Design and fabrication of Solar Induction stove

Fabrication of solar stove

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Abstract : Many people in the developing areas of the world struggle to cook with stoves that emit hazardous fumes and contribute to greenhouse gas emissions. Electric stoves would alleviate many of these issues, but significant barriers to adoption, most notably lack of reliable electric power, make current commercial options infeasible. However, a stove with an input power of 24V DC elegantly solves the issue of intermittent power by allowing car batteries to be used instead of a grid connection, while also allowing seamless integration with small scale solar installations and solar-based microgrids. However, we have worked on materials for the manufacturers to produce in an economical way and consumers to buy on budget whether the buyers are from rural or urban areas. This stove is the one of its kind and represents a new contribution to both the field of induction cooking and the field of clean cooking solutions for the developing world.

IndexTerms **-** Solar, Induction, stove, battery, electric power, microgrids.

I. INTRODUCTION

One of the most serious problems that we are witness is the increasing cost and scarcity of cooking gas. An alternate method is to use electricity for the purpose. But the extensive upsurge in the price of electricity and the lack of availability of large amount of electricity forces us to think about yet another alternative. On the other hand solar energy is the largely available source which we can use for cooking but this energy is not available 24 hours so it is not possible to use it in the night. So this energy has to be stored in the battery. This stored energy can be used to produce the electricity and further for induction heating. Induction cooking is the highly efficient technique for the cooking purpose when it combines with solar system it will provide the future solution for the cooking technology. Although solar based cooking may have high initial cost, but over a long term it is cost effective solution. Induction heating is a well known technique to produce very high temperature such as in melting steel. The technique requires high frequency current supply that enables to induce high frequency eddy current circulating in the target object.

Abbreviationsand Acronyms

Abbreviations

FET	Field Effect Transistor
ASTM	American Society for Testing & Materials
IGBT	Insulated gate bipolar transistor
AC	Alternating current
DC	Direct Current
ZVS	Zero Voltage Switching
MOSFET	Metal Oxide Semiconductor field Effect Transistor
ESR	Erythrocyte Sedimentation Rate
PCB	Printed Circuit Board
PV	Photovoltaic
INR	Indian rupee
LED	Light-emitting diode
LPG	Liquefied petroleum gas
NGO	Non-governmental organization
PV	Photovoltaic
SDG	Sustainable Development Goal

Acronyms

kW/kWh	kilowatt/kilowatt-hour
m^2	Square meter
m^3	Cubic meter

MW/MWh	Megawatt/megawatt-hour
V	volt
A	Ampere
Ω	ohms
Q	Coulomb
W	Watts
Hz	Hertz
G	Coundance
Db	Decibel
lb	Pound
gm	Gram
cm^2	Centimeter Square
psi	Pound per Square Inch
ft	Feet
in	Inch
°F	Fahrenheit
°C	Celsius
Ohm	Ohm

Equations

Skin depth of different materials

$$L = \mu_0 \frac{N^2 A}{l} \qquad (1)$$

Heat reductioin formula

$$Q=UxAx\Delta T \qquad (2)$$

Magnetic induction on copper wire

$$\Phi B = B.ACos\theta \text{ x } B.ACos \qquad (3)$$

I. RESEARCH METHODOLOGY

The methodology section outline the plan and method that how the study is conducted. This includes Universe of the study, sample of the study,Data and Sources of Data, study's variables and analytical framework. The detailsare as follows;

3.1 Challenges

Developing countries and rural areas in developed countries present unique challenges to the design of any electric stove. The largest hurdle to overcome is the lack of readily available andreliable electric power. Consider India as an example. Many areas outside of the city have accessto 220VAC wall outlets. However they experience frequent power outages, interruptions andpoor power quality. Further outside the city in rural areas there may be no gridconnection whatsoever. For electricity these areas might rely on small solar installations or townsize micro grids. Finally any solution must be relatively low cost or it will not be adopted.These challenges are not adequately met by available electric stoves. Resistive elementelectric stoves suffer from low efficiencies. A single low efficiency stove may overwhelm ahome solar installation while a number of them drawing power at the same time may overwhelma micro grid. Commercial induction stoves have high efficiencies but even higher efficiencies aredesirable. No existing solution is capable of coping with an intermittent grid connection. Theproposed thesis project aims to address these shortcomings.

3.2 General Approach

Our approach addresses these problems by undertaking the design of a high efficiency inductionstove powered by 24V DC. This represents a previously un-researched area as there are currentlyno commercial induction stoves or literature available in academia regarding induction stovespowered from a low voltage DC power source.

