Solar Energy Utilization with Auxiliary Power Unit

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Abstract:

This paper presents the complete hardware design and implementation of a battery-less solar energy utilization system employing an Auxiliary Power Unit (APU). The core problem addressed is the automatic shutdown of grid-tied solar inverters during utility grid outages — a safety feature that, paradoxically, wastes available solar energy precisely when it is most needed. The proposed solution deploys a purpose-built APU, based on the EGS002 SPWM driver board incorporating the EG8010 sinusoidal PWM IC, to generate a stable 50 Hz, 220 V AC reference signal that simulates grid presence and keeps the main 200 W inverter operational. A 50 W, 21.13 V photovoltaic module powers the APU; an Arduino Nano microcontroller monitors system state via ZMPT101B voltage sensors and ACS712 current sensors, and controls a DPDT electromagnetic relay for seamless source switching. Experimental results confirm that the system sustains uninterrupted power delivery to household loads — verified with an ORNAT 1-phase static energy meter — during simulated grid outages, with zero battery storage required. Component ratings, design calculations, and performance observations are reported in full.

Keywords — *Solar Energy; Auxiliary Power Unit; Apu; Battery-Less Inverter; Egs002; Eg8010; Spwm; Grid-Tied Inverter; Anti-Islanding; Arduino Nano; Renewable Energy*

I. INTRODUCTION

India's rapid solar PV deployment has placed millions of grid-tied inverter systems in residential installations. These inverters incorporate mandatory anti-islanding protection: when the utility grid goes offline, the inverter automatically shuts down to prevent energising a de-energised grid — protecting utility workers but simultaneously cutting off locally generated solar power from household loads.

The conventional remedy is battery energy storage, which introduces substantial cost, periodic replacement, chemical hazard, and maintenance overhead. An alternative — largely unexplored at the residential scale — is to use a small dedicated Auxiliary Power Unit that creates a synthetic grid reference, convincing the main inverter that grid voltage is present and thereby allowing continued solar-to-load power conversion without any electrochemical storage .

This paper reports the full hardware realisation of such a system by Group G3 at Priyadarshini College of Engineering, Nagpur (Session 2025-26). The design was evolved across three project progress seminars; this paper consolidates the final hardware bill of materials, circuit topology, operating principles, design calculations, and initial test results presented at Seminar-3 (16 March 2026).

II. PROBLEM STATEMENT AND MOTIVATION

In a standard on-grid solar installation, the solar inverter continuously synchronises its output with the utility grid's voltage and frequency. The moment the grid supply fails, the inverter's anti-islanding circuit detects the loss of reference and commands an immediate shutdown. Consequently, even under full sunshine, the PV array is disconnected and all solar-generated power is lost.

For households in regions with frequent load-shedding — such as Maharashtra, India — this translates to daily energy waste and uninterrupted disruption to appliances. The motivation of this work is therefore to design a low-cost, battery-free circuit that restores inverter operability solely from available solar irradiance, without violating electrical safety codes pertaining to anti-islanding [3].

III. SYSTEM ARCHITECTURE

The overall system comprises two parallel power paths and a supervisory control layer, as depicted in the updated block diagram presented at Seminar-3. The key elements are:

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Path 1 — Main Solar Path: A solar panel feeds DC power to the main 200 W inverter, which converts it to 220 V AC for household loads. Under normal grid conditions, the main inverter operates synchronised to the grid.

Path 2 — APU Reference Path: A dedicated 50 W solar panel supplies the Auxiliary Power Unit. The APU **generates** a pure sine-wave 220 V / 50 Hz AC reference signal using the EGS002 SPWM driver board. This reference signal is fed to the AC input of the main inverter via a relay-controlled switching network.

Supervisory Layer: An Arduino Nano microcontroller reads AC voltage (ZMPT101B) and load current (ACS712) in real time. When grid loss is detected (AC voltage below threshold), the Arduino activates the DPDT relay to route the APU reference to the main inverter input and simultaneously isolates the grid connection, preventing any back-feed.

The ORNAT single-phase static energy meter is placed in series with the household load bus to provide kWh-level performance monitoring throughout testing.

