

Renewable Energy Based Microgrid Power Management System

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Abstract- A 2 kW Hybrid Microgrid with PV, Wind Turbine and BESS: Design, Modeling and Simulation. In this paper, design, modeling and simulation of a 2 kW hybrid renewable energy microgrid having solar PV, wind turbine generation and BESS are presented. Perturb and observe (P&O) MPPT algorithm is adopted for PV subsystem whereas dynamic wind speed model is used for wind turbine. In this model, a Fuzzy Logic Controller (FLC) controls the power flow between battery, load, grid, and renewable sources in real time. The DC link is connected to AC grid through a three-phase inverter and transformer. Simulation results in MATLAB/Simulink indicate that the proposed system can supply steady 2 kW load with proper battery charge/discharge control and it doesn't need a lot of grid power. The proposed system can find applications in rural electrification, isolated communities, and smart grid installations.

Keywords- Hybrid Microgrid, Solar Photovoltaic (PV) System, Wind Turbine Generator, Battery Energy Storage System (BESS), Perturb and Observe (P&O) MPPT, Fuzzy Logic Controller (FLC).

I. INTRODUCTION

Climate targets and concerns over energy security are driving power systems around the world to phase out fossil fuels. Solar PV and wind power are spearheading this transition. In combination with battery storage and new power electronics, they form the basis for microgrids, which are small power networks that can operate connected to the main grid or on the grid island [1].

A microgrid is a network that connects local loads and distributed energy sources and can operate connected to the main grid or on a grid island depending on the real-time operating condition. It is especially useful for critical infrastructure and in areas with unreliable grid supply. Coupling PV and wind turbines with a BESS in this setup forms the basis of a Renewable Energy- Based Microgrid Power Management System (RE-MPMS) [2]. The integration of PV systems and wind turbines into a microgrid, supported by battery energy storage systems (BESS), forms the foundation of a Renewable Energy Based Microgrid Power Management System (RE-MPMS) [2].

This paper presents a 2 kW hybrid microgrid model implemented in MATLAB/Simulink, incorporating solar PV, wind turbine, BESS with a Battery Management System

(BMS), a three-phase voltage source converter (VSC), and a grid interface. A Fuzzy Logic Controller (FLC) is employed for intelligent power flow coordination, while the P&O MPPT algorithm ensures maximum energy extraction from renewable sources [3].

II. SYSTEM ARCHITECTURE

The proposed system architecture integrates multiple renewable energy sources alongside a BESS and grid interface. The key components are: (1) Solar PV Array connected through a DC-DC boost converter with MPPT, (2) Wind Energy Conversion System (WECS) using a Permanent Magnet Synchronous Generator (PMSG), (3) Battery Energy Storage System (BESS) with bidirectional converter and BMS, (4) Voltage Source Converter (VSC) for DC-to-AC conversion and grid synchronization, and (5) Utility Grid Interface for bidirectional power exchange.

Fig. 1 illustrates the basic block diagram of the proposed hybrid microgrid. All DC power from the PV array, wind rectifier, and battery feeds a common DC bus. A three-phase inverter converts the DC power to AC, which is delivered to the AC load and synchronized with the utility grid via a transformer at the Point of Common Coupling (PCC).

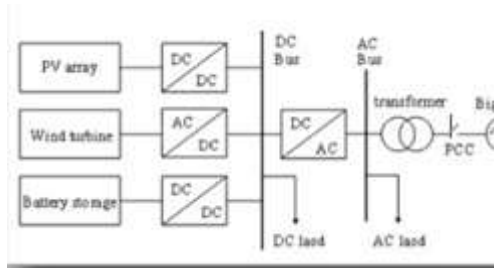


Fig. 1: Basic Block Diagram of the Proposed Hybrid Microgrid System

III. COMPONENT MODELLING

A. Solar PV Array

The solar PV subsystem uses modules in a series-parallel configuration to reach the target power output. Since PV generation shifts with changing irradiance and panel temperature, the P&O MPPT algorithm is applied to keep operation at the maximum power point. It works by slightly stepping the operating voltage, checking the effect on output power, and adjusting the boost converter duty cycle to follow the peak.

