Coordinated Control and Energy Management of a Hybrid Marine Energy System

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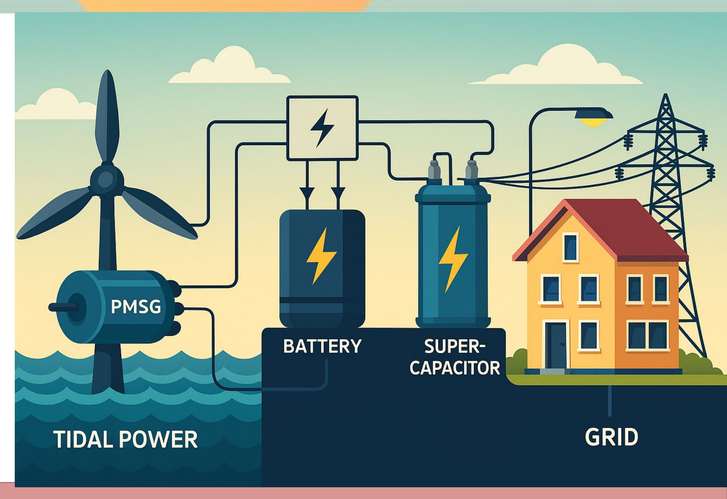

- Tidal energy paired with hybrid storage ensures reliable power for marine microgrids.
- SOC-based control coordinates BESS and SCESS to manage both sustained and rapid load demands.
- Simulations confirm stable, autonomous operation under varying tidal and load conditions.

Abstract

- The growing demand for clean and autonomous energy has driven interest in marine renewables.
- Tidal energy offers predictable and sustainable power with minimal land or visual impact.
- However, isolated marine grids face challenges such as:
  - Dynamic and nonlinear marine loads
  - Inflexibility of tidal sources to handle fast transients
  - Harsh environmental conditions
- A robust energy management framework is essential to ensure stable and reliable operation.

System Description

- The proposed system integrates:
  - Tidal energy converters (operating with MPPT).
  - A Hybrid Energy Storage System (HESS) consisting of:
    - Battery Energy Storage System (BESS) for medium-duration support.
    - Supercapacitor Energy Storage System (SCESS) for rapid transients.
- This hybrid approach leverages the complementary strengths of both storage types to meet the full spectrum of power demands.

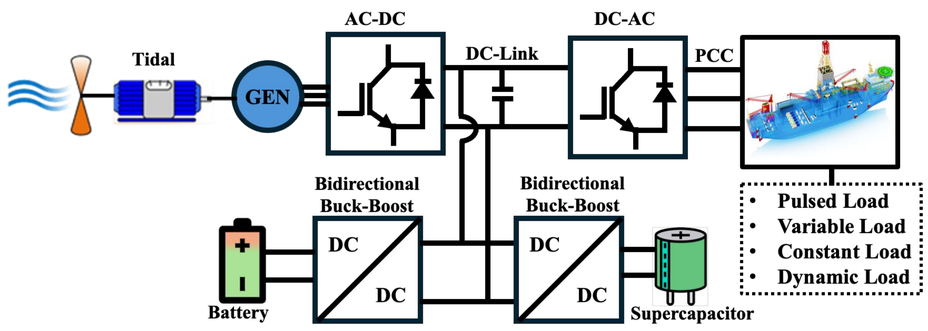

Fig. 1: Integrated Tidal Energy System with Hybrid Energy Storage and Load Interface

Table 1: Parameters Used In integrated Tidal Energy System

Parameters	Values
Tidal Turbine Parameters	
Tidal Turbine Radius	3.2m
Rated Power	100 kW @ 2.5 m/s
PMSG Parameters	
No. of Poles	40
Flux Linkage	1.2v.s
ESS Ratings	
Battery Ratings	480V, 100Ah
Supercapacitor Rating	27.8 F
Voltage at PCC	600 V
Frequency	60 Hz

