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A new induction water heating system design for domestic heating

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Abstract

In the Middle Eastern and North African countries (between N36-N26 latitudes) where temperatures do not drop heavily in winter times, the resistance-boilers connected to the solar panels in serial offer a practical and economical solution for domestic heating. In this way, while solar power is benefited at the highest level, the desired room temperature can be achieved easily through the boiler having low resistance power. However, due to failure of resistances at short intervals and the need of laborious effort during the changing process, reduce the appeal of resistance-boilers. At this point, the boiler having a low breakdown probability and heating the water with induction heating principle offer a quite attractive solution. The aim of this study is to research induction water heating technique for electrical boiler applications. To this end, a special induction water-heating system was designed and produced. The designed system was run by single and two-phase electrical connection and satisfactory results were obtained. It is expected that an efficient heating system having low-cost operation and maintenance can be developed by improving this technique applicable for market.

Keywords: Induction water heating boiler; Heater; Domestic heating

1. Introduction

In recent years, induction heating technology has a wide range of usage areas such as melting, annealing, welding, tight passing, hardening, forming, cooking and plasma physics [1]. There are various induction water heaters developed recently. But those heaters were designed for water heating. Also academic studies have been focused on water heating [2]. Thus, an induction water heater system seems to be a useful innovation.

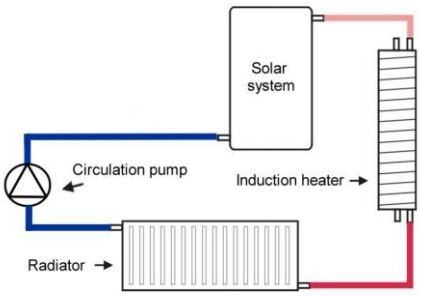

Fig. 1. Schematic diagram of domestic solar+induction heating cycle.

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Usually, the boilers used in the latitude of Europe and even in the latitude of Turkey are produced for an average resident within the range of 18,000 to 25,000 kcal/h corresponding to a nearly 20-30 kW/h electrical power. These electrical power values remain quite high for housing. In North Africa and Middle East regions, by connecting the solar panel to the heating system serially, the amount of needed energy corresponds to the 1/3 of the pre-mentioned value.This approximately corresponds to a value about 6.5-10 kW electrical power, which is within the reasonable limits for housing.

Although there is wide range of usage of induction heater, there are no uses of them for water heating. In this study, the induction heating system is considered for water-heating. A new domestic solar+induction water heating system is illustrated in Fig. 1. The system was designed for house heating and manufactured. In this study, induction water heater component of the system was examined and results are presented which we name it as "unver" water heater.

2. Materials and method

A schematic illustration of the induction heater is given in Fig. 2. The outer body was produced with Ø160mm diameter steel and 32 pieces CrNi-disks drilled from opposite sides sized Ø154mmx2mm were in the inner side aligned with Ø21mm pipe passing from the middle. It was aimed to benefit both from the heat occurring on the steel shell and the discs.

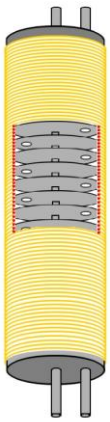

Fig. 2. Designed induction heating boiler.

Water input and output connections were provided with OD: Ø21mm and ID: Ø16mm pipes placed through the shell. A great attention was paid to avoid any pressure loses during the water flow through the discs and holes.

The water supplied from the city water network was used in the boiler. To avoid the risks of abrupt temperature increment, the experimental set up was not designed as closed cycle. The water coming out of the boiler was sent to the sewer system.The inductor winded outside the heater body was made of fiberglass insulated Ø4mm copper wire.

The system was designed as 2 stages. The first stage has 300 turns for low level voltages at single phase. The second stage has 350 turns for high level voltages at two-phase. The values obtained from the measurement are given in Table 1.

Table 1. Values for the designed induction heating boiler.

Turns	L [mH]	R [Ω]
300	3.023	0.213
350	4.136	0.249

The capacitor values which were needed to obtain resonance were computed with the impedances that were calculated via measured values for both stages [3].

