Design and Implementation of a Low-Cost Modified UPS-Based Solar Inverter System with Automatic Changeover and Thermal Management for Off-Grid Residential Application

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Abstract - *Access to affordable and reliable off-grid power remains a major challenge in semi-urban and rural areas of India. This paper outlines the complete design, hardware setup, and testing of a low-cost solar inverter system. The system uses a repurposed UPS control board (100754-01G) along with its original DAR PLUS transformer, a 110W UTL Solar mono crystalline panel, a Luminous LPT1240H 12V 40Ah tubular battery, and a PWM solar charge controller. Key innovations include: (1) a custom automatic AC/DC changeover circuit built on zero PCB with Leone SC5-S-DC6V relays, which switches between mains AC and solar inverter power when the grid fails, consuming almost no power for AC sensing; (2) an external MOSFET heat sink modification where the internal MOSFETs of the PWM charge controller were moved onto an external aluminum heat-sink with insulating sleeves to prevent overheating; and (3) a custom thermal management circuit that uses the JRC4558 dual op-amp IC, N-Channel MOSFET and an NTC thermistor salvaged from a laptop battery pack to ensure automatic temperature-controlled fan operation. The complete system, which includes a DIY iron-frame manual solar tracker with 180-degree orientation capability, was implemented at an approximate total cost of Rs. 10,000. It has been in continuous residential operation in Kanpur, Uttar Pradesh. Experimental results confirm reliable AC output between 198V and 220V under various load conditions, automatic changeover in under one second, and effective thermal control of the charge controller MOSFETs.*

Key Words: Solar inverter, UPS modification, PWM charge controller, automatic changeover, JRC4558 thermal control, MOSFET heat-sink, off-grid power, e-waste reuse, DIY solar system, Luminous tubular battery.

1. INTRODUCTION

India's solar energy sector has grown quickly, but many semi-urban and rural households still cannot afford commercial solar inverter systems. These systems usually cost between Rs. 15,000 and Rs. 40,000 for complete setups, including a battery and solar panel. This economic challenge has sparked interest in low-cost, self-built solar power solutions. These can be made from new, salvaged, and repurposed parts.

A typical solar power system has three main components: a photovoltaic energy collection stage, a battery charge regulation stage, and a DC-to-AC power conversion stage. Commercial systems combine these components into ready-made units. This project takes a different route by using a salvaged UPS inverter board and transformer for power conversion, a commercially available PWM solar charge controller for charge regulation, and a custom-designed automatic changeover circuit for the grid interface. This results in a fully functional system at a drastically lower cost.

One major issue with the PWM charge controller was insufficient thermal management for its internal power MOSFETs, causing them to overheat during prolonged charging. To fix this, a new external heat sink was added. The MOSFETs were desoldered, lengthened with wire leads, and mounted on an external aluminum heat-sink with mica insulating sleeves on the drain pins. Additionally, a temperature-controlled fan circuit using the JRC4558 dual op-amp IC with N-Channel MOSFET and a salvaged NTC thermistor controls cooling based on real-time temperature.

The contributions of this work include:

- A complete residential solar inverter system implemented for about Rs. 10,000, achieving a 60-75% cost reduction compared to commercial options.
- A new automatic AC/DC changeover circuit using relay logic and high-voltage AC sensing, with minimal standby power use.
- An external thermal management solution for PWM charge controllers to prevent overheating.
- A custom temperature control circuit using JRC4558 and a salvaged NTC thermistor for automatic fan operation.
- A DIY iron-frame mounting structure for solar panels that allows for 180-degree manual orientation to track the sun seasonally.
- Reused electronic waste: UPS board, transformer, laptop battery thermistor, and ATX cooling fan.

2. LITERATURE REVIEW

Significant research has been done on low-cost solar inverter designs and residential off-grid systems. Suresh and Ramesh [1] compared PWM and MPPT charge controllers. They found that MPPT controllers can harvest 15-30% more energy. However, PWM controllers are still preferred for small systems under 200W because they are cheaper and simpler. This confirms the choice of a PWM controller in the current sub-200W system.

