HYBRID PASSIVE FILTER FOR MITIGATION OF DISTORTED DISTRIBUTION SYSTEM AND VOLTAGE IMPROVEMENT

Compiled as one of the requirements for completing the Undergraduate Study Program in the Department of Electrical Engineering, Faculty of Engineering

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APPROVAL

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SCIENTIFIC PUBLICATION

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Surakarta 19, February 2021

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Abstrak

Hal terpenting dalam utilitas kelistrikan adalah meningkatkan kualitas tegangan pada jaringan listrik industri. dengan menggunakan perangkat elektronik untuk menggerakkan beban non-linier, setelah perangkat ini digunakan sistem akan terpengaruh dengan harmonisa. Harmonic telah menjadi masalah utama untuk kualitas daya, untuk membatasi jumlah harmonisa atau menghilangkannya perlu dilakukan penelitian terhadap komponenkomponen pemodelan.

Dalam proyek ini, analisis harmonik sistem tenaga dilakukan menggunakan perangkat lunak ETAP dan keseluruhan proses dijelaskan secara rinci. Pertama, jaringan dirancang hanya dengan 7 Bus yang dimodelkan sebagai sumber harmonik untuk menyuntikkan arus harmonik melalui jaringan listrik. Kemudian untuk menganalisis pengaruh arus harmonisa dilakukan analisis aliran beban harmonisa dan distorsi harmonisa ditentukan.

Untuk menghilangkan distorsi harmonik ini, berbagai jenis teknik telah diikuti. Ini adalah desain filter simetris, kapasitor bank, dll.

Hasil keseluruhan filter Tanpa tindakan tambahan. dibahas secara rinci untuk mengukur efisiensi analisis harmonik ini berdasarkan pengukuran kualitas daya.

Kata kunci: harmonik, filter, Beban nonlinier.

Abstract

The most important in electrical utility is to improve voltage quality in industrial power grids. by using electronic devices to drive the non-linear load, once these devices are used the system will get affected with harmonics. Harmonic has become the main issue for power quality, to limit the number of harmonics or remove it is need to investigate modeling components.

In this project, the harmonic analysis of the power system was performed using ETAP software and the whole process was described in detail. First, the network is designed simply with 7 Buses modeled as a harmonic source to inject harmonic current through the power grid. Then, to analyze the effect of harmonic current, the harmonic load flow analysis was performed and the harmonic distortion determined.

To eliminate this harmonic distortion, various types of techniques have been followed. These are the design of symmetric filters, bank capacitors, etc.

The overall results of filters Without additional measures. are discussed in detail to measure the efficiency of this harmonic analysis based on power quality measurements.

Keywords: harmonic, filter, nonlinear Load.

1. INTRODUCTION

1.1Background

In electrical power systems aim to deliver power with better quality. loads appear as a sinusoidal voltage from the utility in usually but may inject a non-sinusoidal current into the system. These loads draw nonlinear since. Non-linear loads cause non-sinusoidal currents or non-sinusoidal voltages named harmonic. Harmonic effects devices connected to the electrical system, it may reduce lifetime. Loads are preferably linear according to developments in semiconductor technology in the past 40 years, the number of nonlinear loads in the system is increasing rapidly.

Nonlinear loads affect the system by generating current harmonics and voltage harmonics. Transformers, converter high-power induction motors, UPS systems and, etc. Harmonic current and voltage also cause extra power loss, heat system elements, and damage to the system's installation components. The presence of high order frequency is very difficult to fix by using protection relays and may relays fail or even get damaged.

Variable frequency drives (VFDs) increasingly are used in all applications used in maritime drives and compressors to meet the energy efficiency and control performance under a good condition. the loads that have nonlinear characteristics may cause non-sinusoidal harmonic injection currents when starting operating The harmonic reduction in the power system is the most important among other solutions and filtering is the most broader approach.

Reducing harmonic can be done by using a power quality conditioner and filters (passive, active, and hybrid) passive filters are cost-effective, easy for user control, and provide an acceptable current harmonic cancellation.

There are many kinds of power system software that can be used to determine and analyze the Harmonic on power networks such as Matlab, PISM, or ETAP. In this study, the ETAP Software application was selected because it is simplified and easy to model harmonic sources.

ETAP is a completely integrated Electrical Engineering software solutions. ETAP can provide the best tool for the study of harmonics in the power system. With ETAP we can easily study the Harmonic analysis of any circuit's type also ETAP helps us to study the Harmonic spectrums.

There are 6 types of harmonic filters provided by the ETAP program. These would have the advantage of minimizing harmonic distortion to meet the rules standard. on top of that ETAP can do other functions such as:

* Battery Discharge Sizing
* Transient Stability Analysis
* Load Flow Analysis
* Unbalanced Load Flow Analysis
* Motor Acceleration Analysis
* Optimal Power Flow Analysis
* Reliability Assessment
* DC load flow analysis

1.2. Problem Formulation:

Designing harmonic filters to improve the power quality study and fix the network system it may face some challenges, problems in this study can be formulated as follows:

1. Planning the design of circuits and collecting the data.
2. Installation and calibration of ETAP software to suit this research.
3. Creating and simulating the circuit equipment.
4. Testing different sets and comparing the output results.

1.3 Aim and Objectives

The main objective of the project is to perform a Harmonic Study on a power system using ETAP software, make corrections by adding Filters to the system, and compare the results before and after adding the filter in the system.

To achieve this, the study is subject to a list of goals as shown below:

1. Understanding the Harmonic Analysis module using ETAP software.
2. Modelling different types of power networks that will include Harmonic Sources in the power network.
3. Perform harmonic analysis on these power networks so that harmonic distortion can be easily identified.

4. To limit the harmonic distortion and resonance Conditions in the power network, design/test filters, and Identify possible violations of the distortion limits.
5. Comparison of the result before and after adding the filters.
6. able to understand how to protect the power system equipment from Harmonic causes understanding of ETAP software and how to create power system networks

All mentioned key issues of the project will be taken according to IEEE519 standard, where the Harmonic indices will be set accordingly in the software.

2. METHOD

The research method used is a means to achieve the desired research goals. The purpose of this project is to propose the design of a Hybrid Passive Filter, and to propose to form an ideal solution for two main types of analyses that could be performed during harmonic analysis are voltage harmonic distortion and current harmonic distortion in which the individual and total current and voltage harmonic distortions are calculated at the various buses then the results are compared with the relevant contractual limits on the power grid system.

