November 12, 2023

Reply to the reviewer's comments of article (reviewer 2)
Hydesign: a tool for sizing optimization for grid-connected hybrid power plants including wind, solar photovoltaic, and Li-ion batteries

The authors would like thank the reviewer for providing detailed and thorough comments that have made the article better. We have addressed all your comments. In this document you will find the reviewer comments in red and a summary of the modifications done including line number references of where to find them on the new document.

General:

This paper presents a modelling framework, coupled to an optimizer, that can be used to optimize various essential components and the control strategy of a co-located hybrid power plant. It includes performance and cost models for various disciplines along with degradation effects of PV panels and Li-ion batteries. The use of NPV normalized with investment as an objective function, instead of LCoE, makes the results relevant to the wind-based hybrid community. Overall, the study uses a comprehensive modelling approach with case studies to demonstrate the capabilities of the framework. However, the presentation of results and the translation of results to high level insights is missing. The paper needs major revisions w.r.t. the following aspects:

- Paper structure: The methodology section discusses the 'modelling framework'. The general problem formulation (which is currently section 3) is essentially a part of the methodology. It might be useful to have a separate section called ' case study description' that shows 'weather' and 'electricity price' specifically for the locations in India.
- Results section: A detailed discussion w.r.t. the results is missing.
- Conclusions: The conclusions are a short summary of the results, and do not provide any additional higher level insights. For instance, a discussion about how various scenarios/objectives/model parameters drive the HPP design would be useful.

Reply to general comments:

- The *Methods* section has been revised and rewritten to make sure that the methods are understandable, reproducible and complete.
- A new Section 5 *Study Cases* presents the examples sites, their specific input data, including an overview of their weather. See Figures 8 and 9.
- The *Results* section has been rewritten to highlight the results. Key results are presented in Table 3 for the main costs scenario. While a sensitivity analysis of the sizing optimization to changes in costs of batteries is presented in Figure 11.
- The *Conclusions and Future Work* section has been rewritten to highlight major findings, and to include limitations and future work.

Specific comments:

- Abstract: Some information about key findings from the application of the tool should also be mentioned.
- The abstract now includes an overview of the results and conclusions.
  1.Introduction

- Is the objective to have a modelling framework that includes effects that are mostly missing in other modelling frameworks commonly used in literature? Maybe it's better to explicitly state the research objective post line 60.
- The research objective is to build a framework for optimization of hybrid power plants that can be extended to include: sizing and physical design. This sentence has been added in the Introduction.

2.Methodology

- Before diving into the models, having the general problem formulation where the objective function and the design variables (Current Section 3) are defined would be more helpful.
- The *HPP sizing optimization* section that describes the outer problem formulation is now part of the *Methods*, section 2.1.
- The interaction between components, like turbines shadowing the panels, for instance, are not included. That's fine but can be added to the simplifications in line 74.
- A sentence has been added.
- Section 2.2, a brief explanation of the behaviour observed in Figure 3 and 4 is needed. Is min_WT_spacing a consequence of the generated layout or is it a constraint?
- A sentence has been added to Section 2.3.
- In Figure 4, the wake losses for the lowest specific power turbine are the highest in the partial load region. Is that because it has a larger diameter and hence, lower normalized spacing for the same absolute spacing?
- This has been added. That is correct. For two plants with turbines with the same rated power, number of turbines and installation density (and therefore same plant area), the one that has lower specific power will have larger rotor diameter and therefore less WT spacing and higher wake losses. Note also that CT is the same for at low wind speeds for all turbines.
- Section 2.5, the plant capacity in equation 4, SMW, is not introduced in the text.
- A sentence has been added to Section 2.6.
- Section 2.5, some additional information on the reason for degradation along with the rationale behind using 0.5% must be given.
- References have been added to the assumptions in Section 4.
- Section 2.6, as mentioned, the elements specific to the case study can be a separate section. The source for the PPA prices must be mentioned. Values of 200-300 Euros/kWh (in Figure 5) look extremely high. Are the units of Pr correct?
- Section 4 provides a description to the use cases. Note that the price in Figure 6 is the black line and take values of 32.1 or 82.4 Euros/kWh.
- Section 2.7, the grid capacity (G) used in equation 5 is not introduced before.
- Definition added in Section 2.8.
- Sections 2.7-2.9 are a bit difficult to follow. Section 2.7 discusses a revenue-maximizing control strategy where a perfect forecast is assumed. The factor C_{bfl} also prevents the ramping of batteries and in a way, accounts for battery degradation in the form of an economic penalty.
- Section 2.8 then discusses a detailed degradation model but its implementation is not clear. Does it use the SoC from the idealized EMS operation to calculate the health followed by the replacement of batteries (and hence added CAPEX) every time the battery reaches 70% state of health?

