Comparison between single tuned filter and c-type filter performance on the electric power distribution network

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Abstract. Harmonics is one of the parameters of electricity quality. They have a lot of influence on equipment performance and losses in the electrical system. This paper presents the performance of a Single Tuned Filter and C-Type Filter which is used to reduce harmonic content in an electric power distribution network system in the cement industry. To make it easier to do harmonic analysis, software is used namely ETAP 12.0. Based on the simulation results, it was found that the single performance tuned filter the tuning frequency is better than the C-type filter type in reducing harmonic content. However, the C-type filter has better performance in conditions above the tuning frequency and for below the tuning frequency single tuned filter have better performance. The addition of these two types of filters does not have a significant effect on improving the voltage profile or power factor.

1. Introduction
The quality of the electric power system is determined by the harmonic content. This case has been a problem since the industrial electricity for several decades [1]. Basically, the electric power system does not harmonics because in the electrical energy generated at the power plant centers and its distribution already contains harmonics on it. Harmonics increase system losses up to 20%. In the Electric Power System (EPS) with a good system the losses due to harmonics vary from 1% to 1.5% of the total energy consumption including technical losses which increase up to 2-25% [2], [3]. Recent studies reveal that additional power losses in Electric Power Distribution System (EPDS) can range from 4 to 8.5% due to harmonics [4]. Institute of Electrical and Electronic Engineering (IEEE) 519-2014 defines harmonic as a sequence of a bigger component than the first Fourier series of periodic amount.

Distribution network is one of the systems in EPS which directly relates to the consumption of electricity, either industrial consumers or household consumers. In Indonesia in general EPDS uses 20 kV voltage level. Because EPDS related directly to the load so it will be susceptible in harmony. The harmonic sources in STL are non-linear loads such as transformer, compact fluorescent lamps (CFLs), rectifiers, inverters, arc furnaces, switch mode power supplies (SMPS), and adjustable speed drives (ASD).

Harmonic measurement can be called a harmonic index, known as Total Harmonic Distortion (THD) which consists of THD voltage (THD-v) and THD current (THD-i), this harmonic index is measured in percentage (%). In accordance with the IEEE 519-2014 standard at a voltage of 1kV - 69 kV the allowable THD-v limit is 5.0% and the individual harmonic is 3.0%. Low value harmonics with the smallest probability will have an effect on electricity networks and high value harmonics with high probability of having an effect on large industries. The effect of harmonics on an EPDS that passes through the limits of IEEE standard 519-2014 can cause, for example, an electric motor to experience heating, vibration and excessive noise. In the transformer will cause core loss and winding loss, which can cause power losses. On the cable will cause excessive heat and error reading on protection devices and control systems and industrial process efficiency [5]–[8].
In general, there are 3 techniques to minimize the harmonics arise in EPDS, passive filter [9]–[11], active filter [12]–[14] and hybrid filter [15]. This research will focus on passive filters in the case of single tuned filter and C-type filter, this is because passive filters are an effective and simple, and economical method [16], [17]. Passive filter placed on the load that is not linear and results the most significant current frequency. This type of filter is economical and simple, but some of them are difficult to implement. In general, this filter consists of passive elements such as resistors, inductors, and capacitors [17], [18].

The aim of this research is to get a comparison between single tuned filter performance and C-type filter in which the most effective in suppressing harmonics that occur in EPDS in Semen Bosowa Maros (SBM) company. By getting a comparison between those two types of filters, it can be determined the type of filter which is good in suppressing harmonics at Semen Bosowa Maros Company. Other parameter that will be reviewed are voltage and power factor profiles with the installation of both types of filters.

2. Passive Filter

2.1. Single-tuned filter
This type of filter shown in Figure 1 (a) is very simple and most commonly used. So that investment costs and power losses are low. This filter has zero impedance at the resonant frequency, so that it becomes an almost perfect filter on the tuning frequency. However, it can produce resonance at frequencies below the tuning point which causes new harmonic problems. Furthermore, this type filters harmonics above the tuning point poorly [1], [17].

![Figure 1. (a) single-tuned filter, and (d) C-type damped filter [17].](image)

Parameter calculation of this filter requires data in the form of active power absorbed by the load and its power factor. Both parameters are used to determine the reactive power needed to improve the power factor, calculated by

\[
Q_c = P\left(\tan^{-1}(\cos^{-1}(PF_{ac})) - \tan^{-1}(\cos^{-1}(PF_{ac}))\right)
\]

At the base frequency the capacitance of the capacitor is given by [19]

\[
X_c = \frac{V_c^2}{Q_c} \text{ and } C = \frac{1}{2\pi f X_c}
\]

The resonance condition will occur when the capacitive reactance is the same as the inductive reactance in this case

\[
X_c = X_L
\]

Thus the inductance value can be calculated by

\[
L = \frac{1}{(2\pi f)^2} C \text{ and } X_L = 2\pi f L
\]

Value of reactor reactance with quality factors calculated with

\[
R = \sqrt{X_R X_L / Q} \quad : 30 \leq Q \leq 50
\]

2.2. C-type filter
C-type filter shown in Figure 1 (b) is often used to reduce harmonic distortion, improve system performance, and compensate for reactive power. The C-type filter, compared to other passive filters, has better performance advantages at higher frequencies and has no losses at the base frequency. By observing the frequency response characteristics, the calculation of the parameters is explained in the following [20].