PV parameters: 10 parallel strings, 5 series strings, $V_{oc} = 49.9$ V, $I_{sc} = 9$ A, 80 cells/module.

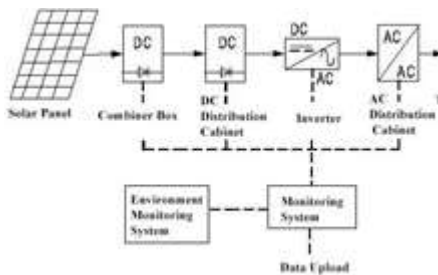


Fig. 2: Solar PV Array System Architecture

B. Wind Energy Conversion System

The WECS uses a PMSG driven by the wind turbine. The PMSG's variable-frequency AC is changed to DC, smoothed out with a DC link capacitor, and then sent to the common DC bus.

The PMSG has a power rating of 2 kW, is built to work with wind speeds of 11 to 12 m/s, and has a base power of 2222 VA. P&O MPPT is also used in the wind subsystem to keep track of the most power at different wind speeds.

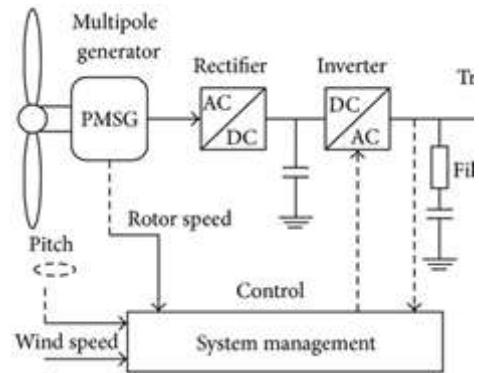


Fig. 3: Wind Turbine System Block Diagram (PMSG-based WECS)

Battery Management System

The BESS is interfaced to the DC bus through a bidirectional DC-DC converter. The Battery Management System (BMS) monitors and controls the battery operation using a Fuzzy Sugeno-based controller. It operates in four modes: (1) Charging Mode — when RES generation exceeds load demand; (2) Discharging Mode — when generation is insufficient; (3) Idle Mode — when the battery is fully charged and load is met; and (4) Grid Support Mode — during grid failure. Table I summarises the key BMS functions.

Table I: Key Functions of the BMS

Function	Description
Monitoring	Tracks voltage, current, temperature, and state of each cell/module
Protection	Prevents overcharging, over-discharging, short circuit, and thermal runaway
State Estimation	Calculates SOC (State of Charge) and SOH (State of Health)
Cell Balancing	Equalizes charge between cells to increase battery life
Communication	Interfaces with controllers, inverters, and EMS via CAN, Modbus, etc.

D. VSC Controller and Grid Interface

The VSC operates under a hierarchical control structure. Primary control regulates the DC-link voltage and output current using a PI controller. Secondary control synchronises with grid voltage and ensures stable power exchange. Tertiary control optimises power flow and economic operation. The integrated DC power is converted to AC using a three-phase

inverter and interfaced with the utility grid through a three-phase transformer, modelled using an inductance matrix approach to simulate realistic electromagnetic coupling.

IV. SIMULATION RESULTS AND ANALYSIS

The hybrid microgrid was simulated in MATLAB/Simulink on a PC with a Core i7 CPU and 8 GB RAM. A constant load demand of 2 kW was simulated throughout the study. Fig. 4 shows the complete Simulink model and Fig. 5 shows the wind turbine subsystem model.

