Elimination of Harmonics of Induction Furnace by Appling PQ-Theory for the Control of Hybrid Selective Active Filter

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ABSTRACT

This paper describes how to calculate the different harmonic sequences that should be filtered with a hybrid selective active filter, for two control alternatives: load current measurement or line current measurement. These results are then generalized for hybrid selective active filters. Passive parameters are chosen considering the resonances with the electric system that appear. Design basis are defined in order to obtain a minimum cost filter which also meet the applicable regulations requirements.

In this paper presents a hybrid selective active filter configuration to mitigate harmonics, which uses shunt passive and active filters. To obtain the switching signals for the active filter have used instantaneous power theory proposed by H.Akagi. Hybrid selective active filter proposed scheme has been verified through various simulations in MATLAB-SIMULINK environment. Finally, results showing the potentiality of the selective filter controlled for the proposed methods are reported.

Keywords - **Induction furnace, Hybrid selective active filter, pq –theory.**

I. INTRODUCTION

An Induction furnace is an unbalanced, nonlinear and time varying load, which can cause many problems to the power system quality. Harmonics, inter-harmonics, voltage flicker & unbalance are the power quality problems which are introduced to the power system as a result of non-linear and stochastic behaviour of the furnace operation [7]. The nonlinear voltage-current characteristic of the arc can cause harmonic currents which when circulating by the net can produce harmonic voltages which can affect to other users [8].

In the last decades, the evolution of two aspects concerning power systems has created conditions for a more extended use of active filters. A first aspect is related to power semiconductor device development. Converters capable of synthesizing voltages and currents with an adequate bandwidth for harmonic current compensation at MVA – level systems are now available at competitive prices. The other aspect is the gradual application of regulations limiting the generation of harmonic currents by the customers. Active filters are ideally suitable for filtering localized harmonic currents in a guided way , this allows to apply the concept "you dirty, you clean". This concept cannot be applied using conventional passive filters. In the same way, active filters allows to eliminate some of the problems of passive filters such as poor tuning due to dispersion of their characteristic parameters and resonances with the impedance of the surrounding electrical network which may appear.

Among the different methods for controlling active filters, the use of pq-theory (active and imaginary power) [1], has demonstrated to be specially suitable. In particular, it has been used for separating the residual harmonics and thus eliminating (as theory indicates) or reducing (as it results in practice) the harmonic distortion. For the control of selective active filters several works use the SRF method (Synchronous Reference Frame) [2] [3] [4] [5] [6] which is definitively a particular case of applying the pq- method with harmonic voltages as references.

II. INDUCTION FURNACE

One of the most economic ways of producing steel is made through the use of induction furnaces. The problem with this kind of furnaces, from an electrical point of view, is the creation of a considerable harmonic distortion. The cause of the distortion is within the induction furnace design and operation. An induction furnace works melting the scrap using a medium frequency magnetic field created by a coil. The coil is fed by the medium frequency AC current supplied by an inverter which is fed by a DC current converter connected to the AC distribution network supply. As the created distortion is very high and affects the voltage supplied by the distribution network, it is highly possible that other loads supplied from the same network will be affected. In this case, it is necessary to have corrective actions in order to fulfil the legislation concerning voltage harmonic distortion. Among these corrective actions, active filters are one of the most effective [12].

2.1. SIMULINK MODEL OF THE INDUCTION FURNACE

All the elements have been modeled using existing Simulink blocks contained in the SimPowerSystems block set. The distribution transformers of the general services and the temper furnaces consume 1800 kW with a cosφ of 0,85. For simulation purposes they have been modeled as a lineal load of these characteristics. This is acceptable as their consumption is only a little portion of the total power consumed in the plant and they do not produce any distortion. As there is no induction furnace electrical model in Simulink, new blocks have been created for the induction furnaces shown in fig.2.

