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Different total harmonic distortion effects on current transformer performance

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ABSTRACT

The used of non-linear loads devices such as rectifiers, converters or power supplies 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. Current Transformer is one of protective equipment which will effects when harmonic exist in power system. Total harmonic distortion also can cause the current transformer saturation. This research work investigates the current transformer performance when supplied with difference percentage of total harmonic distortion. Percentage ratio error of current transformer is measured to obtain the accuracy and efficiency of the current transformer. Power Systems Computer Aided Design (PSCAD) software used to construct, model and simulate the current transformer circuit with total harmonic distortion. The laboratory test with same parameters as simulation software is done to prove the theory state. The current transformer with ratio 15/1A and secondary burden was selected in this research.

Keywords - *Current transformer, Total harmonic distortion, Non-linear loads, saturation, PSCAD.*

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].

CURRENT TRANSFORMER CHARACTERISTIC

Current Transformer 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 1 [4].

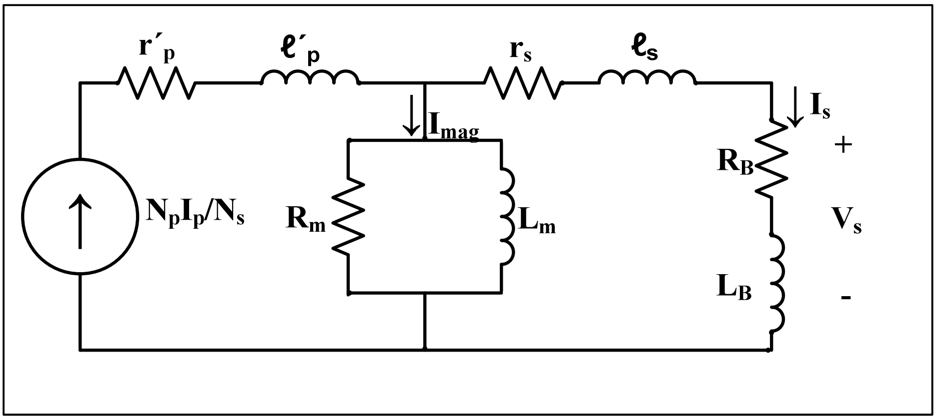

Figure 1: Current transformer equivalent circuit

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 2.

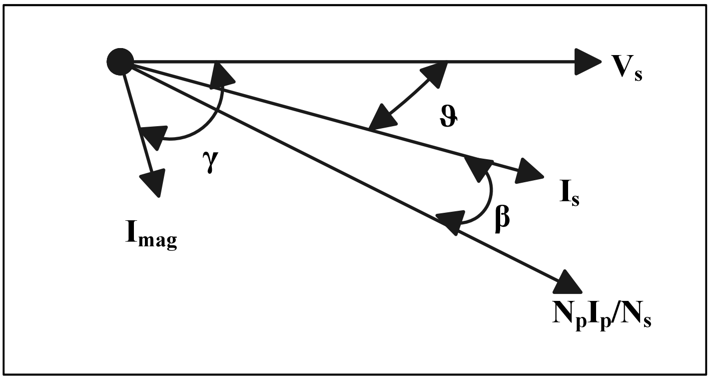

Figure 2: Phasor Diagram

The secondary voltage phasor present as:

$$V_s = (R_B + j\omega L_B)I_s \tag{1}$$

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

$$\frac{N_p}{N_s} = I_s + I_{mag} \tag{2}$$

HARMONIC CHARACTERISTIC

Harmonic are generated by non-linear loads 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 [5]. 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:

$$THD_v = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \tag{3}$$

$$THD_i = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \tag{4}$$

This means that the ratio between rms values of signals including harmonics and signals considering only the fundamental frequency define the total harmonic distortion [6].

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 3, 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 4 and Figure 5.

