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Current Distortion Characteristics of Some Home Appliances in Distorted Voltage Environment for Frequency Range of 2-150 KHz

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Abstract. Many of home appliances equipped by inverter technology because of its benefit of smaller, better of performance, more efficient and save energy. However this technology also generates current distortion regarding to its frequency switching which eventually has an influence on decreasing of power quality. Since the frequency switching of inverter normally in the range of 2 – 150 kHz, that cause the distortions in similar frequency range. Voltage and current distortions in the frequency range of 2-150 kHz is currently subject in research and standardization work. The reasons are that the appliances potentially generating such distortions are increasingly used and that the regulation and standardization are not completely covering and defining the limits and methods for that distortion.

This study investigates the characteristics of current distortion generated by some home appliances in the frequency range of 2-150 kHz. The study is important to analyze the current distortion generated by the load particularly when the voltage supply is distorted due to the decreasing of power quality. The appliances under test are Compact Fluorescent Lamp, LED lamp and Battery Charger. The voltage distortions input were set at 1 Volt for the frequency range of 5 to 70 kHz. The results show current distortion characteristics and impedance properties of all devices under test for each specific frequency distortion. There are unique characteristics of distortion depending on frequency.

Key words

Power Quality, Frequency 2-150 kHz, Current Distortion, Correlation, EMC.

1. Introduction

The level of disturbance for the frequency range below 2 kHz (harmonics) and above 150 kHz (disturbance voltage, disturbance field strength) has firmly regulated by International standards, but the frequency range between 2 kHz and 150 kHz is not sufficiently covered. Some measurements were conducted and informed us that many equipment due to its operation characteristics produce distortion in frequency range of 2-150 kHz [1]. Other measurement also finds that some of photovoltaic inverter generated distorted current in frequency range of 2-150 kHz [2]. Since the lacks of regulation for many devices and the adverse effects of the distortion in this frequency range are not significant yet even the risk of interference are possible [3], the efforts in managing the distortion for that frequency range are less. Some of home appliances equipped with inverter technology are predicted on generating current distortion in frequency range of 2-150 kHz. Since the widely use of these appliances particularly in household installation, it is important to observe the characteristics of distortion in order to ensure their compatibility.

To date, most of researcher focused on measuring the characteristics of distortion generated by appliances for the normal voltage supply condition obtained from main network. There are several measurements have been conducted to observe the distortion characteristics of lighting in frequency range of 2-150 kHz [4].

The study will focused on observing the characteristics of current distortion of some home appliances when the voltage input contains distortion. The devices under test taken are two type of lamp (CFL and LED) and battery charger. The voltage distortions were adjusted both in frequency and level in order to get comprehensive results. The measurement will be conducted for two condition individual and simultaneous operation.

2. Fourier Transform

The Voltage and Current distortions measured in this study were taken in Time Domain signal. The signal then was transformed to Frequency Domain in order to simplify the analysis using Discrete Fourier Transform (DFT) principle.

According to the Fourier theory, a periodic waveform can be expressed as a sum of pure sine waves of different amplitudes where the frequency of each sinusoid is an integer multiple of the fundamental frequency of the periodic waveform. A frequency that is an integer multiple of the fundamental frequency is called a harmonic frequency, i.e., fh = hf0 where f0 and h are the

fundamental frequency and an integer number, respectively. The rms values of the waveforms are computed as the square root of the sum of rms squares of all individual components

$$V_{rms} = \sqrt{\sum_{h=1}^{h_{max}} \left(\frac{1}{\sqrt{2}} V_h\right)^2} = \frac{1}{\sqrt{2}} \sqrt{V_1^2 + V_2^2 + V_3^2 + \cdots + V_{h_{max}}^2} \quad (1)$$

$$I_{rms} = \sqrt{\sum_{h=1}^{h_{max}} \left(\frac{1}{\sqrt{2}} I_h\right)^2} = \frac{1}{\sqrt{2}} \sqrt{I_1^2 + I_2^2 + I_3^2 + \cdots + I_{h_{max}}^2} \quad (2)$$

