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Quasi resonant topology based highly efficient solar-powered induction cooker

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ABSTRACT

The energy crisis is a major issue in developing countries, with fossil fuels being the main source of cooking. Induction cookers have received attention due to their safe operation and eco-friendliness, but traditional AC induction cookers are costly and inefficient due to an inverter and rectifier. In this regard, this paper aims to model and develop a solar-powered, low-cost, and highly efficient induction cooker that can be operated directly by solar panels through a battery. By utilizing the solar panels' maximum output, a maximum power point tracking (MPPT)-based solar power controller has been utilized to charge the battery. A modified coil structure for the cooker is proposed to decrease the coil's excitation time and increase the resonant frequency. A quasi-resonant converter topology has been used in the proposed induction cooker, as it operates at high frequencies above 20 kHz to avert audible noise and below 100 kHz to minimize losses in switching. The performance of the suggested induction cooktop has been validated by modifying the circuit and the coil of a traditional 220 V, 2 kW induction cooker. Based on the outcomes, it is observed that the efficiency of the proposed induction cooker reached 93%, which is better than that of existing induction cookers.

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1. INTRODUCTION

The exploitation of tropical forests, the burning of fossil fuels, and the rearing of livestock are only a few examples of how human actions are changing the earth's climate and temperature [1]. In addition to the greenhouse gases already naturally present in the atmosphere, these activities result in the disclosure of massive greenhouse gas emissions, which are a factor in both global warming and the greenhouse effect [2]. Renewable energy (RE) applications, such as creative solar ovens, are among the most endorsed and encouraged options. Solar power is an excellent and clean form of energy [3]. Solar power may alleviate the world's reliance on polluting and depleting non-renewable resources like coal and other fossil fuels [4], [5]. The nation has acknowledged that rising worries about climate change are a result of the release of greenhouse gases. The Department of Energy (DoE) has created a plan for how the RE industry may flourish and make a beneficial impact on both the national economy and the environment globally [6]. Compared to a gas burner, induction cooking delivers faster heating, better thermal efficiency, and lower emissions [7]. It is a great option because of its high efficiency, fast heating, accurate heat control features, safety measures, and cleanliness [8]. It eliminates health concerns, but its impacts on the environment depend on the method of electricity generation. To make the induction cooking system more environmentally friendly, solar energy can be used to operate the cooker. It can also play an important part in alleviating the carbon emission problem, as well as being an effective RE source to alleviate greenhouse gas emissions and aid to prevent global warming [9], [10].

In Bangladesh, the household sector accounts for 50.18% of all energy consumption. As a result, cooking ranks as the most highly energy-intensive activity nationwide [11]. A small adjustment in cooking methods and fuels might have a big influence on the country's economy. Figure 1 shows Bangladesh's energy use in different economic sectors. There was a liquefied petroleum gas (LPG) shortage during Bangladesh's most recent energy crisis. People began using induction cookers to meet their daily culinary demands [12]. Due to overloading during peak hours, faults in the local distribution transformer were observed, costing significantly more to fix and maintain. While there was no grid electricity, many individuals looked for an alternate way to utilize induction cookers [13]. The only alternative at the time was to utilize a pricey inverter and a battery as a source. Many people were interested in and confused by the prospect of utilizing an induction cooker without the need for more powerful, expensive inverters at that time [14].

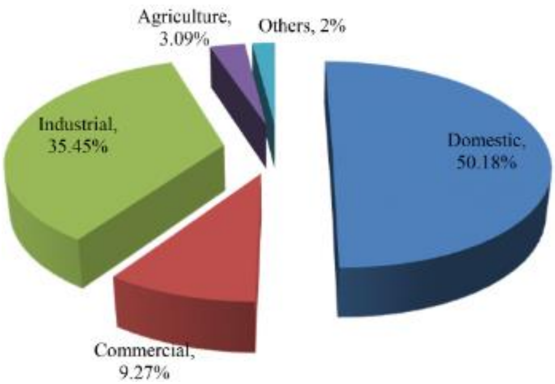


Figure 1. Energy consumption of Bangladesh by different economic sectors [15]

Many research has been conducted on the design, implementation, and performance enhancement of induction cookers in literature. For instance, Adhikari *et al*. [16] conducted a study on a DC-powered induction cooker, demonstrating that it could handle 75 A of current, but the insulated-gate bipolar transistor (IGBT) struggled to handle it in real life. The paper also presents the simulation and design of a DC-powered induction cooker, with a measured simulation efficiency of 90.10% [16]. An examination of the substantial environmental effects of high-power commercial induction cookers is described in [17]. The study in [18] describes a methodical design of an induction cooker system for commercial purposes, with an emphasis on a convex bottom Chinese wok. The effects of high-power commercial induction cookers on the environment are also investigated, emphasizing the importance of energy-efficient design. The study in [19] outlines a realistic implementation of a 0.5–1 kW stove, which provides a solution for cooking in places with inconsistent electric supply by using vehicle batteries instead of a grid connection. A smart electric cooking stove with automatic burning detection system is presented in [20]. The viability of employing solar photovoltaics (solar PV) as a source of energy for cooking is given in [21], with an emphasis on the causes of loss and potential corrective solutions. The articles' economic analyses and experimental findings demonstrate that cooking is doable with far less electricity and energy than is often believed.

Based on the literature mentioned above, it is evident that there is no type of induction cooker which operates by DC energy and functions well, and it is clear that there is no model developed for effectively managing the temperature of a solar-powered electric cooker. In addition, the papers do not give additional information about the precise design and technological components of the prototype solar household e-cooker that was tested. Moreover, the system may not be suited for places with low sunshine or frequent overcast days, since this may reduce the efficiency and effectiveness of the induction stove. Reliability is a concern with solar PV-based cooking since sunlight is only accessible during the day and changes depending on the weather. Therefore, having access to storage of energy, including a battery, can enhance the overall system. In this research, an alternate option, such as a battery backup, is being examined to ensure the electricity source remains reliable. However, the backup battery will boost the overall system cost to a considerably higher level; therefore, the whole concept of solar PV e-cooking may lose its appeal as a potential alternative to traditional cooking. The paper design and suggests optimizing the number of coils turns in an induction cooker to reduce noise and increase magnetic field strength by reducing the coil's excitation time and resonant frequency. Furthermore, a solar-powered DC induction cooker has been developed that can be operated by a solar panel through a 48 V battery. Four 12 V, 55 Ah Hamko batteries have been used to run the cooker properly, and two 250 Wp solar panels are used to charge the batteries. The output power obtained from the proposed cooker is sufficient for a small family. The suggested technology also enables an affordable and effective method of accurately detecting the actual temperature of an electric cooker. Most of the available AC induction cookers used half or full-bridge converter topology due to which issues like noise and switching loss persist in the cooker which affect the efficiency of the cooker. This study uses quasi-resonant converter topology in order to improve efficiency compared to traditional AC induction cookers, as it operates at high frequencies above 20 kHz to avoid audible noise and below 100 kHz to minimize switching losses. The contributions to the paper are as follows:

- A quasi-resonant converter topology is implemented in the solar-based induction cooker, to improve the efficiency of the proposed solar-based induction cooker by avoiding audible noise and reducing switching losses.
- An improved coil structure for the cooker is designed to decrease the coil's excitation time and increase the resonant frequency.
- A prototype of the proposed induction cooker incorporating a quasi-resonant converter and modified coil structure is developed for assessing and validating performance in a realistic setting.
- A comparison between the proposed and available induction cookers is presented based on different features (efficiency and output power) to show the proposed induction cooker's better performance over existing ones.

The paper is structured as follows: the proposed system, as well as the selection topology and coil design that have been done to improve the performance of the cooker, are presented in section 2. Next, the cooker system structure and circuit design are illustrated in section 3. The system efficiency and performance evaluations are also calculated during the whole test in section 4. Section 5 presents the discussion part of the overall system, a comparative summary with previous research, and the limitations and recommendations. Section 6 details the final outcome acquired from the proposed cooker and its future modifications to upgrade its performance further.

2. MODELLING AND DESIGN OF THE PROPOSED INDUCTION COOKER SYSTEM

2.1. Block diagram of the proposed solar induction cooker system

Figure 2 shows the block diagram of a conventional AC induction cooker. The cooker is powered by AC voltage. In this research, an induction cooker has been developed that is operated both by a solar panel and a battery. The block diagram of the suggested solar-powered DC induction cooking system is presented in Figure 3. In a conventional induction cooker, the supplied AC power is converted into direct current to power the resonant converter. This process involves an inverter outside the cooker and a rectifier inside the cooker. This system is ineffective, and the inverter used outside the cooker is very costly. So, to keep the system simple and cost-effective, no inverter is used in the proposed system. The induction cooker can be operated directly by a solar panel or storage. The battery was charged using a maximum power point tracking (MPPT)-based solar charge controller that collected the maximum amount of electricity from the solar panel. An induction coil is included in the design that is magnetized and produces heat for cooking foods. By controlling the power levels (changing the duty cycles), the temperature of the cooker is controlled. The pulse width modulation (PWM) technique is used to give gate signals to the converter.

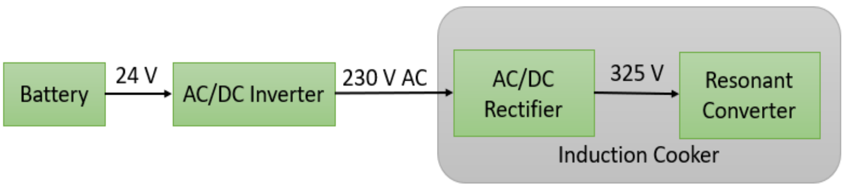


Figure 2. Block diagram of the typical method for using a battery to power an induction stove

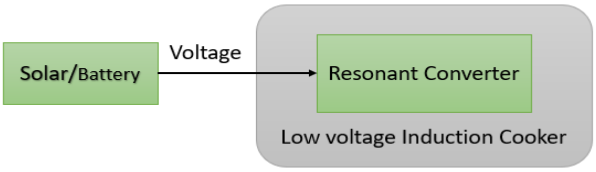


Figure 3. Block diagram of proposed solar induction cooker

2.2. Modeling of quasi-resonant converter

The main function of the inverter induction heating system is that it generates high-frequency alternating current in the induction coil. For such applications, resonant converters should be used, as they operate at high frequencies above 20 kHz to avoid audible noise and below 100 kHz to reduce switching losses [22]. Because of their low switching loss and rapid switching speed compared to other semiconductor devices, IGBT switches were chosen [23]. The converter topology for this study is used is a parallel quasi-resonant converter because of the single switch circuit, which makes the design very inexpensive, compact, and easy for the heat sink and printed circuit board (PCB).

Quasi-resonant converters are really attractive in domestic induction heating, as they simply need one resonant capacitor and one IGBT switch [24]. Figure 4 shows the circuit diagram of the quasi-resonant converter topology. V_{BUS} is rectified DC voltage. L_r and C_r are the inductance and capacitance of the cooker coil, respectively. The cooker pan acts as a load (R), and the combination of these three is responsible for the frequency and time period of the oscillation. T_1 is regulated by a quasi-resonant converter. The resonant tank controls the off-time (Toff), whereas the on-time (Ton) is fixed for a certain power level. As it just needs one resonant capacitor and one switch, often an IGBT, this type of converter is very attractive [25]. The frequency of the quasi-resonant converter ranges from 20 kHz to 30 kHz for all the different power levels.