The rare steps of this research are shown in Fig. in the flowchart below

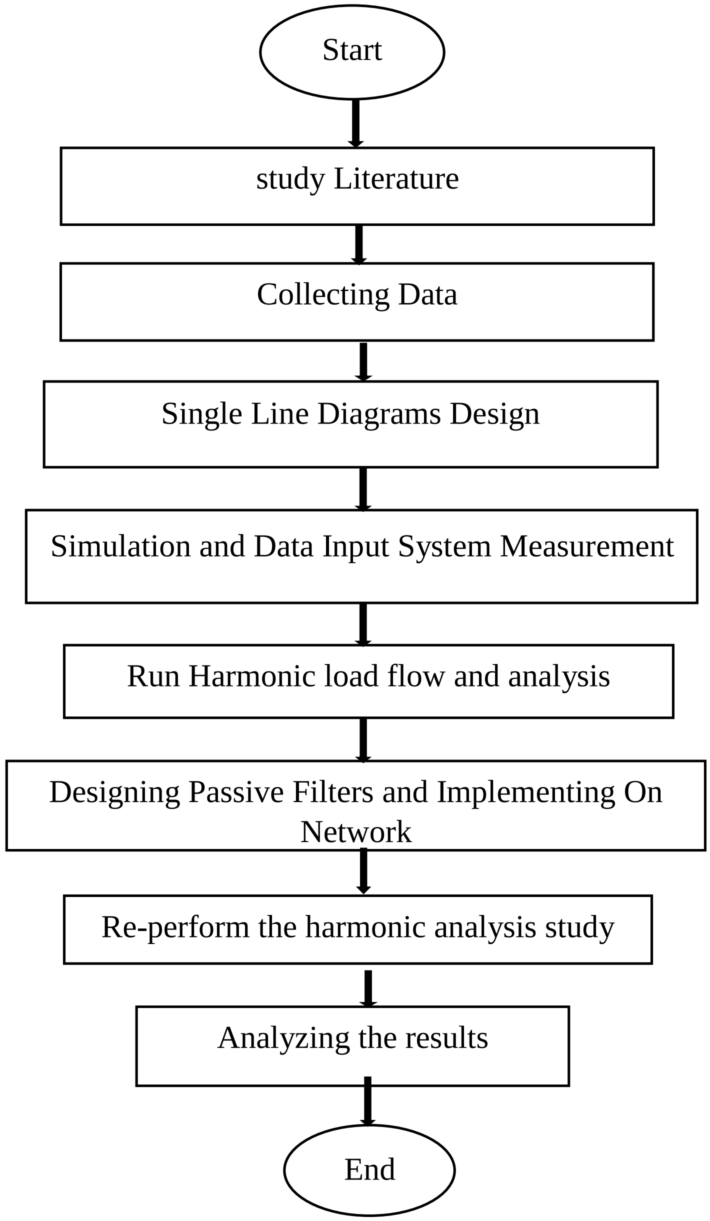

Figure 1. flowchart

2.1 Modeling components for harmonic analysis :

The harmonic filters and life-saving utilities are designed keeping in mind the overall layout and utilities available using ETAP software. The first stage is implemented, and the research begins with the study first in the literature study department so that the research can be carried out and correctly implemented. Literature studies are conducted through reading journals and understanding the various books that can support the steps of conducting research as flow:

1. obtaining a single-line diagram to be able to provide harmonic sources to the network system, design information targeted by the design is done by defining the facilities needed to solve the problems that occur. These facilities are a combination of good power system network design with regard to harmonic sources such as VFDs, chargers, UPS, etc.

To model a nonlinear component as a harmonic current source, the user can select an appropriate harmonic current library via the Library button and Harmonic Library Quick Pick Editor at the Harmonic page of that component. The Harmonic page of a nonlinear load is given below.

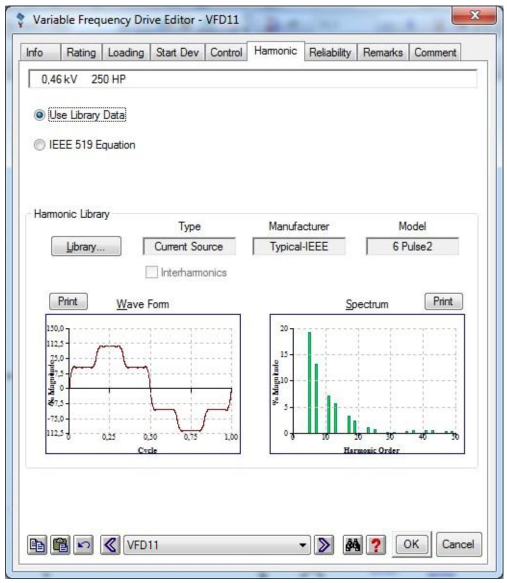

Figure 2. Harmonic Editor page

2. Load flow operation to perform the harmonic analysis of the electrical network in various possible operating scenarios.
3. by Checking the individual and total voltage and current distortion levels at the interested system buses and Check the harmonic frequency spectrum, that may be a plot of every individual harmonic value with relevancy the elemental value versus frequency.
4. If the harmonic distortion results exceed the allowable limits, select an appropriate harmonic mitigation solution and the optimum insertion point for that solution such as filters.
5. Re-perform the harmonic analysis study after adding the harmonic filters to ensure compliance with the standard of harmonic limits.

2.2 Harmonic Indices

The result of harmonics is usually measured in terms of several indicators specified below:

Total Harmonic Distortion (THD) THD values obtained from the comparison of the RMS value of all components other than the fundamental harmonics of the fundamental component RMS value. Large THD (Total Harmonic Distortion) is expressed by the following formula.

$$\text{THD} = \sqrt{\frac{\sum_2^{\infty} f_i^2}{F_1}} \qquad (1)$$

Where :

Here Fi is the amplitude of the i^{th} harmonic, and $F1$ is the fundamental component.

individual Harmonic Distortion (IHD): measures the ratio of a given harmonic component to the principal component. It is highly efficient to design tuned filters.

$$\text{IHD} = \frac{Fi}{F1} \qquad (2)$$

Root Mean Square (RMS): This is the square root of the sum of the squares of the magnitudes of the fundamental harmonics and all the harmonics in the power system. For a power system without harmonics, the total RMS should be equal to the RMS core component

$$\text{RMS}\sqrt{\sum_1^{\infty} F_i^2} \qquad (3)$$

2.3 Desgining Harmonic Filter:

in this project hybrid passive filter has been selected among the available harmonic mitigation solutions in power technology, Because of its high efficiency, performance, simple configuration, and affordable price., passive filter configuration consists of passive components such as inductors, resistors, and capacitors (RLC). Then the filter insertion point has been carefully studied as it greatly affects the performance of the system. There are different types of passive filters in the industries, as shown below in Figure.

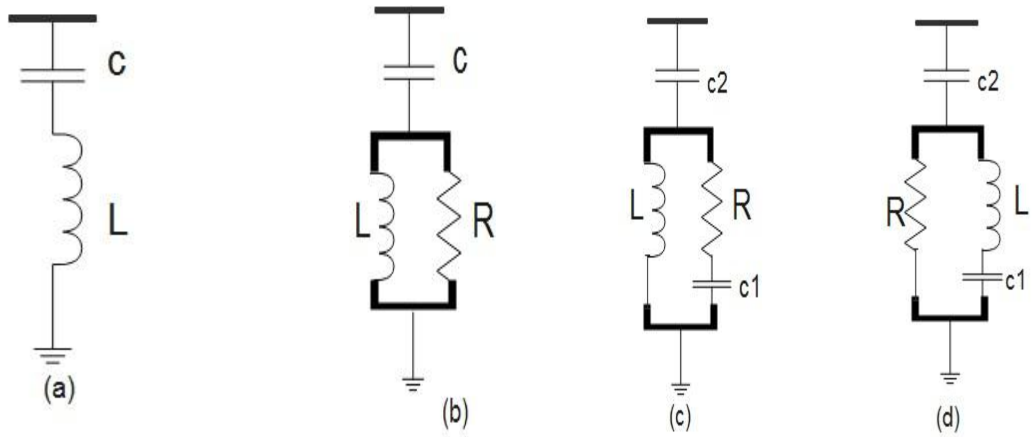

Figure 3.(a) Single-tuned; (b) 2nd order high-pass; (c) 3rd order high-pass; (d) C-type.