Where Vh and Ih are the amplitude of a waveform at the harmonic component h. In the sinusoidal condition, harmonic components of Vh and Ih are all zero, and only V1 and I1 remain.[5]

We can analyze the waveform using spectrum analysis and get the level of frequency disturbance. Spectrum analysis is the process of determining the frequency domain representation of a time domain signal. The most commonly used is the Fourier transform. In this research we used The Discrete Fourier Transform (DFT) to determine the frequency content of analog signals encountered in circuit simulation, which deals with sequences of time values. [6]

Given a sequence of N samples xn , indexed by n = 0,1,..., N-1, the discrete Fourier transform (DFT) is defined as

$$X(k) = \sum_{k=0}^{N-1} x(n)\, e^{-j(2\pi kn/N)} \quad (3)$$

$k = 0,1,\ldots,N-1$

Xk are often called the 'Fourier Coefficients' or 'Harmonics'.

3. Measurement Scheme

This research activity is focused on observing the characteristics of current distortion generated by the some low watt home appliances when the voltage input contains distortion in frequency range of 5-70 kHz. In order to generate adjustable voltage input distortion, the testing circuit contained PC-Based function generator and power amplifier was designed and built as shown in figure 1.

Due to the technical limitation of PC sound card and Power Amplifier frequency range operation, the voltage input distortion was only generated from frequency range of 5-70 kHz. The voltage level and frequency distortion diagram can be seen in Figure 2.

There are two main measurement scenarios that will be conducted in this study in order to get the distortion characteristics. The first measurement is when the appliance (DUT) is operated individually and the second measurement is when the appliances are operated simultaneously.

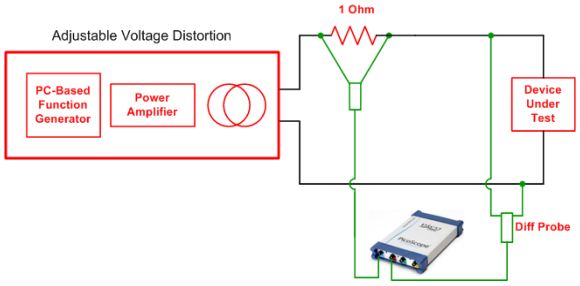

Fig. 1. Measurement Diagram

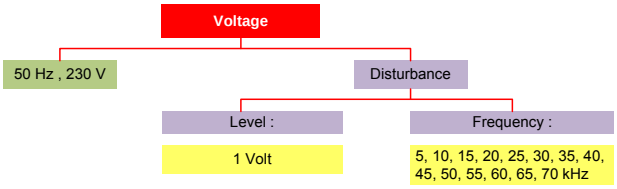

Fig. 2. Voltage Input Distortion Diagram

4. Result and Analysis

A. Distortion Characteristics of individual operation of DUT

This scheme is intended to observe the characteristics of distortion of the DUT for specific level and frequency of voltage distortion when it is operated individually. The DUT used in this measurement are Compact Fluorescent Lamp, LED lamp and Hand phone Charger.

The voltage distortion applied to the DUT is shown in Fig. 3. The level of voltage distortion was set around 1 Volt for frequency range of 5 to 70 kHz.

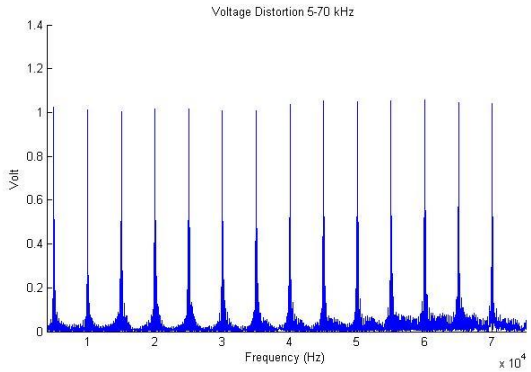

Fig. 3. Voltage distortion level applied to the DUT

The current distortion generated by the CFL-A and CFL-B as an impact of voltage distortion applied to the circuit is shown in Fig. 4 and Fig. 5 respectively. The Figures show the current spectrum of each CFL in absolute value form. As can be seen, the current distortion level of CFL is high at frequency 5 kHz and tends to decrease gradually up to frequency 50 kHz. For the frequency range of 50 kHz to 70 kHz, the current distortion is relatively stable. In general, the characteristics of current distortion have a similar pattern for both CFL lamps.