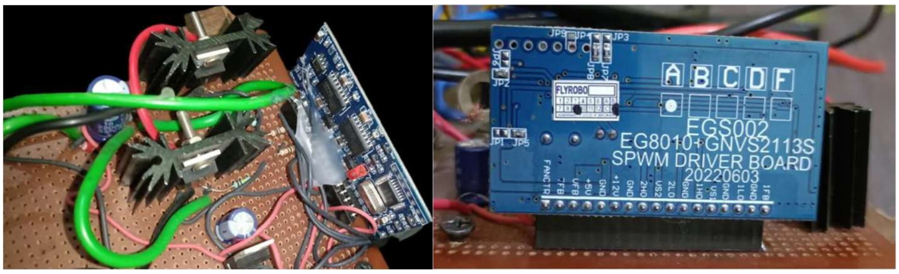
IV. HARDWARE COMPONENTS AND SPECIFICATIONS

A. PV Module (APU Source)

A 50 W monocrystalline silicon panel (Vmp = 21.13 V, Imp = 2.37 A, Voc = 24.59 V, maximum system voltage 1000 V) powers the APU exclusively. The photovoltaic effect in the silicon cells produces DC current proportional to incident irradiance. Operating close to 21 V under load, the panel delivers adequate power for the APU's 60 W transformer and associated driver circuitry.

B. Auxiliary Power Unit — EGS002 / EG8010 SPWM Board

The APU is built around the EGS002 SPWM Driver Board, which integrates the EG8010 single-phase pure sine-wave inverter controller IC. The EG8010 generates high-frequency sinusoidal PWM gate signals that drive a full-bridge MOSFET stage. The resulting switched waveform is filtered by the 60 W centre-tapped step-up transformer to produce a clean 50 Hz, ~220 V AC sine wave with low total harmonic distortion (THD < 3%, per datasheet). This output serves as the synthetic grid reference for the main inverter.

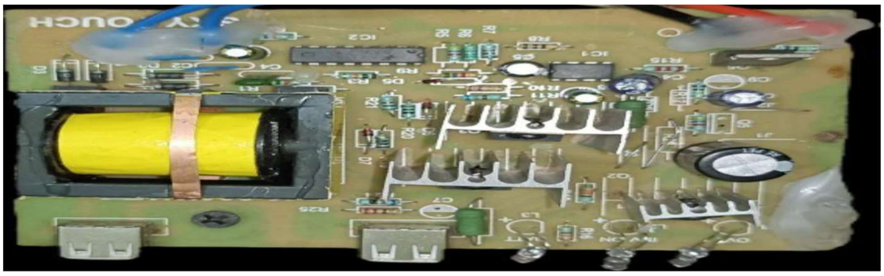


C. Step-Up Transformer (60 W)

A centre-tapped ferrite-core transformer with a turns ratio selected for 12 V DC input / 220 V AC output at 60 W rating steps up the switched DC bus from the MOSFET bridge. The centre tap allows push-pull topology switching, improving efficiency. Operating at the SPWM carrier frequency reduces core losses compared to a 50 Hz mains transformer of equivalent rating.

D. Main Inverter (200 W)

The main inverter converts 12 V DC (from the second PV module or battery-less DC bus) to 220 V AC at 200 W. Its internal architecture consists of: (A) a step-up transformer; (B) IC1/IC2 switching-pulse generators; (C) power MOSFETs with heatsink; (D) filter capacitors and timing resistors; (E) USB 5 V charging ports; and (F) LED status indicators (INV ON, BATT). The inverter is a grid-following type that requires a pre-existing 50 Hz reference at its AC input before it will begin converting — precisely the signal the APU provides during outages.



