Effects of using passive filter for reduce electrical load harmonics

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Abstract. Due to the use of electrical current load that uses a lot of electronic components (passive non-linear electrical loads), so the impact will cause harmonics in the electrical network system. These harmonics can unwittingly cause a relatively large loss in electrical energy consumption and can lower the power factor of an electrical installation. Limits how much the harmonic distortion that is installed on the load adjusted to the IEEE 519-1992 standard. The study was conducted by taking data on a network of electrical installation of a building using measuring devices Fluke 43B Power Quality Analyser. The data is then processed and consulted with the standard IEEE 519-1992. Once the data has a discrepancy with the standard, further made the filter design using linear passive components. The design is then installed on the network installation by means of simulated order harmonic losses can be overcome so that the circuit meets the IEEE standard installation by changing the parameters of the linear load L and C. The results of this study indicate that THDi value decreased after the installation of filters for phase R fell by 9.39%, the S phase decreased by 7.54% and for the T phase decreased by 16.88%. So that meets the IEEE standard by 15%.

1. Introduction
Harmonics is a phenomenon arising from the operation of the non-linear electrical load, which is a source of wave formation at high frequencies that are multiples of its fundamental frequency as 100 Hz, 150 Hz, 200 Hz, 300 Hz, and so on. It can interfere with the electrical system at the fundamental frequency is 50 Hz, so that the current and voltage waveforms are purely sinusoidal ideally will become disabled as a result of harmonic distortion that occurs. The main effect of voltage and current harmonics in the power system [2] are (1) Addition of harmonics due to the level of the series and parallel resonant relationship, (2) The decrease in the efficiency of power generators, transmission and utilization, (3) Interference with telephone circuits (telecommunications) and transmitter as the zero sequence harmonic currents, (4) errors in the meter-gauge rotating disc of energy meter. Harmonics need special attention because they can unwittingly lead to relatively large losses, especially on large energy users such as office buildings and industrial sectors. To dampen harmonics on non-linear load can be used filters. The use of filters in a power system with a high content of harmonics will be very helpful in dealing with disruptions caused by the effect of the harmonics [3]. Filter is a device that has a function to skip a certain frequency. With the addition of a filter on a power system containing the sources of harmonics, harmonic currents then spread to the entire network can be reduced as small as possible. In addition, the frequency of the fundamental harmonic filter can compensate the reactive power and also used to improve the power factor of the electricity grid system [4]. Based on the above
the writer is interested in conducting research as outlined in the title: "Planning Passive Linear Filters To Reduce Electric Charging of Non Linear Harmonics". The problem in this study is: "How do I cope with Harmonics on a network of electrical installations caused by the use of non-linear electrical loads?" In order to widen the issues discussed are not too large, then the scope of the discussion is limited to the analysis of harmonic voltage (THDV) and harmonics current (THDi) as well as the drafting of the filter circuit PSIM simulation program to simulate the measurement results [9].

2. Methodology
Step-by-step outline of research described in the flowchart below.

![Flowchart Research](image)

Data collection was conducted in this study is to perform a direct measurement of the field at the side of the panel supply electrical installations at the time of the operation state. Measuring instruments used for data collection in this study is the Fluke 43B Power Quality Analyzer. This measure can be used to measure current, voltage, power, power factor, harmonics (THD) and others.

Measurement data is limited to the data analyzed and % THDV %THDi. Data THDV measurement results compared to standard IEEE No. 519 -1992 on voltage. Value % is permitted THDV IEEE No. 519-1992 for voltages below 68 kV is <5%, if the measurement value exceeds 5% of the declared voltage harmonic distortion has occurred on the system. While for the data % THDi compared to standard IEEE No. 519 -1992 of the current [5]. Before comparing with the standard, it must first be sought value ISC/IL. IL is the current value of the measurement results while the value of ISC is the short circuit current value, which can be found using the following formula [4]:

\[
I_{sc} = \frac{Full \ Load \ Current}{Impedance} = \frac{I_{fl}}{Z} \quad \text{and} \quad I_{fl} = \frac{S}{380 \times \sqrt{3}} \times 1000
\]

Weight used in the modeling circuit includes: a resistive load resistor, inductor as the load inductor and bridge diode as a source of harmonics. Resistor and inductor values can be determined from the measured data that is of value Vrms, Irms, frequency and cos φ [7].
In this modeling series filter consists of input filters and output filters. Installation of the filter on the input side aims to reduce the current harmonics that occur at the source, while mounting the filter on the output side aims to reduce harmonics that occur at the rectifier output voltage or the load [4].