- The purpose of Section 2.9 is not clear. It is called 'long-term' operation but it looks like it mainly deals with imperfect forecast of wind and solar. Figure 7 and the paragraph before is not clear and needs to be better explained. Is it an update of idealized EMS or is it a new model? If rEMS is the revenue using perfect forecast, is the purpose of this Figure 7 to show the difference in revenue introduced because of imperfect forecast?
- Sections 2.8, 2.9 and 2.10 have been re-written.
- The internal EMS operation optimization model does not compute the degradation, and it assumes non degraded wind, PV and batteries over a shorter period (in this case one year). The resulting idealized operation is repeated over the lifetime.
- The battery degradation model uses the SoC history from the idealized to compute the battery degradation.
- Both EMS models are necessary since it is not computationally feasible to solve the EMS optimization for varying degradation states for the full lifetime within an outer sizing optimization. Instead the rule-based long-term EMS is used to account for the degradation and forecast error in a computationally efficient way.
- The long-term EMS operation model receives the idealized or "planned" operation and tries to follow it as much as possible. The actual operation is different because there is degradation on the generation and battery. The long-term operation then provides the income of the hybrid power plant for all the life-time.
- The paragraph in section (Section 2.9 of the original submitted article) that compares the two EMS methodologies has been removed as it miss-leads the reader. The comparison between solving an EMS problem for degraded components and the proposed correction to the idealized EMS was done for different degradation conditions on HPPs on nine locations (some in Europe). This locations were not discussed in the article and therefore misleads the reader as the article only presents and discusses results in the specified three Indian locations.
- For Section 2.10, it might be necessary to provide more cost details. If a reference turbine is used, mention its characteristics and the source. Since these costs have a major impact on the economic metric, it's useful to see how the turbine cost factor (fWT) changes/scales with D, P, and hh. I'm also not sure why fWT is multiplied with both CWT and CWcivil. For the OPEX, scaling the variable part with AEP is a bit unfair because the O&M costs might depend more on the number of turbines, spare part cost of the RNA, etc. But with this model, a farm with a lower specific turbine will have a much higher OPEX even if other factors (number of turbines, farm rated power) are the same. It may be fine for this work but its better to be aware of how the model choice drives OPEX and hence, the conclusions.
- Costs and technical characteristics of all technologies are taken from the Danish Energy Agency Catalogue. A reference to it has been added to Section 4, and Table 1 has been reformatted.
- The "user" of the tool may not always be the same. It depends on the stakeholder that uses the tool and inputs provided will change depending on who is using the tool.
- All references to users have been removed.
- Section 2.13, the variable (ele_cost) in the section heading might be a typo.
- This has been removed.
- In Section 2.14, if NPV already discounts the cashflows with the WACCtx, I'm not sure why the net yearly revenue (Iy) is multiplied again by (1-WACCtx).
- This has been removed.

3.HPP Sizing optimization

- Turbine's specific power (sp) is commonly expressed in [W/m2]. [MW/m2] might be fine but line 236 uses [m2/MW].
- This typo has been removed.
- The equality constraints shown in equation 17 are not really constraints but intermediate variables that are derived from the design variables.
- The definition of the intermediary variables has been moved to their corresponding components.