2.4 International Harmonic Standards

The ETAP Harmonic Analysis module is fully provided the latest version of the following standards listed below:

• IEEE 519- 2014 Standards, Recommended IEEE Practices, and Requirements for Harmonic Control in Electrical Power Systems.

• IEEE 519-1992 this document introduces many useful recommended practices for harmonics control in electrical networks. This document is widely used in the industrial sector and many consultants/clients use the limits shown in it as contractual limits within their specifications.

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3. RESULTS AND DISCUSSION

The project succeeded and the components of Harmonic analysis are modeled by using ETAP software to create harmonic current and voltages distortions in the power grid, after the harmonic occurred to the system then hybrid passive filters followed to mitigate that harmonic distortion in the grid. The entire process of harmonic analysis will be described as flow:

3.1 system network design :

One Line Diagram shows in figure 4, is designed to perform harmonic analysis. The network consists of 7 main Buses, Bus 16,bus 2,bus41, and bus 24 as High Voltages rating with 132,33, and 13,8KV, bus 7, bus 26, and bus 35 as Low Voltages rating with 0.48 and 0.46 kV .the grid injected by 6 harmonic sources generating harmonic distortion to the system these 5 sources install as flow :

Table 1: types of harmonic sources that installed to the system

Harmonic type		Bus	Voltage KV
2 -Toshiba PWM	ASD	24	13.8
1-Typical I-IEEE	6 pule1	7	0.48
1-Typical I-IEEE	6 pule2	26	0.46
2-Rockwell VFD	6 pulse	35	0.46

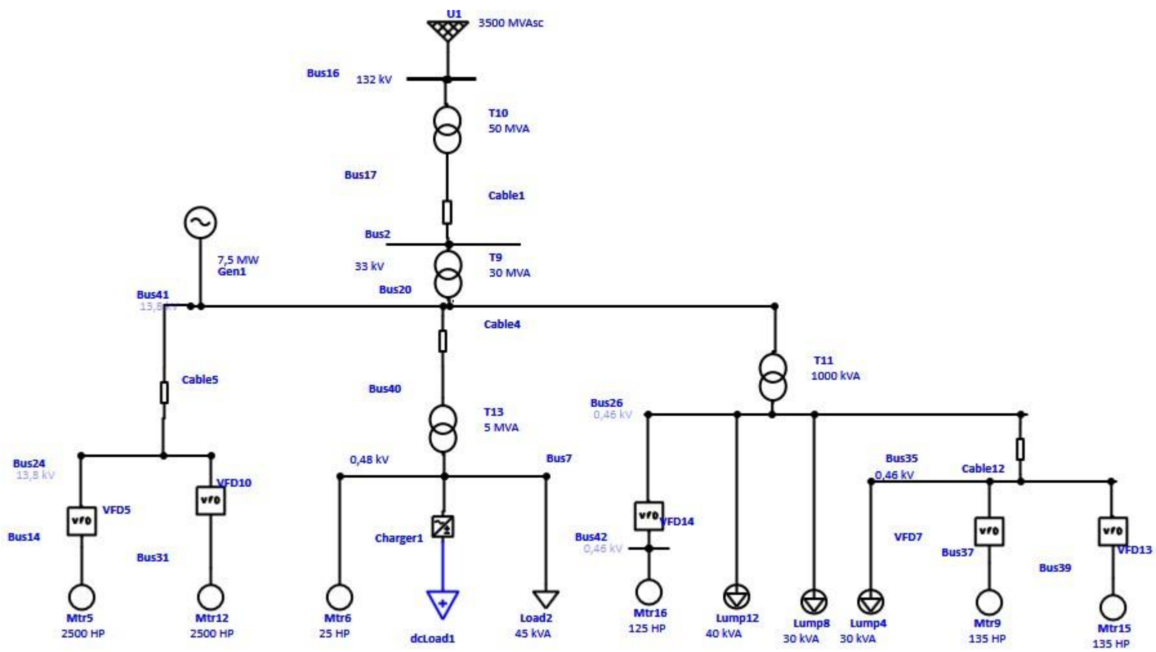

Figure 4.one line diagram of the system

3.1.1 Network Modelling:

The components values of this network are taken references and unmentioned rating taken from the ETAP library. The external grid is connected to 132 kV bus as High voltage and then the voltage level has stepped down from 132 kV to 33 kV using 50 MVA rated 2 winding transformers. Then continued stepping down to MV 13,8 kv and to the LV 0,48and 0,46 kv ,The values of Z% and X/R are typically provided from ETAP library, 5 harmonic sources are VFDs installed with motors as a controller and another harmonic source is a charger connected to the DC load, the harmonic modeled from the Etap library as mentioned in table 3.1 and selecting the harmonic sources from Etap library page shown in figure 5

Figure 5.harmonic sources page from ETAP library

The load flow analysis is very important to determine whether selecting equipment works well and gives a balance to the system, then the values of MVA and Power Factor are needed for filter sizing later on. The result of balanced load flow is shown below on the one-line diagram

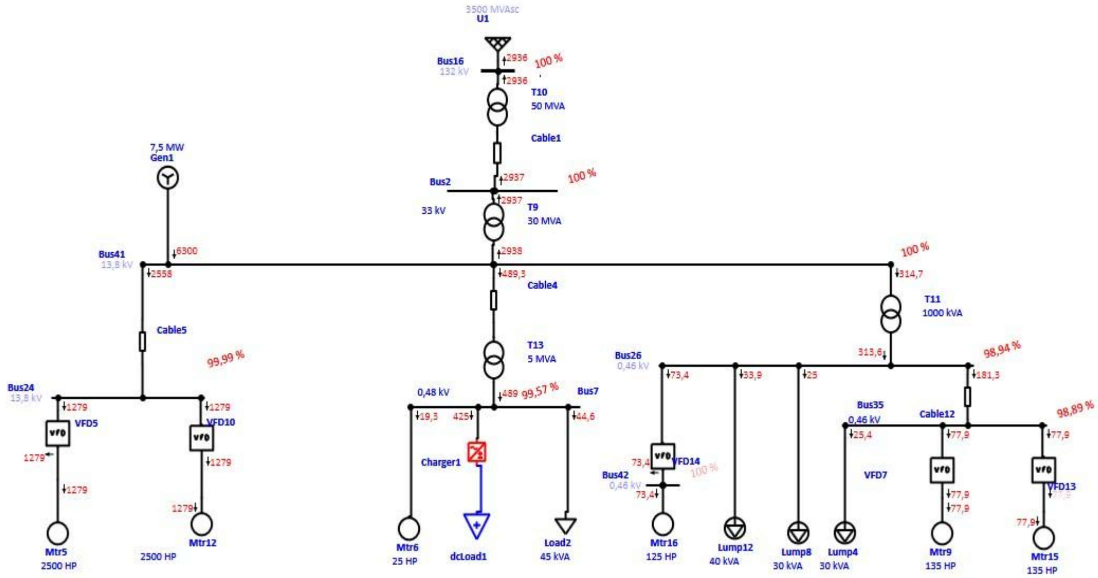

Figure 6.runing load flow analysis

On running the harmonic load flow study figure 7 , the result shows that, there is some harmonic frequency with greater magnitude exceeding the Total Harmonic Distortion THD and Individual Harmonic Distortion IHD limit. in another hand, the alert window (Figure 8) shows 5th,7th,11th, and 13th order harmonics are contributing to different buses. The harmonic commands in the alert window exceed the predefined limit THD and IHD.