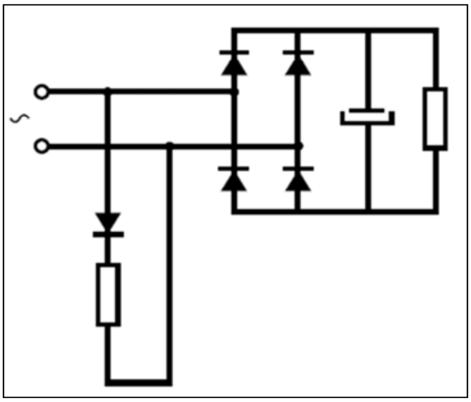

Figure 3: Typical non-linear loads

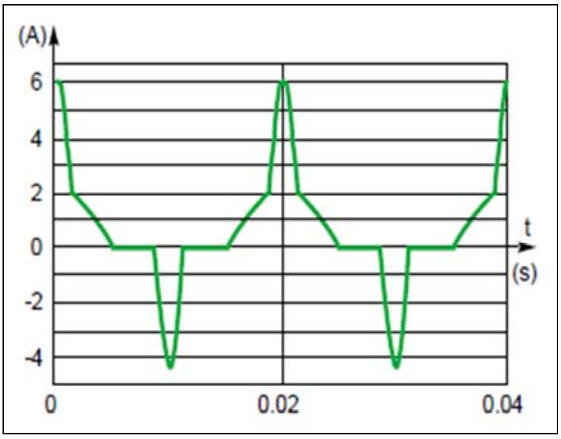

Figure 4: Appearance of the current drawn

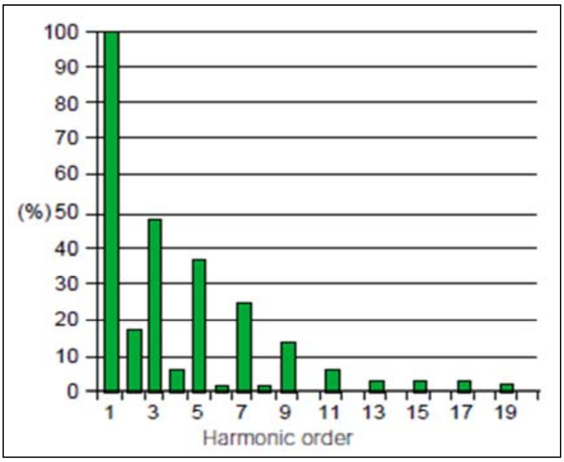

Figure 5: Spectrum of the current drawn

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:

$$f(\omega t+\pi)=-f(\omega t) \tag{5}$$

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:

$$I(\omega t)=I_1 \sin \omega t+I_2 \sin 2\omega t \tag{6}$$

This gives:

$$I(\omega t+\pi)=I_1 \sin(\omega t+\pi)+I_2 \sin 2(\omega t+\pi) \tag{7}$$

$$I(\omega t+\pi)=-I_1 \sin \omega t+I_2 \sin 2\omega t \tag{8}$$

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.

EFFECTS OF HARMONIC ON CURRENT TRANSFORMER

Harmonic brings effect to the current transformer in terms of ratio error, phase angle error and also can cause the current transformer saturate. Current transformer will goes to saturate early with high total harmonic distortion (THD) compare to low THD. Current transformer saturation could 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) [8].

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 [9]. The IEC knee is at a higher voltage than the ANSI knee, as shown in Figure 6. Point A is the ANSI knee and B is the IEC knee [10].

