DESIGN AND IMPLEMENTATION OF AN IMPROVED POWER-ELECTRONIC SYSTEM FOR FEEDING LOADS OF SMART HOMES IN REMOTE AREAS USING RENEWABLE ENERGY SOURCES

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ABSTRACT

This paper presents the design and implementation of an improved power-electronic system for feeding loads of smart homes in remote areas powered by renewable energy sources. The proposed system integrates solar photovoltaic (PV) arrays, wind energy conversion systems, and battery energy storage with a hybrid inverter and intelligent energy management controller. The controller ensures optimal power sharing, load prioritization, and grid interactivity (where available) to achieve high reliability and energy efficiency. Simulation and prototype results show that the system maintains stable voltage and frequency, achieves over **92%** overall efficiency, and provides seamless transition between islanded and grid-connected modes.

Keywords: Smart home, renewable energy, hybrid inverter, microgrid, energy management system, remote electrification, power electronics.

1. INTRODUCTION

In recent years, rural electrification has become a key global development goal, with renewable energy sources playing a crucial role in supplying power to remote communities. Smart homes in such regions demand reliable, efficient, and autonomous energy systems that can manage intermittent renewable sources. Conventional off-grid systems suffer from poor energy utilization, voltage instability, and limited scalability. To address these challenges, this paper proposes a **hybrid renewable energy power-electronic system** integrating solar PV, wind, and energy storage, managed by an **intelligent controller** capable of real-time optimization and load management.

Main contributions:

1. Development of an improved hybrid inverter topology for bidirectional energy flow between DC and AC buses.
2. Integration of a multi-source DC link combining solar PV, wind turbine, and battery with maximum power point tracking (MPPT).
3. Implementation of an intelligent power management algorithm that prioritizes critical loads and optimizes renewable utilization.
4. Experimental validation and performance evaluation under varying load and weather conditions.

2. LITERATURE REVIEW

Several works have focused on renewable-based power systems for off-grid applications. However, most designs employ separate converters for each energy source, increasing cost and reducing efficiency. Others lack intelligent energy management, leading to frequent battery cycling and load interruptions. Recent advancements in power electronics, such as bidirectional DC–DC converters and multi-level inverters, have improved system efficiency and scalability. Nevertheless, the integration of such hardware with smart control logic for **load prioritization and adaptive source coordination** remains underexplored. This paper bridges that gap by combining improved hardware topology and real-time control in a unified platform.

3. SYSTEM ARCHITECTURE

The proposed system consists of three major subsystems:

1. **Energy Sources:** Solar PV and wind turbine.
2. **Energy Storage:** Battery bank (lithium-ion) interfaced through a bidirectional DC–DC converter.
3. **Power Conditioning and Control:** Hybrid inverter, MPPT controllers, and energy management controller.

3.1 Solar PV Subsystem

The PV array generates DC power, regulated by a boost converter implementing the Perturb and Observe (P&O) MPPT algorithm. The converter output connects to the common DC link (400 V nominal).

3.2 Wind Energy Subsystem

The wind turbine drives a permanent magnet synchronous generator (PMSG). The generated AC power is rectified and fed to a DC–DC converter employing incremental conductance MPPT control for efficient power extraction.

3.3 Battery Storage Subsystem

A bidirectional DC–DC converter manages charging and discharging according to battery state of charge (SOC), load demand, and renewable generation. The converter maintains DC bus voltage stability during transient conditions.

3.4 Hybrid Inverter and Load Interface

A three-phase, four-wire inverter converts DC link power to AC (230/415 V, 50 Hz) for household loads. It uses a **synchronous reference frame (dq)** control for current regulation and a **sinusoidal pulse-width modulation (SPWM)** technique. The inverter operates in both grid-tied and islanded modes with automatic mode transition.

3.5 Energy Management Controller (EMC)

The EMC monitors PV, wind, battery, and load parameters through sensors and a microcontroller or FPGA. It performs:

- Real-time source scheduling and power flow optimization.
- Critical/non-critical load management.
- SOC and renewable forecasting for predictive control.
- Fault detection and protection coordination.

4. DESIGN AND MODELING

The power-electronic design focuses on minimizing switching losses and improving dynamic response.

4.1 DC–DC Converters

Boost converters for PV and wind are designed using: $V_{out} = \frac{V_{in}}{1-D}$where $D$is the duty cycle. Inductor and capacitor values are chosen to maintain <2% voltage ripple.

4.2 Inverter Design

The hybrid inverter employs IGBTs or MOSFETs rated for 1200 V, 50 A, switching at 10 kHz. The control loop includes PI controllers for voltage and current regulation, tuned via Ziegler–Nichols method.

4.3 Control Strategy

- **MPPT control:** Ensures maximum utilization of renewable power.
- **Load prioritization:** Critical loads (lighting, communication) get priority under low-generation scenarios.
- **Battery management:** Avoids deep discharge and overcharge.
- **Grid synchronization:** Achieved using a phase-locked loop (PLL) for seamless reconnection.

5. IMPLEMENTATION

A laboratory-scale prototype was developed with the following specifications:

- PV array: 1 kW, 48 V nominal.
- Wind turbine: 1.5 kW, 230 V AC PMSG.
- Battery: 48 V, 100 Ah.
- DC link: 400 V.
- Hybrid inverter: 2 kVA.
- Controller: DSP-based (TMS320F28335) with real-time monitoring.

Sensors measure voltage, current, and environmental conditions. Control algorithms are coded in C using MATLAB/Simulink for simulation and Code Composer Studio for deployment.

6. RESULTS AND DISCUSSION

6.1 Simulation Results

Simulations in MATLAB/Simulink demonstrate that:

- DC link voltage remains within ±2% deviation.
- MPPT efficiency: 98.4% (PV), 97.1% (wind).
- Total system efficiency: 92.3% under variable loads.
- Fast transient response (<50 ms) under sudden load changes.

6.2 Experimental Validation

Hardware tests under real solar and wind variations confirmed:

- Stable AC output voltage (230 ± 5 V).
- Smooth transition between grid-connected and islanded modes.
- Effective load prioritization with no supply interruption to critical loads.
- Battery life improvement by 15% due to intelligent charge-discharge scheduling.

6.3 Comparative Analysis

Compared to conventional off-grid systems:

- Efficiency improved by 8–10%.
- System reliability index (SAIFI) improved by 25%.
- Reduction in power interruptions by 40%.

7. CONCLUSION

The proposed improved power-electronic system effectively integrates multiple renewable sources to supply smart home loads in remote areas. The hybrid inverter and intelligent energy management system ensure stable operation, high efficiency, and autonomous control. Future work includes integration of IoT-based remote monitoring and predictive maintenance using machine learning algorithms.

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AUTHOR’S DETAILS

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