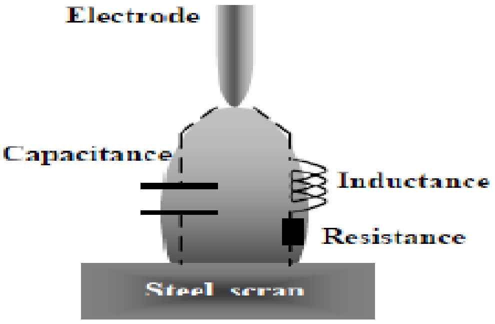

Fig.1.Equivalent circuit diagram of induction furnace

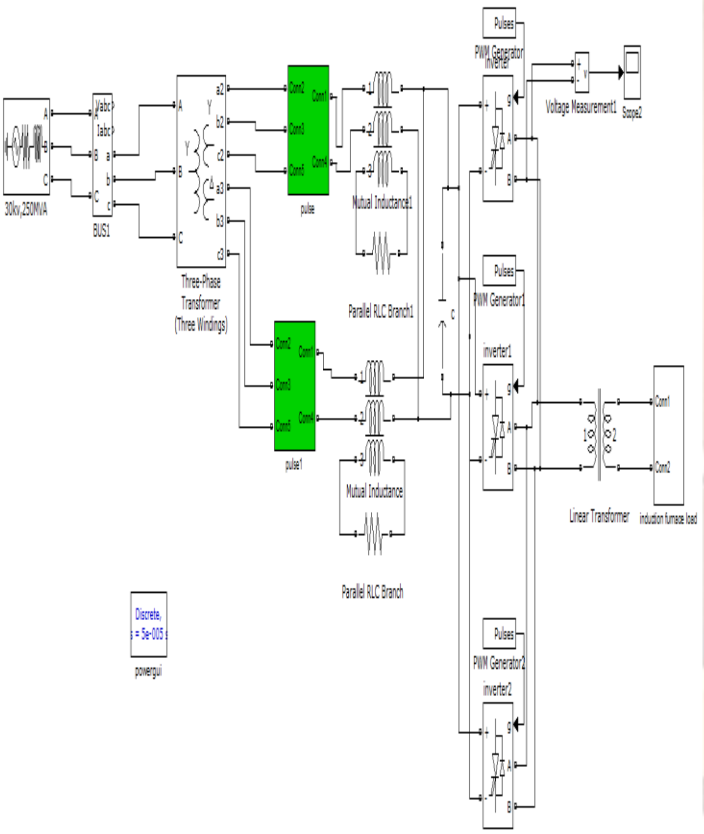

Fig. 2.induction furnace without filter

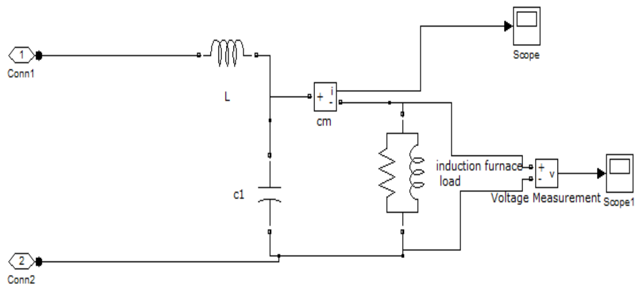

Fig.3. induction furnace load

III. PQ –THEORY

In 1983 Akagi et al.[13],[14] proposed a new theory for the control of active filters in three-phase power systems called "Generalized Theory of The Instantaneous Reactive power in Three phase Circuits" or " Theory of Instantaneous Real Power and Imaginary Power" or " Theory of Instantaneous Active power and Reactive power", or "Theory of the instantaneous power", or simply as "p-q Theory". Since p-q theory is based on the time domain. It is valid both for steady-state and transient operation, as well as for generic voltage and current wave forms, allowing the control of the active filters in real-time.

Another advantage of this theory is simplicity of its calculations, since only algebraic operations are required. The only exception is in the separation of some power components in their mean and alternating values. It is possible to exploit the symmetries of the instantaneous power waveform for each specific power system, achieving a calculation delay that can be small as 1/6 and never greater than 1 cycle of the power system frequency. It is also shown that calculations for reactive power and zero-sequence compensation do not introduce any delay.

Furthermore, it is possible to associate physical meaning to the p-q theory power components, which eases the understanding of the operation of any three-phase power system , balanced or unbalanced, with or without harmonics.

