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Control Optimisation Baselines for Tidal Range Structures—CoBaseTRS

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A R T I C L E I N F O

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A B S T R A C T

In recent years, advancements in renewable and clean energy systems have pushed researchers to revisit a strong and under-explored contributor: Tidal Range Structures (TRS). Given the rising number of reports on TRS control optimisation, we provide with this work six generalisable control optimisation baselines for operating TRS with the goal of maximising energy. Our objective is to help speed up research on the field, while also establishing a reference for novel optimisation algorithms.

Code metadata

Current code version	*v1.0*
Permanent link to code/repository used for this code version	https://github.com/SoftwareImpacts/SIMPAC-2022-106
Permanent link to Reproducible Capsule	
Legal Code License	General Public License (GNU) *v*3.0
Code versioning system used	none
Software code languages, tools, and services used	Python, Jupyter
Compilation requirements, operating environments & dependencies	Microsoft Windows, Linux
If available Link to developer documentation/manual	
Support email for questions	tuliommoreira.tm@gmail.com

1. Control Optimisation Baselines for Tidal Range Structures

Control Optimisation Baselines for Tidal Range Structures (CoBaseTRS) are a collection of six state-of-the-art operational optimisation methods for the Two-Way (TW) scheme control of Tidal Range Structures (TRS), applied to a 0D model simulation of TRS. TRS are a type of marine renewable energy, capable of large-scale power generation that take advantage of the oscillatory motion of tides and an artificial impounded lagoon. They utilise the same principle as hydroelectrics to generate power: hydraulic head, but with the advantage of providing coastal protection (against sea level rise and storm surges [1–3]), without requiring a new flooded area. The TW scheme operation is capable of generating power during both ebb and flood tides, being the primary choice for all latest research on the field [4–9]. The 0D model simulation of TRS is based on the principle of mass conservation for the impounded lagoon, predicting lagoon water level motion based on the total water flow rate (from turbines and sluices) that crosses the impounded structure. Along with this paper, a Jupyter Notebook implementation of CoBaseTRS is provided. All of the CoBaseTRS methods are of the type (i) "prediction-dependent" and (ii)"head-controlled" and, i.e. (i) they utilise tide signal forecasts for (ii) acquiring best operational water heads (difference between ocean and impounded lagoon water levels) for operating TRS. Three of the available methods are based on the work of [6,10], named as "classic" approaches. The remaining three methods consider a novel "variant" operation of TRS, with independent sluice operation (inspired by the work of [5,11]) and first published in [9]. Results using CoBaseTRS were published in [9], for the case study of the Swansea Bay Tidal Lagoon pathfinder project. [9] also provides a thorough overview of the equations utilised for the 0D model, a description of the "classic"

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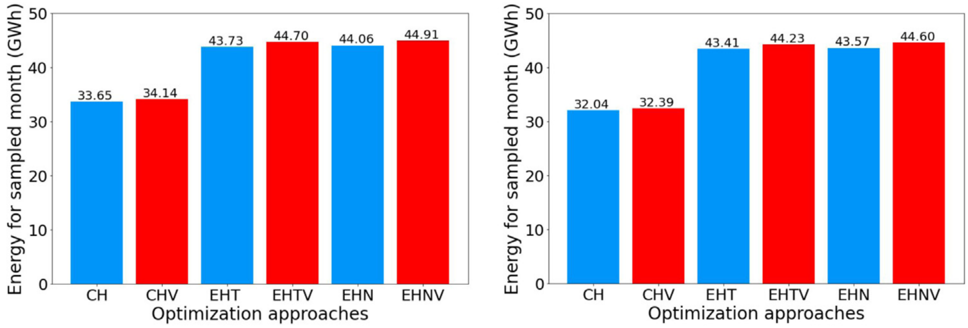


(a) Upper bound Comparison.

(b) Real-time Comparison.

Fig. 1. Upper bound and real-time histogram comparisons of the energy acquired for all CoBaseTRS methods, for a sampled month. Results for classic and variant approaches are shown in blue and red, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Simplified reference table for baselines.