3. Results

Data measurement results can be seen in the table below.

| Parameters       | Phase R | Phase S | Phase T |
|------------------|---------|---------|---------|
| Voltage rms (V)  | 213.8   | 217.8   | 219.7   |
| Current rms (A)  | 45.8    | 81.1    | 62.5    |
| THDv (%)         | 5.3     | 5.7     | 5.3     |
| THDi (%)         | 23      | 7.4     | 15.3    |
| Frequency (Hz)   | 50      | 49.9    | 50.1    |
| P (kW)           | 9.2     | 16.9    | 13.4    |
| S (kVA)          | 9.7     | 17.0    | 13.7    |
| Q (kVAR)         | 3.0     | 2.7     | 2.9     |
| PF               | 0.95    | 0.99    | 0.98    |
| DPF              | 0.98    | 1       | 1       |

Graphic measurement results of each phase can be explained in the following picture:

*Phase R*

![Graph Voltage and Current](image)

*Figure 2. Graph Voltage and Current*

![Graph Harmonic of Current](image)

*Figure 3. Graph Harmonic of Current*

*Phase S*

![Graph Harmonic of Voltage](image)

*Figure 4. Graph Harmonic of Voltage*

![Graph Voltage and Current](image)

*Figure 5. Graph Voltage and Current*
Standard %THDv allowed by the IEEE Standards No. 519-1992 for voltages below 68 kV was < 5%. The measurement data are:

| Phase   | THDV (%) | Standard THDv (%) | Analysis     |
|---------|----------|-------------------|--------------|
| Phase R | 5.3      | 5                 | Not suitable |
| Phase S | 5.7      | 5                 | Not suitable |
| Phase T | 5.3      | 5                 | Not suitable |

Based on the above data, the value of the average measurement THDV not in accordance with the IEEE 519-1992 standard which exceeds the value of 5%. To find current standard % THD can be determined by calculating the ISC / IL, where ISC is the short circuit current and the maximum current IL. ISC value can be determined by the calculation below and to the value derived from the value of IL. IRMS measurement results using 43B Power Quality Analyzer. The results of the calculation can determine the value of % THDi by looking at Table 2 current standard IEEE 519-1992.

Following calculation to determine the value of ISC: Note, Power Transformer = 400 kVA; Working voltage of 20,000 V / 380 V / 220 V; Impedance (Z) = 4%. Calculation of Short-circuit Current:
\[ I_{SC} = \frac{\text{Full Load Current}}{\text{Impedance} Z} \]

\[ I_{SC} = \frac{I_{FL}}{Z}; \quad I_{FL} = \frac{1000}{380 \times 3} \]

\[ = 15.193,425 \text{ A}; \quad \text{So the value of } I_{SC} \text{ is } 15193.425 \text{ A} \]

Table 3 Results Analysis of Measurement THDi

| At    | \( I_{SC} \) (A) | \( I_{L} \) (A) | \( \frac{I_{SC}}{I_{L}} \) | Measurement THDI (%) | Standard THDI (%) | Analysis       |
|-------|-------------------|-----------------|--------------------------|----------------------|-------------------|------------------|
| Phase R | 13.11             | 15.193,425     | 45.8                     | 331.73               | 23                | 15 notsuitable   |
| Phase S | 13.31             | 15.193,425     | 81.1                     | 187.34               | 7.4               | 15 appropriate   |
| Phase T | 13.57             | 15.193,425     | 62.5                     | 243.09               | 15.3              | 15 notsuitable   |

Figure 12. Graph Results Measurement THDi

Based on the above data, it can be concluded that most of the measured values THDi not in accordance with the IEEE standard 519-1992 which exceeds the value of 15%. For the R phase, the measurement data THDi measured value at 13:11 hours is equal to 23%. For the S phase, the measurement data THDi value measured at 13:31 hours that is equal to 7.4% of this value does not exceed the standard. For phase T, the measurement data THDi measured value at 13:57 hours that is 15.3%.

