# A New Approach to the Construction and Life cycle economic analysis of a Solar Powered Low Voltage Induction Cooking System.

Sujit Dhar *Department of Electrical and Electronics Engineering Neotia Institute of Technology Management and Science Kolkata, India*
*dhar.sujit@gmail.com*

Pradip Kumar Sadhu *Department of Electrical Engineering* : *Indian Institute of Technology (Indian School of Mines) Dhanbad, India*
*pradip_sadhu@yahoo.co.in*

Debabrata Roy *Department of Electrical Engineering Techno International Batanaga Kolkata, India debabrataroy1985@gmail.com*

*Soumya Das*
*Department of Electrical Engineering University Institute of Technology Burdwan University, India*soumya.sd1984@gmail.com

***Abstract*—Induction cooking is considered one of the foremost, efficient and cost-effective technologies involved in cooking. With this technology being properly utilized, 90% of the total energy used up in the process is transferred to the food which when compared to about nearly 40% for gas and 74% for traditional electric systems is comparatively better. This paper deals with the solar energy based induction cooking system where the primary source of power is solar power and also a comprehensive review of economic analysis, lifecycle analysis between normal induction stove and solar powered induction stove. The merits of this research work include designing, life cycle analysis and implementation of a solar power based induction cooking system. Here the full bridge converter is being used by the supply voltage to control the output power by changing the operating frequency.**

***Keywords—Induction Cooker, full bridge circuit, battery charging circuit, microcontroller, Life cycle economic analysis.***

## I. INTRODUCTION

Induction Heating is extensively utilized as of late in domestic appliance due to its cleanness, high effectiveness, assurance, low cost proper quality semiconductors and inordinate by and large execution [1- 2]. The cooker offers power sparing with high speed cooking with numerous temperature levels. This exploration depends on the percept of induction heating and execution of compact acceptance cooker, utilizing inexhaustible supply of intensity as the essential wellspring of supply, enhanced through the network vitality. Acceptance of induction cooking is gotten from the rule of electromagnetic enlistment by prompting swirl flows inside cooking object is made of ferromagnetic material to aid in the process of heating. In this examination the point is to make the cooker an independent, transportable, dazzling and brilliant working gadget through exchanging among sun oriented and mains naturally. This will make the unit a standalone unit whilst at the same time increase the performance of the system [3-5].The excessive frequency harmonics from an instantaneous present-day supply is converted to alternating contemporary the usage of current fed parallel bridge converter. The harmonics delivered by utilizing the bridge circuit is used to create heating inside the induction coil [6-8].The cooker likewise are embedded with batteries which can work for around 4 hours without sun powered and the network being available at the time. The reproduction examine is done at particular frequencies [9-10].

## II. PURPOSE OF THE STUDY

The purpose of the study is to present the economic benefits which can be derived from solar powered induction cookers. People prefer food which is cooked fast but with a very low fuel cost. Unlike a normal induction cooker, a solar powered induction cooker does not consume any electrical power from main supply. The initial investment for putting up a solar powered induction cooker maybe high but as solar energy is available in abundance; its fuel cost becomes nil. The solar energy is available in abundance; its generation cost becomes very less. In eastern region (West Bengal) of India, sufficient amount of solar energy is available almost 285 days out of 365 days in a year resulting to which the subject (solar induction cooker) is becoming a field of vast research and development.

## III. INDUCTION COOKING SYSTEM

In this type of cooking, a cooking vessel is heated up by electromagnetic induction, instead of by thermal conduction from a flame, or an electrical heating element. The process is rapid through which we can attain high temperature quickly. Three factors governing the operation of an induction stove are skin effect, electromagnetic induction and heat transfer. In this process the input a.c with constant frequency to be converted to d.c first. Then the d.c is fed to the high frequency inverter. The output of the inverter is a high frequency a.c and this high frequency a.c current passes through working coil. Now if any pot is placed on the flat surface of the induction stove the induced voltage will produce an eddy current which will start producing heat on the pot which will increase the temperature of the pot making the pot ready to cook.

### A. *Concept behind solar induction cooker*

The simulation model of solar induction cooker is being discussed later. The coil and its working are the two parts where the current version mainly focuses. The distribution of the current is even, which is in turning indicated by the modeled coil. The induction cooker resemblance with the heat generated on the secondary side due to the transformer action because of loading effect of the losses of equivalent resistant is discussed in. Here in the present paper it is discussed in detail about all the coil parameters and how the modern density of the coil is differentiating with respect to the various numbers of turns within the coil. "Hard switching" is the mode of switching in the coil, is studied in the information by showing the electronic power device behaving under worrying switching. Additionally it takes notice on the losses when the transfer is exposed to excessive current and voltage during the same time. During switching, the voltage transients are assisted by the snubber circuits at the transfer. The outcomes correspond with the simulations practically. The solar based induction cooker pinnacle is discussed in. The intention of the paper collectively is to enforce a solar energy based gadget with the high feasibility. Initially the installation cost will be high

but subsequently within a span of 5 years; the user can save up to Rs.12000.

## IV. BLOCK DIAGRAM AND EXPLAINING OF SOLAR INDUCTION COOKING SYSTEM

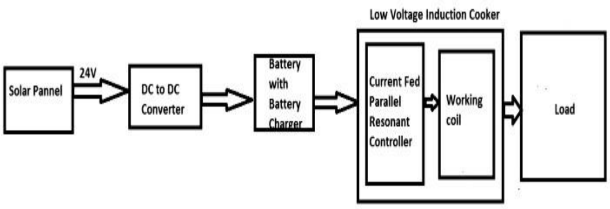



Fig.1. Basic block diagram of low voltage solar power induction cooker

The most important components of a solar power based induction cooking system is as follows: Solar PV array module, Maximum power point tracker (MPPT), Charge controller, Battery bank, Solar powers Induction cooker. In the block diagram (Fig.1) a 24V solar panel is placed on top of the roof with the help of a tracking circuit, which tracks the maximum lighting angle of the day depending on the time and intensity of sunlight throughout the day. This ensures the maximum amount of sunlight falling on the panel in order to get our desired output voltage. Solar panel is used to change the solar energy into electrical energy. The electrical energy available from the photovoltaic cells is converted to direct current. This almost steady d.c voltage is converted to pulsating d.c voltage with high ripple contain and fed into the battery through the battery charger unit. The fully charged battery output is fed to the low voltage side of the solar induction cooker, with the help of the current fed parallel resonant converter circuit and the coil in induction cooker will thus heat up the load. The supply voltage for the induction heater is 24V.Currently no commercial solar induction stoves or any of its literature is somewhat available in research oriented works regarding the induction stoves, which are powered from any d.c power source of such low voltage.

