Simulation of Induction Furnace and Comparison with Actual Induction Furnace

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Abstract: *In this paper, at first, a matlab simulation of induction furnace model optimized resonant capacitor is designed for a practical induction furnace with parallel resonant inverter. Then rectifier and inverter snubber circuit are designed and voltage, current, THD and power were measured. This measured value is compared with actual working industry furnace data and conclusion is made that when furnace is not operate at full load that time its power factor is very low and THD is high.*

Keywords: *Induction furnace, Harmonics, THD, Simulation.*

I. INTRODUCTION

Induction heating is widely used in metal industry for melting or heating thin slab in continuous casting plant because of good heating efficiency, high production rate and clean working environments. A typical parallel resonant inverter circuits for induction heater which we are going to discuss about, have a phase controlled rectifier that provides a constant DC current source. The H-bridge inverter consists of four Thyristor and a parallel resonant circuit comprises capacitor bank and heating coil. Thyristors are naturally commutated by AC current flowing through the resonant circuit. Therefore, this type of inverter is usually called a load commutated inverter. The rated output power and frequency of mentioned induction furnace are 70 kw and 2KHz, respectively. The rated input voltage and frequency are 415 V/ac and 50 Hz. One of the problems is the insuffiency in the output power, and the other problem is the frequent damage of the capacitor bank. Insufficiency in output power was caused by a poor power factor of the inverter. The capacitance of the capacitor bank affects the overall operating factor of induction heater such as resonant frequency, Q-factor, efficiency and power factor.

In this paper power, voltage, current, harmonic and THD measured of the actual arc furnace is compared with proposed matlab simulation.

II. IINTRODUCING A PARALLEL RESONANT CIRCUIT

In this section, internal circuits of converter that are used for feeding power of this actual induction heating furnace are introduced. A converter has a rectifier and an inverter. A converter is highly used in industries.

Often these converters that are used in the induction heating furnaces have a three phase rectifier and a single phase inverter. In these converters, load is coil of induction heating furnace that can be controlled in the form of parallel and series with capacitor bank. If changing current of switches of inverter are varied by changing current load naturally.
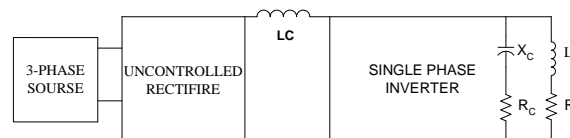

Figure 1.Block diagram of an induction heating furnace.

These inverters usually call load commutation inverter. In this paper, block diagram of a parallel resonant 70Kw induction heating furnace is shown in Figure 1.

This induction heating furnace has problem such as low power factor, insufficient and non-adapted power with load, low efficiency and high system losses especially capacitor loss that are caused frequent damage to the parallel capacitor damage. For these reasons, we optimized this induction heating furnace, Power supply of this induction heating furnace is a three-phase source with voltage amplitude 415V and frequency of 50Hz. Source voltages, after rectifying in an uncontrolled rectifier, are converted into DC voltage and then apply into a single phase inverter. Output voltage amplitude and frequency are 600V and 2000Hz, respectively.

III.DESIGN VALUES OBTAINED FROM ACTUAL WORKING MODEL

A. Furnace Specification

TABLE 1.1 DESIGN VALUES FOR PROPOSED MATLAB MODEL

Power	75 kw
Voltage	415 V
Furnace consumed current	120 Amp
Admittance	7μ Mho
Operating Frequency	2000 Hz
Iron Melting capacity	120 Kg
Maximum temperature	1650 ^{0}C
Inverter	IGBT
Rectifier	Thyrister Bridge

Table 1.1 shows Input design values for the proposed Matlab model.

B. Induction Heating Coil

This schematic consists of the eleven randomize polynomial time algorithms as follows:

For optimization first electrical equivalent circuit of coil induction heating furnace is computed. Coil induction heating furnace is modulated with a series connection of a resistor and an inductor. For the simulation of induction furnace, electrical RC and RL load taken from Matlab library. Power loss in the capacitor bank is the resistor of capacitor model. Electrical Equivalent circuit for induction heating furnace coil connected in parallel with load is shown in Figure 2.
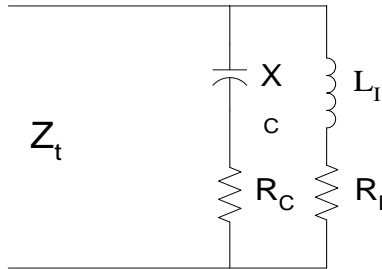

Figure 2.Electrical Equivalent circuit for induction heating furnace coil.

