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A Novel Technique for Harmonic Mitigation & Power Quality Improvement of Induction Furnace by using Filter

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ABSTRACT: The problem of poor power factor and harmonics is becomes critical with the growing use of Industrial Drives and induction furnace. These harmonics require the connection of harmonic filters in the network. Harmonic filters are designed to minimize harmonic distortion caused by harmonic source such as Drives. Several types of Harmonic Filters are effective in minimizing Voltage distortion caused by nonlinear loads in industrial power systems. Before making the final decision on filter configuration, different alternatives for filter design should be considered taking precise reading with the help Fluke Power Analyser Proposed filters are designed and simulated using MATLAB Simulink for particular induction furnace, and designing a prototype model. Main aim of the paper is to make available good quality power.

KEYWORDS: Passive filter, Harmonic distortion, Power quality, Induction Furnace, THD

I.INTRODUCTION

The electric induction furnace is a type of melting furnace that uses electric currents to melt metal. Induction furnaces are ideal for melting and alloying a wide variety of metals with minimum melt losses, however, little refining of the metal is possible. The principle of induction furnace is induction heating. Induction heating is a form of non-contact heating for conductive materials. The principle of induction heating is mainly based on well-known physical phenomena Electromagnetic induction. The energy transfer to the object to be heated occurs by means of electromagnetic induction. Any electrically conductive material placed in a variable magnetic field is the site of induced electric currents, called eddy currents, which will eventually lead to joule heating [1]. The problem with this kind of furnaces is the creation of a considerable harmonic distortion. The cause of the distortion is within the induction furnace design and operation. The induction furnace draws current which is non-sinusoidal in nature because of the rectification/inversion phenomena of their operation from a sinusoidal source which leads to a distorted voltage and current waveform. Non-sinusoidal/distorted voltage and current occur as a result of the presence of harmonic contents in the voltage waveform drawn by this induction furnace [2]. Since induction furnace loads are nonlinear, the harmonic currents generated by the loads will cause a voltage drop across source impedance which causes decrease in power quality. If these distortions exceeds the recommended limit it can cause over voltage and excessive currents, overloading of power factor correction, increased error in energy meters, mal functioning of protective gears such as relays and circuit breakers, tripping of machines at smaller loads and inductive interference with neighbouring communication network. The distortion created by the medium-voltage induction furnace affects the voltage supplied by the feeding distribution network, which in turn could disturb other users supplied from the same network. Therefore, it is necessary to have corrective actions in order to fulfil the regulation concerning voltage harmonic distortion (VTHD) and current harmonic distortion (CTHD): VTHD<=10% and CTHD<=10% [3]. Electric Power Quality (EPQ) is a term that refers to maintaining the near sinusoidal waveform of power distribution bus voltages and currents at rated magnitude and frequency. Thus Electric Power Quality is often used to express voltage quality, current quality, reliability of service, quality of power supply, etc.[4]. Power quality problems occur due to various types of electrical disturbances. Most of the EPQ disturbances depend on amplitude or frequency or on both frequency and amplitude.

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(i) Interruption/under voltage/over voltage

During power interruption, voltage level of a particular bus goes down to zero. The interruption may occur for short or medium or long period. Under voltage and over voltage are fall and rise of voltage levels of a particular bus with respect to standard bus voltage. Such disturbances increase the amount of reactive power drawn or deliver by a system, insulation problems and voltage stability [6].

(ii) Voltage/Current unbalance

Voltage and current unbalance may occur due to the unbalance in drop in the generating system or transmission system and unbalanced loading. During unbalance, negative sequence components appear. It hampers system performance and voltage stability.

(iii) Harmonics

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate (termed the fundamental frequency; usually 50 or 60 Hz). Periodically distorted waveforms can be decomposed into a sum of the fundamental frequency and the harmonics. Harmonic distortion originates due to the nonlinear characteristics of devices and loads on the power system [8].

(iv) Transients

Transients which are the sudden rise of signal may generate in the system itself or may come from the other system.

(v) Voltage Sag

It is a short duration disturbance. During voltage sag, RMS voltage falls to a very low level for short period of time. It is actually a reduction in RMS voltage over a range of 0.1–0.9 pu for a duration greater than 10 ms but less than 1 s.