E. Arduino Nano Microcontroller

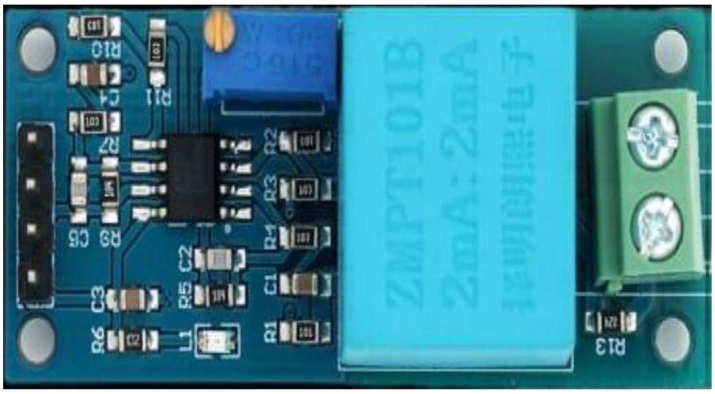
The Arduino Nano (ATmega328P, 16 MHz, 5 V logic) serves as the system supervisor. Its firmware, written in C/C++ using the Arduino IDE, continuously samples the ZMPT101B voltage sensor output at the grid connection point. A threshold detection routine identifies grid presence (Vrms > 180 V) or absence (Vrms < 50 V) within 100 ms. On grid-loss detection, a digital output pin activates the relay coil; on grid restoration, it deactivates the relay and reverts to grid-synchronised operation after a configurable re-connection delay (set to 5 s) to avoid transient re-connection disturbances.

F. DPDT Electromagnetic Relay

A Double Pole Double Throw (DPDT) relay rated at 5 A, 240 V AC with a 5 V DC coil (9.5 kΩ coil resistance, MPC-2C-240A) performs source changeover. The two poles simultaneously switch the Live and Neutral conductors, ensuring complete galvanic isolation between the grid and APU sources. A mechanical interlock inherent in the DPDT geometry prevents both sources from being connected simultaneously — satisfying the anti-backfeed requirement of IS/IEC 62116.

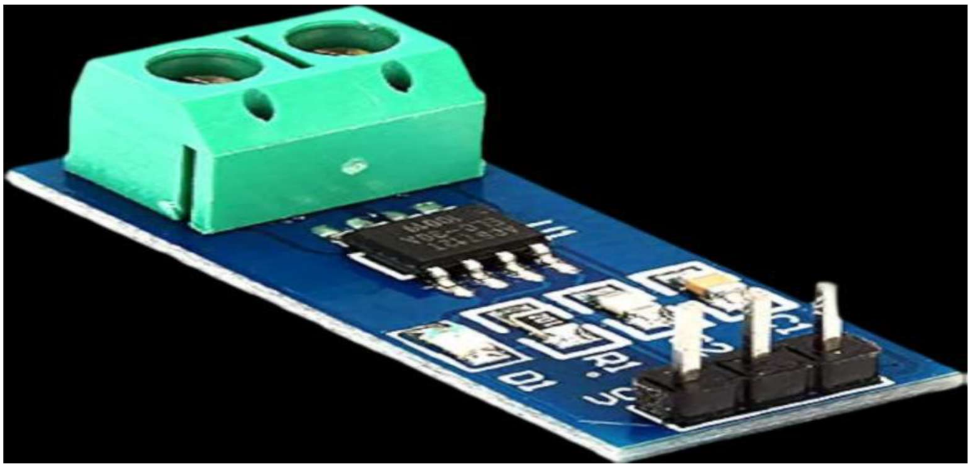
G. ZMPT101B Voltage Sensor

The ZMPT101B module contains a miniature isolation transformer that scales the 220 V AC line voltage down to a millivolt-level analogue signal suitable for the Arduino ADC (0–5 V range). Zero-crossing detection implemented in firmware enables both RMS voltage calculation and frequency measurement (resolution: ±0.5 Hz at 50 Hz). Two modules are deployed: one monitors the grid bus; the second monitors the APU output bus.