IV. SUGGESTED CONTROL METHOD

Output power obtained from the coil of this induction heating furnace is not constant. When the load impedance is equal to source impedance it creates problem of resonance .So, for improving feeding system of furnace We suggest uncontrolled three phase rectifier convert into controlled three-phase rectifier and design a passive controller for system that by changing the rectifier firing angle, fixed output power of this induction heating furnace on the desired power. Also, suggest single phase switches of inverter convert into IGBT switches and for trigger of these switches, unipolar PWM method is used. For analyzing results of these suggestions electrical feeding system circuit part by part simulated and these simulated details are connected to each other. Consequently, entire circuit is simulated. By usage of this simulated circuit, a passive controller is designed for system. Entire system simulated with desired controller is shown in the Figure.3

V. SYSTEM SIMULATION

A. Source And Controller

Induction heating furnace source is simulated by three-phase sources with sequence a, b, c. Every source has maximum of amplitude of 415V and frequency of 50Hz that has 120^0 phase different between phases. A pure inductor 80 µH is connected to each phase. These inductors show source reactance and need reactance to protect the rectifier Thyristor from high di/dt. Also, this reactance is element of snubber's circuit. Simulated rectifier has three-leg and six Thyristors, we are sampling from T1 to T6. For firing of these thyristor we are sampling from the line voltage.
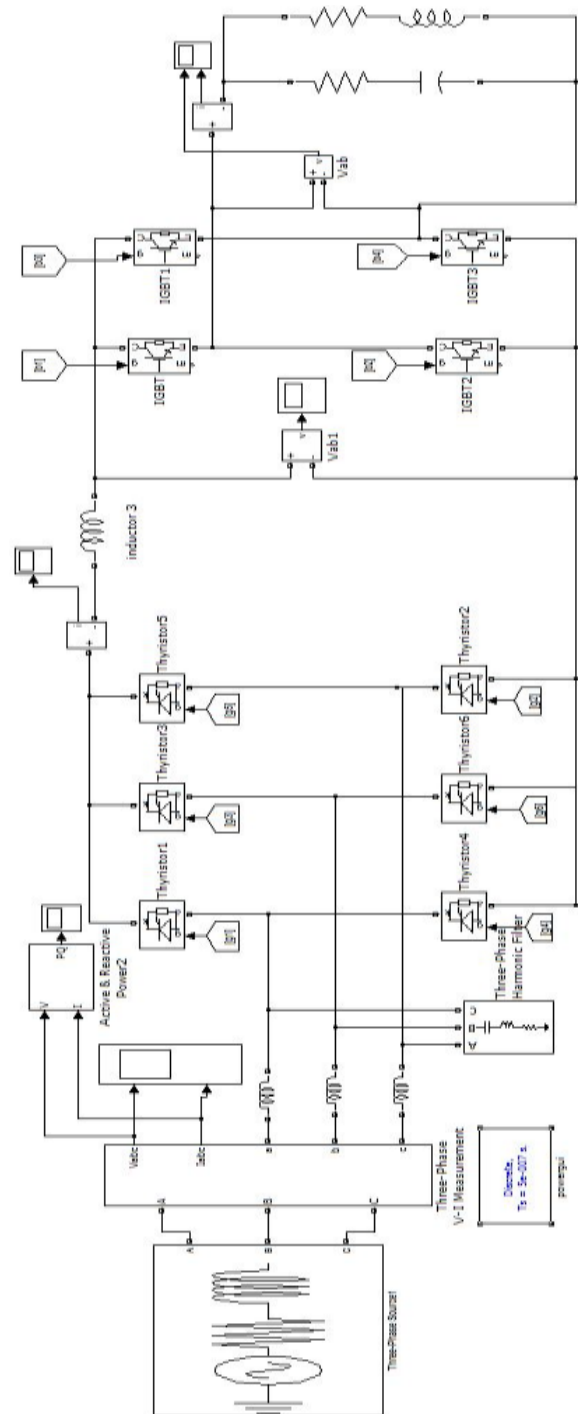
Figure 3. Entire simulated circuit

B. Simulation of Inverter

For connecting rectifier and inverter to each other, an inductor of 20mH is used. Also, for converting DC to ac, according to fig 3, a two leg inverter is used. Every inverter leg has two IGBT switches which with an anti parallel diode are connected. According to fig 4 firing of these switches unipolar PWM method are used. For preparing suitable pulses and applying those into the inverter IGBT switches, at first, a triangular wave form with frequency of 1500 Hz that have 180 phase difference to each other.