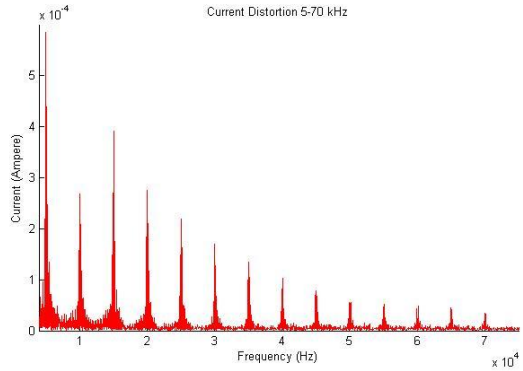

Fig.4. Current distortion generated by CFL-A when operated individually

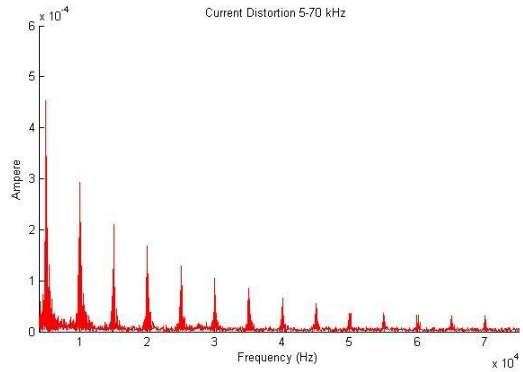

Fig.5. Current distortion generated by CFL-B when operated individually

For LED lamp, the current distortion pattern is also similar with the CFL lamp which is the current generated at 5 kHz is high and decrease gradually up to 50 kHz and the relatively stable for the range of 50 kHz to 70 kHz as can be seen in Fig.6. The difference is only on the value of current distortion. The LED lamp has higher current distortion value than CFL lamp. At frequency 5 kHz, the current distortion value for LED lamp is 3.8 mA while for CFL-A is only 0.58 mA. It is mean that the current distortion of LED lamp is around 6 time higher than the current distortion of CFL-A. This condition is also occurred for almost all frequency range of 5 to 70 kHz.

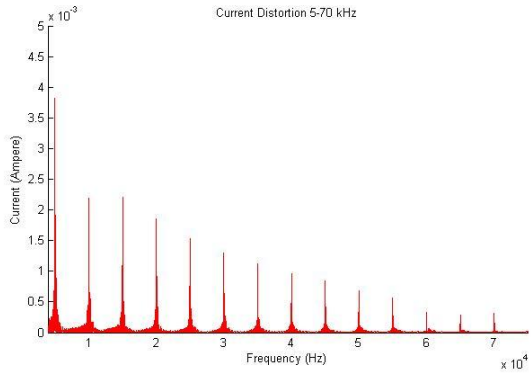

Fig.6. Current distortion generated by LED lamp when operated individually

Figure 7 show the current distortion of hand phone charger for brand A and B respectively. It can be notice that the current distortion generated by both of charger has similar pattern which is the value is high in the beginning (5 kHz) and gradually decrease up to 40 kHz, but then rise up again for the frequency 40 kHz up to 70 kHz. The current distortion pattern of hand phone charger is different with the current distortion pattern of CFL and LED lamps.

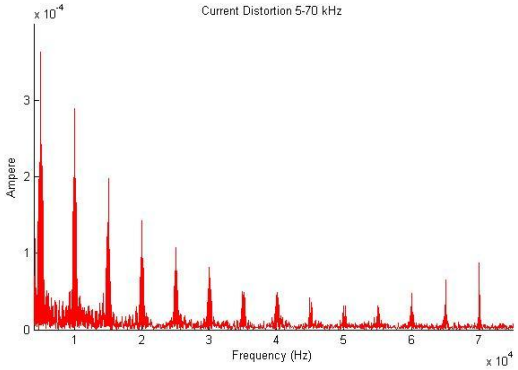

Fig.7. Current distortion generated by Charger-A when operated individually

The average value of current distortion for each DUT can be seen in Table 1.