## V. DESIGN OF LOW VOLTAGESOLAR POWER BASED INDUCTION COOKING SYSTEM

### A. *Solar Pannels*

The solar panel is light weight, frameless and waterproof. These panels consist of solar cells which are much more efficient than the conventional solar panels. They are even effective in low intensity of light. During daytime, PV would be the primary power generator. Each PV module (panel) is rated in accordance with its d.c output power under standard conditions, and typical specification ranges is 300 watts. Fig.2 shows the monthly basis (Jan 2019-Dec 2019) solar radiation chart of the working place (West Bengal, Kolkata, India).

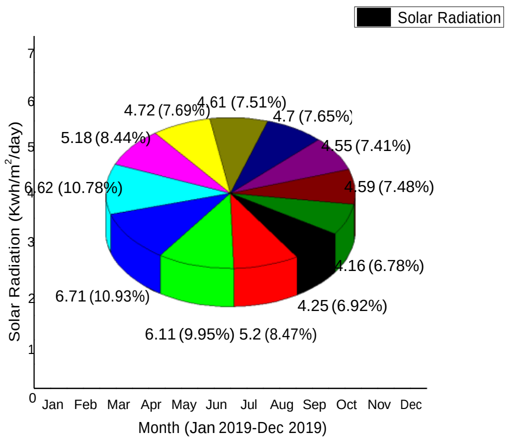



Fig.2. Monthly basis solar Radiation pie chart

### B. *Calculation for number of solar panels*

Based on the solar radiation on hourly basis the power generated by the panel can be calculated by the following method: $W_{dc} = \eta_{pv} \times I_{irra} \times A$ ·········.(1)

where, $W_{dc}$= power generated by the panels in watt;

A = area of cross section of the panels in m;

$I_{irra}$ = **i**ncident solar radiation falling on the panel;

$\eta_{pv}$ = **e**fficiency of the solar panels.

Total power rating ($N$ = 1)numbers of solar panel,

$$W_{Total} = N \times Wdc \quad .........(2)$$

Rating of each solar panel = 300W.

During sunny day, assume sun light available $T$= 6 hours. Therefore, maximum Energy generated /day,

$$E_{max} = T \times W_{Total} \quad ...............(3).$$

$E_{max}$ = maximum energy generated /day/panel = 1800 wh. Now considering the efficiency of the panel is $\eta$ = 80%. Therefore, the total energy obtain from panel,

$$E_{total} = \eta \times T \times W_{Total} \quad .......(4)$$

Therefore, the energy may be collected from the solar panel $E_{total}$ = 1440 Watts-hours.

Total energy consumed by the proposed solar Induction cooker $E_{Induction}$= 1200 Wh. Number of solar panel required,

$$N = \frac{E_{total}}{E_{Induction}} = 1.2 \approx 1 \quad \cdots\cdots(5)$$

The array yield is given by,

$$Y_{a\_yield}(\%) = \frac{W_{dc}}{W_{PV\ rated}} \quad ....(6)$$

The daily average final yield is $Y_{D\_a\_f\_y}(\%)$ the ratio of the generation output to the rated standard test condition (STC).

It is expressed as:

$$Y_{D\_a\_f\_y}(\%) = \frac{g_m}{g_{STC}} \quad ........(7)$$

Where, $g_m$ = Inclined global radiation in MJ/m2.

The variation of the actual irradiance from the reference is expressed as array capture losses. It can be expressed as:

$$LC = Y_{D\_a\_f\_y} - Y_{a\_yield} \quad ............(8)$$

TABLE 1 PV MODULE SPECIFICATIONS USED IN INDUCTION COOKER

| .Component | Specifications |
|---|---|
| Solar panel type | Flexible Polycrystalline Silicon. |
| Dimensions (L×W×D) | 1955×982× 36 mm3 |
| Weight | 20.5 Kg |
| Open circuit voltage ($V_{oc}$) | 45.58V |
| STC power Rating | 300W |
| Module peak Efficiency | 15.63% |
| Maximum Power Voltage ($V_{mp}$) | 37.05V |
| Maximum Power Current ($I_{mp}$) | 8.1A |
| Open circuit voltage ($V_{oc}$) | 45.58V |
| Short circuit current($I_{sc}$) | 8.58A |
| Operating temperature | −20℃ to＋80℃ |
| Normal Operating Cell Temperature (NOCT) | 44℃ |
| Temp. Coefficient Power | -0.41%/K |
| Manufacturer | Vikram Solar Pvt Ltd, India |
| Indian Market price | Rs 8558 Plus 10% GST |

The following panels designed for working in the harshest weather conditions and water-resistant feature for both. The item is easily available in local market because it is an Indian product and the approximate price of solar PV panel is Rs 8558 plus 10% GST. The price of solar module can be varied according to the availability in the Indian market

*Fig. 3. 24V, 300W PV module used in the experimental set up*

*C. Battery Charging Power Equations*

The maximum power that can be stored in a battery can be calculated as follows:

$$p_{battery\_max} = \frac{(1 - e^{\theta t})(\theta_{max} - q)}{T} \quad \cdots\cdots..(9)$$

Where, θ = The rate of flow of charge to the battery during peak hours;

$Q_{max}$ = Maximum charge that can be stored by the battery. The calculation of '$Q_{max}$' can be obtained as follows:

$$Pmax = \frac{(n \times I \times V)}{1000} \quad .\cdots\cdots.\ (10)$$

where, $n$ = The total number of batteries; $I$ = Maximum current; $V$ = Nominal voltage

Equations (9) and (10) are formed on the assumptions of losses of charge:

$$Ploss = \frac{MIN(P_{man} - P_{min})}{N} \quad \cdots..(11)$$

The function of the battery charger here is to limit the charging current and prevent overcharging of the battery by cutting-off the supply after the set state-of-charge (SOC) threshold is reached.

*D. Discharging power Equations of the battery*

It's the ability of the battery to discharge the power stored by it to some load. This is calculated as follows:

$$P_{dmax} = nd\left(P_{max}, P_m\right)............(12)$$

The calculation of the capacity of a lead-acid battery in terms of the rate at which it is discharged can be expressed by Peukert's Law [11].

$$C_{capacity} = T_{discharge}(I_{dischargr})^{K_{con}} \quad .........(13)$$

Where, $C_{capacity}$ is the capacity (one ampere discharge rate) in Ah; $I_{discharge}$ is the discharge current in A; $K_{con}$ is the Peukert's constant; and $T_{discharge}$ is the time of discharge in hours. In this design, two batteries are used, each with the operating voltage of 24V and charges capacity of 150 Ah. When two batteries are combined, they are capable of producing electric power without charging for about four hours.

