Design and Implementation of Harmonic Trap Filter in Conjunction with a Line Reactor using Simulink

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Abstract

In this paper, the design and implementation of harmonic trap filter in conjunction with a line reactor using Simulink is developed in the simulation environment. Simulations are performed & the simulation results are obtained. The simulation results shows the profoundness of the method developed for harmonic suppression.

Keywords — *Elimination, Breakers, Current, Voltage, Control, Simulation, T H D, Power semiconductor devices, Suppression, Power Quality, Harmonics, Distortion.*

I. INTRODUCTION

Distortion of harmonics in power/force appropriation system can be stifled utilizing 2 methodologies in particular, latent/passive and dynamic/active fueling. The passive type of sifting/filter is the least difficult traditional answer for alleviate the mutation in harmonics. Even basically, the utilization of detached components does not generally react accurately to the progression of the electrical energy transmission frameworks. Throughout the years, these detached passive channels have created to the abnormal state of modernity. Some even tuned to sidestep or bypass the particular consonant frequencies [31] - [40].

Harmonics are *v* and *i* frequency components which are embedded on the crest level of the normal sine *v* & *i*. The symphonious distortion in waveform issues are for the most part because of the significant increment of non-straight loads because of innovative advances, for example, the utilization of force electronic circuits and gadgets, in air conditioning/dc transmission connections, or burdens in the control of force frameworks utilizing power electronic or microchip controllers. Harmonic sources are categorized into 3 types of loads, viz., [41]-[50]:

- House-hold load
- Industry load
- Controlling device

Electrical vitality/power is a key element for the modern and all-round advancement of any nation as currently without electricity, the whole world will be in dark & the country's economy falls down drastically as every working device in the universe requires electricity. Hat's off to Thomas Alva Edison, Benjamin Franklin, who invented this great wonder, which is of great importance today. The ideal usage of this type of vitality/energy can be guaranteed by a quality electrical power with no intrusion. The circumstance with power is comparative, the unwavering quality of the supply must be known and the versatility of the procedure to varieties must be caught on [1] – [99].

Our innovative world has turned out to be profoundly reliant upon the ceaseless accessibility of electrical force/energy. Business control, i.e., power available commercially is truly empowering the today's current world to work at its bustling pace. Modern innovation has come too profoundly into our homes and professions, and with the coming of e-trade & commerce is constantly changing the way we interface with whatever is left of world. Electric vitality is a fundamental element for the modern and all-round advancement of any nation. The ideal use of this type of vitality/power can be guaranteed by a quality force/energy/power. The circumstance with power is comparative, the unwavering quality of the supply must be known and the flexibility of the procedure to varieties must be caught on immediately [1]-[10].

As a general rule, obviously, power is altogether different from some other item - it is created a long way from the purpose of utilization and is nourished to the framework together with the yield of numerous different generators and lands at the purpose of utilization through a few transformers and numerous kilometers of overhead and conceivably underground cables. Where the electrical business factories has been privatized, these system resources will be possessed, overseen and kept up by various distinctive associations or companies. Guaranteeing the nature of conveyed force/power at the purpose of utilization is no simple task undertaking and it is extremely unlikely that sub-standard power can be pulled back from the store network or rejected by the client/end-utilizer [11]-[20].

Harmonic spikes have various undesirable consequences for the appropriation framework of the electrical distribution networks. 2 types are there, viz.,

: short & long term effects. Short impacts are generally the most recognizable and are identified with over the top over voltage mutilation. Then again, long haul (term) impacts frequently go undetected and are normally identified with expanded resistive loss or voltage stress likewise, the consonant streams created by non-straight loads can associate antagonistically with an extensive variety of influence framework gear (electrical power equipments), most strikingly capacitors, transformers, and engines, generators, bringing on extra loss, overheating, and over-burdening. Interference with telephone cables, lines will be caused by the development of these harmonic currents. In light of the antagonistic impacts that these harmonic surges have on P Q, standards have been created to characterize a sensible structure for control of harmonic surges. Its goal is to guarantee consistent state harmonic limits that are worthy considered by both electric utilities and their clients. [21]-[30].

