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A novel optimal power management and control strategy for Marine Microgrids Integrated with Renewable Energy Sources and hybrid energy storage devices

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INTRODUCTION & AIM

Marine microgrids, integrating renewable energy sources, represent a promising solution for providing sustainable and reliable power to isolated maritime environments. However, the variability and intermittency of these energy sources pose significant challenges for frequency stability and energy management.

This study proposes an advanced strategy for energy management and frequency control, combining wind turbines, hydraulic turbines, photovoltaic panels, fuel cells, and diesel generators with hybrid energy storage systems. These storage systems, including Superconducting Magnetic Energy Storage (SMESS), ultra-capacitors (UC), and batteries, are designed to meet power and energy intensity needs while extending the battery lifespan [5].

Using optimized PIDN controllers and a filtration-based control method (FBC), this research explores four microgrid configurations to evaluate their performance in terms of frequency stability and efficient energy management. The results highlight the effectiveness of UC/battery [9] and SMESS/FC hybrid systems [2], underscoring their potential to enhance the resilience, sustainability, and longevity of marine microgrids.

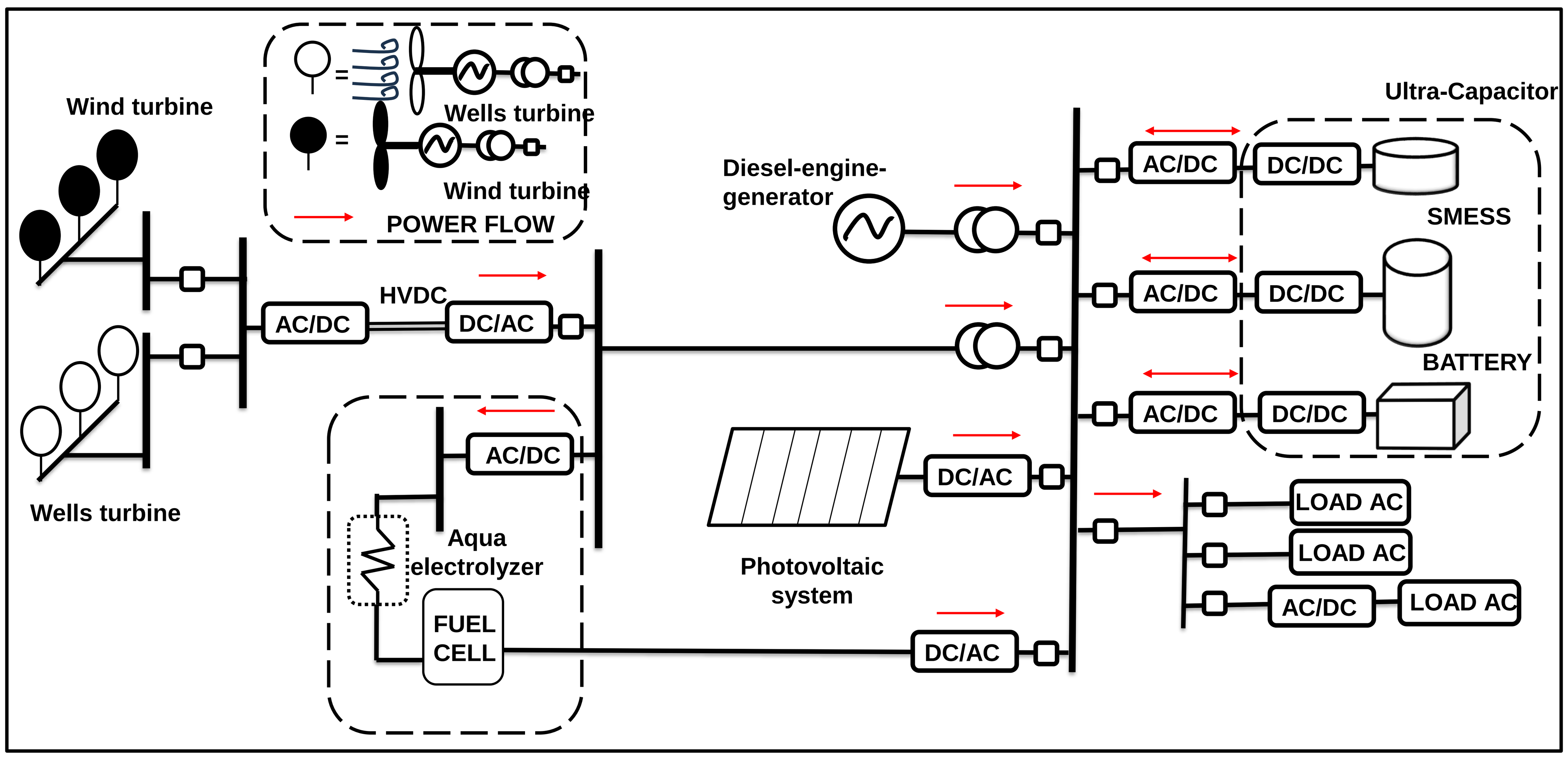


Fig. 1 configuration of the studied marine hybrid PG/HESS.

