Eduvest – Journal of Universal Studies
Volume 3 Number 2, February, 2023
p- ISSN 2775-3735- e-ISSN 2775-3727

IMPLEMENTATION OF HYBRID FILTER FOR HARMONICS REDUCTION IN NON-LINEAR LOADS

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ABSTRACT

The efficiency of electrical power can be improved by improving power quality. Installing capacitor banks is one way to improve power quality by improving the power factor. On the other hand, the use of non-linear loads is increasing. This load produces a non-sinusoidal waveform which causes harmonics to appear in the electric power system. Harmonic problems will become a serious problem in the power system when there is a capacitor bank in the system which will cause resonance risk at the harmonic frequencies. This resonance problem can be solved by installing a detuned filter. Detuned filters can reduce harmonics and protect the system from the resonance risk. However, the detuned filter installation is not sufficient to reduce all harmonics that generated by non-linear loads, so the system needs to be equipped with an active filter. In this study, using a combination of 14% detuned filter and active filter, each of which is attached parallel to the load. The result of power quality improvement can increase the power factor from 0.6 to 0.88, THDi is reduced from 49.5% to 18%, and THDv is reduced from 2.18% to 1.97% after installing the hybrid filter

KEYWORDS *Detuned filter, Filter aktif, Hybrid filter, Harmony, Capacitor bank*

INTRODUCTION

The higher the cost / tariff of electricity, the demand for efficiency in the use of electrical power is the main consideration. The efficiency of electrical power consumption can be done by improving the quality of power. Improving the quality of power, one of which is done by improving the power factor. Capacitor banks are one way to do this power efficiency by fixing the power factor or cosphi. Good electrical power quality when $\cos\theta > 0.85$ value, constant voltage despite variable

How to cite:	Yahya Chusna Arif (2023). Implementation of Hybrid Filter For Harmonics Reduction In Non-Linear Loads. Journal Eduvest. *3* (2): 465-476
E-ISSN:	2775-3727
Published by:	https://greenpublisher.id/

loads, constant frequency, sinusoidal waveform, (Sukir & Soenarto, 1993) (Baggini, 2018) (Hendik et al., 2020)

On the other hand, the use of non-linear loads in electric power systems is increasingly massive and these loads produce non-sinusoidal waves. This creates harmony in the electric power system. Harmonia itself is a disturbance that in the distribution of electric power caused by the presence of distortions of current and voltage waves that cause the formation of non-sinusoidal waves at the frequency of spherical multiples of its fundamental frequency, (Efandi et al., 2016) (Das, 2020), The harmonics that appear have many disadvantages, including: damaging electrical equipment, reducing the lifetime of electrical equipment, increasing the temperature of conductors / conducting wires, causing reading errors in analog measuring instruments, decreasing power efficiency, decreasing power factors, resonance between capacitors and transformers that cause over voltage (Cahyoko, 2020). Harmonics in the electric power system can interfere with the performance of equipment and can even damage it, so that it is detrimental to customers as well as to electrical power providers.

The installation of capacitor banks that are actually functioned to increase the power factor in systems that have non-linear loads will be dangerous because it can pose a risk of resonance both series and parallel resonance. This problem can be overcome by equipping capacitor banks with detuned filters. Detuned filters work by shifting the resonant frequency of the system so that it does not occur at harmonic frequencies so that the risk of resonance can be avoided (Aliyya et al., 2020).

On its implementation detuned filter not yet sufficient to reduce the harmonics produced by non-linear loads, so it needs to be supplemented by filter active to eliminate the lingering harmonics. Combination filter passive and filter active on a system commonly referred to as filter Hybrid (Dahlan, 2009; Setiawan et al., 2018; Sung et al., 2000). Detuned filter as filter Passive deep filter Hybrid Serves as protection of capacitor banks from resonance due to the use of non-linear loads and result from the signal filter active, it also serves to increase the value of low power factor. While filter active on filter Hybrid serves to reduce the harmonic still remaining/appears on the system.

There are several topologies of hybrid filters as in Figure 1, namely: active series filter with parallel passive filter, parallel active filter with parallel passive filter, and active filter series with passive filter (Chen & von Jouanne, 2001; Demirdelen et al., 2013; Nair & Sankar, 2015; Srivatsav et al., 2014; Wong et al., 2008).