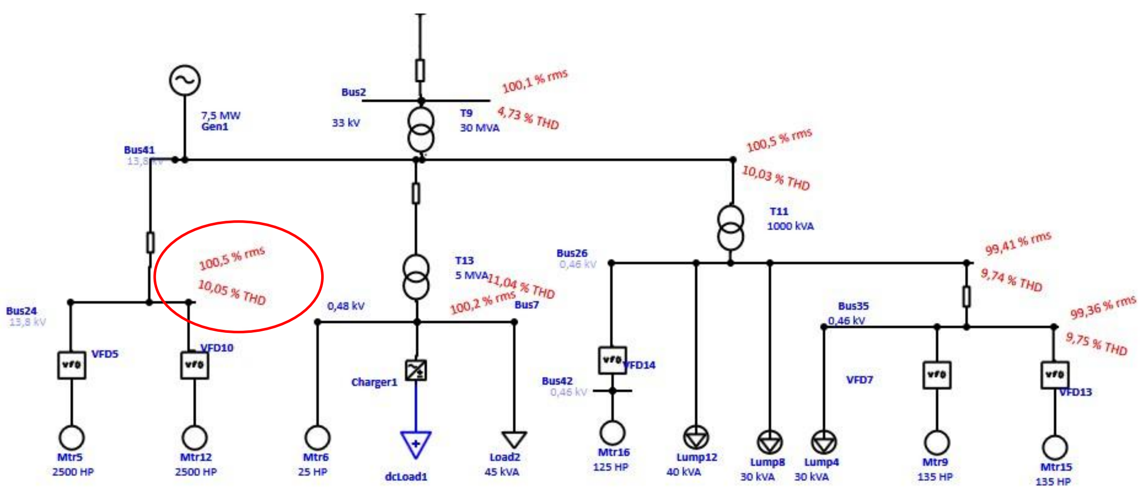

Figure 7.Harmonic load flow Analysis

Harmonic Load Flow Analysis Alert View - Output Report: Untitled

Study Case: HA   Data Revision: Base   Filter: Zone Area Region
Configuration: with filter   Date: 13-02-2021

Critical

Device ID	Type	Condition	Rating /Limit	Operating	% Operating	Harmonic
Bus24	Bus IHD	Exceeds Limit	3	3,85	128,25	5.00
Bus24	Bus IHD	Exceeds Limit	3	5,22	173,92	7.00
Bus24	Bus IHD	Exceeds Limit	3	4,77	159,15	11.00
Bus24	Bus IHD	Exceeds Limit	3	5,17	172,25	13.00
Bus24	Bus THD	Exceeds Limit	5	10,05	200,99	Total
Bus26	Bus IHD	Exceeds Limit	5	5,01	100,14	13.00
Bus26	Bus THD	Exceeds Limit	8	9,74	121,76	Total
Bus35	Bus IHD	Exceeds Limit	5	5,02	100,41	13.00
Bus35	Bus THD	Exceeds Limit	8	9,75	121,86	Total
Bus40	Bus IHD	Exceeds Limit	3	3,84	127,94	5.00
Bus40	Bus IHD	Exceeds Limit	3	5,21	173,54	7.00
Bus40	Bus IHD	Exceeds Limit	3	4,76	158,79	11.00
Bus40	Bus IHD	Exceeds Limit	3	5,16	171,89	13.00
Bus40	Bus THD	Exceeds Limit	5	10,03	200,56	Total
Bus41	Bus IHD	Exceeds Limit	3	3,84	127,94	5.00
Bus41	Bus IHD	Exceeds Limit	3	5,21	173,54	7.00
Bus41	Bus IHD	Exceeds Limit	3	4,76	158,79	11.00
Bus41	Bus IHD	Exceeds Limit	3	5,16	171,88	13.00
Bus41	Bus THD	Exceeds Limit	5	10,03	200,55	Total
Bus7	Bus IHD	Exceeds Limit	5	5,84	116,77	7.00
Bus7	Bus IHD	Exceeds Limit	5	5,71	114,28	13.00
Bus7	Bus THD	Exceeds Limit	8	11,04	137,99	Total

Figure 8.harmonic load Analysis alert window

The voltage waveforms and spectrum of the four distorted buses after Harmonic load flow analysis are diplayed below figure (9) shows that, the wave form of buses 7,24,26 and 35 are the most distorted .because are enjected by Harmonic sourses .

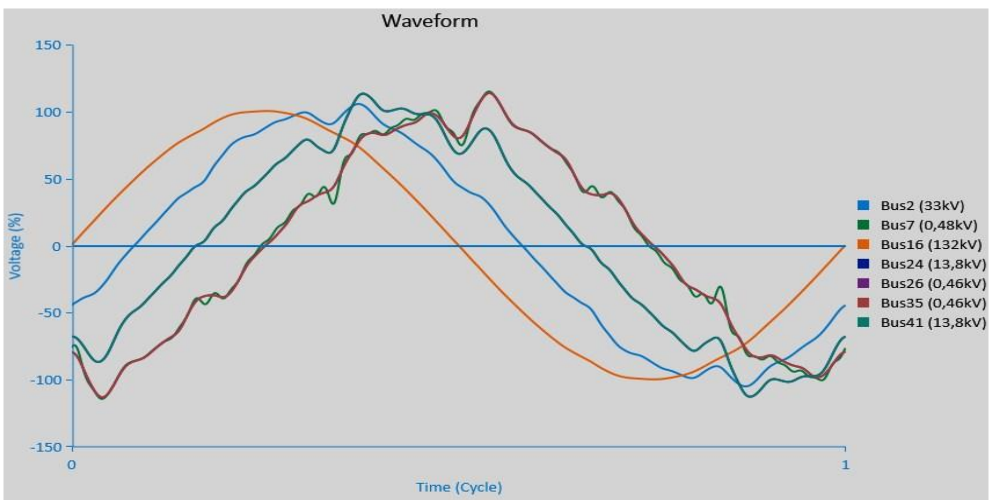

Figure 9.Harmonic Load Flow waveform Plot (all buses)

