Design and Simulation of Harmonic Filters Using MATLAB® Software

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ABSTRACT

*Calculations are a major part of design process in all aspects of engineering applications. This laborious and time comsuming process can be made really easy by the aid of a high level engineering software like **MATLAB®**. This paper deals with the scope and flexibility of **MATLAB®** for:*

1. *Calculation of design parameters for L-C components of different branches of a harmonic filter.*
2. *Graphical analysis of Harmonic Pollution and different Harmonic components.*
3. *Verification of design using **SIMULINK®** and Power System Toolbox before implementation to check any design error that might cause undesireable results.*

1. INTRODUCTION

Recent advancements in the field of electronic computing has shown its effects in every aspect of life. Use of computers for Design and Analysis has reduced the time, energy and resources required to be spent using conventional methods involving manual calculations. Computer aided design and analysis has another edge over orthodox means; we can easily verify the design to catch any errors in the design process. Thus a powerful computer software like **MATLAB®** can greatly reduce the time and effort spent on the calculations required for the design process.Using Graphical User Interface **(GUI)** we can develop a computer program capable of design and graphically analyze the given electrical parameters from the point of application of filter. We can also verify the design by using **SIMULINK®** and Power System Toolbox to tell for any short comings in the design.

2. HARMONICS AND HARMONIC ORDER

Harmonics are the odd integral multiples of fundamental frequency resulting in the distortion of supply waveform due to interferance by superposition. **Harmonic order** or **harmonic number** is a reference to the frequency of the harmonic component e.g 3rd order harmonic component refers to a harmonic component having frequncy 3 times that of fundamental i.e. for a 50 Hz supply 3rd order component is of 3x50=150Hz. **[1]**

Generally the sum of even harmonics is less than 1% of fundamental component thus they are not considered also 3rd, 5th and 7th order harmonics constitute about 97% of harmonic Thus it is most economically suitable to design harmonic filters for these components as these can reduce the pollution level well below the desired limit and being economically justified **.[2]**

2.1 CAUSES OF HARMONICS

Industrial electronic devices and non linear loads are the major cause of harmonic generation. As the current drawn from the supply no longer remains sinusoidal thus the resultant waveform is made up of a number of different waveforms of different frequencies **.[3]**

2.2 EFFECTS OF HARMONICS

Harmonics are a major cause of power supply pollution lowering the power factor and increasing electrical losses. This results in premature equipment failure and higher rating requirement for equipment **.[4]**

2.3 HARMONIC FILTERS

A harmonic filter is a device used to 'filter out' components of different harmonic order from reaching and harming the load thus the name
'harmonic filter'.

2.4 APPLICATION OF HARMONIC FILTERS

Harmonic Filters are applied at different points where power pollution due to harmonics is observed above the desireable limits as recommended by **IEE 519** standards.[5] These are used in parallel to load thus providing a bypass low impedance path for the flow of

Harmonic currents of specific frequency or harmonic number. Thus a separate harmonic filter branch is required for each harmonic order to be removed. Thus a 3 branch filter might be used to filter out 3^{rd}, 5^{th} and 7^{th} harmonic component. **[5]**

3. HARMONIC FILTERS AND CAPACITOR BANKS

Capacitor banks are traditionally used to improve power factor of load thus avoiding financial panelty imposed by supply corporation. Harmonic filters can be used in collaboration with capacitor compensators or as a stand alone equipment. Thus there is no need to remove capacitor banks if we desire to add harmonic filters. But we can also provide capacitive compensation using the same tuning capacitors from the filter thus eliminating the need of capacitor banks for a new load installation**. (Fig:1) [6]**

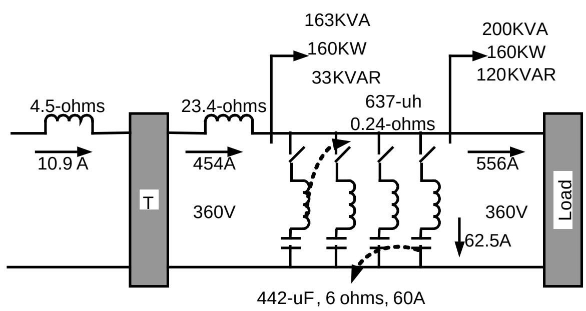

Figure:1 Harmonic Filter Providing Compensation [3].

