# ANALYSIS OF THE SIZE AND LOCATION OF HARMONIC FILTERS FOR DISTORTION MITIGATION, VOLTAGE IMPROVEMENT AND POWER LOSS REDUCTION IN DISTRIBUTION SYSTEMS

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## Abstrak

Sistem Distribusi merupakan bagian yang rentan terhadap distorsi harmonik. Sejumlah beban yang tersambung pada sistem distribusi merupakan beban tak linier yang memberikan distorsi pada sistem. Selain distorsi harmonik, keberadaan beban tak liner juga menyebabkan fluktuasi tegangan dan penambahan rugi daya. Salah satu metode untuk menekan distorsi harmonik adalah dengan memasang filter pasif pada sistem distribusi. Namun ukuran dan letak dari filter merupakan 2 variabel yang harus ditentukan agar mitigasi distorsi cukup efektif. Untuk melakukan asesmen ukuran dan letak harmonik, diperlukan analisis aliran beban harmonik. Untuk keperluan ini dikembangkan program komputer menggunakan bahasa pemrograman MatLab yang kemudian dijalankan untuk sistem distribusi yang melayani sejumlah beban harmonik. Setelah filter dengan ukuran tertentu dipasang pada lokasi tertentu, maka pengaruhnya pada pengurangan distorsi dan perbaikan profil tegangan dan susut daya dianalisis. Diharapkan diperoleh ukuran optimal filter harmonik dan lokasi terbaik yang memberikan mitigasi harmonik yang paling optimal.

**Kata Kunci:** Sistem Distribusi, Beban Tak Linier, Distorsi Harmonik, Filter Pasif, Mitigasi Distorsi.

## Abstract

Distribution system is a part that is prone to harmonic distortion. A number of loads connected to the distribution system are non-linear loads that distort the system. In addition to harmonic distortion, the presence of nonlinear loads also causes voltage fluctuations and additional power losses. One method to suppress harmonic distortion is to install a passive filter in the distribution system. However, the size and location of the filter are two variables that must be determined so that distortion mitigation is effective. To assess the size and location of the harmonics, it is necessary to analyze the harmonic load flow. For this purpose, a computer program was developed using the MatLab programming language which was then run for a distribution system that served a number of harmonic loads. After a filter of a certain size is installed in a certain location, its effect on reducing distortion and improving the voltage and power loss profile is analyzed. It is expected that the optimal size of the harmonic filter and the best location that provides the most optimal harmonic mitigation will be obtained.

**Keywords**: Distribution System, Nonlinear Load, Harmonic Distortion, Passive Filter, Distortion Mitigation.

## 1. INTRODUCTION

The system generates electricity and transmits it from the machine to the consumer. It is necessary to minimize disturbances in current and voltage in order to achieve regulation and stability of electricity supply with good power quality. The combination of power system reliability and cost must be balanced. Old technology, heat loss in transmission and distribution are some of the factors causing the ineffective distribution of electrical energy. The case of power quality is one of the harmonic disturbances that influence the reliability of the electric power system.

Total Harmonic Distortion (THD) is a parameter that measures the level of harmonic distortion in an electrical signal. THD describes the extent to which non-linear harmonics affect the original sinusoidal signal. The lower the THD value, the less harmonic distortion is present in the signal, indicating better quality of the electrical signal.

Harmonics are defined as a sinusoidal wave of high frequency voltage or current, where the frequency is a multiple beyond one of the fundamental frequency (frequency 50 Hz or 60 Hz). The frequency value of the harmonic wave formed is the product of the fundamental frequency and the harmonic number (f, 2f, 3f, etc.). The distorted waveform is the sum of the fundamental wave and harmonic waves (h1, h2, and so on) at multiple frequencies. The more harmonic waves that are included in the fundamental wave, the closer the wave will be to a square wave or the wave will be non-sinusoidal in shape.

The addition of electrical networks in the power system causes the development of power quality problems. Additional load in the form of nonlinear load contributes overall to the addition of current and voltage harmonics. A non-linear load will provide an output waveform that is not proportional to the voltage in each half cycle, so that the output current and voltage waveforms are not the same as the input waveform (the second, third and so on harmonic waveforms are added to the basic wave). The following is a sinusoidal waveform or fundamental wave that is affected by harmonics by adding up the sine waves.

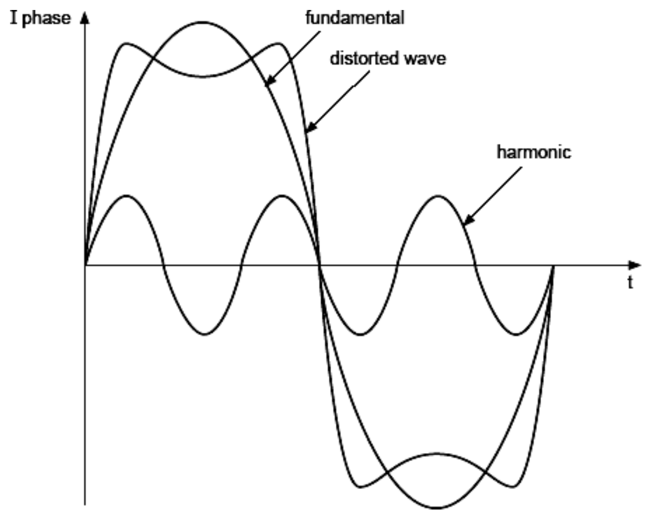


Figure 1. Graphic of Fundamental and Distorted Sine Signals

The most effective and economical method of solving the harmonic problem is the application of passive filters. Most passive filters are designed to redirect harmonic currents to specific undesired sections of the power system. Passive filters are widely used to compensate for reactive power losses due to the presence of harmonics in the installation system. The passive filter circuit consists of components R, L, and C.

Matlab is one of the most widely used computing software in engineering and science. In addition to its accuracy and computational speed, Matlab can not only produce interesting simulations and graphs, it can also be relied on for writing scientific manuscripts and reports. Other programming languages rarely have this capability. This makes the MatLab application very suitable and qualified for harmonic distortion mitigation programs in distribution systems.

## 2. METHOD

Distribution system is a part that is prone to harmonic distortion. Several loads connected to the distribution system are non-linear loads that distort the system. In addition to harmonic distortion, the presence of nonlinear loads also causes voltage fluctuations and additional power losses. One method to reduce harmonic distortion is by installing a passive filter in the distribution system. However, the size and location of the filter are two variables that must be determined so that distortion mitigation is effective. To determine the size and location of the harmonics, it is necessary to analyze the harmonic load flow. After a filter of a certain size is installed in a certain location, its effect on reducing distortion and improving the voltage then power loss profile is analyzed.