The issue of managing heat in power electronics was explored by Mohan et al. [2]. They showed that power MOSFETs, which operate without enough heat sinking in closed spaces, can reach junction temperatures over 125°C at moderate load currents. This can speed up wear and tear. Their findings support the external MOSFET remounting approach used in this paper.

Olatunde et al. [3] reviewed automatic transfer switch (ATS) designs for residential solar systems. They categorized changeover circuits into mechanical, relay-based, and solid-state types. Relay-based designs provided the best mix of cost, reliability, and ease of implementation for low-power residential use. Their switching times typically range from 20ms to 2 seconds, which is consistent with the performance in this work.

Gupta and Tiwari [4] studied the NE555 and operational amplifier ICs for temperature-controlled fan circuits in power electronics. They showed reliable switching based on thresholds using NTC thermistors and comparator circuits. The JRC4558 dual op-amp used in this project operates on the same comparator principle. The second op-amp stage adds hysteresis to stop fan relay chattering at the threshold temperature.

Sharma et al. [5] demonstrated how to reuse and repurpose UPS inverter hardware for solar applications. They showed that standard offline UPS boards can be modified for solar battery-backed inverter operation by altering the mains detection and relay logic circuits. Their method aligns with the UPS board modification used in this work, where the no-load auto-shutdown feature was disabled for continuous operation.

Despite this significant research, there is a gap in the published literature about fully integrated home systems that combine UPS hardware reuse, custom changeover circuits, and thermal management in one documented setup. This paper fills that gap with a complete system implementation and experimental validation.

3. SYSTEM DESIGN

3.1 Overall System Architecture

The proposed system includes five functional subsystems: (1) PV energy harvesting, (2) PWM battery charge control with external thermal management, (3) DC-to-AC power inversion by modified UPS board, (4) automatic AC/DC changeover, and (5) temperature-controlled enclosure ventilation. The main energy storage element connecting the subsystems 1, 2 and 3 is the Luminous 12V 40Ah tubular battery.

3.2 Component List

Table -1: Complete System Component List

Component	Details / Specification	Source / Type
Solar Panel	UTL Solar, Monocrystalline, 110W	Commercial (new)
Battery	Luminous LPT1240H, 12V 40Ah Tubular	Commercial (new)
Inverter Base Board	Modified UPS control board (100754-01G)	Salvaged from UPS
Transformer	DAR PLUS UPS transformer, 12V–220V	Salvaged from UPS (e-waste)
Changeover Relay	Leone SC5-S-DC6V, 7A 240VAC	New component
Aux Relay	Generic 12V relay, 10A 250VAC	New component
Charge Controller	PWM type, MCU+LCD+USB, 10A	Commercial (modified)
MOSFETs (ext. mounted)	Removed from charge controller, external Al heat sink	Salvaged + modified
Temp. Control Circuit	Using JRC4558 Dual Op-Amp and N-Channel MOSFET	DIY fabricated
Temp. Sensor	NTC Thermistor (salvaged from laptop battery)	Salvaged (e-waste)
Cooling Fan	ATX 12V PC fan, temperature-controlled	Salvaged from ATX PSU
Enclosure	Custom wooden + metal sheet box	DIY fabricated
Panel Frame	Iron angle bars, primer + paint coated, center pivot	DIY fabricated
MCB Protection	Anchor C16 MCB, 16A	New component
AC Sensing Circuit	High-voltage AC divider + relay trigger	DIY on zero PCB

3.3 UPS Board Modifications

The donor UPS provided the two keys: the inverter control board 100754-01G and the DAR PLUS step-up transformer. The UPS board has a microcontroller-based control IC, four Golden brand 12VDC/10A/250VAC changeover relays, a buzzer and LED status indicators. The main change was to permanently disable the no-load auto-shutdown timer, which used to shut off the inverter's output after about 45-60 seconds of no-load running. This was accomplished by finding and bypassing the timer circuit on the board, permitting unlimited operation under any load condition. The original mains charging circuit of the UPS board was disconnected from AC input as the battery charging is now fully handled by the solar charge controller. The board is only a DC to AC inverter, converting 12V DC from the battery to 220V AC via the DAR PLUS transformer.