3.1. THE P-Q THEORY APPLIED TO HYBRID SELECTIVE ACTIVE FILTERS.

The p-q theory is one of the several methods that can be used in the control active filters [13],[15]. It presents some interesting features, namely:

1-It is inherently a three-phase system theory.
2-It can be applied to any three-phase systems (balanced or unbalanced, with or without harmonics in both voltages and currents).
3-It is based in instantaneous values, allowing excellent dynamic response.
4-It calculations are relatively simple (It only includes algebraic expressions that can be implemented using standard processors).

5-It allows two control strategies: constant instantaneous supply power and sinusoidal supply current.

To control the shunt active filter in such a way as to present zero impedance for the fundamental and pure resistance for the harmonics, the reference output voltage of the shunt active filter is given by Transformation of the phase voltages v_{Lu}, v_{Lv}, v_{Lv} on the load side and source currents i_{su}, i_{sv}, i_{sw} into α-β orthogonal coordinates gives the following expressions:

$$\begin{bmatrix} v_{L\alpha} \\ v_{L\beta} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{Lu} \\ v_{Lv} \\ v_{Lw} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{su} \\ i_{sv} \\ i_{sw} \end{bmatrix} \quad (2)$$

According to [18], the instantaneous real power p and the instantaneous imaginary power q can be defined as:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{L\alpha} & v_{L\beta} \\ -v_{L\beta} & v_{L\alpha} \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \quad (3)$$

The dimension of q is not in watt, volt-ampere, or var because $v_{L\alpha} \cdot i_{s\beta}$ and $v_{L\beta} \cdot i_{s\alpha}$ are defined by the product of the instantaneous voltage in one phase and the instantaneous voltage in one phase and the instantaneous current in the other phase.

The harmonic components Ph and qh are extracted from p and q by using a high pass filter. A first order high pass filter, the cutoff frequency of which is 35 hz, is used in the following experiment, filtering characteristics in the transient states being taken into account. In the calculation circuit of i_{sh} the following calculations are performed.

$$\begin{bmatrix} i_{shu} \\ i_{shv} \\ i_{shw} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} vl\alpha & vl\beta \\ -vl\beta & vl\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_h \\ q_h \end{bmatrix} \quad (4)$$

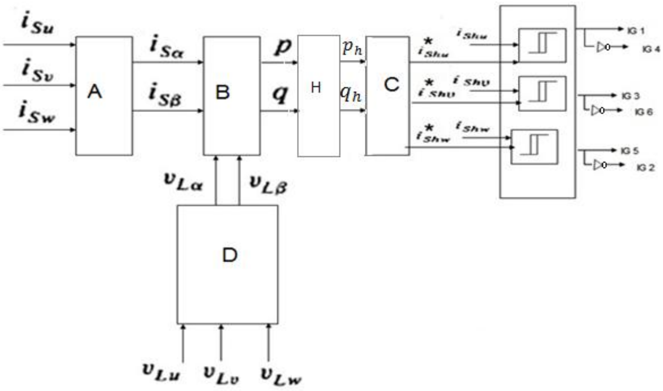

Fig.4..Active power filter controller

Where , A,B,C,and D are the Transfer functions.

$$A = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \quad (5)$$

$$B = \begin{bmatrix} V_{L\alpha} & V_{L\beta} \\ -V_{L\beta} & V_{L\alpha} \end{bmatrix} \quad (6)$$

$$C = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{L\alpha} & V_{L\beta} \\ -V_{L\alpha} & V_{L\beta} \end{bmatrix}^{-1} \quad (7)$$

$$D = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \quad (8)$$

H = Hypass Filter

IV. SIMULATION AND PERFORMANCE INVESTIGATION OF ACTIVE FILTER

In this section the simulation analysis of Hybrid selective active filter is described for Induction Furnace load and the FFT analysis has been carried out simultaneously.