The steps taken in completing this Final Project are as follows:

### 2.1 Study of literature

Literature study is a stage that researchers take to collect information from various source such as books, the internet, national and international journals as a process to complete research.

### 2.2 Data analysis

Analyze and study the MatLab program until it is as desired.

### 2.3 Data processing

The data is processed by inputting the size and location of the filter which is efficient and in accordance with international standards.

### 2.4 Data collection

At this stage, direct data collection from MatLab Program.

### 2.5 Guidance study

At this stage the author provides guidance starting from making the title to the preparation of the proposal by holding discussions with the supervisor and the application of MatLab in research.

### 2.6 Report creation

The researcher makes a final research report as a form of the results of the research that has been carried out.

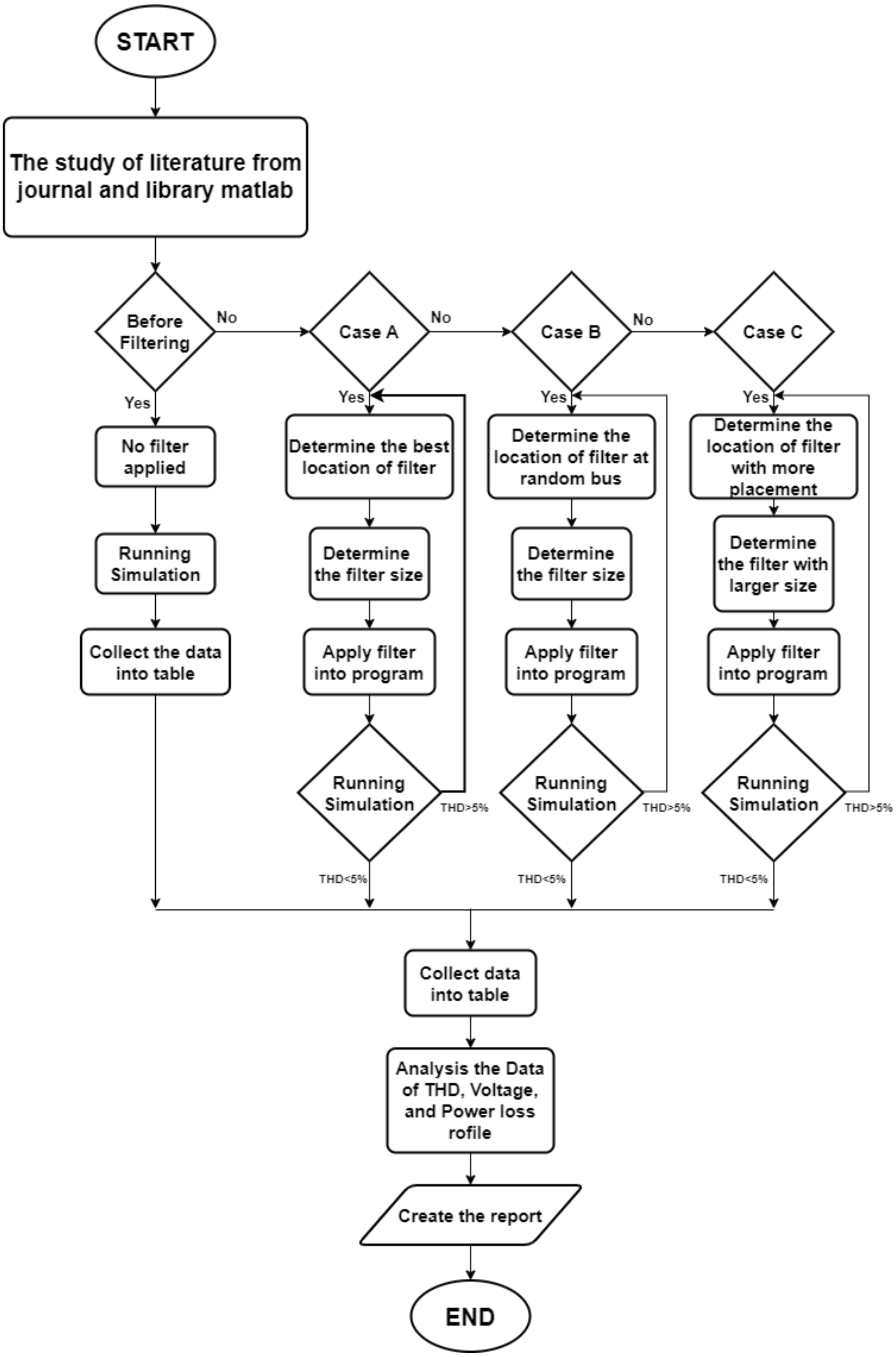


Figure 2. Flowchart of Research Methods

## 3. RESULT AND DISCUSSION

### 3.1 Result

Table 1. Summary Of The Result Before and After The Installation Of Filters

| | Before Filter Installation | After Filter Installation | | |
|---|---|---|---|---|
| | | Case A | Case B | Case C |
| Minimum Voltage | 0.8173 p.u. at bus 15 | 0.8280 p.u. at bus 15 | 0.8265 p.u. at bus 15 | 0.8227 p.u. at bus 15 |
| Maximum Voltage | 1.0024 p.u. at bus 1 | 1.0005 p.u. at bus 1 | 1.0005 p.u. at bus 1 | 1.0004 p.u. at bus 1 |
| Average Voltage | 0,9125 p.u. | 0,9185 p.u. | 0,9175 p.u. | 0,9151 p.u. |
| Minimum THDv | 6.9499 % at bus 1 | 2.9485 % at bus 5 | 2.5943 % at bus 10 | 1.3215 % at bus 15 |
| Maximum THDv | 8.2883 % at bus 21 | 4.0005 % at bus 20 | 5.5522 % at bus 21 | 2.8586 % at bus 30 |
| Average THDv | 7,540618 % | 3,253213 % | 3,372179 % | 1,986916 % |
| Real Losses (MW) | 1.59374 | 1.51308 | 1.89914 | 2.08382 |
| Reactive Losses (MVAR) | 1.18009 | 1.13653 | 1.39639 | 1.54377 |

Table 1 shows the results before and after filtering. There are 4 kinds of cases presented, namely Before Filtering, Case A, Case B, and Case C. The indicators measured are RMS Voltage, average voltage, THDv, average THD, and losses. The placement size and location of the filter affect changes in RMS voltage, losses, and THDv. In Case A, the average RMS increase and losses decrease, while the maximal THD can be reduced become 4% at bus 20. In Case B, there is an increase in THD and Losses, the average of RMS also decrease. These results are not in accordance with the purpose of installing the filter. While in Case C, it has the best attenuation of THD, but the losses increase the most. Before the system was installed with a filter, the minimum THD Voltage was known to be 6.9499% at bus 1, while the maximum THD Voltage formed was 8.2883% at bus 21. This is not in accordance with IEEE 519-2014 rules which regulate the normal THD size. Stated in the following table:

Table 2. IEEE 519-2014

| Bus Voltage V at PCC | Individual Harmonic (%) | Total Harmonic Distortion (%) |
|---|---|---|
| $V \leq 1.0$ kV | 5.0 | 8.0 |
| 1kV $< V \leq$ 69 kV | 3.0 | 5.0 |
| 69kV $< V \leq$ 161 kV | 1.5 | 2.5 |
| 161 kV $< V$ | 1.0 | 1.5 |

The standard of Voltage and THD based on IEEE 519-2014 for the nominal voltage between 1KV and 69KV is 5%. The need for mitigation of distortion in the system so that THD can be controlled below 5%.