Such a stove would address the challenges highlighted in the previous section by utilizinga 24V DC power source. A 24V DC power supply could take several forms a cheap and readilyavailable form of a 24V DC supply is the connection of two car batteries in series. This addressesthe problem in each of the three cases above. Instead of relying on flaky grid power a homecould instead charge two car batteries off the grid when power is available and use the storedpower for cooking in the event of a brownout or similar electrical interruption.

Furthermore 24V is an extremely common output for solar installations and one of onlya few standardized output voltages for photovoltaic panels. This makes it appropriate for directintegration with a roof top solar installation or solar based micro grid traditionally to hookup an electric appliance such as an induction stove an inverter is connected to the solar batteryto produce mains AC voltages. This step is usually at most 90% efficient and frequentlysignificantly less. Then the stove internally must rectify the AC voltage back to DC to use itagain with a loss of efficiency.

3.3 Scope of Thesis

The purpose of this Thesis is to explore the design of an induction stove appropriate for use in developing areas. Included in the scope is an examination of existing methodologies and the proposal of a new solution. The dynamics of the design will be thoroughly detailed and discussed. Additionally simulations have been performed as needed to verify system behavior. However this Thesis does not intend nor purport to provide an optimal implementation. Instead, the implementation presented will be a proof of concept. It will become the ground work for future research and have the ability to be easily scaled toward fully operable, practical designs..

3.4Topology Selection

The overwhelming majority of existing induction stoves use either a series resonant or series quasi resonant design. However as shown in Figure 6 these stoves typically operate with their converter stages fed by a large DC voltage. In contrast our design operates with a low voltage DC input as shown in Figure 7. One simple solution would be to boost the input voltage, but then we are adding an additional stage with loss similar to the conventional design.

Operating a traditional design at a lower voltage is simply not feasible. All other parameters being equal, the input voltage is directly proportional to output power. This is because the minimum impedance of the coil resonant capacitor network is essentially fixed. Building a high Q induction stove to increase resonating current is simply not possible because you want maximum damping. That damping is power transmitted to your load.

As we can see from the discussion of the physics of the system if we wish to increase the power output we need to increase the ampere turns in the coil the frequency or both and at the same time to maintain efficiency we wish to minimize loss.

Increasing only frequency isn't viable. The resistance only scales with the square root of frequency. We are operating at 10x lower input voltage which means we'd need to operate at 100x the speed. This is impractical. Traditional devices and topologies are already near their limit at 30 kHz and switching losses and coil losses would skyrocket.
As stated above simply increasing the turns in the inductor is not a viable option due to system constraints. Counter-intuitively increasing the turns actually reduces the ampere turns because for every time the turns are doubled the current flowing is decreased by a factor of 4. This can be seen from the equation for inductance of a coil in equation 3 and the conservation of energy equation in equation 4. To keep the same switching frequency, we'd need to decrease the capacitance by an equal amount.

3.4.1 Operation Frequency

The operating frequency is one of the primary system parameters. It has a large effect on performance. As operating frequency goes up the skin depth in the pot decreases thus increasing loss in the pot or equivalently the heating effect. This means higher operating frequency is highly desirable.

As frequency increases switching losses in the power devices increase as do losses in the coil from skin effect. This can be significant but it is usually outweighed by the efficiency gains from operating at higher frequencies. The practical limitation in switching frequency is usually the maximum switching frequency of the power device. For IGBTs this is typically in the tens of kHz. For MOSFETs this can be in the MHz range.

Our design operates at 50 kHz. This is approximately twice the switching frequency of the commercial designs examined. Additionally the design presented has the capabilities to easily scale to 100 kHz and beyond. Lower device stresses due to our parallel resonant topology allow faster device switching than conventional designs.

3.4.2 Ideal Current Source vs. Voltage Source & Inductor

The major complication with a practical implementation is that ideal current sources are notreadily available and are hard to emulate. Our design approximates an ideal current source with alarge inductor in series with our battery which is a near ideal voltage source. Apractical implementation of Figure 12 is presented in Figure 12. contains additionalcircuitry and calculated values from further sections this schematic was used for simulationresults presented unless otherwise stated.

