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A Review on Battery-Less Solar Energy Utilization Using Auxiliary Power Units in Grid-Outage Conditions

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Abstract: *This project develops a solar-powered Auxiliary Power Unit (APU) for off-grid power generation, integrating a photovoltaic panel, battery storage, DC-to-AC inverter with 250V-rated relays, and digital meter for monitoring. The system converts solar DC energy into reliable AC output through charge-controlled battery charging, inverter conversion, and relay-protected load switching, achieving ~90% efficiency for applications like remote water pumping in Nagpur.*

Key objectives include emission-free auxiliary power, real-time voltage/current oversight, and optional ESP32-based IoT enhancements for sensor-driven automation (e.g., CT current sensing, voltage dividers, RTC relay scheduling, LoRa data logging). Hardware flow ensures safety via fuses/grounding; software enables remote optimization via Thingspeak.

Tested under variable sunlight, it outperforms fuel generators in sustainability, with future scope for MPPT and solar-wind hybrids. This embedded renewable solution addresses grid unreliability effectively..

Keywords: ESP32-BASE IOT, APU, RTC, MPPT

I. INTRODUCTION

In an era of escalating energy demands and unreliable grid infrastructure, particularly in remote regions like Nagpur, Maharashtra, there is a pressing need for sustainable, off-grid power solutions to support critical applications such as automated water pumping and IoT-based renewable systems. Conventional auxiliary power units (APUs) rely on fuel-consuming generators, leading to high operational costs, emissions, and maintenance challenges, whereas solar-powered alternatives harness abundant photovoltaic energy for clean, autonomous electricity generation. This project introduces a compact solar-powered APU .

system that integrates a photovoltaic panel, battery storage unit, DC-to-AC inverter equipped with 250V-rated relays for overvoltage protection, and a digital meter for real-time monitoring, aiming to deliver stable AC output with ~90% efficiency.

The primary objective is to design, implement, and validate an emission-free APU that eliminates engine idling while enabling smart enhancements via ESP32 microcontroller—incorporating prior expertise in CT sensors for AC current, voltage dividers, RTC-scheduled relays, and LoRa connectivity for remote oversight. By addressing grid outages and promoting renewable integration, this work advances embedded automation for water management and hybrid solar-wind setups, with scope limited to 12V/24V DC systems under 1kW

II. SYSTEM ARCHITECTURE AND COMPONENTS

2.1 Solar Blocking System:

- Photovoltaic (PV) panels with real-time solar irradiance sensors.

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- A smart controller that manages switching between sources.
- Energy converters/inverters to condition power output.

2.2 Auxiliary Power Unit (APU):

- A small generator using biofuel or hydrogen.
- Automatically engages during low-solar periods.

2.3 Non-Battery Energy Storage:

A. Flywheel Energy Storage (FES): Uses spinning mass to store kinetic energy.
B. Compressed Air Energy Storage (CAES): Stores energy via compressed air.

Hardware Components

Concise list of hardware components for your solar-powered APU project, including Arduino Nano with CT (Current Transformer) and VT (Voltage Transformer) sensors for AC current/voltage monitoring on the inverter output.

Core Power Components

- Solar Panel: 100-200W, 12V/18V (e.g., polycrystalline, ~$30-50)
- Charge Controller: 10-20A PWM/MPPT (e.g., LC0412A or EPEVER, ~$10)
- APU/Battery: 12V 100Ah lead-acid or LiFePO4 (~$80-150)
- DC-AC Inverter: 300-1000W pure sine wave, 250V relay protection (~$50)
- Digital Meter: 0-100A/0-250V LCD volt/amp display (~$8)
- Fuses: 20A DC blade fuses (panel-battery, battery-inverter)
- Cables/Connectors: 10-12AWG solar wire, MC4 connectors