3.1 DESIGN OF HARMONIC FILTERS

Harmonic filters are composed of series or parallel Inductor-Capacitor branches tuned to specific frequencies to provide a low impedance path to the harmonic components. These values are load dependant so these are designed according to the electrical parameters of point of application of harmonic filter. Thus we have to design a separate harmonic filter for each different location.This means that we need a quick and efficient way to calculate for a variety of load conditions**.[7,8,9]**

3.2 VERIFICATION OF DESIGN DATA

While designing a harmonic filter it must be considered that it might not cause parallel resonance with the load equipment.Thus it is necessary to test the design before implementation.This can be done using **SIMULINK**® and Power System Toolbox reducing the risk and time reqired for field testing to the minimum**.[3]**

3.3 HARMONIC ANALYZER

A **harmonic analyzer** is used to obtain data in terms of electrical parameters for any point we are interested in for the application of harmonic filters. This device not only shows data on the spot but can also store data digitally which can later be retrieved using computer and a software provided by the harmonic analyzer manufacturer.

4. MATLAB® AND SIMULINK®

MATLAB® is the solution for all these problems. It has a high level language compiler very close to natural writing techniques. It has a vast collection of well designed functions and tools to aid in all kinds of applications.

It supports Object Oriented Programing (OOP) thus same functions can be used again and again. It has support for drawing all kinds of 2-dimentional and 3-dimentional graphs as well as charts and function mapping techniques.

It has a Graphical User Interface Development Environment **(GUIDE)** which can be used to make input of data and output of results easier to understand and comprehend for a novice user. **GUI** is a way to interact with user by virtue of friendly graphical instructions or decisions which are easy to understand and follow.Any programmer can use its flexibility and strength to add various options as well as user decision levels as required**[11].**

MATLAB® application software is developed by **MathWorks**® Inc. It rightfully claims to be the 'Language of Technical Computing'. It can be used for extensive graphical and technical facilities and functions available for all kinds of computation and calculations involving simple everyday procedures to complex higher order mathematical applications.

SIMULINK® is a simulation program used to virtually observe a circuit under working conditions. Power System Toolbox is a collection of tools related to power systems used to generate different kinds of power circuits for simulating in **SIMULINK**®. There are a number of toolboxes available for different applications in **MATLAB**®. For further references throughout this paper we are considering **MATLAB**® Version 7.0, release 14, May 6 2004**.[11]**

5. PROGRAM FLOW

A simple **GUI** based **MATLAB** program will have these essential components: [Flow Chart Shown in Fig:2]

- Ø A front end data input form where data from harmonic analyzer is filled along with desired power factor improvement to be achieved.
- Ø A back end software for calculations and mathematical procedure for evaluating filter component parameters.
- Ø A front end design output showing the calculated values for filter components.
- Ø Different graphs and charts for graphical analysis of harmonics.

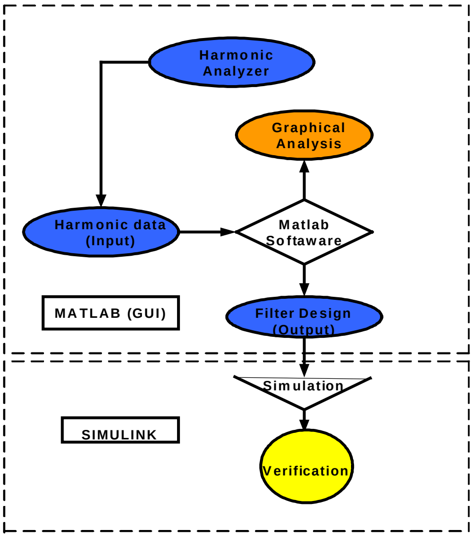

Figure:2 Flow Chart for design and analysis of harmonic filters using mat lab.

- Ø Whereas the simulation portion will consist of circuit elements represented by a one-line diagram.
- Ø Putting the design values and running the simulation will testify whether the design will work or not.