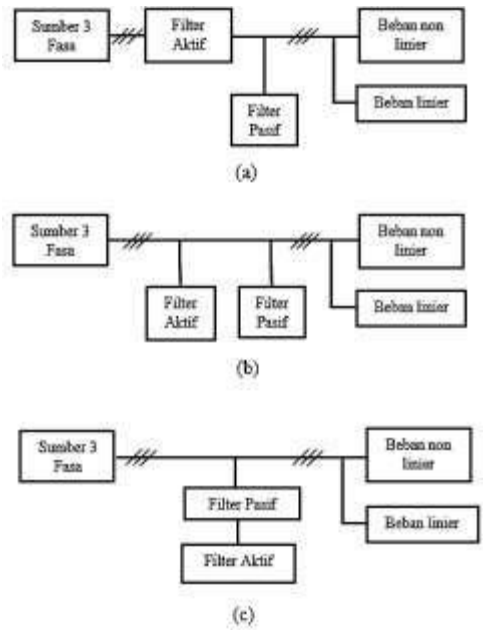

Figure 1 Types of hybrid filter topologies: (a) active series filters with parallel passive filters; (b) parallel active filter with parallel passive filter; (c) Series active filter with passive filter

Hybrid power filters are used as a solution to the shortcomings of active filters and passive filters when each of these filters is used individually, when combined into a hybrid filter. Active filters can solve harmonic problems in dynamic non-linear loads that passive filters cannot overcome. Meanwhile, passive filters are able to overcome the weaknesses of active filters by reducing the need for active filter ratings so that the costs needed to provide and install active filters are not too expensive. Hybrid filters are generally designed to reduce the cost and rating of active filters by combining with detuned filters that function to reduce harmonics at the most dominant harmonic frequencies and supply the reactive power required by the system (Luo et al., 2009).

From the background that has been explained, the implementation of hybrid filters with topologies in parallel as in Gb. 1 (c) which consists of a detuned filter and active filter that is functioned to improve power factor and harmonic reduction so that the existing harmonics are in accordance with the allowable IEEE 519-199 standard 2 (Engineers, 2014).

RESEARCH METHOD

This research took measurement data at the Electric Power System Laboratory at the Surabaya State Electronics Polytechnic Campus. The hybrid filter in this study was shown at Figure 2 with the topology of each filter installed in parallel to the load. In this topology, the detuned filter works by shifting the resonant frequency below the most dominant harmonic frequency and also serves to compensate for the reactive power required by the load so that the power factor increases. Active filters work by compensating for harmonics that are still left on the system The loads used are inductive linear loads and non-linear loads.

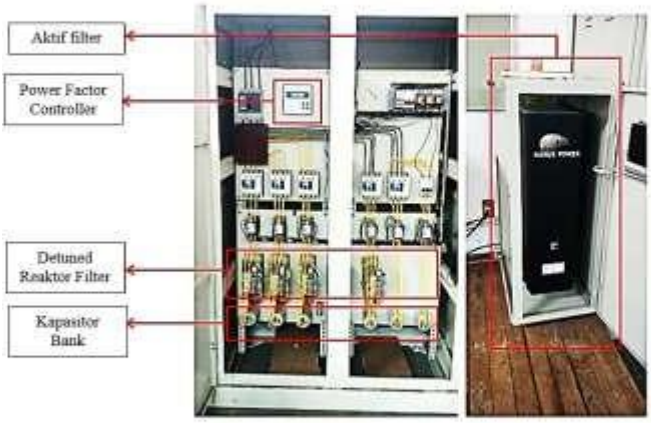

Figure 2 Hybrid Filter Panel

From the data of the n devotees, the initial parameters are obtained as in Table I. This data is further used for the purposes of calculating capacitor banks and inductors for detuned filters, as well as for determining the capacity of active filters.

