Reducing of total harmonic distortion by simulating passive filters to suppress harmonic currents with the case: Faculty of Engineering Building, Universitas Kristen Indonesia Jakarta

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Abstract. Today’s electrical appliances use power electronics to save electricity. However, this equipment generates non-sinusoidal current, causing wave defect, expressed as total harmonic distortion (THD). As the %THD increases, the greater risk of equipment damage. For this reason, the research was carried out in the Faculty of Engineering Building, Universitas Kristen Indonesia Jakarta (FT UKI Jakarta) where there are many load combinations such as computers, various types of lights, laboratory equipment such as transformers, electric motors and so on. The research was conducted using quantitative method. Data collection is carried out directly in the main panel. Based on the measurement results, the calculation of the maximum load current ($I_L$) and short circuit ($I_{SC}$) is carried out. Through these values, it can be seen that whether the odd dominant harmonic values and orders meets the IEEE 519-2014 standards or not. Calculations and analysis of the measurement results have shown that the %THD$_L$ in the FT UKI building has not meet the standard. Therefore, it is necessary to simulate the filter design to reduce the %THD$_L$, so that the results can meets the IEEE 519-2014 standard, which is below 5%.

1. Introduction

The electrical equipment technology currently has developed rapidly and uses a lot of power electronics to save energy, for example, such as compact fluorescent lamps (CFL), light emitting diode (LED) lamps, and so on. In electrical equipment based on power electronics technology, the input current is non-sinusoidal, contains harmonics, and experiences wave defects called non-linear loads [1].

THD is the percentage value between the total harmonic components and its fundamental components [2]. THD affects the risk of equipment damage [3]. In the FT UKI Building, which consists of 3 floors, there are many non-linear electrical loads such as computers, electric motors, and electrical practices equipment such as generators, and power electronics equipment that can cause harmonic problems.

Study on the elements and levels of harmonics in laboratories and buildings generated by various non-linear loads was carried out by Radzi et al. [4], and a study on the consequences of using non-linear loads in the form of electronic equipment contained in building was carried out by Putra [5]. Koerniawan and Hasanah [6] conducted a study on efforts to emphasize the content of harmonics in the power consumption of buildings, the design of passive filters using the single tuned method to contaminate...
harmonic currents was carried out by Meliala [7] and the study of non-linear loads modeling using a current source methods on the MATLAB Simulink has been carried out by Amalia and Nazir [8].

Many previous studies have been carried out to analyze THD in buildings using the direct measurement method using a power quality analyzer (PQA) measuring instrument, as has been done by Radzi et al. [4], Putra [5], Koerniawan and Hasanah [6], Syafrudin and Rachman [9]. Putra [5] stated that the results of measurement and analysis of the effect of non-linear loads on measurements at the Computer Center Building of Universitas Riau indicate a large %THD. Similar research by Syafrudin and Rachman [9] states that due to non-linear loads causes %THD to exceed the limit of IEEE 519 Standard. Suryadi [10] also said that through the study of current and voltage harmonics at the campus of Politeknik Enjinering Indorama, that the conditions of the harmonic content are above the IEEE 519 Standard. Research by Radzi et al. [4] in 2019 stated that through an observational case study in laboratory and office buildings, it was found that the THD level exceeds the maximum limit set by the standard. However, the studies above have not designed and made harmonic filters to reduce %THD levels that exceed the IEEE 519 Standard.

Amalia and Nazir [8] has developed a comparative study on 3-phase non-linear load modeling on Simulink MATLAB for laboratory testing (3-phase non-linear load) using simulation modeling methodology with harmonic current source method using harmonic current data (with each current source representing one harmonic order), where this research is needed to representing the real harmonic source (non-linear load) into the simulation which will be used to create a harmonic filter simulation design.

In Koerniawan and Hasanah [6], through the study of harmonics on the use of electricity in the Building of STT PLN Jakarta, the calculation of component values was carried out to design a harmonic filter. However, in this research, the filter design is only limited to calculating the value of the components, there are no test results from the implementation of the filter in the system, either through simulation or in direct installation and testing. The calculation of the value of the harmonic filter component only suppress the 3rd harmonic order content.

Based on the references and also the explanation above, it has explained that the application of non-linear loads on a building, especially in buildings that are used for office activities or as an electrical laboratory, have an impact on the amount of %THD value on the building's electrical system. Therefore, it is necessary to make a harmonic filter design to reduce the %THD value so that the possible impact of harmonic distortion on the electrical system (such as equipment damage) can be overcome or minimized.

This study aims to improve THD in the FT UKI Building through \( I_{sc}/I_L \) calculations, so that the dominant harmonic source can be found. Through the dominant harmonic source, the design of the filter created through the simulation, as to reduce THD to meet the IEEE 519-2014 standard.