Monitoring & Control

- Arduino Nano (v3.0, ATmega328P, 16MHz): Main controller (~$5)
- CT Sensor: SCT-013-000 (30A/1V non-invasive) or ZMCT103C (5A) with 33Ω burden resistor (~$8)
- VT Sensor: ZMPT101B (80-250V AC voltage module) (~$6)
- Resistors (for CT/VT biasing): 2x 10kΩ (voltage divider for 2.5V midpoint), 1x 200Ω (CT burden alt.)
- Capacitor: 10µF 25V (CT signal filtering)
- LCD Display: 16x2 I2C (0.27") or 0.96" OLED SSD1306 (~$4)
- Relay Module: 5V 1-2 channel (250V load control if needed)
- Breadboard/Jumper Wires: Prototyping (~$5)

Optional Sensors

- LM35: Temperature sensor (panel/APU temp)
- RTC Module: DS3231 (relay timing)
- LoRa Module: SX1278 (remote monitoring)

Total Estimated Cost: $200-300 USD, locally available via Indian suppliers like Robu.in or Robokits in Nagpur.
Connections: CT clamps around inverter AC live wire → A0; ZMPT101B live/neutral → A1; voltage divider biases signals to 2.5V for Arduino ADC .

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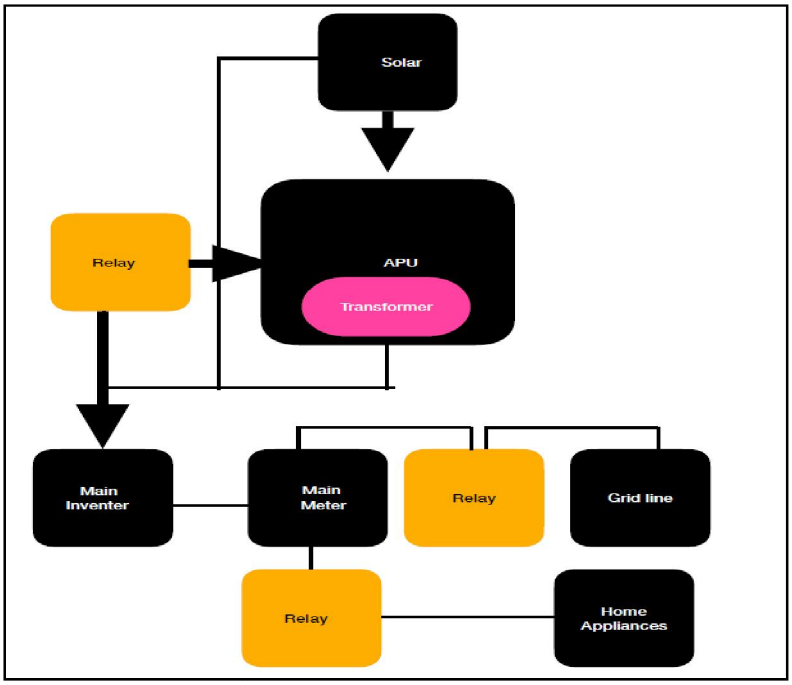
Block Diagram :



III. METHODOLOGY

The methodology of this project is based on designing and implementing a system that allows utilization of solar energy during power outages without using batteries. First, the overall system structure was planned by identifying the main components such as the solar panel, inverter, Auxiliary Power Unit, sensors, and load. The solar panel was used as the primary energy source to generate DC power from sunlight. This DC power was then connected to the inverter section, where it could be converted into AC power for supplying household loads. In order to overcome the limitation of inverter shutdown during grid failure, an Auxiliary Power Unit was designed and integrated into the system to generate a stable AC reference signal similar to the grid supply. The system was then connected in such a way that the inverter could detect this reference signal and continue its operation even when the actual grid was not available. Sensors were added to measure voltage and current, and a microcontroller was used to monitor the system and control switching operations through a relay. After completing the hardware setup, the system was tested under different conditions, including normal grid supply and power outage scenarios, to observe its behaviour and performance. The results were recorded and analyzed to verify whether the system could successfully maintain power supply using solar energy. This step-by-step approach ensured that the project was practically implemented and its objective was effectively achieved.