	Constant Head		Every Half-Tide		Every Half-Tide and Next	
	CH	CHV	EHT	EHTV	EHN	EHNV
Grid-search algorithm	✓	✓	✓	✓	✓	
Basin-hopping algorithm						✓
Classic approach	✓		✓		✓	
Variant approach		✓		✓		✓
Non-flexible operation	✓	✓				
Flexible operation			✓	✓	✓	✓

Table 2
Swansea Bay Tidal Lagoon 0D model parameters.

N^o of Turbines	16
N^o of Gp	95
Grid frequency (Hz)	50
Turbine Diameter (metres)	7.35
Turbine Capacity (MW)	20
Turbine Orientation (Ebb or $Flood$ $oriented$)	Ebb
Turbine Discharge Coefficient ($dimensionless$)	1.36
Sluice Area (m^2)	800
Sluice Discharge Coefficient ($dimensionless$)	1

and "variant" approaches for TRS control and the parametric equations utilised for estimating flow rate and power from sluices and turbines. In Table 1, the six state-of-the-art methods and their main characteristic features are presented. Differences between non-flexible and flexible methods and the type of optimisation algorithm (grid search or basin-hopping) are also discussed in [9].

For running CoBaseTRS, the user needs to provide the design parameters of a TRS together with a representative ocean signal (in vector form, with 15 min sampling resolution). The available Jupyter notebook contains the parameters and ocean signal for the case study of the Swansea Bay Tidal Lagoon (projected to be constructed in the Bristol Channel, UK), extracted from [9]. The design parameters utilised for the Swansea Bay case study are shown in Table 2. Furthermore, a variable lagoon surface area representation (digitised from [6]) is also required. For the ocean signal representation, data from British Oceanographic Data Centre (BODC) at the location of Mumbles station were utilised. The BODC data contains the tidal measurements and concurrent tidal predictions for 26 months.

When running the CoBaseTRS, upper bound and real-time estimates for all six methods of control are provided. Upper bound estimates consider a perfect forecast of the ocean signal, i.e. they utilise only tidal measurements, returning the maximum energy that can be extracted from the TRS, when subjected to a certain ocean signal. Real-time estimates, on the other hand, consider a more realistic control of TRS, where the optimised operation of TRS is acquired through tidal predictions and then applied to the actual measured ocean level.

Considering some ocean input data, the outputted results for each of the six optimisation methods in CoBaseTRS (for upper bound and real-time estimates) are summarised as:

- Sequence of best operational heads.
- Ocean water level variation.
- Lagoon water level variation.
- Turbine flow rate.
- Sluice flow rate.
- Power output (MW).
- Total energy (MWh).

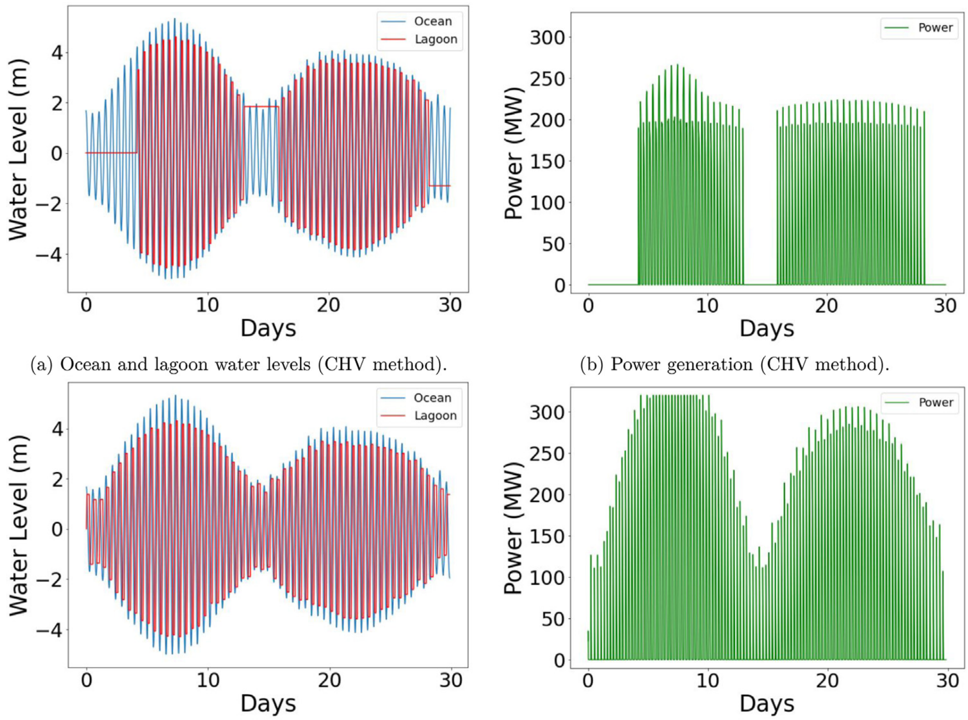
Considering the same month of input data (ocean data), a comparison of the upper bound and real-time energy estimates for all CoBaseTRS methods is shown in Fig. 1. A more detailed comparison, showcasing lagoon water level variations and power output for the same month is shown in Fig. 2, considering the real-time estimate of CHV and EHTV methods.

