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Solar Powered Induction Cooking System

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Abstract

Induction cooking is widely used nowadays due to its high efficiency and safety. Induction cooking is derived from the principle of electromagnetic induction by inducing eddy currents in the coil that get excited in the ferromagnetic material to cause heating [1]. In this research, solar energy is used as a source of power for the induction stove. This project aims to design and build a solar powered induction cook top supplemented by the mains power using half bridge topology and control the power output by varying operating frequency.

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Keywords: Induction cooking, solar powered, half bridge circuit, microcontroller, battery charging circuit.

1. Introduction

Solar energy is a good and clean source of energy, which can help the world in experiencing the dirty and short of non-renewable resources, such as coal, etc. Induction heating is widely used nowadays in domestic appliances because of it cleanness, high efficiency, safety, low cost advanced power semiconductors and high performance [2]. Induction heating is commonly used in industries for melting, hardening and brazing [3]. High efficiency comes

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with the idea that all the magnetic field created between the coil and the pan is at least 80% transferred to the coil [4]. The cooker presents the quick warming energy saving with high speed cooking with many temperature ranges [5]. Domestic and commercial cookers work in the same principle and the performance is identical. This research is based on the induction heating principle and implementation of portable induction cooker using renewable source of energy as the Primary source of supply, supplemented by the grid power using auto switching method. Induction heating is the process of heating electrically ferromagnetic (conductive) materials by a process called electromagnetic induction. One of the many applications of induction heating is cooking. Induction cooking is derived from the principle of magnetic induction by inducing eddy currents in the coil that get excited in the ferromagnetic material to cause heating [1]. This research is more about making the cooker a standalone, portable and smart in operation by switching between solar and mains automatically. This increases the efficiency of the system at the same time makes it a standalone. Also the high frequency harmonics from a direct current supply is converted to alternating current using half bridge inverter. The harmonics produced by the half bridge circuit is utilized to produce heat in the induction coil.

The FEM simulation model of conventional induction cooker is discussed in [6].This model focuses more on the two parts; namely wok and the coil. The modelled coil shows the even distribution of current in it. The overall simulation study conclude that magnetic field of the conventional cooker is uneven and localized which can lead to hot spot in the coil during operation and result in poor performance. The effect of the pan material in an induction cooker and the topologies for an induction converter circuit is discussed in [7]. The comparison of the boost converter (quasi resonant) and resonant converter (half bridge) is studied. Five pans were tested. The frequency increases with the decrease in current and power proportionally. It concludes that pushing switching frequencies higher will reduce the cost of the coil, resonant capacitor, and increase the efficiency of the cooker. The induction cooker as a working electric transformer that generate heat on the secondary due to loading of the equivalent resistant of the losses is discussed in [8] The paper discusses in detail all the parameters from the coil to how the current density differs with respect to the number of turns in the coil. The modes of switching “hard switching” are studied in details showing how the power electronic device behaves under stressful switching. It also looks at the losses when the switch is exposed to high voltage and current at the same time. Snubber circuits assist in voltage transients on the switch during switching. The simulations also support the theory in explanation. The control algorithm for both the topologies is discussed of which shows a slight difference between the two. The pan detection and circuit protection is presented in details in the flow chart. The practical discussion of the results corresponds with the simulations. The solar-based induction cook top is discussed in [9]. This paper discusses about the solar powered induction cooking system. Each stage from solar panel, control circuit, battery, inverter and cook top is presented in details. The microcontroller and the LCD (liquid crystal display) for cooking level indications and control. The aim of the paper together with its conclusion was to implement a solar-based system with the idea of looking at the feasibility and advantage of using solar rather than electric or gas supply. The study proved that the installation can be costly but after 5 years, the user will be saving a large amount of Rs 12000.

