A Predictive Energy Management Framework for Low-Emission and Resilient Waterfront Microgrids

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Motivation & Research Gap

5149 GW
global renewable capacity, 2025

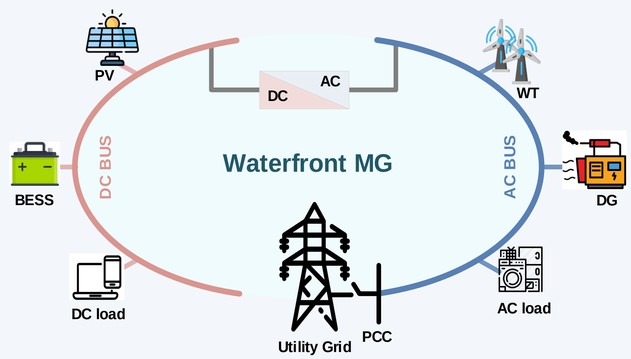
+692 GW
added in 2025; ~97% solar and wind

- **Waterfront sites** (marinas, ports, coastal platforms): strong wind/solar, variable loads, limited grid access.
- Variable renewables add uncertainty, especially when **islanded**.
- Existing EMS treat scheduling, real-time control and load management **separately**; no unified framework with an explicit resilience response.

Contributions

- **Day-ahead MILP:** minimizes operating cost and GHG emissions
- **Receding-horizon MPC:** corrects forecast deviations in real time
- **Event-driven fail-safe:** priority-based load shedding protects critical services

Waterfront Microgrid Test System



- **PV** 1 kW, WT 1 kW
- **DG** 5 kW (min. 1.25 kW)
- **BESS** 0.576 kWh, SoC 20-90%
- **Grid import** ≤ 3 kW
- 12 V **DC** and 110 V / 60 Hz **AC buses**

Proposed Three-Level EMS

Level 1 | Day-ahead MILP
24-h schedule minimizing cost + GHG

DA reference trajectories

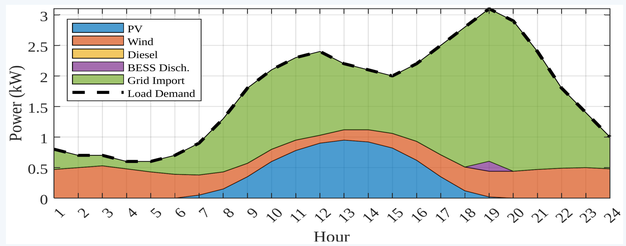
Level 2 | Real-Time MPC Corrective Dispatch
15-min corrective dispatch (96 steps) for forecast deviations

MPC infeasible fail-safe override

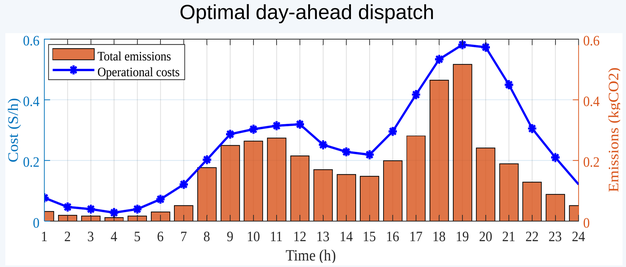
Level 3 | Event-driven fail-safe
Priority-based load shedding when MPC becomes infeasible to preserve critical services

Results & Discussion

Level 1 — **Nominal day: forecasted conditions**
Day-ahead MILP schedule · load peaks at 3.1 kW at hour 19



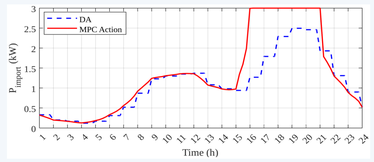
Optimal day-ahead dispatch



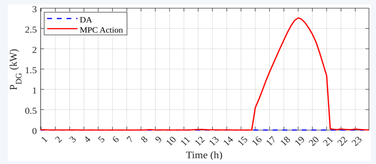
Hourly cost and emissions (peak ≈0.6 $/h, ≈0.5 $kgCO_2$)

- **Renewables first**; the BESS discharges in hours 18-20 and the grid covers the evening peak
- **Diesel never runs**: the grid (0.233 $kgCO_2$/kWh) beats it (0.65) on cost and emissions, so it stays a fail-safe reserve

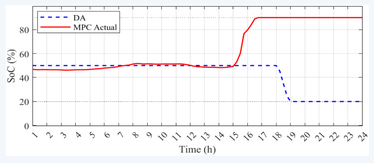
Level 2 — **+100 % load surge, hours 16–21**
Real-time MPC correction · peak net demand ≈6.2 kW



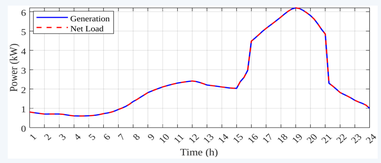
Grid import hits 3.0 kW



Diesel covers ≈2.3 kW



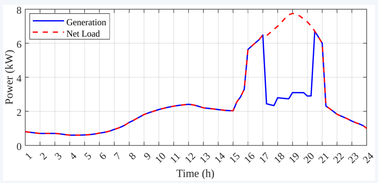
SoC profile (20% → 90%)



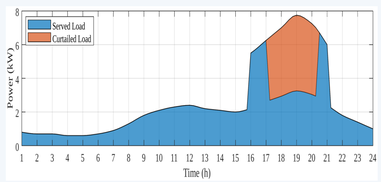
Generation tracks the net load

- **MPC revises the plan every 15 min**: grid import hits its limit and the diesel supplies the remaining deficit
- The **BESS flips from discharging to charging** up to its 90 % SoC limit, rebuilding reserve margin

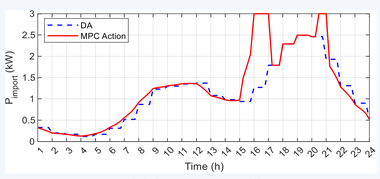
Level 3 — **+150 % load surge, hours 16–21**
Fail-safe activation · peak demand ≈7.8 kW exceeds capacity



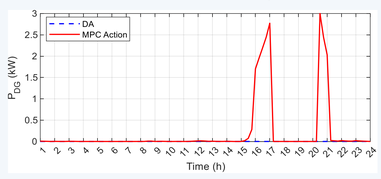
Demand exceeds supply



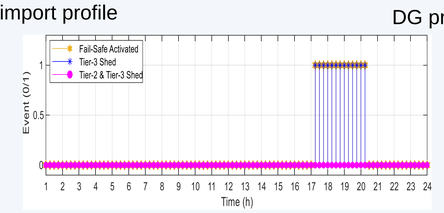
Tier-3 shed ≈60 % of peak



Grid-import profile



DG profile



Fail-Safe Events Log

- **Shedding Tier-3 loads** restores a feasible MPC problem while Tier 1–2 loads stay supplied
- **Diesel runs near its maximum** before and after the shedding window; the grid stays within its import limit

CONCLUSION & KEY FINDINGS

- ✓ **MILP day-ahead scheduling maximizes renewable utilization while minimizing cost and emissions**
- ✓ **MPC correction maintains close tracking of the DA schedule under real-time forecast and load uncertainty**
- ✓ **The priority-based fail-safe layer preserves critical loads through selective shedding under extreme, MPC-infeasible disturbances**
- ✓ **Together, the three layers deliver a reliable, flexible, and sustainable waterfront microgrid EMS**