At the base frequency, the inductor reactance \( X \) and capacitors \( X_{c_1} \) are similar \( X = X_{c_2} \). Therefore, the filter reactance \( X_{c_1} \) is

\[
X_{c_1} = V^2 / Q_{c_1} \text{ and } Q_{c_1} = P\left(\tan^{-1}(\cos^{-1}(PF_{ac})) - \tan^{-1}(\cos^{-1}(PF_{ac}))\right)
\]

\[
(6)
\]
Which \( V \) and \( P \) are the voltage (V) and fundamental voltage (W) on the bus to be placed in the filter \( Q_{cr} \) is the reactive power to correct the current power factor \( (PF_{cr}) \) becomes desired value \( (PF_{des}) \).

The basic frequency reactance values of the LC series can be calculated as

\[
X = X_{cr} \left( 1/h^2 - 1 \right)
\]

(7)

So the resistance value \( R \) is calculated by

\[
R = (hX)/Q \quad ; 30 \leq Q \leq 50
\]

(8)

which \( h \) is the harmonic order that will be pressed and \( Q \) is quality factor

3. Methodology

This research is a simulation based research. The software used in this study is ETAP 12.0. This software is run on a computer with Intel (R) Core (TM) i5-3320M CPU @ 2.60GHz (4 CPUs), ~ 2.6GHz, using Windows 10 operating system and 8192 MB RAM. ETAP is one of the popular tool for simulation and harmonic modeling.

The object of this research is to take one of the distribution systems in the PT Semen Bosowa Maros Cement Industry, namely Sub Station Electrical Room 3-Burning Area. The selection is based on previous research by [21] where in this section is the biggest contributor to harmonics in EPDS at PT. SBM. Briefly electrical loads on the existing distribution network p ER-3, there are 8 pieces of transformer, 7 pieces of ASD, 1 piece rectifier, 7 pieces induction motor, 1 DC motors and lighting loads are generally used lamp types FT. In ER-3 the main bus has a voltage rating of 11 kV and then lowered to 0.69 kV for motor loads, and 0.4 kV.

The method used to place filters is by looking at the highest THD value on all buses as conducted by [17]. This study does not use a specific search method for filter placement because it provides the possibility of further research on optimal methods for filter placement or filter size using certain algorithms to obtain maximum results in minimizing THD.

The filter design is focused on reducing the odd-order harmonics between 1 and 25, by selecting the largest IHD among the order. This is because the order is significant compared to higher order harmonics [22]. Besides this in the harmonic order range, it has an effect on EPDS. The component parameters required in the design of both types of filters calculated by equation (1) to (8).

4. Simulation Results and Discussion

4.1. Existing Conditions ER-3 Burning Area

This condition is the EPDS existing conditions at this time at ER-3 PT. Semen Bosowa Maros. Based on the simulation results obtained THD-v on ER-3 bus is 4.52%. Whereas at connection points of load on this bus the THD-v value varies from 4.74% in MCC-471 up to a maximum of 9.34 % at 441-FN1-U1. For complete results are presented in Table 3 below. In this condition there are 6 buses namely buses 4P1-1V3, 441-FN1-U1, 441-FN2-U1, 471-FNF-U1, 471-FNF-U2 and 561-KL1-V1, respectively 5.21%, 8.36 %, 8.27%, 7.61%, 7.64% and 9.34 % which exceeds the required IEEE standard limits of 5% at voltages below 69 kV. Whereas IHD-v in the 11th order that passed the stipulated limits on all buses and order 13 was on buses 441-FN2-U1, 471-FNF-U1, 471-FNF-U2, 561-KL1-V1 and MCC-471. In this condition the permitted limit is 3.0%. The 11\(^{\text{th}}\) harmonic on the average has a significant value compared to other harmonic orders. This is because the harmonic order is odd, because in general the value is more significant than the harmonic order because of p [27].

4.2. Passive Filter Design

Designing filters to reduce the harmonics needed is voltage, power factor, reactive power and system of frequency. Things to consider in designing this filter is the harmonics order (n) that will be reduce the numbers. In this design the reference is the 11\(^{\text{th}}\) order harmonic, because the value exceeds the set threshold.