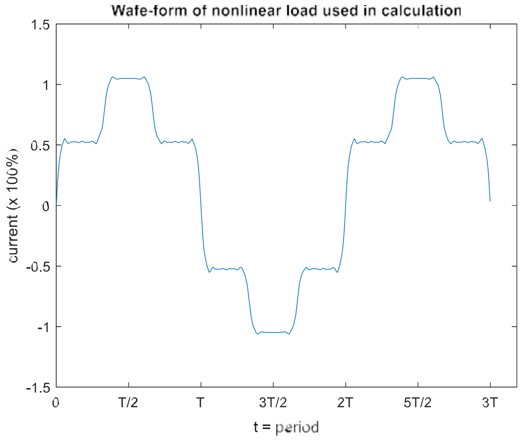


Figure 3. Graphic of Non-Linear Load 1

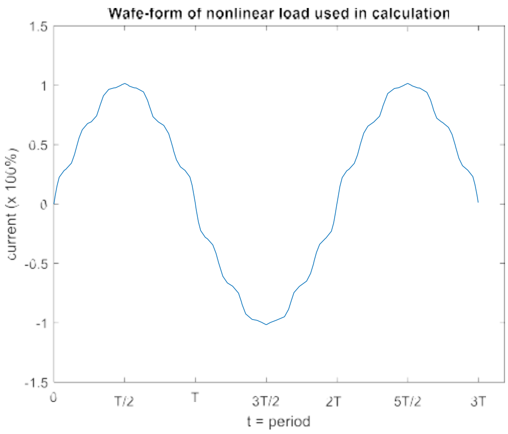


Figure 4. Graphic of Non-Linear Load 2

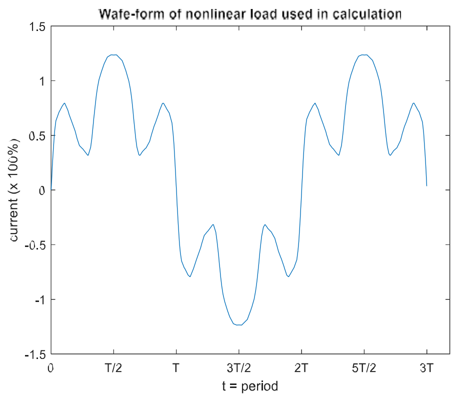


Figure 5. Graphic of Non-Linear Load 3

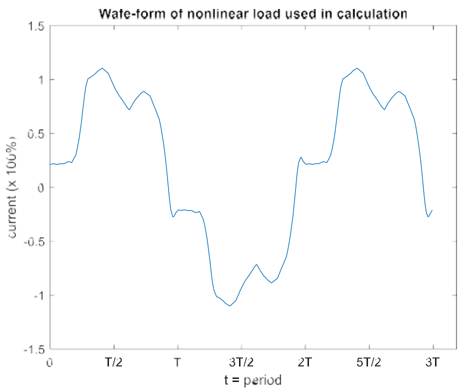


Figure 6. Graphic of Non-Linear Load 4

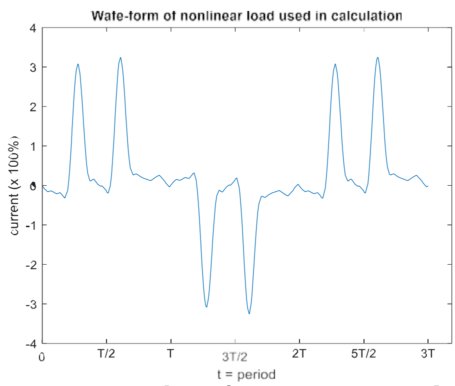


Figure 7. Graphic of Non-Linear Load 5

Non Linear Load located on bus 6, 20, 21, 25, 30 generates 5 graphs. Each non-linear load forms a different graph. The results will remain the same after the system is installed with a filter.

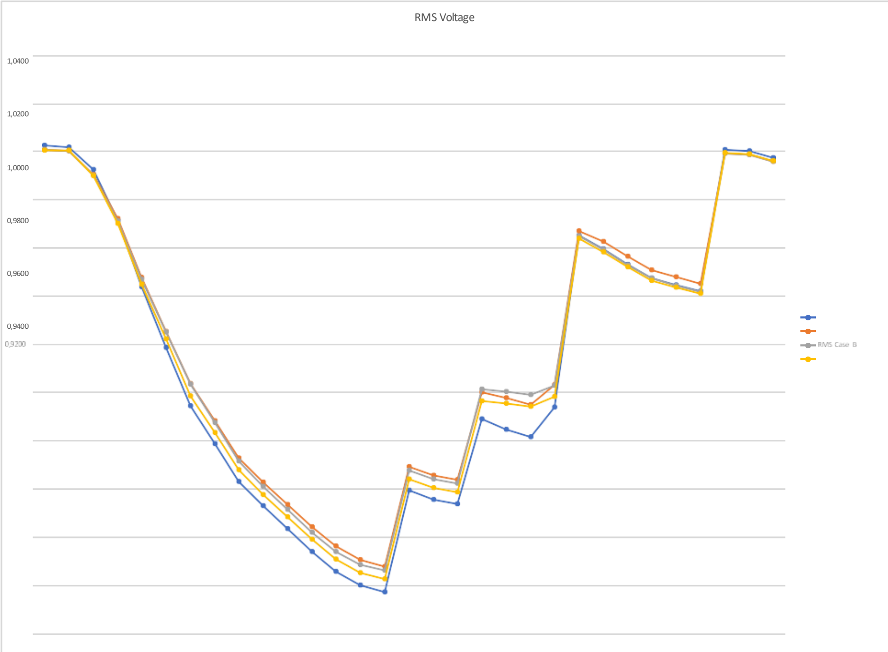


Figure 8. Graphic of RMS Voltage

Figure 8 is a graph of the RMS voltage comparison for each case. In the case Before Filtering, the average RMS Voltage shown in the graph is lower than Case A. Case A is the proper distortion mitigation result among other cases. The increase in the average RMS Voltage is one sign of the success of installing filters in reducing harmonics.