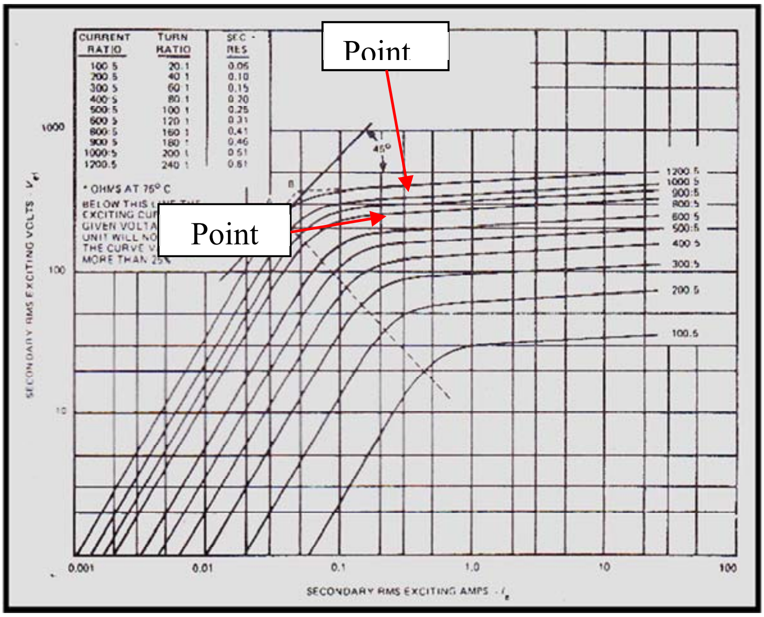

Figure 6: Saturation knee point

TESTING METHODOLOGY

The PSCAD software used to constructed circuit in Figure 7. Single phase 2 winding transformers used as current transformer because same concept is applied. The base operation frequency of the transformer is 50 Hz and the ratio is 15/1A. Only odd harmonic has been injected to the system and the frequency values are based on this formula

$$f_h = (h) \times (fundamental\ frequency) \tag{9}$$

Where h is an integer.

Harmonics that was injected to this circuit were
Fundamental harmonic = 50 Hz
Third harmonic = 150 Hz
Fifth harmonic = 250 Hz
Seventh harmonic = 350 Hz

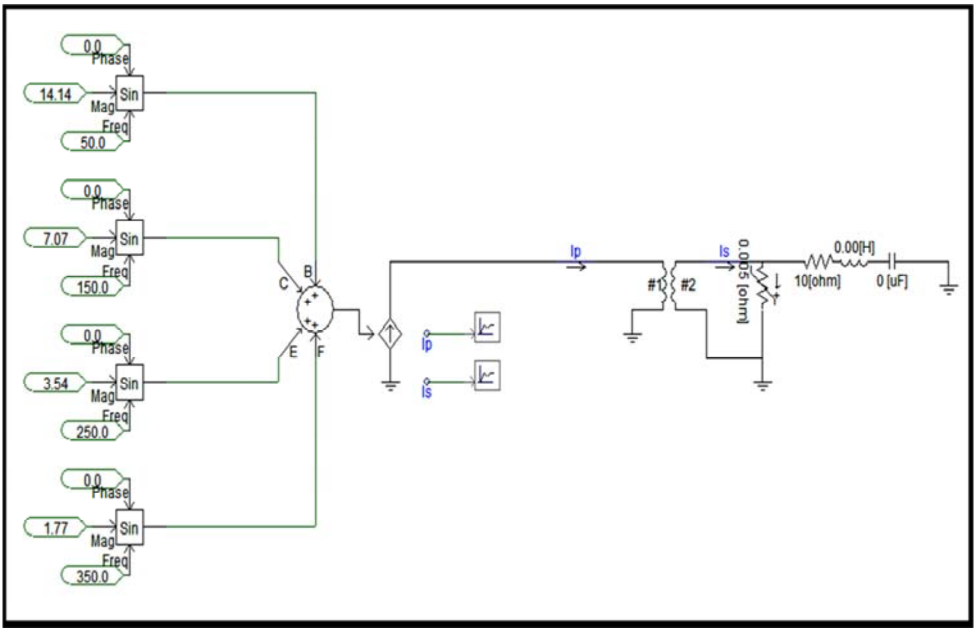

Figure 7: Simulation circuit

The THDi (%) of the system are calculated based on this formula

$$THDi = \frac{\sqrt{\sum_{h=2}^{\infty} I_{h,rms}^{2}}}{I_{rms}} \times 100\% \tag{10}$$

For example, 5%,

Irms1 = 14.14A
Irms3 = 0.7A
Irms5 = 0.113A
Irms7 = 0.106A

$$THDi(\%) = \frac{\sqrt{0.7^2 + 0.113^2 + 0.106^2}}{14.14} \times 100\%$$

$$= 5.07\%$$

All the above procedure is repeated for different values of THD on the CT primary (in this case, THD changes to 10%, 15%, 20%, 25%, 30%, 40%, 50% and 70%) [11].