Any power circulation circuit serving present day electronic gadgets will possess some level of symphonious frequencies. The surge *v* & *i* don't generally bring about issues, yet the more prominent the electrical energy or power is drawn by these advanced gadgets or other non-straight loads, the more prominent is the level of voltage mutilation. There are a number of problems which are related to the harmonic generation, they include the following [51]-[60] :

- Equipment mal-functioning.
- Sudden tripping of the breakers.
- Sudden on & off of the lights.
- Large neutral *i*.
- Conductors in the phase, loads, transformer getting heated,
- U P S suddenly getting failed,
- Transformer suddenly getting failed,
- less power factor.
- Voltage & current surges [61]-[70].
- Capacity of the system getting reduced

How to prevent the harmonics ? The efficient method is to choose a device and have good installation practice which will definitely reduce the overall harmonic contents in the device or circuit or equipment or in a part of the network. On the off chance that the issues can't be illuminated by these basic measures, there are 2 fundamental decisions, viz., to fortify the dissemination framework to withstand *v* or *i* surges or to introduce the gadget to constrict or evacuate the harmonics. Procedures for lessening *v* or *i* surges, from shabby to more costly, incorporate latent symphonious channels, confinement transformers, consonant moderating transformers, the Harmonic Suppression Network (HSN) and dynamic channel filtering mechanisms [71]-[80].

The harmonic effect in the system's *v* or *i* is always decided in terms of the T H D, factor, high & low level harmonic contents. In general, any industry application ask for the load v & I be free of harmonics or at the most < 5 % of harmonics. Majority of the literatures after going through them shows that a number of methodologies have been found out to lessen the T H D [81]-[90].

There are assortments of building arrangements accessible to dispose of or diminish the impact of supply quality issues and it is exceptionally dynamic zone of advancement and improvement. In that capacity, clients should know about scope of arrangements accessible and the relative merits and expenses. A portion of the vital techniques to minimize sounds/surges in *v* & *i*'s are [91]-[99]

- filter which is passive in nature,
- filter which is active nature,
- separation transformer,
- surge reducing transformer,
- surge suppression system, etc…

The flow of the research work is developed one after another as shown below. A background introduction w.r.t. the work done in this paper was presented in the introductory section in section 1. The basic work done is explained in section 2 followed by the design of the circuit in section 3. The specifications are given in section 4 followed by the development of the simulink model in matlab environment for a 1-ϕ case in section 5. The section 6 explains the process, whereas the section 7 gives the observations of the o/p. This is followed by the applications in section 8 and the development of the simulink model in matlab environment for a 3-ϕ case in section 9. The process of operation is explained in section 10, followed by the observations in section 11, whereas the comments on THD & its reduction are depicted in section 12. The FFT analysis is presented in section 13 along with the waveforms. Finally, the conclusions are presented in the section 14, which is followed by the references.

II. BASIC WORK DONE

In this section, a harmonic trap filter is designed which is used as a isolation in between switching device such as an inverter and 1-ϕ & 3-ϕ non linear loads for the harmonics elimination.

It is a well known fact that due to the usage of non-linear elements such as power electronic converters, switching devices (especially, the loads) when used in the power electronics equipments, will generate harmonic currents which are injected into the system during the switching process. This can be rectified by the use of harmonic trap filters. These harmonic trap filters are usually used in conjunction with a line reactor and are usually placed on individual AFD loads. 3ϕ load harmonic filters are nothing but shunt devices which are used in the power systems for decreasing the level of distortion in voltages, currents and for improving the Power Factor (PF).

