International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 10 | Oct - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

A Review of Smart Integrated Renewable Energy System

Tejas P. Mergal[1] Pramila V. Bhagwat[2] Janhavi D. Patel[3] Kartikay V. Bhasin[4] Yash V. Bhagat[5]
Sushil V. Jadhav[6] Riddhi P. Munge[7] Sachin V. Tayade[8]

[1,2,3,4,5]Department of Electrical Engineering
[1,2,3,4,5]Trinity College of Engineering and Research, Pune, Maharashtra, India

Abstract — Photovoltaic (PV) and wind generation are attractive clean sources, but each one fluctuates with the weather. Pairing them on a shared electrical platform together with a battery can give a steadier supply than either source achieves alone. This paper reviews seven published studies that cover six connected themes: solar–wind hybridization, multi-criteria sizing by particle swarm optimization, real-time energy management under pulse loads, a smart hybrid supply for telecom base stations, smart-grid integration of renewable sources, and monitoring based on artificial intelligence (AI) and the Internet of Things (IoT). The studies agree on the importance of correct component sizing, well-chosen converter interfaces, coordinated use of storage, accurate measurement and a reliable communication path. Drawing on these lessons, the paper outlines a laboratory-scale hybrid generator built from a solar PV panel, a small wind turbine, a battery, power converters and an ESP32 microcontroller that reads voltage and current sensors at the source, battery and load branches. A test plan and three performance indicators, namely renewable contribution, efficiency and load availability, are defined for later experimental use. The review also records open issues: limited field validation, differing assumptions between studies, sensor and data quality, and the gap between displaying data and actually controlling energy flow.

Keywords: Hybrid Renewable Energy, Solar PV, Wind Energy, Battery Storage, ESP32, Real-Time Monitoring, IoT, Energy Management

I. INTRODUCTION

Rising electricity demand, fuel costs and environmental concerns are pushing institutions and countries towards renewable generation. Sunlight and wind are the two most accessible resources, yet both are intermittent. PV output follows irradiance, panel temperature, shading and the hour of the day, while a wind turbine delivers useful power only within the wind speeds it was designed for. Because the two resources often peak at different hours and in different seasons, they are regarded as complementary, and a combined system can serve the load more continuously than a single-source installation [1].

A solar–wind hybrid generator links both sources to a shared electrical bus, which may be DC, AC or a mixture of the two. Power converters adapt the voltage and current of each source to that bus, and a battery absorbs surplus energy and returns it when generation falls short. How much of this benefit is actually realized depends on component sizing [2], on how storage is coordinated with changing demand [3], and on the supervisory logic that decides which source or load gets priority [4]. Connecting renewable sources to larger networks adds further requirements for modelling, protection and control [5].

Monitoring makes such a system understandable and manageable. Measuring voltage, current and power at the source, storage and load branches shows how much each source contributes, how the battery behaves and when abnormal conditions appear. Low-cost microcontrollers with wireless connectivity now make it practical to collect these readings and publish them on a local display or an online dashboard, and recent work describes how AI and IoT can extend monitoring towards fault detection and forecasting [6], [7].

This paper reviews seven published studies on these topics and, building on them, proposes a laboratory-scale solar–wind system with ESP32-based monitoring. It is a review and design framework. No measured results are claimed for the proposed system; the evaluation procedure given later is intended to be carried out experimentally.

II. AIM AND OBJECTIVES

The aim is to study a hybrid solar–wind power generation system with real-time monitoring, so that renewable energy is better utilized and power availability and overall performance improve. The specific objectives are:

- To generate electrical energy from a solar PV panel and a wind turbine.
- To combine both sources on a common power platform.
- To condition and convert the generated power with suitable converters.
- To examine how battery storage maintains supply when renewable output is low.
- To measure voltage, current and power in the solar, wind, battery and load sections.
- To acquire data in real time with an ESP32 microcontroller and sensors.

- To observe performance under different sunlight, wind and load conditions.
- To evaluate efficiency, renewable energy contribution and load power availability.

III. REVIEW METHODOLOGY

Seven technical papers were selected to cover the main aspects of a monitored hybrid system. The first [1] discusses hybrid generation from several renewable sources with storage and converters. The second [2] treats system design as a multi-objective optimization problem. The third [3] and fourth [4] concern real-time energy management for pulse loads and for telecom base stations. The fifth [5] addresses smart-grid integration, the sixth [6] reviews AI and IoT for monitoring hybrid energy systems, and the seventh [7] presents a distributed monitoring system for a hybrid DC/AC micro grid.