In this design the intended power factor \( (PF_{des}) \) is equal to 0.95. The data used is obtained from the condition simulation results existing ER3 Determination of values from \( C \), \( X_{cr} \) and \( R \) for single-tuned filters calculated using equation (1) – (5). The results of these calculations are obtained \( C = 9.99 \times 10^{-4} \mu \text{F} \), \( X_{cr} = 8.55 \times 10^{-3} \Omega \) and \( R = 6.71 \times 10^{-4} \Omega \) on buses 441-FN1-U1 and 441-FN2-U1. Whereas on bus 4P1-1P1 the value is \( C = 9.00 \times 10^{-4} \mu \text{F} \), \( X_{cr} = 0.298 \Omega \) and
R = 7.45 \times 10^{-3} \Omega. These values are the parameters needed in a single-tuned filter. For the value of \( C \), \( X \), and \( R \) which is calculated using on (5) - (8) for the C-type filter the value is obtained \( C = 9.99 \times 10^{-3} \mu F \), \( X = 8.35 \Omega \) and \( R = 7.31 \times 10^{-3} \Omega \) for placement on buses 441-FN1-U1 and 441-FN2-U1. Whereas on bus 4P1-1P1 the value is obtained \( C = 9.00 \times 10^{-3} \mu F \), \( X = 92.64 \Omega \) and \( R = 8.11 \times 10^{-3} \Omega \).

4.3 Condition of ER-3 Burning Area with Filter Addition

The simulation results with the addition of the two types of filters is obtained that the overall THD-v value has decreased except on buses 561-KL1-V1. On this bus-v THD value is still above the limit that is equal to 7.23\% for single-tuned filter type and 7.09\% for C-type filter. In accordance with the planning of both types of filters are added to the bus that has an IHD-v value that crosses the line, namely on buses 4P1-1P1, 441-FN1-U1 and 441-FN2-U1. Significantly decreasing with the installation of single-tuned filter type is the 4P1-1P1 bus while the installation of the C-type filter is 4P1-1V1 bus respectively 69\% and 61\%. While the smallest experienced a decrease was on buses 471-FNF-U1 each of 37\% for single-tuned filter and 35\% for C-type filter. As for IHD-v-order odd number of simulation results after the addition of the filter will no exceeding the specified limits. The addition of this filter can reduce individual harmonics, where a significant reduction is 11th order on bus 441-FN1-U1 with the type of filter used is single-tuned filter that is 53\%.

Overall the comparison of the two types of filters is presented in Figure 2 below.

![Figure 2. Comparison of THD-v before and after harmonic filter enhancer](image)

The performance of both filters in suppressing the individual harmonic voltage is shown in Figure 3. Based on image above both types of filters can effectively reduce the IHD-v above the tuning frequency. Frequency tuning that is used as a basis for both this filter is 550 Hz (11th order). So the results can be seen in Figure 3, from the order of 11-25 has decreased. Especially in the 11th order which significantly decreases. While the order below the tuning frequency (5th and 7th order) increases. The performance of these two filters has a difference in suppressing individual harmonics where single tuned filter can suppress well the harmonic order that is below the tuning frequency, while the C-type filter has better performance in suppressing individual harmonics that is above the tuning frequency [22].

![Figure 3. Comparison of IHD-v before and after addition of filters.](image)
single filter Tuned filters reduces by an average of up to 81%. Whereas the addition of the C-type filter can detect the decrease with an average of 51%. Based on the figure, it can be seen that single tuned filter performance is better than C-type filter performance in reducing IHD-v at tuning frequency.

Figure 4. Comparison between Single Tuned Filter and C-type Filter performance on 11th order

4.4 Voltage Conditions and Power Factors Before and After Adding Filters

Table 1 presents the effect of adding a harmonic filter to voltage and power factor. Based on the table, the implications of the two filters that are used do not have a significant influence on either singles tuned filter or C-type filter. This is because the capacitor values used in both types of filters are small. In order to provide a significant influence in improving the voltage and power factor is to use a capacitor bank as conducted by [19].

Table 1. Comparison Voltage and power factor profile before and after adding filters.

| No. | ID Bus | Existing | STF | CTF |
|-----|--------|----------|-----|-----|
|     | Dari   |          |     |     |
| 1   | 4P1-1P1 | 0.398    | 83.2| 0.4 |
| 2   | 4P1-1V3 | 0.4      | 84.0| 0.4 |
| 3   | 441-FN1-U1 | 0.694 | 91.9| 0.699| 94  |
| 4   | 441-FN2-U1 | 0.694 | 91.9| 0.699| 94  |
| 5   | 471-FNF-U1 | 0.694 | 90.7| 0.697| 91.5 |
| 6   | 471-FNF-U2 | 0.691 | 91.1| 0.694| 90.75|
| 7   | 561-KL1-V1 | 0.687 | 84.1| 0.689| 84.14|
| 8   | MCC-471 | 0.398    | 84.2| 0.399| 84.21|

5 Conclusion

This paper discusses the comparative performance of passive filters in reducing harmonics for EPDS on case study in a cement industry. The filter compared to its performance is a single tuned filter and C-type filter. To obtain the data needed, a software ETAP version 12.0 is used. The results reveals single tuned filter performance on the tuning frequency is better than C-type filter performance. C-type filter has better performance above the tuning frequency and single tuned filter has better performance above the tuning frequency. Whereas the effect of adding harmonic filters on voltage and power factor of both types of filters does not have a significant effect, even tends to have no effect on EPDS.

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