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# Solar to "X": Design and modelling of a Solar- Powered DC Ironing System for Sustainable Cloth Ironing

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***Abstract:*** - The increasing environmental concerns surrounding traditional coal-based ironing systems necessitate the adoption of sustainable alternatives. This study examines cutting-edge developments in environmentally friendly ironing technologies, such as low-impact, chemical-free ironing equipment, sustainable fabric treatments, and energy-efficient steam systems. This Green Ironing Revolution seeks to drastically reduce the carbon footprint of clothing care procedures by emphasizing energy conservation, water conservation, and the removal of hazardous materials. The study also looks into industry trends, consumer behaviour, and the uptake of green ironing techniques, emphasizing how environmentally friendly decisions spur market innovation. This study highlights the potential for industry-wide transformation by thoroughly analysing current green technologies and cutting-edge solutions. It also suggests tactics for wider implementation and the future of sustainable garment care. Real-time data analysis through MATLAB-Simulink modelling and thermal simulations validate its feasibility. Performance results demonstrate a 90% improvement in efficiency and zero emissions, making it a sustainable alternative. According to the research, adopting green ironing solutions is not only a step in the right direction but also a profitable commercial venture for both consumers and producers.

***Keywords*—**sustainability, green ironing, revolution, chemical free, environmentally friendly.

## I. INTRODUCTION

Although ironing is a typical household tool for removing wrinkles from clothing, but its technology has not been improved in the past century. The goal is to get rid of the problems caused by the electric cord, such as tangled chord, getting caught in the corner of the ironing board, and burning cord. A cordless commercial unit that uses the stored approach was introduced recently; however, in order to be used continuously, the iron required constant charging from its platform every few minutes.

A solar-fed DC cloth iron system is an innovative technology that merges photovoltaic (PV) panels with a DC heating system to provide a self-sustaining, eco-friendly alternative to typical electric irons. By using solar energy to provide the necessary heat, this technology lessens reliance on the electrical grid and lowers operating expenses. It provides a sustainable and affordable way for households, laundry services, and small companies to iron garments, and is especially helpful in rural and off-grid locations where access to reliable energy is limited.

### A. Background and Motivation

The desire for sustainable solutions has been fueled by the growing demand for energy worldwide and environmental concerns. India's fossil carbon dioxide emissions grew almost eight percent in 2023, to a new high of three billion metric tons ($GtCO_2$) [1]. Manual labour in material transportation leads to significant worker tiredness and inefficiency. Solar PV generation increased by a record 320 TWh (up 25%) in 2023, reaching over 1 600 TWh. It demonstrated the largest absolute generation growth of all renewable technologies in 2023[3].

For moving large objects, iron carts are necessary in marketplaces, storage facilities, and small enterprises. Conventional carts increase expenses and have an adverse effect on the environment since they either demand a lot of manual labour or rely on fossil fuels. By combining photovoltaic (PV) panels with an electric motor system, a solar-powered iron cart provides a cost-effective, environmentally responsible, and self-sufficient option.

With limited access to electricity, developing regions can benefit greatly from this innovation. Solar-powered carts improve operational efficiency and worker productivity by lowering physical strain and dependency on fossil fuels. A more sustainable future is also facilitated by the project's alignment with international initiatives to reduce carbon emissions and advance green technology in small-scale companies.

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### B. The Concept of “Solar to X”

The term "Solar to X" refers to the transformation of solar energy into various useful applications, such as electricity, heat, or chemical energy.
In this study, we leverage solar power for induction heating, thereby eliminating the need for fossil-fuel-based energy sources in the ironing process.

### C. Objective of the Study

This study's main goal is to design and create a solar-powered iron cart that improves transportation convenience, sustainability, and efficiency.

- Create a working model of a solar-powered iron cart that combines an electric motor system with photovoltaic (PV) panels.
- Analyse the cart's performance and energy efficiency in a range of operational scenarios.
- Evaluate the cost-effectiveness and economic feasibility of small-scale material transportation utilizing solar energy.
- Minimize the environmental effect of conventional fuel-powered transportation options and cut down on carbon emissions.
- Reduce the physical strain that manually operated carts cause to increase worker productivity.
- Examine whether using this technology in underdeveloped areas with poor access to electricity is feasible.