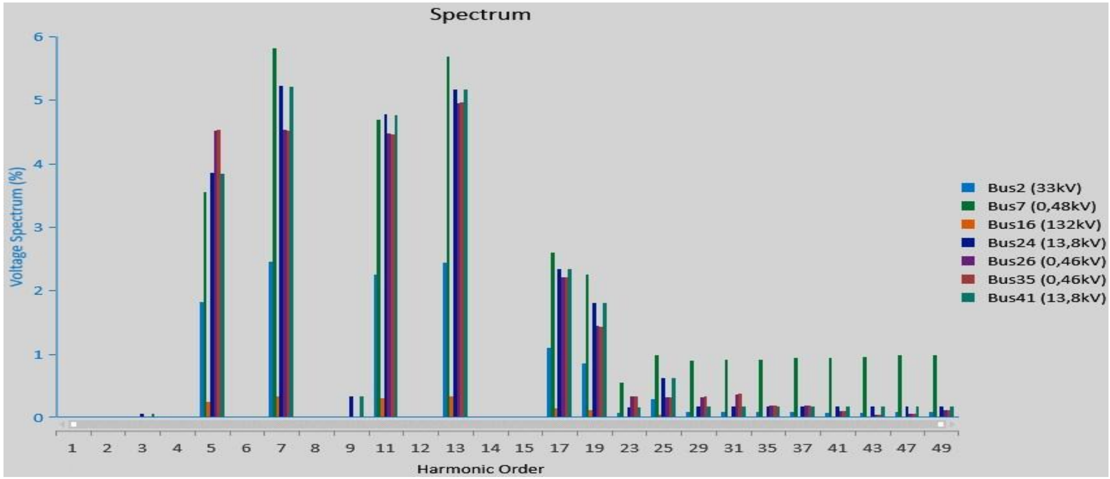

Figure 10.Harmonic Load Flow spectrum Plot (all buses)

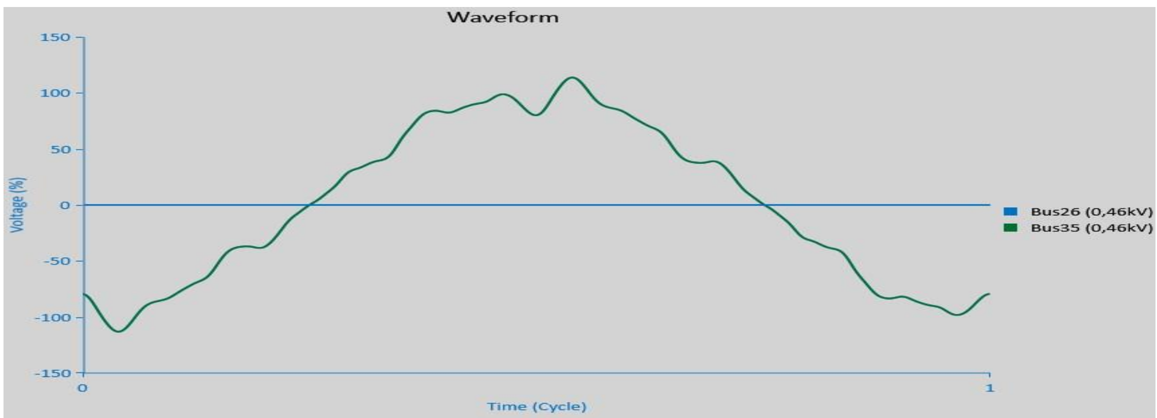

Figure 11.Harmonic Load Flow waveform Plot(buses26and 35)

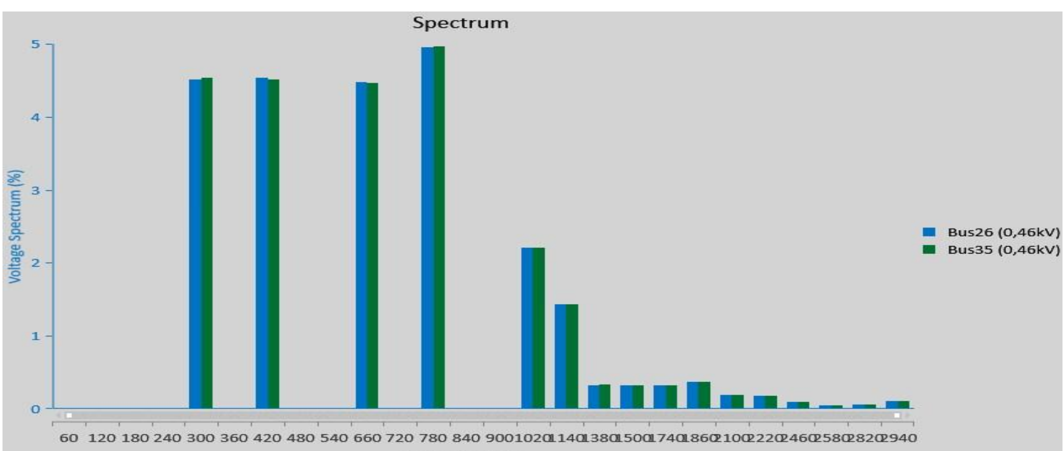

Figure 12.Harmonic Load Flow spectrum Plot (buses 35 and26)

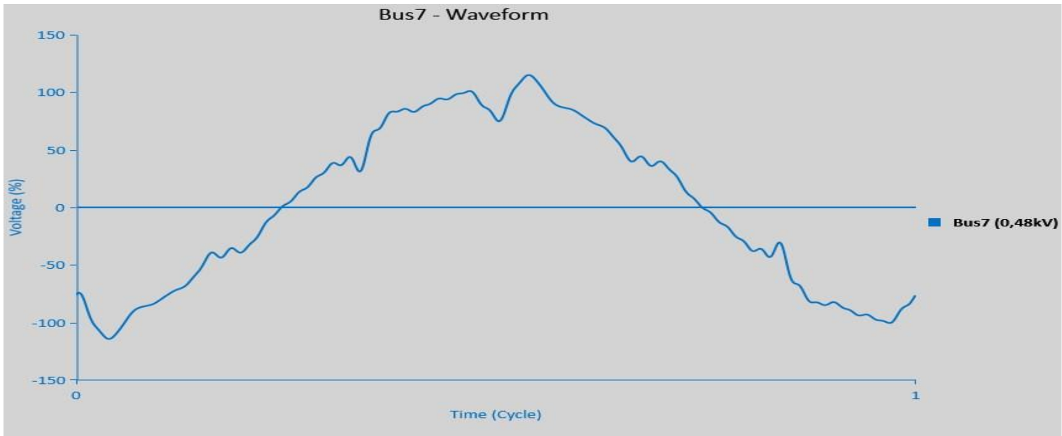

Figure 13.Harmonic Load Flow waveform Plot(bus 7)