(vi) Voltage Swell

It is a short duration disturbance. During voltage sag, RMS voltage increases to a very high level for short period of time. It is an increase in RMS voltage over a range of 1.1–1.8 pu for a duration greater than 10 ms but less than 1 s.

(vii) Flicker

It is undesired variation of system frequency. The voltage variations resulting from flicker are often within the normal service voltage range, but the changes are sufficiently rapid to be irritating to certain end users [5].

Harmonics are a major cause of power supply pollution, lowering the power factor and increasing electrical losses. The effect of harmonic results in equipment failure and also causes of requirement of equipment of high rating. The voltage distortion produced in the system is the major issue with the harmonics distortion. The electronics equipment used in the system usually generates more harmonics. In all type of harmonics, the tripled harmonics are more severe. Examples of triplet harmonics are 3rd 9th 15th. These harmonics produced bigger problem to engineers because they poses more distortion in voltage. The effects of triplet harmonics are overheating in wires, overheating in transformer units & also may become the cause of end user equipment failure [7].

In case of Low Power Factor, Current will be increased, and this high current will cause to the following disadvantages.

1) Large Line Losses (Copper Losses)
2) Large KVA rating and Size of Electrical Equipments
3) Greater Conductor Size and Cost
4) Poor Voltage Regulation and Large Voltage Drop
5) Low Efficiency
6) Penalty from Electric Power Supply Company on Low power factor [9].

Earlier Static Capacitor is used to improve power factor improvement. We know that most of the industries and power system loads are inductive that take lagging current which decrease the system power factor. For Power factor improvement purpose, Static capacitors are connected in parallel with those devices which work on low power factor. Drawbacks static capacitor is Series resonance takes place when only capacitor installed to improve power factor in harmonic environment. The age of static capacitor bank is less (8 – 10 years). With changing load, we have to ON or OFF the capacitor bank, which causes switching surges on the system. If the rated voltage increases, then it causes damage it. Once the capacitors spoiled, then repairing is costly [11].

Another method to improve power factor is synchronous condenser. But it is expensive (maintenance cost is also high) and therefore mostly used by large power users. An auxiliary device has to be used for this operation because synchronous motor has no self starting torque. It produces a noise [10].

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There are many ways to reduce harmonics, ranging from variable frequency drive designs to the addition of auxiliary equipment [12]. Few of the most prevailing methods used today to reduce harmonics are explained below.

(a) Passive Harmonic Filters

Passive filter are also known as harmonic trap filters and are used to eliminate or control more dominant lower order harmonics specifically 5th, 7th, 11th and 13th. It is comprised of a passive L-C circuit which is tuned to a specific harmonic frequency which needs to be mitigated. Their operation relies on the “resonance phenomenon” which occurs due to variations in frequency in inductors and capacitors.

b) Active filters

Active filters are limited in their frequency range. It requires DC power supply for their operation. Active filter can’t handle large amount of power [13].

II.CASE STUDY

33/11KV, 500KW of induction furnace is analysed using power analyser and simulation. The various major’s problems are identified in induction furnace. Incoming voltage is affected which is above 35 KV instead of 33KV. Potential Transformer is damaged. Total Harmonic Distortion is above 150% due to non linear load. Capacitor life Reduced thus transient current increases. Current is unbalanced due to unbalanced load. Energy is loss due voltage and current harmonics to extent of 107 KW.

In table I, Existing Power Quality was measured by using Power Analyser at Furnace and existing meters on the panel.

TABLE I
POWER QUALITY

Parameter	Analyser	Simulation
Voltage range per phase secondary	250-260	245-257
Current Range	3.7 to 850	12-900
Power Factor	0.4 to 0.96	0.94depend on loading
THD	90 to 280%	96%
Harmonic Power Loss	57KWto 170KW	60KW
Active power consumption	197KWto 609KWAvv. Loss 25KW	600KW
Reactive power consumption	7- 37Kvar	42-60Kvar

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Fig.1 shows the MATLAB simulation of analysed 33/11 KV, 500 MW induction furnace.