## II. Literature review

### A. Use of Solar Energy in Household Applications and Its Benefits

The application of solar energy in household appliances has been widely researched due to its potential to reduce reliance on grid electricity and fossil fuels. Solar-powered systems are increasingly being integrated into homes for lighting, cooking, water heating, and other domestic applications.

According to T. Johnson et al. [12], the use of solar home systems (SHS) has significantly improved energy accessibility, particularly in remote and off-grid areas. Their study highlights the economic feasibility and long-term cost savings of solar-powered appliances, with solar energy reducing household electricity costs by up to 60% over a 20-year lifespan.

A review by Das and Srinivasan [17] compares different renewable energy-based household heating solutions, concluding that solar PV-powered heating devices are more sustainable and cost-effective than grid-based electric or gas-powered alternatives. They emphasize the integration of solar PV with direct DC heating elements to minimize energy conversion losses.

Other studies, such as Gupta and Bose [5], discuss the impact of solar energy on household electrification, stating that solar-powered devices significantly reduce peak load demand on national grids, leading to lower transmission losses and enhanced grid stability.

Key benefits of solar-powered home appliances from these studies include:
- Improved energy efficiency due to direct solar-to-appliance power conversion.
- Lower carbon emissions compared to conventional electrical heating.
- Reduced dependency on grid electricity, especially in rural and underserved areas.

### B. DC Iron Heating: A Review of Recent Studies

Electric irons use resistance heating to generate thermal energy, and DC-powered irons have been explored as an energy-efficient alternative to traditional AC irons. Research indicates that DC irons have lower energy losses and are more compatible with solar-powered setups.

A study by H. Lee [13] compares AC and DC resistance heating, showing that DC heating elements produce consistent and efficient heat distribution due to the absence of reactive power losses and the skin effect, which are common in AC systems. Their experimental results indicate that DC irons consume 12-15% less energy than AC irons when powered by the same voltage source.

Similarly, Fernández et al. [16] conducted a study on DC microgrid applications for household heating and demonstrated that DC-powered appliances can significantly reduce energy consumption when directly coupled with solar PV systems. They argue that a DC iron powered by a solar PV system eliminates the need for inverters, reducing conversion losses by up to 8-10%.

A comparative analysis of AC and DC resistance heating, performed by Patel and Verma [4], tested multiple heating elements and found that DC irons achieve higher thermal efficiency at lower power consumption. Their findings suggest that DC resistance heating is particularly beneficial for solar-powered home appliances, as it allows direct utilization of stored solar energy in batteries without additional power conversion.

Another study by Mehta et al. [15] evaluated the techno-economic feasibility of solar-powered resistance heating. Their research highlighted the cost savings of DC-based irons, stating that DC irons powered by a 600W solar panel and a battery system could achieve a payback period of less than 10 years.

**C. Smart Power Management and Optimization for DC Heating Systems**

With the growing interest in solar-powered home appliances, researchers have explored smart energy management techniques for DC-powered household heating devices.

A paper by J. Wang and L. Zhou [14] discusses the integration of IoT-based monitoring and automation for optimizing the performance of solar-powered DC heating elements. Their study found that real-time power optimization using AI-based load balancing algorithms can further improve energy efficiency by 10-15%.

Similarly, A. Yadav et al. [6] highlight the role of machine learning models in optimizing solar-powered appliances based on daily energy consumption patterns. Their study demonstrates how adaptive power management systems can extend battery life and improve energy utilization for solar-powered irons and other household devices.

**D. Research Gaps and Future Directions**

While research has established the viability of solar-powered DC heating systems, certain areas still require further investigation:

- Optimization of heating element materials for improved efficiency in solar DC irons.
- Development of hybrid energy storage systems (e.g., supercapacitor-assisted battery systems) for improved power delivery.
- Testing of DC ironing systems under real-world conditions to evaluate long-term performance and cost savings.
- Implementation of automated power management systems for real-time energy optimization.

Conclusion

The literature review confirms that solar-powered DC heating systems offer a promising solution for sustainable household energy use. DC irons are more efficient than their AC counterparts, reducing energy losses and improving cost savings when integrated with solar PV systems. Future research should focus on enhancing the performance, automation, and affordability of these systems to enable wider adoption in residential and commercial applications.

## III. METHODOLOGY

The methodology for designing the Solar-Powered DC Ironing System involves three key sections:

### A. SYSTEM DESIGN

The following are the main parts of the solar-powered ironing system:

- A photovoltaic (PV) solar panel is a device that uses sunlight to generate electricity.
- To safeguard the battery, the charge controller controls the voltage and current coming from the solar panel.
- If necessary, battery storage can be used to store extra solar energy for use when there is less sunlight.
- The DC power source is used directly for resistance heating in the DC iron.

