Harmonic reduction in IEEE-3-bus using hybrid power filters

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Abstract: The development of industrial applications and the comprehensive uses of power systems has led to the emergence of harmonics, that non-linear loads are the cause of it. A hybrid power filters (HPFs) is an ideal solution in compensating reactive power and mitigating harmonic current. In this paper, the IEEE-3-bus system companied with the hybrid power filter is performed to reduce current harmonics and improved performance under many operation conditions. The system tested with two types of power filters: firstly, a shunt passive power filer and secondly, a shunt hybrid power filter: which consists of a passive power filter in series with an active power filter. Hybrid power filters simulation results with control strategy have the effectiveness in the reduction of current harmonics from (29.85%) to (0.78%) comparing with other types.

1. Introduction

developments in commercial purposes and uses of the electronic device and non-linear loads (power electronic devices such as rectifier, MOSFET, and IGBT switching) have presented complex difficulties in electrical systems, which harm the quality of power. Harmonics have contributed to contemporary energy quality problems and have been one of the most concentrated electrical engineering research areas that led to, numerous problems like high temperature for equipment, low power factor, thermal effects on transformers, abnormal operation of the electronic relay, thermal effects on rotating machines, and interference with communications [1, 2]. The presence of non-linear loads in the system leads to the generation of harmonics current. For harmonic absorption, it is necessary to establish criteria and independently evaluate the different cases that occur in industrial networks, for which it is necessary to consider the concepts and different approaches to solving the problem today. The guidelines for the analysis of harmonic distortion are defined in IEEE STD 519-2014 where it is shown how it is possible to analyze the harmonic contribution of non-linear loads in the voltages and currents of the system through the modeling of the impedances of the elements as a function of frequency[3]. Many methods are available to solve harmonic problems. Filters are one of the solutions used to reduce harmonics. the conventional type of
filter is the Passive power filter (PPF), it is a simple structure and has a low initial cost consisting of resistance, inductor, and capacitor. However, it has much harm to the system, whereas failure to properly adjust its components causes resonance between its elements and the impedance of the system [4, 5]. Active power filters (APF) is another technique for alleviating harmonic, which had a lot of emphasis since the (1970) [6]. The APF can be connected in parallel or the series with the system. shunt APFs are commonly used and have effectiveness in the reduction of current harmonics and another side contributes to compensating reactive power for the network by controlling the dc-link voltage [7]. But they are constrained rising initial cost and handle applications that have low power [2, 8]. Hybrid power filters (HPFs) are defined as a great harmonics arrangement. HPF is consist of a PPF, and APF where they are connected with the network, it can connect PPF in a series and APF in parallel with the network as well as it can be connected APF in series with PPF and both they are connected in a shunt with the network [2, 9]. Parallel PPF is ideally suited to correct for the current harmonic nonlinear loads. Also, it is appropriate to regulate the voltage of the system[2, 10], the HPF technology incorporates the advantages of APF and PPF and the harmonic currents are determined exactly [11, 12].

in this work proposed a hybrid power filter that connected in shunt with the network. HPF has already been implemented to harmonic compensation, where PPF is considering a low resistance path and current harmonics will be forced to pass through this path, while APF is very important for compensate reactive power by using control to regulate the dc voltage of the inverter. HPF adding at a different location after adding a disturbance source to the network that represented by a 3-phase rectifier with an inductive load (nonlinear load) And recording the best position for the performance of the hybrid filter through readings (THD%) as well as the waveforms of voltages and currents for the system. as well as the PI control strategy that is used to reduce many synchronization problems. Simulation-based findings after the filter connected confirmed its effectiveness as THD% values have fallen from 29.85% to 0.78%.