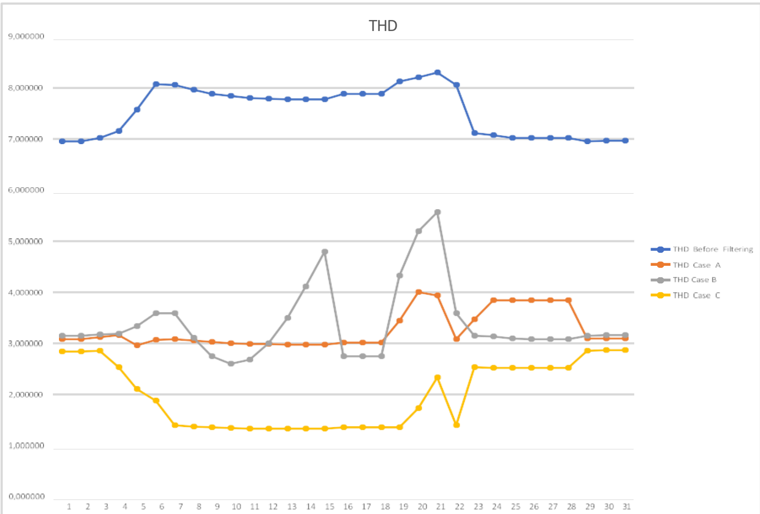


Figure 9. Graphic of THDv

Figure 9 shows the THDv comparison graph for each case. The THD on the graph before filtering is very high beyond the standard limit. In the graph above, the THD in Cases A and C can be lowered below 5%. While Case B still does not achieve the standard in table 2. In Case B there are still several buses that have a THD more than 5%.

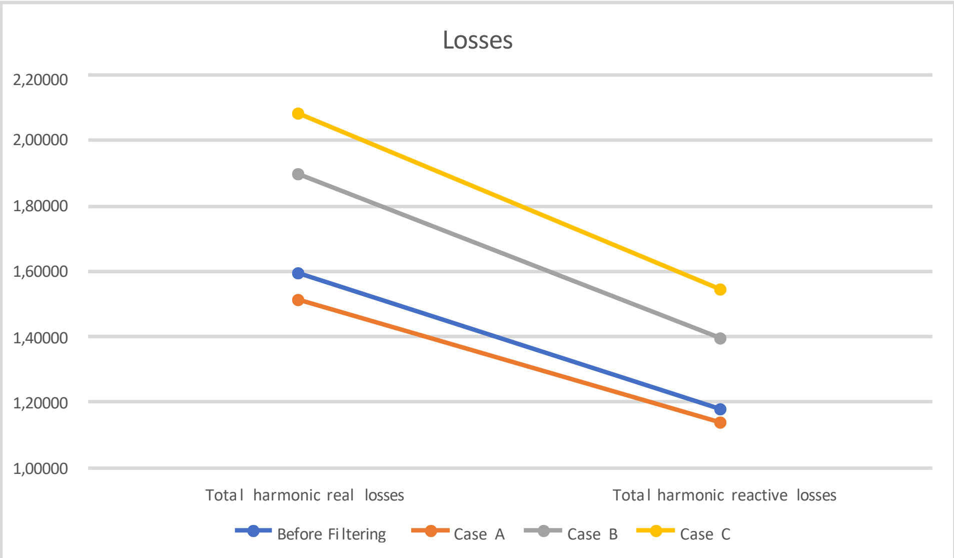

Figure 10. Graphic of Losses

Figure 10 is a Losses comparison chart. After being filtered, losses in Case B and C have increased. This is a sign that their filter installation is uneffective. Case A is an example of successful harmonic filtering, which is characterized by reduced losses compared to before filtering.

### 3.2 Method

#### 3.2.1 Location of Filter

It is important to determine the correct location for filter placement so that distortion mitigation can be optimal. The presence of nonlinear loads creates harmonic currents. The most optimal filter installation is focused around the source of distortion. Placing filters on buses around nonlinear loads can block distortion before it flows to other buses. This is because the filter will make the impedance 0 and pass all harmonic currents that are close to the injected frequency.

3.2.2 Size of Filter

Table 3. Filtersize Experiment Data

| R (Ω) | L (H) | Base MVA | Base KV | Orde | G | B | Cap (F) |
|---|---|---|---|---|---|---|---|
| 10 | 0.1 | 100 | 23 | 5 | 52.9000 | 0 | 4.0528E-06 |
| 100 | 0.1 | 100 | 23 | 5 | 5.2900 | 0 | 4.0528E-06 |
| 1000 | 0.1 | 100 | 23 | 5 | 0.5290 | 0 | 4.0528E-06 |
| 100 | 0.01 | 100 | 23 | 5 | 5.2900 | 0 | 4.0528E-05 |
| 100 | 1 | 100 | 23 | 5 | 5.2900 | 0 | 4.0528E-07 |
| 100 | 0.000001 | 100 | 23 | 5 | 5.2900 | 0 | 0.4053 |
| 100 | 0.000001 | 100 | 23 | 7 | 10.5800 | 0 | 0.4053 |
| | | | | | | | 0.2068 |
| 1000 | 0.000001 | 100 | 23 | 7 | 1.0580 | 0 | 0.4053 |
| | | | | | | | 0.2068 |
| 100 | 0.000001 | 100 | 23 | 11 | 15.8700 | 0 | 0.4053 |
| | | | | | | | 0.2068 |
| | | | | | | | 0.0837 |
| 1000 | 0.000001 | 100 | 23 | 11 | 1.5870 | 0 | 0.4053 |
| | | | | | | | 0.2068 |
| | | | | | | | 0.0837 |

To get the best filtersize, an experiment was conducted using the sample data in Table 3. The results show: The larger R, the smaller the G size. The larger the L size, the smaller the Cap size. The higher the order, the larger the size of G.

## 3.3 Results After Simulation

3.3.1 Before Filtering

Table 4. System Summary Before Simulation

| Number of: | | Value of | P (MW) | Q (MVAr) |
|---|---|---|---|---|
| Bus | 31 | Total Gen Capacity | 600.0 | -250.0 to +300.0 |
| Generator | 1 | On-line Capacity | 600.0 | -250.0 to +300.0 |
| Committed Gen | 1 | Generation | 19.9023 | 8.7889 |
| Linear Load | 21 | Linear Load | 14.14 | 4.65 |
| Nonlinear Load | 5 | Nonlinear Load | 4.17 | 2.98 |
| Branch | 30 | Total Harmonic Losses | 1.59374 | 1.18009 |

Table 4 is a summary of the results of the system before being filtered. The system which consists of 31 buses, 5 nonlinear loads before being filtered shows a Total Harmonic Real Losses is 1.59374 MW. Meanwhile, total harmonic reactive losses were detected at 1.18009 MVAR.

