

# Response to Referee and Editor Comments

Second manuscript revision

## Optimizing the Operation of Energy Islands with Predictive Nonlinear Programming – A Case Study Based on the Princess Elisabeth Energy Island

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December 12, 2025

We thank the Associate Editor and the referees for their constructive comments and for recommending a minor revision of our manuscript wes-2025-102, *Optimizing the Operation of Energy Islands with Predictive Nonlinear Programming – A Case Study Based on the Princess Elisabeth Energy Island*. All points raised in this second review round have been carefully addressed. A detailed point-by-point response is provided below. Modifications in the revised manuscript are highlighted in [blue](#).

### 1 Referee 1

#### Reviewer Comment 1.1

The revised manuscript has addressed all my concerns in the first round of review. So, I think the revised manuscript in the current situation is suitable for publication.

#### Authors' response 1.1

We sincerely thank Referee 1 for the careful re-evaluation of our manuscript and for confirming that all previous concerns have been adequately addressed. We greatly appreciate the positive recommendation for publication.

### 2 Referee 2

#### General Comment

The manuscript describes an optimization framework for power dispatch for an energy island. Multiple case studies are shown involving the Princess Elisabeth Energy Island. The system model focusses on the AC/DC grid, including hydrogen production and battery storage. By optimizing the power dispatch considering fixed constraints regarding hydrogen output and energy delivery, the

farm revenue is maximized. The optimization is performed for representative days for each season. The results demonstrate different operating strategies in various scenarios.

## **Authors' Response to General Comment**

We thank Referee 2 for the careful reading of the manuscript and for the positive summary of our work. We are pleased that the optimization framework, the modelling approach, and the main findings have been clearly understood and well received. No changes are required in response to this general comment.

### **Reviewer Comment 2.1**

The article is mostly well-structured; however, it could improve by more clarification. What is the benefit by utilizing this approach compared to other approaches? Is there a baseline case, to which the optimization could be compared to?

### **Authors' response 2.1**

We thank the reviewer for this comment, which gives us the opportunity to make the advantages of the proposed nonlinear AC approach even more explicit.

The main benefits of using a full nonlinear AC power flow model instead of the more common DC (linear) approximation are:

- Optimal dispatch of turbine-level and BESS reactive power, which is impossible in DC models.
- Accurate voltage control in long offshore collector systems.
- Reduction of active power losses by approximately 1% of total generated energy through optimal reactive support.

This is explained in the manuscript, as detailed in the following paragraph of Subsection 5.2:

*5.2 Energy Management and Optimization for Representative Days on the Princess Elisabeth Energy Island*

⋮

Fig. 10 presents the nodal voltages and turbine-level reactive power injections for the representative autumn scenario, clearly evidencing the correlation between reactive power dispatch and local voltage magnitudes. This relationship is fundamental in offshore AC networks, where voltage regulation plays a critical role in ensuring system stability—particularly during periods of high wind generation or significant power export. Capturing this interaction requires a modeling framework capable of representing both voltage magnitudes and reactive power flows, which is not possible in simplified DC power flow approximations where reactive power is neglected and voltages are assumed constant. To address this, the proposed nonlinear AC power flow formulation explicitly models and optimally dispatches reactive power from both the wind turbines and the Battery Energy Storage System (BESS), enabling coordinated voltage support and reduction of active power losses. In our case study, dispatching reactive power from the wind turbines and the BESS reduced total system losses by approximately 1% compared to an equivalent scenario without such reactive power support. Furthermore, the high sparsity of the network admittance matrix ensures competitive computational performance despite the increased modeling detail: for example, the autumn representative day simulation was completed in approximately 27 seconds on a standard laptop (Intel Core i5-1235U, 16 GB RAM, Python 3.11). This demonstrates that the AC-based nonlinear formulation not only delivers a more accurate and operationally meaningful representation of the energy island but also remains computationally tractable for extended multiperiod and seasonal analyses.

This is also include in the introduction, as follows:

*1. Introduction*

⋮

Linearization, commonly referred to as DC power flow approximation, simplifies the relationships between voltage magnitudes and angles by neglecting reactive power flows and assuming flat voltage profiles, as presented in Ju et al. (2018). Although computationally very efficient, this approach is inadequate for energy islands because it cannot dispatch reactive power from wind turbines or the battery energy storage system, it does not model voltage magnitude constraints, which are frequently binding in long offshore collector systems, and it systematically underestimates active power losses, since optimal reactive support can reduce resistive losses.