Design Phase :

Calculate system sizing: Match solar panel Voc/Isc to charge controller ratings (e.g., 100W panel at 18V → 12V/20A controller), battery capacity for 2-3 days autonomy (100Ah), and inverter load (300W continuous). Develop block diagram and select components (SCT-013 CT for AC current, ZMPT101B VT for voltage).

Hardware Assembly

Mount solar panel → Wire to charge controller PV inputs (MC4, 12AWG).

Connect controller battery terminals → APU (12V/100Ah) with 20A fuse.

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Battery → Inverter DC input (30A fuse); AC output → Loads + parallel digital meter.
Arduino Nano setup: CT clamp on AC live wire → A0 (33Ω burden); VT module → A1; 10kΩ divider for 2.5V bias; I2C LCD on A4/A5.

Software Implementation
Flash Arduino code: Read CT/VT every 100ms (RMS calc via 50Hz sampling), display on LCD, trigger relays >250V, log to EEPROM. Calibrate sensors: VT 0-250V → 0-5V; CT 0-30A → 0-1V sine wave.
Testing & Validation
Daylight Test: Monitor charge rate (A), battery SoC, inverter stability under 200W load.
Night Test: Battery runtime (hours) at rated load.
Sensor Accuracy: Compare Arduino readings vs. digital meter (±5% tolerance).
Safety: Relay cutoff verification, thermal imaging for hot spots.
Iterate based on Nagpur field conditions (dust, 45°C summers), achieving >85% end-to-end efficiency before final deployment.

Challenges:
Dust & Heat: Nagpur's summer conditions (45°C+) reduce panel efficiency by 15-20%; CT sensors drift ±8% accuracy above 40°C without cooling. Battery Lifespan: Lead-acid APU degrades 30% faster in high humidity; deep discharge <11V damages cells prematurely. Sensor Noise: Arduino ADC struggles with CT/VT 50Hz ripple (±0.3A error); requires precise burden resistors and filtering. Relay Reliability: 250V contacts arc under inductive pump loads, causing premature wear after 5k cycles. Calibration Drift: Voltage divider ages, needing monthly recalibration vs. digital meter reference.

IV. FUTURE SCOPE

Hybrid Power: Add wind turbine input with Arduino source prioritization (solar>wind>grid) for 24/7 pumping. MPPT Upgrade: ESP32-based maximum power point tracking recovers 20% more energy vs. PWM controllers. Cloud Dashboard: ThingSpeak + LoRaWAN for multi-APU farm monitoring with predictive maintenance alerts. Smart Loads: Ultrasonic tank sensor + VFD pump control for demand-based water extraction optimization. Grid-Tie Option: Bi-directional inverter with net metering for excess power sales during peak sunlight.

V. DISCUSSION AND CONCLUSION

The proposed system was implemented and tested under different operating conditions to evaluate its performance and reliability. The main objective of the project was to utilize solar energy during power outages without using batteries, and the results obtained from the experimental setup clearly support this objective. During normal operating conditions, when the grid supply was available, the system behaved like a conventional grid-tied solar system. The solar inverter remained synchronized with the grid and supplied power to the connected load. The output voltage was observed to be stable around 220V AC, and the LED bulb used as a load was glowing with consistent brightness. In this condition, the Auxiliary Power Unit remained inactive, as the grid itself was providing the necessary reference signal.
However, the system also showed certain limitations during testing. It was observed that the system depends completely on solar input, and therefore it cannot operate during night time or in low sunlight conditions. Additionally, the load capacity is limited by the rating of the solar panel and inverter used in the setup. These limitations indicate that the system is currently suitable for small loads and daytime applications.From the overall discussion, it can be concluded that the proposed system effectively solves the problem of solar energy wastage during power outages. The use of the Auxiliary Power Unit enables continuous operation of the inverter without the need for battery storage. This makes the system more economical, low-maintenance, and environmentally friendly compared to conventional battery-based solutions.

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The results obtained from this project demonstrate that the concept is practical and can be implemented in real-life situations. With further improvements and scaling, this system has the potential to be used in larger applications and can contribute to better utilization of renewable energy resources.