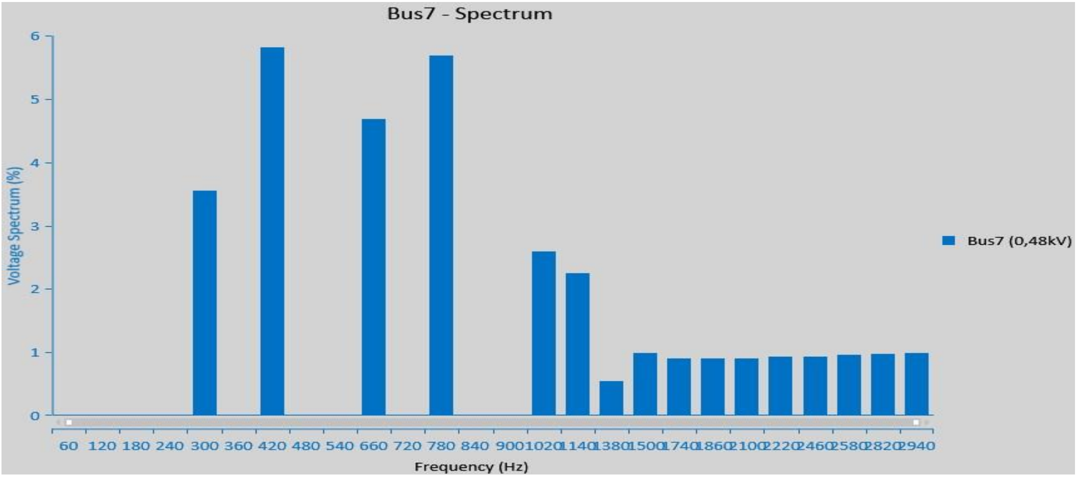

Figure 14.Harmonic Load Flow spectrum Plot (bus7)

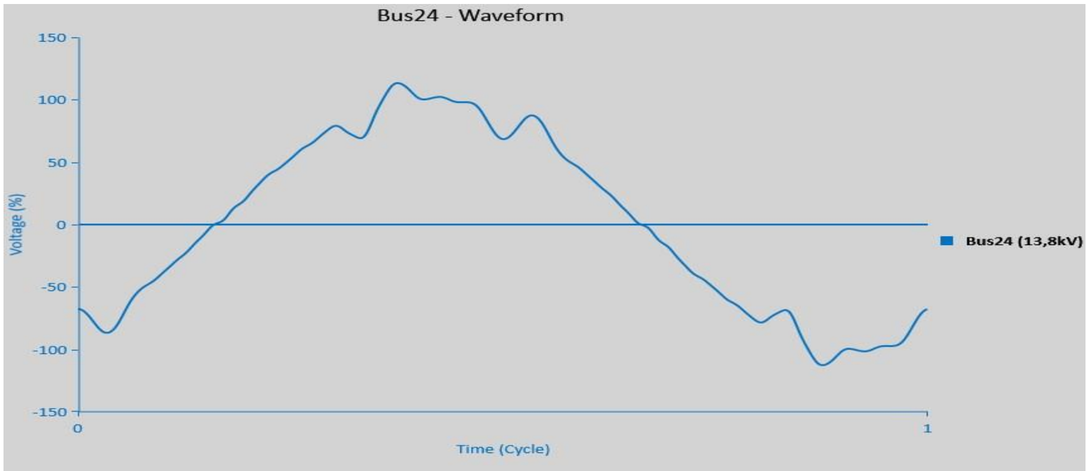

Figure 15.Harmonic Load Flow waveform Plot (bus 24)

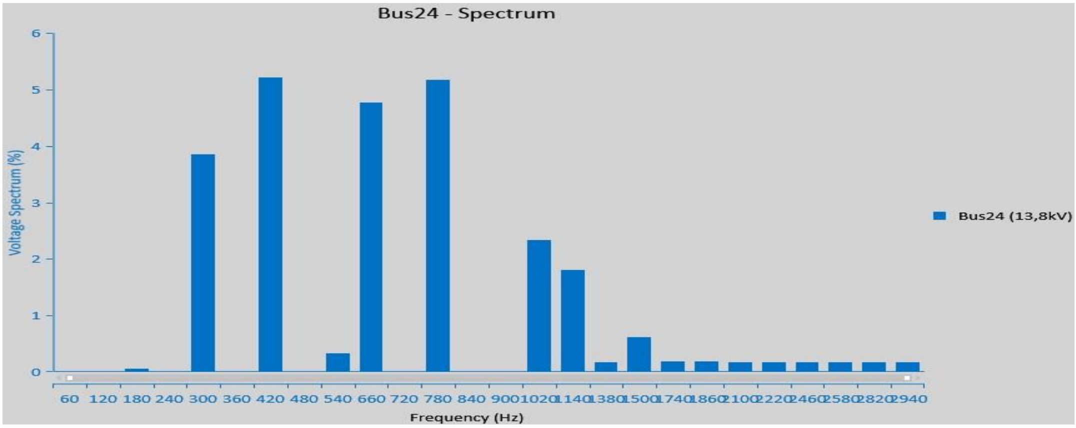

Figure 16.Harmonic Load Flow spectrum Plot (bus24*)*

3.1.2 Eliminate harmonics distortion using filters:

To eliminate the harmonic distortion of the power network, single-tuning filters were selected. Filters design are provided in ETAP library giving enough reactive power to the station network and minimizing losses at the fundamental frequency. This filter can typically size the parameter values based on filter modeling by using the “Harmonic Filter Sizing” option. for calculating the parameter values of each filter, need to click the ‘Size Filter’ button, another page will open and the required harmonic order in which harmonic distortion needs to be eliminated and The harmonic current for each filter size harmonic order must be entered correctly. To size the harmonic current ,MVA,and,PF can be found in the single line diagram especially after running the load flow study at the common coupling point where the harmonic source is connected to the main power grid as shown in figure 3.13. After putting all the values of current, PF,and MVA need to click Substitute.in ETAP filter page then automatically the appropriate values of the capacitor and inductor will update.

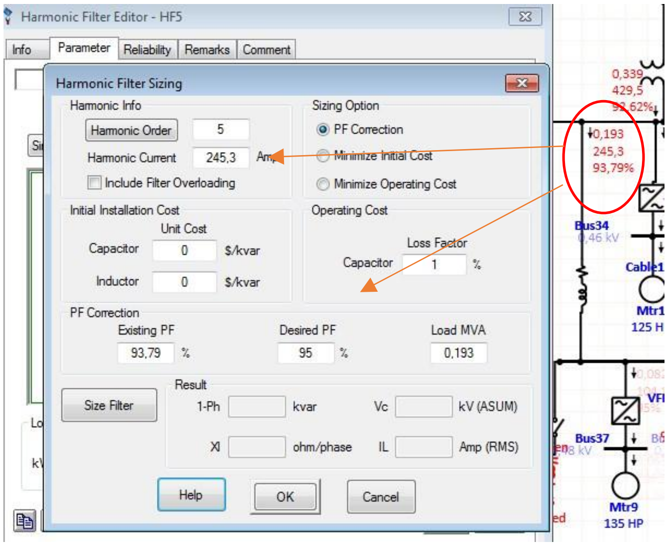

Figure 17.Harmonic Filter Sizing

Finally Filters (tuned filters of 5th ,7th,11th,and 13th added in bus 24 & tuned 17th added to bus 7, The order can be executed through the same procedure as the filter size values for the order are changed.