TABLE 1 OF SYSTEM MEASUREMENT RESULTS

V_{LN}	221 V
V_{LL}	380 V
I	21.58 A
P	5.85 KW
S	9.5 KVA
PF	0,6
THD_V	2,18%
THD_i	49,25%

A. Capacitor Bank Planning

A capacitor bank is an electrical equipment that has capacitive properties that function to compensate for inductive properties or is also a set of several capacitors connected in parallel to the load to obtain the capacitive capacity that will be required by the load. The amount of capacitor bank needs in a system canbe calculated through (1) the following (Shwedhi & Sultan, 2020):

$$Qc = P(\tan\theta \text{ awal} - \tan\theta \text{ akhir}) \quad (1)$$

Installation of capacitor banks in a 3-phase system can be done with 2 hubungs, namely the wye (star) circuit and the delta circuit

From the measurement results, a calculation is needed for the magnitude of the capacitor bank needs. From the measurement results, the pf value is 0.6 and will be corrected with a target of 0.9.

$$\cos\theta \text{ awal} = 0{,}6 \rightarrow \theta = 53{,}13°$$
$$\cos\theta \text{ target} = 0{,}9 \rightarrow \theta = 25{,}8°$$

$$Qc = P(\tan\theta\ \text{awal} - \tan\theta\ \text{target})$$
$$Qc = 5{,}85(\tan 53{,}13 - \tan\ 25{,}8°)$$
$$Qc = 5\text{KVar}$$

Because the system is equipped with a 14 % detuned filter , there will be a shift in the resonant frequency and an increase in voltage in the capacitor. So that the value of the capacitor needs of the bank will also increase.

$$Q_C = \frac{N_C}{(1-p)}$$
$$Q_C = \frac{5}{(1-0{,}14)}$$
$$Q_C = 5{,}8\text{KVar}$$

The large capacitance of the capacitor is:

$$C_Y = \frac{Qc}{2\pi f V^2}$$
$$C_Y = \frac{5{,}8}{2\times\pi\times 50\times 380^2}$$
$$C_Y = 120\mu F$$

The capacitor bank in the system is installed with a delta circuit, so the result is as in the following equation:

$$C_\Delta = \frac{C_Y}{3}$$
$$C_\Delta = \frac{120}{3}$$
$$C_\Delta = 40\mu F$$

From the calculation results above, the amount of delta circuit capacitor needed for power factor improvement is as large as $40\mu F$ where there are 6 steps of capacitor so that the value is 6.67. μF

$$C_\Delta = 6{,}67\mu F\text{per step}$$
$$C_Y = 20\mu F\text{per step}$$

B. Detuned Filter Design

In Figure 3 is an algorithm to determine the magnitude of the detuned factor required by the system. The magnitude of the detuned factor (p) and the shift in its resonance frequency can be seen through Table 2.

TABLE 2 DETUNED FACTOR VALUES AND RESONANT FREQUENCY SHIFTS

p	$\mathbf{f_{res}}$
5%	223 Hz
5,5%	213 Hz
5,67%	210 Hz
6%	204 Hz
7%	189 Hz
8%	177 Hz
12,5%	141 Hz
14%	134 Hz

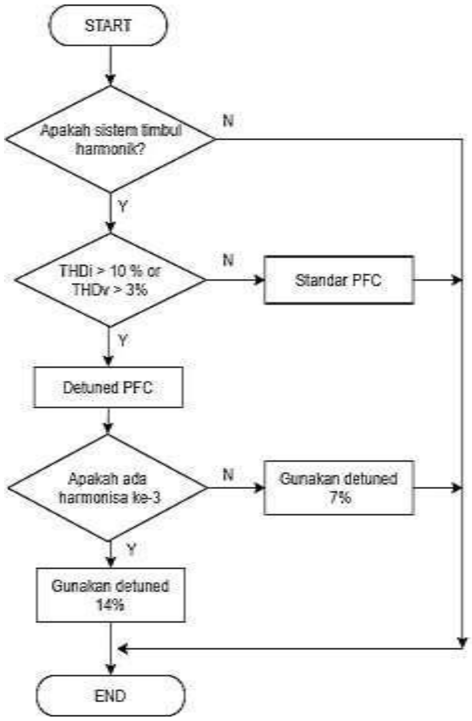

Figure 3 Algorithm determines the detuned factor

From the results of the initial measurements that have been made, there is a 3rd harmonic in the system. The 14% detuned factor was chosen because what is available on the market is this size, and in this study the large 14% detuned filter is the most suitable to avoid resonance in the 3rd harmonisa (f=150Hz). If you choose a 12.5% detuned filter, the shift in its resonance frequency will be too close to the 3rd harmonic. The resonant frequency of the system with p=14% is shifted to 134 Hz according to the calculation below:

$$p = \left(\frac{fn}{fres}\right)^2 \times 100$$

$$f_{res}{}^2 = \frac{50^2}{14} \times 100$$

$$f_{res} = \sqrt{\frac{2500}{14} \times 100}$$

$$f_{res} = 134\text{Hz}$$

Specifies the magnitude of L for the detuned filter fork each step.

$$L = \frac{p}{\qquad}$$

$$L = \frac{14}{100 \times 4 \times \pi^2 \times 50^2 \times 20 \times 10^{-6}}$$
$$L = 70mH$$

From the results obtained thevalue of L for a 14% detuned filter is 70mH.

C. Aktif Harmonic Filter for Hybrid Filter

The way the active filter works is to use power electronics technology that produces specific current components to eliminate harmonic current components due to the use of non-linear loads.

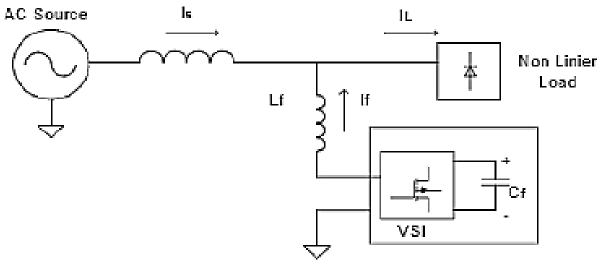

Figure 4 Active Filter

The active power filter on the hybrid filter serves as a current source, compensating for harmonic currents due to the use of non-linear loads. The principle is to inject a compensation current of the same magnitude as the harmonic current, so that the harmonic current is eliminated. The purpose of the active filter is to generate a sinusoidal current with the equation $I_S = I_L - I_F$. (Arif et al., 2021) If the non-linear load current is the sum of the fundamental current components I_{Lh} and the harmonic current I_{LF}, as in the equation below:

$$I_L = I_{Lf} + I_{Lh}$$

Then the compensation current by the active filter will be:

$$I_f = I_{Lh}$$

So that the source current is equal to:

$$I_S = I_L + I_f = (I_{Lf} + I_{Lh}) - I_{Lh}$$
$$= I_{Lf}$$

The capacity of the active filter in this study was calculated through the following equation:

$$I = THDi \times I_{load}$$
$$I = 49{,}25\% \times 21{,}58A$$
$$I = 10{,}62A$$

The active filter in this study has a power capacity of 50A, so it works by injecting 10.62A or about 21% of its total capacity.

RESULT AND DISCUSSION

The real measurement is carried outby combining a 14% detuned filter with an active filter with a capacity of 50A. Based on the results of measurements that have been made, the unfiltered system (hybrid OFF) produces a sinusoidal fixed voltage source but for a current source there is a distortion pat as in Figure.15. THDv and THDi systems are worth 2.18% and 49.25%, respectively. The THDv value is still in accordance with the standard allowed for voltage $< 69kV$, which must be below 5%, while the THDi value exceeds the standard value allowed by IEEE 519-1992, which exceeds 20%. The power factor value on the unfiltered system is 0.6.

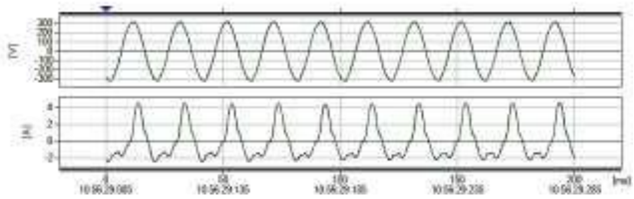

Figure 5 Unfiltered voltage and current waves

Figure 6 Unfiltered current harmonic spectrum

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The measurement results at the time of hybrid filter ON, THDv fell to 1.97% from 2.18% and THDi fell to 18.30% from 49.25% previously.

