Harmonic reduction by using single-tuned passive filter in plastic processing industry

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Abstract. The using of non-linear loads generated by industrial machines may result inconsistent harmonics that do not reach the IEEE 519 - 1992 standards. This study discusses the use of single-tuned passive filters in reducing harmonics in the plastics processing industry. The system modeling using matlab / simulink simulation resulted in total harmonic distortion (THD) of 15.55%, can be reduced to 4.77% harmonics in accordance with IEEE 519 - 1992 standards. From the simulation results also seen that single-tuned passive filter can reduce the harmonics of the current 82.23% harmonic that wants to be reduced and also can reduce other orders harmonics between 7% to 8%.

1. Introduction

Non-linear loads generated by industrial machinery may result the current harmonics that do not reach to IEEE 519 - 1992 standards[1]. The use of a control device composed of electronic components may cause the electrical load to be non-linear[2], [3]. This is due to the switching process of the components. The problem can be solved by doing a harmonic reduction by using a filter. Harmonics is a phenomenon caused by the operation of a non-linear electric load, where a basic frequency wave of 50 Hz or 60 Hz will occur and also cause the ideal current sinusoidal waveform and voltage wave to be not sinusoidal [4-5].

Previously there were several studies on harmonic reduction. We have conducted a literature study of research on single-tune passive filters. Several studies on the reduction of harmonics in the past researchers have been done in table 1.

In this research, we will do the harmonics reduction at a plastic processing factory. Processing machine used consists of electrical components classified as linear load category and non-linear load. Based on previous research, the harmonics reduction will be done by using a single-tuned passive filter.

Table 1. Passive Filter Researches

| Name             | Title of the Study                                    | Research Field          | Results                                                                 |
|------------------|-------------------------------------------------------|-------------------------|------------------------------------------------------------------------|
| Young Sik Cho et al, 2011[6] | Single-tuned passive harmonics filter design considering variances of tuning and quality factor | Single-tuned Passive Filter | THDi 5 decreased from 72.6% to 7.9%, the 7th harmonics from 61.8% to 11.2%, the 11th harmonics from 20.9% to 4.5%, the 13th harmonics from 13.2% to 2.9% |
2. Methods

2.1 Measurement on PCC panel

To perform the harmonic measurements of the research object was done by using portable measuring instruments and PCC panel. Metering tool used is Metrel MI 2392 Power Q Plus Power Quality Analyzer. Measurements have been made on the object of research by means of direct measurement on PCC load. The results of the measurements obtained can be seen in Table 2.

| Symbol | Name            | L1       | L2       | L3       | Total     | Unit |
|--------|-----------------|----------|----------|----------|-----------|------|
| V      | Voltage         | 234.45   | 238.2    | 235.11   | -         | V    |
| I      | Current         | 365.94   | 383.27   | 396.54   | -         | A    |
| THD V  | Voltage THD     | 5.1187   | 5.4279   | 4.2477   | -         | V    |
| THD I  | Current THD     | 2.1836   | 2.2791   | 1.8068   | -         | %    |
| THD I  | Current THD     | 14.93    | 15.399   | 13.707   | -         | %    |
| P      | Active Power    | 80.508   | 85.617   | 89.085   | 255.21    | kW   |
| Q      | Reactive Power  | 29.65    | 31.694   | 27.498   | 88.842    | kVAR |
| PF     | Power Factor    | 0.94 ind | 0.94 ind | 0.96 ind | 0.94 ind  |      |
| DPF    | Displacement Facto | 0.95 ind | 0.95 ind | 0.96 ind |         | -    |
| S      | Apparent Power  | 85.794   | 91.295   | 93.233   | 270.23    | kVA  |

In this study, it is assumed that a 3 phase load is considered to be balanced and the analysis is performed on only one phase. So the data used in the calculation and analysis is the result of measurement at phase L1.

From the Table 2 measurement results above, it can be seen that the THDi current harmonic content in plastic processing industry load of 14.93%. This condition does not meet the IEEE 519-1992 standard ie the allowable THDi is less than 5%. As the resulting harmonics exceed the limits set by the IEEE 519-1992 standard, this research can be continued for harmonic reduction by using filters.

Figure 1 shows the harmonic wave spectrum of the measurement result. The results of the wave spectrum of harmonic current are randomly shaped so that they could not be identified as pure sinusoidal. This phenomenon is caused by a current disturbance known as harmonic current so it must be reduced so that the harmonic current content can be muffled under the standard set in IEEE 519-1992 standard. The measurement results show the total harmonic current distortion is 14.93% exceeds the IEEE 519-1992 standard limit of 7%.
2.2 Single-tuned passive filter calculation

The calculation of the R, L, C filters used to reduce the current harmonics in this study by using the worst current harmonics exceeding the IEEE 519-1992 harmonic standard limits. The order of harmonics to be reduced is only the 5th order. The 3 phases loads are considered in a balanced state so that simulation and data analysis is done on one phase only, which is selected in phase L1 (phase R).