5.Results

- As stated before, a separate case study section is needed that specifically discusses 'India-specific' elements like the prices, resources, grid capacity, etc. Also, the reader should know that the resources, battery prices, etc. are going to be varied. At the moment, it suddenly shows up in the Results.
- The specific inputs and assumptions for the use cases are described in Section 4.
- Line 273: "On the bad solar and bad wind site, a hybrid wind, PV and storage plant is selected for the NPV/CH-based design with a marginally positive business case. This illustrates it is not possible to size HPP sites based on IRR, there are several configurations that will produce negative business cases and therefore have undefined IRR." I'm not sure how the conclusion about IRR follows from the previous line. IRR, as a metric, is quite similar to NPV/CH and they should have similar results. A design resulting in a positive NPV/CH will also result in an IRR higher than the WACC. You could use MIRR instead of IRR to avoid certain issues with IRR but both MIRR and NPV/CH should have a similar behaviour for negative business cases, as long as MIRR values are feasible.
- It is true that if you defined a modified IRR to remove the problems when the $NPV < 0$, then it should behave similarly to the NPV/C_H. The statement explain why we are not using IRR.
- Line 279. It makes sense that an LCoE-optimized design does not result in a mix of technologies. But in case of NPV/CH, there was an incentive to have a high GUF in the form of pricing. In case of LCoE, does it make sense to have something equivalent in the form of a capacity factor constraint?
- This is an interesting idea that we will explore in future work.

6.Conclusions

This section needs to be completely revisited.

- The Conclusion section has been rewritten.
- Discuss how the different economic metrics drive HPP design and make recommendations that can be useful for the community.
- This has been added in Section 6.
- How do different resources drive the design? The study currently just mentions good and bad resource but are there more mechanisms? Like the anti-correlation between wind and solar.
- This has been added to the discussion of the results, in particular for the good wind site when the battery costs are high, in Section 5.
- The effect of including battery degradation and different battery costs needs to be better explained.
- This has been added in Section 5 and 6.
- How do pricing mechanisms drive the HPP. Is the HPP a result of the manner in which

the price incentives are defined in this study?

- This is true, the penalty to provide energy at peak hours is one of the main drivers for the hybridization. This has been discussed in Section 5 and 6.

Grammar and styling:

- Some sentences use 'a HPP' (line 65) while HPP is defined as 'Hybrid power plants' in the first sentence. I suggest you drop the plural and use it consistently throughout the paper.
- This has been corrected in the Introduction.
- Line 24: 'Sizing of HPP plant....'. HPP already includes plant.
- This has been corrected.
- Line 24: MDAO is Multi-disciplinary Design Analysis and Optimization
- This has been added.
- Line 28: 'hybrid pant sizing as an MDAO problem including..'
- The sentence has been rewritten.
- Line 47: Introduces CAPEX but is not defined.
- This has been corrected.
- Line 69: 'In the sizing optimization, several...'
- The sentence has been rewritten.
- Line 105: 'ERA5 (0.1 degrees instead of 0.25 degrees in latitude and longitude resolution), and it shows a better validation metric for individual plant modelling.' Not sure if I understand the second part of the sentence though.
- This has been rewritten.
- Introduce θ_{zenith} , used in equation 2, in the text. Line 109: 'The DHI is estimated using the solar zenith angle (θ_{zenith}), as shown in equation 2.'
- This has been added.
- Line 150: Remove spacing in the brackets. (ESOC(t)) and (BE(t)).
- This has been corrected.
- The subscripts in the variables that are descriptive shouldn't be italicized. For example, Pcurt(t) in line 141, Prmax in line 146, ηcharge, ηdischarge in line 151. This is currently used throughout the paper and needs to be corrected.
- This has been corrected.
- Consistently use 'Figure', 'Equation', 'Table' throughout the paper.
- This has been corrected.
- Line 275-277: 'This illustrates why 275 it is not possible to size HPP sites based on IRR, there are several configurations that will produce negative business cases and therefore have undefined IRR. Note that PV-only plants are in general over-planted (320 MW over 300 MW grid), the reason for this is to obtain a better annual energy production (AEP) and grid utilization factor (GUF).' Reframe. Either start a new sentence or use a conjunction.
- This sentence has been rewritten and moved to conclusions.
- Line 282: An NPV/CH based design is possible, but not an NPV/CH based site. Rephrase.
- This has been corrected.