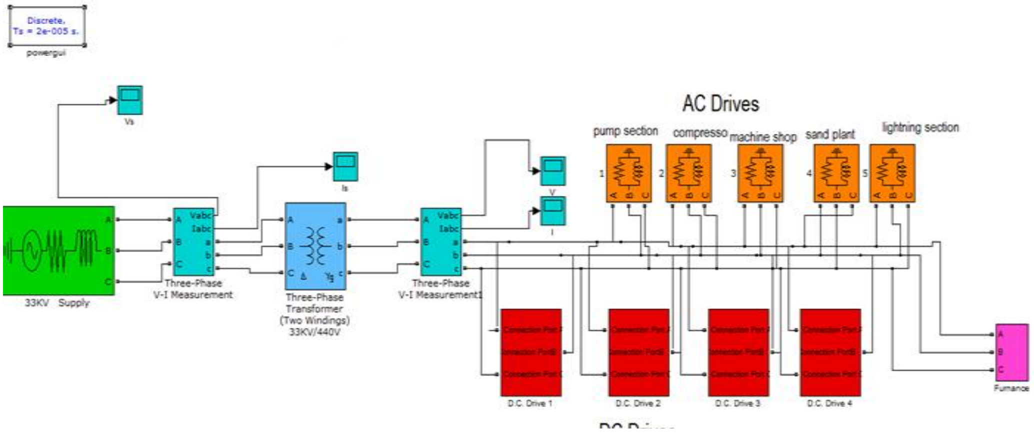

Fig.1. Simulation without filter

III.METHODOLOGY

Any combination of passive (R, L, C) and/or active (transistors, op-amps) elements designed to select or reject a band of frequencies is called a filter. Filters are used to filter out any unwanted frequencies due to nonlinear characteristics of some electronic devices or signals picked up by the surrounding medium.

Filters are one of those corrective solutions aimed at overcoming harmonic problems and to keep them within safe limits. They provide a low impedance path or trap to a harmonic to which a filter is tuned, hence are called tuned circuits. The process of tuning aims at setting the circuit to fr where the response is or at maximum. The circuit is then said to be in state of resonance.

A. Types of filters

1. Passive filters
2. Active filters
3. Hybrid filters

We will be dealing with only Passive Filters as these are the main concern of this paper.

1. Passive Filter

Passive filters are basically topologies or arrangements of R, L and C elements connected in different combinations to gain desired suppression of harmonics. They are employed either to shunt the harmonic currents off the line or to block their flow between parts of the system by tuning the elements to create a resonance at a selected frequency. They also provide the reactive power compensation to the system and hence improve the power quality. Passive filters are used for elimination of a particular harmonic frequency, so number of passive filters increase with increase in number of harmonics on the system. They can be classified into:

a. Passive shunt filter with pf

b. Passive series filter

Passive shunt filters are the main focus of study in this paper.

a. Passive shunt filter

Fig.2 shows the different types of passive shunt filter.

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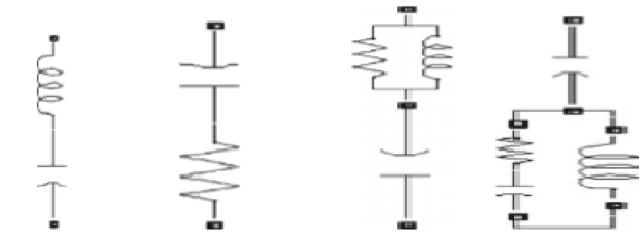

Fig. 2.Types of passive shunt filter

The most common type of passive filter is the single-tuned "notch" filter. This is the most economical type and is frequently sufficient for the application. The notch filter is series-tuned to present low impedance to a particular harmonic current and is connected in shunt with the power system. Thus, harmonic currents are diverted from their normal flow path on the line through the filter Notch filters can provide power factor correction in addition to harmonic suppression. In fact, power factor correction capacitors may be used to make single-tuned filters. They are tuned at low harmonic frequencies. At the tuned harmonic, capacitor and reactor have equal reactance and the filter has purely resistive impedance.

B. Design of proposed filter

In design of the filter, the proper selection of the capacitor size is very essential from power factor point of view. A series-tuned filters is a capacitor designed to trap a certain harmonic by adding a reactor such that $Xl = Xc$ at the frequencyfn.