This method in practice presents two problems. First when the devices are turned off theinductor will continue to conduct into a high impedance node which results in a voltage spike.D5, D6, and R3 were added to limit and damp the voltage spike.Second we cannot directly control the current produced by our approximate currentsource. Instead the current produced is a function of the input voltage and the system dynamics.So what constraints does the inductor impose? Steady state conditions mandate that the volt secondsacross the inductor in one cycle must be equal. Therefore the average voltage on rightside must equal the input voltage. This is an extremely important result for the design of thisconverter. A ringing resonator switched perfectly at the zero voltage crossing a 50% dutycycle will result in the right side of L2 seeing a rectified sine wave. The average value of arectified sine wave is $2/\pi$ times the peak voltage. Or equivalently the peak voltage in theresonator can be no more than $\pi/2$ times the input voltage Vdwhen switched at 50% duty cycleon the zero voltage crossing. This equation is represented in Equation 5. This means that the peakvoltage during operation off a 24V source is less than 40V.

An equally important result to understand is that the peak voltage increases the further weoperate off resonance. If we switch slower than resonance Vsense goes negative for part of thecycle and therefore the peak voltage must rise to compensate. If we operate faster thanresonance the waveform shape gradually changes from a sinusoid to a saw tooth. This can beexplained by the small angle approximation the sooner we switch in the resonant half periodthe smaller the argument to the sine is. Furthermore since switching flips the polarity Vsense seesthe sawtooth starts negative thus increasing peak voltages. Overall peak voltage reaches itsmaximum at 4x Vdd.

3.4.3 Material Properties

Acetal is the common name for a family of thermoplastics with the chemical name Poly Oxy-Methylene. Acetal is available in a general purpose copolymer grade, a homopolymer version (Delrin), and several filled grades. Acetal provides high strength and stiffness, enhanced dimensional stability, and is easy to machine. As a semi-crystalline material, acetal is characterized by a low coefficient of friction and good wear, high strength, stiffness, dimensional stability, very low moisture absorption, good wear and abrasion resistance and a wide range chemical resistance.

Acetal is a high strength, low friction engineering plastic that has excellent properties in both wet and dry environments. Easy to machine, acetal makes an outstanding choice for applications that require complex and tight tolerances.

IV. RESULTS AND DISCUSSION

4.1 Results of Descriptive Statics of Study Variables

Table 4.1: Depending on typical properties

ASTM or UL test	Property	Acetal co polymer	Delrinhomopolymer	Delrin AF PTFE-filled
PHYSICAL				
D792	Density (lb/in^3) (gm/cm^3)	0.051 1.41	0.051 1.41	0.054 1.5
D570	Water absorption, 24 hrs (%)	0.2	0.2	0.2
MECHANICAL				
D638	Tensile strength (psi)	9500	11000	8000
D638	Tensile modulus (psi)	400000	450000	435000
D638	Tensile elongation at break (%)	30	30	15
D790	Flexural strength (psi)	12000	13000	12000
D790	Flexural modulus (psi)	400000	450000	435000
D695	Compressive strength (psi)	15000	16000	16000
D695	Compressive modulus (psi)	400000	450000	350000
D785	Hardness, rockwell	M88/R120	M89/R122	M85/R115
D256	IZOD impact notched (ft-lb/in)	1	1	0.7
THERMAL				
D696	Coefficient of linear thermal expansion (x10^{-8} in./in./°F)	5.4	4.7	5
D648	Heat deflection temp (°F/°C) at 264psi	220/104	250/121	244/118
D3418	Melting point temp (°F/°C)	335/168	347/175	347/175
-	Max operating temp (°F/°C)	180/82	180/82	180/82
C177	Thermal conductivity (BTU-in/ft^2-hr-°F) (x 10^{-4}cal/cm-sec -°c)	1.6 5.5	2.5 8.6	-
UL94	Flammability rating	HB	HB	HB

ELECTRICAL				
D149	Dielectric strength (V/mil) short time, 1/8" thick	420	450	400
D150	Dielectric constant at 1MHz	3.8	3.7	3.1
D150	Dissipation factor at 1 MHz	0.005	0.005	0.01
D257	Volume resistivity (ohm-cm) at 50% RH	1015	1015	3.0 x 10^{18}
All values at 73°F (23°C) unless otherwise noted. DELRIN is registered trademark of DuPont				

Table 4.1 Describes the properties:

This thesis has investigated the design of an induction stove for the developing world andpresented a novel solution to the problem. The design incorporates the following innovations