TABLE 2 Battery Specifications Used in Solar Induction Cooker

| Parameters | Specifications |
|---|---|
| Operating voltage, Stored Energy of a completely charged battery | 24 V, 150 Ah, 3.84kWh. |
| Continuous Disc. Current | 12.0 A |
| Charging Time | 8 ~ 10 hour |
| Weight | 28.48kg |
| Battery Material | Lead acid |
| Lifetime | 6-8 years. |
| Manufacturer | Exide India Ltd. |
| Dimension | 500×240×220nn3 |
| Indian Market price | Rs 10000 Plus GST Charge. |

### E. Battery and charging method.

In this design a couple of batteries, each of 24V and 150Ah capacity forming 24V and 300Ah capacity. The battery is partially charged by solar power. During the monsoon season or when charged from the power grid, a separate charger is used for this purpose. The boost converter is used to charge the battery by using the PWM technique. Half bridge series resonant converter is used to convert stored d.c energy to a.c energy of 25 kHz frequency by grid power every day from 6 pm to 2 am (8 hours). This generates 4 hours of battery output (approximately) at night without charging. TABLE 3 gives the technical specification of a battery charger.

TABLE 3 Specifications of a Battery Charger.

| Characteristics | Values |
|---|---|
| Charging Voltage | 12/24V, (47-63)Hz |
| Universal Input | 90-260Va.c |
| Charging Current | 5.5-7.5Amps |
| Weight | 2.2 Kg |
| Charger Dimension | 230mm × 160mm ×100mm |
| Charging Time | 8 ~ 10 hour |

The battery is charging at home through normal 15/32A three pin plugs, single phase (90-260V, 50Hz) a.c supply with trickle charging facility. The approximate cost of the battery charging unit in Indian market is around Rs 3000/- (excluding 10% GST) and the average lifetime of the charger is around 4-6 years.

### F. Flot

The float stage is where the charge voltage is reduced to around 2.25V per cell, which is around (27-29) $V_{d.c}$ and held constant, while the current is reduced to less than 1% of battery capacity. This mode can be used to maintain a fully charged battery pack indefinitely. Some chargers shut off instead of maintaining a float voltage, and monitor the batteries, initiating a charge cycle if necessary. This type of combined chargers is used in charging of the battery system. The utilization of float cum boost charger is as follows: This system is activated when the battery charging is fully charged up at this point it is pointless to charge the battery so in this case the float will bypass the battery charging and will provide direct d.c to the induction coil. In this system, the d.c generated from the solar panel which passes through the d.c to d.c converter then through the charger at this point seeing the battery is fully charged the float will bypass the system resulting of direct supply of d.c from the charger itself.

### G. Boost Converter

The use of boost system is to prevent quick discharge of the battery. Boost converter comes in use in such a case if low voltage gets an input to charger the boost converter converts the low input to a desirable high voltage output required by the battery specification. It is in this way boost prevents deep-discharge. So, a combination of this result to float cum boost where one prevents unnecessary charging while other prevents deep discharging of the battery.

### H. Solar Induction Cooker

In this approach addresses by the design of a induction stove which is of quite high efficiency (more than87%) powered by a d.c source of 24V. A 24V d.c power supply is one of the most common solar installations output, and mainly only one of few output voltages that are standardized for photovoltaic panels and battery. This in turn makes it perfect for direct integration with a roof top solar-based micro-grid or solar installation.

### I. Converter Circuit Topology

In this proposed design, the most suitable converter is current-fed parallel resonant converter [12] used in industrial heating applications, but there is no prior information available about the topologies used in induction cooking. Fig.4 shows the conceptual schematic of a current-fed parallel resonant converter. This type of electrical power converter has within itself a network of capacitors and inductors called resonant tank and also these are resonated and then they are tuned to a specific frequency. Appropriate frequency should be opted depending on the skin-depth requirement and work piece geometry in regard with each application. Among the large number of topologies have been developed in this particular area current-fed and voltage-fed inverters are the most common used [13]. The output power for current source resonant inverter can be controlled only by using phase-controlled rectifier and also by adjusting the d.c- link. A transformer is used for matching load impedance in the conventional current source resonant inverter while high voltage spike and increases on the voltage stress on switches are produced by leakage inductances. And in order for this problem to be solved, the inverter must work with leading power factor load. To decrease the switch's current, more number of legs can be paralleled to the inverter, so that the total efficiency can improved significantly and also the transformer can be removed.

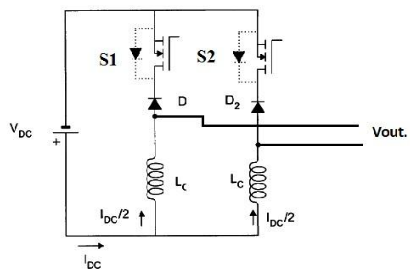



Fig. 4. operating circuit topology for Current-fed parallel resonant converter

### J. Induction coil

Fig.5 shows the construction and top view of the induction coil. The metallic strips with huge thickness are used to heat the utensils. With a number of new structures being evolved lately, transverse flux induction heating (TFIH) is doubtlessly very promising and appealing.

Fig. 5. Induction Coil in the proposed design [14].

Journeying wave induction heating (TWIH), as one of the multiphase induction heating systems, has specific features which lead them to appealing for utility to induction cooking system. The main advantages and the precise traits of TFIH and TWIH systems consisting of the effect of slots on prec- ipitated strength distributions has been studied. Throughout the entire cooking process efficiency of the induction heater is almost 83%.

### K. *Impact of Pan Resistance*

The pan resistance ($R_{eq}$) of the utensils regulates maximum heat generation. To get maximum power, practically pan resistance of utensils needs to be changed. With the change of load power, the heating effect will be maximum. The maximum power is achieved by changing the equivalent resistance ($R_{eq}$) so as to obtain maximum heating effect. This equivalent resistance is the summation of internal resistance of working coil (R1) and the resistance of cooking pan (R2) which is referred to primary side.

That is: $Req = R1 + R2$ ……..…..(14),

Where, R2 is the key regulating parameter of the $R_{eq}$ and which is variable with the change of cooking pan.

### L. *Operating Frequency*

The operating frequency of the design is 45 kHz, which is more or less double the switching frequency of the commercial designs. Also, the presented design has the chances to easily rise up to around 100 kHz and even more. Therefore, the best choice is the IC IRFP4310P of all the 4 switching devices and the specifications are 100V N-channel MOSFETs with 6mOhmRds(on) and 170 nC total gate charge. Lower device stresses due to this low voltage current-fed parallel resonant converter (ZVS) which allows faster device switching than conventional designs. The biggest advantage of the design is that the resonant current energizes entirely the resonant tank. The power electronics device only needs to carry the current actually delivered to the load. 1kW of heating is required for a 24V source for the maximum load current to be 40A.

## VI. BLOCK DIAGRAM AND EXPLAINING OF SOLAR INDUCTION COOKING SYSTEM

Fig 6 shows the basic block diagram of the grid charging system. Generally, the battery bank of the solar cooker is partially charged by solar module during sunny day but it is fully charged by normal single phase a.c supply during night/evening time and the approximate time taken for battery charging is (6-8) hours.