Table 1. The average value of current distortion for each DUT

Freq (kHz)	Current Distortion (mA)			
	CFL A	CFL B	LED A	Charger A
5	0.586	0.415	3.826	0.234
10	0.273	0.278	2.197	0.192
15	0.395	0.205	2.205	0.139
20	0.280	0.168	1.860	0.103
25	0.218	0.132	1.532	0.081
30	0.172	0.104	1.303	0.068
35	0.135	0.083	1.119	0.056
40	0.102	0.069	0.968	0.051
45	0.076	0.052	0.840	0.049
50	0.052	0.034	0.689	0.057
55	0.030	0.022	0.563	0.064
60	0.028	0.024	0.324	0.075
65	0.031	0.026	0.286	0.087
70	0.033	0.027	0.314	0.094

Based on the result of measurement, the current distortion characteristics of each DUT are unique but for similar type of load has similar pattern. There is a difference in the behavior depending on frequency. The differences are caused by the characteristics of the inverter used by the DUT (i.e. technology and frequency switching) and types of load itself.

B. Load Interaction characteristics of simultaneous operation of appliances

After measuring the characteristics of current distortion of each DUT when operated individually, now we continue when it operated simultaneously. Due to the limitation of voltage distortion supply capacity, at this study, we only measured 2 DUT operated simultaneously. This stage is focused on comparing the distortion characteristics of each appliance between individual and simultaneous operation. We expected that there are some differences in the distortion characteristics due to load interaction between appliances.

Figure 9 shows the current distortion of CFL-A when operated simultaneously. The measurement was taken only in one lamp. Comparing the current distortion between individual (Fig.3) and simultaneous (Fig.8)

operation, we can notice that the level of current distortion when the lamp operated simultaneously is lower than when it operated individually, even though both of the measurement was taken in the same lamp (only for one CFL lamp). The reduction of the current distortion was varying for each frequency range. For the frequency range 5 to 50 kHz, the reduction is more than 20 % and the rest of frequency around 10 %. Beside the reduction of current distortion for specific frequency, we can also notice that the new current distortion also appears at frequency range 38-39 kHz.

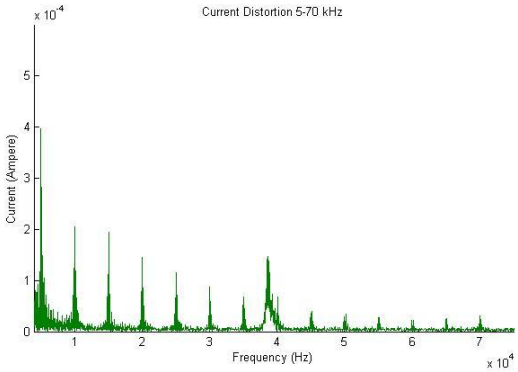

Fig.8. Current distortion generated by CFL-A when operated simultaneously

For CFL-B the condition is also similar, there is a reduction in current distortion level when the lamp operated simultaneously as we can see in Fig.9. The reduction also vary for each frequency, for the frequency range 5 – 50 kHz the reduction is around 30 % and for the frequencies above 50 kHz is around 5 %. A new current distortion is also significantly appears at the range frequency of 27-28 kHz.

The LED lamp also shows the reduction of current distortion when operated simultaneously. One of the differences is that there is no significant new current distortion appear in LED lamp when operated simultaneously, only a little new current distortion appear at frequency 66 kHz. The current distortion characteristics of LED lamp is shown is Fig.10. The level of current reduction varies for each frequency. For the frequency range 5-60 kHz, the reduction can reach 40 % while for frequency above 60 kHz is around 25 %.

