Reducing of total harmonic distortion using passive filter simulation to suppress harmonic currents with the case: General Hospital, Universitas Kristen Indonesia Jakarta

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Abstract. With the increasing need for and use of electrical energy amid increasingly rapid technological advances, especially in the use of electronic equipment in hospitals, it is necessary to pay attention to the problem of harmonics due to the use of non-linear electrical equipment. Therefore, it is necessary to measure the current and voltage THD for each non-linear equipment user. If the current and voltage THD values do not meet the standards, then a filter design is carried out so that the THD values meet the standards. Based on the results of THD measurements on the Main Distribution Panel (MDP) of RSU UKI, it was found that the THD of the voltage varied between 0.7877% - 2.4363% and the current THD varied between 5.3073% - 9.2363%. The measured THD value refers to the IEEE 519-2014 standard. If the THD value of the measurement results exceeds the IEEE 519-2014 standard, a harmonic filter is needed. With the simulated single tuned filter design, the current THD decreases within the standard value. The THD value of the current after installing the filter at the three MDP’s of the RSU UKI, namely MDP A of 1.72%, MDP B of 0.64% and MDP C of 1.30%.

1. Introduction

Seeing the increasing use of electrical energy today, it is important to pay attention to the power quality of the electrical equipment used and to know the Total Harmonic Distortion (THD). Poor electrical power quality is where there is a problem/deviation of current, voltage or frequency that results in failure of the electrical equipment used. One aspect of the reduction in the quality of electric power is a reduction in energy efficiency, so it can be said that the quality of electric power is one of the parameters that need to be considered in the management of electrical energy in a sector [1]. Hospitals also require a large amount of electrical energy in the use of medical devices where the loads used usually consist of linear loads and non-linear loads. Some medical equipment may fail due to poor power quality and improper electrical installation [2]. In a scientific paper written by I Made Suartika [3] explains the research conducted at Sanglah Hospital Denpasar, Bali, namely by grouping non-linear loads in each room in the MLTP (Main Low Terminal Panel) and each MDP (Main Distribution Panel), calculates the total active power capacity (watts) of non-linear loads in each room and analyzes the THD, both current THD and voltage THD using the device MATLAB Simulink software. The harmonic standard used is IEEE 519-1992.
After seeing and reviewing the published studies, the authors made a study at the General Hospital, Universitas Kristen Indonesia (RSU UKI) by measuring THD using a Power Quality Analyzer (PQA) measuring instrument and analyzing the quality of electrical power by comparing the measurement results to the IEEE standard 519-2014. The results of the THD for voltages and currents that do not meet the standards will be simulated using the MATLAB application to reduce the THD, so that the quality of electrical power at the RSU UKI is in good condition.

2. Theoretical basis

2.1. Electrical power quality

The quality of electric power is determined by the quality of the current, voltage, frequency, harmonics, power losses, power factor and grounding (grounding), and the balance of the system. The quality of electric power can be said to be good if the current, voltage, and frequency found in a place or sector are in constant condition [1,4,5].

2.2. Harmonics

Harmonics are a symptom of the formation of waves with different frequencies which are the multiplication of an integer with their basic frequency. The basic frequency of the electric power system in Indonesia is 50 Hz, so the harmonics have a frequency with a value of multiples of 50 Hz. Figure 1 shows a harmonic distortion waveform with a basic frequency of 60 Hz [1,3,5].

![Figure 1. Harmonic waveforms with a base frequency of 60Hz [1,5].](image)

2.3. Linear and non linear load

Linear load is a load whose current component is proportional to the voltage. Non-linear load is a component whose current is not proportional to the voltage component (See Figure 2) [3,4,6].

![Figure 2. Current and voltage waveforms at (a). linear load, and (b). non-linear loads [4].](image)

2.4. Total Harmonic Distortion (THD)

THD is the ratio between the rms value of all harmonic components to the rms value of the fundamental, THD is usually expressed in terms of percent (% THD). THD is expressed in equation (1):

\[
\text{THD} = \frac{\sqrt{\sum_{n=2}^{N} V_n^2}}{V_1}\times 100
\]
The THD is the rms value of the harmonic order component and M1 is the rms value of the fundamental component. % VTHD is the percentage of the total amount of voltage distorted by the harmonics and % ITHD is the percentage of the total amount of current distorted by the harmonics.