To design series-tuned following step are followed:

Determine the capacitor size Qc in MVAR; say the reactive power requirement of the source.

The capacitor reactance is

$$Xc = \frac{KV^2}{Qc} \quad (1)$$

Capacitance for filters is calculated by

$$C = \frac{1}{2*\Pi*f*Xc*n} \quad (2)$$

Where n = number of filter

The resonance condition will occur when capacitive reactance is equal to inductive reactance as:

$$Xl = Xc \quad (3)$$

To trap the harmonics of order h, the reactance should be of size

$$L = \frac{1}{(2\Pi hf)^2 \times C} \quad (4)$$

The resistance of filter depends on the quality factor (Q) by which sharpness of the tuning is measured.

$$R = \frac{Xl - Xc}{Q} \quad (5)$$

Where Q is the quality factor and for series tuned is 30<Q≤100.

IV.SIMULATION AND RESULTS

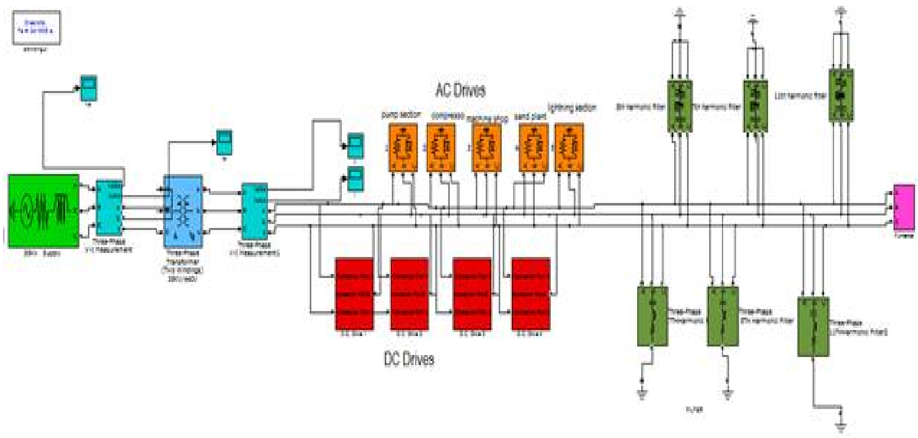

Fig.3. Simulation with filter

Fig.3 shows the simulation of proposed filter scheme is connected parallel to analysed induction furnace to improve power quality and reduce the harmonics.

TABLE II
SIMULATION RESULTS

Parameter	**Simulation without filter**	**Simulation with filter**
Voltage range	245-257 V	237-245
Current Range	12-900 A	10-400
Power Factor	0.94 depend on loading	0.98 for the worst power factor
THD	96%	40%
Harmonic Power Loss	62KW	21KW
Active power consumption	602KW	561KW
Reactive power consumption	42-61Kvar	1-8Kvar

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In Table II, power quality is improved and harmonics gets reduced after the adding proposed filter scheme in analysed induction furnace simulation.

V.PROPOSED FLOWCHART

First we analysed all the measurement THD, current harmonic of all the order, real power, reactive power, power factor, by using artificial intelligence. Compare 5^{th} Harmonic current magnitude if it's exceed 10% turn on proposed 5^{th} harmonic filter if not then compare for 7^{th}. Similarly we will do for 11^{th} and 13^{th}. Next we analysed power factor if power factor is less than 0.9 to 0.99 range turn on proposed 5^{th} harmonic filter, similarly for range 0.8-0.9, 0.7-0.8 and 0.6-0.7.

Fig.4 shows the flow chart of proposed algorithm for automatic power factor correction.