For single-phase connection (300 turns for 220V 50Hz);

$$X_{L300} = \omega \times L_{300} = 2 \times \pi \times f \times L_{300} = 0.95\ \Omega \quad (1)$$

$$Q_{C300}= U^2 / X_{L300} = 230^2 / 0.95 = 55.7 \text{ kVAR} \quad (2)$$

$$C_{300}= Q_{C300} /(\omega \times U^2) = 55.7/(2\times\pi\times50\times230^2) = 3.353 \text{ mF} \quad (3)$$

For two-phase connection (350 turns for 380V 50Hz);

$$X_{L350}= \omega \times L = 2\times\pi\times f\times L_{350}= 1.30\ \Omega \quad (4)$$

$$Q_{C350}= U^2/X_{L350} = 400^2 / 1.30 = 123.0 \text{ kVAR} \quad (5)$$

$$C_{350}= Q_{C350} / (\omega \times U^2) = 123 / (2\times\pi\times50\times400^2) = 2.45 \text{ mF} \quad (6)$$

capacitor must be connected.

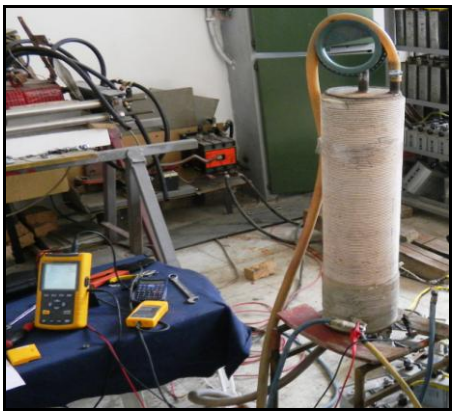

Fig. 3. The developed experimental setup.

In the experiment, temperature of the water inside the boiler was measured as T_{11} = 27.3 °C in single-phase connection, and T_{12} = 77.8 ºC (Fig. 4.) for the water coming out from the boiler and the water flow as 133.33 kg/h. Here;

$$\Delta T= T_{12}-T_{11} = 77.8-27.3 = 50.5\ ^\circ\text{C} \quad (7)$$

$$Q_{W300}= m\times c\times\Delta T = 133.33\times1\times50.5 = 6{,}731 \text{ kCal} \quad (8)$$

were obtained. While the energy supplied into the water is 6,731 kCal, the electrical energy taken from the network was obtained as (Fig. 5.);

$$Q_{L300}= P_{L220}\times860 = 8.7\times860 = 7{,}482 \text{ kCal} \quad (9)$$

Then, the efficiency is obtained as;

$$\eta= Q_{W300} / Q_{L220}\times100 = 6{,}731/7{,}482\times100 = 90.0\% \quad (10)$$

As it is seen, ΔT_1 = 50.5ºC in the water temperature was obtained, and this is accepted as a quite reasonable value for domestic use, which is fortified with a solar panel pre-heater.

As the temperature difference will be higher when the system is set up two-phase connection, the water flow rate was increased up to k = 533.33 kg/h. During the experiment, the temperature of the water inside the boiler was measured as T_{21} = 21.7 ºC, and T_{22} = 59.1 ºC for the water coming out of the boiler.

The result was obtained as follows;

$$\Delta T= T_{22}-T_{21} = 59.1-21.7 = 37.4^\circ\text{C} \quad (11)$$

$$Q_{W350} = m \times c \times \Delta T = 533.33 \times 1 \times 37.4 = 19{,}946.54 \text{ kCal} \quad (12)$$

Fig. 4. Temperature measurement of the water coming out from the boiler.

While the energy supplied into the water was 19,946.54 kCal, the energy taken from the network was measured as (Fig. 6);

$$Q_{L380} = P_{L380} \times 860 = 25.0 \times 860 = 21{,}500 \text{ kCal} \quad (13)$$

And, the efficiency is obtained as follows;

$$\eta = Q_{W350} / Q_{L380} \times 100 = 19{,}946.54/21{,}500 \times 100 = 90.0\% \quad (14)$$

When the system is operated with two phases, a ΔT_2=37.4ºC temperature increase was obtained. This value is considered as quite sufficient for wider houses. Electrical values of the single and two phase connection are shown in Table 2.