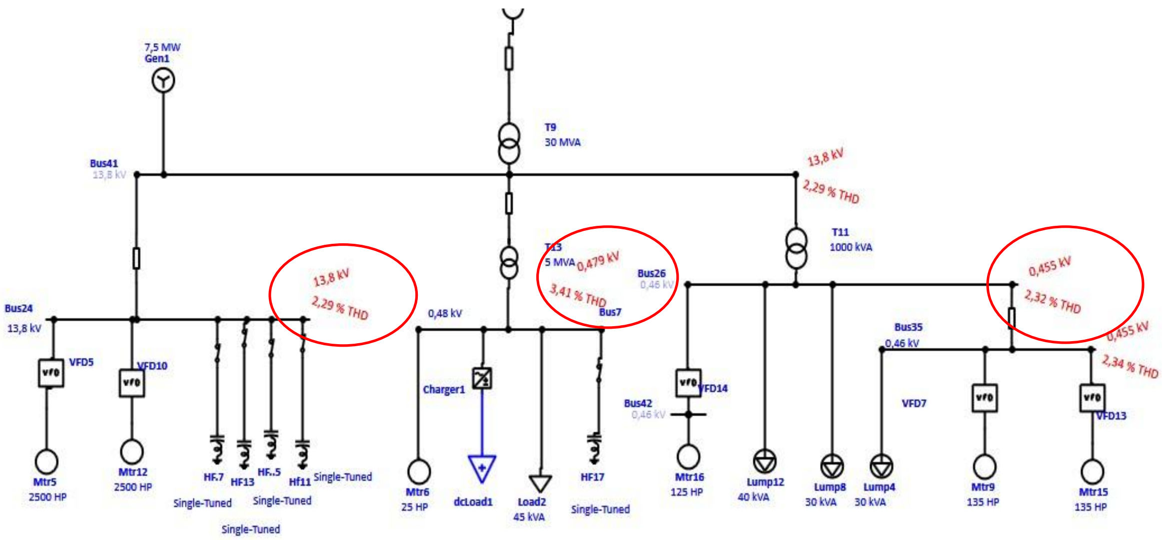

Figure 18.The harmonic load flow

comparing with the result of pervious harmonic load flow analysis before adding filter at figure 3.4a we can see that the percentage of THD and RMS reduced as mentioned in table 3.2. and There is no alert shown on the Alert View figure 19.

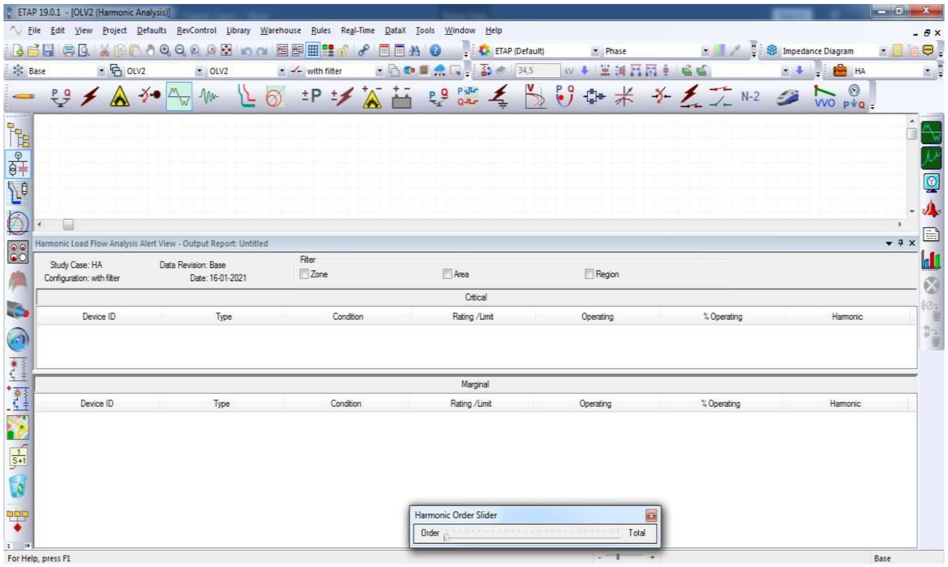

Figure 19.Alert window after adding filters

The wave form and voltage spectrum for 4 distorted buses are given below.

