Harmonic analysis in electrical system at Andalas University Hospital

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Abstract. In this paper, harmonic distortion in the electrical system at Andalas University Hospital is analyzed. The Total harmonic distortion (THD) was measured by The Fluke 430-II power analyzer for three days from 27th - 29th June 2018. The data were recorded every ten minutes. The THD of the current was from 3.09 % on Thursday at 08.40 (in phase L3) to 9.35 % on Thursday at 23.00 (in phase L1). The values of the THD show that high values of the THD occur at night from 18.00 to 08.00 at morning. The low values for the harmonic distortion of the installation occur during the day from 08.00 to 18.00 that occur for low active power. The harmonic distortion in the electrical system during the day was quite low. The current harmonic distortion was depending on the type of load. The non-sinusoidal current has harmonic content that interacts with the electrical system will create voltage distortion in the electrical system even if the supply is sinusoidal.

1. Introduction

The definition of power quality in the IEEE 100 Authoritative Dictionary of IEEE Standard Terms is the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment [1]. The widespread use of electronics has raised the awareness of power quality and its effect on end-use equipment [2]. Power quality has been widely used to explain interactions between end users and equipment. The widespread use of the electrical equipment with non-linear loads such as power electronic, telecommunication technology, information technology, sensitive control equipment, energy-efficient lamps, some office equipment has increased power quality problem. Electrical equipment can be affected directly on low power quality. Low power quality occurs if there are unwanted variations in voltage and current signals that are not mitigated properly. The concern of end users in the quality of power is the quality of voltage and current. Low power quality Power quality is a serious problem for domestic, commercial and industrial consumers, such as Poor power quality may cause bulb and electrical equipment to malfunction or not operate at all and which eventually leads to early failure [3]-[4]. Power quality disturbances can be classified as either voltage sags and interruptions, transient overvoltages, long duration voltage variations, or harmonic distortion. Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate (termed the fundamental frequency; usually 50 or 60 Hz) that periodically distorted waveforms can be decomposed into a sum of the fundamental frequency and the harmonics [5]. The harmonic currents can increase losses, overhead equipment and high neutral current and early failure equipment, therefore, that increase significant operating costs.
Public Buildings such as hospital and healthcare facilities have a high priority in the power quality [6]. The electrical system at hospital consists of an emergency system and equipment system so the quality of power and continuity power supply must be a priority. Harmonics cause power losses and failure of equipment operation, at the hospital with the essential system that consists of the life safety branch, it can result in loss of life. Based on the situation, the authors analyze harmonic in the electrical system at Andalas University Hospital in Padang, Indonesia. A type of hospital facility many non-liner loads distort voltage and current signals as harmonic. This paper will be updated knowledge and could give characterize the harmonics behavior of the actual hospital equipment.

In this paper, detail analysis and measurement method are given in Section II, the result and discussion are given in Section III, and Section IV includes the conclusions.

2. Methodology

2.1. Measurement Method
This research was conducted in the electrical system at Andalas University Hospital in Padang, Indonesia. Raw power measurement data in 1200 kVA electrical system at Andalas University Hospital is measured by The Fluke 430-II Power Analyser. This instrument is used to measure voltage, current, power, and harmonic in the electrical system at Andalas University Hospital. The data log during the period 27 - 29 June 2018. The data was recorded every ten minutes. The measurement result is analyzed.

![Figure 1. The connection of Analyzer to the 3-phase electrical system](image)

For a 3-phase system make the connections as shown the figure 1. First put the current clamps around the conductors of phase A (L1), B (L2), C (L3), and N (Neutral). The clamps are marked with an arrow indicating the correct signal polarity. Next, make the voltage connections: start with Ground and then in succession N, A (L1), B (L2), and C (L3). For correct measuring results, always connect the Ground input. Always double-check the connections. Make sure that current clamps are secured and completely closed around the conductors. For single phase measurements, use current input A (L1) and the voltage inputs Ground, N (Neutral), and phase A (L1). An (L1) is the reference phase for all measurements.