Configuration system
As shown in Figure 1, the IEEE-3-Bus network single line diagram is presented by using E-draw Max software, the network is consisting of:

- number of generators = 2
- number of lines = 3
- number of bus = 3
- number of loads = 2 (linear and nonlinear load)

The parameters of the network, as shown in appendix A

![Figure 1. the IEEE-3-Bus network](image-url)
1.1. Hybrid power filters

The elements of the hybrid power filter (HPF), as appear in Figure 2. It consists of a PPF, connected in series with APF. PPF is commonly used in distributed generation systems to reduce harmonic and current distortion. on the other side, PPF effects inverter harmonic injection as well as the harmonic of a coupling non-linear load. The resonance frequency is determined from:

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

(1)

APF is consist of a voltage source inverter (VSI) with a coupling inductor is connected in parallel with the network. The parallel APF has greater advantages than the serial APF because it is more economical, it only transports the harmonic currents for which it was tuned, it provides a part of the reactive power to the system. For the following reasons, the inverter output voltage must be controlled: first, for controlling the variance of the input dc. Secondly, inverter voltage regulation and continuous voltage and frequency control. Finally, in general, APF is important for currents compensation that is required to cancel harmonics while PPF is used to support the APF part to cancel other harmonics orders.

1.2. Location of filter:

There are two options to locate an HPF: firstly, the medium voltage feeder in order to reduce system losses. Secondly, near the non-linear load, to avoid the injection of harmonic current components to the system by the load. As well as, the filter location depends on two criteria are: firstly, the existence of highly nonlinear loads: The filter must be located on the low voltage side; In this way, the power transformer serves as a shock absorber (harmonic

![Figure 2. Elements of HPF](image)

![Figure 3. adding HPF in the network at different locations](image)
insulator) for both the harmonic currents from other loads and the harmonic currents generated by the load, managing to isolate the problem. Secondly, the existence of distributed harmonic loads. The filters must be located in medium voltage and in strategic (optimal) places to avoid excessive circulation of harmonic currents through the system. As shown in Figure 3, where the filter is added at bus1, bus2, and bus3, the performance of the system is observed and analyzed, and the results are recorded as shown in the results.

2. Current Control strategy

In one of the control methods, the magnitude and phase angle of the reactive power between the network and APF is regulated by regulating the output voltage of VSI. This leads to ensures that the dc input variance is treated and the inverter voltage is regulated in this article. The DC-Link voltage is kept constant with PWM hysteresis via the PI controller as shown in Figure 4. Depending on a try and error method, the values of (KP, and KI) are determined as showing in the table in appendix A.

![Figure 4. PI control loop](image)

3. Result and discuss

The work was carried out by the Simulink/Matlab environment by using a three-phase power system with a proportional-integral (PI) controller as shown in Figure 5. This system will be examined and analyzed by two strategies at firstly adding PPF, secondly adding HPF, using total harmonic distortion as dominance criterion and contrasting the system with the HPF, and without HPF, as shown in Figures 6, 7, 8, and 9 for generator 1, generator 2, load current, compensating current of the filter, and spectrum of the load current. The IEEE-3-Bus load flow results in Matlab/simulation of the system are listed in Table 1.

![Figure 5. IEEE-3-Bus network in Simulink/Matlab](image)
Table 1. Load flow of IEEE 3-bus

|         | Bus 1          | Bus 2          | Bus 3          |
|---------|----------------|----------------|----------------|
| Voltage, \(v\) | 1.025 pu       | 1.001243 pu    | 1.03 pu        |
| Angle, \(\delta\) | 0°             | -2.1°          | -1.36851°      |
| Real power, \(p\) | 100 Mw         | 400 Mw         | 300 Mw         |
| Reactive power, \(Q\) | 90.51 Mvar     | 136.93 Mvar    | 200 Mvar       |

In Table 2, shows a comparison between the results of this article with other works in total harmonic distortion reduction, the contributions in reduction results, displayed as percentages.

In Table 3, shows the performance of the network studied under normal operation, which is presented by the presence of the linear load in the system whereas the disturbance source for the network is presented by the presence of non-linear load in the network. the THD in case the linear load in the system for each bus was 0.03% and there is no distortion in the waveform as shown in Figure 6, while at non-linear load the THD was 29.85%, it can be observed this issue throw the distortion as shown in Figure 7 and harmonic spectra of the load current.