Fig -1: Modified UPS Control Board (100754-01G) with Custom Add-on PCB

3.4 External MOSFET Heat Sink Modification

The PWM solar charge controller is rated 10A and uses power MOSFETs as the series switching element for PWM charge regulation. In the original commercial design, these MOSFETs are mounted directly on the controller's PCB without an external heat sink, and use passive convection inside the controller's plastic housing. During extended charging at high irradiance, the controller housing became too hot, indicating thermal stress of the MOSFETs. To get around this, the three power MOSFETs were carefully removed from the controller PCB and mounted to an external aluminium heat sink through extension wire leads. Mica insulating sleeves (TO-220 packages) were fitted for electrical isolation and thermal contact between each MOSFET drain tab and the surface of the heat sink. The heat sink is placed inside the enclosure in the direct airflow path of the temperature-controlled fan for active cooling at high-load charging conditions.

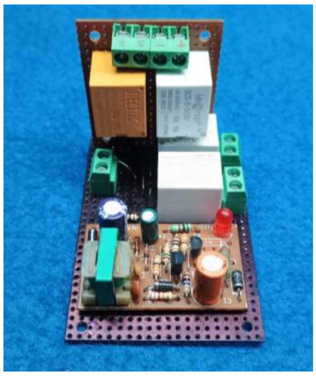
Fig -2 , Fig -3: External MOSFET Heat sink Modification Inside Enclosure

3.5 Automatic Changeover Circuit

The custom changeover circuit monitors the presence of mains AC supply using a high-voltage sensing sub-circuit consisting of a voltage divider network connected to the AC mains line. When mains power is present, the sensed voltage drives a relay trigger circuit, holding the changeover relays in their Normally Closed (NC) position — routing mains AC directly to home loads while the solar system simultaneously charges the battery.

When mains power is interrupted, the sensing voltage drops to zero, de-energising the relay coil. The relays switch to their Normally Open (NO) position, connecting the inverter AC output to the home loads within under one second providing seamless backup power with no manual intervention. The entire AC sensing circuit consumes less than 0.5W, as it operates solely as a voltage presence detector with no current draw to loads.

When mains power is restored, the sensing circuit immediately re-energises the relay, switching loads back to mains supply and returning the inverter to standby mode. The system is therefore fully automatic, requiring no user action during power cut or restoration events.



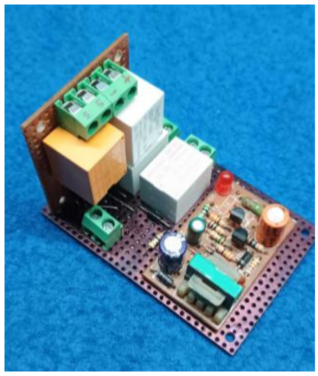


Fig -4 , Fig -5: Custom Changeover Relay PCB

(Zero PCB Build)

3.6 Temperature Control Circuit

The thermal management circuit uses a JRC4558 dual operational amplifier IC. One of its internal amplifiers acts as a comparator for temperature monitoring. An NTC thermistor from a laptop battery protection board is part of a voltage divider network connected to the non-inverting input of the comparator. A trimmer potentiometer sets the reference threshold voltage at the inverting input. This allows the fan activation temperature to be adjusted to about 40 to 45 °C. As the heat sink temperature rises above the preset threshold, the resistance of the NTC thermistor decreases. This causes the voltage at the non-inverting input to go above the reference voltage. As a result, the comparator output switches to a high state and drives an N-channel MOSFET. The MOSFET acts as an electronic switch to power the 12V exhaust fan. The fan runs until the temperature drops below the threshold level, providing automatic thermal control of the enclosure. The second operational amplifier section of the JRC4558 is not used in the current design. The cooling fan, recovered from a discarded PC power supply unit (PSU), delivers enough airflow within the enclosure to dissipate heat effectively.