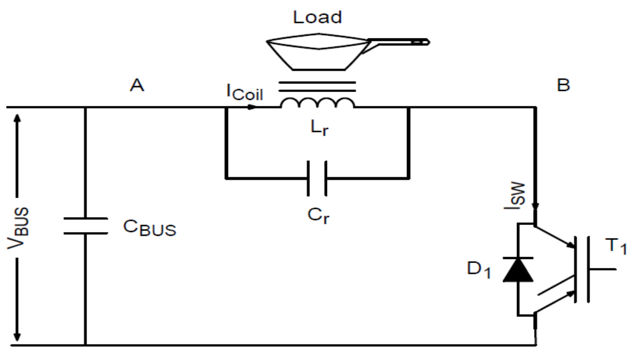


Figure 4. Topology of quasi-resonant converter [26]

The switch and resonant capacitor's maximum power level and main voltage for a specific load state may be determined using quasi-resonant theory [27]. Where E represents the energy held during the T_{ON} phase in the inductive component of the load.

$$V_{res} = \sqrt{\frac{2.E}{C}} \tag{1}$$

The peak current is proportional to T_{ON}, V_{dc-bus}:

$$E = \frac{1}{2}\, L. I_{pk}^2 \tag{2}$$

The resonant voltage V_{res} can bbe expressed in terms of T_{on} and V_{dc-bus}:

$$I_{pk} = T_{ON}.\frac{V_{dc-bus}}{L} \tag{3}$$

Usually, T_{ON} remains constant throughout the duration of the mains semi-period.

$$V_{res} = \frac{T_{ON} \cdot V_{dc-bus}}{\sqrt{LC}} \tag{4}$$

T_{ON} is typically kept constant for a given loading scenario. The T_{ON} controls the quasi-resonant converter. The on-time (T_{ON}) for a given power level is fixed, while the off-time (T_{OFF}) is regulated by the resonant tank circuit. The PWM driving signal may be used to control the on-time. Figure 5 shows the R_L model of coil-pot coupling is used in this quasi-resonant circuit. The analogous resistance and inductance of the cooking pot may be reflected back into the circuit using a simple transformer analogy. As a result, the induction coil, cooking pot, and their connection may all be represented by an equivalent resistor-capacitor series combination. The actual power delivered to the load is denoted by the power wasted in the resistor R_0.

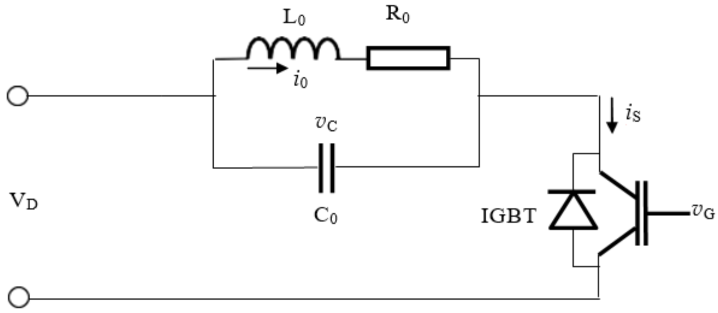


Figure 5. Quasi-resonant circuit with RL model of coil-pot coupling

2.3. Coil design of the induction cooker

In this research, the induction coil used is a coil that is made for AC induction cookers available on the market. As this coil is designed for an AC voltage supply, it needs some modifications to be used in a DC induction cooker. Initially, when the original coil is powered by 48 V DC, the cooker generates a very high-pitched sound that continues during the whole time of running the cooker. This sound is too irritating to hear. The conventional coil is designed for AC voltage. So, when 220 V AC is supplied to the cooker, the coil gets excited by switching the IGBT. The length of the coil can be increase by (5):

$$L = \frac{N^2 \mu_r \mu_0 A}{I} \tag{5}$$

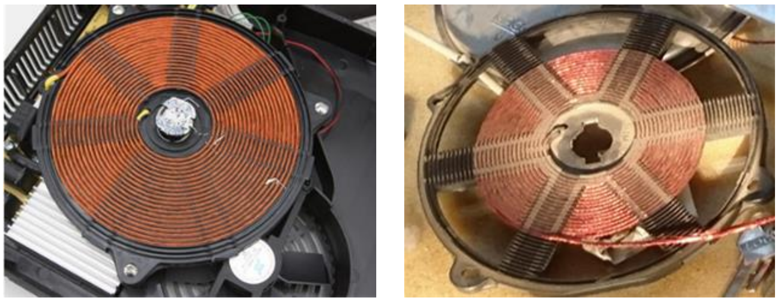
Here, L is inductance of coil in henry (H). μ_r is relative permittivity and μ_0=1.26×10^{-6} T-m. The area of the coil is presented in A and I represent the average length of coil in meters. Without iron cores, the coil in the induction cooker is termed an air core cylindrical coil. The inductance is separated into two parts: self-inductance and mutual inductance. The analytical formula for estimating the self-inductance of a single turn circular coil is as (6):

$$L_s(l) = \mu_0 R_l (ln \frac{8R_l}{r} - \frac{7}{4}) \tag{6}$$

In (6), $L_s\,(l)$ represents the self-inductance of a single-turn circular coil with radius R_l and wire radius r, whereas μ_0 represents vacuum permeability. The resonant frequency generated due to the switching is above the human hearing range, which is 20 Hz–20 KHz. So, no unwanted noise is generated while operating the cooker on AC voltage. The DC voltage has been applied, and it is much lower than the AC voltage, so the time required for exciting the coil increases. That means the time period increases. As a result, the resonant frequency decreases. If this frequency is within the range of human hearing, then the sound generated by the electromagnetic field of the coil is heard. This sound is very loud and intolerable.

To solve the problem, the length of the coil should be reduced in order to decrease the coil's excitation time. As a result, the time period can be reduced, and the resonant frequency can be increased. A conventional coil whose initial turn is 24 is selected. The trial-and-error method has been used to find the optimal number of turns of the coil where no audible noise is generated. To determine the coil's optimal number of turns, the number of turns has been decreased gradually by cutting the coil, and for each reduced turn, condition data is taken to analyze if the noise still exists or not.

While decreasing the number of turns, it is noticed that the intensity of the noise is decreasing gradually. Finally, when the number of turns is reduced to 21, no noise is heard at any of the power levels. This means that the problem of noise generation has been solved after 21 turns of the coil. To see the frequencies at different power levels, the oscilloscope is again connected to the cooker. When the turn of the coil is again reduced to 18, the magnetic field produced in the coil is not sufficient to detect the pan placed on the cooker. So, the cooker cannot be operated at this number of turns. So, the optimized number of turns of the coil is 19. Figure 6(a) shows the scenario of the coil before modification. After modification of the coil of the cooker, as shown in Figure 6(b), all the necessary components are assembled together to run the cooker properly, as shown in Figure 7.