In Table 4, is presented the strategies which that used in the system to provide a good solution to reduce harmonics. Firstly, Passive power filter (PPF) has been added to the system, at the first PPF added to bus1 and noticed the THD for all system (Bus1, Bus2, and Bus3) as well as noticed the waveform for the current source1, the current source2, load current, compensating current of PPF and Harmonic Spectra of the load current as shown in Figure 8. Then PPF added to Bus2, and Bus3 respectively and repeat the same sequence. the THD when added PPF is reduced from 29.85% to 1.17%, at bus2 (near the load)

Secondly, in Table 4, the proposed hybrid power filter (HPF) technique has been added to the system at Bus1, Bus2, and Bus3 and for each case absorbed the THD for the system, the THD when added HPF is reduced from 29.85% to 0.78% at Bus2 (near the load) ,this result is considered better than when added PPF lonely to the system, and it can be observed by the waveforms for the current source1, the current source2, load current, compensating current of HPF and Harmonic Spectra of the load current as shown in Figure 9. Through the obtained results, it is explained that the highest efficiency and performance of the filters used to reduce harmonics in the system can be obtained near the source of disturbance, represented by the non-linear loads that presence in the system, which is a major cause of generating harmonic currents and increasing total harmonic distortion.

Table 2. the comparison result research in this article with other works

| Type of filter | reduce of THD% as a percentage |
|----------------|-------------------------------|
| PPF [5]        | 15                            |
| APF [11]       | 21                            |
| HPF            | 30                            |
Table 3. THD% for the network under normal and disturbance operation without HPF.

| Linear Load          | Non-Linear Load     |
|----------------------|---------------------|
| THD1%                | THD1%               |
| Bus1                 | 0.03                | 29.85               |
| Bus2                 | 0.03                | 29.85               |
| Bus3                 | 0.03                | 29.85               |

Table 4. THD% for the system with passive power filter and hybrid power filter.

| Filter in Bus1  | PPF | HPF |
|-----------------|-----|-----|
|                 | THD1%| THD1%|
| bus1            | 0.59 | 0.70 |
| bus2            | 29.85| 29.85|
| bus3            | 29.85| 29.85|

| Filter in Bus2  | PPF | HPF |
|-----------------|-----|-----|
|                 | THD1%| THD1%|
| bus1            | 1.17 | 0.78 |
| bus2            | 1.17 | 0.78 |
| bus3            | 1.17 | 0.78 |

| Filter in Bus3  | PPF | HPF |
|-----------------|-----|-----|
|                 | THD1%| THD1%|
| bus1            | 29.85| 29.85|
| bus2            | 29.85| 29.85|
| bus3            | 29.85| 0.70 |
Figure 6. Waveforms of the system without disturbance source (with linear load): (a) current source 1, (b) current source 2, (c) the load current (e) Harmonic Spectra of the load current
Figure 7. Waveforms of the system with disturbance source without HPF: (a) current source 1, (b) current source 2, (c) the load current, (e) Harmonic Spectra of the load current
Figure 8. waveforms of the system with PPF at (a) Bus1 (b) Bus2 (c) Bus3 (e) Harmonic Spectra of the load current
Figure 9. waveforms of the system with HPF at (a) Bus1 (b) Bus2 (c) Bus3 (e) Harmonic Spectra of the load current
4. Conclusion
In this article, a hybrid power fitter (HPF) companies with the system. HPF is connected in shunt with the network, the element of HPF is a passive filter in a series with an active filter. The voltage source inverter (VSI) of APF is adjusted depending on the proportional-integral (PI) controller, KP, and KI values of PI is setting by trial and error. The effectiveness of the HPF was cleared. By changing the HPF location on the system to obtain the best filter performance and reduce harmonics, the best results are fixed at bus2 near the non-linear load. This article provided, an improvement in the signal waveform of current and voltage of the generators, and the elimination of harmonics produced from non-linear load in the network led to the enhancement of power quality. The THD1% is reduced from (29.85%) to (0.78%) and THD% confirm that the filtering efficiency is fine and reasonable compensation for reactive power, improving power quality.

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Appendix A

**Table appendix A.** the parameters of the system

| parameters                      | The values |
|--------------------------------|------------|
| AC supply voltage              | 10Kv       |
| Dc voltage of the inverter     | 220v       |
| Dc link capacitor              | 3000uF     |
| Frequency                      | 60Hz       |
| Ls                              | 52.7uH     |
| CF                              | 2500uF     |
| LF                              | 1.67uH     |
| R                               | 20 Ω       |
| RL                              | 25mh       |
| PL                              | 400 MW     |
| QL                              | 200 Mvar   |
| Hysteresis band                | ±0.2 A     |
| PI-value                        |            |
| KP                              | 0.005      |
| KI                              | 0.3        |