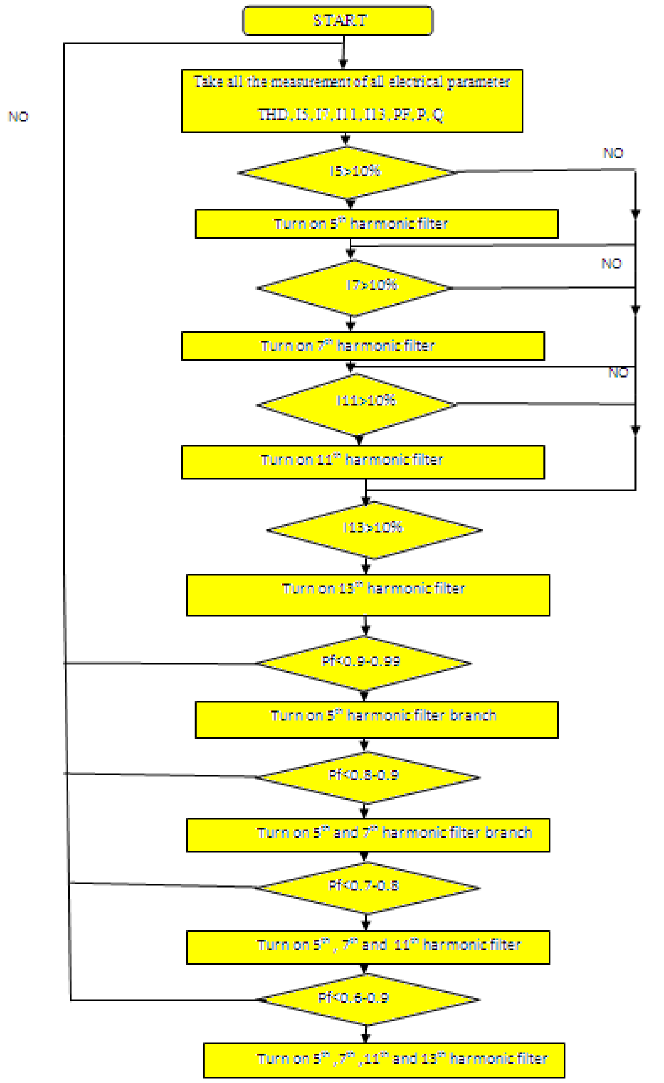

Fig.4. Flow chart of proposed algorithm

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VI.PROTOTYPE MODEL

Prototype Model of filter is connecting to system to improve the power quality and mitigation of Harmonics. Before the implementation filter we measure harmonics of the system and power quality with help of Fluke Power Analyser with help of proposed topology of prototype filter implant to get desired power factor and achieve minimum distortion.

Fig.5 shows experimental setup of prototype model.

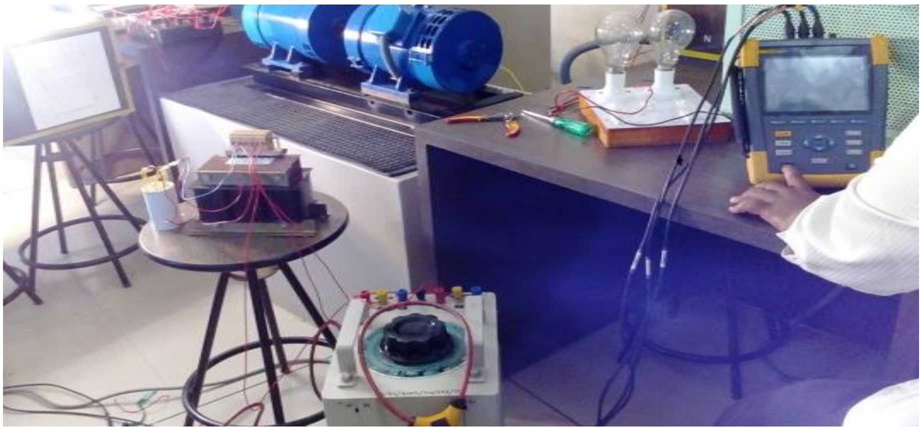

Fig.5. Experimental setup of Prototype Model

VII.CONCLUSION

A new filter scheme for induction furnace is proposed in this paper. A proposed filter scheme has collective advantage of improve power quality i.e. adjusting voltage range and current range to prescribed limit, improve the power factor, mitigate the harmonics specially current harmonics, reduce the power loss, suppress the active power consumption, compensate the reactive power. The proposed topology has to reduce total power consumption in tangibly and intangibly i.e. reduce the chances of equipment damage and mal-operation of relay, increase the production capacity, reduce the production cycle time and carbon footprint.

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