(a) (b)

Figure 6. Coil of induction cooker; (a) before modification and (b) after modification

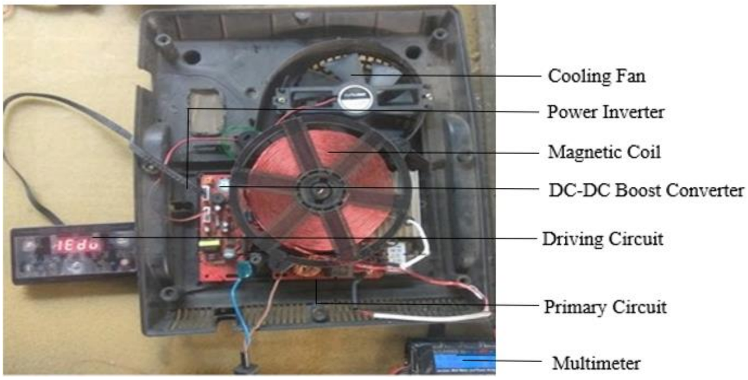


Figure 7. Prototype of solar based DC induction cooker using modified coil

2.4. Power optimization the induction cooker

In an induction cooker, the IGBT’s switching frequency is related to the frequency of AC that circulates through the induction coil. The higher the switching frequency, the lower the inductance of the coil. According to the skin effect, current density equations are expressed as (7):

$$J = J_S e^{\frac{d}{\delta}} \tag{7}$$

J_S is the current density at the conductor’s surface, where J is the current density [A/m^2]. The skin depth is denoted by δ, and depth is denoted by d. The angular frequency is ω. If the frequency increases, the current density J increases. This current (eddy current) flows through the bottom of the pot and is mainly converted into heat according to the Joule heating law (also known as ohmic heating). This effect is also known as Joule’s first law [28].

$$Q = P = R.I^2 \tag{8}$$

where, Q and P stand for the power that is transferred from electrical to thermal energy, I is the conductor’s current (in this case, the eddy current), V represent the voltage drop across the element (in this case, the electromagnetic field), and R is the conductor's equivalent resistance (in the case of induction heating, this is the resistance of the pot's bottom layer). The quantity of heat emitted is proportional to the square of the current, according to (7). Moreover, voltage induced in an induction coil is expressed in (9) and (10) [29]:

$$V_L = -L\frac{di}{dt}(V) \tag{9}$$

$$L = \frac{V_L}{\frac{di}{dt}} \tag{10}$$

Where *di/dt* is the rate of change of current in amperes per second (A/s), V_L is the voltage across the coil, and L is the inductance in Henries. From the above-mentioned discussion, by reducing the length (turn of the coil), the switching frequency increases and the inductance of the coil decreases. This results in an increase in both current and power. As the heat depends on the power generated, by increasing the power, the heat is also increased. This heat is used to cook the foods in an induction cooker. So, to increase the power of the induction cooker, a few more turns of the coil are made. The number of turns on the coil is reduced gradually. By using the trial-and-error method, the single turn of the coil is reduced. Then it is checked to see whether the power of the cooker is satisfactory or not.

3. IMPLEMENTATION OF PROPOSED SOLAR INDUCTION COOKER SYSTEM

3.1. Proposed induction cooker system structure and design

After redesigning the circuit of the conventional induction cooker to work with DC voltage instead of AC voltage, a prototype has been implemented to evaluate its performance. It is composed of a solar panel, a charge controller, a battery, and an induction cooker. The connection diagram of the whole system is presented in Figure 8.

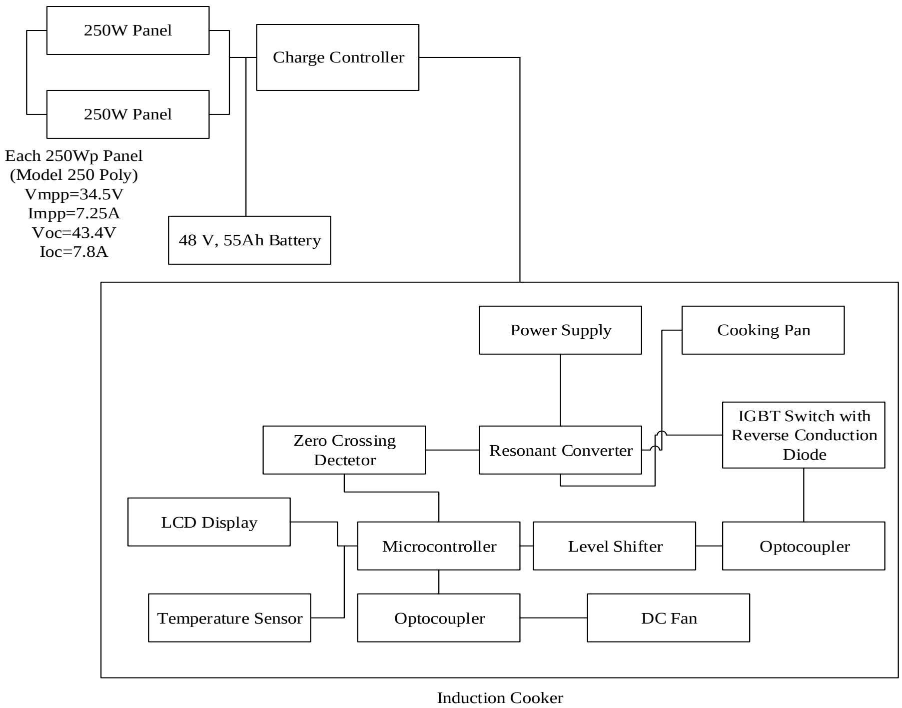


Figure 8. Schematic of the solar DC induction cooking system

The proposed DC induction cooker consists of several components, including a zero-crossing detector, a resonant converter, and an IGBT switch. Here, a zero-crossing detector, resonant converter, IGBT, and microcontroller are working as power converters. For turning the IGBT on and off, the level shifter has been used. It shifts the 5 V logic level signal to a 15 V logic signal. The pan detection algorithm also runs with a zero-crossing direct interrupt. Pan-on detection is executed every two seconds while the system is idle. A minimum detectable area on the top of the induction cooker is defined for pan detection. In order to prevent the cooker from causing damage, a fan is used. This fan is always on if the IGBT temperature is higher than 55 °C. An optocoupler is used with the fan for cooling purposes.

