Demonstration of Sustainable
Hydropower Refurbishment

M8 Meta-code for optimal control of hybrid plants

Work Package	WP2
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Milestone reached	25.10.2025

Task: T2.1 – Hybridization of cascade hydropower with batteries

Milestone: M8 Meta-code for optimal control of hybrid plants

Description:

This task focuses on the development of a control algorithm for hybrid hydropower plants. The algorithm developed in this work is based on the existing **Double Layer Model Predictive Control (DLMPC)** framework presented by F. Gerini[1]. In the DLMPC structure, the **Upper Layer** acts as a **State of Energy (SoE) manager** for the Battery Energy Storage System (BESS) and remains unmodified in this work. Conversely, the previous **Lower Layer** optimally allocated the power setpoint between the turbine and the BESS in real time. The present work extends this approach by implementing **four generation groups** instead of one in the dispatch strategy, and by introducing a mechanism to forecast and manage the **water level of the dam**.
The implementation of a **head level model** is achieved through a **linear regression** fitted on five months of measurement data collected by EDF at the Vogelgrun hydropower plant.
Equations (1) – (14) describe the **Lower Layer Model Predictive Control (LLMPC)**.

- **Equation (1)** defines the minimisation of the cost function, which reduces both the **tracking error (TE)** and the **number of actuator movements** for each of the four groups.
- **Equations (2)–(8)** represent the **constraints** ensuring that the BESS operates within its physical limits, as detailed in Gerini's original work.
- **Equations (9)–(11)** are adapted from the same source to accommodate four generation groups instead of one, ensuring that the hydropower plant remains within its physical boundaries.
- Finally, **Equations (12) and (13)** describe a **linear model for the head level** and define the permissible variation limits around a given setpoint.

[1] F. Gerini, *Advanced Control Strategies to Exploit the Hydropower Potential Enhancing Ancillary Services Provision to the Power System*, EPFL PhD Thesis No. 10437, 2024.

$$[\mathbf{P}^{\text{HPP}}_{s:s+T}, \mathbf{P}^{\text{BESS, set}}_{s:s+T}] = \underset{\mathbf{P}^{\text{BESS}} \in \mathbb{R}^{T} | \mathbf{P}^{\text{HPP}} \in \mathbb{R}^{4 \times T}}{\text{argmin}} \quad \mathbf{TE}_{s:s+T} + \sum_{i=1}^{4} \omega_c^i \cdot \|\Delta \mathbf{P}^{\text{HPP},i}_{s:s+T}\|_1 \tag{1}$$

$$\text{s.t.} \quad \text{P}^{\text{BESS}}_s \leq \xi(\upsilon^{\text{DC}}_s, \upsilon^{\text{AC}}_s, \text{SOE}_s) \tag{2}$$

$$\text{P}^{\text{DC}}_s = \begin{cases} \text{P}^{\text{BESS, set}}_s \cdot \eta_{\text{ch}}, & \forall \text{P}^{\text{BESS, set}}_s \geq 0 \\ \text{P}^{\text{BESS, set}}_s / \eta_{\text{dch}}, & \forall \text{P}^{\text{BESS, set}}_s < 0 \end{cases} \tag{3}$$

$$\upsilon^{\text{DC}}_s = \phi_\upsilon x_{s-1} + \psi_i \upsilon^{\text{DC}}_i + \psi_\upsilon \mathbf{1} \tag{4}$$

$$j^{\text{DC}}_s \approx \frac{\text{P}^{\text{DC}}_s}{\upsilon^{\text{DC}}_s} \tag{5}$$

$$\upsilon^{\text{AC}}_s \approx \upsilon^{\text{AC}}_{s-1} \tag{6}$$

$$\text{SOE}_s = \text{SOE}_{s-1} + j^{\text{DC}}_s \upsilon^{\text{DC}}_s \frac{1}{C_B} \tag{7}$$

$$\text{SOE}_{\text{min}} \leq \text{SOE}_s \leq \text{SOE}_{\text{max}} \tag{8}$$

$$\text{P}^{\text{HPP},i}_s = (1 - \frac{\Delta s}{\tau_W}) \cdot P^{\text{HPP},i}_{s-1} + \frac{\Delta s}{\tau_W} \cdot P^{\text{HPP,set},i}_s \tag{9}$$

$$\text{P}^{\text{HPP}}_{\text{min}} \leq \text{P}^{\text{HPP},i}_s \leq \text{P}^{\text{HPP}}_{\text{max}} \tag{10}$$

$$-\dot{\text{P}}^{\text{HPP}}_{\text{max}} \leq \Delta \text{P}^{\text{HPP},i}_s \leq \dot{\text{P}}^{\text{HPP}}_{\text{max}} \tag{11}$$

$$\text{H}_s = \text{H}_{s-1} + \beta_1 \cdot \sum_{i=1}^{4} \text{P}^{\text{HPP},i}_{s-1} + \beta_0 \tag{12}$$

$$\text{H}^{\text{co}} - \Delta\text{H} \leq \text{H}_s \leq \text{H}^{\text{co}} + \Delta\text{H} \tag{13}$$

$$\forall s \in [s, \ldots, s+T], \quad \forall i \in \{1,2,3,4\} \tag{14}$$

The code corresponding to the developed control algorithm has been fully implemented in **MATLAB**, following the structure of the DLMPC framework. The implementation was designed to ensure computational efficiency and robustness, enabling the control system to operate reliably in real-time or near real-time conditions. The algorithm is tested using **frequency data from the electrical grid**, which is serving as a reference signal for the **dispatch tracking**.

DISCLAIMER / ACKNOWLEDGMENT

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