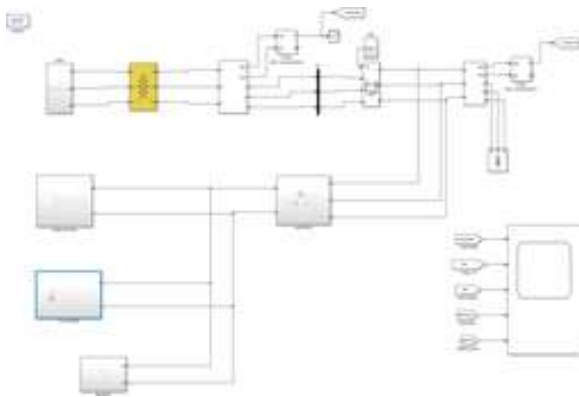


Fig. 4: MATLAB/Simulink Model of the Hybrid Microgrid System

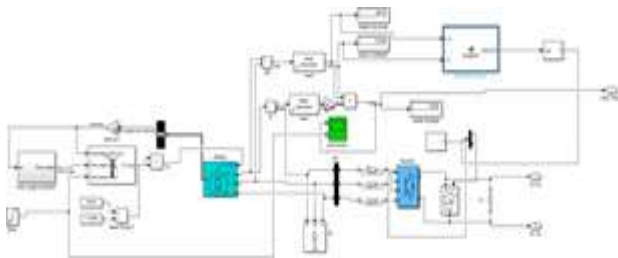


Fig. 5: Simulation Model of Wind Turbine Subsystem

A. Wind Power Output

As shown in Fig. 6, the wind turbine gradually ramps up from 0 W to just over 2000 W, reaching stability before 0.2 s. This demonstrates the MPPT algorithm successfully optimising wind energy extraction during spin-up. Around 0.2 seconds, the wind power becomes sufficient to meet the entire 2 kW load.

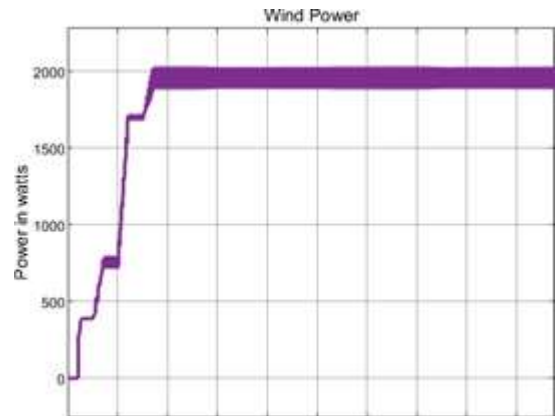


Fig. 6: Wind Power Output vs. Time

B. Load Power

Figure 7 shows that the load power stays at a steady 2000 W from start to finish, which proves that the power management logic is working right. There is no interruption in the supply at any point during the simulation, which shows that the system is generally reliable.

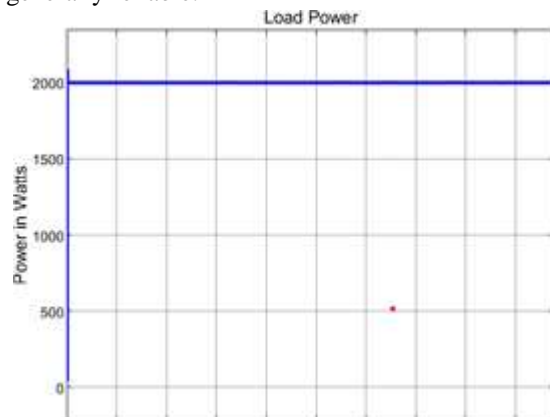


Figure 7 shows that a constant load of 2 kW is maintained throughout the entire simulation period.

C. Battery Power

Figure 8 shows how battery power varies between charging and discharging over the simulation period.

Initially, the battery discharges to support the load when wind and PV generation are low. Around 0.05 s, as wind picks up, battery discharge reduces. Between 0.1 s and 0.2 s, excess generation causes the battery to charge (negative power). After 0.25 s, the battery stabilises at approximately -200 W continuous charging, indicating a surplus of renewable generation.