VI. CASE STUDY

In The factors under consideration are key management, data redundancy, integrity and memory power & CPU capability in user's description for performance.

Harmonic Analysis was conducted for below rated Induction Furnace.

Measuring Points:
- 12 MT Furnace, 12 Pulse
- 06 MT Furnace, 12 Pulse

Conditions:
- On VCB of 12 MT Furnace- Individual (Different Power Level)
- On VCB of 06 MT Furnace- Individual (Different Power Level)
- On VCB of 12 MT Furnace- 06 MT Furnace on Full Power (Different Power Level of 12 MT Furnace)
- On VCB of 06 MT Furnace- 12 MT Furnace on Full Power (Different Power Level of 06 MT Furnace)

Location-1: 12 MT furnace
Condition: Single furnace & auxiliaries only. Minimum Power Pot.
KW: 76, kVA: 269, kVAr: 257.9, P.F.: **0.28**, Amp: 5.02, 4.72, 4.73.

Amp. Harmonics				Voltage Harmonics			
H. Oder	R-Phase	Y-Phase	B-Phase	H. Order	R-Phase	Y-Phase	B-Phase
THD	18.2	20.3	18.5	THD	1.9	1.5	1.5
2	0.4	0.3	0.4	2	0.3	0.2	0.2
3	0.7	7.5	5.4	3	0.7	0.4	0.2
4	0.6	0.6	0.5	4	0.1	0.1	0.1
5	9.3	8.4	6.3	5	1	0.7	1.1
7	0.8	1.6	1.9	7	1.1	1	0.7
11	11.6	12.1	12.2	11	0.4	0.2	0.2
13	0.8	1.4	1.2	13	0.3	0.2	0.2

Table 1.2 Readings of 12MT Furnace with Minimum Power plot.

Above Table 1.2 shows Readings of 12MT Furnace with Minimum Power plot (Initially started lower loaded furnace)

Figure 4 shows Harmonic spectrum of 12MT Furnace with Minimum Power plot (Initially started lower loaded furnace)

Location-2: 6 MT furnace
Condition: Single furnace & auxiliaries only. Half power pot.
KW: 1032, kVA: 1461, kVAr: 1032, P.F.: **0.7,** Amp: 26.33, 25.99, 25.69

Amp. Harmonics				Voltage Harmonics			
H. Oder	R-Phase	Y-Phase	B-Phase	H. Order	R-Phase	Y-Phase	B-Phase
THD	12	11.9	12.1	THD	2.4	1.7	1.6
2	0.8	0.7	0.7	2	0.1	0.1	0.1
3	1	0.7	0.2	3	0.8	0.9	0.4
4	0.3	0.3	0.3	4	0	0	0
5	0.6	0.4	0.4	5	0.3	0.4	0.4
7	0.4	0.4	0.4	7	0.4	0.3	0.2
11	8.2	8.1	8.4	11	1.1	0.9	0.4
13	4.9	4.9	4.9	13	0.3	0.2	0.1

Table 1.3 Readings of 6 MT Furnace with Minimum Power plot.

Above Table 1.3 shows Readings of 6 MT Furnace with Minimum Power plot (Initially started lower loaded furnace)
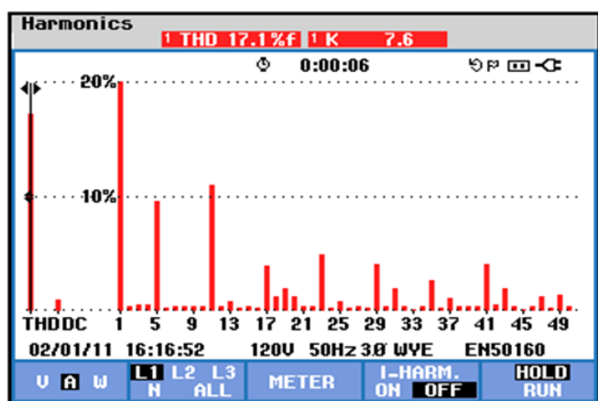**Voltage harmonics: 23rd: 0.8, 25th: 0.7, 35th: 1, 37th: 0.7.**