2.2. Harmonic Analysis
In an electrical system, the voltage and current are sinusoidal if the loads are linear otherwise if the loads are non-linear. Electrical system parameter will produce a different result depending on the non-sinusoidal expressions that are absorbed by the non-linear loads are used. The non-linear loads produce distorted voltage and current signals as harmonic According to the IEEE 1459 standard [7]. The number of harmonics result in the main RMS value of the voltage, and the current is called Total Harmonic Distortion (THD). It can be expressed as,

\[V^2 = V_1^2 + V_n^2,\]  (1)
\[ I^2 = I_1^2 + I_H^2, \]  \hspace{1cm} (2)

Where \( V_1 \) is the first harmonic component of the voltage wave or the fundamental harmonic, \( V_H \) is the first harmonic component of the current wave. \( V_H \) and \( I_H \) is refer to all the other harmonics of the voltage and current wave.

The Total Harmonic Distortion or THD of the voltage and the current is defined as follows,

\[ \text{THD}_V = \frac{V_H}{V_1}, \]  \hspace{1cm} (3)
\[ \text{THD}_I = \frac{I_H}{I_1}, \]  \hspace{1cm} (4)

Where \( \text{THD}_V \) is the overall deviation of the distorted voltage wave from its fundamental, \( \text{THD}_I \) is the total harmonic distortion of the current.

The fundamental active power \( P_1 \) is given by,

\[ P_1 = V_1 I_1 \cos (\theta_1), \]  \hspace{1cm} (5)

Where \( P_1 \) is the fundamental active power at the fundamental frequency. And harmonic active power \( P_H \) can be expressed as,

\[ P_H = P - P_1, \]  \hspace{1cm} (6)

Harmonic active power \( P_H \) indicate the presence of harmonic. To calculation of power consumption due to their energy input to the electrical signal and to determine the non-fundamental active power can follow,

\[ P_H = V_0 I_0 + \sum_{h \neq 1} V_h I_h \cos \theta_h = P - P_1 \]

Where \( V_0 \) and \( I_0 \) are the direct voltage and current respectively and \( h \) is the number of the harmonic component [5]. It is useful to separate the fundamental active power \( P_1 \) from the harmonic active power \( P_H \) [6].

The apparent power is consists of apparent fundamental power \( S_1 \), current and voltage distortion power, and harmonic apparent power \( S_H \) as follows,

\[ S_1 = V_1 \cdot I_1, \]  \hspace{1cm} (7)
\[ S_H = V_H \cdot I_H, \]  \hspace{1cm} (8)
\[ D_I = V_I \cdot I_H, \]  \hspace{1cm} (9)
\[ D_V = V_H \cdot I_1, \]  \hspace{1cm} (10)

Where \( D_I \) is the current distortion power that produced the fundamental harmonic with all of the current harmonic component. Similarly, voltage distortion power is related to product of the current distortion power.

Fundamental apparent power \( S_1 \) is consisted of the fundamental active and reactive power \( Q_1 \) as follows,
\[ S_i^2 = P_i^2 + Q_i^2, \]  

(11)

Where the fundamental reactive power is obtained as follows,

\[ Q_1 = \frac{\omega}{kT} \int_{\tau}^{\tau+kt} i_1 [\int v_1 \, dt] \, dt, \]  

(12)

therefore the next equation of the fundamental reactive power is obtained as follows,

\[ Q_1 = V_1 I_1 \sin \theta_1, \]  

(13)

And the apparent harmonic power, also the harmonic is consists of the harmonic active power and harmonic distortion power as follows,

\[ S_H^2 = P_H^2 + D_H^2, \]  

(14)

The non-fundamental apparent power \( S_N \) is defined by,

\[ S_N^2 = D_I^2 + D_V^2 + S_H^2, \]  

(15)

### 3. Result and Discussion

Harmonic measurement is used in Total Harmonic Distortion (THD). The THD of the current or the voltage is defined as the ratio between the root sum square over all of the harmonic components and the fundamental component. The THD is typically expressed in percent. The THD of the current and the voltage obtained from the 24 hours in the three-phase in electrical system at Andalas University Hospital.

![THD A L1](image1)

![THD A L2](image2)

(a)

![THD A L3](image3)

(b)
A comparison of the three phases for phase L1, phase L2 and phase L3 can be seen in figure 2. The current waveform distortion shows a significantly higher in phase 1 than the other phase. The THD of the current was from 3.09 % on Thursday at time 08.40 (in phase L3) to 9.35 % on Thursday at 23.00 (in phase L1). In this case, THD of the current in phase 1 was close to 10 %. However the values the THD of the current of the installation were still below IEEE 519-192 standard. The values of the THD in figure 2 shows that high values of the THD occur at night from 18.00 to 08.00 at morning. The low values for the harmonic distortion of the installation occur during the day from 08.00 to 18.00.

