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Solar Ironing Cart

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Abstract – By replacing the charcoal used in cast iron boxes with electricity, a solar ironing cart significantly improve air quality. The moving cart's roof is a 750 W, 48 V(DC), monocrystalline solar panel. A high gain tapped coupled boost converter is used to increase the input voltage of 48 V to 450 V(DC). Finally, it is switched to 230 V (AC) to power a 750 W dry iron box which consumes 7500Wh energy in a day. In order to power the cart during the rainy seasons, a 48 V, 60 Ah lead acid battery supports the 1kW cart. The ironer is mobile and can iron clothes at doorways. The proposed cart removes the respiratory problems caused by charcoal burning that are brought on by breathing in smoke. Additionally, it offers clean ironing and gets rid of ashes and grime from the ironed items. It can avoid the problem of uneven heating of iron box due to the usage of charcoal and save energy. The final prototype is scaled down to 100 W and tested for an input voltage of 48V that produces an output of 230 V(AC) due to different physical laboratory constraints. A product called Solar Ironing cart is proposed in this paper.

***Key Words*:** Tapped boost DC/DC Converter, Single phase full bridge Inverter, Solar PV source, Battery energy storage

1.INTRODUCTION

On a worldwide scale, the energy sector is undergoing major changes. Traditional energy sources are running out and becoming more expensive to extract, while new energy sources are developing. Global warming is occurring more quickly now that there are more greenhouse gases in the atmosphere. These two challenges have forced world to develop a plan for the adoption of renewable energy sources in order to have clean and sustainable energy. But it faces challenges such as lack of efficiency in energy transportation and conversion. In recent years, solar energy systems have become more affordable, sparking a surge in demand. The development of renewable energy technologies for the electrification of rural areas is gaining popularity [3].

In order to provide continuous and dependle power to consumers, freestanding photovoltaic systems must include storage devices with backup power. The source, energy storage, and load are typically connected using three distinct DC-DC converters. They have some drawbacks, such as the need for a larger number of conversion devices, a more sophisticated architecture, and communication capabilities. Multiport topologies have been designed to alleviate these issues. Due to a single power stage, quicker reaction, and compact centralized control, they have a smaller footprint, are less expensive, and are more efficient. It is recommended to interface a solar PV source, a battery energy storage system, and a load using a tapped boost generated DC-DC converter. This converter provides a high step-up ratio and exceptional efficiency without the usage of isolation. One of the applications of this technology is detailed in this paper [2,3].

An innovative solar ironing cart significantly improve air quality by eliminating the need of charcoal as in traditional heavy cast iron ironing boxes. After ironing, the charred charcoal is placed on the ground to cool and eventually thrown away together with waste. This is a game changer in the fight against climate change, with an estimated ten million ironing carts across India emitting a lot of smoke and burning fifty million kilos of charcoal per day [3].

Aims to create a mobile ironing cart with solar panels for roof, which would power a dry iron box instead of using traditional charcoal. We also want to include a light source, a small fan, and a charging port for mobile phones on the cart. In the lack of sunlight, the cart can be powered by pre charged batteries. The roof of the cart doubles as a solar panel, absorbing sunlight and converting it into electricity to power the iron box. Surplus energy is stored in the battery for use after the sun sets and on gloomy days. The most significant advantage of solar ironing carts is that they eliminate the need for coal in the ironing process. Because the cart can be driven by a bicycle, the vendors may travel around and give services at their customer's doorsteps, increasing their daily earnings [3].

As a green energy source, solar energy doesn't emit harmful gases into the atmosphere. This research suggests a cost-effective, non-polluting energy source for powering an electric iron. The project is aimed at the 'ironer', who irons clothes. We propose solar powered ironing carts to make their job easier, boost efficiency, reduce manual labour, and lower running costs [2,3].

2.BLOCK DIAGRAM

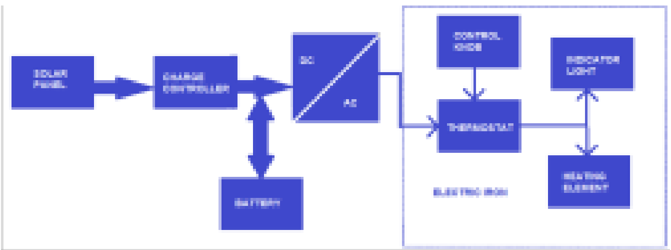

Fig -1: Block Diagram

Fig.1 shows the proposed topology of the solar ironing cart. The panel outputs an estimated 48V (DC) to the charge controller/DC/DC boost converter. The output is delivered to the inverter after increasing the 48V input voltage to 450V. The iron box needs a 230V, 50Hz single phase supply to operate properly, which the inverter delivers. Using a multiport topology, a PV Source, Battery pack and Load are integrated. It is possible to charge and discharge batteries depending upon the need and usage.