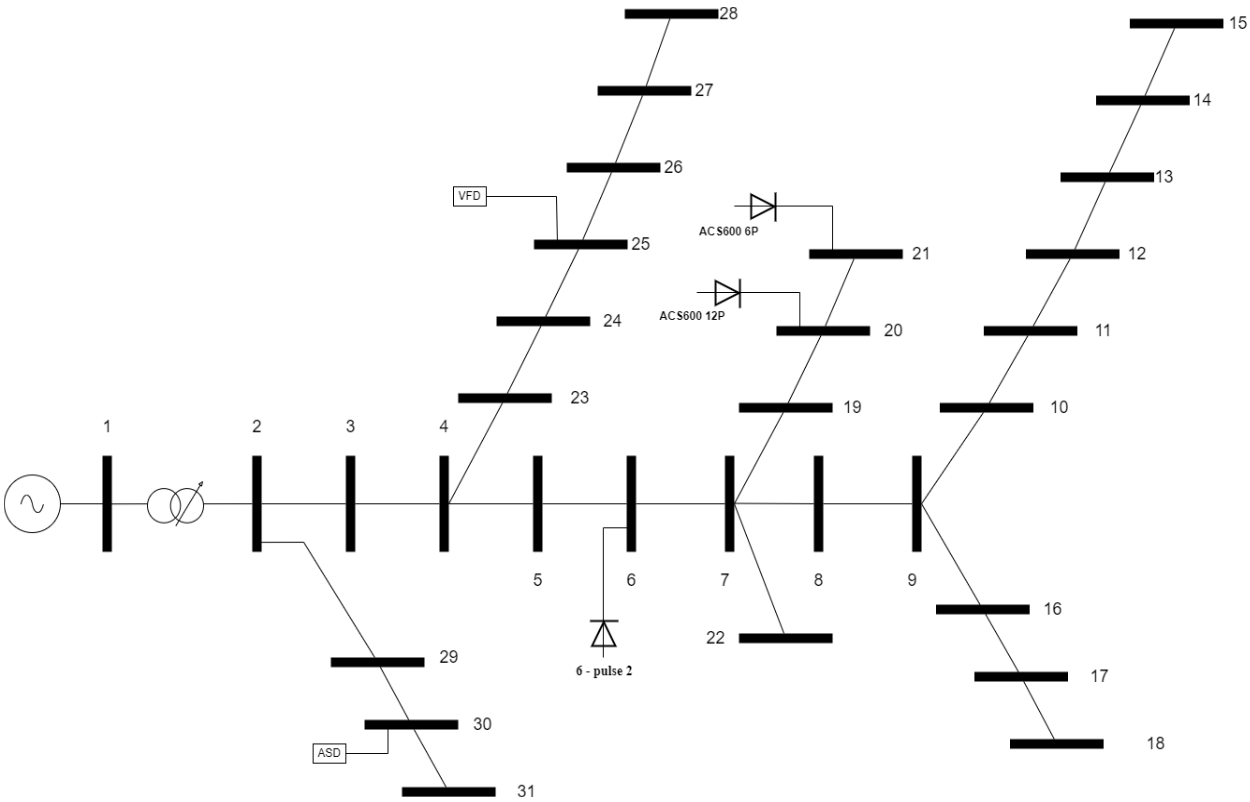


Figure 11. The IEEE 30-Bus System Used for Simulations

The 23 kV distribution system is used in this simulation. Several nonlinear loads are placed at various locations. A PWM-adjustable speed drive (ASD), commonly used for motor speed control by adjusting the pulse width in the voltage waveform, is placed at bus 25. Meanwhile, a variable frequency drive (VFD), used to control the speed of an electric motor by adjusting the frequency of the electrical power supplied to the motor, is located at bus 30. Additionally, pulses are also spread across buses 6, 20, and 21. At the fundamental frequency, all loads, including nonlinear drives, are considered as constant power loads. Three cases will be considered.

Harmonic analysis before the installation of passive filters indicate very high distortion of both voltage and current waveforms due to the presence of the 5 nonlinier loads with relatively high power ratings. According to the IEEE-519 standard allowable level of THD is not larger that 5%. If hormonic current has resulted in unacceptable of THDv levels, the electric utility has the right to reject (disconnect) these non linear loads.

The common procedure is to require the consumers of nonlinear load to installation passive filter banks at the terminals of the AC drives.

3.3.2 Case A

Case A is the most effective harmonic filter installation. THD is reduced to below 5%, losses can be minimized, RMS Voltage can increase, and it utilizes a minimal number and size of filters.

Table 5. Location of Filter in The Program Case A

| Bus | Type | Pd(MW) | Qd(MVAR) | Gs | Bs | Area | Vm | Va | BaseKV | Zone | Vmax | Vmin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 150 | 1 | 1.05 | 0.95 |
| 2 | 1 | 0.522 | 0.172 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 3 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 4 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 5 | 1 | 0.938 | 0.308 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 6 | 1 | 0 | 0 | 0 | 0.9 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 7 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 8 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 9 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 10 | 1 | 0.189 | 0.062 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 11 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 12 | 1 | 0.336 | 0.110 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 13 | 1 | 0.658 | 0.216 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 14 | 1 | 0.784 | 0.258 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 15 | 1 | 0.730 | 0.240 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 16 | 1 | 0.478 | 0.157 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 17 | 1 | 0.550 | 0.181 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 18 | 1 | 0.478 | 0.157 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 19 | 1 | 0.432 | 0.142 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 20 | 1 | 0.673 | 0.221 | 0 | 1.5 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 21 | 1 | 0.496 | 0.163 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 22 | 1 | 0.207 | 0.068 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 23 | 1 | 0.522 | 0.172 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 24 | 1 | 1.920 | 0.631 | 1.59 | 3 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 25 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 26 | 1 | 0.117 | 0.367 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 27 | 1 | 0.550 | 0.181 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 28 | 1 | 0.793 | 0.261 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 29 | 1 | 0.883 | 0.290 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 30 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 31 | 1 | 0.884 | 0.290 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |

Using filter that installed with a size of 1.5870 at bus 24 and placement of capacitors around nonlinear load there are buses 6, 20, 24. A hybrid passive filter with three shunt branchs tuned to the $5^{th}$, $7^{th}$, $11^{th}$ with R=1000Ω, L=1000mH, $C^{(5)}$ $= 4.05$µF, $C^{(7)} = 2.06$µF, $C^{(11)} = 0.83$µF.