The harmonic currents flowing through the resistances, reactances, impedances will produce harmonic voltage distortion. Then, it will have an effect on the power quality which will result in erroneous power supply to the load. In order to achieve an acceptable distortion, several banks of filters of different types are usually connected in parallel. To avoid this, harmonic filters will be used by diverting the harmonic currents in low impedance paths, thus suppressing the harmonics, viz., single tuned, double tuned, high pass, C-type high pass, etc… which are shown below in the figure.

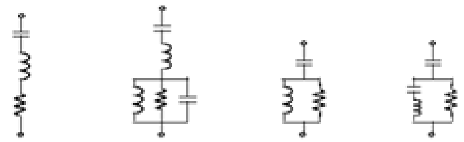

Fig 1 : Types of Filters That Can be Modelled with the 3-ϕ Harmonic Filter Block

The 1-ϕ or 3-ϕ harmonic filters are used to eliminate the harmonic distortions caused by the *n*-ϕ non-linear loads. Specifically, harmonic filters are designed to attenuate / eliminate the potentially dangerous effects of harmonic currents active within the power distribution system, but they have to be designed properly to suppress the harmonics. Also, the harmonic filters can be designed to trap the currents through the use of a series of capacitors, coils, and resistors and as well as shunting the elements to ground so as to take the harmonic currents to pass through the least resistance path.

A filter may contain several elements, which are designed to compensate a particular frequency or an array of frequencies, usually a shunted L-C filter is installed at the line side of the AFD and they are tuned below the 9th harmonic, so as to reduce the largest component of harmonic distortion along with this a significant amount of 11th harmonic distortion will also be absorbed. Meanwhile a filters can also be used to compensate higher order harmonics. More care is needed with the application of harmonic trap filters than with other methods, because they will tend to try to filter the entire distribution system of harmonic components.

If additional AFD or non-linear loads are added without filtering, the previously installed filters may become overloaded (they are generally fused for protection). The line reactor is used in conjunction with the filter to minimize the possibility of this occurring and to enhance filter performance. A harmonic analysis is required to guarantee compliance with guidelines. The main advantages of this type of design is it allows a higher percentage of AFD system loads than line reactors and chokes. The synthesized wave is shown in the figure below.

III. DESIGN OF THE CIRCUIT

Harmonic analysis can made at the generator, consumer, and transmission line points to check the non-linear currents and waveforms. The design is as follows, consider for the case 1, with the addition of one small component, such as a capacitor can transform a low pass filter into a filter with near infinite attenuation at a designed trap frequency, which is called as an harmonic trap filter design.

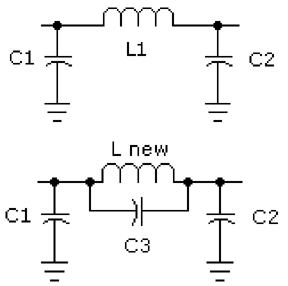

Fig 2 : Low Pass Filter and A Harmonic Trap Filter

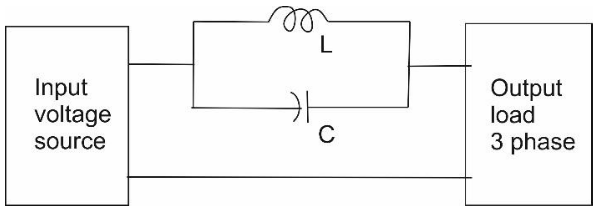

Fig 3 : Harmonic Trap Interface Between The I/P and O/P

To construct a harmonic trap filter insert a capacitor C3 as shown in the figure with $X_{C1} = X_{C2} = X_L = R$. Here, R is the circuit impedance, where L_{new} is given by

$$L_{new} = L_1 \times \left(1 - \frac{F_{op}^2}{F_{trap}^2}\right)$$

for the harmonic trap filter, where F_{op} is the original low pass frequency used in this design and of course F_{trap} is the harmonic trap frequency for that matter, at which you may want greater or infinite attenuation. Calculate L_{new} using the formula for the harmonic trap filter, where F_{op} is the original low pass frequency used in your design and of course F_{trap} is the harmonic or, any frequency for that matter, at which you may want greater or infinite attenuation.