The papers are compared qualitatively by purpose, approach, contribution to hybrid-system design and limitations. The review is thematic rather than a statistical meta-analysis, so numerical results from different studies are not pooled. Findings are described at the level reported by each paper's authors; readers who need exact figures should consult the original sources.

IV. ARCHITECTURE OF A SOLAR–WIND HYBRID SYSTEM

A typical system comprises a PV array, a wind turbine with generator, power-conditioning circuits, a common DC link, a battery with its controller, a load interface and a monitoring unit (Fig. 1). The PV branch usually contains a

DC–DC converter with maximum power point tracking (MPPT). The wind branch normally needs rectification and voltage regulation because the generator output varies in both amplitude and frequency. A charge controller or bidirectional converter governs battery charging and discharging, and an inverter is added when the load is AC.

In the proposed arrangement an ESP32 microcontroller acts as the monitoring and communication unit. Voltage and current sensors in each branch feed its analog-to-digital converter, and the firmware computes power from the calibrated readings before displaying or transmitting them. Before building, the designer should verify sensor isolation, divider ratings, the measuring range of the current sensors, calibration and the protection arrangements.

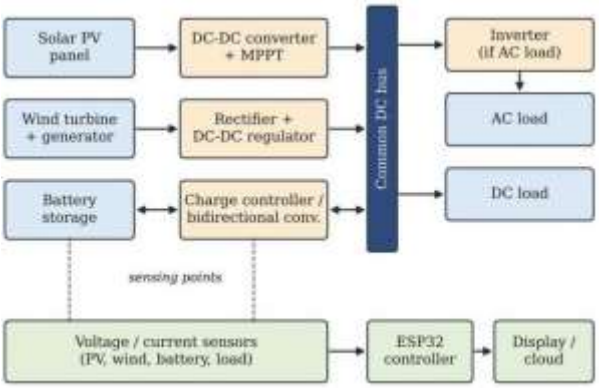


Fig. 1: Block diagram of the proposed solar–wind hybrid generation and monitoring system.

Table I: Main Components and Their Roles

Component	Role	Key design factor
Solar PV panel	Converts sunlight to DC power	Rated power, irradiance, temperature, shading
Wind turbine and generator	Converts wind energy to electricity	Usable wind-speed range, generator output, safe operation
Power converters	Match voltage levels and regulate power flow	Ratings, efficiency, thermal limits
Battery and controller	Stores surplus energy and supports the load	Capacity, current limits, protection
Component	**Role**	**Key design factor**
ESP32 controller	Reads sensors and reports data	ADC range, sampling interval, connectivity
Voltage/current sensors	Measure electrical quantities	Calibration, isolation, accuracy
Load and inverter	Use power in DC or AC form	Load rating, starting current, losses

V. LITERATURE REVIEW

A. Hybrid Power Generation from Multiple Sources

Hossain et al. [1] discuss hybrid generation that combines several renewable resources, for example solar with wind and wind with tidal power, and describe the roles of storage, converters and turbine emulation. Their central point is that combining resources raises availability compared with relying on one, although the gain depends on what the installation site offers. The paper is mainly a technical and configuration-level discussion and does not offer a longterm field dataset.

For the present project the useful lesson is that PV and wind outputs should first be measured separately, so that each

source's contribution and the battery's charging and discharging periods can be identified. A common bus with suitable converters is also necessary, because sources with different electrical characteristics cannot simply be connected in parallel.

B. Multi-Criteria Design with Modified PSO

Wang and Singh [2] formulate the design of hybrid generation as a multi-objective problem and solve it with a modified particle swarm optimization (PSO) algorithm. The objectives include cost, reliability and emissions, while uncertain renewable output and varying load are taken into account. The method yields a set of alternative configurations instead of one design that is best for every objective.

This is relevant to selecting PV capacity, turbine rating and battery size: a larger battery may improve continuity but raise cost, while a larger generator may reduce shortfalls yet increase surplus energy. The limitation is that results depend on assumed weather data, equipment cost and failure rates. For a student prototype a simple sizing calculation is adequate, and optimization can be left as future work.

C. Real-Time Energy Management for Pulse Loads

Mohamed, Salehi and Mohammed [3] propose a real-time energy management algorithm for hybrid AC/DC micro grids that supply pulse loads. The approach coordinates fast acting storage, such as batteries, supported by forecasting and control, to soften sudden changes in demand. The study shows that storage is more than a backup source: it can help stabilize voltage and absorb the mismatch between generation and demand.