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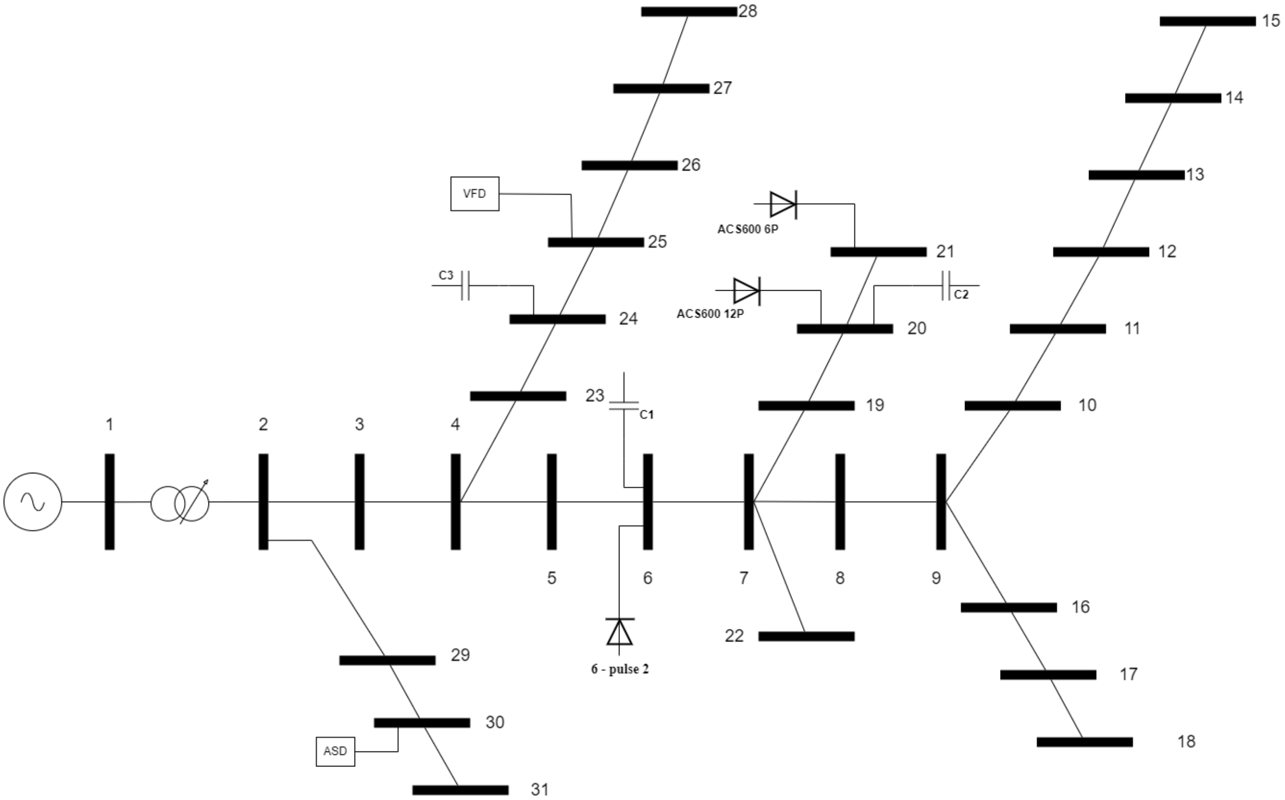


Figure 12. The IEEE 30-Bus System Used for Simulations Case A

In the figure above, the stepdown transformer lowers the voltage from 150KV to 23KV. At the fundamental frequency, all loads including nonlinear drives are considered as constant power loads. Figure 12 is the single line of placing capacitors on the bus around a nonlinear load. The THD reduction is carried out by providing filters on bus 24 and installing capacitors on buses 6, 20, 24.

Table 6. System Summary After Simulation Case A

| Number of: | | Value of | P (MW) | Q (MVAr) |
|---|---|---|---|---|
| Bus | 31 | Total Gen Capacity | 600.0 | -250.0 to +300.0 |
| Generator | 1 | On-line Capacity | 600.0 | -250.0 to +300.0 |
| Committed Gen | 1 | Generation | 21.2917 | 3.9767 |
| Linear Load | 21 | Linear Load | 14.14 | 4.65 |
| Nonlinear Load | 5 | Nonlinear Load | 4.17 | 2.98 |
| Branch | 30 | Total Harmonic Losses | 1.513079 | 1.136533 |

Table 6 is the result of a system consisting of 31 buses and 5 nonlinear loads. After filtering, the system shows a decrease in total harmonic losses compared to before filtering become 1.513079 MW. Meanwhile, the total harmonic reactive losses detected was 1.136533 MVAR. It demonstrates successful THD reduction in a system using only 1 filter sized 1.5870, in the right location without much capacitor installation.

### 3.3.3 Case B

Table 7. Location of Filter Case B

| Bus | Type | Pd(MW) | Qd(MVAR) | Gs | Bs | Area | Vm | Va | BaseKV | Zone | Vmax | Vmin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 150 | 1 | 1.05 | 0.95 |
| 2 | 1 | 0.522 | 0.172 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 3 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 4 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 5 | 1 | 0.938 | 0.308 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 6 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 7 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 8 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 9 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 10 | 1 | 0.189 | 0.062 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 11 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 12 | 1 | 0.336 | 0.110 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 13 | 1 | 0.658 | 0.216 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 14 | 1 | 0.784 | 0.258 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 15 | 1 | 0.730 | 0.240 | 1.59 | 3 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 16 | 1 | 0.478 | 0.157 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 17 | 1 | 0.550 | 0.181 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 18 | 1 | 0.478 | 0.157 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 19 | 1 | 0.432 | 0.142 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 20 | 1 | 0.673 | 0.221 | 0 | 1.5 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 21 | 1 | 0.496 | 0.163 | 0 | 0.9 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 22 | 1 | 0.207 | 0.068 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 23 | 1 | 0.522 | 0.172 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 24 | 1 | 1.920 | 0.631 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 25 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 26 | 1 | 0.117 | 0.367 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 27 | 1 | 0.550 | 0.181 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 28 | 1 | 0.793 | 0.261 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 29 | 1 | 0.883 | 0.290 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 30 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 31 | 1 | 0.884 | 0.290 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |

Case B is a simulation of randomly placing capacitors on several buses, with the same number and size as Case A. Filter Case B shown in Table 8 is placed on bus 15 and placement of capacitors on buses 15, 20, 21. Using a hybrid passive filter with three shunt branchs tuned to the $5^{th}$, $7^{th}$, $11^{th}$ with

R=1000Ω, L=1000mH, $C_f^{(5)} = 4.05$μF, $C_f^{(7)} = 2.06$μF, $C_f^{(11)} = 0.83$μF.

