Current Transformer Performance with Difference Total Harmonic Distortion and Secondary Burden

M.N.K.Anuar ,N.Indra, D.Ismail , A.M.Hafiz
Electrical Energy and Industrial Electronic Systems Cluster. School of Electrical Systems Engineering, Universiti Malaysia Perlis (UniMaP)
pucheh07@yahoo.com

Abstract

The used of non-linear loads in industrial system has increased accordance to the present technology. However, non-linear loads are the main problem that supplies harmonic distortions into the distribution system. This paper investigates the current transformer performance when supplied with difference percentage of total harmonic distortion and used difference burden. The current transformer with ratio 7.5/1A and 15/1A were used with 0.5 ohm, 10 ohm and 25 ohm secondary burden.

1. Introduction

The current transformer will be affect when receive harmonic distortion from the loads. These harmonics are generated when non-linear equipment draws current in short pulses. The harmonic distortion can sometimes result overheated transformers, phase angle error, ratio error and increase transformer losses [1]. Effects of these harmonic call for transformer derating or upgrading with a larger and more economical unit [2]. Recommendations for the matching of a given load with the right transformer, or for computation of the needed derating at a given load, are provided in ANSI/IEEE C57.110/D7, 1998 [3].

2. Harmonic Characteristics

Harmonics are generated by non-linear laods that can be a saturable reactance, a rectifier, or a set of mechanical switches that open and close periodically. On account of the nonlinearity, the current will not be sinusoidal. It will contain a fundamental component I_F and harmonics I_h [4]. The fundamental component is produced by the sinusoidal voltage, E, but the harmonic components are generated by the load.Total harmonic distortion (THD) is an important index widely used to describe power quality issues in transmission and distribution systems. THD considers the contribution of every individual harmonic component on the signal. THD is defined for voltage and current signals as follow:

$$THD_v = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \tag{1}$$

$$THD_i = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \tag{2}$$

This means that the ratio between rms values of signals including harmonics and signals considering only the fundamental frequency define the total harmonic distortion [5].

3. Linear and Non-Linear Loads

Linear loads such as resistance, bulb and others are the load that not generate harmonic, while the non-linear loads are produce harmonic current. It can be a saturable reactance, a rectifier, or a set of mechanical switches that open and close periodically.

The fundamental component is produced by the sinusoidal voltage, E, but the harmonic components are generated by the load. The most common loads of this type are those based on rectifier circuits. A typical non-linear load, such as that shown in Figure 1, draws a current containing all harmonic orders, both odd and even. In addition, the appearance of the current drawn, which has two different half-waves, and its harmonic spectrum are shown in Figure 2 and Figure 3.