A prototype with only a battery can still observe how battery voltage and current respond when generation or load changes.

D. Smart Hybrid Power for Base Transceiver Stations Diamantoulakis, Ghassemi and Karagiannidis [4] describe a smart hybrid power system for base transceiver stations that combines hybrid supply, sensing and communication, consumption scheduling and real-time energy management. Live information on demand and supply is tied to operating and economic decisions.

The lesson for this work is that monitoring is more valuable when it informs control: data can be used to select a source, schedule a load or warn of low battery. Results obtained for a modelled telecom station, however, cannot be transferred directly to a small prototype or to a different tariff and climate.

Table II: Thematic Comparison of the Reviewed Studies

Theme [ref.]	Main focus	Relevance and caution
Hybrid generation [1]	Multi-source combinations, storage, converters	Basis for source integration; needs site-specific validation
Modified PSO [2]	Cost, reliability and emission trade-offs	Guides sizing; depends on model assumptions
Pulse-load management [3]	Coordinated storage, real-time control	Shows value of battery and load monitoring; hardware differs
Base-station management [4]	Sensing, scheduling, operating cost	Links monitoring to control; depends on load and tariff
Smart-grid integration [5]	Scalable modelling, supervisory control	Coordinated control principle; grid tie not assumed
AI and IoT monitoring [6]	Data collection, anomaly and fault detection	Start with reliable acquisition; AI needs good data
DC/AC micro grid monitoring [7]	Distributed measurement, state estimation	Architecture guide; scaling limits apply

E. Smart-Grid Integration of Renewable Systems Shahid [5] presents scalable modelling and control for integrating renewable sources into a smart grid. In the proposed structure, conventional plants and distributed renewable units are joined through power-electronic interfaces under a supervisory controller, and simulation models are used to study the integration and its transient response. The message is that renewable integration needs coordinated control, not merely physical connection.

The same principle applies at small scale: each source needs a suitable interface, readings should be taken at meaningful points, and the battery and load should sit behind protection and control circuits. The proposed system is not assumed to be grid-connected; a grid-tied version would need protection, synchronization and compliance with the applicable standards.

F. AI and IoT for Monitoring Hybrid Energy Systems Nishtar and Afzal [6] review the use of AI and IoT for realtime monitoring of hybrid energy systems. The topics they cover include data acquisition from sensors, visualization, spotting anomalies, diagnosing faults, planning maintenance in advance and optimizing energy use.

Because the review depends on the quality and diversity of published work, its benefits should not be assumed for every installation. The first stage of the present project should therefore be reliable acquisition and clear visualization. Once a sufficiently large labelled dataset exists, simple anomaly thresholds or forecasting models can be tested.

G. Monitoring of Hybrid DC/AC Micro grids García et al. [7] implement a hybrid distributed/centralized real-time monitoring system for a DC/AC micro grid with energy storage. Distributed measurement units process electrical signals and send results over TCP/IP to a central server, which performs power-flow-based state estimation, drives a graphical interface and stores the data. The authors identify the processing capacity of the units, local network bandwidth and server capacity as the practical limits to scalability.

This directly informs the proposed architecture. A small prototype can start with on-site measurement and a local display, and later gain a Wi-Fi link and remote viewing. Each record should carry a timestamp and units, and the software should recognize invalid readings or a dropped connection. Note that a microcontroller dashboard falls well short of micro grid state estimation, so only the features actually built should be claimed.

VI. PROPOSED SYSTEM DESIGN

A. Generation and Power Conditioning

The first phase generates energy from a PV panel and a small wind turbine and brings both outputs onto a common bus. The converter topology should be chosen to suit the ratings of the available hardware: the PV branch can use a regulated DC–DC converter and the wind branch a rectifier followed by DC regulation. Protection is needed against reverse current, excess voltage or current, and unsafe battery conditions.

The battery supports the load when generation is low and stores surplus energy when generation exceeds demand. It must always be used with a compatible charge controller or battery-management arrangement, and its chemistry, voltage, capacity, charge limits and protection devices must be specified from the components actually used. A battery should never be connected directly to an uncontrolled renewable source.

B. Monitoring and Data Handling

The second phase uses the ESP32 and sensors to collect readings from the PV, wind, battery and load sections. The firmware samples the sensor outputs, converts them to engineering units with calibration factors, computes power and sends the results to a display or dashboard. A basic version reports live voltage, current, power and the battery charge/discharge trend, with optional logging for later comparison.