IV. SPECIFICATIONS

The designed parametric values for a harmonic trap filter are summarized in a table (specifications) as

DC link voltage	V_{dc}	440 V
DC side capacitance	$C_1 C_2$	1000 F
AC side inductance	L_c	50 mH
AC side resistance	R_c	100 Ω
Capacitance	C_3	2000 F
L new	L_{new}	100 mH

TABLE 1 : DESIGNED PARAMETRIC VALUES FOR A HARMONIC TRAP FILTER (SPECIFICATIONS)

Two cases have been considered, viz.,

for a 1- ϕ case & for a 3-ϕ case separately.

V. DEVELOPMENT OF THE SIMULINK MODEL IN MATLAB ENVIRONMENT FOR A 1- ϕ CASE

In this section, we develop a simulink model to reduce the harmonics developed in the input signal due to switching for a 1- ϕ case as well as for a 3- ϕ case. The basic functional elements in the available simulink library blocks such as, thyristor bridge, diode brdige, step signals, comparators, gain blocks, integrators, switches, FWDs, loads, multiplexers, sinks, scopes, etc. which are available in the simulink library are which is used in the development of the simulink model. The modelling of the harmonic trap filter is done in Matlab-Simulink environment as a sub-system and is named as 'harmonic trap & the power elelctronic model as a sub-system'.

Scopes are connected at various points to observe the voltage & current waveforms. The necessary simulation parameters are set inside the relevant boxes and devices in the said environment. The reference waveforms are given as the input (Iq ref & Id ref) to the harmonic trap filter & power electronic model, the output of which is given to the load through a mux. Closed loop connectivity is done from the output to the input through the summing points and the control blocks, which help in the recution of the harmonics when the load swithching takes place. The sub-system reduces the harmonic contents.

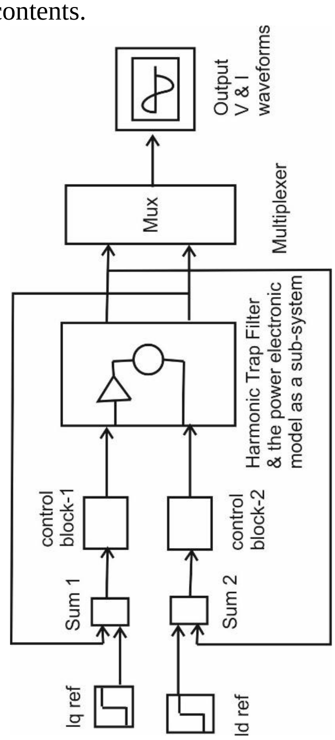

Fig 4 : Circuit Using Simulink Model For Elimination of Harmonics Using Harmonic Trap Filter

VI. PROCESS

When the 1- ϕ load is switched on, reactive power is drawn from the mains and the waveforms gets distorted, which introduces harmonics of the n^{th} order in the supply. If these harmonics are allowed to exist for a lot of time, then overheating, damaging of the device takes place. Hence, a harmonic trap filter is introduced near the PCC. A multiplexer in place after the control block is used for the observation of the current and voltages. The advantage of using the mux is, it has many inputs and one o/p

VII. OBSERVATIONS OF O/P

The developed simulink model is run and the various responses with and without the harmonic elimination unit are observed on the scopes. From the waveforms, it is clear that the harmonic trap filter has removed all the noises and the harmonics, which is clear from the output waveforms. From the Matlab simulation and the Simulink model results, it is clear that the harmonic trap filter has worked satisfactory with the designed values as it has given good output smoothened waveforms eliminating all the harmonics [54].