**Reviewer Comment 2.2**

Line 36: Please elaborate which kind of security constraints are considered here. Is it regarding (system) grid stability or cyber-security? The term appears in multiple places in the manuscript.

**Authors' response 2.2**

We appreciate the reviewer's comment. Throughout the manuscript, the term "security constraints"

refers exclusively to conventional steady-state operational limits in power systems (e.g., voltage limits, thermal limits, and converter ratings), and not to cyber-security aspects. This has now been clarified in the revised manuscript as follows:

*1. Introduction*

⋮

The complexity of the optimal operation of these systems arises from the nonlinear interactions between their subsystems, the fluctuating availability of wind power, and the requirement to comply with fundamental physical and steady-state security constraints, namely voltage magnitude limits, thermal loading limits of AC and DC transmission lines, and current and power ratings of converters and other power system components.

**Reviewer Comment 2.3**

Line 72: What is the lack that current technologies have regarding AC/DC grids? Please elaborate more.

**Authors' response 2.3**

We thank the reviewer for the opportunity to clarify this point. The “lack” referenced in Line 72 does not refer to a technological limitation of AC/DC hardware itself, but rather to a gap in the existing Optimal Power Flow (OPF) formulations for hybrid AC/DC grids.

To make this clear, the manuscript has been revised as follows:

*1. Introduction*

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To address this gap in existing OPF methodologies, specifically the limited ability of current models to represent the operational interactions and requirements characteristic of hybrid AC/DC energy islands, AC/DC OPF frameworks offer a promising foundation for developing more comprehensive and realistic operational strategies.

**Reviewer Comment 2.4**

Line 113: Are other approaches than a centralized operational strategy investigated in the literature, or is this the only considered way?

**Authors' response 2.4**

The operational coordination of energy islands remains relatively underexplored in the literature, and the studies available rely on centralized OPF-based strategies. In our review, we did not identify any decentralized approaches specifically targeting the operation of AC/DC energy islands.

**Reviewer Comment 2.5**

Line 238: Why are the initial and final energy state enforced by a constraint? Does this not limit the optimization? Please elaborate, a consistent energy state is otherwise not necessarily given.

### Authors' response 2.5

We thank the reviewer for the comment regarding the constraint enforcing identical initial and final states of charge of the BESS. This condition is intentionally imposed to enable the assessment of system performance over a single representative day in a manner that is independent of boundary conditions from adjacent days. By enforcing charge neutrality over the daily horizon, the model avoids biased operating conditions, such as unrealistically favorable fully charged initial states or unfavorable depleted ones. Moreover, this assumption naturally supports a rolling-horizon optimization framework, whereby each day can be optimized independently without intertemporal coupling of the BESS state. The rationale has been clarified in the revised manuscript.

### 3.3 Battery Energy Storage System Model

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To ensure continuity between time windows, the initial ( $E_0$ ) and final ( $E_f$ ) energy states are enforced in constraint (26). This ensures that the energy state of the system is consistent and maintains a seamless transition from one time window to the next.

### Reviewer Comment 2.6

Line 262: What kind of degradation for hydrogen production is considered? The model does not show a degradation value.

### Authors' response 2.6

Hydrogen production degradation is not considered in the proposed model. This is because the study focuses on short-term operational analysis of energy islands over representative daily horizons, for which degradation effects are negligible. Degradation becomes relevant primarily in long-term planning problems with multi-year time horizons, which are outside the scope of this work.

### Reviewer Comment 2.7

Section 3.5: Please name explicitly the optimization variable next to the objective function. The revenue is maximized by optimizing which variables?

### Authors' response 2.7

The revenue is maximized with respect to the active power exported to each country over time, i.e., the market dispatch variables  $P_{i,t}^m$ . These variables are the decision variables of the optimization problem and are endogenously determined through the AC/DC network constraints and operational limits.

### 3.5 Objective function

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where  $C_{i,t}$  represents the power price at country  $i$  during period  $t$ , and  $P_{i,t}^m$  is the optimization (decision) variable representing the active power delivered to country  $i$  in period  $t$  within the time window  $\mathcal{T}$ .

### **Reviewer Comment 2.8**

Line 388: Figure 8 shows a high fluctuation in after hour 12 for PE\_II in the Winter case. However, the other farms do not show such behavior. Can this still be considered as a representative day? It seems more like a special situation to include derating from the grid operator. Consider not only the mean value to determine a representative day. Temporal behavior is also important.