Measurement data is then made modeling using PSIM 4.1 program. In the modeling will be made a model with a large load current load current approaches the measurement results. Load modeling is made using 1-phase full-wave rectifier with load R and L are used to describe the harmonic currents. Here will be described a series of modeling, waveform, shape FFT spectrum analysis results of PSIM program and the current value of each order harmonics of each measurement before and after using the filter using a filter.

To create a network test on PSIM required parameters on components used in network modeling. Component calculation load on each phase, taking the measurement data can be explained as follows. Phase R. When the voltage of 217.1 volts, current is 55.4 amperes, frequency of 50.1 Hz, and \( \cos \phi \) of 0.97 lagging, then raised the resistance of 3.8 ohms and inductance of 3.02 mH. Similarly to the S phase, when the voltage of 223.8 volts, current is 44.3 amperes, and setting frequency of 49.9 Hz, and \( \cos \phi \) of 0.96 lagging, then raised the resistance of 4.85 ohms and inductance of 4.5 mH. As for Phase T, when voltage of 218 volts, current at 56.5 ampere, and setting frequency 49.9 Hz, and \( \cos \phi \) of 0.98 lagging, then raised the resistance of 3.78 ohms and inductance of 2.46 mH.

3.1. Calculation filter L and C

3.1.1. filter Input
Filter on the input side aims to reduce harmonics that occur in the source stream. To determine the value of the filter L and C, can be calculated using the formula:

\[ f_0 = \frac{1}{2\pi \sqrt{LC}} \]

The result of the calculation gives a chance filter with resonance frequency of 50 Hz, and 20 mH inductance value, the value of C of 352 uF.

3.1.2. filter Output
Installation of filters on the output side aiming to reduce the amount of harmonics that occur in the rectifier output voltage or the load. The formula for determining the value of L and C in the same filter
as the output filter insert. Resonance frequency of the output filter to be set to 100 Hz and L = 5 mH, the obtained C of 507 uF.
In a series of simulations were made to approach the ideal measurement values, then there are some components that are adjusted value is the value of L in S phase and phase T.

![Network Modeling Before Using Filter](image1)

Figure 13. Network Modeling Before Using Filter

Modeling the circuit in the image above drawing load on the measurement, where harmonic load on each phase containing the third and fifth harmonics as well as the seventh. In a series of surrogate modeling made on 4 pulse rectifier load with a load R, L which can result in the third and fifth harmonics. Data obtained from the simulation results that we are setting the value of the measurement approach. The simulation results above produces the following waveform before using filters.

![Figure 14 Form of Current Wave](image2)
![Figure 15 Shape Spectrum Current Harmonic](image3)

From Figure 14, it appears that wave form is characterized by containing ripple waveform is not smooth, it shows that the system of harmonic disturbances. With FFT analysis will be more visible harmonics that occur, as it is known-order harmonics where the greatest. As shown in Figure 15, the shape of the current spectrum is not flat on the odd-order harmonics multiples.

From the above simulation results obtained percentage value THDi flowing in each phase is the phase of 18:38% R, S phase of 19:19% and 22:38% for the T phase, where the value exceeds the specified standard (15%).

3.2. After a series of Simulation Filter Installation

![Network Modeling After Using Filters](image4)

Figure 16. Network Modeling After Using Filters
Network modeling on the network in picture 16 have been added to the input filter on the source and output load filter consisting of components A and C, the shape of the waveform and spectral flow after installation filters as below.

![Figure 17. Shape of Current Wave](image)

![Figure 18. Form of Spectrum Current Harmonics](image)

From the above simulation results obtained percentage value THDi flowing in each phase after the phase R filter mounted at 8.68%, the S phase by 12.4% and amounted to 8.73% T phase, so that the value meets the specified standards (15%). From the simulation results it is known that the value of harmonic currents that occur at each order harmonics decreased significantly.