The next section is the laboratory test for the current transformer performance with different percentage of THD. The values of percentage of THD were controlled by the number of non-linear loads. Personal computers in the laboratory are used as the nonlinear loads in this experiment. An experiment circuit as in Figure 8 was constructed. TNB source is connected through the loads and PM 6000 in the primary side of the current transformer. While, PM 6000 and burden connected in the secondary side. PM 6000 used to measure the percentage of THD, primary current, secondary current, primary harmonic current and secondary harmonic current.

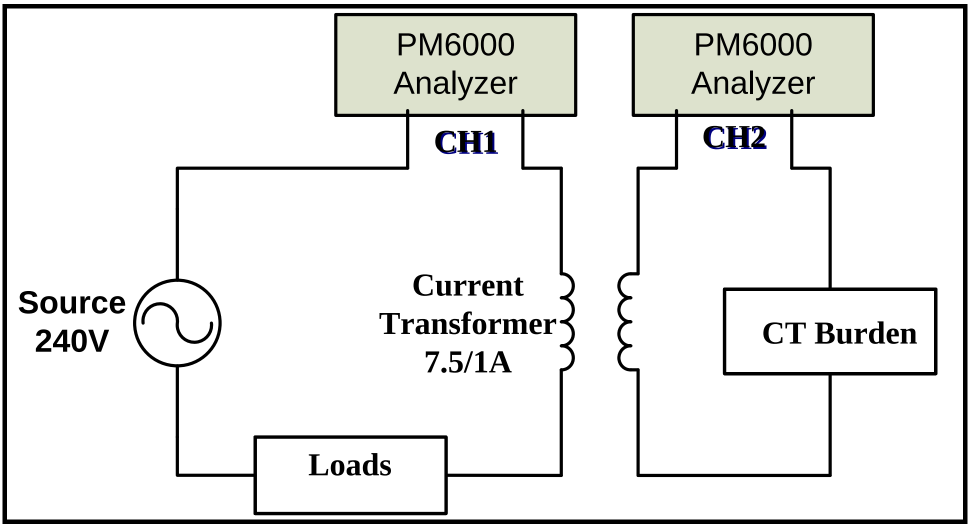

Figure 8: Experiment layout

RESULTS

From the simulation testing, graph in Figure 9 shows the primary and secondary current waveforms with THD 5%. The waveform is still in sinusoidal without any sign of distorted. This is because less harmonic pollution is supplied. However, the shape of waveform changed to hardly distorted when percentage of THD increased. This can be seen in Figure 10 (THD 25%) and Figure 11 (THD 70%). This distorted current brings effect on current transformer accuracy.