A control circuit is designed using Samsung's microcontroller S3F84B8 to control the power level and temperature of the cooker. According to the user instructions, the power level of the cooker can be changed by the circuit. The current state of the power level is displayed on the cooker's LCD. Figure 9 shows the working procedure of the control circuit. After turning on the induction cooker, the system sets up its ports with the necessary logic level. This time, the system remains at a low power level. The gate signal of the IGBT is based on the duty cycle. The induction coil charges during the period of Ton, and at the time of Toff, the IGBT is turned off. At this time, the circuit resonates, and with the help of a zero-crossing detector, the end of the cycle is determined. The power level of the cooker is changed by changing the ton. Hardware switches can be used to shut off the system.

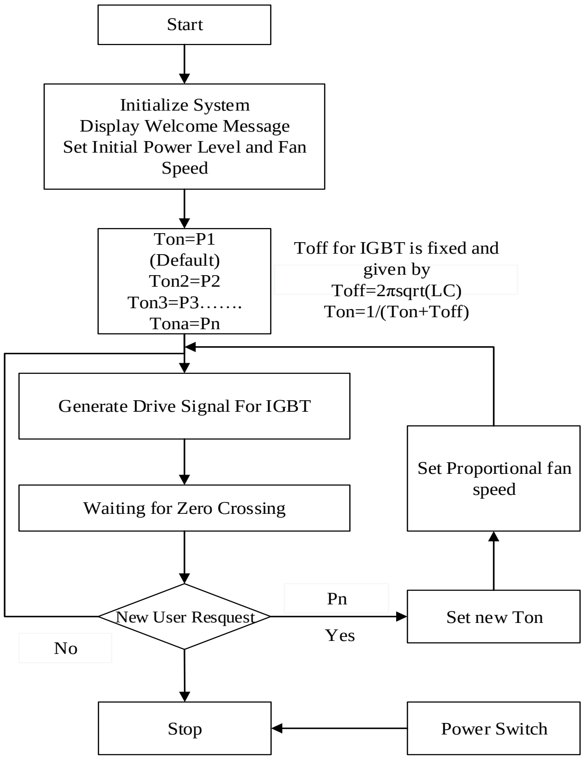


Figure 9. Flowchart of the induction cooker control system

The proposed induction cooker can be operated by solar energy. Both the solar panel and storage can be used to supply the power of the cooker. As the induction cooker requires stable power to operate, it is not feasible to connect solar panels directly. Instead, solar panel can be used to charge the battery which can operate the cooker. Moreover, using the batteries one can run the cooker even at night.

3.2. Development of the cooker control circuit

Figure 10 shows the control circuit diagram of the proposed solar-powered DC induction cooker. When constructing the circuit for 48 V DC, high-value components are removed and replaced with the resistors shown in the figure which are used as a voltage divider to deliver the required voltage to the microcontroller. Due to these resistors, if 48 V DC is given rather than 220 V AC, the microcontroller gets voltage in the microvolt range, that is extremely difficult to perceive. For the microcontroller to accurately sense the voltage, the suggested solution substitutes resistors with tiny values. In this study, the traditional circuit's architecture is altered to enable the induction cooker to run on DC electricity. Since the voltage source in the proposed circuit is DC, a rectifier is not necessary, hence it has been eliminated. S3F84B8 is the microcontroller that is employed in the suggested design which is manufactured by Samsung. The suggested induction cooker is powered by either a 48 V DC battery or a solar PV panel. Figure 11 depicts the PCB layout of control circuit for the recommended induction cooker.