5.1 EXAMPLE

Let us consider an example of a simple **GUI** based software developed to analyse and design a 3-branch harmonic filter. When developed the program will consist of many different files dealing with the coding for **GUI** and calculations individually but as far as user is concerned after executing the main program file it will look like as follows **:[3]**

5.1.1 DATA INPUT FORM

Here user will enter the data obtained from harmonic analyzer and click **'Submit'.** At the back end all the calculations will be made and results displayed in a different window**.[3]**

5.1.2 DESIGN RESULTS OUTPUT FORM

Within 10~15 seconds this form will show up with the values of inductor and capacitor for each branch along with their KVAR ratings. These values are in micro-farad(•f) and milli-henry(mH) for ease of use**.[3]**

5.1.3 GRAPHICAL ANALYSIS OF HARMONICS

These are 6 different graphs showing different graphical representations of harmonic and fundamental current waveforms and magnitudes before and after filters are applied, from Fig:3, to Fig:8 **[3].**

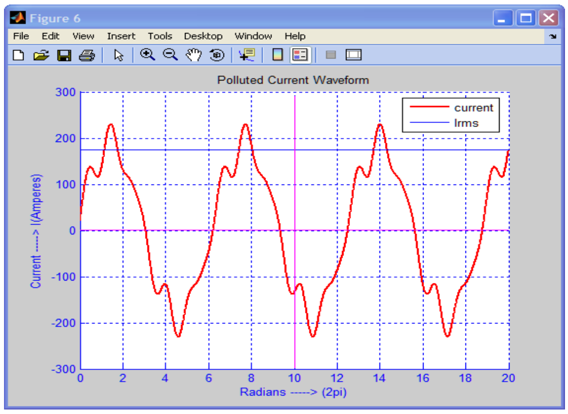

Figure 3: Polluted Current Waveform to be filtered .

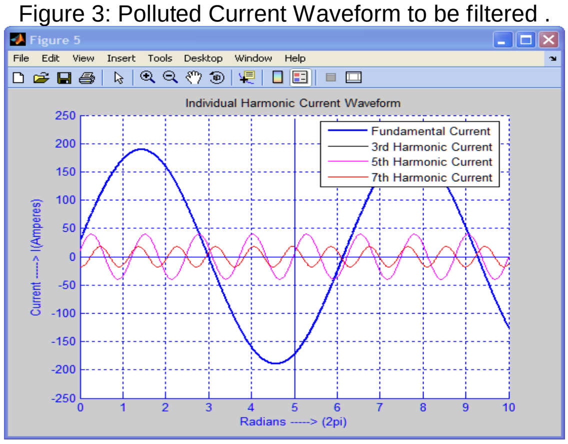

Figure 4: Individual Harmonic Components [3].

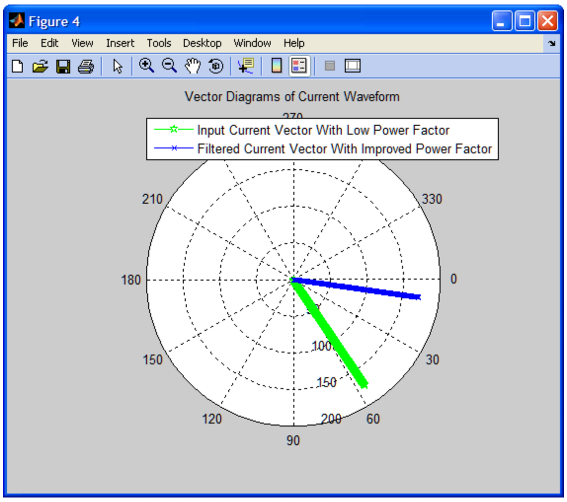

Figure 5: Vector Diagram before and after Filteration [3].

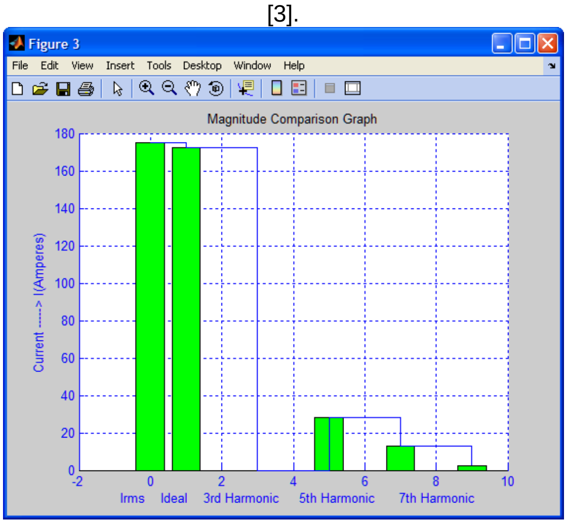

Figure 6: Harmonic Components magnitude comparison graph [3].