Table 2. Electrical values of the single and two phase connection

V_{line} [V]	I_A [A]	P_{line} [kW]	Q_{line} [kVAR]	S_{line}[kVA]	PF	Cos Ø
229.1	46.2	8.7	0.5	8.7	0.83	1.00
397.8	73.3	25.0	2.5	25.1	0.85	1.00

3. Discussion

There have been efforts to bring about innovations for economical home heating systems. Combining thermal and electrical systems [4], using ground coupled heat pomp systems [5], and solar heat pomp systems [6] are works as exciting as induction water heating systems [7-15]. The induction water heating system can be add to these systems. Induction water-heating system hasn't been used for home heating before in 50 Hz frequency. In this study, a new induction water heater was designed and its behavior under two different voltages was monitored.

Power and harmonics values of the system are seen in Figs. 5 and 6. In the figures, harmonic effects are seen in the system. This effect is due to the fixed coil wound around the boiler body. The vibration on the windings changes the inductance and it then creates harmonic current flows. In order to have effective control on the windings and to observe the experiment more easily, the windings were not fixed and the system was not insulated. By fixing the windings firmly on the boiler, harmonic effect is thought to diminish dramatically.

The heat occurring on the copper wire while in single-phase connection can be calculated as follows [7]:

$$Q_R = 0.24 \times I^2 \times R \times t = 0.24 \times 462 \times 0.213 \times 3.6 = 389 \text{ Cal} \quad (15)$$

$$P_R = 389/860 = 500 \text{ W} \quad (16)$$

This is quite a low value and it also contributes to warm the water since there isn't any insulation between the coil and the boiler. Performing the insulation on the outer side of the coil in this heater was thought to be appropriate in terms of efficiency. Thus, in accordance with joule law, the heat generated on the coil was thought to contribute to warm the water.

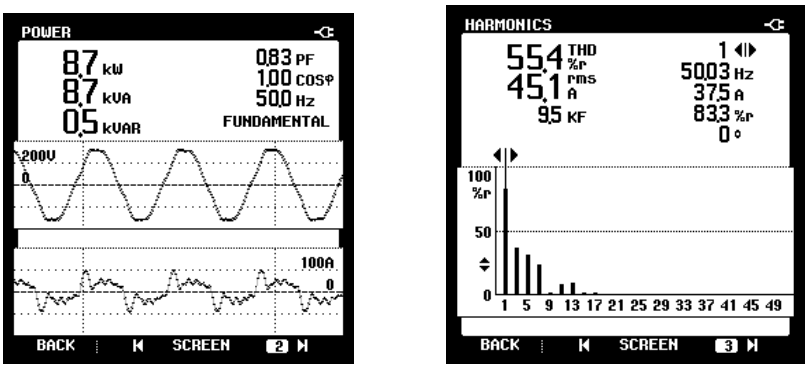

Fig. 5. Power and harmonic values in single phase

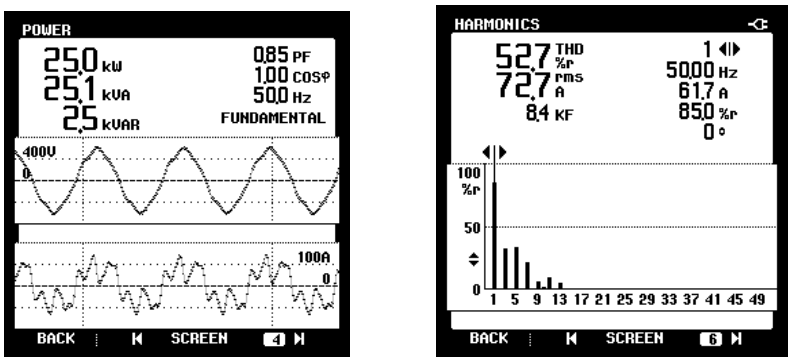

Fig. 6. Power and harmonic values in two-phase.

4. Conclusion

There are 32 pieces CrNi disks, which have been placed into steel body of the designed induction water heater. A coil with 300+50 windings was placed outside the body. Single and two phases were applied to the system as two different voltage stages and the electrical values were taken. Considering the obtained values, it is seen that the efficiency of the designed system is quite high. The system can be more efficient by means of a proper insulation. This system can be used in the regions especially between the parallels of 36-26 by connecting the solar panels serially. In this way, what will be achieved besides a safe durable boiler by this means is the advantage of having the benefits of the solar energy at the maximum level.

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