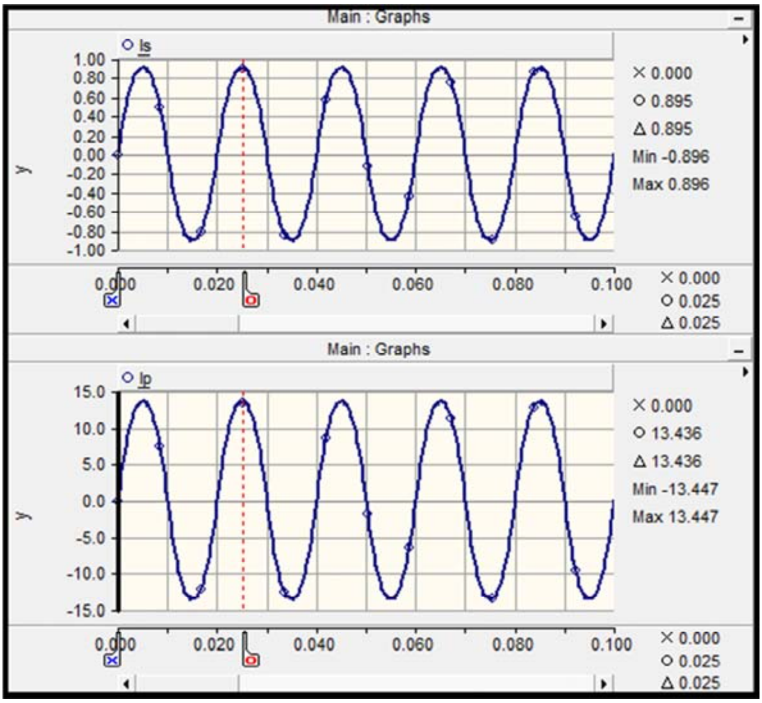

Figure 9: Secondary and primary current waveform with THD 5%

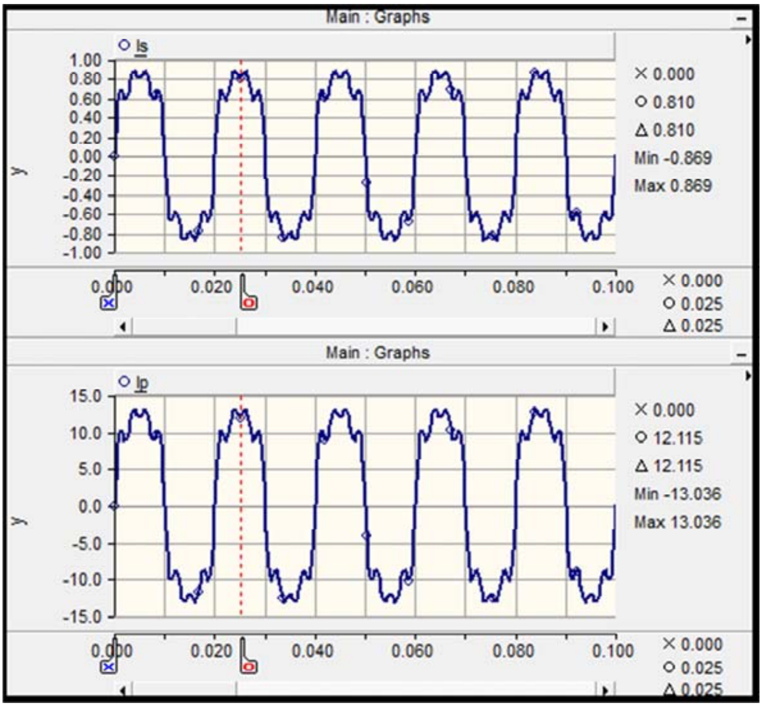

Figure 10: Secondary and primary current waveform with THD 25%

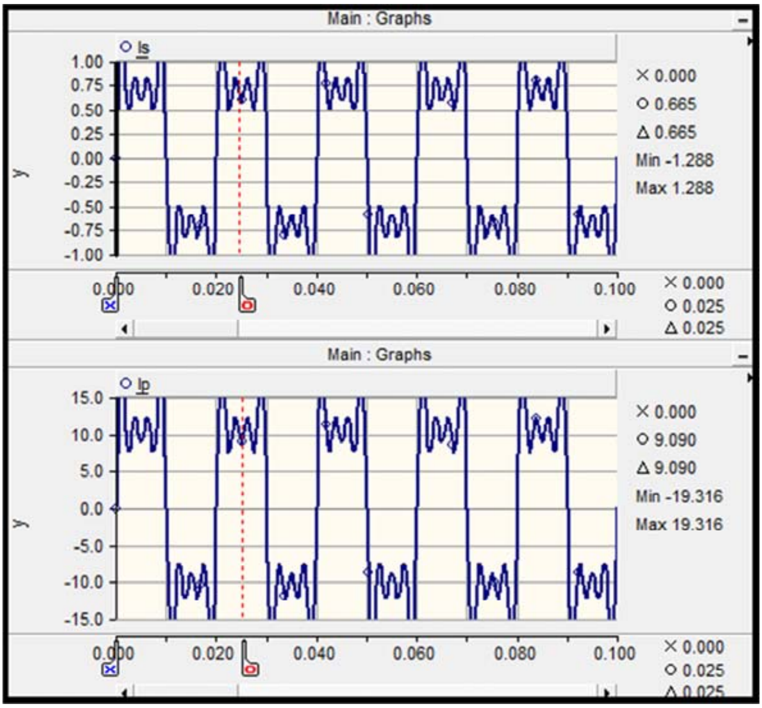

Figure 11: Secondary and primary current waveform with THD 70%

The primary and secondary current of each level of THD are measured to get the measured ratio. From the data, the percentage ratio error was manually calculated. These are shown in Table 1.