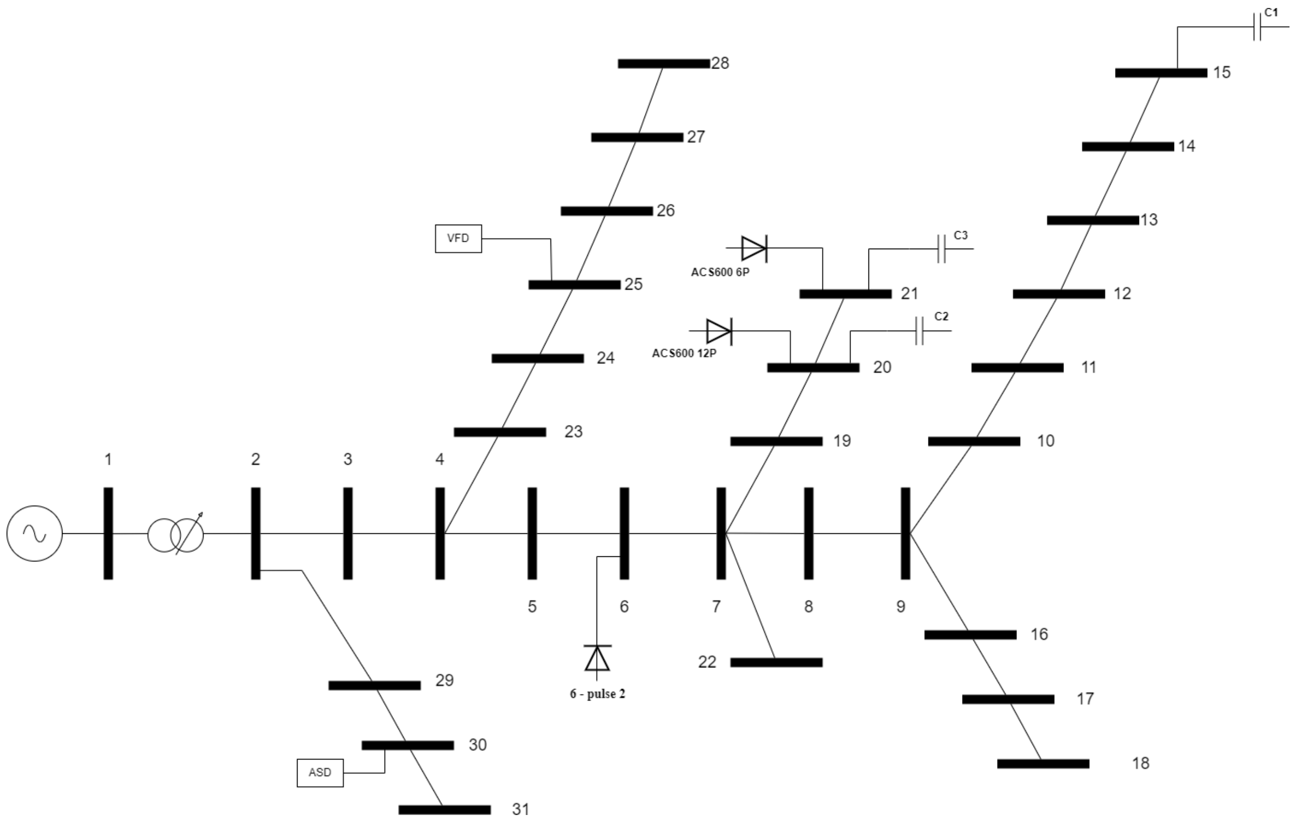


Figure 13. The IEEE 30-Bus System Used for Simulations Case B

In the figure above, the stepdown transformer decrease the voltage from 150KV to 23KV. At the fundamental frequency, all loads including nonlinear drives are considered as constant power loads. Figure 13 is the single line of placing filter on several randomly buses. The THD reduction is carried out by providing filter on bus 15, installing capacitors on buses 15, 20, 21.

Table 8. System Summary After Simulation Case B

| Number of: | | Value of | P (MW) | Q (MVAr) |
|---|---|---|---|---|
| Bus | 31 | Total Gen Capacity | 600.0 | -250.0 to +300.0 |

| | | | | |
|---|---|---|---|---|
| Generator | 1 | On-line Capacity | 600.0 | -250.0 to +300.0 |
| Committed Gen | 1 | Generation | 21.2796 | 4.9773 |
| Linear Load | 21 | Linear Load | 14.14 | 4.65 |
| Nonlinear Load | 5 | Nonlinear Load | 4.17 | 2.98 |
| Branch | 30 | Total Harmonic Losses | 1.899142 | 1.396389 |

Table 8 is the result of a system consisting of 31 buses and 5 nonlinear loads. After filtering, the system shows a increase in total harmonic real losses compared to before filtering become 1.899142 MW. Meanwhile, the total harmonic reactive losses detected was 1.396389 MVAR. This indicates the same size and number of filter, if the location is not right then the harmonic blocking will not be optimal.

### 3.3.4 Case C

Case C is a simulation of the filter installation with a larger size and more numbers. The use of large and excessive filters not only makes companies spend larger budgets, but also cannot guarantee success in the distortion mitigation process.

Table 9. Location of Filter Case C

| Bus | Type | Pd(MW) | Qd(MVAR) | Gs | Bs | Area | Vm | Va | BaseKV | Zone | Vmax | Vmin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 150 | 1 | 1.05 | 0.95 |
| 2 | 1 | 0.522 | 0.172 | 0 | 1.5 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 3 | 1 | 0 | 0 | 0 | 0.6 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 4 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 5 | 1 | 0.938 | 0.308 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 6 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 7 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 8 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 9 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 10 | 1 | 0.189 | 0.062 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 11 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 12 | 1 | 0.336 | 0.110 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 13 | 1 | 0.658 | 0.216 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 14 | 1 | 0.784 | 0.258 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 15 | 1 | 0.730 | 0.240 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 16 | 1 | 0.478 | 0.157 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 17 | 1 | 0.550 | 0.181 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 18 | 1 | 0.478 | 0.157 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 19 | 1 | 0.432 | 0.142 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 20 | 1 | 0.673 | 0.221 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 21 | 1 | 0.496 | 0.163 | 2.65 | 6.01 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 22 | 1 | 0.207 | 0.068 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 1 | 0.522 | 0.172 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 24 | 1 | 1.920 | 0.631 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 25 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 26 | 1 | 0.117 | 0.367 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 27 | 1 | 0.550 | 0.181 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 28 | 1 | 0.793 | 0.261 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 29 | 1 | 0.883 | 0.290 | 0 | 0.9 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 30 | 1 | 0 | 0 | 0 | 0.9 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |
| 31 | 1 | 0.884 | 0.290 | 0 | 0 | 1 | 1 | 0 | 23 | 1 | 1.05 | 0.95 |