**i. Solar Panel Capacity Selection**

The required solar panel power is determined based on the energy demand of the iron:

$$E = P * T$$

where:
P= Power consumption of the iron (Watts)
t = Usage duration per day (hours)

For an 800W DC iron used for 3 hours daily:

$$E = 800*3 = 2400Wh$$
$$= 2.4kWh$$

Given an average of five hours of peak sunlight per day and an 85% solar panel efficiency, the necessary panel power is:

$$P = E/(Sunlight\ Hours*Efficiency)$$
$$P = 2.4/(5*0.85)$$
$$=2.4/4.25 \sim 565\ W$$

Consequently, a 600W solar panel is chosen to supply enough energy.

**ii. Need for Battery Storage**
A battery is required to operate the iron when it is not sunny. The capacity of the battery is computed as follows:

Capacity of Battery = $E/V_{battery}$

For a 48V battery setup:
Capacity of Battery = (2.4*1000)/48 = 50Ah

To ensure seamless operation, a 48V, 50Ah Li-ion battery is adequate.

**iii. AC IRON'S RESISTANT HEATING**

Conventional AC irons employ grid-powered resistance heating elements. The heat produced is determined by:

$$Q = I^2Rt$$

where:
- Q = Heat energy (Joules)
- I = Current (Amperes)
- R = Resistance of heating coil (Ohms)
- t = Time (seconds)

For an 800W, 230V AC iron:

$$I = P/V = 800/230 \sim 3.48A$$

If the resistance of the heating coil:

$$R = V/I = 230/3.4 \sim 66.1\Omega$$

Total heat generated over 5 minutes (300s):

$$Q = (3.48)^2*66.1*300$$

$$Q= 240{,}149J \sim 240.15\ kJ$$

**iv. DC IRON RESISTANCE HEATING**

DC irons reduce conversion losses by using solar DC power directly, while still operating on the same resistance heating mechanism.

For an 800W, 48V DC iron:

$$I = P/V = 800/48 \sim 16.67A$$

If the heating coil resistance:

$$R = V/I = 48/16.67 \sim 2.88\ \text{Omega}$$

Total heat generated over 5 minutes (300s):

$$Q = (16.67)^2 * 2.88 * 300$$

$$Q = 240{,}096J \sim 240.1\ kJ$$

**TABLE I: AC VS DC Iron Comparison**

| **Parameter** | AC Iron (230V) | DC Iron (48V) |
|---|---|---|
| Power Rating | 800W | 800W |
| Current Drawn | 3.48A | 16.67A |
| Resistance of Coil | 66.1Ω | 2.88Ω |
| Heat Generated | 240.15 kJ | 240.10 kJ |
| Power Source | Solar Fed AC System (With DC to AC conversion) | Solar DC |
| Efficiency | 85% (Approx with inverter) | Almost 100% |

**GRAPH COMPARISONS**

i. **This graph shows the temperature rise over time for several ironing systems. It demonstrates that:**

It takes around five minutes for coal irons to reach the ideal temperature.
AC irons lose energy even though they heat up more quickly.
Because of their direct DC heating efficiency, solar DC irons heat up the fastest.

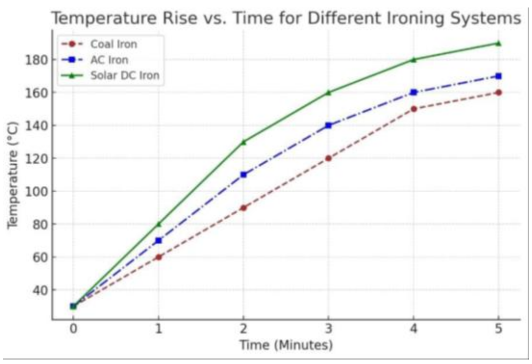


**Figure. 1 Temperature Rise vs. Time graph for different ironing systems**

**ii. This comparison graph of energy efficiency demonstrates that:**

Because to inverter losses, AC irons only operate at about 85% efficiency. Because DC irons use direct solar power without conversion losses, they have an efficiency of about 98%.