### A. *Supply voltage*

The supply main gives a.c during bad weather when there is an inadequate supply of sun light and the rating of supply mains socket is 230V, 65A.

### B. *A.C to D.C Converter*

The output of the converter is fed into d.c to d.c converter through 24V auto selection switch. The firing angle of the converter is controlled by microcontroller. The main function of d.c to d.c converter is to convert the d.c voltage into pulsating and controllable d.c. A booster converter unit is used to boost the charging voltage into nearly 30V of the battery charger.

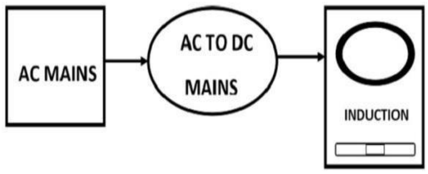



Fig.6: Block-diagram of charging system

## VII. BLOCK DIAGRAM OF THE WHOLE SYSTEM

The proposed structure centers additionally around the auto-choice in middle of the two-control sources, to be specific sun based power and mains grid control. The capacity of auto choice is to choose any accessible wellspring of intensity between any of the two. The cooker uses the batteries that will be charged by both solar based and mains yet treating the sun based as a priority so as to advance the utilization of free vitality when it accessible.

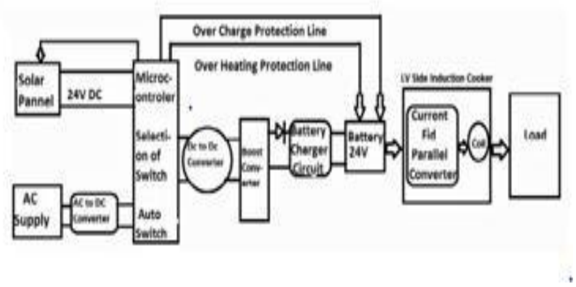



Fig.7: Block diagram of the whole system

Block diagram of the entire solar panel cum main line connection system is to get the d.c voltage to charge the battery and then supply the power to the solar induction cooker subsystem used in this research work is shown in Fig.7.The proposed low voltage d.c induction cooking system consists of several components out of which current-fed parallel resonant converter, Zero crossing detector, and IGBT along with arduino microcontroller (ATmega328) are used to implement the power converter.

### *A. Explanation of block diagram*

In this block diagram they are two sections as we see in the diagram first section is for the solar panel part where the d.c current is generated. The other second section has the source from the main supply of 230V which will be on use when there is a lack of d.c supply from the solar panel in case of climatic abnormality. Now let us talk on how different section will function.

First section : in this section solar panel is connected, where a low voltage d.c is generated which is fed to a microcontroller connected with auto switch which can be used to switch over when a microcontroller senses that there is very low d.c generate from the panel (a value is set with a microcontroller for switch over) so the voltage passes to a d.c to d.c converter for improving the voltage of the d.c as required for the battery then it is passed through a boost converter to prevent deep discharge which is feed to the charger which will charge the battery from this source we will connect our induction cooker which hence fourth will heat up the load placed above the cooker. Second section: Mains is considered for the supply. This condition is only used when there is very low voltage generated from the solar panel. Mains current is fed to a.c to d.c converter. The switch over is done with the help of auto switch. Then to d.c to d.c converter and rest of the process will follow as described in first section.

## VIII. OPERATION OF THE SOLAR POWER BASED INDUCTION COOKING SYSTEM

### *A. Auto Switch Control*

Microcontroller, miscellaneous I/O and signal conditioning components are the main control circuitry of the auto switch control device. The software based auto control broadband is the cause for the digital driving of the switches. Depending on the power demand analysis, availability and the efficiency at that particular moment, the auto select switches helps in the auto selection between solar and the grid. In this analysis, the solar power is the major priority for its economic feasibility, availability and widespread usage. The power levels of the batteries are compared before the switching state selection. In this plan, the auto switching circuits are modified in such a way along these lines that the wellspring of intensity is chosen before each cooking state. On the off chance that the sun based board isn't adequate to supply the required power for the cooking state chosen and for the determined amount of time, the mains power will be chosen and the battery will be charged either from sunlight based or from the mains consequently. Another main function of microcontroller is to provide protection for overheating and overcharging.

### *B. Auto Switching*

Based on the power demand analysis, availability and the efficiency at that particular moment, the auto select switches helps in the auto selection between solar and the grid. For economic feasibility, inexpensive usage and widespread usage, the solar power is the major priority of this analysis. The power level of the batteries is compared before the selection of switching state. If the power and voltage level of the battery is sufficient the induction cooker is powered from the battery. In this new design, the software based auto switch is programmed in such a way that before each cooking state the source of power is selected. The mains power will have to be selected and the battery will have to be charged automatically from the solar or from the mains only if the solar panel is not sufficient or in a state to supply the required power for the cooking state selected and also for the duration calculated.

***Operation:*** A negative going ramp but a positive going ramp may also use. The ramp voltage value is continuously compared with the solar charging battery voltage. At the instant the value of is equal to that of battery voltage a coincidence circuit, called input comparator, generates a pulse which opens a gate. Therefore, a logic high input signal will come to auto switch and solar charging circuit is connected to induction cooking equal to that of battery voltage a coincidence circuit, called input comparator, generates a pulse which opens a gate system. Initially the battery of the solar system is fully charged but after some time the battery will discharge to certain value called reference value. The ramp voltage slope is continuing to decrease till it reaches reference level. At this instant another comparator called reference comparator generates a pulse. This pulse comes to auto switch and disconnects the battery of the solar circuit. In this time, the induction cooking system operates through main supply (220 Volt, 50 Hz). Battery is continuously charging through solar panel, again charge is developed and induction cooker is connected to solar circuit automatically through auto switch. This is a continuous process; a huge amount of power will be saved when the cooker is connected to a solar system. FPGA based technology is popular now a days, but in this proposed research, production cost is one of the prime factors, therefore to reduce the production cost, FPGA based circuit are not used.

### *C. Sensor, Relay and Flowchart Diagram.*

In the Fig.8 represent a simple logic control operation for controlling of relay with using microcontroller. In this an input line voltage is sent though attenuator and other is sent to the relay.