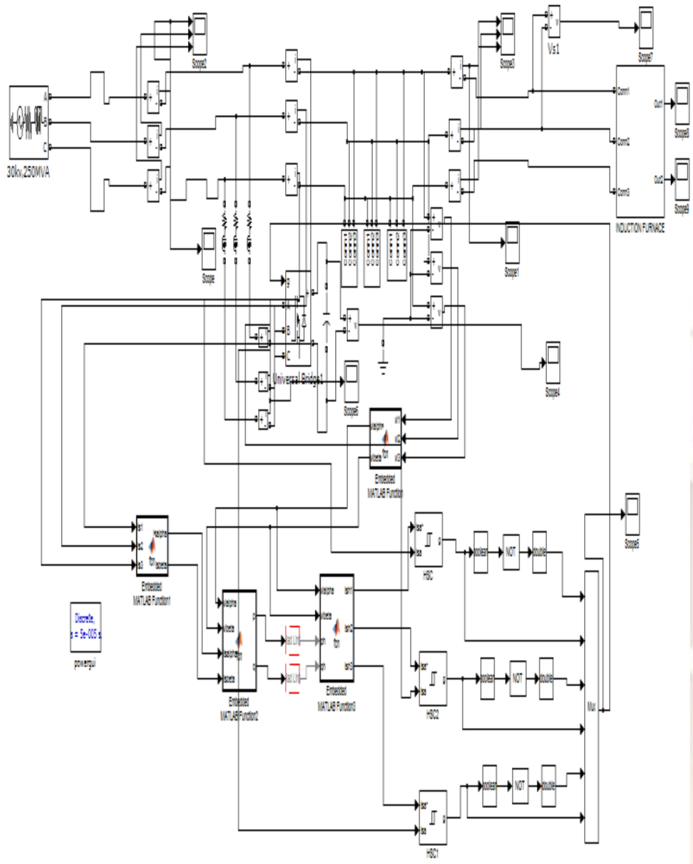

Fig.5.Induction furnace with filter circuit

4.1. SIMULATED RESULTS

Fig 6.shows a set of simulated results of furnace current, furnace voltage, three phase supply current with and without using filter. and the THD measured for all three phase line . The waveform of source current is close to fundamental sinusoid, showing that harmonic current is eliminated from the source current. Therefore, it can be concluded that the proposed hybrid active filter can compensate harmonic current.