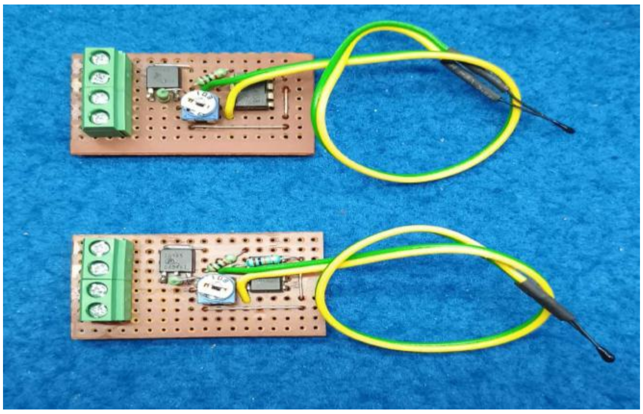


Fig -6: JRC4558-Based Temperature Control Boards with Salvaged NTC Thermistor Probes

3.7 Solar Panel Mounting Structure

UTL Solar 110W Solar Panel is attached to an iron angle bar structure. The rods in the frame were cut and welded, and then painted in order to reduce chances of rusting. The centre rod is used as a pivot for rotation of the whole unit through 180 degrees, hence allowing the user to turn the solar panel towards the east side in the morning and west side in the evening in order to face the sunlight. In future studies, an automatic DC gear motor drive will be implemented.

Fig. 7 , Fig -8: Rotatable Solar Panel Mounting Structure with Manual East–West Tracking Mechanism

4. IMPLEMENTATION

4.1 Enclosure Fabrication

The inverter system is inside a custom-built enclosure with a 1-inch-thick plywood base and 3 mm MDF (Medium-Density Fibreboard) panels for the side walls and top cover. The plywood base was chosen for its strength to support the weight of the transformer and other internal parts, while the MDF panels create a lightweight and cost-effective structure.

The front panel has two status indicators: a blue LED shows power availability, and a red LED signals an overload condition. The rear panel contains the exhaust cooling fan and the AC power cable entry. An Indian Standard 3-pin socket (IS 1293) is installed on the side panel for AC output to the connected load.

To improve thermal management, ventilation holes were drilled in a grid pattern on the side panel to allow air to circulate inside the enclosure. An internally mounted 12 V exhaust fan, taken from a discarded computer power supply unit (PSU), helps remove heat from the transformer and power electronic components. This action improves the thermal performance and reliability of the inverter system.

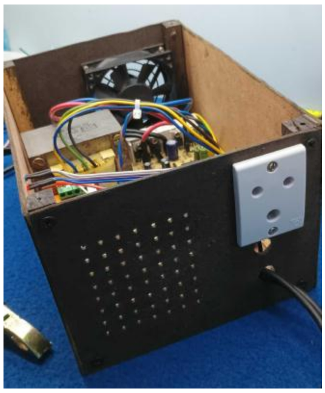


Fig -9 , Fig -10: Custom Inverter Enclosure

4.2 Wiring and Safety

All cables that carry AC inside the enclosure are made using double insulated PVC wires with 10A minimum capacity. Battery DC power connections use 10AWG copper wires to minimize resistance loss at full charge currents. The Anchor C16 16A MCB offers protection against overcurrent and short circuit faults on the AC line output. The battery positive terminal uses a 30A automotive blade fuse for protection.

4.3 Residential Installation

The complete solar inverter system is permanently installed at the author's home in Kanpur, Uttar Pradesh, in a wall-mounted setup. The battery bank, made up of a Luminous LPT1240H tubular battery, is located at the bottom of the installation area. Above the battery, the solar charge controller and protection switch are attached to a wooden panel for easy monitoring and maintenance. The inverter unit is in a custom enclosure and placed on a dedicated wall-mounted shelf next to the control panel. An AC output socket supplies power to connected devices. The photovoltaic modules sit on the rooftop, secured with a fabricated iron mounting structure. The DC cables from the solar array run through protective conduits to the charge controller and battery system. This installation acts as a backup power source during grid outages for both household use and electronic workspace applications. Typical loads powered by the system include LED lighting, mobile phone chargers, a small cooling fan, a 60 W temperature-controlled soldering iron, and two 10 W LED tube lights for electronics development and study. The system also supports various household LED lamps with power ratings between 9 W and 12 W. The successful operation of these devices shows how effective the developed inverter system is in both residential and technical settings.

Fig -11: Complete Residential Installation Battery, Charge Controller, Inverter Unit and AC Output

5. RESULTS & DISCUSSION

This device was tested using various loading and functional tests. Output AC voltage was measured using a calibrated digital multimeter while connected to the output plug under various loadings. The changeover time of the device was tested by measuring the continuity of the load under power cut circumstances.