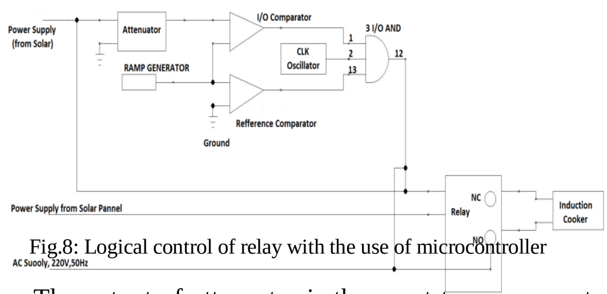



Fig.8: Logical control of relay with the use of microcontroller

The output of attenuator is then sent to a comparator with one is feed with a ramp generator. With the comparator of set voltage logic is generator which will be 1 or 0. This generated output is set as an input for three input AND gate with other input is feed with a clock oscillator and other input is feed from the reference comparator which also has a input from ramp generator. The logic 1 or 0 generated from the 3 input AND gate is set to the relay which will determine the relay to stay close or open. Fig.9 shows the connection diagram of sensor, relay and microcontroller.

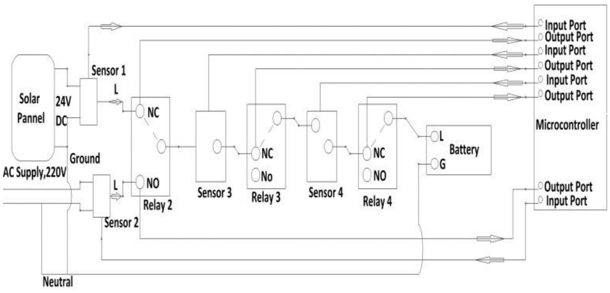
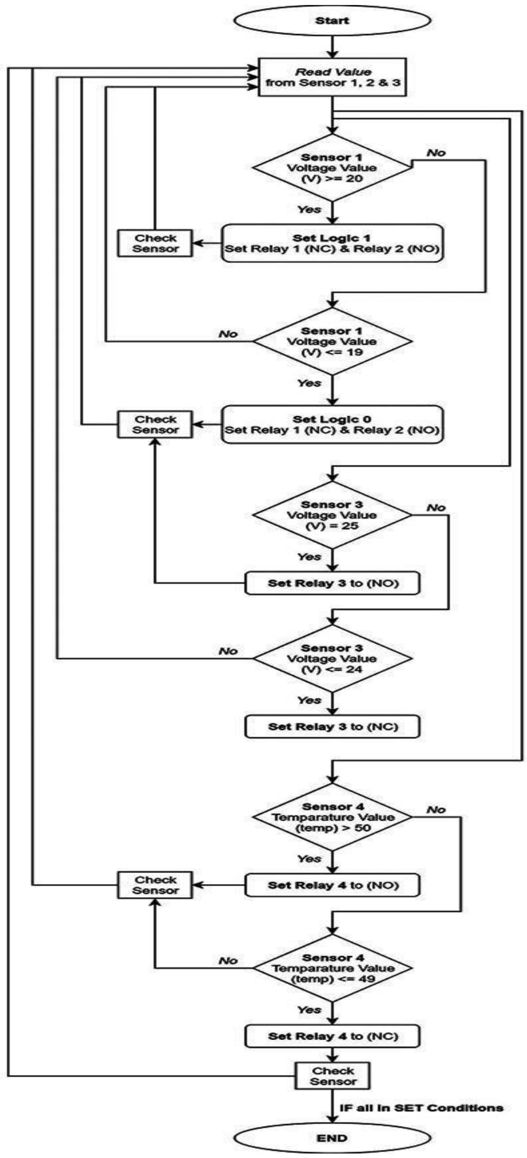



Fig.9: Sensor, Relay, and Microcontroller connection diagram.

*D. Flowchart of the System Operation*




Sensor 1: for observing P.V. generation;
Sensor 2: for observing mains line;
Sensor 3: for observing over load voltage,
Sensor 4: for observing temperature.
Relay 1: NC (Normally closed);
Relay 2: NO (Normally open);
Relay 3: NC (Normally closed);
Relay 4: NC (Normally closed).

Relay 1 connected to solar panel;. Relay 2 connected to main line; Logic 1: Solar panel and relay 1 are connected to auto switch; Logic 0: solar panel is disconnected but connected to main line and relay 2 is connected to auto switch.

Flow chart 1 represents the software program that is uploaded to the microcontroller for controlling the sensors and then relays to operate the function of power system in order to charge the battery.

*E. Sensor, Relay and Microcontroller Control circuit*

In the fig 7, it is seen that there are 4 types of sensors used as well as 4 relays used. Sensor 1 and 2 are used for checking the voltage change from both the source, whereas relay 1 and 2 are used to change-over supply distribution when solar power production is low.

| Sensor 1 | Relay 1 | Relay 2 |
|---|---|---|
| 0 | 0 (NO) | 1 (NC) |

TABLE 4 Logic when Solar Panel has Sufficient Production (V≥ 20)

| Sensor 1 | Relay 1 | Relay 2 |
|---|---|---|
| 1 | 1 (NC) | 0 (NO) |

TABLE 5 Logic when Solar Panel Production (V<20)

| Sensor 1 | Relay 1 | Relay 2 |
|---|---|---|
| 0 | 0 (NO) | 1 (NC) |

*F. Protection against Over load voltage and Temperature change.*

Sensor 3 is responsible for checking the over load voltage.

Relay 3 is normally closed but there is an overload which will be set open resulting to the stopping of charging of the battery till the overvoltage decreases.

TABLE 6 Over Load Voltage Logic.

| Condition (Over voltage) in V | Sensor 3 logic | Relay 3 Logic condition |
|---|---|---|
| V>25 | 1 | NO |
| V<=24 | 0 | NC |

Sensor 4 is responsible for temperature change in the system

Relay 4 will respond to the change in temperature.

TABLE 7 Temperature Change logic

| Condition (Temperature Change) | Sensor 4 logic | Relay 4 Logic/ Condition |
|---|---|---|
| T >50C | 1 | NO |
| T ≤ 49C | 0 | NC |

## IX. RESULTS ANDANALYSIS

*A. Testing results*

Table 8 shows the solar panel voltage(from 24.4V to 10V) that are induced from the different intensities of the sun light. Fig.10 shows the important bar graphs of the battery voltage with respect to time and in Fig.11 the battery voltage, PV module voltage with respect to time for analysis of the physical conditions and characteristics of PV modules and batteries are being shown. The experimental setup has been developed in a research laboratory; Google map of experimental area has been shown in fig.12.A.c to d.c converter will not operate up to the solar panel voltage of 20V, but it will operate from 19V to 10V. A microprocessor-based auto switch will control that operation. Here, position 1 indicates that selection of the solar power voltage and position 0 indicates the selection of a.c main respectively. Correspondingly, the booster converter voltages, battery voltages and battery temperatures are indicated in TABLE 7. Hence it will conclude that the normal charging voltage of the booster converter lies between 30V to 26.6V. The voltage of the booster converter should not exceed 30V to avoid over-heating, over voltage and over charging problems of the battery and for the life cycle economy analysis it will reduce the life span of the battery.