The analysis of an induction-heating device with half bridge resonant inverter is presented in [10]. The circuit analysis and simulations of the inverter shows the eight function models of the circuit structure. The phenomenon of the skin effect plays a role in the analysis of the circuit. The study also look at the two factors that resulted in the temperature of the coil i.e. loss during current flow in the coil and the heat produced by the pot during operation.
In summary, all the papers discuss about the principle of induction cooking using mains as a supply and only one that discusses about the working of the cooker using renewable energy as a source of energy. The cookers on market as the above focuses more on the pan material and on how it affect the performance in terms of heating the coil and producing more electric field. It also covers more deeply in the switching frequencies and on how changing the frequency can be done using power electronic switches. The protection also plays a vital role since the generated magnetic field can cause such high currents in the plate. The topology selection is very important as they all play different roles with respect to efficiency and cost effectiveness. The study on this research is a smart induction cooking system that works in a similar manner using the principle of magnetic fields induction to cause eddy current to flow in a ferromagnetic material resulting in heating. The study focuses also on the auto selection between two-power sources, namely solar power and mains AC power. The auto selection is to select any available source of power between the two. The cooker uses the batteries that is to be charged by both solar and mains but treating the solar as a priority always in order to promote the use of free energy when it available. The cooker also work with batteries alone of which makes it completely portable and being a standalone product that can work for about 4 hours without solar and the grid being present at the time. In this research, the simulation study is done for testing the heating levels at different frequencies. The practical implementation using solar and mains switching is also shown.

2. Design of the system

Induction heating is the process of heating electrically ferromagnetic (conductive) materials by a process called electromagnetic induction. The block diagram description of the research is shown in fig. 1. The design includes an induction coil which is supplied from solar panel and supplemented by the mains power using the Half-Bridge inverter Topology. The battery charging and power control unit to control the output power at varying operating frequency chosen by the cooking setting.

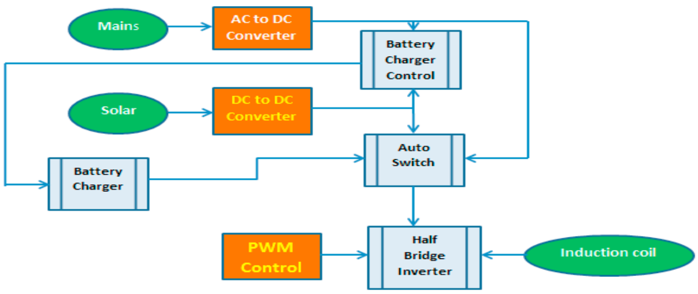


Figure 1: Block diagram of the system

2.1 *Mains*

The mains power gives alternating current from the grid. The grid voltage is converted to direct current supply via AC to DC converter. 230V 30A mains socket is used in both simulation and practical as it is a standard voltage.

2.2 *AC to DC Converter*

A simple AC to DC converter is used to convert the Mains input to DC for further conversion using boost converter to charge the battery. The simulation of the AC to DC converter is shown in fig. 2.

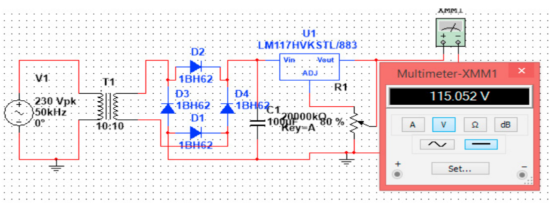


Figure 2: AC to DC converter

This converter makes it convenient for the batteries and the half bridge converter to work perfectly since the implementation needs only DC supply. A 230V mains AC voltage that is converted to 115V DC at 1200W power level. The other most important factor is to make it flexible in the range of frequencies for different power levels in the inverter section.

2.3 *Solar*

The solar is the primary source of supply for the cooker. Solar is made up of photovoltaic cells that converter solar energy into electrical energy in the form of direct current [11]. PV modules generate electricity from sun [12]. Due to the non-linear characteristics of PV system, the output power is not constant all the times throughout the day. In this design, batteries, DC-to-DC converter work together with PV systems to regulate the voltage of the PV systems. In this research, solar is the main source power for heating the induction coil and a 300W solar panel is used. This unit depends on the sun radiation to supply energy.

2.4 *DC to DC Converter*

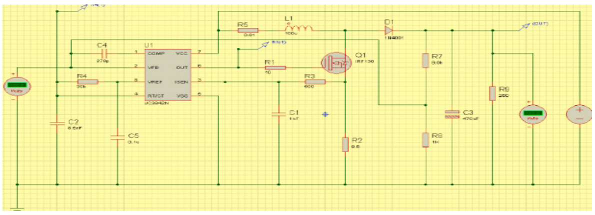


Figure 3: DC converter

The converter regulates the unregulated DC supply of the solar panel. The smooth DC supply is necessary for the charging unit to be regulated DC for charging purposes and to supply the inverter with smooth supply. 48VDC to 115VDC converter is used in the simulation while the practical power ratings for the 3 power levels were taken as 48VDC to 65VDC. The practical results shown were just a demo to investigate the possibilities of the implementation of the project. The simulation ratings are the one that will be used in the second phase of the project.