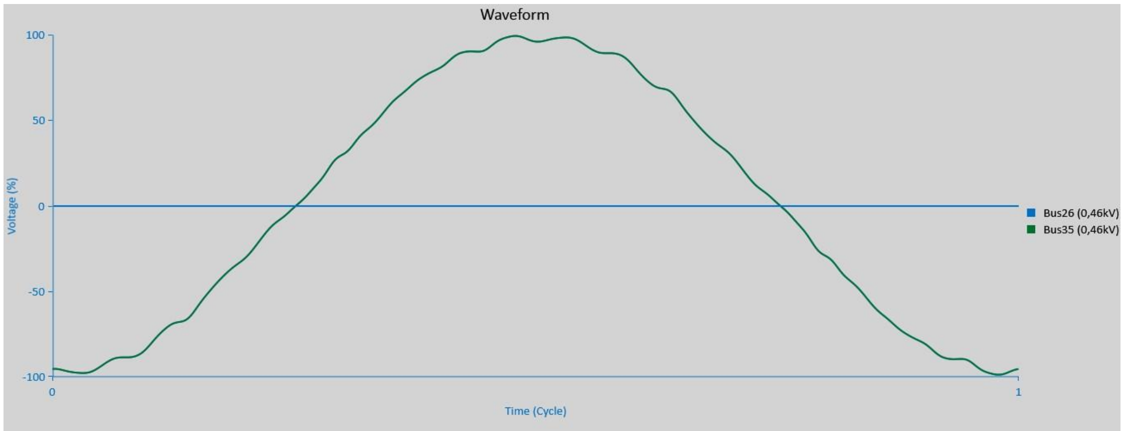

Figure 20 Harmonic Load Flow waveform Plot (buses26and 35)after adding filters

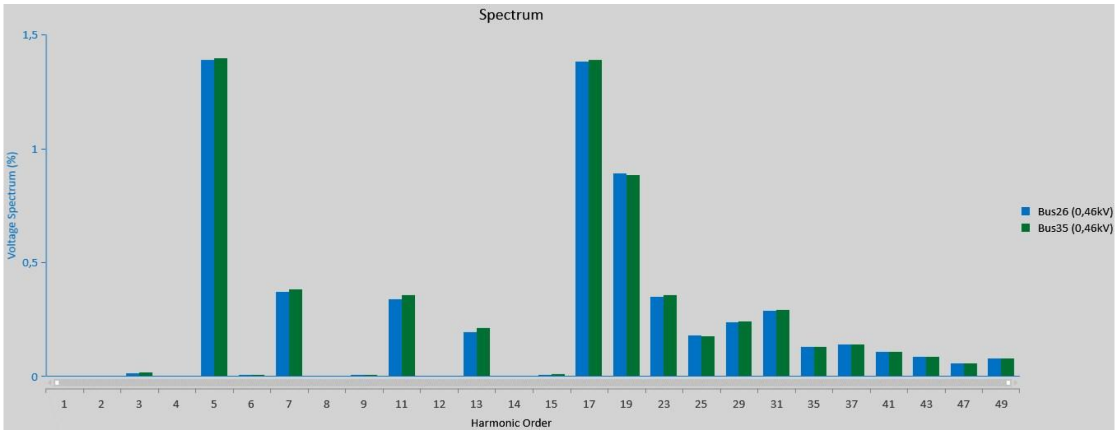

Figure 21.Harmonic Load Flow spectrum Plot (buses26 &35)after adding the filters

Figure 22.Harmonic Load Flow waveform Plot(bus24)after adding filters

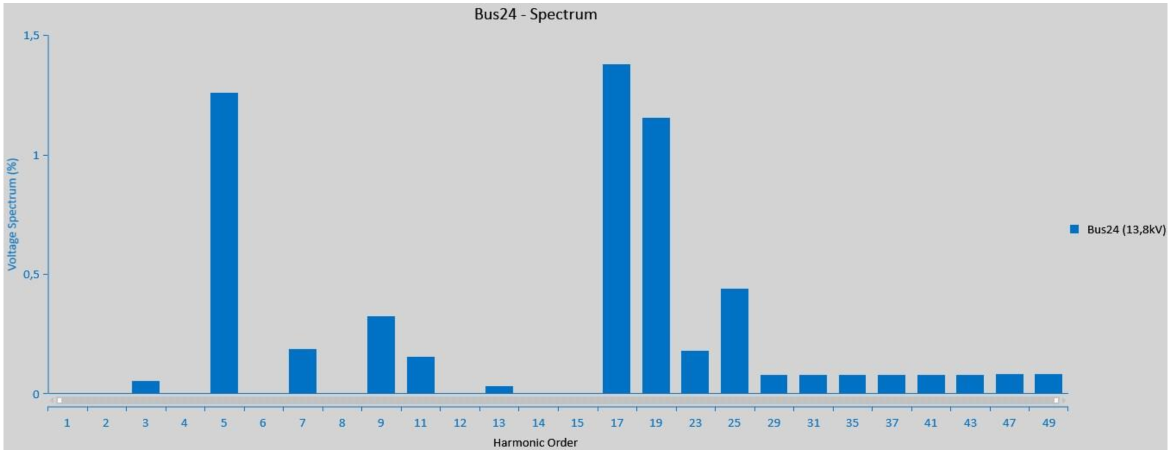

Figure 23Harmonic Load Flow spectrum Plot (bus24)after adding the filters

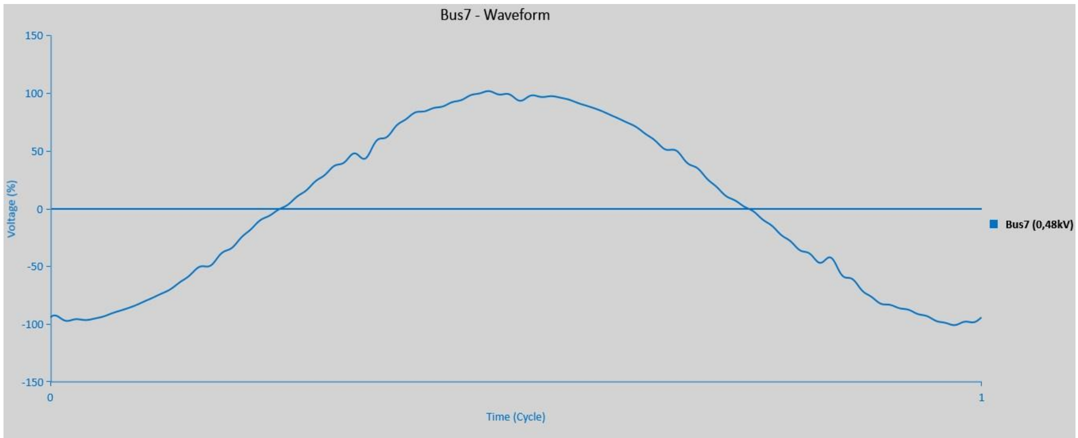

Figure 24.Harmonic Load Flow waveform Plot(bus7)after adding filters

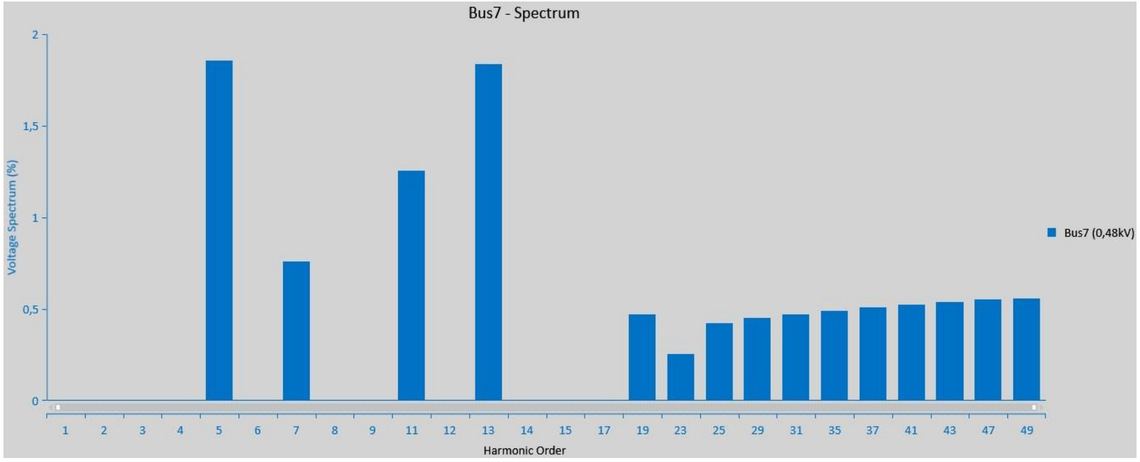

Figure 25.Harmonic Load Flow Spectrum Plot (bus7) after adding the filters

the tables below show the results of THD and RMS before and after adding the filter

Table 2 Results of THD and RMS with filter and without filter for Voltage Distortion

bus	kv	Rms without filter %	Rms with filter %	THD without filter %	THD with filter %
35	0.460	99.36	98.03	9.75	2,33
26	0.460	99.41	98.08	9.74	2.32
24	13.8	100.49	100.1	10.05	2.29
7	0.480	100.18	99.7	11.04	3.41

3.2 Summary:

The purpose of this chapter was to analyze harmonics with all the possible criteria. the steps start by generating harmonic currents from specified harmonic sources and identified the problem by running Harmonic Load Flow Analysis. Then filters are designed and successfully eliminated the harmonic distortion.

4.Conclusion

A simple power network was modeled to analyze power system harmonics. The harmonic sources were modelled to create harmonic distortion in the power network. Once the Harmonic Load Flow study is run, harmonic distortions were shown on the one-line display and plotted curve.

the components are modeled past on the IEEE standards 519. The harmonic sources were modeled from the harmonic library are Toshiba 2 PWM ASD, Typical IEEE 6 pule1, Typical IEEE 6 pule2, and 2-Rockwell VFD 6 pulse, and the single-tuned filter was designed from the predefined filter of the ETAP library.

Display Alert is a very effective option to display any component beyond its standard rating. The filters are designed by considering of THD and IHD exceeded in the alert display. In ETAP, it is easy to eliminate harmonic distortion for a specific harmonic arrangement by placing the harmonic value order and related parameters on the filter to resize the page. This filter design option is one of the most effective ETAP software tools.

In ETAP the user can create and save an unlimited number of study cases. Load flow calculations are performed and reported according to the study state settings defined in the network buses. Users can easily switch between study cases without the hassle of resetting study case options every time. This unique feature that most other packages do not have will save a similar amount of effort and time

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