The rms value itself can be obtained if the rms value of the first harmonic component and the THD value is known by equation [4,6,7]:

\[
\text{rms} = \sqrt{\sum_{h=1}^{h_{\text{max}}} M^2 h} = M_1 \sqrt{1 + \text{THD}^2}
\]  

2.5. IEEE 519-2014 voltage THD standard

The THD standard for voltage is based on the IEEE 519-2014 standard regarding the maximum limit value of voltage harmonic distortion in the electrical system can be seen in Table 1 [4,6].

| Bus Voltage (V) at PCC | Individual Harmonic (%) | Total Harmonic Distortion (%) |
|------------------------|--------------------------|-------------------------------|
| \( V \leq 1 \text{ kV} \) | 5.0 | 8.0 |
| 1 kV < \( V < 69 \text{ kV} \) | 3.0 | 5.0 |
| 69 kV < \( V < 161 \text{ kV} \) | 1.5 | 2.5 |
| 161 kV < \( V \) | 1.0 | 1.5 |

2.6. IEEE 519-2014 current THD standard

The current THD limit is recommended for customers connected to systems where the voltage ranges from 120 V to 169 kV according to the short circuit ratio (See Table 2) [4,6,8]. Short Circuit Ratio can be calculated by:

\[
\text{Short Circuit Ratio} = \frac{I_{sc}}{I_L}
\]  

\( I_{sc} \) is a short circuit current which can be determined by equation (4):

\[
I_{sc} = \frac{1000 \times \text{MVA}}{\sqrt{3} \text{kV}}
\]  

\( I_L \) is the full load current which can be determined by equation (5):

\[
I_L = \frac{P}{\text{PF} \sqrt{3} \text{kV}}
\]

The real power and line voltage represent the three-phase short circuit capacity in MegaVoltAmpere and KiloVolts.

| Maximum Harmonic Current Distortion (MHCD) |
|-------------------------------------------|
| Individual Harmonic Order (IHD)           |
| \( I_{sc}/I_L \) | 3 \( \leq h \leq 11 \) | 11 \( \leq h \leq 17 \) | 17 \( \leq h \leq 23 \) | 23 \( \leq h \leq 35 \) | 35 \( \leq h \leq 50 \) | THD (%) |
| < 20<sup>o</sup> | 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 |
| \( \geq 1000 \) | 15.0 | 7.0 | 6.0 | 2.5 | 1.4 | 20.0 |
2.7. Passive filter

Harmonic filters are used to reduce the THD of non-compliant voltages and currents, improve the power factor and reduce the frequency amplitude of harmonic voltages and currents.

Passive filters have resistance (R), inductance (L) and capacitance (C) elements configured and installed to control harmonics. Passive filters are widely used to compensate for reactive power losses due to harmonics in the installation system [3,9,10].

The single tuned filter is arranged with the RLC series circuit. The reactor of the Single Tuned Filter can be expressed by equation (6):

\[ X_{\text{filter}} = \frac{V^2}{Q_c} \]  

(6)

Determining the compensated reactive power requires calculating the initial power factor \((p_f_0)\) and the final power factor \((p_f_1)\) averages.

\[ Q_c = P \left( \tan \theta_{\text{initial}} - \tan \theta_{\text{final}} \right) \]  

(7)

Find the quantity of capacitive reactance with equation (8):

\[ X_C = \frac{X_{\text{filter}} h^2}{h^2 - 1} \]  

(8)

Calculation of the required capacitor and inductor ratings can be found with equations (9) to (11):

\[ C = \frac{1}{2\pi f X_C} \]  

(9)

\[ X_L = \frac{X_C}{h^2} \]  

(10)

\[ L = \frac{X_L}{2\pi f} \]  

(11)

Figure 3 shows a single tuned filter consisting of inductor and capacitor components connected in series.