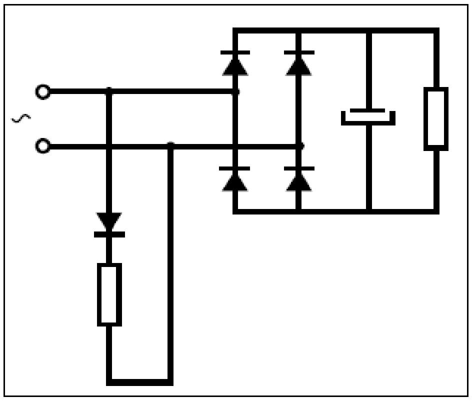

Figure 1: typical non-linear load

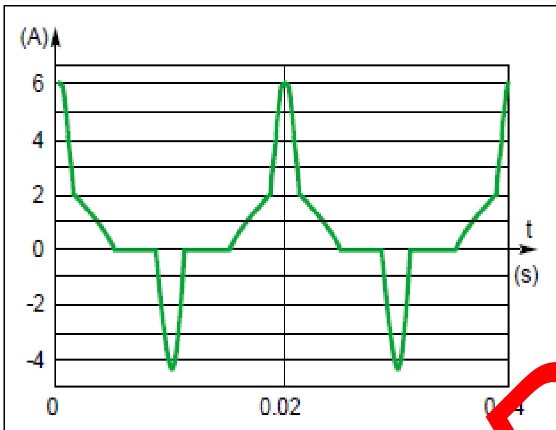

Figure 2: Current Harmonic Waveform

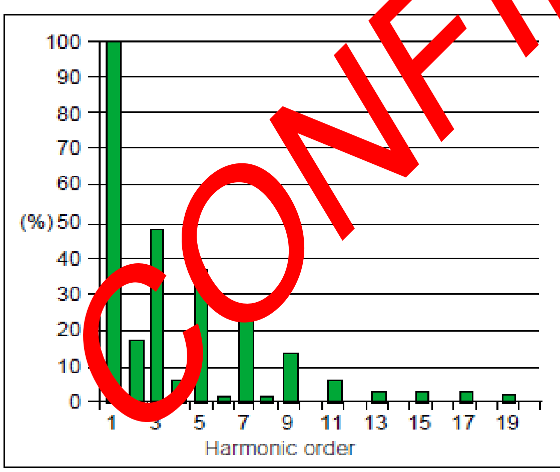

Figure 3: Harmonic Current Spectrum

4. Symmetrical Non-Linear Loads

Majority of the loads connected to the network are symmetrical as current half-waves are equal and opposing. This can be expressed mathematically by the equation:

$$f(\omega t + \pi) = -f(\omega t) \quad (3)$$

In this case, the even order harmonics are zero. Assuming that the current includes a second order harmonic, it is possible to write for example:

$$I(\omega t) = I_1 \sin \omega t + I_2 \sin 2\omega t \quad (4)$$

This gives:

$$I(\omega t + \pi) = I_1 \sin(\omega t + \pi) + I_2 \sin 2(\omega t + \pi) \quad (5)$$

$$I(\omega t + \pi) = -I_1 \sin \omega t + I_2 \sin 2\omega t \quad (6)$$

This can be only being equal to $-I(\omega t)$ if I_2 (magnitude of the second harmonic) is zero. This reasoning can be extended to all even order harmonics.

5. Current Transformer Characterization

From [6], CT performance under non-sinusoidal conditions may depend on the following variables and parameters, phase angle, minor hysteresis loops shape, ratio and air-gap.

Current transformers are instrument transformers that are used to supply a reduced value of current to meters, protective relays, and other instruments. Current transformer provide isolation from the high voltage primary, permit grounding of the secondary for safety, and step down the magnitude of the measured current to a value that can be safely handled by the instrument.

Operation of the current transformer is based on Ampere's law, $N_p i_p = N_s i_s$, where N_p, N_s are the primary and secondary number of turns and i_p, i_s are the primary and secondary currents. The secondary terminals supply an equivalent load, called burden, with the impedance $Z_b = R_B + j\omega L_B$. The current transformer equivalent circuit observed from the secondary side for sinusoidal conditions as shown in Figure 4.

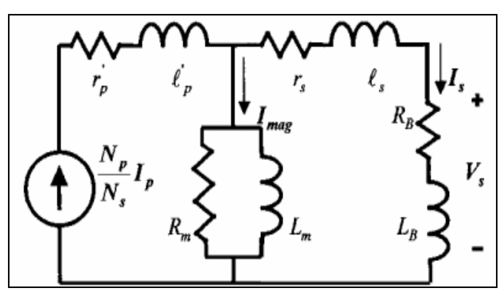

Figure 4: Current transformer equivalent circuit

The primary current phasor I_p is transferred to the secondary side as $(N_p/N_s)I_p$. The secondary winding resistance r_s and leakage inductance ℓ_s increase the effective burden. The magnetization branch consists of the magnetizing inductance L_m in parallel with the resistance, $R_m = V_s^2 / \Delta P_{Fe}$, where ΔP_{Fe} are the magnetic core hysteresis and eddy current losses. The equivalent circuit phasor diagram is shown in Figure 5.

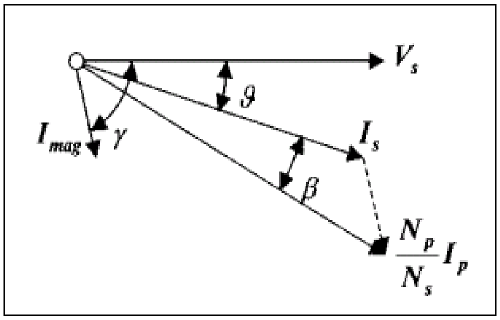

Figure 5 : Phasor Diagram

The secondary voltage phasor present as:

$$V_s = (R_B + j\omega L_B) I_s \qquad (7)$$

While, the magnetizing current phasor I_{mag} lags behind V_s with the angle γ. Kirchhoff's current law gives

$$\frac{N_p}{N_s} = I_s + I_{mag} \qquad (8)$$

6. Current Transformer Saturation

Current transformer saturation can have a negative impact on the ability of the transformer protection to operate for internal faults (dependability) and not to operate for external faults (security) [7].