3. DC/DC BOOST CONVERTER

Three converter topologies—buck, boost, and buck-boost converter circuits—are employed in non-isolated tapped inductor DC–DC converters. Different configurations of a power semiconducting switch, tapped inductor, a capacitor, and a diode are used in these three circuits. The duty cycle of the converter is set to the appropriate value at the operating point as a result of tapping the inductor. It makes sure that the circuit's component utilization and efficiency are maximized. Additionally, it provides a selection of circuit components with various ratings for voltage and current. High or low voltage transfer ratios can be obtained by utilizing a tapped inductor, which has a good component cost but a relatively high efficiency [2,3].

The tapped boost converter consists of two magnetically connected windings. The tapped-inductor DC/DC boost converter contains two windings with N_1 and N_2 turns that are magnetically coupled to one another. They are the self-inductance, L1 and L2. Let's assume that n is the turns ratio and k is the coupling coefficient. The steady state analysis can be used to compute the voltage gain [2,3].

$$\frac{V_0}{V_{in}} = \frac{1 + nkD}{1 - D} \quad (1)$$

Where, V_0 = Output voltage, V_{in} =Input voltage, and D is the duty ratio.

A. TAPPED BOOST DERIVED CONVERTER

The derived topology is produced by replacing the power semiconducting switch in the tapped boost converter described in with an H bridge. Proper H bridge switching enables battery charging or draining as well as voltage amplification from source to load [1,2,3].

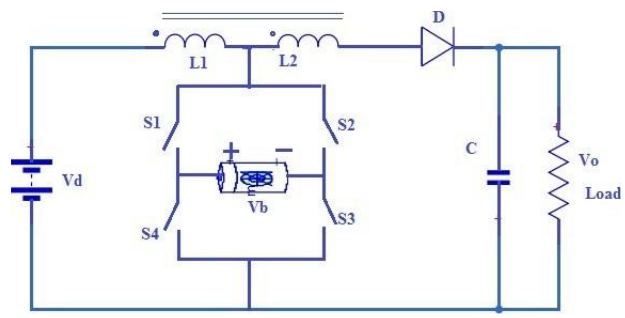

Fig -2: Tapped boost DC/DC Converter

B. WORKING OF THE CONVERTER

1) Working modes: The converter can be used in three different ways. The phase will be determined by the power balance between the PV source, the load, and the batteries' state of charge. The battery system balances the electricity properly from load to source [3].

1. Source Only: The battery has been fully charged, and the power from the solar energy is adequate to carry the load. As a result, the battery is not connected to the circuit. Close both switches in one of the legs to activate this mode (S1, S4 or S2, S3). It will now function as a straight forward tapped boost converter [2,3].

2. Battery Charging: The excess energy can be stored when the solar power output exceeds the necessary level (during the summer or at noon) and the battery is not fully charged. The converter must be operating, and the switches S1 and S3 must be turned on with the proper duty ratio for the

batteries to be charged. Keeping other pair of switches off [3].

3. Battery Discharging: The source must be supported by a battery storage system if there is insufficient solar energy (during the rainy season or at night) to meet the demand. The converter should operate in battery discharge mode when the switches S2 and S4 are turned on with the appropriate duty ratio [3].

Battery charging and discharging are triggered by any change in the reference parameters sensed by the sensors, and they must maintain a steady output in all modes of operation.

C. DESIGN AND IMPLEMENTATION

The input voltage for the single phase tapped coupled DC/DC boost converter is (V_{in}) of 48V (DC). This is accomplished with the Solar Ironing Cart by connecting two 24V panels in series. High efficiency and a step-up of the input of approximately 9.375 times characterize this specific type of converter. Output voltage, V_o= 450V (DC). In order to achieve a low duty ratio, the inductor's turns ratio, n, is chosen to be 10 [1]. According to calculations, k is 0.98, the coupling coefficient. The following formula can be used to calculate the duty ratio [3]:

$$D = \frac{\frac{V_{out}}{V_{in}} - 1}{\frac{V_{out}}{V_{in}} + nk} = 0.44 \qquad (2)$$