### **Authors' response 2.8**

We thank the reviewer for the comment. The representative days are selected based on the seasonal median of the daily average power, as described in the manuscript. The higher fluctuation observed for PE\_II in the winter case is not related to any grid operator derating, but reflects the natural temporal variability of the wind resource at that location. Although the selection is based on the daily mean value, the full temporal profile is preserved without smoothing. Therefore, the selected winter profile is still considered representative of realistic wind behavior for operational analysis.

### **Reviewer Comment 2.9**

Section 5.2 and Section 5.3. I am missing a comparison plot of the nominal and the optimized curtailed operation. How much curtailment can be avoided using this approach? How much revenue would the wind farms produce, without the energy island?

### **Authors' response 2.9**

This point is clarified as follows. Under nominal transmission conditions, curtailments are not observed in the base case because the available wind power is obtained from a realistic wind energy model that explicitly accounts for wake losses, so the physically achievable peak generation levels are not reached for most of the time. In addition, the Princess Elisabeth Energy Island is equipped with multiple HVDC interconnections whose aggregated capacity is sufficient to accommodate the available offshore wind power under normal operating conditions. Therefore, a nominal curtailment case does not arise in a realistic setting.

However, curtailment remains a highly relevant concern in two realistic situations that justify the analysis in Subsection 5.3:

- Severe contingencies or prolonged maintenance of one or more HVDC links.
- Future design stages in which developers may deliberately downsize HVDC capacity to reduce very high upfront infrastructure costs, accepting a certain level of controllable curtailment that can be absorbed by onboard flexibility resources (BESS and Green Hydrogen Production Systems).

For this reason, the curtailment analysis is intentionally conducted under the contingency scenario introduced in Subsection 5.3, where HVDC capacities are reduced to 33% of their nominal values. In this case, Fig. 16 clearly shows how the transmission limits become binding and how the proposed framework mitigates curtailments through the coordinated use of the BESS and the hydrogen system. In this constrained scenario, the proposed methodology allows to avoid 9.8% of the potential wind curtailment.

### *5.3 Optimizing Curtailment Mitigation with BESS and Hydrogen Systems under Constrained Transmission Conditions*

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This subsection presents a case study to evaluate the effectiveness of the proposed approach in mitigating curtailments under constrained transmission conditions. To simulate a contingency scenario, the capacity of all HVDC transmission interconnections is reduced to 33% of their nominal value, representing a severe limitation in power export capability, such as might occur during maintenance or unexpected outages. This case scenario analysis tests the robustness of the proposed nonlinear optimization framework, described in Section 3, by assessing its performance under atypical operating conditions. The optimization objective, focused on maximizing revenue from offshore wind generation, indirectly minimizes curtailments by prioritizing efficient resource allocation, including BESS charging/discharging and hydrogen production scheduling. Under this constrained scenario, the proposed methodology achieves a curtailment reduction of 9.8% with respect to the uncontrolled case. The results demonstrate how the BESS stores excess energy during periods of high wind generation and constrained transmission, while the hydrogen production system absorbs surplus power to meet daily production targets, thereby reducing curtailments and enhancing economic performance.

#### **Reviewer Comment 2.10**

General clarification about the system model is required: The wind speed seems to be considered as an open loop input into the framework. However, wake losses influence the power extraction of the wind turbines. When operating points change due to operator curtailment, the wake also changes. This affects the total available power. Thereby, a feedback loop would be created. Would this be included in this model? If not included, this should be considered in future developments.

#### **Authors' response 2.10**

We appreciate the reviewer's comment. In the proposed framework, wind power generation is derived from detailed wind park simulations that already include wake losses, based on realistic wind speed and direction data. These wake effects are therefore embedded in the representative wind power profiles used as inputs to the operational model. However, the dynamic feedback between real-time curtailment actions, turbine operating points, and wake interactions is beyond the current scope. We agree that incorporating this aerodynamic–operational coupling is a valuable extension and have included it as a direction for future work.

## 6. Conclusions

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Potential directions for future research may include:

- i) Integrate detailed techno-economic assessments of subsystems into the planning framework for hybrid energy islands to evaluate their impact on overall system performance and cost-effectiveness.
- ii) Apply stochastic optimization techniques to extend the proposed strategies, enabling robust planning of hybrid energy islands across both representative days and long-term horizons under uncertainty.
- iii) Incorporate advanced wake interaction models to capture the coupling between aerodynamic effects, wind turbine operating points, and curtailment strategies.
- iv) Extending the analysis to other energy island projects, such as Denmark's Energy Islands and the Bornholm Energy Island, to verify the proposed methodology across different geographical and operational contexts, leveraging project-specific data and configurations to enhance the generalizability of the model.