Observatory case study on total harmonic distortion in current at laboratory and office building

M Z Mohd Radzi, M MAzizan and B Ismail
School of Electrical System Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.

E-mail: zulhisham02@gmail.com

Abstract: This paper discusses the level of harmonic distortion in current power distribution system for laboratory and office building. These two places often house a significant number of equipment such as computers, air conditioners, etc which are significant nonlinear loads. The high number of these nonlinear loads affects the quality of the power system and energy at the linked grid. This is due to harmonics components in current that is resulted by the conversion and switching processes by the nonlinear loads. This case study is located at main operation buildings at School of Electrical System Engineering, Universiti Malaysia Perlis at Pauh Putra Campus. This case study is intended to study the severance level of harmonics in current distortions at the said power distribution system. The tool used for data mining and analysis is the Fluke 1750, which records the data for 30 days. The analysis includes the level of harmonics in current at the point of common coupling at the power distribution system. It is benchmarked against relevant standards related to harmonics in current and power quality in grid. It is found that the harmonic distortion level exceeded the maximum value set by standards. This highlighted that the quality of power at this grid is low and results in losses of energy

1. Introduction

These days the type of load is becoming nonlinear. This is due to the high use of electronic equipment in computers, air conditioners, cooling systems, and others, which are a necessity in daily life, whether for residential, commercial and industrial users. Typical load at consumers are tabulated as in Table 1:

| Type of User | Type of Load       | Electrical Characteristic |
|--------------|--------------------|--------------------------|
| Domestic     | Incandescent Lamp  | Resistive                |
|              | Water Heaters      | Resistive                |
| Commercial   | Computers          | Nonlinear                |
|              | Fluorescent Lamp   | Nonlinear                |
|              | Water Heaters      | Resistive                |
| Industrial   | Motors             | Inductive                |
|              | ASDs               | Nonlinear                |
|              | Arc Furnaces       | Nonlinear                |
|              | Pumps              | Inductive                |

Source: [1]

However, the operation of these electronic loads often requires switching and conversion process that leads to harmonics component existence. For example, switch-mode power supplies are often available at personal computers and televisions, and they cause the injection of pulses in Power Distribution System (PDS) during the switching processes. As results, current in PDS nowadays consists of fundamental and harmonic components. This causes the RMS value of current to increase, alongside the frequencies of the harmonic orders in the current waveform. The consequences of these events are the power quality of the PDS becoming low, and the distorted current with harmonics components giving severe risks to the PDS at the load side stream.
Consumer load characteristics would determine the kind of power provided by the system authorities' quality of energy. The enhanced usage in distribution systems of the nonlinear and electronically switched loads has led to an increased harmonic distortion for both load voltages and waveforms. The scenario outlined in Figure 1 demonstrates a mixture of linear and nonlinear charges supplied from a sinusoidal supply and sharing the same impedance of supply. The voltage at bus #2 will be sinusoidal if the supply impedance ignored. It will lead to each load in distinct present waveforms. There will be harmonics in the complete supply present[2].

![Figure 1: Linear and nonlinear load sharing the same impedance](image)

2. Nonlinear Load

This kind of load is very demanded worldwide, whether industrial or residential users. Computers, air conditioners, and televisions are examples of this type of load, and it is impossible to eliminate them away, even their impact on the power system is already well documented. The nonlinear load defined as a class of load that, when subjected to sinusoidal voltage sources, would draw non-sinusoidal current into the system[3]. A nonlinear load produced harmonics, which is a severe power quality problem [4]. Its impact involves overheating transformers and energy wires, overloading circuit breakers and blowing a fuse, overloading, and failure of capacitors, signal interference in converters, interference with telecommunication circuits and ripple control systems, increased transmission losses and excessive neutral current in neutral wire [5]. The simple diagram of the block in Figure 2 demonstrates the present issue of distortion owing to low voltage harmonics. Figure 2 displays a distortion of the voltage waveform at the Point Common Coupling (PCC) owing to the harmonic current produced by electronic or non-linear energy. This impact will increase the distortion of line currents, decrease the power factor (PF), and contribute to the inefficient use of electrical energy at the same time[6].