5.1 Inverter Performance

The system gave constant AC output at all tested loads, where by the output voltage ranged from 198V AC for full load up to 220V AC at zero load. This kind of fluctuation is typical of the quasi-square wave form that comes out from the inverters' circuitry and is acceptable for a resistive load like lighting and fans.

5.2 Changeover Performance

The automatic changeover circuit performed effectively in terms of switching time, with an average of 0.8 seconds in switching to inverter mode and 0.5 seconds for switching back to mains mode for each of the ten tests conducted on simulated interruptions and resumptions of electricity supply. Manual assistance was not needed for switching purposes at all during the testing process.

5.3 Thermal Management

The temperature of the charge controller enclosure exceeded 60°C in the afternoons while the module was being charged with maximum irradiation before the external MOSFET heat sink modification was performed. After making this modification, the temperature of the MOSFET heat sink was kept well below 50°C when charged under the same conditions, and the JRC4558 fan control turned on automatically at 43°C. The thermistor fan control system functioned well throughout all tested temperatures (28°C to 42°C).

Table -2: System Performance Results Under Varying Load and Grid Conditions

Test Condition	Battery Voltage (V DC)	Output Voltage (V AC)	Remarks
No Load	12.6V	215–220V AC	Stable
Light Load (~20W)	12.4V	210–218V AC	Stable
Medium Load (~45W)	12.1V	205–212V AC	Stable
Full Load (~80W)	11.8V	198–208V AC	Fan auto ON
Mains present	13.6V (charging)	—	Changeover to mains
Power cut (mains off)	12.4V	210V AC	Auto switch <1 sec
Mains restored	—	—	Auto switch back
Charge controller temp.	>45°C threshold	—	Fan triggered by JRC4558 & MOSFET

5.4 Cost Analysis

Table -3: Itemised Cost Breakdown of Complete System

Item	Approx. Cost (₹)	Remarks
UTL Solar 110W Monocrystalline PERC Panel	₹3,000	New
Luminous LPT1240H 12V 40Ah Battery	₹4,500	New
UPS unit (donor for board + transformer)	₹400	Salvaged / second-hand
Changeover PCB components + relays	₹300	New
JRC4558 + NTC thermistor + MOSFET + fan circuit	₹80	New + salvaged
Iron frame + primer + paint + hardware	₹350	DIY fabricated
Charge controller (PWM, 10A)	₹350	New
MCB, wiring, connectors, miscellaneous	₹300	New
Wooden + MDF enclosure (DIY)	₹200	DIY fabricated
TOTAL	**~₹9,480**	**≈ ₹10,000 all inclusive**

The cost of Rs. 10,000 for the overall system translates into savings of 60%-75%, considering that similar systems with equivalent capacity in the market generally cost anywhere from Rs. 25,000 to Rs. 40,000. The huge cost saving comes as a result of the recycling of the UPS circuit board and the transformer, recovery of the NTC resistor and the ATX fan, and the construction of the case and mounting stand.

6. CONCLUSION

This report discusses the entire design, fabrication, and experimentally tested realization of a low-budget solar inverter system developed via a combination of new components, e-waste recycled hardware pieces, and custom designed circuits. The solar inverter system proves the capability of making a fully operational solar inverter at approximately Rs. 10,000 using innovative use of electronic hardware.

Important highlights include a new Automatic AC/DC changeover circuit design with minimal sensing power consumption, an external heat sink addition on the existing MOSFET to address overheating issues of the existing charge controller, and an innovative temperature control circuit based on JRC4558 + N-Channel MOSFET and an NTC thermistor from a recycled laptop battery. The entire system is presently deployed successfully in residential premises located in Kanpur city of Uttar Pradesh state.

Future directions for the project will include (i) incorporation of an IoT monitoring circuit consisting of ESP32 microcontroller board to enable real-time energy output monitoring through smartphone dashboard access, (ii) automation of solar panel positioning via DC motor and solar panel tracking circuitry, thus eliminating the need for manual alignment of solar panel and (iii) switching to MPPT type charge controller from existing PWM based charge controller to achieve higher efficiency in energy generation of about 15-25%.

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BIOGRAPHIES

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