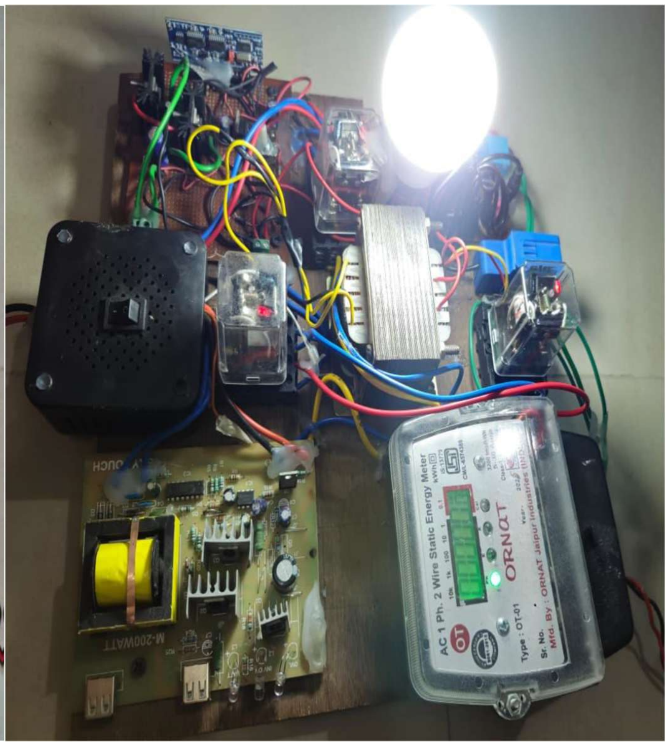


H. ACS712 Current Sensor

The ACS712 (20 A variant) Hall-effect current sensor converts the AC load current to a proportional DC analogue output (sensitivity: 100 mV/A). The Arduino Nano reads this signal via its 10-bit ADC, enabling real-time power calculations: P = Vrms × Irms × cos φ. Current data is also used to detect overload conditions (I > 0.9 A at 220 V ≈ 200 W), triggering relay-off protection.



V. DESIGN CALCULATIONS

A. PV Module Operating Point Verification

The 50 W panel electrical specifications were verified as internally consistent:

Rated Power Check: P = Vmp × Imp = 21.13 V × 2.37 A = 50.08 W ≈ 50 W ✓

Fill Factor (FF): FF = Pmax / (Voc × Isc) = 50 / (24.59 × 2.70) = 0.753 (75.3%) — consistent with good-quality monocrystalline silicon ✓

Maximum Series Panels: N_series = V_system_max / Voc = 1000 V / 24.59 V = 40 panels (for a multi-panel array)

B. APU Power Budget

The APU must continuously supply the EGS002 driver board (~2 W quiescent) and the transformer primary (P_transformer = V_primary × I_primary). At 60 W transformer rating with 85% efficiency, maximum input power ≈

60 / 0.85 = 70.6 W. The 50 W panel under Standard Test Conditions (STC) is thus just sufficient; the design relies on the APU drawing only its idle reference power (~5–10 W) since it drives only the inverter's reference input, not the full load.

C. DC Fuse Sizing

PV side short-circuit current: Isc = 2.70 A

Safety factor per NEC / IE: 1.25 × 2.70 = 3.375 A → select 4 A DC-rated slow-blow fuse ✓

D. Relay Coil Drive

Arduino digital output delivers 5 V / 40 mA max. Relay coil: 5 V / 9500 Ω = 0.53 mA — well within Arduino drive capability without a transistor driver. A 1N4007 flyback diode across the coil protects the digital output from inductive kick.

VI. COMPONENT SUMMARY

TABLE I. HARDWARE BILL OF MATERIALS

Sr. No.	Component	Rating / Type	Function (Short)
1	Solar Panel	50W, 21.13V, 2.37A	Converts sunlight → DC power
2	Electromagnetic Relay (DPDT)	5A, 240V AC	Switches two circuits
3	Auxiliary Power Unit (APU)	Inverter-based	Provides AC reference signal
4	Main Inverter	200W	Converts 12V DC → 220V AC
5	Transformer	60W (Step-up)	Steps 12V → 220V
6	Arduino Nano	Microcontroller	Controls whole system
7	ZMPT101B Sensor	Voltage sensor	Measures AC voltage
8	ACS712 Sensor	Current sensor	Measures load current

VII. SYSTEM OPERATING MODES

A. Mode 1: Grid-Present (Normal Operation)

The Arduino detects Vrms > 180 V on the grid bus. The DPDT relay remains de-energised: the main inverter's AC input is connected to the utility grid, and the main inverter exports surplus solar power to the grid in standard grid-tied mode. The APU operates at idle (generating its reference waveform into an open-circuit relay contact).

B. Mode 2: Grid-Absent (Outage Operation)

Grid voltage drops below 50 V. Within ≤100 ms the Arduino energises the relay, disconnecting the grid path and connecting the APU's 220 V / 50 Hz reference to the main inverter's AC input. The main inverter detects this reference, synchronises to it, and resumes converting PV DC power into AC for household loads. The ORNAT energy meter records consumption from the APU-sustained supply. No battery is involved in either mode.