METHOD

System Configuration

The configuration of the proposed marine microgrids, integrating renewable energy sources and hybrid energy storage devices, is shown in **Fig. 1**. This hybrid energy generation and storage system studied in this research includes the following components: [1] [3][7]

Hybrid Generation Sources | **Hybrid Energy Storage Systems** | **Energy Conversion and Management**

Net Power generated

$$P_s = P_{WTG} + P_{Wells} + P_{PV} + P_{DEG} + P_{FC} \pm P_{SMESS} \pm P_{BESS} \pm P_{UC}$$

$$P_s = P_{WTG} + P_{Wells} + P_{DEG} + P_{FC} + P_{PV} - P_r$$

Mathematical Models and Transfer Functions

Management and Control Method

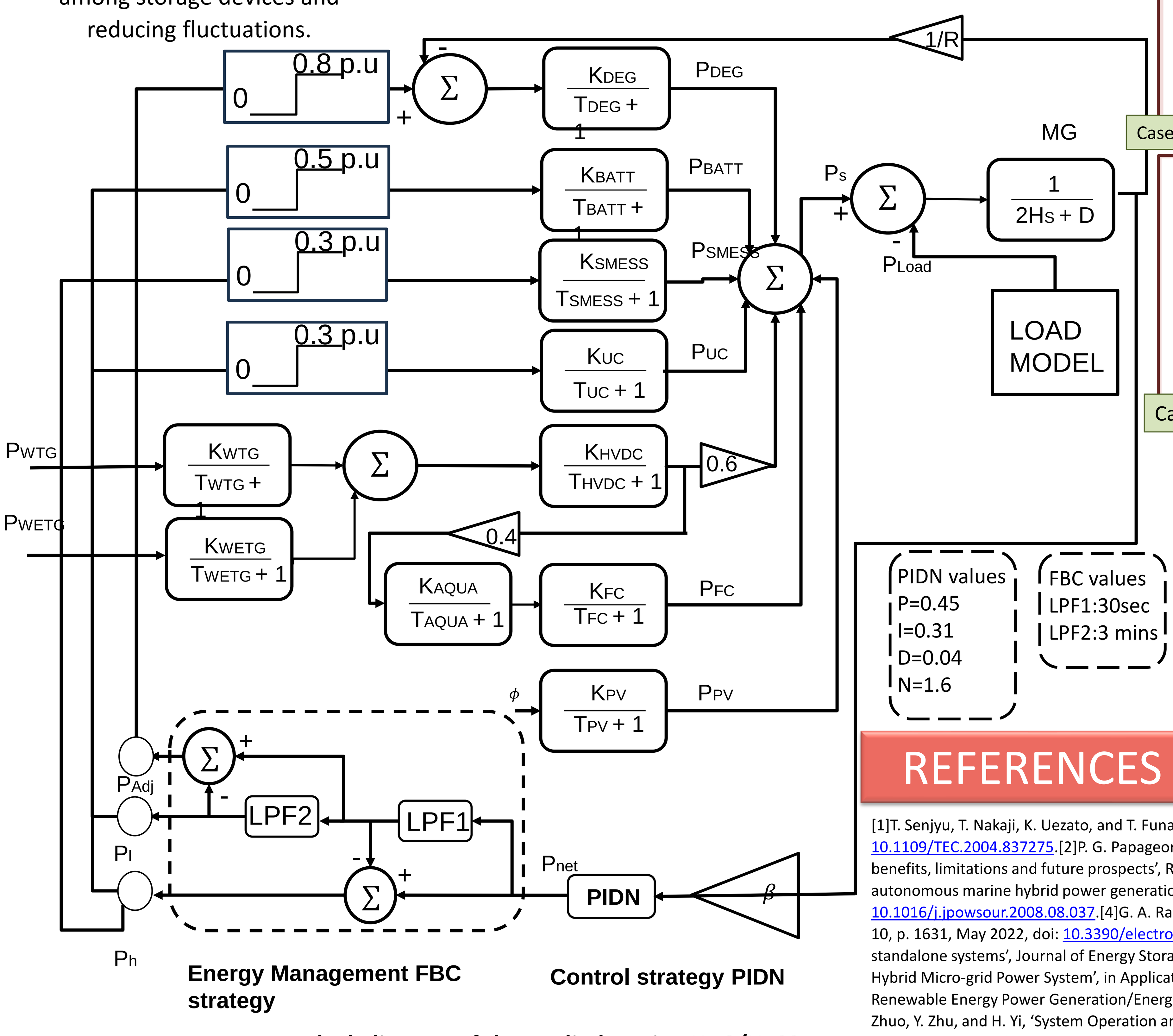
Energy Management Strategies

We use a **filtration-based strategy** [4] [8] to manage energy, distributing power among storage devices and reducing fluctuations.

Control Strategies

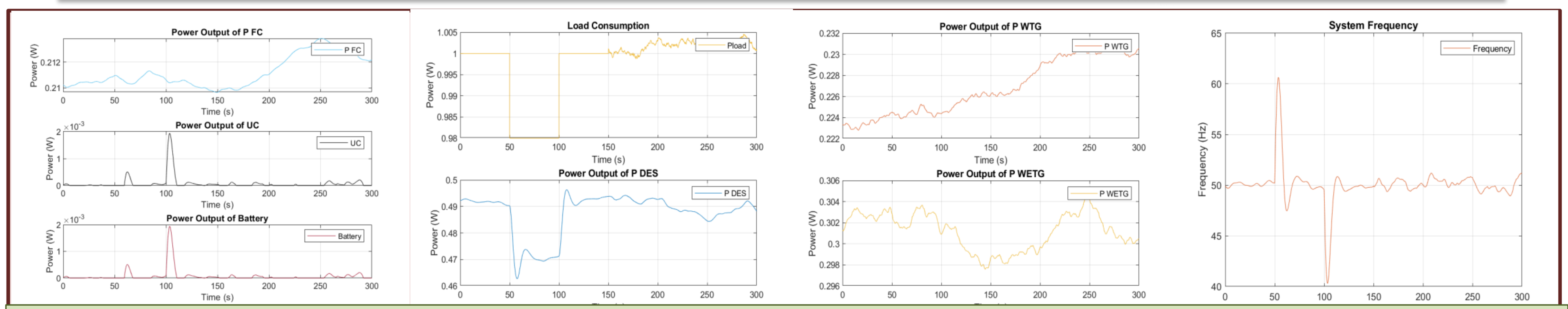
PIDN controllers regulate the components of the microgrid for fast and precise responses