For DC quantities, power is estimated as

$$P = V \times I \quad (1)$$

when voltage and current are measured at the same point and instant. For AC loads, multiplying RMS voltage and RMS current gives apparent power, which equals real power only at unity power factor, so an appropriate meter or a power factor measurement is needed. The measurement method should be stated clearly.

Table III: Monitoring Variables and Their Purpose

Variable	Where measured	Purpose
PV voltage, current, power	PV output branch	Assess solar contribution
Wind voltage, current, power	Wind conversion output	Assess wind contribution
Battery voltage and current	Battery branch	Show charging or discharging trend
Load voltage, current, power	Load branch	Assess demand and supply quality
Temperature (optional)	Converter or battery enclosure	Observe thermal conditions where safely instrumented
Timestamp and status	Controller and data platform	Support comparison and detect missing data

C. Monitoring Flow

The monitoring routine is summarized in Fig. 2. After initialization, each cycle reads the channels, applies calibration and plausibility checks, calculates power and energy, updates the display, logs timestamped data and compares readings with thresholds before repeating.

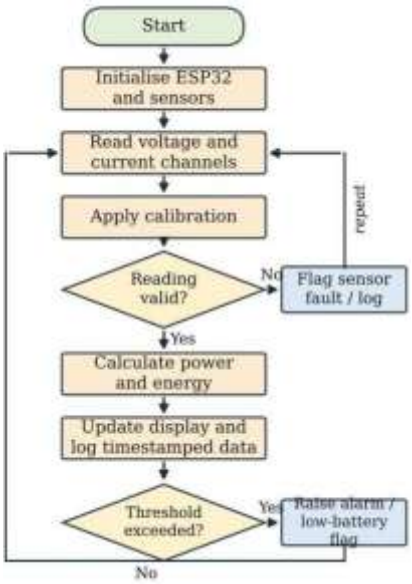


Fig. 2: Flowchart of the proposed monitoring routine.

D. Operating Logic

- Sample the PV and wind outputs at fixed intervals.
- Track battery voltage and current to tell whether it is charging or discharging.
- Compare the load demand with what the renewable sources can supply.
- If generation is higher than demand and the battery can take more charge, send the excess through the charge control stage.
- If generation is lower than demand, discharge the battery only within its allowed limits and otherwise signal a likely supply shortfall.
- Show or record abnormal values, a low battery state and any loss of communication.

The list above outlines a supervisory monitoring scheme. Source switching and battery control should be implemented only where the hardware and protection circuits support them; if the prototype only measures and displays values, it should be described as monitoring and not as closed-loop energy management.

VII. PERFORMANCE EVALUATION PLAN

The prototype should be tested with one consistent procedure. Readings are taken under different sunlight, wind and load conditions and during battery charging and discharging, always recording the same variables at the same sampling interval. Readings taken at different times should not be compared without noting changes in irradiance, wind speed and load. Table IV lists suggested test cases.

Table IV: Suggested Test Cases

Case	Condition	What to observe
A	Sunlight available, low wind	PV contribution and battery behavior
B	Wind available, low sunlight	Wind contribution
C	Both sources available	Combined contribution and any surplus
D	Low renewable generation	Battery support within safe limits
E	Load changes	Response to demand variation
F	Communication interruption (safe simulation)	Whether missing data is flagged

A. Performance Metrics

Energy over a test interval is obtained by summing sampled power:

$$E \approx \Sigma P_i \Delta t \quad (2)$$

The renewable contribution ratio is the renewable energy supplied divided by the total energy delivered to the load:

$$RC\ (\%) = (E_{ren} / E_{load}) \times 100 \quad (3)$$

The definition should state whether energy discharged from the battery is counted as renewable energy previously stored or treated separately. Efficiency needs a clearly defined boundary: stage efficiency compares the output and input of one converter, while overall efficiency includes converter, storage, wiring and inverter losses.

$$\eta\ (\%) = (E_{out} / E_{in}) \times 100 \quad (4)$$

Load availability is the share of the test time in which the load receives power within stated voltage and power limits; the thresholds and sampling interval should be given:

$$A\ (\%) = (t_{ok} / t_{total}) \times 100 \quad (5)$$

VIII. ADVANTAGES OF MONITORED HYBRID SYSTEMS

- Better continuity of supply than a single source, because the resources are complementary.
- Reduced reliance on conventional generation.
- Battery buffering of both surplus and shortfall.
- Visibility of each source's contribution through monitoring.
- Early identification of abnormal conditions and sensor faults.
- Low-cost implementation with a microcontroller and common sensors.
- Remote access to data through IoT connectivity.