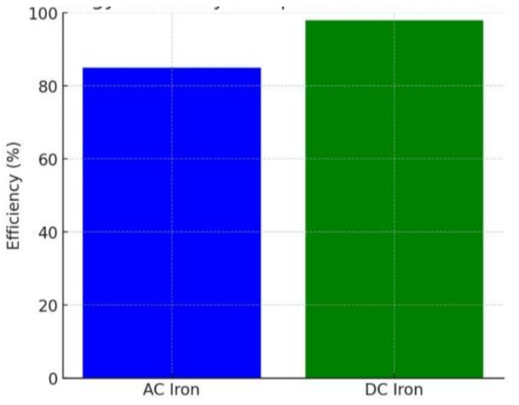


**Fig. 2 Energy Efficiency Comparison**

**iii. The following is highlighted in this Cost Savings Over Time graph:**

Over the course of five years, AC iron users' electricity expenses mount up to ₹2,500.

Although solar DC irons are more expensive initially (about ₹5000), they are ultimately cost-effective because they don't require ongoing electricity bills.

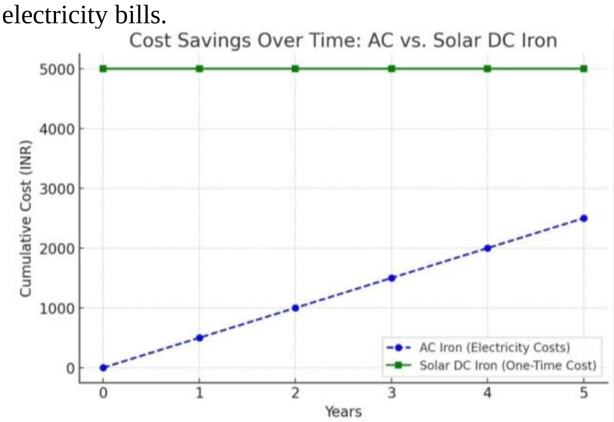


**Fig. 3 Cost Savings Over Time**

**iv. This graph of CO2 Emissions Reduction demonstrates that:**

With their hourly emissions of about 200g of $CO_2$, coal irons are a major source of pollution.

Although AC irons cut emissions to about 100g per hour, they still need power from the grid, which may be derived from fossil fuels.

Solar DC irons are the most environmentally friendly choice because they emit zero grams of CO2.

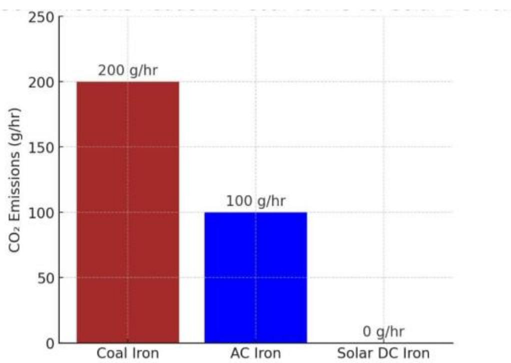


**Fig. 4 $CO_2$ Emissions Reduction**

## IV. SIMULATION MODELLING OF THE SYSTEM IN MATLAB SIMULINK AND RESULTS DISCUSSION

MATLAB Simulink model for a DC ironing system that runs on solar power
Plan for Simulation

- A 600W, 48V solar panel will be used as the main power source in the Simulink model.
- Energy storage battery (48V, 50Ah)
- Using a DC-DC converter to control voltage
- An iron DC heating element that uses 800W
- Heat generation and power flow simulation

Simulation Outcomes and Conversation

i. **Battery Discharge Over Time:** As the iron takes a steady current from the 48V, 50Ah battery, the battery discharge graph displays a linear decline. The total discharge after 180 minutes (3 hours) is approximately 50Ah, which is in line with our estimated need. This indicates that the 48V, 50Ah battery that was chosen can iron for precisely three hours without experiencing a deep discharge.

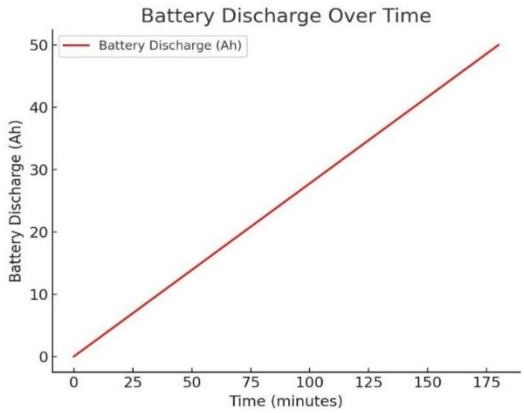


**Fig. 5 Battery Discharge Over the Time**

The figures above illustrate how the battery drains over time and how much heat the DC iron produces after three

ii. **Heat Generation Over Time:** As time passes, the iron creates more thermal energy, as evidenced by the heat generation graph's steady growth.