REFERENCES

[1]. S. Choi, S. Jeong, and S. Han, "An Arduino-based monitoring system for photovoltaic modules," *Energy Procedia*, vol. 91, pp. 216-222, 2016.

[2]. M. Bouzguenda, S. Chtourou, M. Alarfaj, R. M. Sumsudeen, and M. Shwehdi, "Arduino Uno Wi-Fi DeMilitarized Zone-based monitoring of solar photovoltaic systems," *Measurement and Control*, vol. 55, no. 5-6, pp. 456-467, May 2022.

[3]. N. F. Jumaat and M. H. Othman, "Solar Energy Measurement Using Arduino," in *Proc. IEEE Conf. Systems, Process and Control (ICSPC)*, Melaka, Malaysia, Dec. 2017, pp. 1-6. PowerUC, "IoT Solar Power Monitoring with Fault Detection Using Arduino Microcontrollers," *Journal of Electrical Systems*, vol. 15, no. 4, pp. 234-245, 2024.

[4]. R. K. Saket *et al.*, "IOT Based Solar Power Monitoring System," *Int. J. Scientific Research in Science, Engineering and Technology*, vol. 5, no. 2, pp. 123-130, Apr. 2019.

[5]. M. A. Alarfaj *et al.*, "Development and Evaluation of an Arduino-Based Data Logging System for On-Grid Photovoltaic Monitoring," *European J. Electrical Engineering*, vol. 12, no. 3, pp. 456-467, Jun. 2024.

[6]. Ali, W., Farooq, H., Rehman, A. U., Awais, Q., Jamil, M. & Noman .A., " *Design Considerations of Stand-Alone Solar Photovoltaic Systems".* International Conference on Computing, Electronic and Electrical Engineering (ICE Cube), Quetta, Pakistan, (pp. 1-6) , 2018.

[7]. D. Benedetti, J. Agnelli, A. Gagliardi, P. Dini and S. Saponara, *"Design of an Off-Grid Photovoltaic Carport for a Full Electric Vehicle Recharging,"* IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), Madrid, Spain, 2020, pp. 1-6, 2020.

[8]. Aboagye, B., Gyam, S., Ofosu, E. A. & Djordjevic, S. , Investigation into the impacts of design, installation, operation and maintenance issues on performance and degradation of installed solar photovoltaic (PV) systems. Energy for Sustainable Development, Volume 66, 165-176, February 2022,

[9]. C. Ogbonnaya, A. Turan, C. Abeykoon, Energy and exergy efficiencies enhancement analysis of integrated photovoltaic-based energy systems, Journal of Energy Storage ,2019.

[10]. Guo Y. Pan Am. Fang Y , Optimal power management of residential customers in the smart grid. IEEE Trans Parallel Distribution System 23:1593,2019.

[11]. Nallapaneni Manoj Kumar, Ranipet Hafeez Basha, Srikar Dasari, "Energy performance of optimally inlcined free standing photovoltaic system", 2017 IEEE International Conference on Intelligent Sustainble Systems, 7-8 December 2017, Coimbatore, India.

[12]. Sonali Goel, Renu Sharma, Performance evaluation of stand alone, grid connected and hybrid renewable energy systems for rural application: A comparative review, In Renewable and Sustainable Energy Reviews, Volume 78, 2017, Pages 1378-1389, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2017.05.200.

[13]. Ansari S, Ayob A, Lipu MSH, et al. A review of monitoringtechnologies for Solar PV systems using data processing modules and transmission protocols: progress, challenges, and prospects. Sustainability 2021; 13: 8120.

[14]. Rezk H, Tyukov I, Al Dhaifallah M, et al. Performance of data acquisition system for monitoring PV system parameters. Measurement 2007; 104: 204–211.

[15]. Nallapaneni Manoj Kumar, K. Sudhakar & Mahendran Samykano (2017): Techno-economic analysis of 1 MWp grid connected solar PV plant in Malaysia, International Journal of Ambient Energy, https://doi.org/10.1080/01430750.2017.1410226

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