TABLE 8 Analysis of Solar Charge and Normal Charge System(1: Select Solar power, 0: select A.C Main)
O.V = Over Voltage; N.V = Normal Voltage

| SL NO. | Time in hour | Solar Panel Voltage (In Volt) | A.C to D.C Converter Voltage (in Volt) | Position of Microprocessor Control Auto Switch | Booster Converter Voltage in Volt | Battery Voltage in Volt | Selection of Auto Switch | Battery Temperature in $C^0$ | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 09am | 23 | 0 | 1 | 29.2 | 25 | solar panel | 51 | OV |
| 2 | 10am | 23.5 | 0 | 1 | 29.4 | 25.4 | solar panel | 52.2 | OV |
| 3 | 11am | 24.1 | 0 | 1 | 29.7 | 25.7 | solar panel | 53 | OV |
| 4 | 12am | 24.4 | 0 | 1 | 30 | 26 | solar panel | 53.4 | OV |
| 5 | 01pm | 23.6 | 0 | 1 | 29.3 | 25.2 | solar panel | 51.5 | OV |
| 6 | 02pm | 22 | 0 | 1 | 28 | 24.3 | solar panel | 49.9 | NV |
| 7 | 03pm | 21.6 | 0 | 1 | 27.5 | 23.9 | solar panel | 49 | NV |
| 8 | 04pm | 21 | 0 | 1 | 27 | 23.7 | solar panel | 48.2 | NV |
| 9 | 05pm | 20.1 | 0 | 1 | 26.6 | 23.4 | solar panel | 47.3 | NV |
| 10 | 06pm | 19 | 23 | 0 | 28.7 | 23.5 | A.C Main | 48 | NV |
| 11 | 07pm | 16 | 23.1 | 0 | 28.8 | 24.2 | A.C Main | 49 | NV |
| 12 | 08pm | 13 | 23.1 | 0 | 28.9 | 24.8 | A.C Main | 49 | NV |
| 13 | 09pm | 10 | 23.1 | 0 | 29 | 25.3 | A.C Main | 50 | OV |
| 14 | 10pm | 10 | 23.1 | 0 | 29 | 25.4 | A.C Main | 50 | OV |

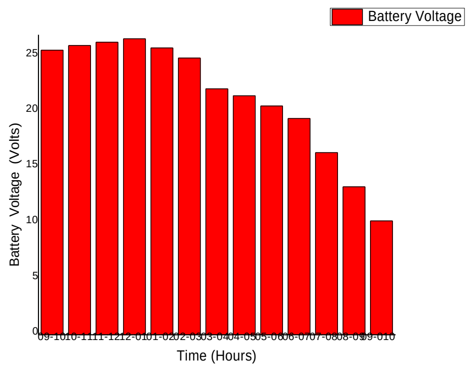



FIG.10: BATTERY VOLTAGE VS TIME

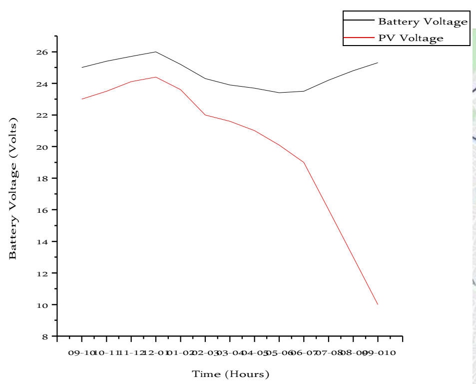



FIG. 11: BATTERY POWER VS SOLAR CHARGING POWER

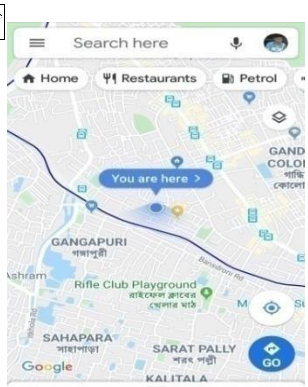



FIG 12: GOOGLE MAP OF THE EXPERIMENTAL AREA

*B Simulation results*

The experimental set up and simulation results are shown in figures 13 to 17 using PSIM software as well as hardware. The switching frequencies are taken from 40 KHz to 100 KHz. Fig.17 shows the experimental set up of the proposed induction cooking system designed in the laboratory.

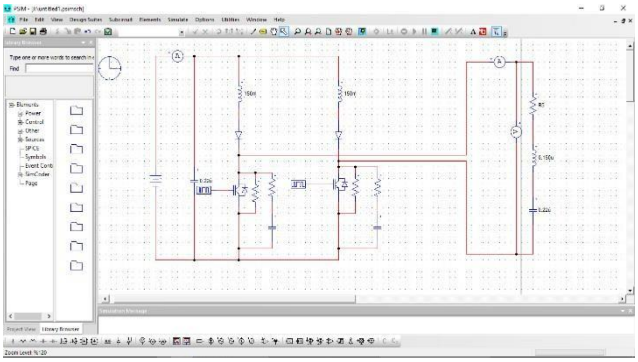


Fig.13: Current-fed parallel resonant converter

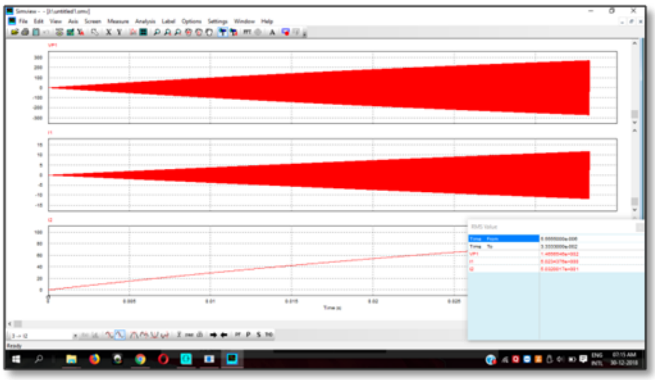


Fig.14: Output current of the proposed induction coking system at 30 KHz.

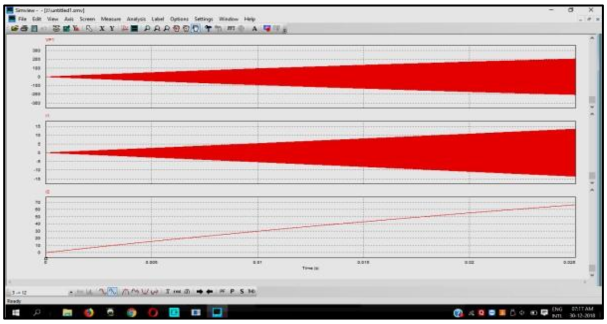


Fig.15: Output current of the proposed induction coking system at 45KHz

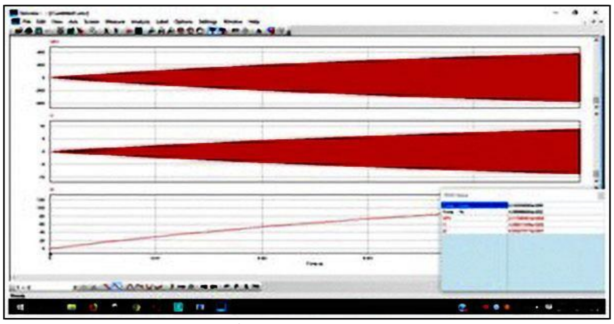


Fig.16: Output current of the proposed induction coking system at 65KHz

Fig 17: Experimental set up of induction coking system.