![Figure 3. Single tuned filter [6].](image)

3. Research methodology

In this research, the method used is quantitative method. In the process of collecting quantitative data in this study, it can be seen from direct measurement using a Power Quality Analyzer (PQA) measuring instrument. Measurements were carried out in three Main Distribution Panels (MDP) found at the RSU UKI and the measuring time was for six days, from Monday to Saturday. The results of the data obtained through direct measurements at the RSU UKI will be analyzed and data processing is carried out, to be able to see the quality of the electric power in good condition and meet the IEEE-519-2014 standards or not meet the standards. The data being analyzed is the THD of the voltage and current on each of the Main Distribution Panels. The THD of a voltage or current that does not meet the standards will be simulated using the MATLAB application to reduce the THD, so that the quality of the electrical power meets the predetermined standards.
4. Measurement and analysis results
The electricity system at RSU UKI is supplied from the PLN network and two generators, each of which has a capacity of 200KVA in the new building and a capacity of 250 KVA in the old building of the RSU UKI. There are two transformers that supply loads to the three MDP’s with their respective capacities being MDP A (197 kVA), MDP B (197 kVA) and MDP C (329 kVA). From each MDP, electrical power is then channeled to ± 19 Sub Distribution Panels (SDP) RSU UKI.

4.1. THD voltage according to IEEE 519-2014 standard
The maximum limit of the voltage harmonic standard (THDv) based on IEEE 519-2014 can be seen in Table 3 and to determine the maximum limit of THD voltage seen from the secondary side of the transformer (PCC) that supplies loads on MDP of 400 V, so that the IEEE 519-2014 Standard table which is used is $V \leq 1kV$ with a maximum limit of 8% THD voltage.

| MDP | Phase | THD Voltage (THDv) | IEEE Standard 519-2014 | Remarks |
|-----|-------|--------------------|------------------------|---------|
| MDP A | R     | 1.3170              | 8%                     | comply with standards |
|      | S     | 1.0870              | 8%                     | comply with standards |
|      | T     | 0.7872              | 8%                     | comply with standards |
| MDP B | R     | 2.4263              | 8%                     | comply with standards |
|      | S     | 1.9336              | 8%                     | comply with standards |
|      | T     | 2.1596              | 8%                     | comply with standards |
| MDP C | R     | 1.0816              | 8%                     | comply with standards |
|      | S     | 1.1973              | 8%                     | comply with standards |
|      | T     | 0.9078              | 8%                     | comply with standards |

Table 3. THDv measurement results with IEEE 519-2014 standards.

| MDP | Phase | THD Voltage (THDv) | IEEE Standard 519-2014 | Remarks |
|-----|-------|--------------------|------------------------|---------|
| MDP A | R     | 1.2676              | 8%                     | comply with standards |
|      | S     | 0.8193              | 8%                     | comply with standards |
|      | T     | 0.7013              | 8%                     | comply with standards |
| MDP B | S     | 1.6733              | 8%                     | comply with standards |
|      | T     | 1.3360              | 8%                     | comply with standards |
|      | R     | 1.0157              | 8%                     | comply with standards |
| MDP C | S     | 0.8791              | 8%                     | comply with standards |
|      | T     | 0.8178              | 8%                     | comply with standards |

Table 4. THDv measurement results with IEEE 519-2014 standards.

Tables 3 and 4 show the results of the comparison of the THD voltage with the IEEE 519-2014 Standard. The results of the THD measurement for each MDP and its phase meet the standard or the THD value does not exceed the standard used.

4.2. THD current is based on IEEE 519-2014 standard
The IEEE 519-2014 standard for current THD requires calculating the value of Short Circuit Ratio (to determine the maximum current THD limit, by knowing the value first $(SC_{ratio})I_S/I_L$).

The results of THD measurements for each MDP exceed the maximum limit of 5%.
Table 5. THDi measurement results with IEEE 519-2014 standards.

| MDP  | Phase | THD Current (THDi) | IEEE Standard 519-2014 | Remarks                  |
|------|-------|--------------------|-------------------------|--------------------------|
| MDP A| R     | 7.0410             | 5%                      | not comply with the Standards |
|      | S     | 6.3626             | 5%                      | not comply with the Standards |
|      | T     | 5.9493             | 5%                      | not comply with the Standards |
|      | R     | 8.5473             | 5%                      | not comply with the Standards |
| MDP B| S     | 5.3696             | 5%                      | not comply with the Standards |
|      | T     | 8.3796             | 5%                      | not comply with the Standards |
|      | R     | 6.3580             | 5%                      | not comply with the Standards |
| MDP C| S     | 7.1083             | 5%                      | not comply with the Standards |
|      | T     | 5.3073             | 5%                      | not comply with the Standards |