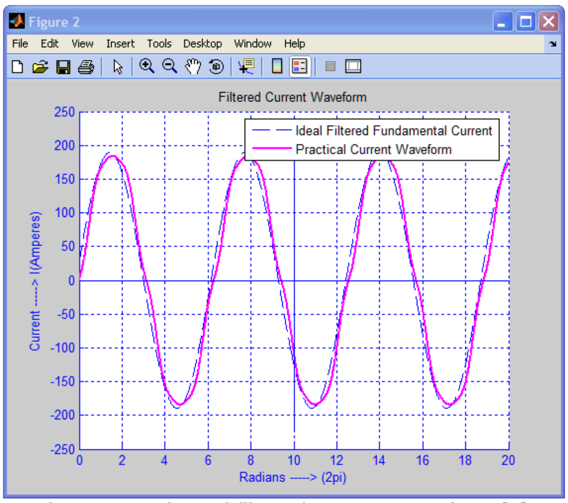

Figure 7: projected filtered current waveform [3].

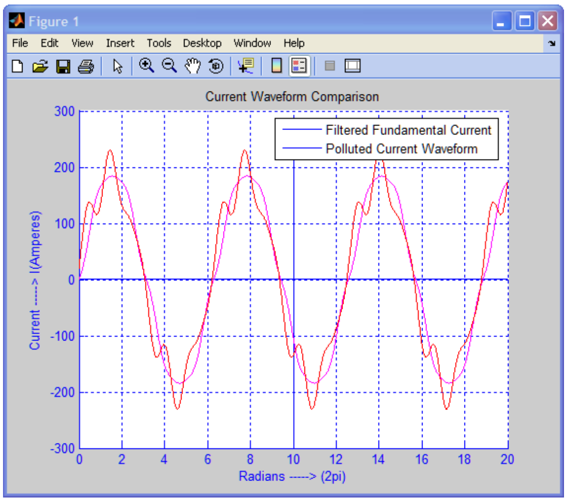

Figure 8: Current waveform before and after Filteration [3].

5.1.4 SIMULATION

Now we can simulate the condi tion before and after the application of harmonic filters thus observing the effectiveness of our

design. Different harmonics can be considered as different current sources superimposed on each other. There will be two simulat ions; one before filteration (Fig:9,10 and 11) and one afterwards (Fig:12 and 13) **[3].**

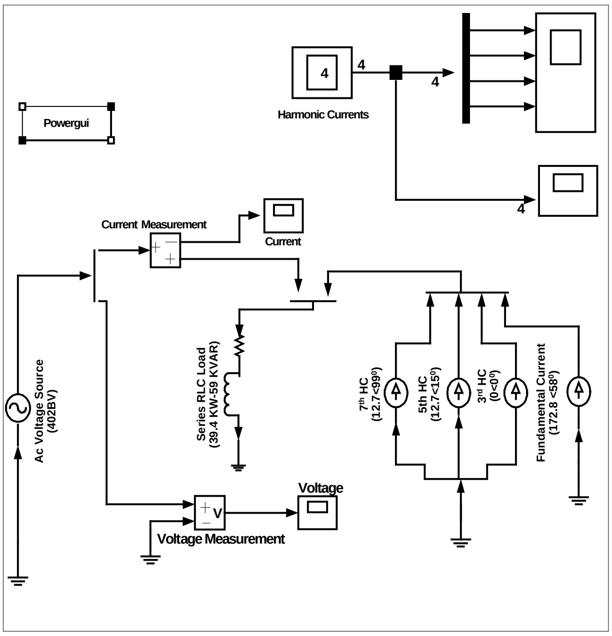

Figure: 9 Simulation of Circuit Without harmonic filter [3].