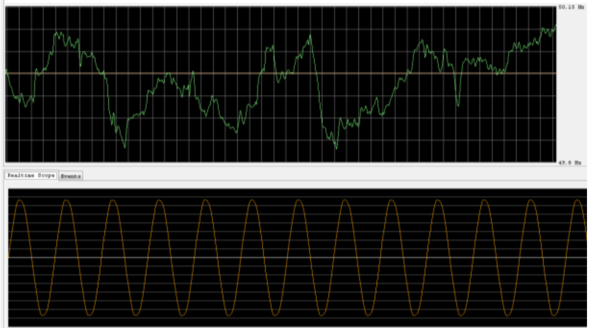

Fig 5 : Output Voltage Waveform From the Simulink Model (Before-Distorted and After the Introduction of The Harmonic Trap Filter at the Receiving End-Smooth)

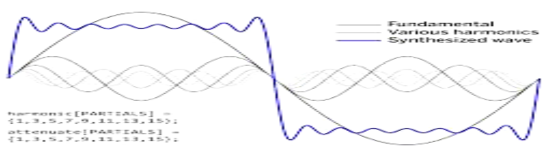

Fig 6 : Matlab Simulation Result for One Time Period of Synthesized Wave.

VIII. APPLICATIONS

In HVDC installations, AC harmonic shunt filters are used to reduce the harmonic voltages and currents in the power system and to supply the reactive power consumed by the converter. In this context, a 500 MVA rectifier is simulated in the simulink environment.

IX. DEVELOPMENT OF THE SIMULINK MODEL IN MATLAB ENVIRONMENT FOR A 3-ϕ CASE

In the 2nd case, a 3-ϕ inductive load is considered with the model being developed in simulink and the firing angle being set to a certain value. The basic functions, library blocks such as the step signals, comparators, gain blocks, integrators, switches, FWDs, loads, multiplexers, sinks, scopes, etc.. available in the simulink library are used in the development of the simulink model.

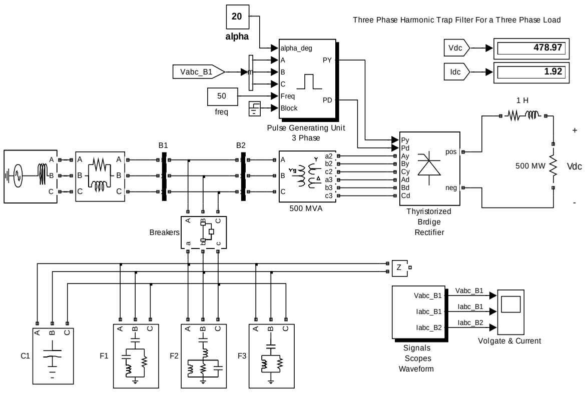

Fig 7 : Circuit Using Model in Simulink for Harmonic Trap Filter for a 3-ϕ Load (50 Hz, α = 20°), the 4 Filter Banks Shown at Bottom Used as Fundamental, 3rd 5th 7th Harmonic Elimination

A generator is shown in the simulink diagram with a grid B1. Circuit breakers are used in between the 4 filter banks and the generator-grid unit. Scopes are connected at various points to observe the voltage & current waveforms along with display boxes for seeing the numerical values of the voltages & the currents. The necessary simulation parameters are set inside the relevant boxes and devices in the said environment. A 500 MVA transformer is used to connect the generator-grid-filter bank to the output load & the thyristorized bridge rectifier and is mainly used for the isolation purposes. A pulse generating unit (3-ϕ) is used for triggering purposes for the thyristorized bridge rectifier, which acts as the controller (harmonic reduction).

X. PROCESS OF OPERATION

A frequency of 50 hz with a firing angle of α = 20° is considered for the simulation purpose. The model is developed in Matlab-Simulink environment. With all the parametric values set, the model is run with respect to the time domain simulation. Runing the simulation with an alpha firing angle of 20 degrees (which can be seen from the simulink model), a DC voltage level of 480 kV is obtained (shown in the display box). The currents flowing into the grid Buses, B1 and B2 are observed on the scope 1. If the FFT tool in the '*powergui*' is used, then the harmonic trap filter reduce the THD of the current injected in the system from 86.46 % to 4.88%.