2.5 *Battery charging circuit*

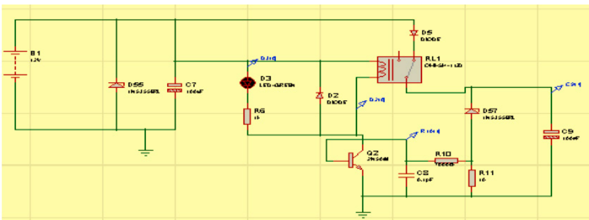


Figure 4: Battery charger

The battery storage is for energy accumulation that has electrochemical cells. Portable size rechargeable batteries are used in order to maintain load levelling [13]. The charger controller circuit controls the charging and the discharging of the battery level to extend the life of the battery.

2.6 *Auto Switching*

The auto select switch makes the auto selection of any available supply between solar and the grid and select whichever is sufficient by doing power demand analysis. The solar power is priority in the analysis for cheap selection and usage. In simulation, the auto switch is controlled by microcontroller program. The battery power level is compared to the switching state selected. If the battery level is sufficient the coil is powered from the battery. In this design, the auto switch is programed such that the source selection is done at the beginning of each cooking state. If the battery is not sufficient to supply the required power for the cooking state selected and for the duration calculated, the mains power will be selected and the battery will be charged either from solar or from mains.

2.7 ***Half bridge inverter***

The half bridge circuit is designed to convert the direct current from PV and mains to alternating current. The advantage of using half bridge is that the high frequency harmonics can be utilized to produce heat in the coil. The simulation design of half -bridge circuit with cooking coil is shown in fig. 5.

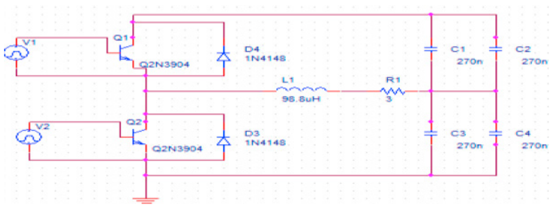


Figure 5: Half bridge inverter with the cooker coil

The half bridge circuit shown in fig. 5 is designed using two IGBTs to convert DC into AC. A 115VDC source is fed to the two IGBTs which is converted to an alternating current by sending opposite PWM signals to the switches. The amount of voltage created on the coil depends on the switching frequency and the pot material used. The power ranges from 200W to 1200W. L1 and R1 represent the cooker coil and the pot respectively. The four capacitors shown in fig. 5 is the resonant tank for continuation of supply during rising and falling of the sine wave. It also continues to give supply during 5% dead time of the switches in their state change. Voltage and frequency is controlled by pulse width modulation by changing duty ratio. The inverter makes it easier in the flexible range of frequencies. The frequency ranges from 10 KHz to 65 KHz for all different power levels.

2.8 ***Control circuit***

The control circuit is designed by using atmega-328 to process controls such as charging, monitoring, displaying and auto switching. The programming algorithm and flow chart for the control unit is shown in fig. 6. The circuit controls the power levels according to the user selection input. The LCDs are cable of displaying characters [14]. The Liquid crystal displays the power usage and the level selected by the user. It also indicates if the system is not getting any supply for the sources. Voltage and current sensing uses voltage divider and shunt resistor respectively.

The control circuit does all switching.

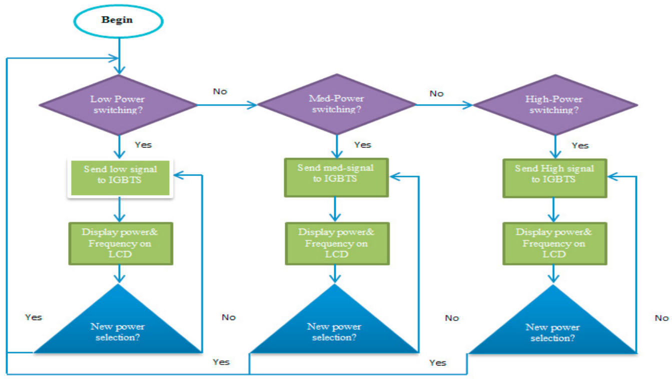


Figure 6: Power Control Flow chart

2.9 *Induction coil*

Induction cooking works in the principle of electromagnetic induction by heating the cooking vessel directly. The cooking vessel is a ferromagnetic material of which is capable of allowing Eddy currents to flow and produce heat on the material. Oscillating magnetic field induces current in the pot [15]. The cooker is faster and gives more than 80 % of efficiency during cooking [16].

