HyDesign: a tool for sizing optimization for grid-connected hybrid power plants including wind, solar photovoltaic, and Li-ion batteries

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.

Specific comments:

Abstract: Some information about key findings from the application of the tool should also be mentioned.

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.

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 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.
- 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? 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?
- Section 2.5, the plant capacity in equation 4, S_{MW}, is not introduced in the text.
- Section 2.5, some additional information on the reason for degradation along with the rationale behind using 0.5% must be given.
- 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 2.7, the grid capacity (*G*) used in equation 5 is not introduced before.
- 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 r_{EMS} is the revenue using perfect forecast, is the purpose of this Figure 7 to show the difference in revenue introduced because of imperfect forecast?
- 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 (f_{WT}) changes/scales with *D, P*, and *hh*. I'm also not sure why f_{WT} is multiplied with both C_{WT} and C_{Wcivil}. 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.
- 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.
- Section 2.13, the variable (ele_cost) in the section heading might be a typo.
- In Section 2.14, if NPV already discounts the cashflows with the $WACC_{tx}$, I'm not sure why the net yearly revenue (I_y) is multiplied again by ($1-WACC_{tx}$).

3.HPP Sizing optimization

- Turbine's specific power (sp) is commonly expressed in [W/m^2]. [MW/m^2] might be fine but line 236 uses [m^2/MW].
- The equality constraints shown in equation 17 are not really constraints but intermediate variables that are derived from the design variables.

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.
- Line 273: "*On the bad solar and bad wind site, a hybrid wind, PV and storage plant is selected for the NPV/C_H-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/C_H and they should have similar results. A design resulting in a positive NPV/C_H 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/C_H should have a similar behaviour for negative business cases, as long as MIRR values are feasible.
- Line 279. It makes sense that an LCoE-optimized design does not result in a mix of technologies. But in case of NPV/$C_{H,}$ 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?

6.Conclusions

This section needs to be completely revisited.

- Discuss how the different economic metrics drive HPP design and make recommendations that can be useful for the community.
- 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.
- The effect of including battery degradation and different battery costs needs to be better explained.
- 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?

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.

- Line 24: 'Sizing of HPP plant….'. HPP already includes plant.
- Line 24: MDAO is Multi-disciplinary Design Analysis and Optimization
- Line 28: 'hybrid pant sizing as an MDAO problem including..'
- Line 47: Introduces CAPEX but is not defined.
- Line 69: 'In the sizing optimization, several…'
- 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.
- 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.'
- Line 150: Remove spacing in the brackets. ($E_{\mathrm{SOC}}(t)$) and ($B_{\mathrm{E}}(t)$).
- The subscripts in the variables that are descriptive shouldn't be italicized. For example, P_{curt} (t) in line 141, Pr_{max} in line 146, η_{charge}, $\eta_{discharge}$ in line 151. This is currently used throughout the paper and needs to be corrected.
- Consistently use 'Figure', 'Equation', 'Table' throughout the paper.
- 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.
- Line 282: An NPV/C_{H} based design is possible, but not an NPV/C_{H} based site. Rephrase.