2. Methods

In this study, quantitative research methodology is used, which is a method for collecting data in numerical and statistical forms, by measuring THD at the FT UKI Building. After going through the data collection process, then data processing is carried out based on the measurement data on the main panel of the FT UKI Building. The data used are the measurement results of voltage and current harmonics on the main panel using the average value for each phase. From this data, it is processed in the form of a bar chart and tabulation, so that the value and order of the voltage and current harmonics per phase can be found for each floor. Based on the data from the measurement results for each phase, calculations are carried out regarding the maximum load current \( I_L \) and short circuit current \( I_{sc} \). Through the \( I_{sc}/I_L \) value, it can be seen whether the harmonic value (for odd orders) in the FT UKI Building meets the IEEE Standard 519-2014 [11], and it can also be seen the value and order of the dominant harmonics that do not meet the criteria of the IEEE Standard 519-2014. After going through the calculation, passive harmonic filters are designed to reduce the THD [12] based on the dominant harmonic order which does not meet the criteria of IEEE 519-2014 Standard, through simulation. Then,
the research results are processed and analyzed to obtain conclusions, which will clarify the picture of the object under study.

3. Results and discussions

3.1. Measurement data based on the electrical parameters of the FT UKI Building

From the measurements on the main panel for 1st, 2nd, and 3rd floors in the FT UKI Building, the data obtained from the measurement results are tabulated in table 1.

| Parameter | 1st floor | 2nd floor | 3rd floor |
|-----------|-----------|-----------|-----------|
|           | R         | S         | T         | R         | S         | T         | R         | S         | T         |
| V rms (V) | 238.7     | 241.7     | 237.6     | 238.8     | 240.5     | 237       | 238.4     | 238.9     | 235       |
| I rms (A) | 65.33     | 47.1      | 53.39     | 48.6      | 51.91     | 44.45     | 29.33     | 51.07     | 47.99     |
| THD\(_V\) (%) | 1.1       | 0.95      | 1.037     | 1.02      | 0.88      | 1.166     | 1.095     | 0.923     |
| THD\(_I\) (%) | 6.09      | 6.09      | 5.445     | 6.812     | 5.688     | 5.839     | 13.28     | 7.182     | 6.077     |
| P (kW)   | 14.58     | 10.13     | 11.27     | 10.52     | 11.5      | 10.13     | 6.865     | 11.2      | 10.96     |
| S (kVA)  | 15.60     | 11.38     | 12.69     | 11.6      | 12.48     | 10.53     | 6.99      | 12.2      | 11.27     |
| Q (kVAR) | 5.548     | 5.187     | 5.831     | 4.89      | 4.852     | 2.891     | 1.311     | 4.826     | 2.661     |
| PF       | 0.934     | 0.889     | 0.887     | 0.906     | 0.92      | 0.961     | 0.981     | 0.917     | 0.971     |

Table 1 shows the results of measurements on 1st, 2nd, and 3rd floors by assuming all electrical loads are turned on, for the rms voltage (V), rms current (A), THD\(_V\)\%, THD\(_I\)\%, frequency (Hz), active power (kW), reactive power (kVAR), apparent power (VA) and power factor in phases R, S, T.

3.2. Measurement data of the harmonic content in the FT UKI building

Results of the harmonic content measured by a power quality analyzer (PQA) Kyoritsu 6315 include voltage and current harmonics for each phase R, S, T. Based on the data of the harmonic content measured using PQA Kyoritsu 6315 for each phase R, S, T, assuming that all electrical loads are turned on before using the filter, on the 1st floor, THD\(_I\) phase R = 6.55% and phase S = 7.35%. The results of the measurement of current harmonics on the 2nd floor, THD\(_I\) phase R = 6.89%, phase S = 5.77%, and phase T = 5.86%. The results of the measurement of current harmonics on the 3rd floor, THD\(_I\) phase R = 13.72%, phase S = 7.21% and phase T = 6.17%.

The greatest harmonic values are found in the phase S for voltage and in the phase R for current. This can happen because there is an effect of load on each phase.