3. Results and Analysis

3.1 Simulation results and analysis

The simulation results for selection of various power levels are shown in figures 7 to 14. The simulation design is tested using Proteus software. The results include pulse width modulation, current in the coil and the load voltage in the presence of the pot. The results differ with switching frequency. The frequency ranges from 10 KHz to 65 KHz.

PWM 62.5 kHz	Load current 6A	Load voltage 60V

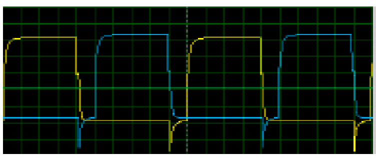
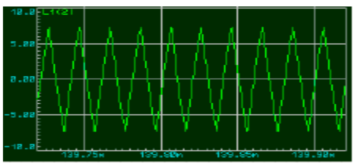
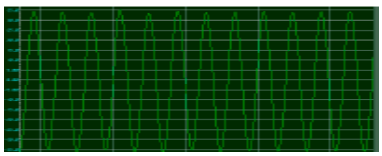

		

Figure 7: Power level one		
PWM 50 kHz	Load current 7.5A	Load voltage 60V

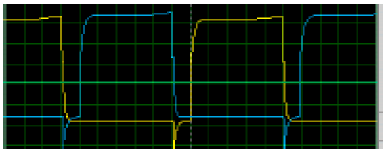
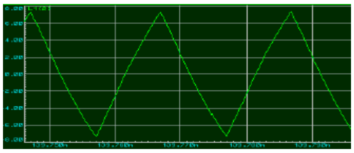
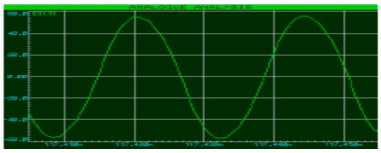
		

Figure 8: Power level two		
PWM 41.67 kHz	Load current 12A	Load voltage 60V

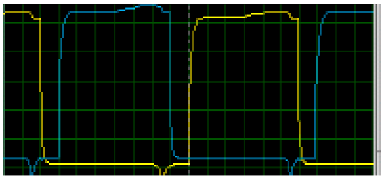
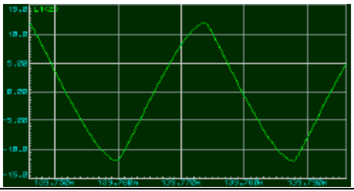
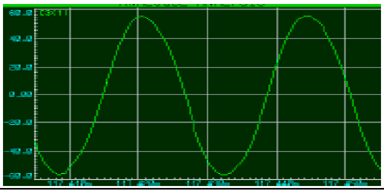
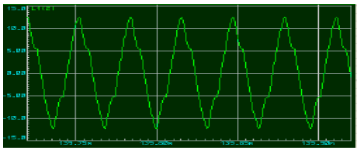
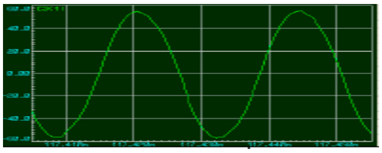

		

Figure 9: Power level three		
PWM 35.71 kHz	Load current 13A	Load voltage 60V
		
Figure 10: power level four		
PWM 27.78 kHz	Load current 15A	Load voltage 60V

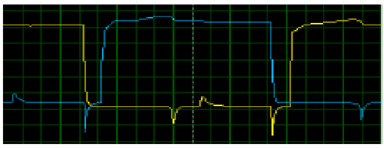
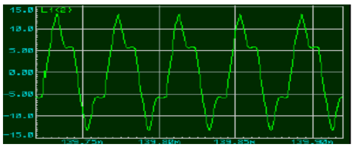
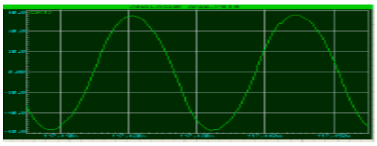