1. INDUCTOR DESIGNING

The switching frequency, f_{sw} of the converter is set to 20kHz in order to reduce core loss. The converter's output current, I_o is calculated as 2.22A. By considering, average output boundary current, $I_{o,av,bd}$ and change in peak to peak second inductor's current,

$\Delta i_{L2(pk-pk)}$

, L_2 is designed for 5.1mH. First inductor [2,3],

$$L_1 = \frac{L_2}{n^2} = 50\mu H \ (3)$$

Mutual inductance, M = 490μH. Equivalent inductance,

$$L_{eq} = L_1 + L_2 + 2M = 6.13mH \ (4)$$

M of L_1 and L_1 are aiding each other. Maximum current, I_m is calculated and rounded to be 5A(DC) and selected core material depending upon f_{sw} and application. Ferrite core was chosen over iron core because of its high permeability and benefit of having fewer turns. For ferrites, maximum flux density, B_m = 0.2 T, above which the core gets saturated. But, saturation value of iron core is 1.5T. Core loss is selected to be 100 mW/cm^3 from data sheet. EE Core was chosen because of its accessibility and affordability. The area product calculation can be used to choose the core size, A_p and selecting one from manufacture's data sheet [6].

$$A_p = A_c.A_w \ (5)$$

where, A_c=Core area and A_w= Window area. A_c is the area of magnetic path supporting the flux and A_w is the area of the window supporting the electric current[6]. Selected core dimension of E65 (65mm length) in-order to house the tapped inductors. Selected copper as the conducting material. Area of cross section of the conductor,

$$a_w = \frac{I_m}{K_c J} = 1.67mm^2 \ (6)$$

Where, k_c is called crest factor. For DC, k_c = 1 and for AC, k_c = 1.414. Current density, J = 3 A/mm^2, for natural cooled copper conductor. By calculating peak current passing through L_1, from standard wire table, a copper conductor of 18 SWG (Standard Wire Gauge) having adequate area of cross section of bare conductor with 1.167mm^2 which carries peak current safely is selected. Similarly, for winding L_2, an enamel coated copper conductor of 25 SWG having area of cross section of bare conductor with 0.2027mm^2 is chosen [6].

To obtain an appropriate inductance value, inductors are wound using a winding machine with a set number of turns. Mylar insulation tape with an ant-flame adhesive is used to insulate each layer of windings. LCR meter is employed to measure inductance. In practical for getting correct inductance value, a greater number of turns were required than designed. L_1 required 45 turns and L_2 required 288 turns for making designed inductance. It happened as a result of an air gap between the windings. Additionally, the conductors weren't crammed in very closely. So, Window factor, K_w is assumed to be 0.35 for round conductors. A tapping is taken from the end formed by joining finishing end of L_1 and starting end of L_2 and is connected to upper half of power switches in H - Bridge.

It is assumed that core reluctance is very very less than gap reluctance and fringing field at gap is negligible.

2) Capacitor designing: Output capacitor,

$C_o = (I_o.D.T_{sw}) / (\Delta V_{c,pk\text{-}pk}) = 10.77\mu F$ (7)

where, T_{sw} is the switching time period and $\Delta V_{c(pk-pk)}$ is the peak-to-peak change in capacitor voltage.

$\Delta V_c = 1\%$ of V_o (8)

3) Design and Selection of Other Components: The diode is RHRP15120, while the MOSFET is a KF12N60 N-Channel MOSFET [1]. The Arduino UNO microcontroller is used to regulate and carry out the switching of MOSFETs in various modes. Because IR2110 Gate driver IC_s are used in the control circuit, common ground problems are eliminated. Each MOSFET has a heat sink available to it in order to lessen the temperature effect brought on by loading. In this case, the boost converter's load is the inverter, and both devices are cascaded.

4.INVERTER

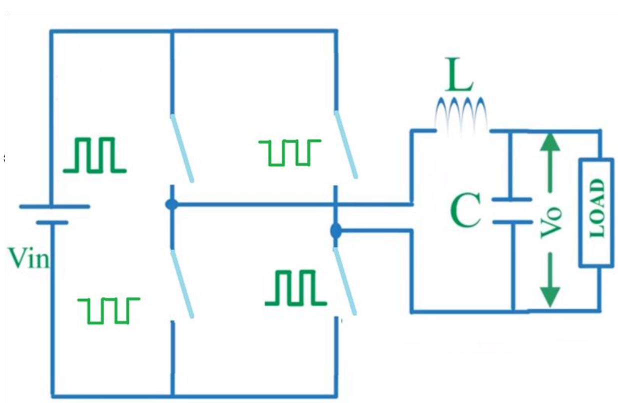

Fig -3: Inverter

In higher power ratings, a H-bridge inverter, which comprises of four semiconducting switches, is recommended over other designs. A full-bridge inverter has a higher maximum output voltage than a half-bridge inverter with the same dc input voltage. In other words, for the same power, the output current and switch currents are half of what they would be for a half-bridge inverter. Due to the fact that it requires less device paralleling at high power levels, this provides a notable advantage [4,6].

