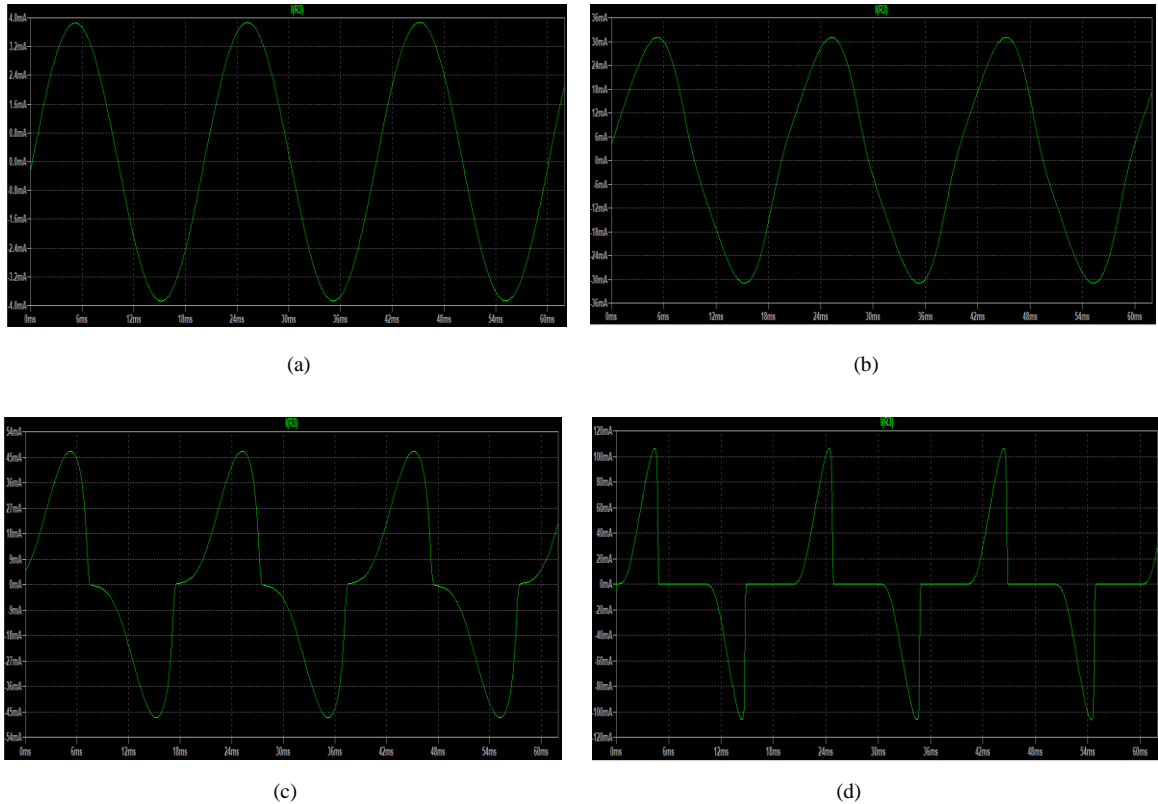


Fig. 5. (a)No saturation (b)Light saturation (c)Medium saturation (d)Heavy saturation

VII. CONCLUSION

Current transformer was simulated and analysed. As the burden on the Current transformer is increased saturation occurs earlier and waveform distortions are clearly visible. For 100ohms burden core saturation was not observed for entire input current range. After increasing the burden to 1000 ohms and 2000 ohms the same current transformer started saturation at 0.1 amperes and 0.07 amperes respectively.

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