![Figure 2: Harmonic Distortion at Point of Common Coupling](image)

| Modern Type of Nonlinear Load | THDi (%) | 3rd (%) | 5th (%) | 7th (%) | 9th (%) | 11th (%) |
|------------------------------|---------|---------|---------|---------|---------|---------|
| Fluorescent Lamp             | 11.1    | 10.7    | 2.0     | 1.8     | 0.9     | 0.6     |
| Freezer                      | 61.8    | 11.0    | 4.7     | 11.0    | 7.1     | 7.1     |
| Amplifier                    | 48.1    | 32.1    | 30.7    | 14.2    | 7.8     | 2.6     |
| Television                   | 72.5    | 55.1    | 36.8    | 20.3    | 11.4    | 10.8    |
Table 2 demonstrates that the non-linear load modern set draws from the supply a non-sinusoidal current and leads to current distortion. These current distortions deviate from an ideal sine wave and are made up of many harmonic currents like 3rd, 5th, 7th, 9th, and 11th. The measurement from Table 2 shows that laptop and printer have higher Total Harmonic Current Distortion (THDi) compared to others.

3. Harmonics

Harmonics Definition
Harmonics are currents or voltages with multiple integer frequencies of the fundamental frequency of power. For instance, in a system with a fundamental frequency of 50Hz, the sinusoidal current that contains the frequency of 250Hz is called the 5th harmonic current. In power quality scenario, harmonics is termed as the non-sinusoidal state of current or voltage, as they combine both fundamental and harmonic components. Total Harmonic Distortion (THD) is a term used to describe the net deviation of a nonlinear waveform, be it current or voltage from ideal sine waveform [4]. Total harmonic current distortion is the contribution to the basic of all harmonic frequency measurements. Current harmonics are an issue because they cause additional losses in the parts of customers and utilities[7]. THD is the most commonly used index for purposes of harmonic analysis. There are two definitions of it, one measuring the harmonic content of a waveform with essential elements (THDF), and the other measuring the harmonic content of the waveform to its maximum value (THDR)[4].

\[ THDF = \sqrt{\frac{\sum_{n=2}^{\infty} I_n^2}{I_1}} \]  
\[ THDR = \left( \frac{\sum_{n=2}^{\infty} I_n^2}{\sum_{n=1}^{\infty} I_n^2} \right)^{1/2} \]

Where \( I_n \) is either the RMS value or the amplitude of the harmonic. THDF is a far better measure of the content of harmonics. THDR introduces a significant mistake in the measurement of the distortion factor when measuring large harmonic waveforms. Thus, THDF and THDR interchangeably used as a parameter measuring the RMS proportion of all harmonics to the fundamental element.

Harmonic Sequences
The sequences are one of the harmonic parameters that are important to look into it. In order to identify the harmonic sequences, the nature of 3rd, 5th, and 7th up to nth harmonics can be assessed and particularly in three-phase systems and their implementation it is highly essential, especially the 3-phase motors. Each stage can be resolved to positive, negative and zero sequences, vector of the produced harmonic current. The expression of harmonic phase currents, for example, is below:
Where ω is the angular speed, ω = 2πf, t = time and θ = phase difference between currents. For each phase current, the phase differences were measured between harmonics and the basic components. Current of phases R, Y, B, consisting of the fundamental component as well as of the 3rd, the 5th and the 7th until nth harmonic order. Equation simplification (4) and (5) leads to the third harmonics being the same for each phase of R, Y, and B. It is feasible to rotate the stage present, by taking the present level and positioning it for everyone in a single axis. The harmonic sequence tabulation is, therefore like the following in Table 3.

| Harmonic Order | Sequence |
|----------------|----------|
| 1, 4, 7, 10, 13, 16, 19 = (3k +1)th | Positive |
| 2, 5, 8, 11, 14, 17, 20 = (3k −1)th | Negative |
| 3, 6, 9, 12, 15, 18, 21 = (3k)th | Zero |

The only harmonic order that is applicable for three phases is the third order, particularly for neutral driver present charging, as the positive and negative harmonic sequence cancels each other. In summary (3), (4) and (5), the harmonic in third-order will add up in place while the fifth harmonics in the first-order can be cancelled owing to its inverse characteristics of the stage. Only odd orders are available in FFT for halfwave symmetrical waveform. If function f(t) = -f(t+T/2), the waveform has the symmetric half-wave character. Triple harmonics flow as a neutral current for a balanced but harmonic 3-phase structure. 3h+3 harmonic orders are triplen, but the conditions are the same. Other harmonic orders have been cancelled and are not in neutral current. Third harmonic (I_3) is the most significant among triplen harmonic orders[8]. Many studies have shown that I_3 alone is sufficient for harmonic analysis[9]. Even IEC 60364-5-52 uses I_3 only when it comes to determining the harmonic effect on cable size.

