RL-Enhanced Model Predictive Control for Adaptive Microgrid Energy Management

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A multi-timescale RL-MPC framework adaptively adjusts MPC objective weights to changing microgrid conditions while preserving constrained control. Evaluation against sensitivity-tuned MPC over 16 representative days demonstrates condition-dependent adaptation and multi-objective performance trade-offs.

Problem Description

Microgrid EMS requires balancing competing economic and operational objectives under varying load, renewable generation, and electricity prices. Conventional MPC handles operational constraints effectively, but fixed objective weights impose a fixed trade-off under changing conditions.

Objective: Adapt MPC priorities online according to operating conditions while retaining MPC constraint handling.

Methodology

A hierarchical RL-MPC architecture combines adaptive supervisory learning with constrained predictive control. The RL agent observes the microgrid state and adjusts four MPC objective weights:

$\mathbf{W = [W_{grid}, W_{curt}, W_{deg}, W_T]}$.

The agent updates the weights every **15 min**, while MPC solves the constrained control problem every **5 min** over a **6-h prediction horizon**.

A DDPG agent is trained for **1000 daily episodes** using microgrid-scale profiles derived from 2025 ENTSO-E data.

RL-MPC was compared with sensitivity-tuned MPC over **16 representative days** covering four seasons and diverse operating conditions.

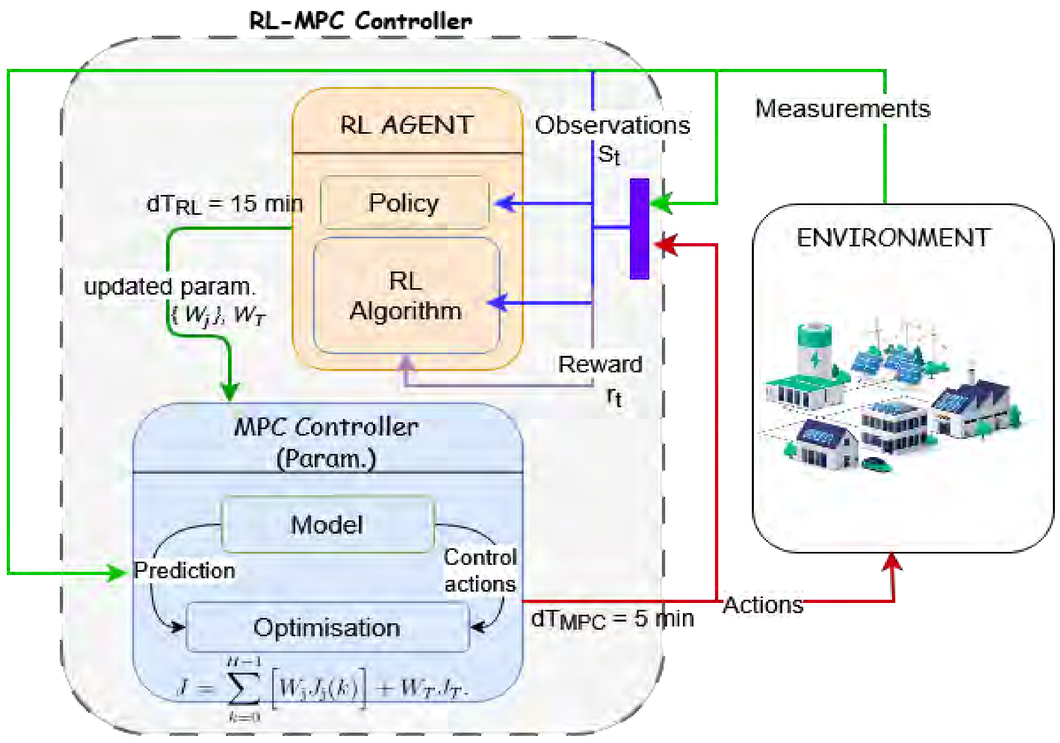


Figure 1: *Multi-timescale RL-MPC control architecture*

Results

The comparison reveals a clear redistribution of performance across the competing objectives:

- ≈-24% renewable curtailment & ≈-2% grid-energy use
- ≈+14% battery throughput & ≈+5% grid cost

→ RL-based adaptive weighting yields condition-dependent trade-offs rather than uniform improvement across all objectives.

