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MILP-Based Optimal Sizing of a Hybrid Battery-Hydrogen Energy Storage in a Grid-Connected Photovoltaic System

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Introduction

The increasing integration of renewable energy sources introduces significant variability in power systems, requiring efficient and flexible storage solutions. While battery energy storage systems (BESS) are well-suited for short-term fluctuations, they remain limited for long-duration energy balancing. In this context, hydrogen storage emerges as a promising solution to complement batteries. This work investigates the optimal sizing and operation of a hybrid BESS-hydrogen storage system. A combined MILP-based optimization and rule-based strategy is used to assess system performance over a three-year period.

System description

The system is composed of PV generation, a battery energy storage system (BESS), and a hydrogen storage system, which includes an electrolyzer, a hydrogen tank, and a fuel cell (Fig. 1). A MILP-based optimization is used to determine the optimal sizing of the system components. The obtained sizing is then used in a rule-based strategy to simulate system operation over a three-year period.

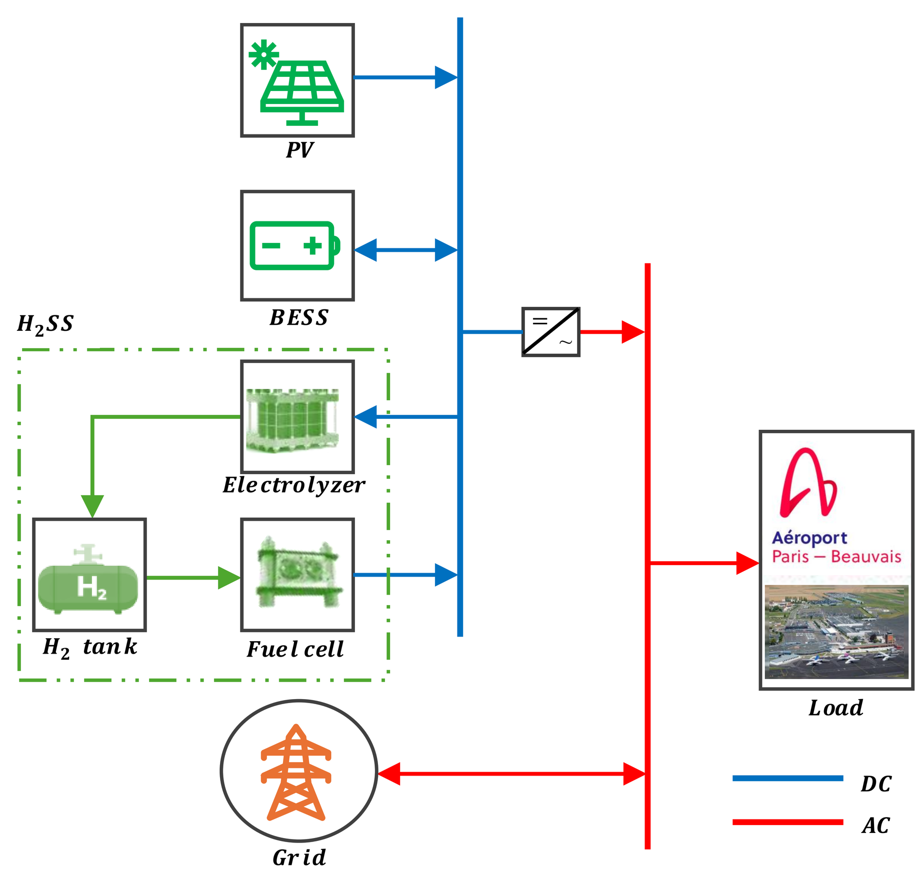

Fig. 1: System description

Methodology

The system is optimized using a MILP formulation that minimizes the total cost, including investment (CAPEX) and operational (OPEX) costs, to determine the optimal sizing of the storage components (1).

$$min(CAPEX + OPEX) \quad (1)$$

The optimal sizing results are used within a rule-based energy management strategy (Fig. 2) to simulate system operation over the study period, prioritizing PV self-consumption, storage utilization, and grid support when necessary.