A. FILTER

Minimize output ripple voltage and limit the high frequency ripple current of inverter switches are the main duties of the output LC filter. The filter's cutoff frequency controls how much of the switching frequency voltage is attenuated at the output. The cutoff frequency of the filter also places a restriction on the inverter's bandwidth. The controller's bandwidth must be high for rapid action to a step or nonlinear load, and the filter's cutoff frequency must be low for excellent ripple voltage attenuation. As a result, there is an exchange between filter loss and controller bandwidth. Finding the L and C values is crucial because they have an impact on ripple current of inverter switches, inverter output impedance, efficiency, transient responsiveness, and inverter cost when the filter's cutoff frequency is chosen. The Fourier series of the inverter output voltage is used to design the cutoff frequency of the LC filter. The correlation between the filter capacitor and the circuit time constant is then used to derive the values of the capacitor and inductor. The L and C are selected to minimize the nonlinear load, or reactive power, of the filter [5].

B. SINUSOIDAL PULSE WIDTH MODULATION (SPWM)

By comparing a sinusoidal reference voltage signal (V_{sine}) with a high-frequency triangle carrier voltage signal (V_{tri}), sinusoidal pulse width modulation (SPWM) generates gate control signals. The turn-on and turn-off instants of the switching devices are determined by the places at which the triangular carrier voltage signal and the sinusoidal reference voltage signal intersect [7].
When $v_{sine} > v_{tri}$: S1 and S3 are closed then: $u = V_{DC}$ When $v_{sine} < v_{tri}$: S2 and S4 are closed then: $u = -V_{DC}$ .This version of PWM is bipolar because the output alternates between $+V_{DC}$ and $-V_{DC}$.
The two most crucial factors that define the SPWM: - The frequency modulation ratio m_f , defined as the ratio of the frequencies of the carrier and reference signals:

$$m_f = \frac{f_{tri}}{f_{sine}} \quad (9)$$

The amplitude modulation ratio m_a , defined as the ratio of the amplitudes of the reference and carrier signals[5,7]:

$$m_a = \frac{V_{m,sine}}{V_{m,tri}} \quad (10)$$

$f_{sine} = 50Hz, m_f = 7, m_a = 0.53$

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C. DESIGN AND IMPLEMENTATION

Selection of α depends on the switching frequency and maximum acceptable ripple current, $\omega_r = 2\pi f_r$ and f_r is the cut off frequency of the LC filter [5].

$$\omega_1 = 2\pi f_1 = 2\pi \times 50 = 314$$

$$\alpha_1 \geq 0.025,\ \omega_r = 6300$$

Maximum load:

$$C = \frac{1}{R_{LM}}\sqrt{\frac{\omega_1{}^2}{\alpha^2\,\omega_r{}^4 - \omega_1{}^4}} = \frac{1}{576}\sqrt{\frac{314^2}{0.025^2 \times 6300^4 - 314^4}} = 55.2\mu F \quad (11)$$

$$L = \frac{R_{LM}}{\omega_1}\sqrt{\alpha^2 - \frac{\omega_1{}^4}{\omega_r{}^4}} = \frac{576}{314}\sqrt{0.025^2 - \frac{314^4}{6300^4}} = 45.6mH \quad (12)$$

where f_1 is the fundamental frequency and k is the k factor. Conditions to be satisfied,

$$\omega_r > \frac{\omega_1}{\sqrt{\alpha}} \qquad \& \qquad f_s > \frac{k}{\sqrt{\alpha}} f_1$$

The amplitude of input voltage at the switching frequency depends on DC input voltage and duty ratio of PWM signal. It will be maximum when the duty ratio is 50% [7], m_f = frequency modulation ratio, m_a = amplitude modulation ratio, f_{sine}= 50Hz, f_{tri}=350Hz.