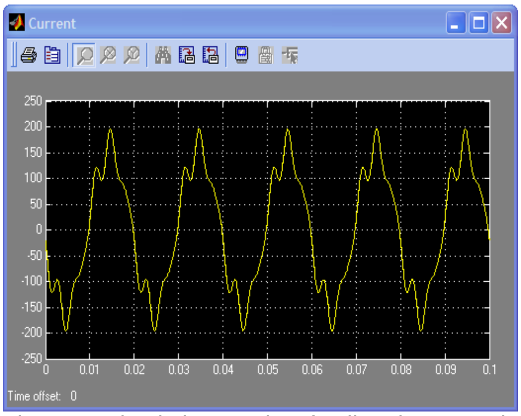

Figure10: simulation results of polluted current circuit without filteration [3].

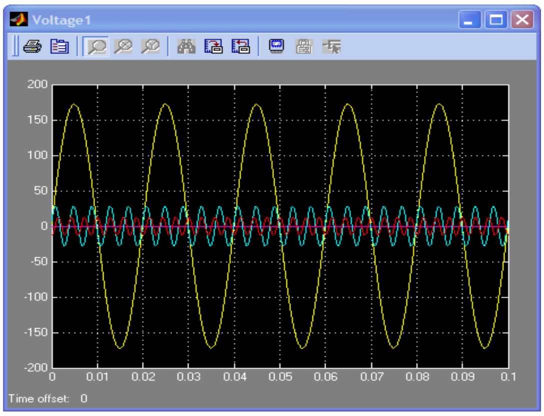

Figure11: simulation of harmonic components [3].

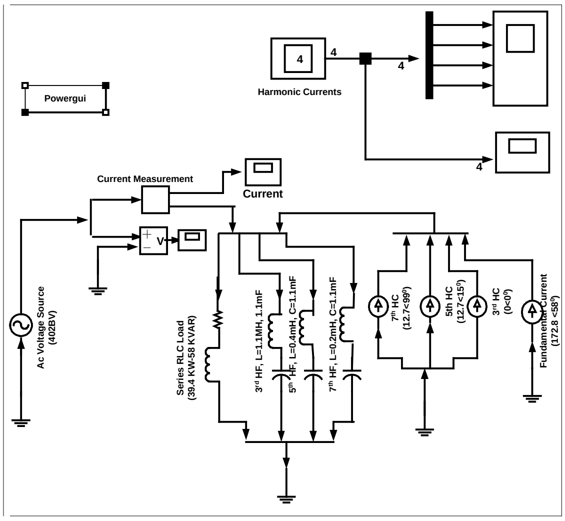

Figure 12: Simulation of Circuit with use of filters [3].

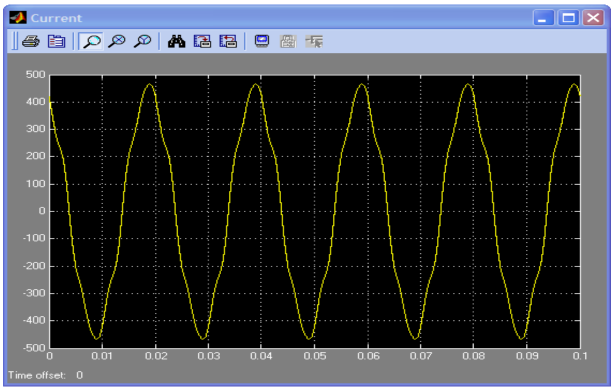

Figure 13 : current waveform after filteration [3].

6. CONCLUSIONS

- Harmonic pollution is a major contributor to power quality degradation and must be kept under **IEEE 519** standard.
- Harmonic Filters not only reduce the effects of harmonics but also provide reactive power for power factor improvement.
- Designing of component parameters for a harmonic filter can be made quick and easy with the help of **MATLAB**®.
- Using a Harmonic Analyzer circuit harmonic analysis is done and data is fed to **MATLAB** program.
- **MATLAB**® **GUI** provides user friendly approach and can be used for any input data again and again.
- **MATLAB**® can regenarate graphical analysis for the given case using the data from harmonic analyzer.
- The design values thus obtained are tested using **SIMULINK**® to check whether the filter design will work or not.
- Hence the whole process of analysis, design and verification only takes a few minutes using a few keystokes and mouse clicks as compared to conventional methods which can take hours.

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