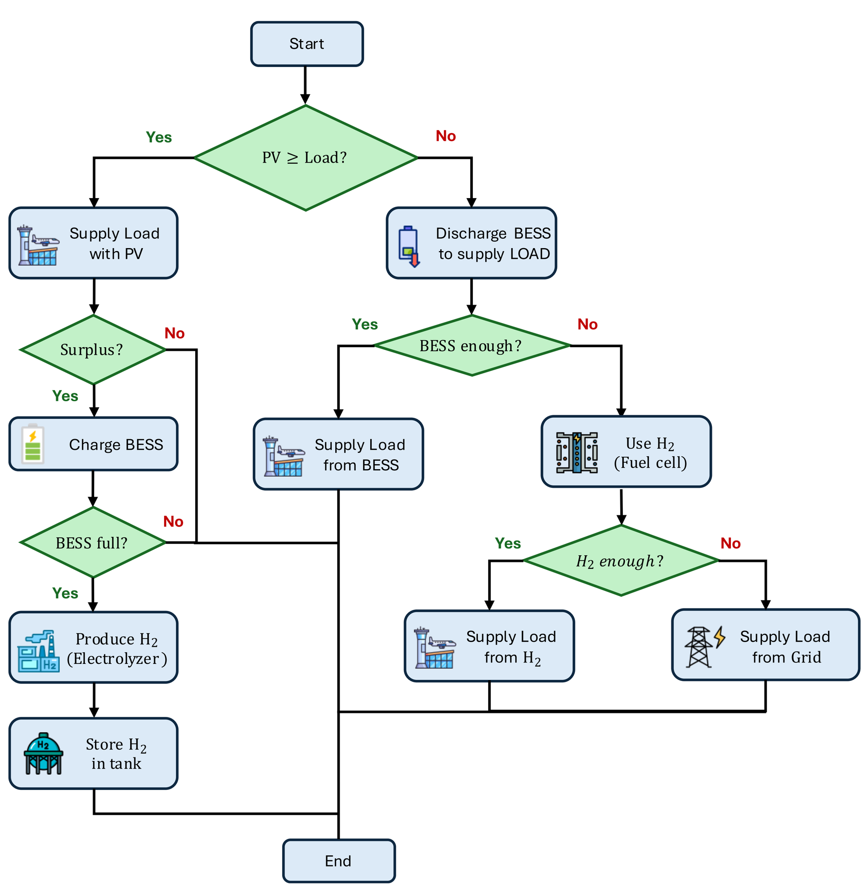

Fig. 2: Schematic of the proposed rule-based dispatch

Results

Monthly energy contributions for the BESS-only (Fig. 3 upper) and hybrid (Fig. 3 lower) configurations are illustrated below.