		

Figure 11: Power level five		
PWM 20 kHz	Load current 13A	Load voltage 60V

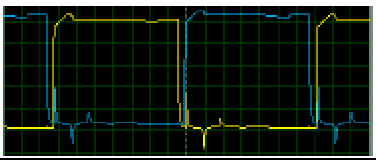
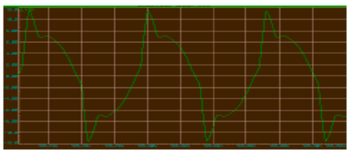
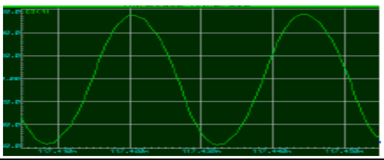

		

Figure 12: Power level six		
PWM 15.15 kHz	Load current 14A	Load voltage 65V

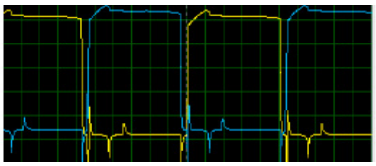
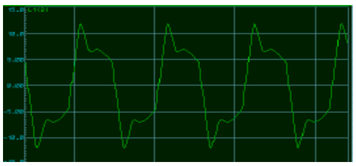
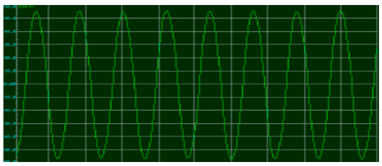

		

Figure 13: Power level seven		
PWM 10 kHz	Load current 12A	Load voltage 180V

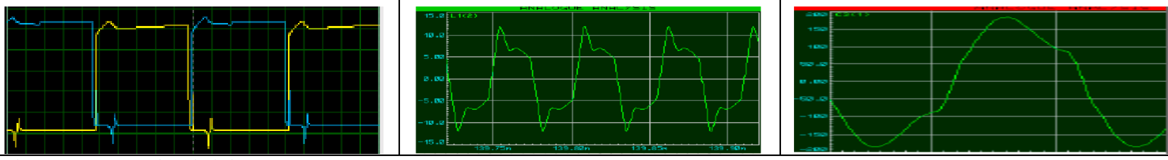


Figure 14: Power level eight

3.2 Practical cooking levels

The practical cooking setup using solar panel is shown in fig. 15. The solar input is connected to the system using a boost converter which supplies 65V, 4A to the half bridge circuit. Maximum power of the panel is 300W and it is impossible to draw the maximum power from the panel since the direction of the sun is changing each minute of the day.