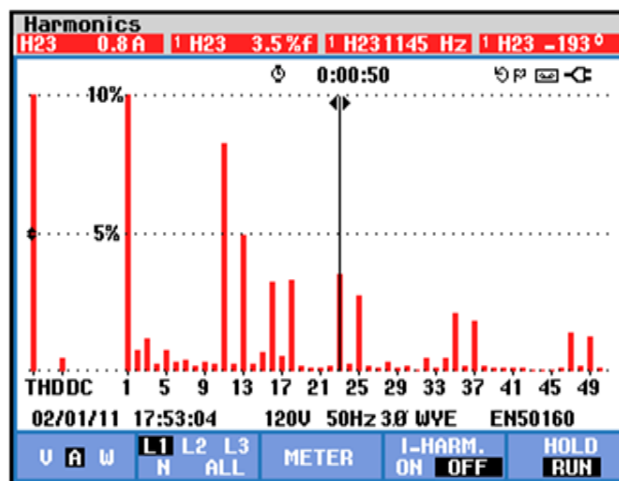**Figure 4 Harmonic Spectrum 6 MT Furnace with Minimum Power plot (Initially started lower loaded furnace)**

Location-3: 6 MT furnace
Condition: Single furnace & auxiliaries only. Full power pot.
KW: 2227, kVA: 2282, kVAr: 487, P.F.: **0.97**, Amp: 41.35, 40.56, 40.41

Amp. Harmonics				Voltage Harmonics			
H. Oder	R-Phase	Y-Phase	B-Phase	H. Order	R-Phase	Y-Phase	B-Phase
THD	10.5	10.4	10.6	THD	3.8	2.4	3
2	0.3	0.4	0.4	2	0.1	0.2	0.1
3	0.8	0.5	0.3	3	0.7	0.7	0.3
4	0.6	0.7	0.7	4	0.1	0.1	0.1
5	0.4	0.4	0.4	5	0.6	0.6	0.7
7	0.8	0.8	0.8	7	0.4	0.5	0.4
11	5.4	5.5	5.6	11	1.4	1.3	0.6
13	4	3.9	3.9	13	0.8	0.7	0.8

Table 1.4 Readings of 6MT Furnace with Full Power plot.

Voltage Harmonics- 49th: 1.1
Current Harmonics -15th: 0.9

VII.   SIMULATION AND ANALYSIS RESULT

A. Simulation

The simulation of Induction furnace power controlling mainly two type, one is power control by rectifier firing angle and second one is power control by inverter, we are increasing rectifier firing angle smoothly and accomplished the simulation by observing output inverter voltage and current, system stability can be studies numerically, rectifier firing angle increases until system becomes unstable at the rectifier firing angle of approximately 120^{0}.

Also some of assumption is taken that practically furnace have cooling system is not considers, this simulation is consider as small segment melting industry so that haven't affordable filtering equipment, but removal of harmonics they have to use only capacitor bank or APFC only. This simulation run in matlab 7.8.0(R2009a) and all the data properties is shown below table and getting output result is shown in fig. Simulation furnace main specifications write down as upper shown and remaining is below table.

Line Filtering Inductor	1e-03 Henry
Inductor between Inverter and rectifier	300e-3
RL load specification	
Voltage	600 Volt
Frequency	1500 Hz
Active Power	150KW
Inductive Power	10e-3 var
RC load specification	
Voltage	600 Volt
Frequency	1500 Hz
Active Power	130KW
Capacitive reactive Power	10e-3 var

Table 1.5 data table load and filter for proposed matlab model

Table 1.5 shows values for matlab simulation for R-L Load, R-C Load and Line filter Inductor.

B. Analysis

➢ Practically induction furnace output current is quasi square wave (sinusoidal) type, but at here simulation output current is sinusoidal because of adding simple passive filter.