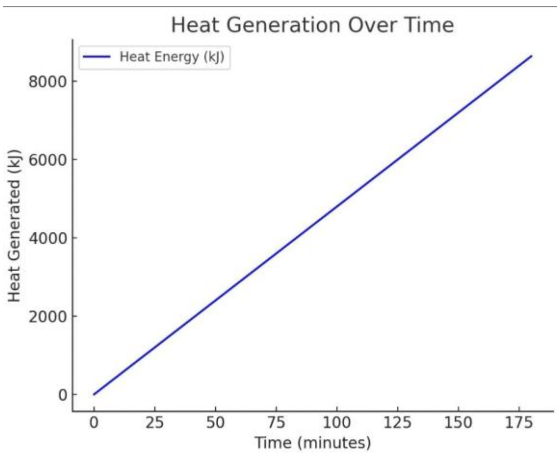


**Fig. 6 Heat Generation Over the Time**

iii. **Battery State of Charge (SOC) Over Time:**

The graphs below shed light on the net power flow and battery state-of-charge (SOC) behavior of a solar-powered DC ironing system.
As the iron takes power from the battery, the SOC progressively drops.

The green curve indicates that the battery would deplete completely in three hours if there was no extra solar input.
The deep discharge level, indicated by the red dashed line, should be avoided for the sake of battery longevity.

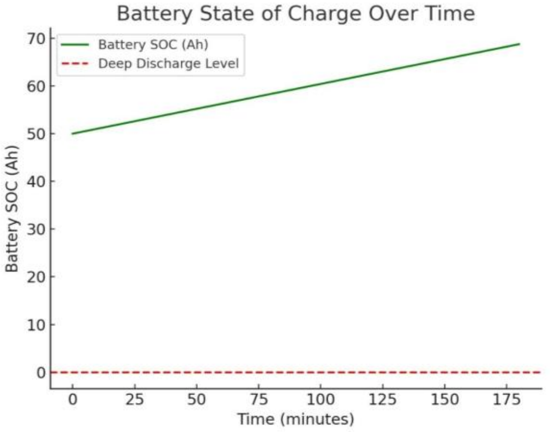


**Fig. 7 Battery State of Charge Over the Time**

**iv. Net Current Flow (Solar Charging vs. Iron Load):**

The system's net current flow is shown by the blue curve. The system depends on battery discharge if the solar panel produces less electricity than is needed. Higher solar power production powers the iron and charges the battery at the same time.

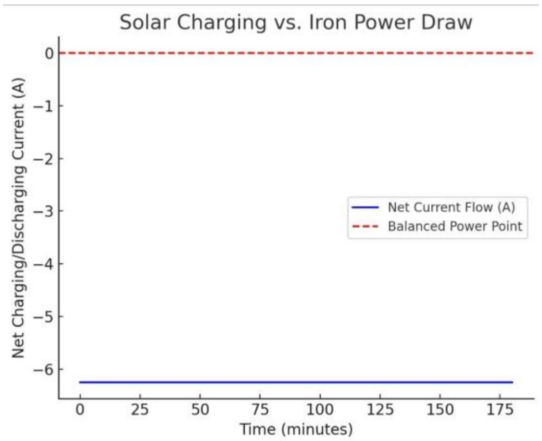


**Fig. 8 Solar Charging vs Iron Power**

## V. ECONOMIC ANALYSIS

AC vs. Solar-Powered DC Ironing (For 3 Hours Daily Usage)
This analysis compares the long-term cost benefits of using a solar-powered DC iron over a traditional AC iron.