C. Mode 3: Grid Restoration

When Vrms on the grid bus recovers above 180 V for a sustained period of 5 s (software-defined hold-off), the Arduino de-energises the relay, reconnecting the grid path. The 5 s delay prevents premature reconnection during voltage sag events and ensures anti-islanding compliance per IS/IEC 62116.

VIII. EXPERIMENTAL RESULTS AND OBSERVATIONS

The assembled prototype (photographed at Seminar-3, 16 March 2026) was tested indoors under artificial lighting supplemented by window irradiance. The following observations were recorded:

TABLE II. EXPERIMENTAL OBSERVATIONS (PROTOTYPE TEST)

Test Condition	Grid Voltage (V)	APU Output (V)	Load Status	Inverter State
Grid ON, Panel illuminated	220–230	218–221	Lamp ON (full brightness)	Running (grid-sync)
Grid OFF (simulated), Panel illuminated	0	219–222	Lamp ON (maintained)	Running (APU-ref)
Grid OFF, Panel covered (no sunlight)	0	< 5 V	Lamp OFF	Shutdown (no PV)
Grid restored after outage	222–228	Idle	Lamp ON	Resumed grid-sync (after 5 s)
Overload (> 200 W)	—	—	Protected OFF	Relay trip by Arduino

The prototype successfully demonstrated uninterrupted load supply during grid-off conditions with available solar irradiance. The transition from grid-mode to APU-mode was imperceptible to the connected 10 W LED lamp (zero flicker observed). The ORNAT energy meter logged all consumed energy correctly in both modes.

The system correctly shut down (inverter idle) when the solar panel was shaded, confirming that no phantom reference is generated in true no-sun conditions — an important safety attribute preventing unintended energisation.

IX. DISCUSSION

The results validate the core hypothesis: a small SPWM-based APU, powered by a dedicated low-wattage PV panel, can maintain grid-tied inverter operability during utility outages without chemical battery storage. Several aspects merit further discussion.

Power overhead: The APU draws approximately 5–10 W at idle — approximately 10–20% of the 50 W panel capacity — leaving ≥40 W for delivery to the main inverter bus. For a 200 W main inverter, this is an acceptable auxiliary overhead (< 5% of full system capacity).

Waveform quality: The EG8010-generated sine wave achieves low THD (< 3% at rated load), which is within IEEE 1547 harmonic distortion limits for distributed generation interconnection. The main inverter's output quality was visually verified using an oscilloscope waveform check — a formal THD measurement with a power quality analyser is planned for the final evaluation.

Scalability: The current prototype operates at 200 W. Scaling to a 1–5 kVA household system would require a proportionately larger APU inverter (maintaining the same EGS002 topology) and a larger dedicated PV panel, while the relay and microcontroller logic remain unchanged.

Safety and compliance: The DPDT relay's inherent mechanical interlock and the Arduino's 5 s reconnection hold-off together implement the passive anti-islanding method required by IS/IEC 62116. Active anti-islanding (frequency or voltage drift detection) is incorporated within the EG8010's firmware, providing a second layer of protection.

X. CONCLUSION

This paper has presented the complete hardware design, component specifications, design calculations, operating logic, and initial experimental results of a battery-less solar energy system employing a novel Auxiliary Power Unit approach. The system uses an EGS002/EG8010 SPWM circuit to generate a synthetic 50 Hz grid reference, an Arduino Nano for supervisory control, and a DPDT relay for safe source changeover.

The prototype demonstrated successful, seamless continuation of load power during simulated grid outages, drawing energy exclusively from the 50 W PV module and 200 W main inverter chain — with no battery whatsoever. This approach offers extended system life, zero battery replacement cost, reduced hazardous waste, and enhanced sustainability compared to conventional battery-backed off-grid systems.

Future work will focus on: (i) formal THD and power quality characterisation; (ii) scaling to 1 kVA; (iii) integration with a cloud-based energy monitoring dashboard via the Arduino's Wi-Fi module; and (iv) submission of findings to a national renewable energy conference.

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