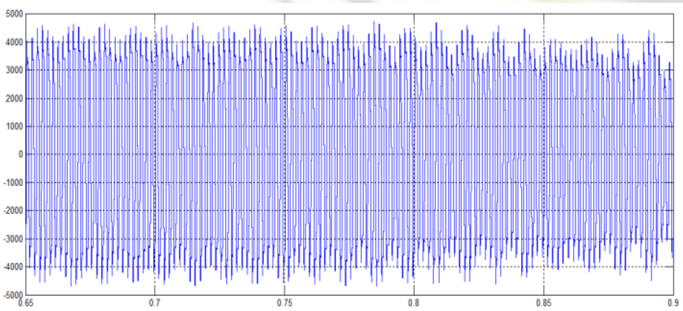

Fig.6.(a).Furnace current

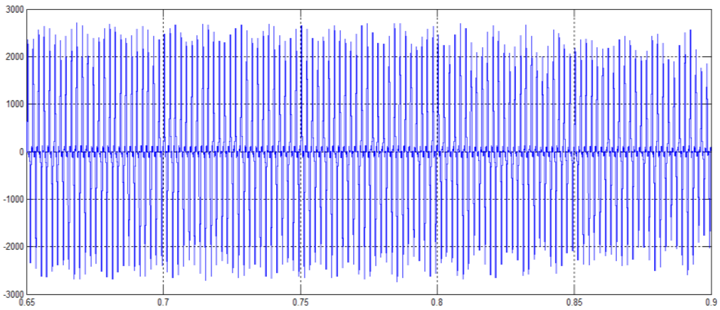

Fig.6.(b).Furnace voltage

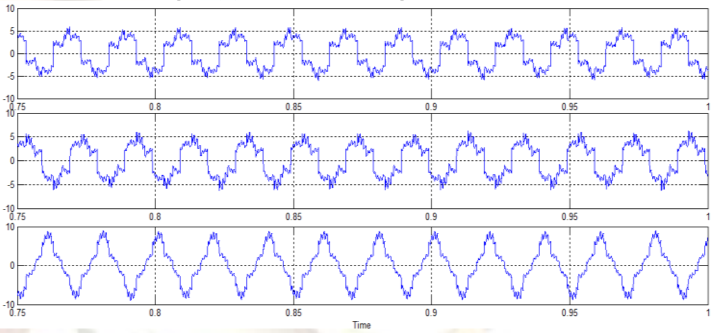

Fig.6.(c)Source current without filter

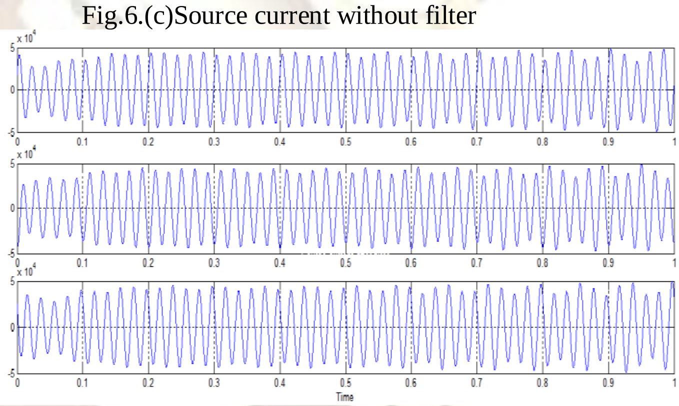

Fig.6.(d)Source current with filter

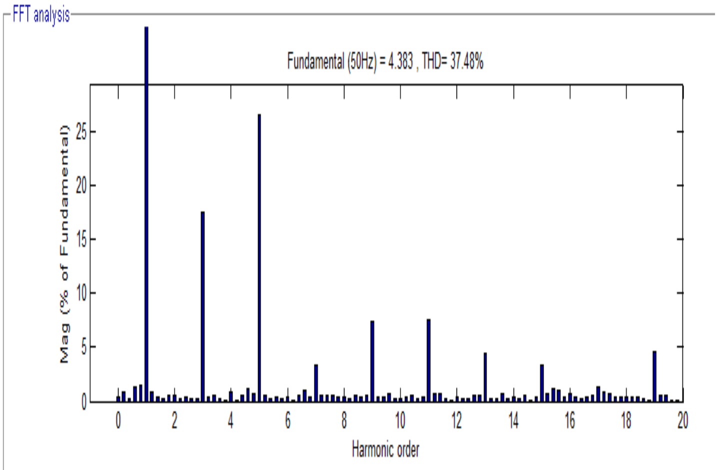

Fig.6.(e).THD of supply current Line-1 without filter

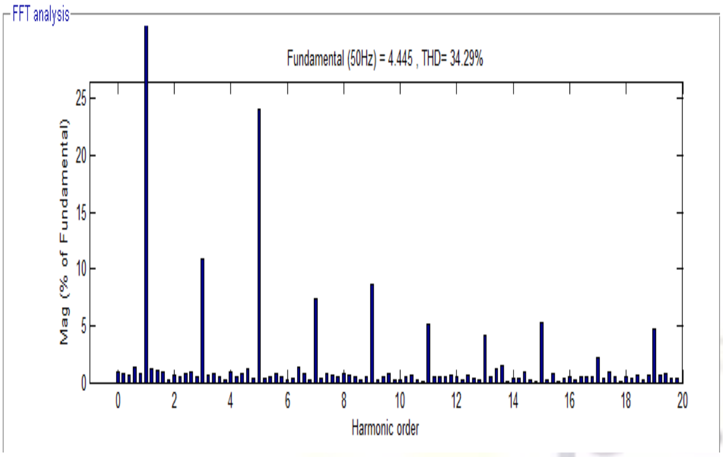

Fig.6.(f).THD of supply current Line-2 without filter

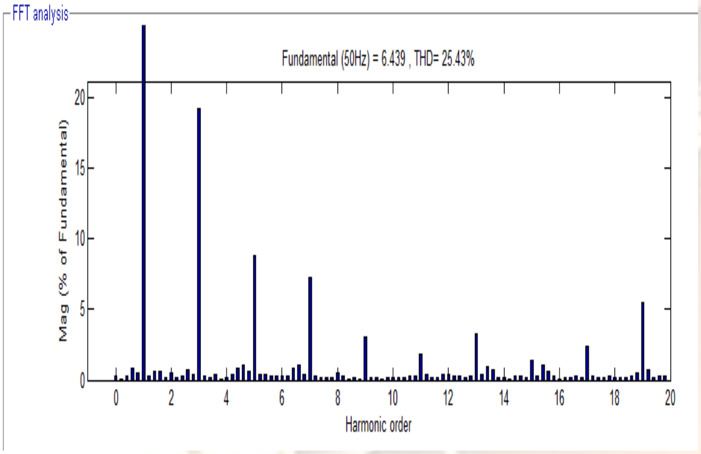

Fig.6.(f).THD of supply current Line-3 without filter

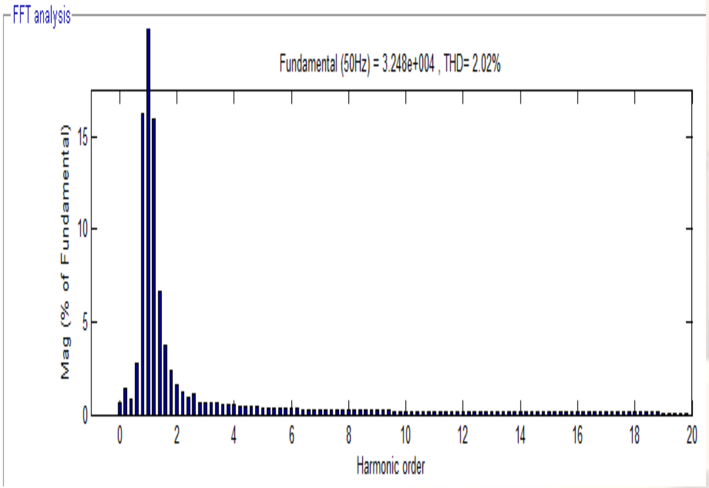

Fig.6.(g).THD of supply current Line-1 with filter

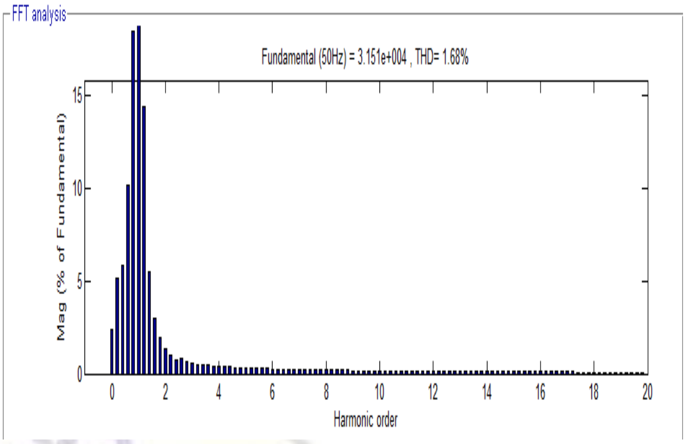