*c. Analysis*

TABLE 9 here shows the input the output voltage and the power of the induction heater at three respective frequencies ranges namely 30 KHz, 45 KHz and 65 KHz. The percentages of efficiency achieved are 91.42%, 80.96% and 67.12% respectively. It is observed that there is a sharp drop in the efficiency when it is compared to operation at 30 KHz (91.42%) with the power level two (80.96%). In spite of having this level of efficiency which is somewhat less than the efficiency at 30 KHz, it is still considered one of the best and superior methods to most other cooking methods that are prevalent. The commercial domestic induction cook-top is mostly most used in a domestic setting or at least used for the longest period at the "simmer" power level and the efficiency found at this frequency is 67.12 % (65KHz). TABLE 10 shows the specifications of low voltage solar induction cooker installed in our proposed project.

TABLE 9 Output Voltage and Power at Different Frequency.

| **Load** | **$V_{rms}$ in Volts** | **$I_{rms}$** | **Power in Watts** | **Position of Auto Switch** | **Types of Supply System** |
|---|---|---|---|---|---|
| Power Supplied for load 1 | 24 | 10.02 | 240.5 | 1 | Solar Panel |
| Output power for load 1 | 23 | 9.36 | 215.2 | 1 | Solar Panel |
| Power Supplied for load 2 | 23.7 | 6.34 | 150.33 | 1 | Solar Panel |
| Output power for load 2 | 15.2 | 8.26 | 125.7 | 1 | Solar Panel |
| Power Supplied for load 3 | 23 | 3.28 | 75.4 | 1 | Solar Panel |
| Output power for load 3 | 10.3 | 4.16 | 43.2 | 1 | Solar Panel |
| Power Supplied for load 1 | 24.1 | 9.97 | 240.5 | 0 | A.C. mains |
| Output power for load 1 | 23 | 9.43 | 217 | 0 | A.C. mains |

TABLE 10 SPECIFICATION OF SOLAR INDUCTION COOKER

| SN | Descriptions | Rating of Low Voltage Induction Tabletop |
|---|---|---|
| 1. | Construction | Heat resistant ceramic top with SCHOTT glass 600. |
| 2. | Supply system | Single phase, 24V DC supply. |
| 3. | Operating frequency, wattage | 45-100 KHz PWM, 1200W |
| 4. | Input current for cook top | 9.0 - 10 Amps |
| 5. | Efficiency | >92 % |
| 6. | Temperature Min./Max. | 50 /300$^0$C |
| 7. | Working temperature | 12-45$^0$C |
| 8. | Noise Level | Less than 45 dB |
| 9. | Temperature control | Thermostat control |
| 10. | Overheating cut-off | Temperature Relay |
| 11. | Cooling System | Axial fan forced air-cooling |
| 12. | Different Protections | Over current / Over voltage |
| 13. | Switching | Zero voltage switching |

## X. LIFE CYCLE ECONOMIC ANALYSIS (LCEA)

Now with every design of the induction heater, the impact comes directly to the economical cost of the heater. So, with the change in design, economic analysis will also change. The various impacts that affect the economic analysis are discussed in article X.

Life Cycle Economic Analysis (LCEA)is said to be the total calculation of the money that is being spent on a service delivered during the entire life span of a project. Life cycle cost (LCC) analysis is a tool used in statistics which helps assign values to expenses, initial as well as to possible future expenses which provides a cost approximation.

### *A. Effective present value (EPV)*

The life cycle analysis makes us aware of the functionality of the instrument. It helps us to estimate the additional price needed for the instrument in the long run.

### *B. Net system cost*

The total cost of the system of an induction stove incorporates three components related to three different phases considered in analysis of life cycle economic such as Initial capital cost, recurring or regular costs, and replacement or non-recurring costs.

### *C. Economic criteria*

It mainly depends on the life cycle of induction stove under consideration. The economic criteria depend on the availability of raw material in the local market as it reduces the over-all cost of the induction stove.

## XI. COMPARATIVE STUDY BETWEEN SOLAR INDUCTION STOVE AND NORMAL INDUCTION STOVE, BOTH OF CAPACITY 1200W.

In this comparative study we are studying the amount of wattage consumption done by 1200W in the duration of 2 hours or 120 min. In the analysis below, we see how much wattage and time is used up when cooking a particular item.

### *A. Mathematical Analysis.*

*Normal Induction Stove (with respect to time and wattage).*

It is known that an induction stove has the function of changing the wattage requirement according to the type of food which is being cooked. So, let us take a case study for cooking various types of food items for 2-hour (120 min). TABLE 11 shows the normal ac powered induction cooker with different wattage for various type of cooking food.

TABLE 11 Normal Induction Cooker with different Wattage for different Food.

| Food being cooked | Wattage required for different types of food (approx) | Time required for cooking in minutes (approx) | Electrical Energy (E) In Wh |
|---|---|---|---|
| Rice | 500 | 30 | $E_1 = 250$ |
| Meat | 750 | 40 | $E_2 = 500$ |
| Tea | 300 | 10 | $E_3 = 50$ |
| Other Item | 600 | 40 | $E_4 = 400$ |

***Case Study I.***

Total electrical energy required per day, = $(E_1 + E_2 + E_3 + E_4)$ = 1200Wh =1.2KWh …………..(15)

Per Unit cost of electricity = Rs 6.55/-(approximately).

Per day electricity cost of induction stove = Rs7.86/-

Per year electricity cost of induction stove = Rs 2829.60/-Total Electricity cost for 5 years, $C_1$ = Rs14,184/-.

Replacement or non-recurring costs in 5 years, $C_2$ = Rs 1000/-(approximately). Initial capital cost for induction stove in Indian market, $C_3$= Rs 2500/-(approximately).

Total expanses after 5 years,$C_4$ = $(C_1 + C_2 + C_3)$ ….....(16)

= Rs 17,648 ≈Rs 17,700/-(approximately).

### *B. Solar Induction Stove (with respect to time and wattage).*

So, let us take a case study for cooking various type of food items for two hours (120 min) = 2 hours. TABLE 12 gives the results of a low voltage solar powered induction cooker for the same types of cooking food.