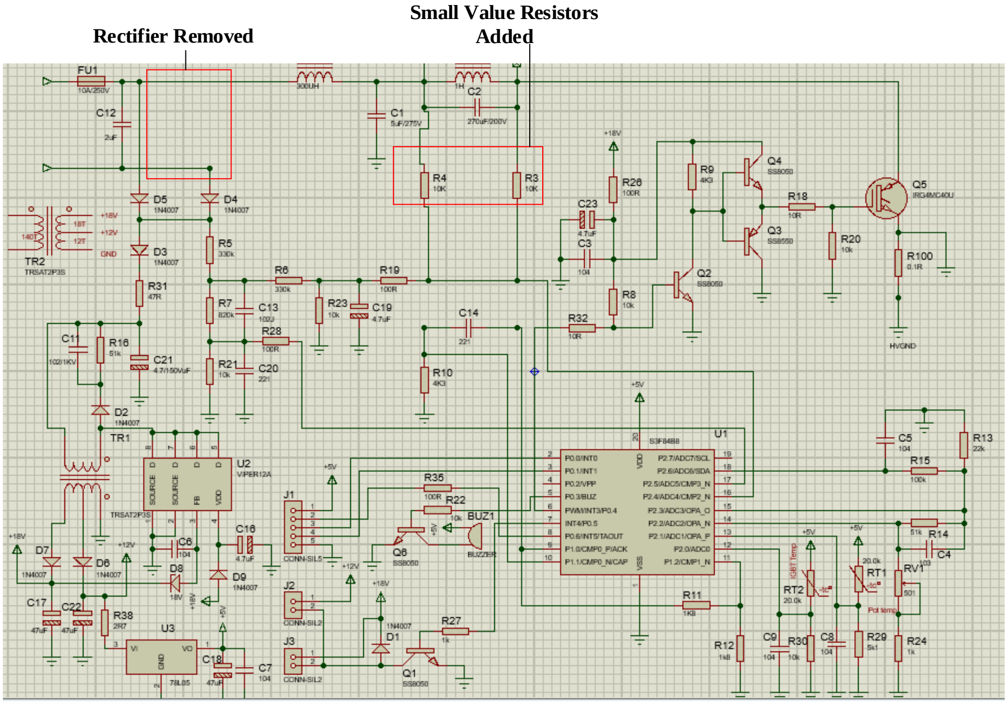


Figure 10. Control circuit diagram of proposed induction cooker

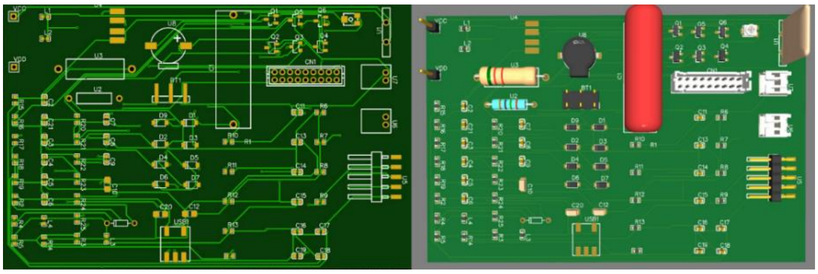


Figure 11. PCB layout of the induction cooker's controller circuit

The experimental setup of the proposed induction cooker is shown in Figure 12. Maintaining a power consumption near 300 W was the main design objective for the system. Since the heating element's power is kept so low, even minute quantities of heat loss might cause the design to malfunction. It takes more than just designing the stove with enough insulation to cook food at such a low wattage. Insulation for the pan and stove was also part of the original concept. Choosing high-quality insulation at a reasonable price proved to be the most difficult aspect of the design. Without the pans, the cooker costs about USD 25 in total. It is anticipated that the cost would drop to about USD 16 with mass production. The parameters of the developed induction cooker are presented in Table 1. The performance of the proposed induction cooker is presented in the result and analysis section.

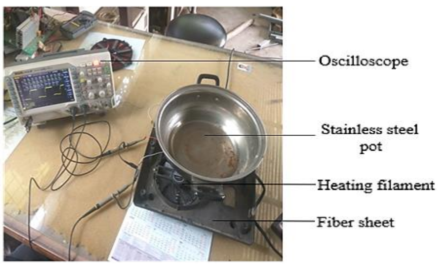


Figure 12. Proposed induction cooker's experimental setup

Table 1. Parameter used for the experiment

Parameters	Values	Units
Specific heat capacity of water (C_w)	4200	J/Kg-k
Weight of water (m_w)	01	Kg
Input power (P_{in})	391	Watt
Initial temperature (T_i)	32	°C
Final temperature (T_f)=70 °C	71	°C
Change of temperature (dT)	39	°C
Time spent (t)	450	second

4. RESULT AND ANALYSIS

4.1. Performance analysis of the induction cooker at different power levels for different number of coil turn

After designing the cooker, it has been powered by a 48-volt DC voltage. The voltage, current, and power of the cooker have been recorded for different power levels, as shown in Table 2. While the number of turns of the coil was being reduced, the maximum power (at level 5) was increasing. From Table 3, it is seen that maximum power increases gradually from 198 W (at turn no. 24) to 266 W (at turn no. 21) due to the reduction of coil turn as well as the length of the coil.

Table 2. Current, voltage, and power at different levels of power

Level of power	Current (A)	Voltage (V)	Power (W)
1	0.79	49.28	35
2	1.49	49.1	73.31
3	2.27	48.76	112.2
4	3.38	48.4	164.1
5	4.6	48.03	198

Table 3. Powers at coil turn no. 21 to 24 at different power levels

Level of power	Turn no. 24 power (W)	Turn no. 23 power (W)	Turn no. 22 power (W)	Turn no. 21 power (W)
1	35	38	40	50
2	73.31	79.7	82	85
3	112.2	127.2	130.4	109.2
4	164.1	180.3	186.5	177.1
5	198	243.6	251.1	266

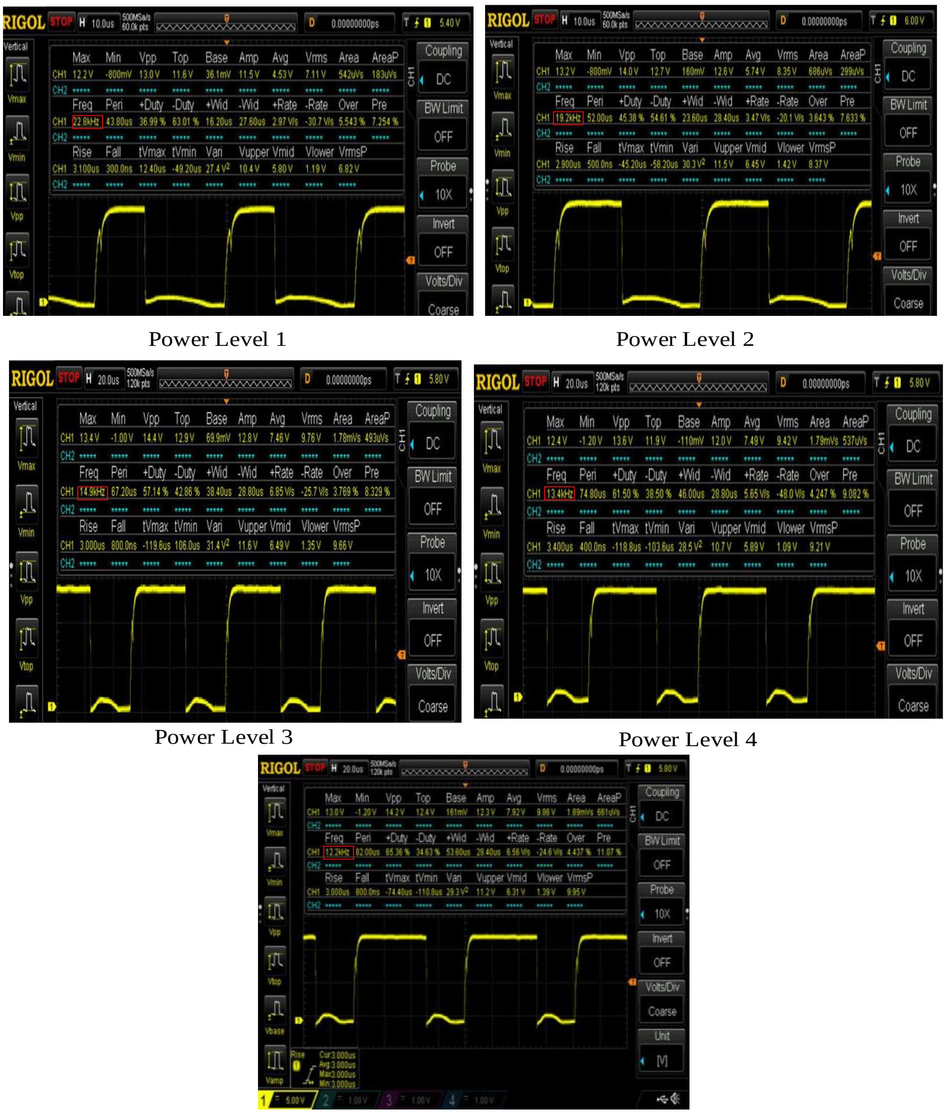
Table 4 shows the power of the induction cooker at different levels for turn 19 and 20 which is below optimum coil turn no. 21. In power level 1, it is seen that for turn 19, the power is 67.7 W, and in power level 5, this power is increased to 391.1 W. For turn 20, the power is less than the power for coil turns no. 19 at different power levels. For efficient cooking, temperatures should be controlled, and these power levels help to control the temperature by changing the power (W). The powers obtained at different power levels are satisfactory for cooking purposes in a small family.