Control Strategy

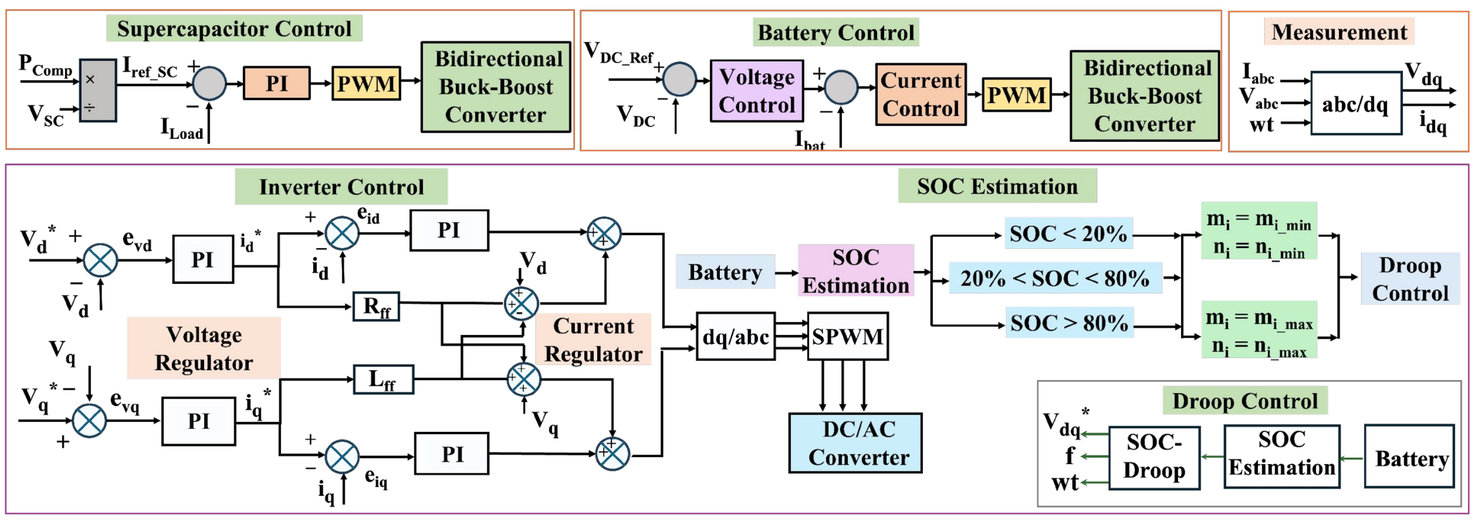

Fig. 2: Coordinated Control Architecture Incorporating Droop Mechanism, Inverter Regulation, and Energy Management

Simulation Results

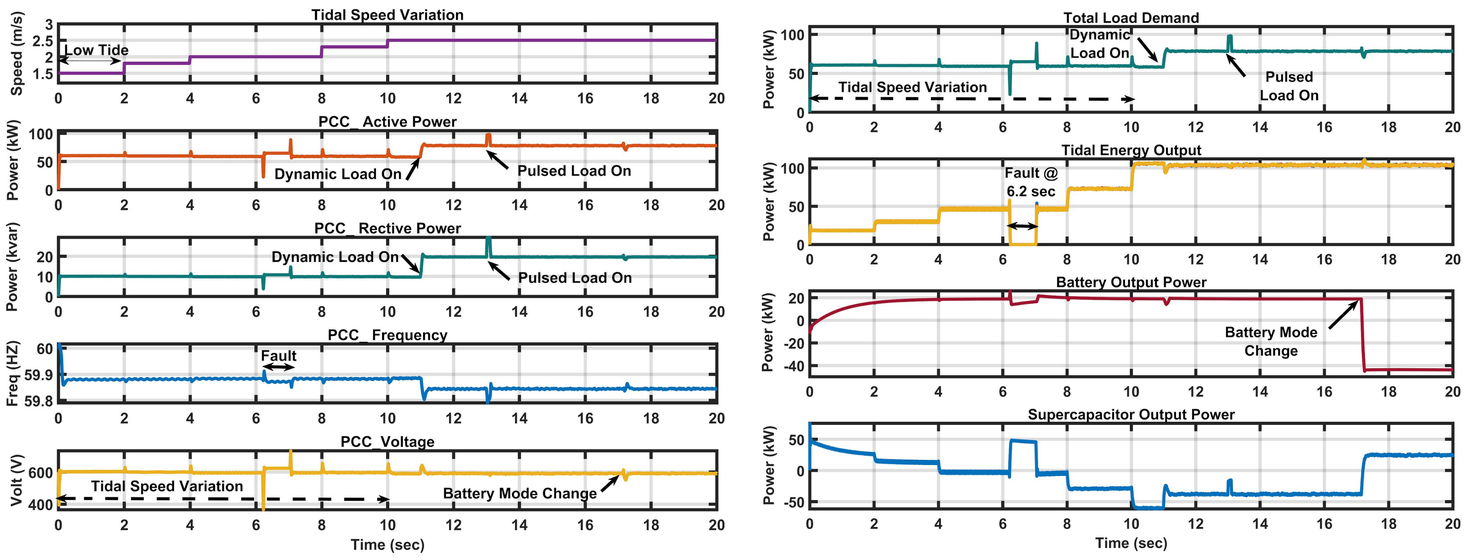

Fig. 3: Dynamic Response of Tidal-HESS: Voltage, Frequency, and Power Coordination

Table 2: Overview of Validation Scenarios and Test Event

Events	Description	Rating	Time Interval (sec)
1	Constant PQ Load	P = 50 kW, Q = 10 kvar	t*on*=0
2	Constant Resistive Load	P = 10 kW	t*on*=0.05
3	Pulse Load	P = 20 kW, Q = 10 kvar	t*on*=13, t*off* =13.1
4	Dynamic Load	P = 20 kW, Q = 10 kvar	t*on*=11
5	Tidal Speed Variation	1.5 – 2.5 m/s	t*on*= 0, t*off* =10
6	Symmetrical Fault	–	t*on*= 6.2, t*off* =7

Conclusion

- Tidal-based hybrid system maintained stable operation under variable load and fault conditions.
- Supercapacitor effectively managed fast transients; battery handled sustained energy balancing.
- PCC voltage and frequency stayed within acceptable limits during disturbances.
- Smooth mode transitions ensured reliable power delivery without instability.
- Validates suitability for autonomous marine microgrids with coordinated control.

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