XI. OBSERVATIONS

The developed simulink model is run and the various responses with and w/o the harmonic elimination unit are observed. Simulations are performed with different values of α. The change on the DC level and on the generated harmonics is carefully observed.

It can be noted at this instant that the AC harmonic trap filters are used to reduce the harmonic voltages and currents in the power system, supply the reactive power consumed by the converter. The waveforms are observed with the breaker open & with the breaker closed. It is clear from one set of results that with the breaker closed, the harmonic contents are well reduced in the 3-ϕ supply as this becomes a closed loop control system.

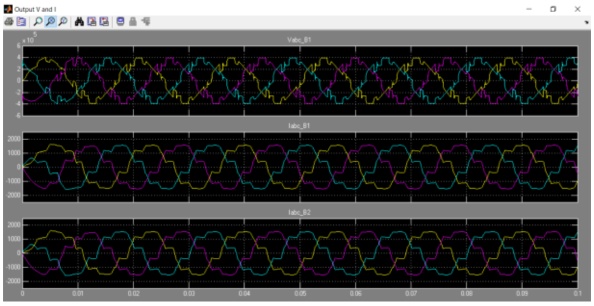

Fig 8: 3-ϕ Results on the Scope of the Simulink Model of the Harmonic Trap Filter (Breaker Open)

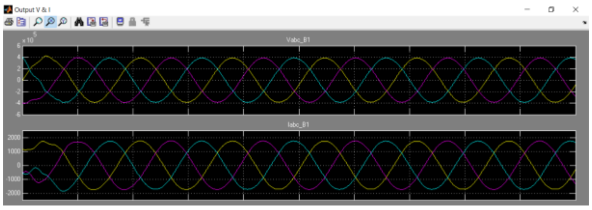

Fig 9 : 3-ϕ Results on the Scope of the Simulink Model of the Harmonic Trap Filter (Breaker Closed)

XII. COMMENTS ON THD & ITS REDUCTION

The total harmonic distortion for the output waveforms was calculated using the THD formulas for the current and voltage and the results were tabulated neatly in the form of a THD reduction table. From these quantitative results, it can be inferred that using a selective harmonic elimination scheme, i.e., eliminating a particular harmonics, the technique has worked successfully as before the introduction of the harmonic filter, the THD was 0.8546 and after the introduction of the filter, the THD was 0.0481, i.e., there is a substantial reduction in the harmonic contents of the load current.

Similarly, the THD was 0.9635 before the introduction of the filter and after the introduction of the filter, the THD was 0.2214, i.e., there is a substantial reduction in the harmonic contents of the load voltage. This can be seen from the Matlab output THD waveform results. The net power factor was also improved to 0.87. This improvisation in the harmonic reduction can be seen from the quantitative results present in the table below.

Type of harmonic elimination method	Harmonic trap filter
THD before harmonic suppression (load *v*)	0.9635 96.35 %
THD after harmonic suppression (load *v*)	0.2214 22.14 %
THD before harmonic suppression (load *i*)	0.8546 85.46 %
THD after harmonic suppression (load *i*)	0.0481 4.81 %
Power Factor	0.87
No. of harmonics removed	10

TABLE 2 : QUANTITATIVE RESULTS OF HARMONIC ELIMINATION METHOD (CURRENT)…THD USING THE HARMONIC TRAP FILTER METHOD

XIII. FFT ANALYSIS

The FFT analysis was performed on the voltage & current waveforms in the Simulink environment. From the FFT analysis, we can see the %age of the THD reduction. The plot of impedance and phase of the output *vs* frequency is also observed on the scope , i.e., the frequency response is also plotted. It can also be seen from the FFT analysis that the total harmonic deduction is very good and substantially reduced. From the results, it can be seen that the harmonic trap filters almost eliminate the harmonics generated by the converter when the convertor is on (when the breaker is closed) *and* when it is off, i.e., the breaker is open, the harmonics still persists in the system as shown in the simulated results which are taken from the scope as it becomes a open loop control system.