IX. CHALLENGES

- Variable and site-dependent renewable output.
- Correct sizing of generators and battery.
- Converter losses and protection requirements.
- Battery ageing and charge-control limits.
- Sensor calibration, noise and measurement accuracy.
- Communication reliability and bandwidth.
- Scalability of centralized processing.
- Model assumptions that limit how widely results apply.
  – Limited field validation.

X. RESEARCH GAP

The reviewed studies show clear progress, but several gaps remain. First, many rely on models, simulations, laboratory set-ups or literature synthesis, so testing across real weather and load conditions is needed. Second, studies use different assumptions and metrics, which makes direct comparison difficult. Third, calibration, noise, missing readings, timestamps and communication loss can distort conclusions about performance. Fourth, optimal component ratings depend on location, load profile, cost and tariff, which limits general design rules. Fifth, displaying data does not by itself improve efficiency; control actions and their safety must be demonstrated. Finally, AI-based anomaly detection and forecasting should be validated against measured data with defined accuracy metrics.

These gaps motivate a low-cost prototype that brings generation, storage and load variables into one monitoring interface. By recording readings under different sunlight and wind conditions, such a prototype gives an experimental basis for comparing source contributions and observing battery support. Its contribution should be reported only in terms of the hardware, measurements and tests actually completed.

XI. FUTURE SCOPE

- Improved forecasting of solar and wind output.
- Validated anomaly and fault detection.
- Optimized component sizing for specific sites.
- Closed-loop energy management once measurement and protection are verified.
- Long-term field validation.

XII. CONCLUSION

This paper examined seven studies spanning solar–wind hybridization, multi-objective sizing, real-time energy management, smart-grid integration, micro grid monitoring and AI/IoT techniques. Across them, source integration, suitable power conversion, coordinated storage and reliable measurement emerge as the main requirements for making better use of renewable energy. The literature also shows that model assumptions, site conditions, communication limits and scarce field validation restrict how widely the results can be applied.

A solar–wind system that pairs battery storage and converters with an ESP32 and voltage/current sensors is a practical way to watch how renewable generation and the load behave. It should be evaluated with timestamped measurements under several operating conditions, and efficiency, renewable contribution and load availability should be computed from stated definitions and measured data. Future work may add source forecasting, validated anomaly detection, optimized sizing and closed-loop energy management once the basic measurement and protection functions are verified.

REFERENCES

[1] M. I. Hossain, A. Hossain, T. H. Galib, and A. Hoque, "Hybrid power generation using multiple sources of energy: Bangladesh perspective," in Proc. 2013 Int. Conf. Informatics, Electronics and Vision (ICIEV), 2013, pp. 1–5, doi: 10.1109/ICIEV.2013.6572571.

[2] L. Wang and C. Singh, "Multicriteria design of hybrid power generation systems based on a modified particle swarm optimization algorithm," IEEE Trans. Energy Convers., vol. 24, no. 1, pp. 163–172, Mar. 2009, doi: 10.1109/TEC.2008.2005280.

[3] A. Mohamed, V. Salehi, and O. Mohammed, "Real-time energy management algorithm for mitigation of pulse loads in hybrid microgrids," IEEE Trans. Smart Grid, vol. 3, no. 4, pp. 1911–1922, Dec. 2012, doi: 10.1109/TSG.2012.2200702.

[4] P. Diamantoulakis, M. A. Ghassemi, and G. K. Karagiannidis, "Smart hybrid power system for base transceiver stations with real-time energy management," in Proc. IEEE Global Communications Conf. (GLOBECOM), 2013, doi: 10.1109/GLOCOM.2013.6831494.

[5] A. Shahid, "Smart grid integration of renewable energy systems," in Proc. 2018 7th Int. Conf. Renewable Energy Research and Applications (ICRERA), 2018, pp. 944–948, doi: 10.1109/ICRERA.2018.8566827.

[6] Z. Nishtar and J. Afzal, "A review of real-time monitoring of hybrid energy systems by using artificial intelligence and IoT," Pakistan J. Eng. Technol., vol. 6, no. 3, pp. 8–15, Sep. 2023, doi: 10.51846/vol6iss3pp8-15.

[7] P. García, P. Arboleya, B. Mohamed, A. A. C. Vega, and M. C. Vega, "Implementation of a hybrid distributed/centralized real-time monitoring system for a DC/AC micro grid with energy storage capabilities," IEEE Trans. Ind. Informant., 2016, doi: 10.1109/TII.2016.2574999.