$$V o = m_a V_{dc} \quad (13)$$

Output Voltage, $V_o = 240V\ (ac)$,

Input Voltage, V_{dc} = 450V (dc)

$$m_a = \frac{V_{sine}}{V_{tri}} = 0.53$$

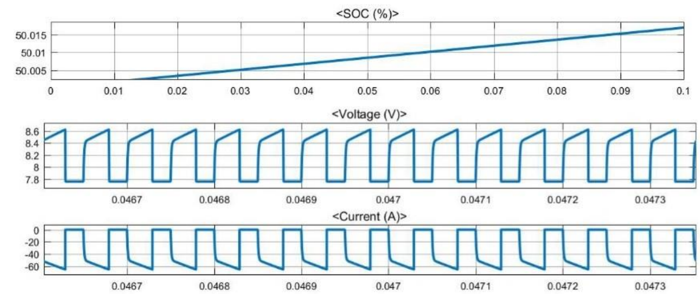
$$m_f = \frac{f_{tri}}{f_{sine}} = 7$$

1) Design and Selection of Components: The diode used is IN4003, while the MOSFET is a KF12N60 N-Channel MOSFET. The Arduino UNO microcontroller regulates and carry out the switching of MOSFETs in different cycles. The common ground problems are eliminated because of the IR2110 Gate driver IC's in the control circuit [7]. Each MOSFET has a heat sink to lessen the temperature effect brought on by loading. Inverter is the load of the boost converter, so they are cascaded.

5. SAVINGS AND PAYBACK PERIOD

	Conventional Iron Box	Electric Iron Box
Price of charcoal	Rs.22/kg	Nil
Daily Consumption	5kg	Nil
Annual Cost	Rs. 39,600	Nil
Cash Inflow	Rs.1,08,000 (Rs. 300/day)	Rs.1,08,000(Rs. 300/day)
Savings	Rs.68,400	Rs.1,08,000

Table 1: Savings



An estimated 5 kg of charcoal is required daily, according to information gathered locally from ironers. If the cost of charcoal is 22 rupees/kg, it will eventually cost 39,600 rupees annually. If an ironer's daily profits are determined to be 300 rupees, their annual cash flow would be 1,08,000 rupees. After deducting the cost of charcoal, the ironer would save 68,400 rupees per year if a traditional cast iron box was used. (Source: local data collected from ironers of Kerala)

The initial investment for buying the proposed cart will be 50,000 rupees (estimated from prototype implementation cost and others based on current market value). If it is used for 10 hours daily for 360 days/year, annual cash inflow wouldbe still 1,08,000 rupees/year.

$$Payback\ period = \frac{\text{Initial investment}}{\text{Annual Cash flow}} \ \ldots\ldots\ldots\ldots\ldots\ldots \ (14)$$

It would take about six months. Following the payback term, all the earnings would be used for savings. Because, there are no fuel cost, running cost and maintenance cost (for minimum of 2 or 3 years).

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6. SIMULATION AND RESULTS

The output voltage and current waveforms are same in all the modes of operation. In the Source only mode the battery state of charge is retained as 100% and the respective voltage and current waveforms are shown in the fig.4.

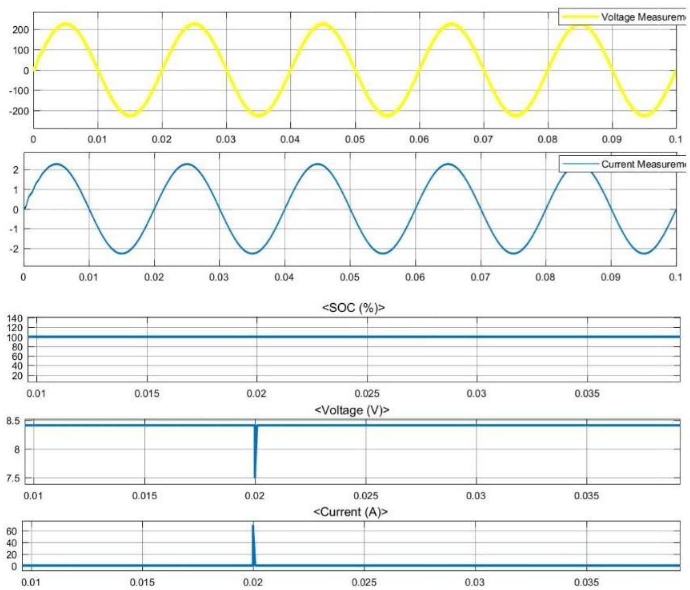

Fig. 4. Output Voltage and Current of SIC, SOC, Voltage and Current of the battery