Table 6. THDi measurement results with IEEE 519-2014 standards.

| MDP  | Phase | THD Current (THDi) | IEEE Standard 519-2014 | Remarks                  |
|------|-------|--------------------|-------------------------|--------------------------|
| MDP A| R     | 7.3796             | 5%                      | not comply with the Standards |
|      | S     | 7.0013             | 5%                      | not comply with the Standards |
|      | T     | 6.8423             | 5%                      | not comply with the Standards |
|      | R     | 7.7847             | 5%                      | not comply with the Standards |
| MDP B| S     | 6.8327             | 5%                      | not comply with the Standards |
|      | T     | 8.7347             | 5%                      | not comply with the Standards |
|      | R     | 8.3373             | 5%                      | not comply with the Standards |
| MDP C| S     | 9.2363             | 5%                      | not comply with the Standards |
|      | T     | 7.4943             | 5%                      | not comply with the Standards |

Tables 5 and 6 show the results of the comparison of the current THD standard with the maximum limit set by IEEE 519-2014, which is 5%, indicating that the current THD in the three MDP RSU UKI exceeds the standard limit, then it is necessary to make a filter simulation using the MATLAB application.

4.3. Filter simulation results

Figure 4 shows a single tuned passive filter simulation on MDP A, there is a harmonic source from the 3rd to 13th order. The passive filter circuits used are L and C. This simulation image is also applied to other MDP’s, only different values of the filter component are calculated.

Figure 4. Single tuned filter simulation.

4.4. THD current measurement and simulation to IEEE 519-2014 standard

The results of installing a single tuned filter show a decrease in the THD of the current on each MDP, so that the simulation results will be compared with the IEEE 519-2014 standard to show that the current THD has met the standards or has not met the set standards.
Table 7 shows the THD of the measurement current that has been averaged and the THD of the simulation result before installing the filter has a difference that is not too far away, namely around 0.77% - 1.54%, but still passes the predetermined standard.

| MDP   | THD Current | IEEE 519-2014 Standard | Remarks                  |
|-------|-------------|-------------------------|--------------------------|
|       | Measurement (%) | Simulation (%)       |                          |
| MDP A | 6.76%       | 5.99%                   | 5%                       | not comply with the Standards |
| MDP B | 7.608%      | 6.66%                   | 5%                       | not comply with the Standards |
| MDP C | 7.35%       | 5.81%                   | 5%                       | not comply with the Standards |

Table 8 shows the current THD after being simulated with a single tuned filter at each MDP’s of the RSU UKI. The simulation results are compared with the IEEE 519-2014 standard and show that the current THD has decreased and has met the standard.

| MDP   | THD Current of Filter Simulation Results | IEEE 519-2014 Standard | Remarks (After Filter) |
|-------|----------------------------------------|-------------------------|------------------------|
|       | Before (%)                      | After (%)               |                         |
| MDP A | 5.99%                          | 1.72%                   | 5%                      | comply with standards       |
| MDP B | 6.66%                          | 0.64%                   | 5%                      | comply with standards       |
| MDP C | 5.81%                          | 1.30%                   | 5%                      | comply with standards       |

5. Conclusion
- The results of the THD analysis of the voltage at three MDP’s at the RSU UKI meet the standards set in IEEE 519-2014 with a maximum THD limit of 8% for voltages below 1kV, while the current THD does not meet IEEE 519-2014 standards with a maximum limit of 5% THD for calculations below 20. The THD Voltage results varied between 0.701% - 2.42% and the current THD was between 5.3% - 9.2% ($S_{\text{ratio}}$).
- Current THD that does not meet IEEE 519-2014 standards is made filter simulation to reduce THD so that it meets predetermined standards. The filter simulation design uses a single tuned filter on three MDP’s whose THD currents do not meet the standard. The filter simulation results obtained that the THD of current in each MDP, namely: MDP A of 1.72%, MDP B of 0.64% and MDP C of 1.30% at MDPs RSU UKI have met the standards.

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