Fig.6.(h).THD of supply current Line-2 with filter

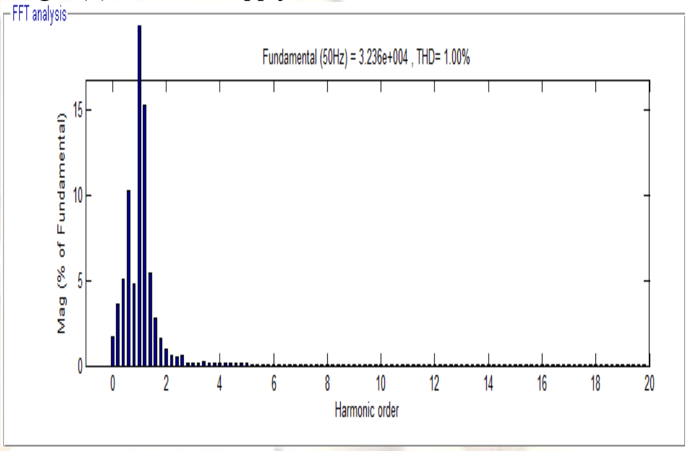

Fig.6.(i).THD of supply current Line-3 with filter

THD's of supply current before and after filtration

Table 1

Supply current line no.	Before filtration	After filtration
THD of supply current Line-1	37.48%	2.02%
THD of supply current Line-2	34.29%	1.68%
THD of supply current Line-3	25.43%	1.00%

CONCLUSION

A MATLAB based model of the hybrid active power filter has been simulated for Induction furnace load by Appling pq-theory for the control of hybrid selective active filter. The simulation results show that the supply current harmonics are compensated very effectively by using the hybrid selective active filter.

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