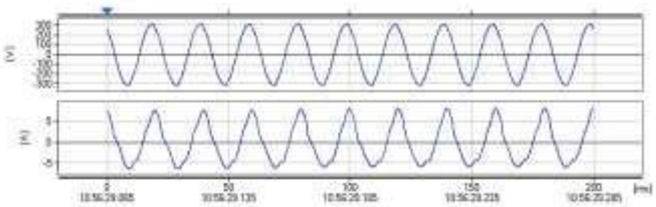

Figure 7 Voltage and current waves when hybrid filter ON

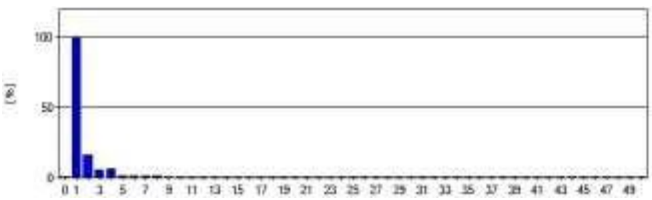

Figure 8 Harmonic spectrum current when hybrid filter ON

For more details on the harmonic values of the measurement results can be seen in Table V and Table VI. Meanwhile, the power factor value increased thelevel from the previous one without a filter was 0.6 to 0.88 after the installation of a hybrid detuned filter of 14%.

TABLE 3 COMPARISON OF THD AND POWER FACTORS

Parameters	Hybrid filter OFF	Hybrid filter ON
THDi	49,25%	18,30%
THDv	2,18%	1,97%
Power Factor	0,6	0,88

The settings on the active filter are not made maximum due to the limited capacity of the active filter so that the THDi is only reduced to 18.30%. However, this THDi value already meets the standards allowed by IEEE 519-1992 so that it is safe for installation on load and does not interfere with the source.

TABLE 4 COMPARISON OF VOLTAGE HARMONS IN SYSTEMS

Order of the Harmonisa	Hybrid Filter OFF	Hybrid Filter ON
3	0,43%	0,43%
5	1,18%	1,08%
7	0,74%	0,73%
9	0,34%	0,45%
11	0,88%	0,78%
13	0,46%	0,22%
15	0,47%	0,13%
17	0,84%	0,85%
19	0,43%	0,37%
21	0,12%	0,12%
23	0,03%	0,08%
25	0,02%	0,12%
27	0,04%	0,04%
29	0,05%	0,03%
31	0,01%	0,05%
33	0,02%	0,02%
35	0,01%	0,04%
37	0,02%	0,02%
39	0,01%	0,01%
41	0,02%	0,02%
43	0,01%	0,03%
45	0,02%	0,03%
47	0,01%	0,01%
49	0,02%	0,02%
THDv	**2,18%**	**1,97%**

TABLE 5 COMPARISON OF CURRENT HARMONS IN SYSTEMS

Order of harmonics	**Hybrid Filter OFF**	**Hybrid Filter ON**
3	9,04%	5,14%
5	6,85%	2,58%
7	2,38%	1,45%
9	0,49%	0,34%
11	0,41%	0,47%
13	0,41%	0,18%
15	0,59%	0,20%
17	0,60%	0,50%
19	0,22%	0,13%
21	0,28%	0,14%
23	0,23%	0,18%
25	0,37%	0,04%
27	0,12%	0,03%
29	0,18%	0,13%
31	0,04%	0,03%
33	0,03%	0,03%
35	0,15%	0,05%
37	0,08%	0,06%
39	0,06%	0,01%
41	0,13%	0,05%
43	0,07%	0,04%
45	0,05%	0,01%
47	0,08%	0,03%
49	0,04%	0,01%
THDi	**49,25%**	**18,30%**

CONCLUSION

From the results of the study, it was concluded that hybrid filters with an active topology of parallel filters and detuned parallel filters are able to reduce the harmonic value of current and voltage while improving the power factor in the plan system. The power factor increased from the previously unfiltered one was 0.6 up to 0.88 after installing the hybrid filter. In addition, the THDi, which was originally 49.25%, dropped to 18.30% where this value met the IEEE519-1992 standard, which was below 20%. THDv, which was originally 2.18%, fell to 1.98%. The condition meets the IEEE 519-1992 standard of 5% for a voltage of 69 kV

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