KPI	Winter	Spring	Summer	Autumn	All 16
Grid [kWh]	2483/2481	1467/1351	958/935	1594/1591	**6502/6358**
Grid [EUR]	357/368	108/137	96/92	126/124	**688/722**
Curt. [kWh]	0/0	220/119	140/141	71/68	**431/328**
Batt.Thr[kWh]	209/189	265/221	382/467	151/268	**1008/1146**
$\lvert SOC_{REF}\text{-}SOC_T \rvert$	.080/.078	.050/.028	.019/.079	.054/.048	**.051/.058**

Table1*: Seasonal and 16-day aggregate performance (Tuned MPC / RL-MPC).*

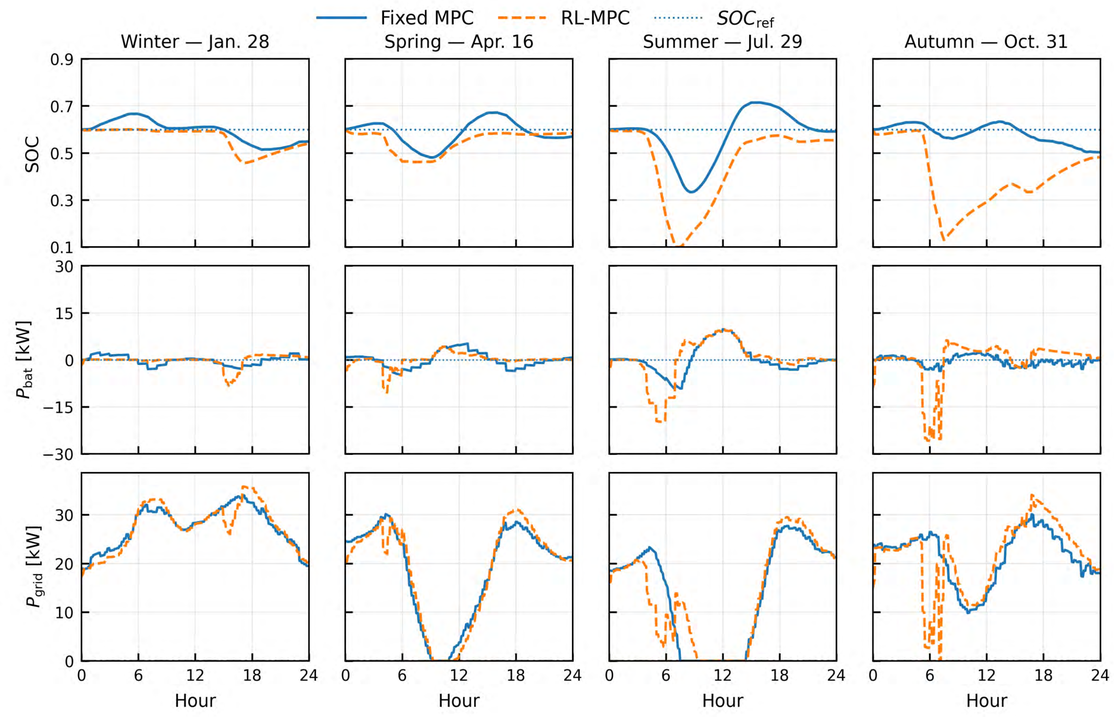


Figure 2: *Seasonal operation of Tuned MPC and RL-MPC*

Future Work

- Reward redesign for improved objective balancing
- Forecast uncertainty in load, renewable generation, and electricity prices.
- A detailed battery degradation model to quantify long-term aging costs.
- Broader evaluation and alternative MPC/RL update intervals.

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