*Case Study II.*

TABLE 12 A Solar Induction Cooker with Different Wattage for Different Food.

| Food being cooked | Wattage required for different types of food (approx.) | Time required for cooking in minutes(approx) |
|---|---|---|
| Rice | 550 | 35 |
| Meat | 800 | 40 |
| Tea | 350 | 10 |
| Other item | 600 | 35 |

Total electrical energy required per day = ( 320.83 + 533.33 + 58.33 + 350 ) Wh = 1262.49Wh ≈ 1.26KWh.

Per Unit cost of electricity = Rs 0 (as we are generating our own energy we are not buying from a 3rd party). Per day cost of electricity for induction stove = Rs 0.Per month cost of electricity for induction stove =Rs 0. Per year cost of electricity for induction stove = Rs0.Total electricity cost for 5 years, $C_5$ = Rs 0

Replacement or non-recurring costs in 5 years, $C_6$ = Rs 5000/-(Approximately).Initial capital cost for induction stove in Indian market, $C_7$ = Rs 2500/-.

Therefore, total expanses after 5 years,

$C_8$ = Rs ( $C_5$+ $C_6$+ $C_7$ + $C_{11}$) = Rs 84,400/- ………(17)

Government giving subsidy 30%, $C_9$ = $C_8 \times 0.3$…….(18)

=Rs 25,320/-.

Total investment cost, $C_{10}$= ( $C_8$ − $C_9$) = Rs 59,080/- ..(19)

*C. Considering Without Government subsidy.*

Breakeven point, $B_2$ = $B_1$ = C8/C4 ≈ 4.8 years…..(21)

The total installation cost of the proposed project is shown in TABLE 13.

TABLE 13 Installation item cost of the proposed project

| Item Used | Makers Name | Quantity | Price Range (Rs) |
|---|---|---|---|
| Solar Panel 300W, 24V D.C | Kenbrook Solar | 1 | 13,500 |
| Float Cum Boost Battery Charger. | Sai-Tech. Engineers | 1 | 10,000 |
| A.C To D.C Converter | Powertek Energy System | 1 | 10,000 |
| D.C To D.C Converter | LM259C D.C To D.C Boost Converter | 1 | 200 |
| Exide Battery 150AH | Exide Insta Brite Battery | 4 | 10,800 × 4 = 43,200 |

Therefore, the total cost = $C_{11}$ =Rs 76900/-

*D. Net Present Value (NPV)*

NPV determinate the current rates of investment taking into account the changes in the value of capital over time. Universally recognized principles of assessing the profitability of investment projects determine that the investment is profitable when NPV is higher or equal to zero. TABLE 14 shows the year Vs cash flow study.

$$NPV = \sum_{i}^{n} \frac{\text{nCFt}}{(1+r)^t} \quad \text{…………(22)}$$

Where, CFt= balance of cash flow in period t; n = duration of project; r = discount rate; t = time unit.

TABLE 14 Year Vs Cash Flow study

| Years No. | Cash Flow in Rs | Years No | Cash Flow in Rs |
|---|---|---|---|
| 0 | 59,080 | 3 | 17,700 |
| 1 | 17,700 | 4 | 20,000 |
| 2 | 17,700 | 5 | 20,000 |

*NPV* =1,04,200.656 − 59,080 = Rs 45,120.656/-.

*E. Internal Rate of Return ( IRR )*

It is the discount rate which makes the net present value(NPV) equal to zero the discount rate will equate the present value of future cash flowing with initial investment.

$$Here, Invesment = \sum_{i}^{n} \frac{\text{nCFt}}{(1+r)^t} \quad \text{…………..(23)}$$

Let us assume r = 20% = 1.20

Investment= Rs 60,320.327/-.

In 20%, IRR is higher than the investment with a difference of 60,320.327 - 59,080 = Rs 1240.33/-.

Let assume r = 19% = 1.19, Investment = 58,904.67/-

In 19%, IRR is lower than the investment with a difference of (59,080 − 58,904.877) = Rs175.123/-.

*To find the value follow the steps.*

**Step 1:** find the closest value of

20% = Rs 1240.327/-; 19% = Rs 175.123/-

**Step 2:** find the sum of both the closest value:

1240.327 + 175.123 = Rs 1415.45/-

**Step 3:** calculate the ratio of smallest discount rate:

$$\frac{175.123}{1415.45} = 0.123$$

**Step 4:** add the value obtained in step 3 to the smallest discount rate: 19 + 0.123 = 19.123%

So IRR is 19.123%

### *F. Advantage of the proposed design.*

- It also uses less energy and cooking is faster than normal stovetop cooking.
- Reduction of manufacturing cost due to elimination of various element.
- Induction heater can also be used when there is an unavailability of a.c. source.
- This design is environment friendly.
- Design has been simplified.
- Design has been done for d.c supply.
- The battery is partially charged by solar power and rest of the charge is done by grid power.
- No electromagnetic wave radiation, suitable for pregnant women, old people and children to use etc

TABLE 15 shows the comparison of dc supply induction cooker Vs a.c supplied induction heater.

TABLE 15 Comparison of D.C supplied induction heater vs A.C. Supplied induction heater

| D.C supplied induction heater | A.C supplied induction heater |
|---|---|
| Manufacturing cost is relatively less as compared to a.c fed induction heater. | Manufacturing cost is more as compared to d.c supplied induction heater. |
| Environment friendly | Comparatively less environment friendly. |
| Battery is used for the supply of induction stove. | To use battery as supply d.c. has to be converted to a.c. for the supply |
| It can work even when there is power surge. | It cannot work when there is a power surge. |

## XII. BENEFIT OF SOCIAL LIFE WITH THE USE OF SOLAR INDUCTION COOKER

One of the direct benefits towards the social life when using the solar induction stove is that it helps to reduce the pollution which is being caused by the generation of energy. It is well known that the primary sources of energy are generated from non-renewable sources, which are the major contributors of pollution towards our environment. In order to counter the pollution caused by non-renewable resources it is proposed that we start the use of solar powered induction stove, because solar is a renewable source of energy it has no pollution effect towards the environment. With the use of renewable resources, we will not have to fear the depletion of such resources. With the use of solar powered stoves, we are one step closer to make our environment a better place to live in.

## CONCLUSION

With the increase in demand for cooking gas day by day and the increase in fuel price, people are looking forward for alternatives. Fire wood/coal is no more an acceptable solution because of the various pollution issues. Induction based cooking system is pollution free and efficient but it consumes too much electrical energy which makes it less economical. People are looking forward to economical, efficient and pollution free options. This is how solar based induction cooking system finds its place. The solar energy is available in abundance for free of cost and over 90% of it has not been utilized. The design provides a standalone product, whereby the solar and the grid power helps in the charging of the battery. When comparing with the conventional heating systems, the solar induction system has various advantages over the former such as in terms of time. In this paper we have made a comparison with the use of solar panel power induction cooker with respect to induction cooker feed from main line.

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