### Harmonics Standard

IEEE 519-2014 Standards on power quality is one of the proposed recommendation practices that currently available. It produced in view to limiting both utility voltage, and user ends current distortion. Limits for harmonic current components and THD at 69.0kV by IEEE tabulated as in Table 4.

| Harmonic Order (Odd) | 3 ≤ h < 11 | 11 ≤ h < 17 | 17 ≤ h < 23 | 23 ≤ h < 35 | 35 ≤ h ≤ 50 | THD |
|-----------------------|-------------|-------------|-------------|-------------|-------------|-----|
| < 20                  | 4.0         | 2.0         | 1.5         | 0.6         | 0.3         | 5.0 |
| 20 – 50               | 7.0         | 3.5         | 2.5         | 1.0         | 0.5         | 8.0 |
| 50 – 100              | 10.0        | 4.5         | 4.0         | 1.5         | 0.7         | 12.0|
| 100 – 1000            | 12.0        | 5.5         | 5.0         | 2.0         | 1.0         | 15.0|
| > 10000               | 15.0        | 7.0         | 6.0         | 2.5         | 1.4         | 20.0|

Source: [10]

According to IEC 6100-3-4, IEC 6100-3-6 the maximum amount of current distortion with subjected to fundamental as mention in Table 5

| Harmonic Order | Maximum Current Distortion | THD |
|----------------|---------------------------|-----|
| 3 ≤ h < 11     | 4.0                       | 5.0 |
| 11 ≤ h < 17    | 2.0                       |     |
| 17 ≤ h < 23    | 1.5                       |     |
| 23 ≤ h < 35    | 0.6                       |     |
| 35 ≤ h ≤ 50    | 0.3                       |     |
| > 10000        | 15.0                      |     |

Source: IEC 6100-3-4, IEC 6100-3-6
| Harmonics | Maximum Permissible Current (%) |
|-----------|--------------------------------|
| Total Harmonic Distortion (THD) | 16.0 |
| 3rd | 21.6 |
| 5th | 10.7 |
| 7th | 7.2 |
| 9th | 3.8 |
| 11th | 3.1 |

Sources: [11]

Based on Table 4 and Table 5, THD of current should not exceed the appropriate mentioned figures. That means nonlinear loads should know in quantity, before designing the power for a building to limit the impact of harmonics.

4. Detail of Harmonic Survey

Load Survey
A survey conducted at School of Electrical System Engineering, Universiti Malaysia Perlis, in Pauh Putra Campus located at Arau, Perlis, Malaysia. It consists of four laboratories building and lecture office. Each block has its dedicated Sub Switch Board (SSB) and supplied 415V from Main Switch Board (MSB). Data measured at Point of Common Coupling at each SSB as in Figure 3. Significant load at all buildings are nonlinear load, which is desktop, printer, and laptop. Detail load for each building is as tabulated in Table 6.

| Block | 36W Fluorescent Lamp | Desktop Computer | Laptop | Printer | 1.0 hp Split Unit Air Conditioner | Air Handling Unit | Network Switch |
|-------|----------------------|------------------|--------|---------|----------------------------------|------------------|----------------|
| Block 2 | 188 | 123 | 4 | 7 | 6 | 1 | 4 |
| Block 3 | 188 | 4 | 21 | 23 | 4 | 1 | 1 |
| Block 4 | 188 | 7 | 3 | 3 | 4 | 1 | 1 |
| Block 6 | 188 | 3 | 21 | 21 | 4 | 1 | 1 |