Harmonic can effects and cause the current transformer goes to saturate. The higher total harmonic distortion (THD) will cause the current transformer saturate earlier.

The knee or effective point of saturation is defined by the ANSI/IEEE standard as the intersection of the curve with a 45° tangent line. However, the International Electrotechnical Commission (IEC) defines the knee as the intersection of straight lines extended from the nonsaturated and saturated parts of the exciting curve. The IEC knee is at a higher voltage than the ANSI knee, as shown in Figure 7. Point A is the ANSI knee and B is the IEC knee [8].

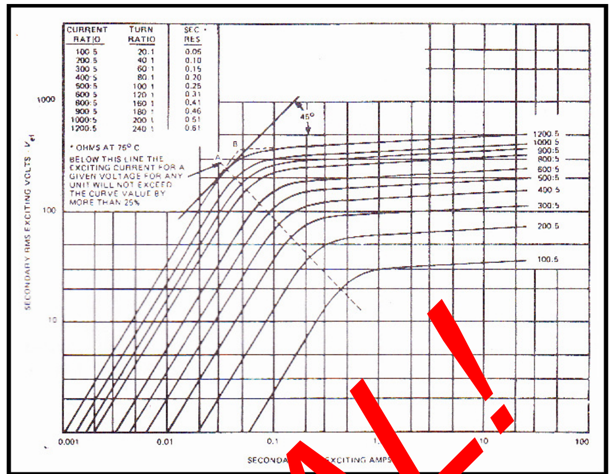

Figure 7: Saturation knee point

The secondary burden brings impact on CT saturation. As the burden was increased, the waveform distortion was more visible. This prove that even relative small burden can influence CT accuracy if the fault current is not correctly anticipated [9]. This can be seen in Figure 8.

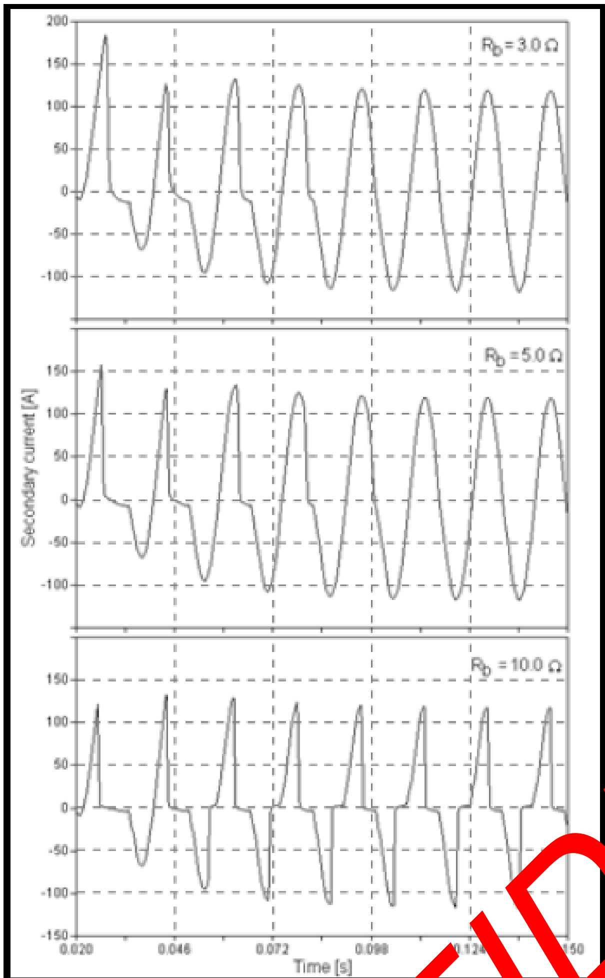

Figure 8: Distortion on secondary current dependent on CT burden

7. Testing Methodology

An experiment as shown in Figure 9 was set up to see the reaction of current transformer with the loads. Both linear and non-linear loads were used to control the value of primary current and percentage of THD. Power Meter Analyzer (PM6000) used to measure primary and secondary current, THD value and current harmonic from fundamental until 21st harmonic. The TNB source was supplied to primary side of current transformer. The linear and non-linear loads were connected in primary side while burden was connected in the secondary side.