2. Impact overview

Modern research on the operational optimisation of TRS aim to find operational strategies that can maximise energy and revenue generation of these systems, while reducing operational costs. While very interesting approaches have been recently suggested in the literature [5,6,9,12,13], they all lack a common ground of comparison, so that their weaknesses and strengths can be compared against each other. CoBaseTRS aims to fill this gap, by providing already established set of state-of-the-art approaches to be used as baselines for novel optimisation methods.

Results from CoBaseTRS have been used as baselines in Ref. [9], helping to understand the capabilities of a novel method for TRS control that utilises Deep Reinforcement Learning (DRL). By using CoBaseTRS to calculate the baselines, the authors were capable of concluding that the novel DRL method has state-of-the-art performance (in power generation) when operating TRS in real-time, with the additional advantage of not requiring future (concurrent) tidal predictions. Since the advantages of the novel DRL method were only possible to measure by utilising CoBaseTRS, [9] is an example of how CoBaseTRS can be used in future research, when assessing the capabilities of other operational optimisation approaches.

To the best of our knowledge, CoBaseTRS is the first "head-controlled" operational optimisation routine (i) freely available to the industry and academics and (ii) that provides real-time control approach to TRS. Since previous research on the field have only considered upper bound estimates for power and revenue extraction capabilities of TRS (apart from the DRL method by [9]), CoBaseTRS can be helpful studying the deviation between upper bound and real-time approaches and the capabilities of prediction-dependent TRS methods in realistic, real-time operation scenarios. Furthermore, since our provided baselines have state-of-the-art performance, CoBaseTRS



(a) Ocean and lagoon water levels (CHV method).

(b) Power generation (CHV method).

(c) Ocean and lagoon water levels (EHTV method).

(d) Power generation (EHTV method).

Fig. 2. Ocean and lagoon water levels and power generation results when following CHV and EHTV control optimisation methods, considering a real-time estimate. Results for CHV are shown in (a) and (b), while results for EHTV are presented in (c) and (d).

can also be used in studies that optimise the design of TRS (e.g. lagoon wetted area, sluice area, number of turbines, turbine diameter and orientation).

The advantages of CoBaseTRS can be summarised as:

- First head-controlled TRS optimisation routine freely available to academics.
- First head-controlled TRS optimisation routine capable of real-time control of TRS, by utilising future tidal predictions.
- Applicable to any TRS design.
- Few parameters to set when using.

The current CoBaseTRS can be extended to include additional TRS features. In particular, pumping capabilities of the turbines are being introduced in an updated version (in progress) for use as a basis of comparison with an AI-Driven TRS model also capable of pumping.

CRediT authorship contribution statement

Túlio Marcondes Moreira: Conceptualization, Investigation, Methodology, Software, Validation, Writing – original draft. **Pedro O.S. Vaz-de-Melo:** Supervision, Investigation, Writing – review & editing. **Gilberto Medeiros-Ribeiro:** Supervision, Investigation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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