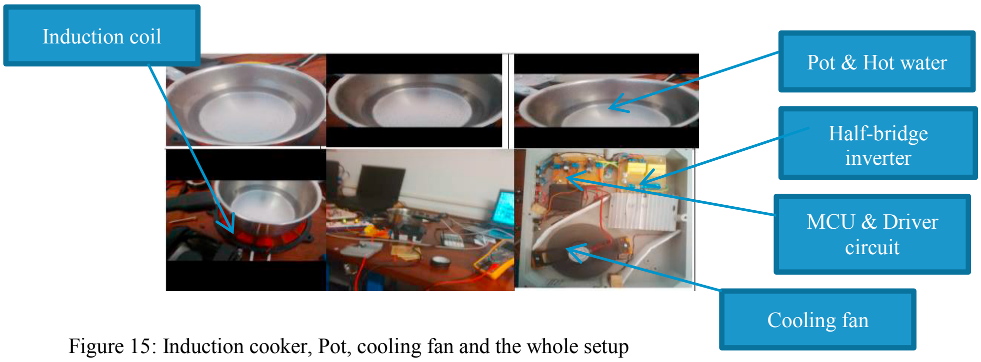


Figure 15: Induction cooker, Pot, cooling fan and the whole setup

The induction cooker was capable of heating a pot containing approximately 600ml of water to about 90°C. It observed from the practical implementation that the energy consumed to heat the water from 90°C to 100°C is higher than that used up to 90°C. This is because with an increase in temperature the faster the molecules are moving in the water. However, the speed increase is not proportional to temperature increase as evidenced by the physical manifestation of the molecule movements when water reaches boiling thusly to reach 100°C the input power would have to be drastically increased to adequately boil water. This is due to the latent heat required to convert a liquid to gas. The simulations shows eight different cooking levels in the form of load voltage, load current and pulse width modulation waveform with a dead time of 5 % to allow smooth switching. The variation of frequencies allows the cooker to have plenty of cooking levels. The above analysis indicates eight power levels but only three levels have been presented in this research paper. The output current supplied to the induction coil at various cooking levels are shown in fig. 16 to 18. The highest power is supplied to the coil at 30 KHz selection which is seen as 35 KHz in simulation. It can be observed that these current curves are similar to the simulation results.

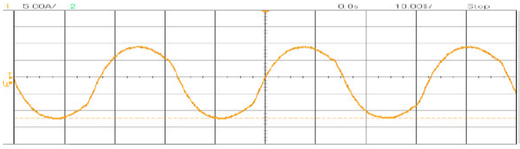


Figure 16: Load current at 30 KHz (5A per division)

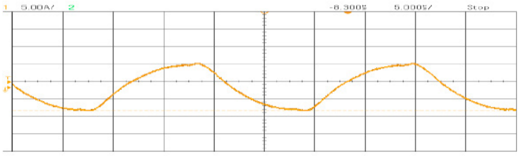


Figure 17: Load current at 45 KHz (5A per division)

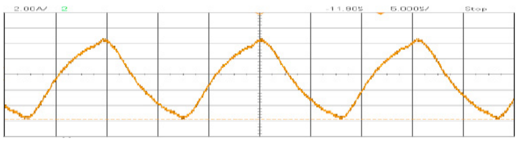


Figure 18: Load current at 65 KHz (2A per division)

It is clear that when the switching frequency is increased, output power decreases and the current waveform becomes less sinusoidal. This means that lower power operating frequencies are much less efficient than those are closer to the resonant frequency. It is because of this phenomenon that Dual-Mode Induction Heating Systems are being examined. A Dual-Mode Induction heater comprises of two Half Bridge inverters; a Class D Half Bridge is used in the high power output range, whereas a Class DE operates in the medium to low power output range. The mixture of these operating modes achieves high efficiency levels over a wider range of power output levels [17].

3.3 Analysis

The power levels at the input and output are listed in Table 1 according to the selection of the cooking level.

Table 1 Power levels at 30, 45 and 60 KHz

Power supplied (1)		Power supplied (1)		Power supplied (1)		Load output (1)		Load output (1)		Load output (1)	
V_{rms}	65 V	V_{rms}	65 V	V_{rms}	65 V	V_{rms}	29 V	V_{rms}	15.99 V	V_{rms}	9.97 V
I_{rms}	3.66 A	I_{rms}	1.39 A	I_{rms}	0.76 A	I_{rms}	7.5 A	I_{rms}	4.58 A	I_{rms}	2.83 A
Power	237.90W	Power	90.45W	Power	49.40W	Power	217.50W	Power	73.23 W	Power	28.22W

Table 1: Power levels at 30, 45 and 60 kHz

Table 1 shows the voltage and power at the input and output of the induction heater at 30 KHz, 45 KHz and 65 KHz respectively. The efficiency achieved is 91.42 %, 80.96 % and 57.12 % respectively. It can be seen from power level two (80.96 %) that there is a sharp drop in efficiency when compared to operation at 30 KHz (91.42 %). Although this level of efficiency is significantly less than the efficiency at 30 KHz, it is still commendable and superior to most other cooking methods. In a commercial domestic induction cooktop this would essentially be the "simmer" power level and is probably the most used in a domestic setting or at least used for the longest period. The efficiency at this frequency is 57.12 % (65 KHz).

4. Conclusion

In this paper solar powered induction cooking system is presented. The designed is a standalone product where by the batteries are charged from solar and grid. The grid charging is selected when the solar power is not available. The selection is done using auto switch. This makes the system environmental friendly as it is using clean free energy from sun. The cooker is also powered by the mains power to make it flexible in terms of power supplies in the case of one being not available. The simulation study and practical results are presented for various cooking levels. It can be seen that efficiency drops as the cooking level in increased.To improve the efficiency of the system at lower power levels, two half bridge inverter consisting of a class D and class DE half bridges can be used to operate at high power and low power output ranges.

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