Table 4.1: Simulation results data

THD(%)	Ip	Is	Ratio	Percentage Error (%)
5.07	13.436	0.895	15.0123	0.0819
10.04	12.837	0.856	14.9965	0.0234
15.09	12.172	0.812	14.9901	0.0657
20.5	12.483	0.833	14.9856	0.0960
25.15	12.115	0.81	14.9568	0.2881
30.42	11.835	0.792	14.9432	0.3788
40.01	11.354	0.789	14.3904	4.0642
50.24	10.447	0.738	14.1558	5.6278
70.82	9.09	0.665	13.6692	8.8722

Based on the table 4.1, a graph of percentage ratio error against THD was plotted as in Figure 12.

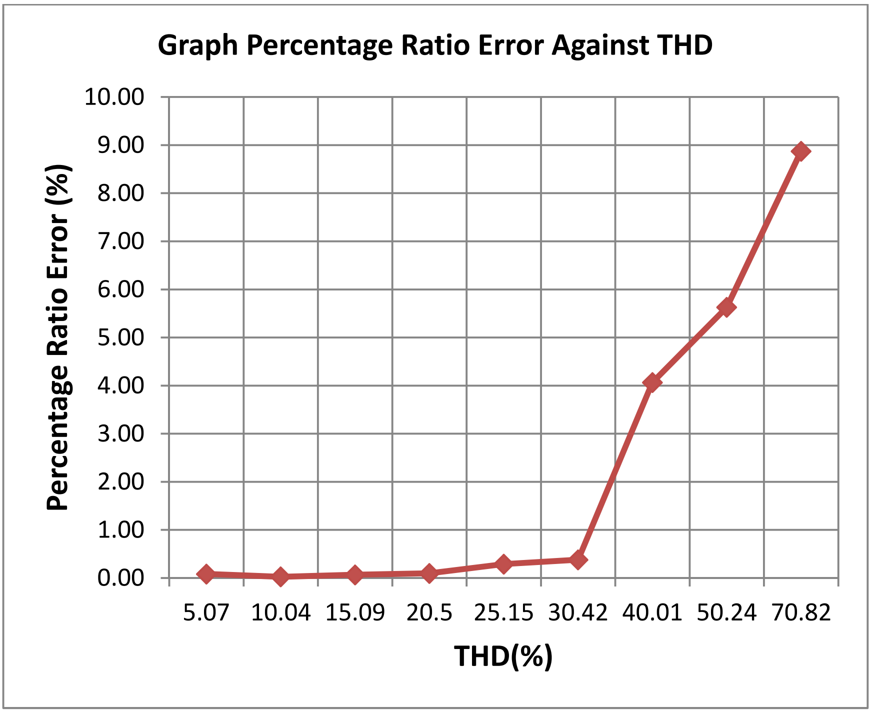

Figure 12: Graph Percentage Ratio Error against THD for simulation

The ratio error of the current transformer increased when the total harmonic distortion was increased. This means current transformer performs very well in non-harmonic conditions and start to loss it accuracy when harmonic was injected.

From the hardware testing, primary and secondary current are measured and percentage ratio error are calculated by using this formula:

$$Percentage\ ratio\ error\ (\%) = \left|\frac{actual\ ratio - measured\ ratio}{actual\ ratio}\right| \times 100\%$$

The result from laboratory test is same as simulation. The percentage ratio error increased with high THD as in graph in Figure 13.