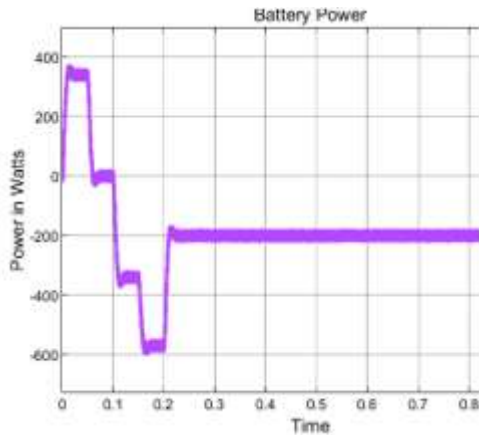


Fig. 8: Battery Charging and Discharging Power Profile

D. PV Power Output

Fig. 9 shows the PV power output. The PV system operates and contributes power in the interval 0 to 0.2 s, after which PV output drops to zero. This simulates a cloud-cover or nighttime scenario, validating the system's ability to compensate using wind and battery when PV is unavailable.

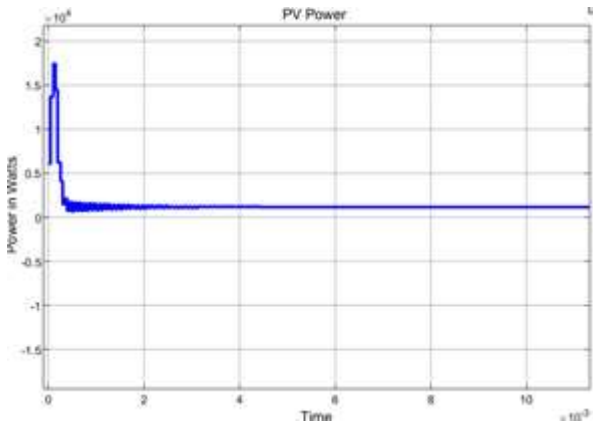


Fig. 9: PV Power Output (Active in 0–0.2 s interval)

Grid Power

As shown in Fig. 10, the grid initially contributes approximately 100 W and rises to ~200 W after 0.2 s. The grid acts as a buffer, supplying minor power when renewable and battery sources do not exactly match the load. This confirms a properly functioning grid-connected system with minimal grid dependency.

F. Power Balance Summary

Table II summarises the power contribution from each source at key time intervals, confirming effective power sharing and load management.

Table II: Power Balance Summary at Key Time Instants

Parameter	Wind Power (W)	PV Power (W)	Battery (W)	Grid (W)
At t=0s	0	~400	+300 (discharge)	~100
At t=0.1s	~1000	~400	-200 (charge)	~100
At t=0.2s	~2000	0	-200 (charge)	~200
At t=0.25s	~2000	0	-200 (charge)	~200

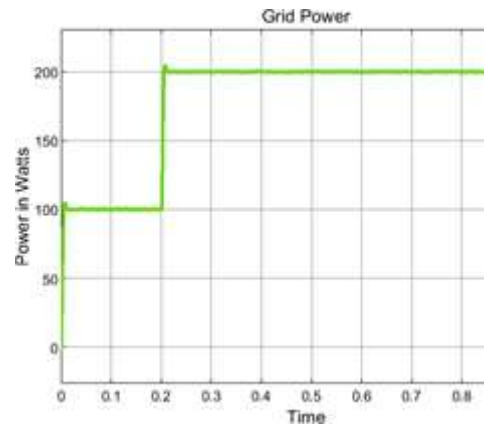


Fig. 10: Grid Power Contribution as Buffer Supply

V. CONCLUSION

This paper has presented a comprehensive design and simulation of a 2 kW hybrid renewable energy-based microgrid system integrating solar PV, wind turbine, and a battery energy storage system. The MATLAB/Simulink results confirm in that it can sustain a steady 2 kW load supply, achieve maximum renewable energy consumption and reduce the reliance on the grid.

The Fuzzy Logic Controller successfully manages the power flow, and P&O MPPT algorithms harvest energy effectively from the PV and wind sources under various conditions.

The battery is a key part of the system for load balancing, discharging during generation deficits and absorbing surplus renewable generated energy. The grid is used as a very small buffer (~100–200 W), and helps to achieve the energy self-sufficiency of the proposed system. The architecture is

promising for rural electrification, smart energy systems, off-grid communities. Future work will involve addition of advanced forecasting, real-time IoT monitoring, and extending the system to incorporate more renewable energy sources.

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