➢ Initially, starting of induction furnace power factor is low, but when it operates at full load it is between 0.8 to 0.9, so improvement of Power factor add APFC or capacitor bank, which is shown in upper cash location 1, location 2 and location 3.

➢ Matlab simulation, Current harmonics analysis THD is less as compare to the harmonics data of practical data.
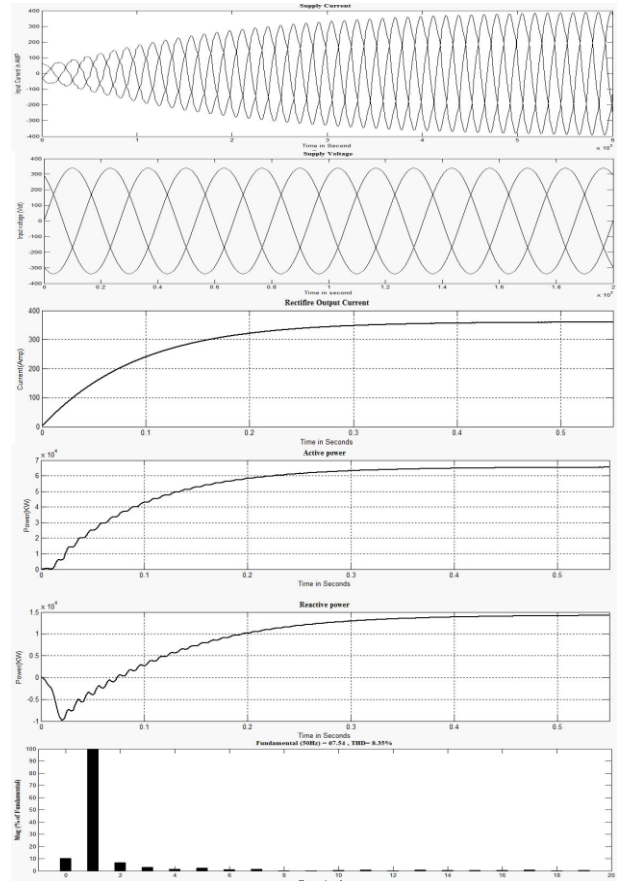
C. Waveforms

Figure 6 Simulation Circuit Wave Forms

Figure 6 shows waveforms of Input voltage, load current at source side, Active and Reactive power for proposed matlab Model.

Matlab Total harmonic distortion of various phases is shown in Table below.

S.R No	Voltage Harmonic	THD%
1	R-phase	0.10%
2	Y-phase	0.12%
3	B-phase	0.11%

Table 1.6 Readings obtained of voltage harmonic distortion in matlab for each phases of proposed circuit.
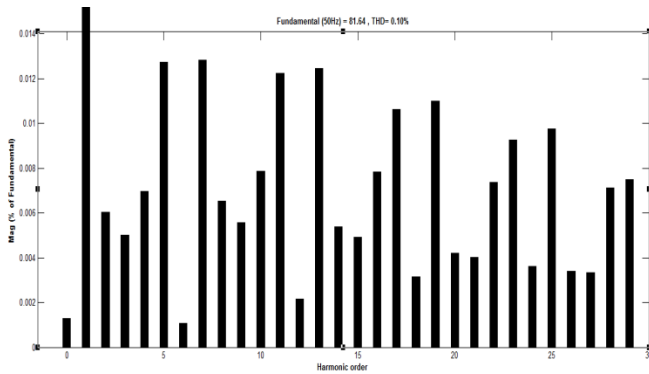
Figure 7: voltage harmonic of R-phase

Figure 7 shows voltage harmonic of R-phase obtained with matlab. Readings of all the 3-phases is shown in table.

VIII. CONCLUSION

In this paper, Harmonics and power factor are closely related. In fact, they are so tightly coupled that one can place limitations on the current harmonics produced by nonlinear loads by using the widely accepted concept of power factor, providing that true power factor is used rather than displacement power factor.

We have actual practical harmonic analysis data and compare with our Matlab simulation data and current and voltage Harmonics analysis comparison.

- ➤ When the full load is connected to the system and APFC connected then its power factor is near to the unity, if not then power factor is reduce.
- ➤ Matlab simulation, Current and voltage harmonics analysis THD is less as compare to the harmonics data of actual practical data.

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