To determine the capacitor capacity \( Q_c \) it is assumed that the power factor is improved from \( \text{pf}_1 = 0.94 \) to \( \text{pf}_2 = 0.99 \). To calculate the capacitor capacity required as a harmonic filter is:

\[
Q_c = P\{\tan(\cos^{-1}\text{pf}_1) - \tan(\cos^{-1}\text{pf}_2)\} \tag{1}
\]

To determine the reactance of the capacitor \( X_c \) is as follows:

\[
X_c = \frac{\nu^2}{Q_c} = X_c = -\frac{(234.45)^2 \nu}{17748.733 \text{VAR}} = 3.0969423 \Omega \tag{2}
\]

To determine the capacitance of the capacitor \( C \) is as follows:

\[
C = \frac{1}{2\pi f_0 X_c} = \frac{1}{2\pi \times 50 \times 3.0969423} = 1027.8 \mu F \tag{3}
\]

Assuming the quality factor of single-tuned passive filter \( Q \) = 100, then determine the value of resistance \( R \) in the filter as follows:

\[
R = \frac{X_n}{Q} \tag{3}
\]

Based on the calculation of Single-tuned Passive Filters of R, L, C components which will be used in this study to reduce the current harmonics are shown in table 3.

**Table 3. Single-tuned Passive Filter Calculation Results**

| No | Filter Components | Symbol | Unit | Value      |
|----|-------------------|--------|------|-----------|
| 1  | Reactance         | R      | Ω    | 0.0061939 Ω |
| 2  | Inductance        | L      | H    | 0.3943 mH  |
| 3  | Capacitance       | C      | F    | 1027.8 μF  |
2.3 Simulation without using filter

Figure 2 is a series of simulated object research system based on the measurement results. The simulation in figure 2 above is a circuit without using a filter. The circuit simulation results shows individual harmonic as shown in table 4.

![Simulink Simulation without using Filter](image)

**Table 4. Simulation Results without Harmonic Filters (IHDI %)**

| IHDI Order | Measurement | Filterless Simulation | IEEE 519-1992 Standard |
|------------|-------------|-----------------------|-------------------------|
| 1          | 100.00      | 100.00                | 7.0                     |
| 3          | 2.20        | 2.31                  | 7.0                     |
| 5          | 14.22       | 14.97                 | 7.0                     |
| 7          | 2.35        | 2.47                  | 7.0                     |
| 9          | 0.84        | 0.88                  | 7.0                     |
| 11         | 1.21        | 1.27                  | 7.0                     |
| 13         | 1.03        | 1.08                  | 7.0                     |
| 15         | 0.49        | 0.51                  | 7.0                     |
| 17         | 0.84        | 0.88                  | 7.0                     |
| 19         | 1.02        | 1.06                  | 7.0                     |
| 21         | 0.24        | 0.25                  | 7.0                     |
| 23         | 0.81        | 0.84                  | 7.0                     |
| **Total THD** | **14.95** | **15.55**            |                         |

Table 3 shows the result of simulation without using harmonic filter, total recorded current harmonic is 15.55% difference 0.6% from real measurement that is 14.95%. So that the simulation circuit in figure 2 can be illustrated as the condition of the harmonics in the plastics industry undertaken in this study. IHDI value exceeding the IEEE 519-1992 standard limits that must be reduced by using a filter, in Table 3 it appears that only at the first five orders of the current IHDI are well above the IEEE 519-1992 standard limit of 14.97% with the allowed limit being 7%.

![Waveform Graph](image)
The current waveform generated by Matlab / Simulink simulating software without using a filter can be seen in figure 3. It shows that the current wave is not pure sinusoidal, there is a wave ripple and almost forming a square wave.

2.4 Simulation by using single-tuned passive filter

The circuit drawing of Matlab Simulation by using Single-tuned Passive Filter consisting of components R, L and C can be seen as figure 4. Single-tuned Passive filter simulation by using Matlab program is done in several stages same with the filterless simulation, then added with an RLC filter in parallel with load. RLC value has been calculated and obtained value R = 0,0061939 Ω, L = 0, 3943 mH, C = 1027,8 μF. This value became the block parameter value of the RLC filter.