3.3. Ratio of the maximum load current (I\(_L\)) and the short circuit current (I\(_SC\))

Referring to the IEEE Standard 519-2014, the % THD\(_V\) and % THD\(_I\) in the FT UKI Building at this time can be known by the I\(_SC\)/I\(_L\) ratio in equation (1) and equation (2).

\[
I_{SC} = \frac{1000 \times S}{\sqrt{3}V_L} A \quad (1)
\]

\[
I_L = \frac{P}{PF \sqrt[3]{V_L}} A \quad (2)
\]

From the results of I\(_SC\)/I\(_L\) calculations, based on the IEEE 519-2014, the standards used as the basis for the review are as follows:
3.4. Calculation of the harmonic filter components

In order to reduce the \( \%\text{THD}_1 \) value, the author has chosen an LC passive harmonic filter referring to Shah [12]. The following criteria are used to determine the harmonic filter component value required for simulations, related to the reduction of THD values that do not meet the IEEE 519-2014 standards, as shown in Table 2.

| Floor | Phase | V  | f(Hz) | PFi | PFs | P(W) | \( \Phi_i \) | m | n(%) | Qc | Xc (\( \Omega \)) | C(F) | Xs (\( \Omega \)) | L(H) |
|-------|-------|----|-------|-----|-----|------|---------|---|-----|----|--------------|-----|---------------|-----|
| 1st   | R     | 238.7 | 50    | 0.927 | 0.9345 | 14580 | 22.10 | 20.8 | 5 | 4.75 | 332 | 1.71 | 0.00 | 0.3 | 0.001 |
|       | S     | 241.7 | 50    | 0.89    | 0.8905 | 10130 | 27.18 | 27.0 | 5 | 4.75 | 770 | 7.57 | 0.00 | 1.5 | 0.005 |
|       | T     | 237.6 | 50    | 0.888 | 0.8945 | 11270 | 27.43 | 26.5 | - | - | 881 | 0.64 | 0.00 | - | - |
| 2nd   | R     | 238.8 | 50    | 0.837 | 0.9064 | 10520 | 33.22 | 24.9 | 5 | 4.75 | 412 | 1.38 | 0.00 | 0.2 | 9E-04 |
|       | S     | 240.5 | 50    | 0.872 | 0.9208 | 11500 | 29.35 | 22.9 | 5 | 4.75 | 492 | 11.7 | 0.00 | 2.4 | 0.008 |
|       | T     | 237  | 50    | 0.918 | 0.9611 | 10130 | 23.35 | 16.0 | 3 | 2.85 | 436 | 1.28 | 0.00 | 0.4 | 0.001 |
| 3rd   | R     | 238.4 | 50    | 0.979 | 0.9817 | 6865 | 11.79 | 10.9 | 5 | 4.75 | 399 | 0.14 | 0.02 | 0.0 | 1E-04 |
|       | S     | 238.9 | 50    | 0.78 | 0.9179 | 11200 | 38.73 | 23.3 | 5 | 4.75 | 418 | 13.6 | 0.00 | 0.2 | 9E-04 |
|       | T     | 235  | 50    | 0.955 | 0.9713 | 10960 | 17.29 | 13.7 | 3 | 2.85 | 828 | 0.06 | 0.04 | 0.0 | 7E-05 |

Table 2 shows each harmonic order that does not meet the standards, and the calculation results for the LC component for designing a passive filter.

3.5. Analysis of the result data based on the electrical parameters of the FT UKI building

Based on the measurement data tabulated in table 1, it can be observed that the electrical load conditions in the FT UKI Building are not balanced. This is indicated by the difference in the value of current and power in each phase. The greatest loads are found on the 1st floor in phase R, where the current in phase R = 63.33 Ampere.

The allowable voltage from the voltage standard of 220 V, which is decrease by 10% and increase by 5% is the exposure limit, which ranges between 198 - 231 V. The voltage measurement results on the main panel of FT UKI Building for phase R, S, T is above the allowable threshold.

3.6. Analysis of the harmonic filter simulation results

Based on the data results from the calculation of the LC passive harmonic filter component, a simulation was made on the MATLAB Simulink which is shown in figure 1 and figure 2.
Figure 1. Harmonic filter simulation circuit.

Figure 1 shows the circuit of simulated harmonic filters before each phase is integrated. Current harmonic sources are modeled by current sources arranged in the "Subsystem" block. The filters are arranged in the "LC Subsystem Filter" block, which is installed parallel to the current harmonic source.

Figure 2. Integrated harmonics filter simulation for each phase at FT UKI Building.

Figure 2 shows the circuit of simulations at the FT UKI Building for each floor. The circuit simulation is based on the data obtained in the previous calculations.

The THD measurement results after using the harmonic filter on the 1st floor at the phase R = 3.80%, while the THD value of the phase S = 8.57%. On the 2nd floor, the THD value of the phase R = 3.46%, while the THD value of the phase S = 6.76%, and the THD value of the phase T = 1.53%. On the 3rd floor, the THD value of the phase R = 0.69%, the THD value of the phase S = 4.05%, and the THD value of the phase T = 0.68%.

4. Conclusion
Based on the result from the measured data and simulations that have been carried out on the main panel of the FT UKI building, it can be concluded overall that the simulation results shows not all current THD values can be reduced, but the average current THD value for each phase has decreased and these results meet the standard of IEEE 519-2014, which is below 5%.
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