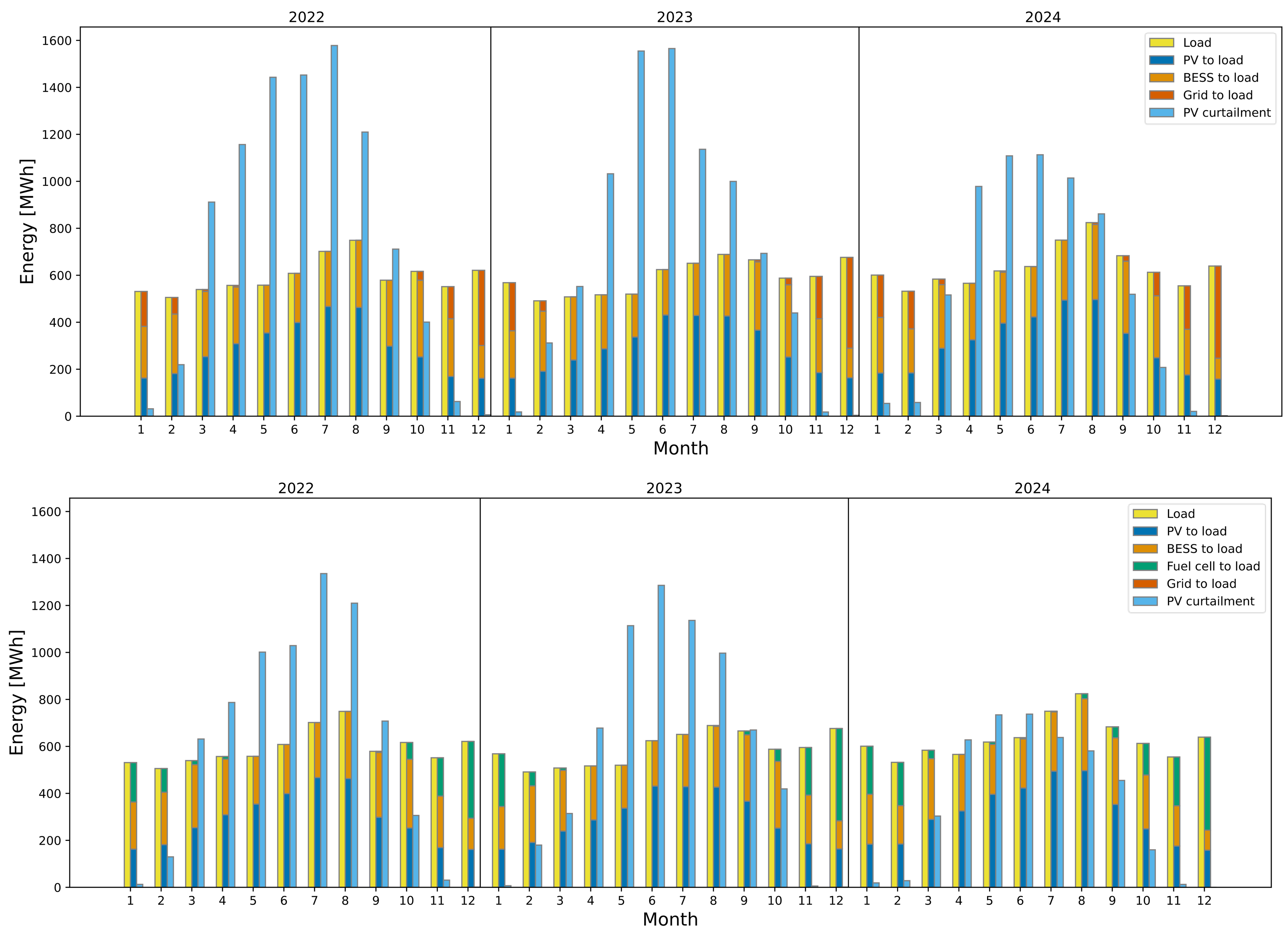

Fig. 3: Monthly contribution of each source

The hybrid configuration significantly reduces winter grid dependency and improves the utilization of surplus PV generation. A reduction in PV curtailment is also observed, indicating a more effective use of renewable energy.

The storage dynamics of the hybrid configuration are illustrated through the temporal evolution of the BESS state of charge (SoC) and hydrogen storage level (H) (Fig. 4).

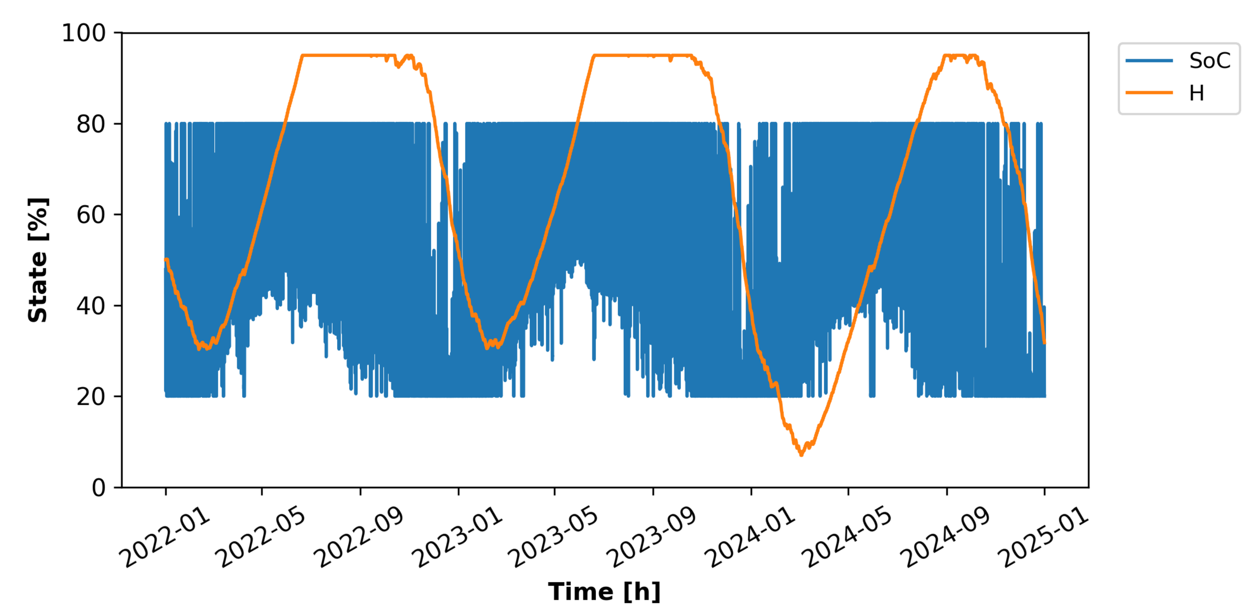

Fig. 4: State of Charge and hydrogen level

The BESS exhibits rapid charge/discharge cycles, while hydrogen storage evolves more gradually and provides long-duration energy support during extended deficit periods.

Conclusion

The proposed hybrid BESS-hydrogen storage system improves renewable energy utilization and significantly reduces grid dependency by combining short-term and long-term storage capabilities. The operational analyses demonstrate the complementary behavior of battery and hydrogen storage under varying seasonal conditions. In addition, the remaining PV curtailment highlights the potential of integrating flexible loads such as electric vehicles to further enhance renewable energy valorization.