The voltage waveform distortion in figure 3 shows a significantly higher in phase 1 than the other phase. The THD of the voltage was from 1.09 % on Friday at 12.20 (in phase L3) to 2.71 % on Thursday at 20.30 (in phase L2). In this case, THD of the voltage was proportional to THD of the current. Voltage distortion produced by the interaction between current harmonics and source equivalent impedance. If impedance equivalent of the voltage source is small, current harmonic cause small voltage harmonic distortion too. Therefore THD of the voltage is not related to the load condition in the electrical system.
Comparing figure 4 with figure 2 shows that high values of the THD occur for low active power. It was noted that the loads during the day outside medical equipment, telecommunication equipment and some of the office equipment were very high due to presence of air conditioning equipment, water pump equipment, elevator, medical gas installation and the installation for supporting equipment (such as washer for two unit, drying cabinet and ironer machine). Linear loads can be classified as resistive, capacitive, inductive, or combinations of some of them. The high loads in hospital installation during the day are more the linear loads that do not contain harmonics with the composition for 70 % of the total loads otherwise the medical equipment, telecommunication and some of the office equipment are the non-linear loads with the composition for 30% that main cause harmonic generation in the electrical system. Therefore harmonic distortion in the electrical system during the day was quite low. The values of the THD of the current during at night increased while the loads connected to the hospital installation decreased. It should further be noted that the loads during at night outside air conditioning equipment composited from medical equipment, telecommunication equipment, and lighting. The type of equipment more non-linear loads distort voltage and current signals as harmonic. Almost these circuits can contain semiconductor power devices. The widespread use of the energy-efficient lamps will increase harmonic distortion in the electrical system [9-10].

4. Conclusion.
The THD of the current in electrical system at Andalas University Hospital in Padang was significantly higher in phase 1 than the other phase. The current harmonic distortion was depending on the type of load. The voltage and current are sinusoidal if the loads are linear otherwise if the loads are non-linear. The non-linear loads produce distorted voltage and current signals as harmonic. The high loads in hospital installation during the day from 08.00 to 18.00 are more the linear loads therefore harmonic distortion was quite low. The high values of the THD occur at night from 18.00 to 08.00 at morning. The values of the THD of the current during at night increased while the loads connected to the hospital installation decreased because there were many non-linear loads such as the energy-efficient lamps for lighting that increased the harmonic distortion in hospital installation. The non-sinusoidal current has harmonic content that interacts with the electrical system will create voltage distortion in the electrical system even if the supply is sinusoidal.

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References
[1] IEEE 2000 IEEE 100 The Authoritative Dictionary of IEEE Standards Terms, 7th edition; IEEE Press, New York.
[2] Jeff G Dougherty, Wayne L Stebbins 1997 Power Quality: A Utility and Industry Perspective, IEEE Explore.
[3] Daniel O Johnson, Kabiru A Hasan 2016 Issues of Power Quality in Electrical Systems. International Journal of Energy and Power Engineering, Vol. 5, No. 4, pp. 148-154.
[4] Alberto Dolara, Sonia Leva 2012 Power Quality and Harmonic Analysis of End User Devices. Energies, 5, 5453-5466.
[5] Roger C Dugan, Mark F McGranaghan, Surya Santoso and H Wayne Beaty 2004 Electrical Power Systems Quality, Second Edition, McGraw-Hill.
[6] Emmanuel Gullen-Garcia, Angel L Zorita-Lamadrid, Orca Duque-Perez, Luis Morales-Velazquez, Roque Alfredo Osornio-Rios, Rene de Jesus Romero-Troncoso 2011 Power Consumption Analysis of Electrical Installations at Healthcare Facility. Energies, 10, 64.
[7] IEEE 2000 IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions, IEEE Standard 1459-2000; IEEE Explore, New York.
[8] IEEE 2014 IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems, IEEE Standard 519-2014, New York.
[9] MHJ Bollen, SK Rönnberg, EOA Larsson, M Wahlberg, CM Lundmark 2011 Harmonic Emission from Installations with Energy-Efficient Lighting. 11th International Conference on Electrical Power Quality and Utilisation.
[10] Zahari Ivanov, Hristo Antchev 2015 Energy Saving Lamps as Sources of Harmonic Currents. American Journal of Electrical Power and Energy Systems, vol. 4, no. 6-1, pp. 13-18.