Table 4. Powers at coil turn no. 19 and 20 at different power levels

Level of power	Turn no. 20 power (W)	Turn no. 19 power (W)
1	46	67.7
2	95.2	138.6
3	162	220.3
4	300	300
5	320	391.1

4.2. Performance analysis of the proposed induction cooker at optimum coil turn number

Even though it is found that at different power levels with different number of coils turns the performance of the proposed induction cooker is satisfactory, however, the issue of noise still needs to be fixed to get better output from the proposed induction cooker. To minimize the noise, IGBT gate voltages at various power levels for different number of coil turns are observed. The IGBT gate voltages at various power levels are shown in Figure 13 for different frequencies at turn no. 24. It is seen from the figure that frequency (shown in the red box in Figure 13) decreases with an increase in power level. Though the human hearing range lies between 20 Hz and 20 kHz, the actual hearing threshold is almost 16 kHz [30]. It means that humans can normally hear sounds with a frequency less than 16 kHz. In Figure 13, the frequency is above 16 kHz during power levels 1 and 2. After increasing the power further, the frequency becomes less than 16 kHz, and noise is produced from the cooker. The intensity of the noise increases continuously with the increase in power level. The frequencies are 14.9 kHz, 13.4 kHz, and 12.2 kHz for power levels 3, 4, and 5, respectively, as shown in Figure 13.



Power Level 1 Power Level 2

Power Level 3 Power Level 4

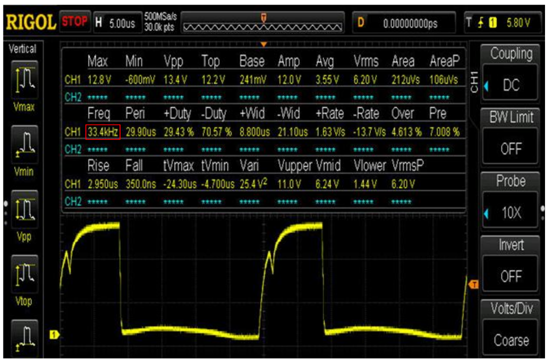
Power Level 5

Figure 13. Gate voltage waveforms at different power levels at coil turn no. 24

In Figure 14, the IGBT gate voltages at various power levels for turn no. 21 are depicted. It is seen from Figure 14 that the lowest frequency at power level 5 is 19.2 kHz. At 21 turns of the coil, no noise is heard. It can be said that the problem of noise generation has been solved by reducing the coil turn to 21 as the frequency is above 16 kHz.

4.3. Cooking performance evaluation

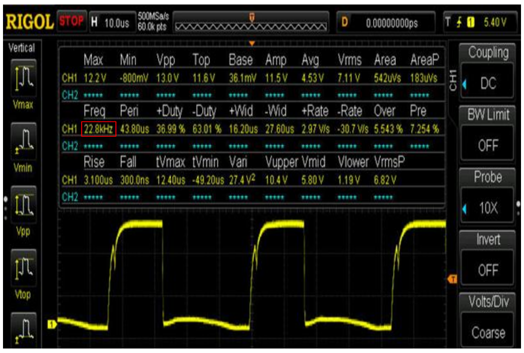
From Figure 15, it is seen that the proposed induction cooker has taken more time than a gas stove while cooking different food items. The difference in cooking time is not that huge. As the proposed induction cooker is much more beneficial than the gas stove, this time difference can be ignored. The food was cooked within a decent period and it can be used for a small family (4-5 person). The efficiency of the proposed cooker has been calculated. The input power has been measured with the help of a wattmeter, and the output power is calculated using the thermodynamic law. The system's output power is 364 watts. The total losses are 27 watts. This results in the system consuming 391 W at 364 W output. As a result, the induction cooker's efficiency is 93%.



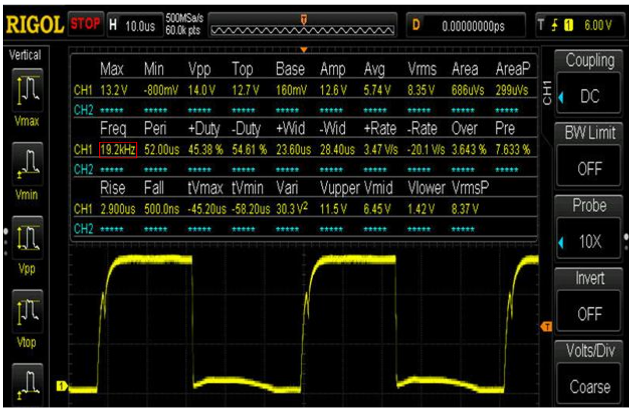
Power Level 1

Power Level 2

Power Level 3



Power Level 4



Power Level 5

Figure 14. Gate voltage waveforms at different power levels at coil turn no. 21

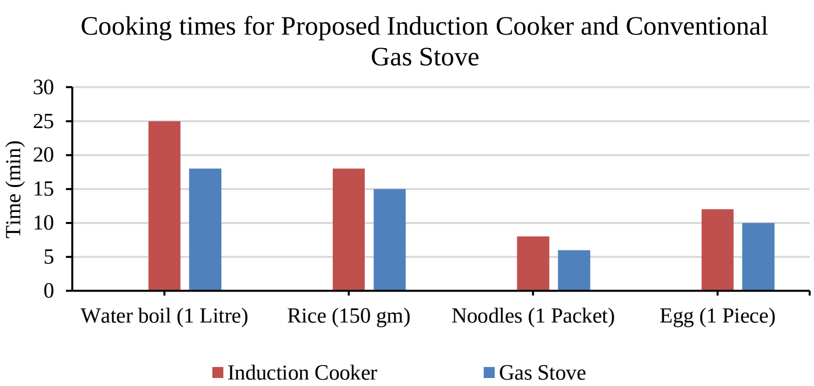


Figure 15. Cooking time comparison of proposed induction cooker and conventional gas stove