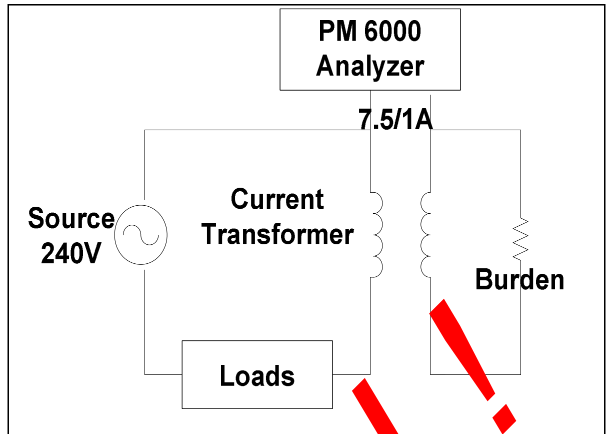

Figure 9: Experiment layout

Details of the current transformer that was used are:

Brand: SES | Ratio: 7.5/1A
Acc.Class: 3 | Rated Burden: 5VA
Frequency: 50/60Hz | Voltage: 0.72/3.0kV
Material using: Grade | Silicon steel: CRGO
Enameled copper wire: EIW | PVC Tape: Non adhesive
Bobbin: Nylon 6

Different burdens were used in this experiment. The burdens that were used are resistors bank of 25 ohm, 10 ohm and 0.5 ohm. These can be seen in Figure 10. This test also used current transformers in differences terms of ratio and class.

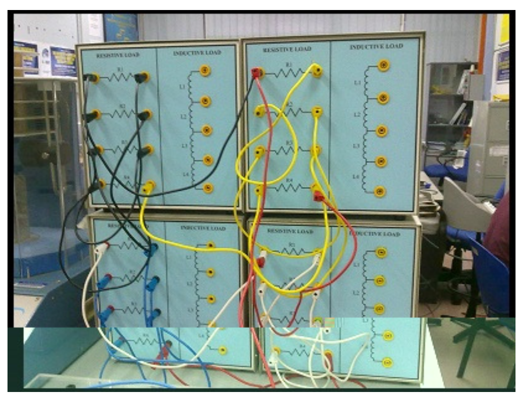

Figure 10: burden

The 7.5/1A Class 3 current transformer was tested with 25Ohm burden in the first part. Then, the data for difference percentage of current THD was collected. The same step was done for CT 15/1A Class 3 and Class 1 for burden 10 Ohm and 0.5 Ohm.

8. Results

From the experiment, the current transformer with ratio 7.5/1A and burden 25Ohm start to saturate when primary current reach to 7.5Amp. These can be seen in Figure 11.