- Low voltage operation for use with batteries.
- Parallel resonant conversion for efficient power transfer.
- IGBTs instead of MOSFETs to achieve higher frequencies and lower costs.
- Ability to operate with a cheap copper or aluminum tube as the resonant coil.
- Acetal instead of plastic to reduce the manufacturing and buying cost.
- Twice the switching frequency of commercial designs with the ability to scale higher**.**
- State of the art efficiency compared to other induction stoves. Massive efficiency gains when used in a battery system by eliminating the DC or AC inverter**.**

This design successfully utilizes a converter topology from other applications to create aunique contribution to the field of induction stoves. This enabled the design of the first efficientlow input voltage induction stove. When integrated with a car battery or solar micro grid systemthis system has the ability to deliver massive efficiency improvements

Figures

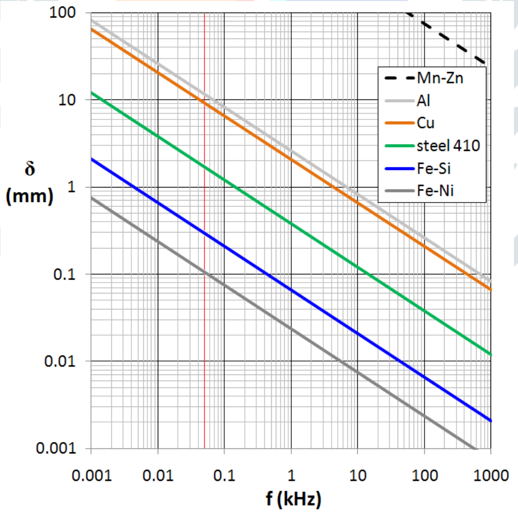

Fig. 1: Graph of Skin Depth vs Frequency for Different Materials.

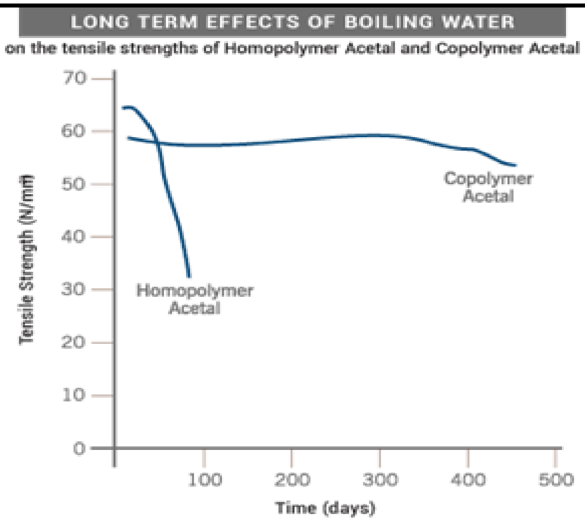

Fig. 2: Graph of long term effects of boiling water

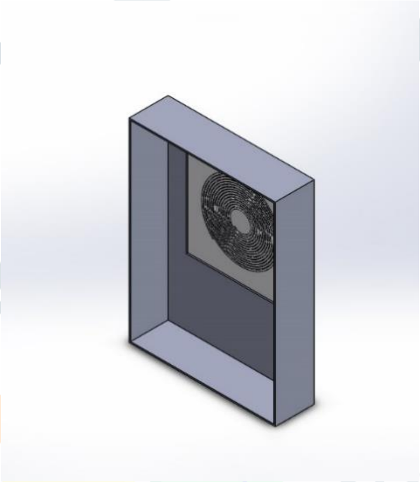

Fig. 3: Solid works 3D model of solar induction stove.

Fig. 4: Depiction of CookTek Stove Coil.

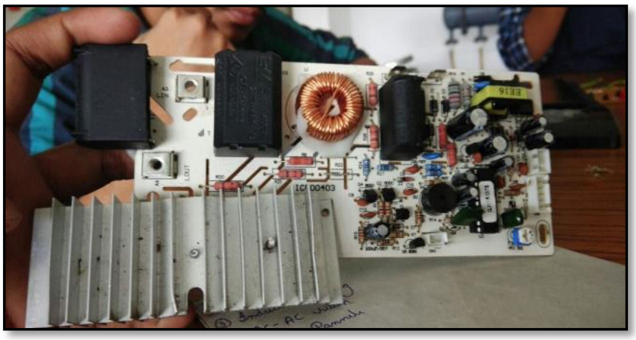

Fig. 5: Depiction of Phillips Stove PCB

Fig. 6: Induction Stove.

II. ACKNOWLEDGMENT

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