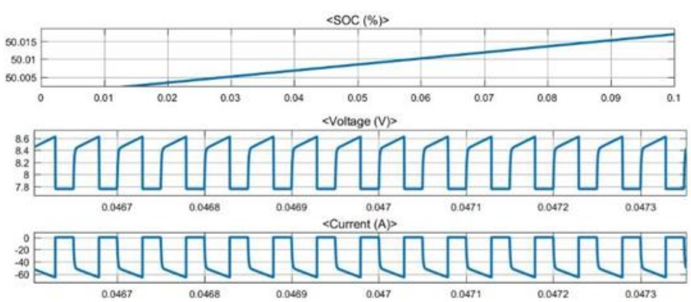

Fig. 5. SOC, Voltage and Current of the battery in charging mode of the battery

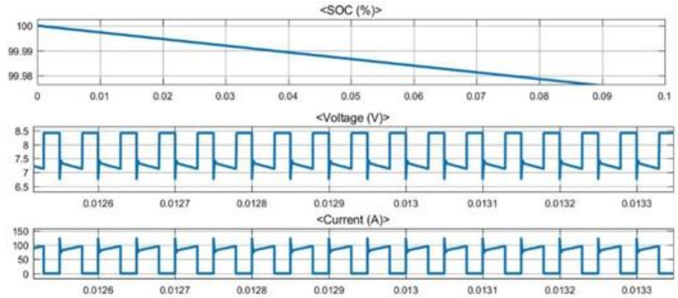

Fig. 6. SOC, Voltage and Current of the battery in discharging mode of the battery

In the battery charging mode, the state of charge of the battery is assumed to be at 50% and gradually increases and the respective voltage and current waveforms are shown in the fig.5

In the battery discharging mode the state of charge of the battery is assumed to be at 100% and gradually decreases and the respective voltage and current waveforms are shown in fig 6.

The total harmonic distortion is calculated and obtained as 2.22%.

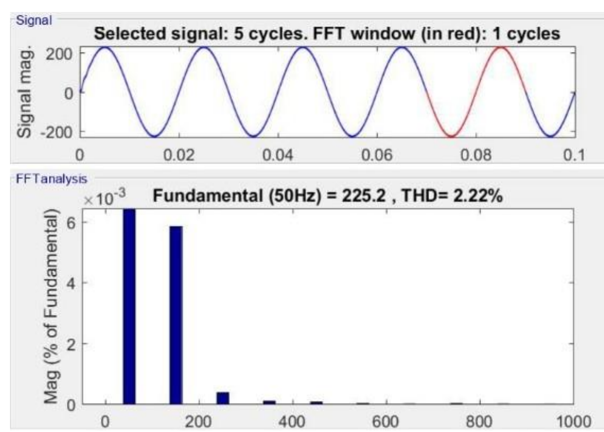

Fig. 7. Total Harmonic Distortion

The table shows the output voltage obtained for all the modes of operation.

	Vin	R	SOC	Vo
Mode 1	48V	200Ω	100%	230V
Mode 2	48V	202.5Ω	50%	230V
Mode 3	40V	100Ω	100%	230V

Table 2: Output voltage for all modes of operations

7. CONCLUSIONS

MATLAB was used to simulate a cascaded boost converter and inverter circuit. A prototype with 100W, 230V was designed, setup and tested successfully in the laboratory. The efficiency was acceptable.

Non-renewable and non-green energy sources should bephased out in favor of the present renewable and green energysources as technology develops.

Fig.8 Prototype

Traditional ironing carts can be swapped out with solar-powered ones. Traditional ironers who use ironing carts must buy fuel for the cast iron boxso the operational costs will consequently increase. Without a doubt, the proposed design just requires a single investment and has little ongoing expenditures. Only after two or three years will a battery change be necessary. Additionally, a lack of charcoal drives up the demand for a new design. This item is dependable and has the ability to integrate several energy sources. It can undoubtedly help India meet its goal of having net-zero emissions by 2070.

8.FUTURE SCOPE

It is necessary to explore and create more effective ways to make solar panels smaller and more effective, which can help reduce the product's overall weight. Furthermore, the system could become more compact in the future by using a single circuit that can boost DC as well as invert it to AC. But it requires effective switching and control methods. Additionally,an effective system that uses a steam iron box with a power output exceeding 1.5 kW and makes ironing simple can be devised and put into place. However, it must be remembered that this raises the product's overall power rating.

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