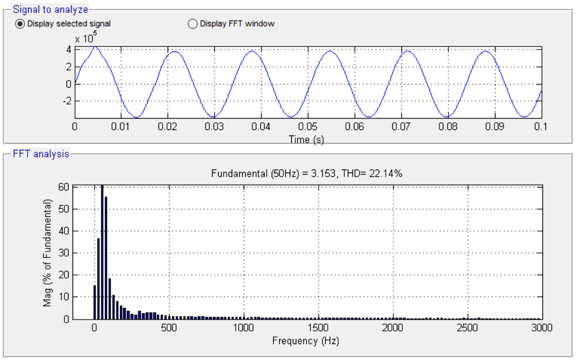

Fig 10 : FFT Analysis Showing the Total Harmonic Reduction by 22.14 % (Voltage)

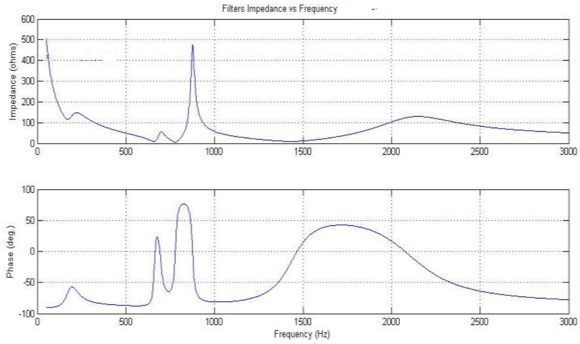

Fig 11 : Plot of impedance and phase of the output w.r.t. the frequency

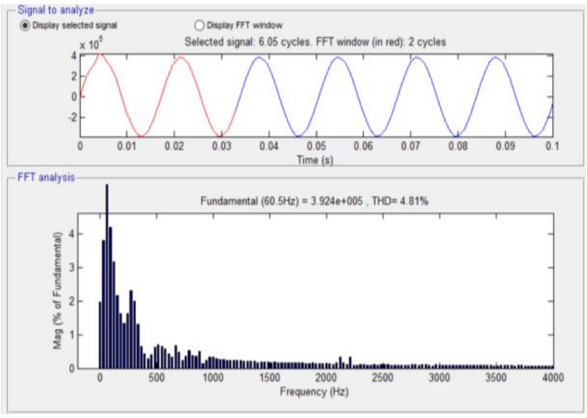

Fig 12 : FFT Analysis Showing the Total Harmonic Reduction by 4.81 % (Current)

XIV. CONCLUSIONs

Research was done w.r.t. analysis of the surge-harmonic effects on the system components & its effectiveness was studied in greater depth resulting in a number of contributions towards the same during the switching on/off of the device process. The early location, concealment of sounds in electrical, electronic, PC, instrumentation, mech. and aviation framework systems is an essential parameter which must be considered w.r.t. the wellbeing, unwavering quality, effective operation of a wide range of system frameworks which are working on power and must be handled genuinely & intelligently. Extensive literature survey was being carried out in this exciting field.

In this context, the design and implementation of harmonic trap filter in conjunction with a line reactor using simulink was presented in this paper along with the simulation results. As the simulations were performed by the software package Matlab-Simulink, the simulated o/p's show a new development in this paper development. The development of trap filter & the o/p signals were observed after running the simulations for a requisite amount of time. Fast Fourier Transform analyses are also obtained to show the reduction of the harmonic contents. The development of the new proposed schemes in this paper definitely will prove the powerfulness of the methodology & can be used to improve the power quality.

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