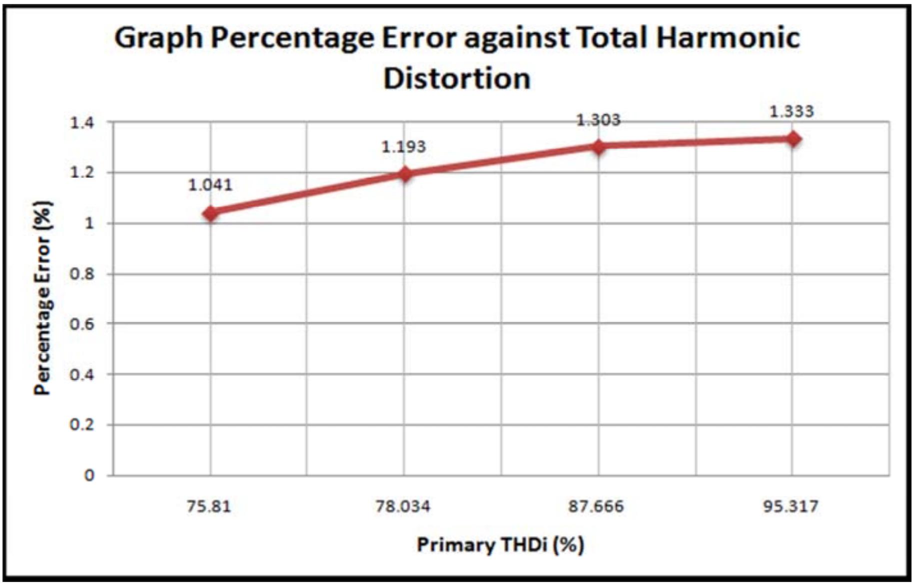

Figure 13: Graph Percentage Ratio Error against THD for laboratory test

Another effect that is cause of total harmonic distortion is saturation of current transformer. This effect is concerned to see which level of THD that attend to current transformer saturates earlier. Figure 14 show the graph of secondary current against the primary current changes. Current transformer with ratio 7.5/1A was used in this experiment.

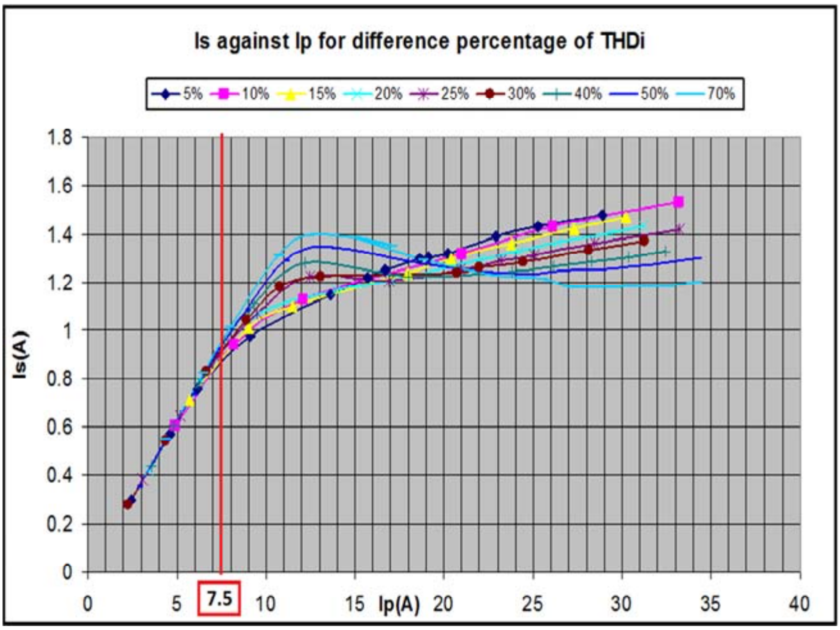

Figure 14: Graph secondary current against primary current

From the graph, each level of THD will bring the current transformer saturation with the increasing of primary AC current. However, THD with highest percentage (in this case 70%) make the current transformer fully saturate early compared to others level. This means current transformer performs in lower percentage of THD takes a long time to saturate compare to the higher THD.

CONCLUSION

The current transformer behaviour with total harmonic distortion was tested. The simulation results show that the current transformer has high efficiency when operates with less total harmonic distortion. The current transformer starts loss accuracy and the ratio error rising when total harmonic distortion increased. The laboratory test proved the simulation results. In addition, the current total harmonic distortion (THDi) with highest percentage value will make the current transformer fully saturate early compared to the current transformer with low percentage of THDi. 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.

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