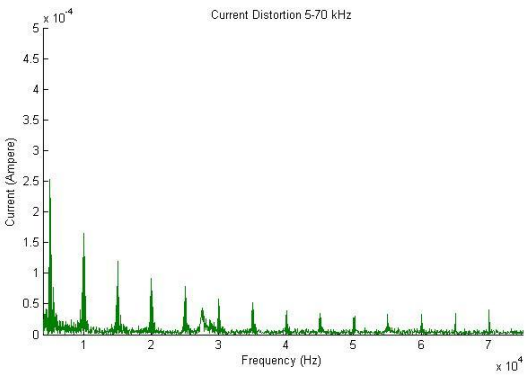

Fig.9. Current distortion generated by CFL-B when operated simultaneously

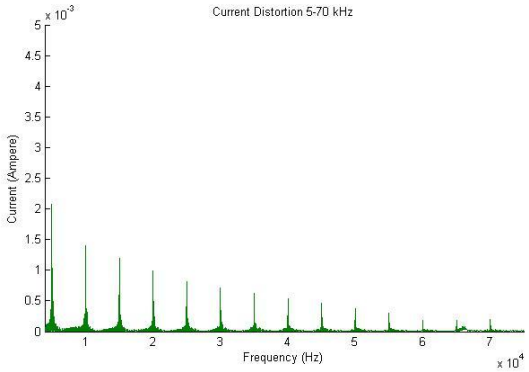

Fig.10. Current distortion generated by LED lamp when operated simultaneously

Figure 11 shows the current distortion of hand phone charger when operated simultaneously. In case of charger, the current distortion of individual and simultaneous operation is almost same. There is no effect of load interaction between them.

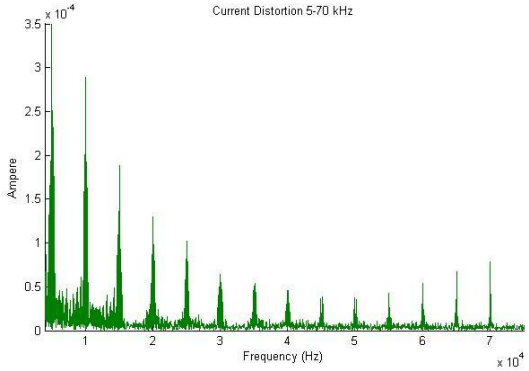

Fig.11. Current distortion generated by charger-A when operated simultaneously

Refer to the all measurement result, the current distortion of each single DUT (CFL and LED) significantly reduced by 5 - 40% when appliances are operated simultaneously than individually. The amount of reduction is depending on the frequency distortion. Generally for the frequency range of 5 – 50 kHz, the amount of reduction is higher than for the frequency above 50 kHz. Besides we can also notice that there is a new current distortion significantly appears when the DUT operated simultaneously. These conditions occurred due to load interaction effect between appliances. One of that is particularly interesting is the possibility of a filtering effect occurred between the loads at frequency of 5 – 70 kHz.

5. Conclusion

The measurement gives us two characteristics of current distortion for frequency range of 2-150 kHz. The first is that the current distortion generated by each DUT has different pattern. For the lamp type, the current distortion level generally is high at frequency 5 kHz and tends to decrease gradually up to 50 kHz then relatively stable for

the frequency above 50 kHz. Even though the pattern is almost similar but the value of current distortion generated by each lamp is different. For the charger type, the current distortion is high in the beginning (5 kHz) and gradually decrease up to 40 kHz, but then rise up again for the frequency 40 kHz up to 70 kHz. The unique characteristics of current distortion generated by the DUT is due to the characteristics of the inverter used by the DUT (i.e. technology and frequency switching of inverter) and types of load itself. The second characteristic is that when appliances operated simultaneously, the current distortion generated by each appliance is reduces by 2-40 % compare with individual operation. These conditions occurred due to load interaction effect between appliances which may be causing the filtering effect between them. This phenomenon should be observed deeply in the next study in order to get comprehensive characteristics of current distortion of appliances when operated simultaneously in distorted voltage environment.

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