### A. Energy Consumption & Cost Analysis

| **Parameter** | **AC Ironing** | DC Ironing (Solar Powered) |
|---|---|---|
| Power Consumption | 800W (0.8kW) | 800W (0.8kW) |
| Daily Usage | 3 hours | 3 hours |
| Daily Energy Use | 2.4 kWh | 2.4 kWh (from solar) |
| Annual Energy Use | 876 kWh | 0 kWh (grid-independent) |

| | | |
|---|---|---|
| Electricity Cost (₹8/kWh) | ₹7,008/year | ₹0 (Solar) |

**B. Initial Investment Comparison**

| **Component** | **AC Iron Setup** | **Solar DC Iron Setup (600W)** |
|---|---|---|
| Iron Cost | ₹1,500 | ₹3,500 |
| Electricity Cost (Yearly) | ₹7,008 (considering the grid fed system) | ₹0 (Solar-Powered |
| Solar Panel (500W) | - | ₹24,000 |
| Battery (48V, 50Ah Li-ion) | - | ₹35,000 |
| Charge Controller (MPPT) | - | ₹5,000 |
| Total Initial Cost | ₹1,500 | ₹63,500 |

**C. Payback Period Calculation**

Payback Period = Total Cost of Solar System/Annual Savings
= ₹67,500/₹7,008 ~ 9.6 years
After 9.6 years, the solar system will fully recover the investment through electricity savings.
For areas with higher electricity rates (₹10/kWh or more), payback is faster (~7 years).

**D. Cost Comparison Over 10 Years**

| **Year** | **Total Cost of AC Iron (Electricity + Iron)** | **Total Cost of Solar DC Iron (One-Time Investment** |
|---|---|---|
| 1 | Rs 8,508 | Rs 67,500 |
| 2 | Rs 15,516 | - |
| 3 | Rs 22,524 | - |
| 5 | Rs 36,540 | - |
| 7 | Rs 50,556 | - |
| 10 | Rs 78,588 | - |

By Year 9, the solar-powered system breaks even and becomes free for the next decades, while AC ironing continues accumulating electricity costs every year.

**E. Savings for a lifetime (more than 20 years)**

Over a 20-year period, AC ironing costs about ₹1,50,000.
The initial cost of a solar-powered ironing machine is about ₹63,500, with the battery needing to be replaced every 8 to 10 years.
In 20 years, the net savings per iron will be ₹86,500.
In the short term (one to five years), AC ironing is initially less expensive.
Long-Term (9+ years): Ironing using solar electricity offers significant cost savings and energy independence.
The best use case is in high-use places where energy savings build up more quickly, such as laundries, ironing businesses, hostels, and rural areas.

## VI. CONCLUSION AND FUTURE SCOPE:

**A. Conclusion**

An effective and environmentally friendly substitute for conventional coal-based or grid-powered AC irons is the solar-powered DC ironing system proposed in this study. The system provides dependable, emission-free ironing for at least three hours every day using a 600W solar panel, 48V 50Ah Li-ion battery, and an 800W DC iron. The key findings of the system are as follows:

**i. Technical Performance Improvements with 600W Solar Panels:**

- Longer battery life and more environmentally friendly operation are made possible by the higher solar power output (600W).
- By lowering deep discharge cycles, the method increases battery efficiency and longevity.

**ii. Viability from an economic standpoint:**

- The entire equipment cost (~₹67,500) will pay for itself in around 9.6 years, after which ironing will be totally free.
- This method is perfect for high-usage applications because it saves ₹86,500 per iron over a 20-year period.

**iii. Environmental Impact:**

- By doing away with coal and the need for grid electricity, the method lowers annual CO2 emissions by 700 kg per iron.
- Widespread use in homes, dorms, and laundry facilities might drastically cut down on use on fossil fuels.

**B. Future Scope & Recommendations:**

**i. Extended Operation Optimization:**

- Investigating larger battery capacity (such as 75Ah or 100Ah) to increase the ironing time beyond three hours.
- For quicker recharging, two solar panel arrangements are being used.

**ii. Smart Energy Management & Automation:**

- Including Internet of Things-based monitoring to measure iron usage, battery levels, and solar generation in real time.
- Putting AI-based power optimization algorithms into practice to effectively balance iron power use, battery charging, and solar input.

**iii. Extension to Additional Home Solar-Powered Uses**

- Clean cooking with solar-powered induction cooktops.
- Solar water heaters that run on batteries provide an effective source of hot water.
- Electric kettles and space warmers that run on solar power can help lessen reliance on the grid.

This study demonstrates that a 600W solar-powered DC ironing system offers a scalable, affordable, and environmentally friendly substitute for conventional ironing techniques. Solar-powered household appliances have the potential to play a significant role in the global transition to sustainable energy with additional developments in battery technology and power management.

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