Case C is a simulation of the filter installation with a larger size and more numbers. By using a filter sized 2.6450, Table 9 shown filter is placed on bus 21 and the placement of capacitors is on buses 2, 3, 21, 29, and 30. Using R=1000Ω, L=100mH, a hybrid passive filter with five shunt branch tuned to the $5^{th}$, $7^{th}$, $11^{th}$, $13^{th}$, and $17^{th}$ . $C_f^{(5)} = 4.05$μF, $C_f^{(7)} = 2.06$μF, $C_f^{(11)} = 0.83$μF, $C_f^{(13)} = 0.6$μF, $C_f^{(17)} =0.35$μF.

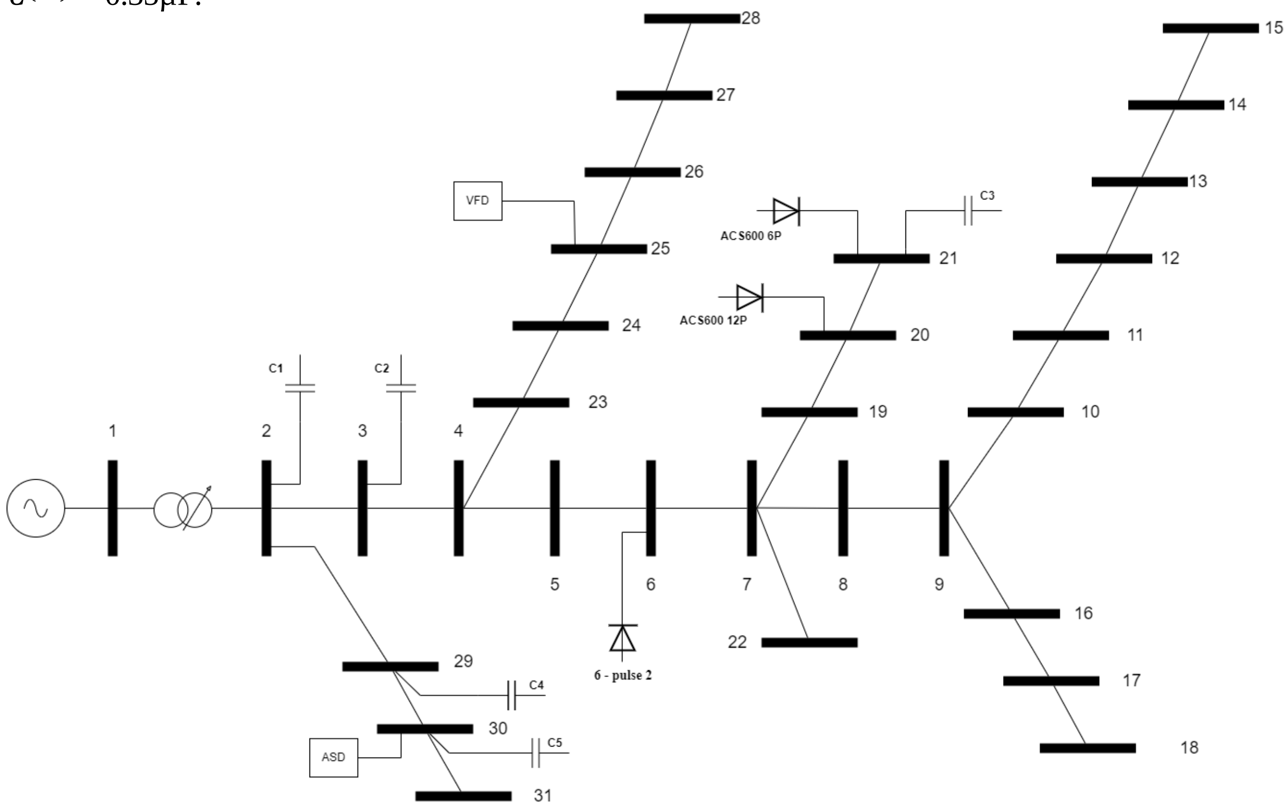


Figure 14. The IEEE 30-Bus System Used for Simulations Case C

In the figure above, the stepdown transformer decrease the voltage from 150KV to 23KV. At the fundamental frequency, all loads including nonlinear drives are considered as constant power loads. Figure 14 is the single line of placing capacitors larger size and more numbers. The THD reduction is carried out by providing filter on bus 21, installing capacitors on buses 2, 3, 21, 29 and 30.

Table 10. System Summary After Simulation Case C

| Number of: | | Value of | P (MW) | Q (MVAr) |
|---|---|---|---|---|
| Bus | 31 | Total Gen Capacity | 600.0 | -250.0 to +300.0 |
| Generator | 1 | On-line Capacity | 600.0 | -250.0 to +300.0 |
| Committed Gen | 1 | Generation | 22.5085 | 0.4554 |
| Linear Load | 21 | Linear Load | 14.14 | 4.65 |
| Nonlinear Load | 5 | Nonlinear Load | 4.17 | 2.98 |
| Branch | 30 | Total Harmonic Losses | 2.083820 | 1.543773 |

Table 10 is the result of a system consisting of 31 buses and 5 nonlinear loads. After Case C was filtered, there was an increase in losses compared to before filtering. The table above shows total harmonic real losses become 2.083820 MW. Meanwhile, the total harmonic reactive losses is 1.543773 MVAR. There is still an increase in losses indicating the filtering is still not effective. This means that providing a large and spread out filter size may not be able to completely overcome the distortion.

## 4. CONCLUSION

From the research, the following conclusions can be drawn:

1. After installing the filter, there is an improvement in voltage.
2. Power losses can be reduced after filtering.
3. Total harmonic distortion can be suppressed well according to standards.
4. In successful filtering, there will be increase in voltage, reduction in power losses, and total harmonic distortion can be controlled according to standards.
5. In addition to mitigating distortions, this research can also assist in managing the company’s budget by using the number and size of filters to be as effective as possible.
6. Installation of filters around the location of nonlinear loads is very effective in reducing harmonics.
7. If the location is suitable, then the use of small and few filters will be more

effective than the use of large and many filters.

8. Although the number and size of filters is effective, if placed in the wrong location, the distortion cannot be effectively blocked.
9. Even though the THD is smaller, the voltage and power losses are not necessarily improved.

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