$$P_{net} = P_s - P_{load} \qquad P_{net} = P_H + P_L + P_{adj}$$

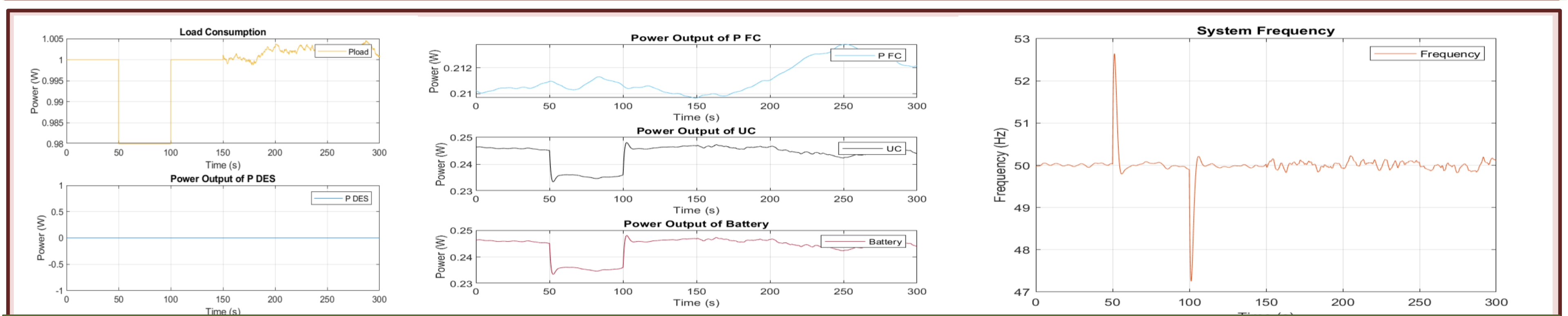


Block diagram of the studied marine HPG/HESS

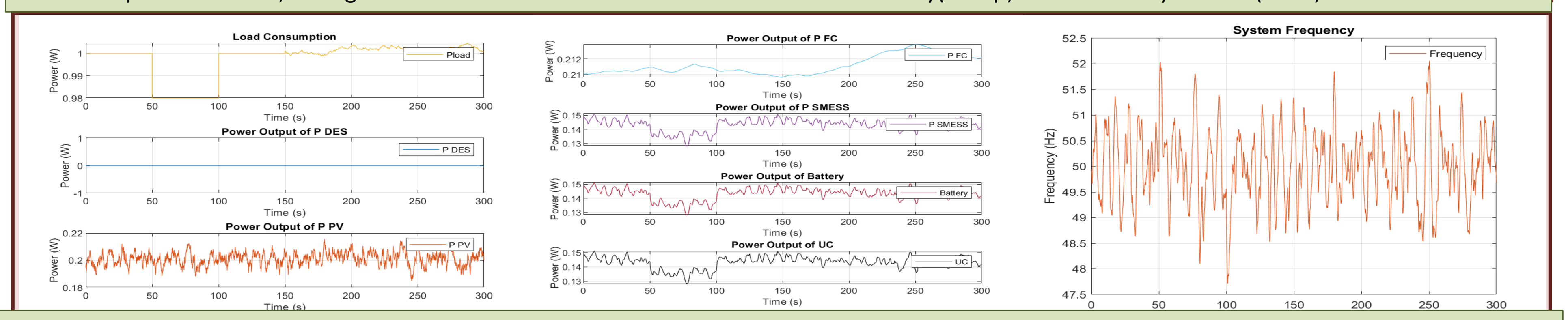
RESULTS & DISCUSSION



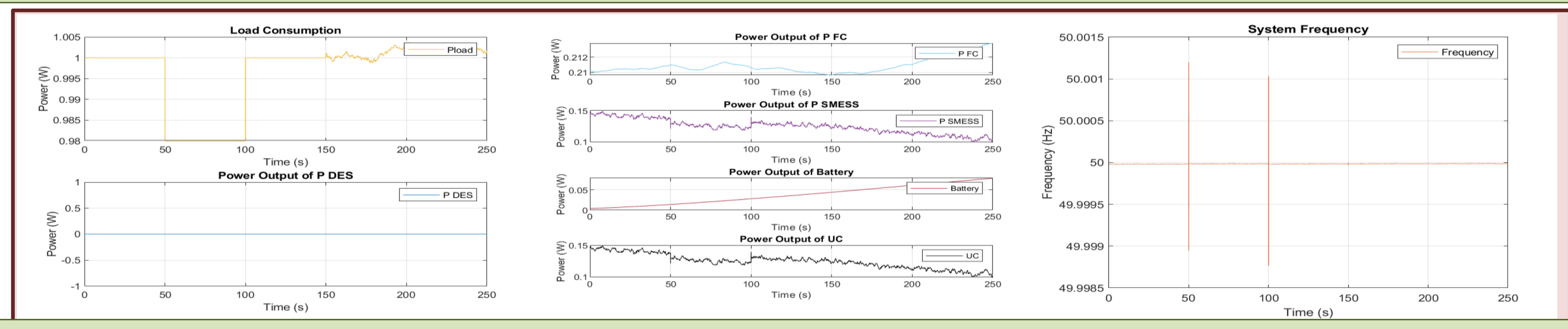
Case 1: Basic Configuration, Sources:(WTG),(WETG), (FC),(UC), (Batt), (DEG)./Control: DEG: Primary(droop), secondary (PI)./UC ,Batt: On-Off control.



Case 2: Improved Control, Configuration Sources: Same as in Case 1.Control DEG: Primary(droop) and secondary control (PIDN). UC and Batt: PIDN.



Case 3: Addition of PV and SMESS, Configuration Sources: Addition of (PV) and SMESS in Case 2. Control: Same as in Case 2, PIDN also applied to SMESS.



Case 4: Advanced Management Strategy (FBC), Configuration, Sources: Same Case 3.Control: Using the FBC management strategy.

CONCLUSION

An advanced strategy for optimizing energy management and frequency control in marine microgrids was presented in this work. Four configurations were simulated to evaluate system performance. The results demonstrate that PIDN controllers and filtration-based management (FBC) enhance frequency stability. The integration of PV and SMES diversifies energy sources, requiring advanced management to maintain stability.The effectiveness of UC/battery and SMES/FC hybrid systems is shown, providing a sustainable solution for marine microgrids while extending battery life and reducing reliance on fossil fuels.

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