![Diagram of Single-tuned Passive Filter](image)

Figure 4. Matlab/Simulink Simulation by Using Single-Tuned Passive Filter

The result of current harmonic reduction by simulation using single-tuned passive filter shows the magnitude of individual harmonic flow as shown in table 5. Table 5 is the result of simulating current harmonic reduction by using single-tuned passive filter, this filter can reduce the total current harmonics from 15.55% to 4.77%. When it is viewed from individual harmonic currents, the simulation results show that the entire IHD Order of harmonics has been reach the IEEE 519-1992 standard.

| IHD Order | Single-Tuned Passive Filter Simulation | IEE 519-1992 Standard | Description |
|-----------|----------------------------------------|------------------------|-------------|
| 1         | 100,00                                 | 7,0                    | Match       |
| 3         | 2,31                                   | 7,0                    | Match       |
| 5         | 2,66                                   | 7,0                    | Match       |
| 7         | 2,20                                   | 7,0                    | Match       |
| 9         | 0,80                                   | 7,0                    | Match       |
| 11        | 1,17                                   | 3,5                    | Match       |
| 13        | 1,00                                   | 3,5                    | Match       |
| 15        | 0,47                                   | 3,5                    | Match       |
| 17        | 0,81                                   | 2,5                    | Match       |
| 19        | 0,99                                   | 2,5                    | Match       |
| 21        | 0,23                                   | 2,5                    | Match       |
| 23        | 0,78                                   | 1,0                    | Match       |
| **Total THD** | **4,77** |                        |             |

The current waveform generated by using Matlab / Simulink with single-tuned passive filter can be seen in figure 5 shows that the resulting waveform has been sinusoidal shape that also indicating the system has been seperated from current harmonic interference.
Figure 5. Single-Tuned Passive Filter Simulation Test Results Waveform Graph

3. Result and Discussion
Single-tuned Passive Filter can reduce harmonics to fulfill the IEEE 519-1992 standard in each orders. Single-tuned Passive Filter is able to reduce current harmonics from total THD by 15.55% to 4.77%, as shown in figure 6.

Figure 6. Graph of Harmonic Current with IEEE Standard 519-1992

Single-tuned passive filters can also reduce from current harmonics by 15.55% to 4.77%, indicating that the total THD current is reduced by 69.32% from filterless testing results. The filter reduction level in decreasing the harmonicity in each order can be seen in table 6. Table 6 shows that there is no change of harmonic current in 3rd order IHD ie 2.31%. In the 5th order IHD, which is the target of harmonic to be reduced, it can be seen that the single-tuned passive filter can decrease the current harmonics by 82.23% from the current harmonics of 14.97% can be reduced to 2.66%. The decrease of harmonic level on the 7th order IHD was 10.93%, the 9th order was 9.09%. Decrease in current harmonic after filter in 11th order and so on is relatively stable between 7% and 8% of current harmonics before using single-tuned passive filter.
Table 6. Harmonicity Decreasing Rate by Using Single-tuned Passive Filter

| IHD Order | Filterless Simulation (IHDi %) | Simulation by Using Single-tuned Passive Filter (IHDi %) | Decrease Rate by Using Single-tuned Passive Filter |
|-----------|-------------------------------|--------------------------------------------------------|--------------------------------------------------|
| 3         | 2,31                          | 2,31                                                   | 0,00%                                            |
| 5         | 14,97                         | 2,66                                                   | 82,23%                                           |
| 7         | 2,47                          | 2,20                                                   | 10,93%                                           |
| 9         | 0,88                          | 0,80                                                   | 9,09%                                            |
| 11        | 1,27                          | 1,17                                                   | 7,87%                                            |
| 13        | 1,08                          | 1,00                                                   | 7,41%                                            |
| 15        | 0,51                          | 0,47                                                   | 7,84%                                            |
| 17        | 0,88                          | 0,81                                                   | 7,95%                                            |
| 19        | 1,06                          | 0,99                                                   | 6,60%                                            |
| 21        | 0,25                          | 0,23                                                   | 8,00%                                            |
| 23        | 0,84                          | 0,78                                                   | 7,14%                                            |
| Total THD | 15,55                         | 4,77                                                   | 69,32%                                           |

4. Conclusion

Based on this research, then obtained the following conclusions:

1. Simulation modeling by using Single-tuned Passive Filter shows that THD (Total Harmonic Distortion) Current from 15.55% has been reduced to 4.77%. The Single-tuned Passive Filter can reduce the total THD of the system to fulfill the IEEE 519-1992 standard requirements.

2. Single-tuned passive filter has capability in decreasing one desired harmonic order and only slightly reducing other order harmonics.

References

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