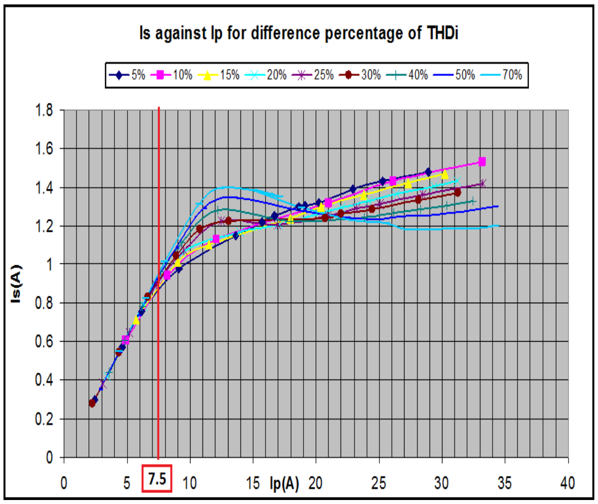

Figure 11: CT 7.5/1A Class 3 with burden 25Ohm

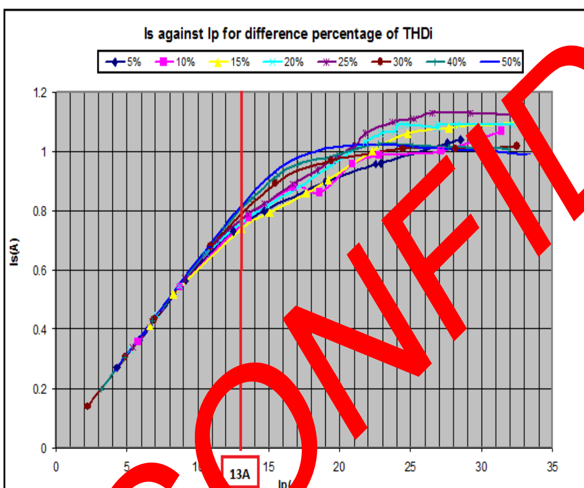

Figure 12: CT 15/1A Class 3 with burden 25Ohm

However, the current transformer goes to saturate with more high current when the CT change to 15/1A ratio. This is shown in Figure 12. The current transformer operates well until the primary current increase to 13 Amp that indicate the point moving to saturation.

Then, the same CT was used (CT 15/1A Class 3) but with difference burden that were 25 Ohm, 10 Ohm and 0.5 Ohm. For burden 25 Ohm, the result is same as in Figure 12, while for burden 10 Ohm, the result shown in Figure 13. From the graph burden 25 Ohm and 10 Ohm, there shown that the curve clearly goes to saturate with higher burden. This proves that secondary burden brings impact on CT saturation. In addition, Figure 14 show the CT performance with the lowest burden (0.5 Ohm) and it get a straight line that stated CT does not goes to saturate with the lowest burden.

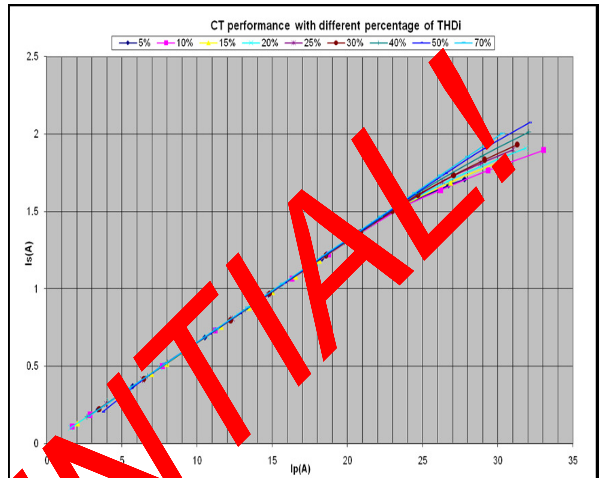

Figure 13: CT 15/1A Class 3 with burden 10 Ohm

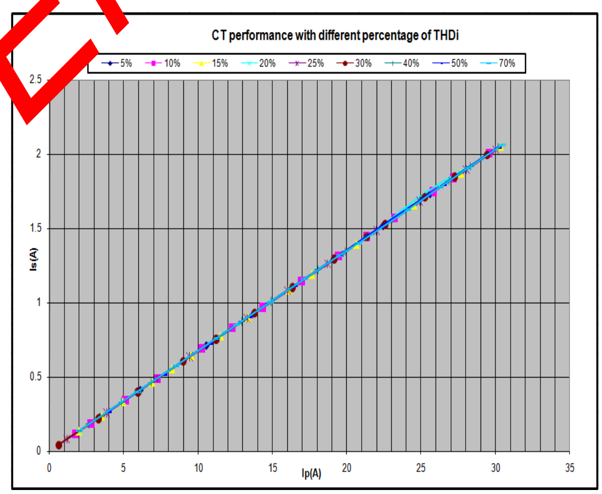

Figure 14: CT 15/1A Class 3 with burden 0.5 Ohm

9. Conclusion

The current transformer behavior with total harmonic distortion was tested. The current transformer also tested with difference secondary burden values. The experimental results show that the CT with lower ratio will goes to saturate early with lower primary current compared to CT with high ratio. The secondary burden of the CT also brings effect to the CT saturation value. The distortion and saturation was more visible when the secondary burden was increased. According to this study, the factors that cause the CT saturation can be known. Finally the study in this field is contributed to enhance current transformer performance in power quality system.

10. References

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