To find large changes in the value of harmonic currents before and after the installation of filters at each phase, can be seen in the following table.

| Order Harmonics | Measurement results [ampere] | Before Filter Simulation Results [ampere] | Simulation Results After Filter [ampere] |
|----------------|-----------------------------|------------------------------------------|----------------------------------------|
| 1              | 52.2                        | 50.13                                    | 31.18                                  |
| 3              | 8.4                         | 7.25                                     | 2.46                                   |
| 5              | 3.3                         | 3.8                                      | 0.9                                    |
| 7              | 2.3                         | 2.61                                     | 0.57                                   |
| 9              | 1.6                         | 1.9                                      | 0.42                                   |
| 11             | 1.1                         | 1.57                                     | 0.33                                   |
| 13             | 0.1                         | 1.2                                      | 0.28                                   |
| 15             | 0.6                         | 1.1                                      | 0.24                                   |
| 17             | 0                           | 0.9                                      | 0.21                                   |
| 19             | 0.1                         | 0.8                                      | 0.19                                   |
| **THDI**       | **18.26%**                  | **18.28%**                               | **8.89%**                              |

Table 4 shows that the total current harmonic (THDi) for phase R after the installation of the filter is equal to 8.89%. Whereas before the installation of the total current harmonic filters (THDi) is approximately 18.28% where there has been a decline of 9.39%. So the value THDi meet IEEE 519-1992 standard that is equal to 15%.

| Order Harmonics | Measurement results [ampere] | Before Filter Simulation Results [ampere] | Simulation Results After Filter [ampere] |
|----------------|-----------------------------|------------------------------------------|----------------------------------------|
| 1              | 41.2                        | 38.54                                    | 34.97                                  |
| 3              | 7.6                         | 4.98                                     | 3.48                                   |
| 5              | 3.6                         | 3.3                                      | 1.5                                    |
| 7              | 2.1                         | 2.67                                     | 0.96                                   |
| 9              | 1.21                        | 2.07                                     | 0.75                                   |
| 11             | 1.03                        | 1.67                                     | 0.62                                   |
Table 5 shows that the total current harmonic (THDi) in the S phase after the installation of the filter is equal to 11.78%. Whereas before the installation of the total current harmonic filters (THDi) is approximately 19.32% where there has been a decline of 7.54%. So the value of THDi meet IEEE 519-1992 standard that is equal to 15%

Table 6 Comparison of Harmonic Phase Value Phase T

| Orde Harmonics | Measurement results [ampere] | Before Filter Simulation Results [ampere] | Simulation Results After Filter [ampere] |
|----------------|-----------------------------|------------------------------------------|-----------------------------------------|
| 1              | 52.8                        | 49.17                                    | 33.76                                   |
| 3              | 8.4                         | 7.91                                     | 1.41                                    |
| 5              | 7.7                         | 4.95                                     | 0.9                                     |
| 7              | 1.2                         | 3.5                                      | 0.53                                    |
| 9              | 0.5                         | 2.7                                      | 0.42                                    |
| 11             | 0.7                         | 2.2                                      | 0.33                                    |
| 13             | 0.8                         | 1.9                                      | 0.27                                    |
| 15             | 0.2                         | 1.7                                      | 0.23                                    |
| 17             | 0.1                         | 1.5                                      | 0.2                                     |
| 19             | 0.1                         | 1.37                                     | 0.18                                    |
| THDI           | 21.82%                      | 22.47%                                   | 5.59%                                   |

Table 6 shows that the total current harmonic (THDi) on phase T after the installation of the filter is equal to 5.59%. Whereas before the installation of the total current harmonic filters (THDi) is approximately 22.47% where there has been a decline of 16.88%. So the THDi meet IEEE 519-1992 standard that is equal to 15%

4. Conclusion

Based on the data of measurement and data analysis can then be concluded as follows:

1. Data from the study showed that the total harmonic current distortion (THDi) measured at the sample panel are out of bounds (above) specified by the IEEE 519-1992 standard (the standard limit of 15%), that for the phase R THDi is the largest of 26.4%; phase S of 21.1%; and to phase T of 21.6%.

2. Data from the study showed that the total harmonic voltage distortion (THDV) are also exceeds the IEEE 519-1992 standard (the standard limit of 5%), which is to phase R of 6.1%; phase S of 5.2%; and to phase T of 5.4%.

3. Based on data resulting from the simulation has been done to show that the decline THDi done after the installation of filters. As the figures decline can be explained as follows: for the phase R down of 9.39% (from 18.28% to 8.89%), to phase S drop by 7.54% (from 19.32% to 11.78%), and phase T down of 16.88% (from 22.47% to 5.59%). As the simulation results show that the third phase of the THDi to meet IEEE 519-1992 standard that is below the 15%.

In connection with these results, the researchers recommended that the building be carried out installation of filters to improve the efficiency of electricity consumption associated with to reduce harmonic interference has occurred.
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