5. DISCUSSION, COMPARATIVE STUDY, LIMITATIONS AND RECOMMENDATIONS

In this study, a prototype of a solar-powered DC induction cooker was developed. The circuit of an existing 220 V, 2 kW induction cooker is modified to operate with DC voltage for the proposed induction cooker. After designing the cooker, two separate optimizations were conducted for its smooth run. The first stage reduced the turn of the coil from 24 to 21 to alleviate the noise production by the cooker. Again, the power of the induction cooker was optimized by reducing the turn of the coil to 19. The result shows that the output power increased from 198 W to 391 W because of the reduction of the coil turn. The switching frequency at different power levels was also monitored, and it can be demonstrated that there is reduced noise.

By employing the quasi-resonant converter topology, the induction cooker functions at high frequencies cutting over 20 kHz to avoid sound pollution and below 100 kHz as much as possible to reduce switching losses. The modified coil structure and resonant converter contribute to increased resonant frequency, reduced switching losses, and improved overall efficiency of the cooker. Experimental results verify the resonant converter's performance by modifying a conventional induction cooker's circuit and coil to show the enhanced efficiency of the suggested design.

In Bangladesh, a 500 Wp solar panel costs around USD 350, with a maximum extraction of 75% of power. With an interest rate of 12%, a 25-year life, and a 6% annual maintenance and operational cost, the cost will be (using discounted cash flow) 65.62 USD/year. When the daily insolation in Bangladesh is considered, the energy generated by the panel amounts to a total of 0.102 USD/kWh at an average insolation of 5 kWh/m^2. In the study, the monthly cost of electricity for cooking is 3.67 USD/month, which is smaller than non-metered double burner domestic gas users in Bangladesh, which stand at 7.28 USD/month [31]. In terms of the current cost of cooking fuel, this is a very appealing cost estimate.

Table 5 shows the difference between the proposed and existing induction cookers based on different features like efficiency, output power, and converter topology. Hardware implementation is not presented in [19], [20], but the proposed system provides a concrete and tangible way to demonstrate that the research can be replicated as well to evaluate the performance of the research in a realistic setting by implementing hardware. The proposed system uses DC power for precise control of the electromagnetic fields, which reduces the risk of overheating or other safety hazards. The output power is sufficient for the proposed system which is not in [18], [19]. The proposed system uses quasi-resonant converter topology instead of half bridge or full bridge inverter topology to reduce the switching losses and minimizes the voltage and current spikes, which in turn results in lower power losses as well as a lower level of harmonic distortion in the output waveform as compared to half bridge [16] or full bridge inverter [20] topologies. As a result, the proposed induction cooker reached an efficiency of 93%, which is higher than that of other existing induction cookers.

Table 5. Comparison between the proposed and existing induction cookers

References	Hardware implementation	PV powered	Output power	Converter topology	Efficiency (highest power level) (%)	Coil design
[16]	Yes	Yes	Sufficient	Half bridge	90	No
[18]	Yes	Yes	Insufficient	Half bridge	91.42	Yes
[19]	No	No	Insufficient	Quasi resonant	87	No
[17]	No	No	Sufficient	Full bridge	88.33	No
Proposed model	Yes	Yes	Sufficient	Quasi resonant	93	Yes

The proposed solution intends to design and build a solar-powered, low-cost, and highly efficient induction cooker that can be fueled directly by solar panels via a battery. Although the systems have numerous advantages, there are also limitations because the developers did not account for probable generational losses or equipment breakdowns. As a result, the findings of this study should be interpreted as approximations.

- The study ignores possible obstacles or hurdles to the broad use of e-cooking, such as infrastructural needs or cultural preferences.
- The prototype of the cooker is designed for use in rural area and it is not clear how well it would perform in other environments or under different conditions.
- A shorter lifespan for other parts including PV panels.

The lifetime and optimum performance of the PV panels and other components depend on routine maintenance and observation. The impediment to the broad adoption of e-cooking must be removed with initiatives that prioritize capacity building and infrastructure development. Furthermore, capacity-building initiatives can address issues with e-cooking equipment, long-term sustainability, and accessibility. By incorporating these solutions, the quasi-resonant topology based highly efficient solar-powered induction cooker can be adapted and optimized for use across diverse environments, ensuring its effectiveness and longevity in rural and other settings worldwide.

6. CONCLUSION

This study presents a solar-powered and highly efficient induction cooker that can be operated directly by solar panels through a battery. According to the study, the performance of the proposed induction cooker has been validated through experiments, and it is observed that the efficiency of the cooker reached 93%, which is better than existing induction cookers. The quasi-resonant converter topology contributed to increased resonant frequency to improve efficiency. Additionally, the power optimization and coil design effectively solved the issue of undesired noise generation when using the cooker on DC voltage, resulting in an efficient cooking experience. Due to the reduction of coil turn from 24 to 21 as well as the length of the coil, the maximum power increases gradually from 198 W to 266 W. The research also highlights the potential of solar-powered induction cookers as a low-cost and eco-friendly solution for cooking in developing countries, reducing reliance on fossil fuels.

In comparison to the other literature, the proposed cooker stands out for its high efficiency, cost-effectiveness, and capacity to work directly with solar power, making it a feasible choice for cooking. The primary technical obstacle of this study was preparing meals quickly enough at such low power. The cost analysis shows that integrating solar cookers with solar home systems can be cost-effective compared to usual cooking costs. Increased power capacity can enable households to use more equipment, potentially improving their quality of life.

A more sophisticated microcontroller can be used in future instead of the Samsung semiconductor microcontroller, to enhance the performance of the solar cooking system. With the use of intelligent controllers like fuzzy logic-based controllers or model-predictive controllers instead of PI controllers, the performance of the system circuit can be further improved. It would be interesting to investigate in the future how adaptive control algorithms might be used to enhance energy transfer efficiency for a variety of cooking jobs while accounting for differences in load characteristics.

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