Figure 3: Point of Common Coupling at Laboratory and Office Building

Measurement Data
In terms of usefulness, harmonic research is essential at the point of common coupling because bad
energy quality impacts grid efficiency. Measuring the amount of harmonics injection is carried out on the LV side of the 415-V bus bar in the distribution box. For a full spectrum, the electrical parameters such as voltage, present, frequency, energy etc. and harmonic distortion rate tracked and measures. Data was measured using Fluke 1750 and analyse using Fluke Power Analyzer 2.4. The Power Quality meters recorded RMS voltage and currents (magnitude and phase angle) measurements per stage and neutral up to the 50th harmonic, as well as some associated quantities (Total Harmonic Distortion, Total Demand Distortion, Unbalance Factor, Complex Power, and others.). The measured values recorded in 10 minutes intervals and within 30 days cycle accordance to IEC 61000-4-7[12]. Measurement conducted during the laboratory and lecture office were fully used. Measurement data for each block are shown in Figure 4 until Figure 11 respectively.
5. Discussion & Conclusion

The objective of the paper is to determine the level and elements in laboratory and office buildings of harmonics produced by the various non-linear loads. The level and nature of harmonics produced by different types of load were identified. Total harmonic distortion current factor should be less than 16% throughout a block distribution system as per the standard. The number had exceeded 16% investigated thoroughly Table 7. shows comparison RMS current before and after harmonic penetration into the system, which clearly shows that the amount of current RMS had increased by 12% - 20% from fundamental value. This is a serious issue that should be taken into consideration as it will cause increased transmission losses and excessive neutral current in neutral wire[5].

| Table 7: Comparison RMS Current Before and After Harmonic Penetration |
|-------------------------------------------------------------|
| ** Fundamental RMS Current | ** THD RMS Current |
| R | Y | B | R | Y | B |
| Block 2 | 54.74 A | 54.31 A | 45.01 A | 65.08 A | 61.29 A | 54.14 A |
| Block 3 | 36.40 A | 34.13 A | 35.26 A | 40.60 A | 38.39 A | 46.95 A |
| Block 4 | 35.25 A | 25.78 A | 29.87 A | 42.26 A | 33.19 A | 39.68 A |
| Block 6 | 54.74 A | 54.31 A | 45.01 A | 67.04 A | 62.15 A | 55.76 A |

The number of nonlinear loads had given a significant effect on current THD, as can be seen on data recorded for all blocks, a higher number of nonlinear load cause higher current THD. For block 2, 3 and 6, which contains a large number of laptops, printer and desktop will give a significant effect on THDi value. A fluorescent lamp, which commonly used, also contributes to this value. Even, the THDi for the single fluorescent lamp is lower compared to other equipment as in Table 2 with a large number of fluorescent lamps installed in the building, it will give a significant effect on this value.

During measurement period for block 2, 58.95% of all time, value THDi had exceeded the maximum limit with the maximum THDi was 123.39% at 6.10 pm on the blue line. For block 3, the maximum THDi recorded was 61.85% on the blue line at 8.00 am with 70.94% of the recorded period, value current THD had exceeded the limit. At 2.50 pm on the yellow line, current THD had exceeded the limit at block 4 and this the only time THDi exceed the limit at this block. This is due to a smaller number of nonlinear loads; although the laboratory had been thoroughly used during the measurement period. Machine laboratory located at block 4, which contain electrical machine, and this was an inductive load, so it will not produce harmonic and contaminated the power system. During 30 days measurement period, 71.69% data for block 6 exceeded the permissible limit. Maximum THDi recorded was 91.44% at 5.40 pm on the blue line.

The distortion of harmonics is growing fast daily. It is triggered not only by the non-linear industrial load but also by housing load. In addition to energy loss, harmonics also lead to lousy power factor and failure to function devices requiring a pure sinusoidal current input. Electronic power loads such as desktop and home entertainment appliances tend to be highly present, almost 100%. From Table 7, the increment of RMS current in the presence of harmonic had increased by 16% to 22%.
Consequently, their real power factors are usually below 0.707, although they are close to uniformity [13]. Harmonic distortion also relies on electronic components of the circuitry of the device. The harmonics caused by these loads cannot overlook because the number of non-linear loads is rising every day. That leads to the overload of the distribution transformer and is one of the main reasons why the distribution transformer fails prematurely.

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