INCREASING THE ENERGY PRODUCTION OF A MRE FARM CONSIDERING THERMAL AND TECHNO-ECONOMIC ASPECTS

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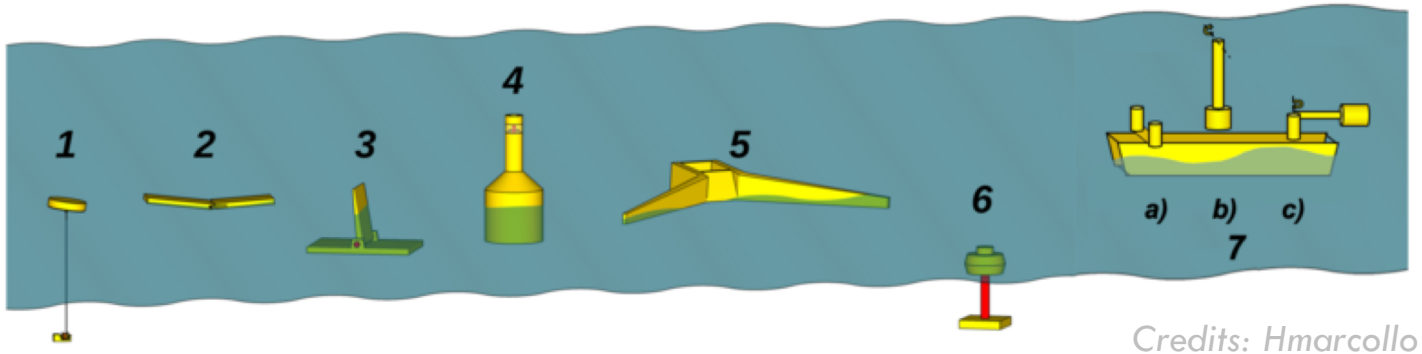
INTRODUCTION

- Wave energy not yet economically competitive
- Maximizing the use of offshore electrical infrastructures
- Ampacity: maximum allowed current (I_{max}) in cables

→ limiting factor: temperature ($T \leq T_{max}$)

https://www.themilitarytimes.co.uk

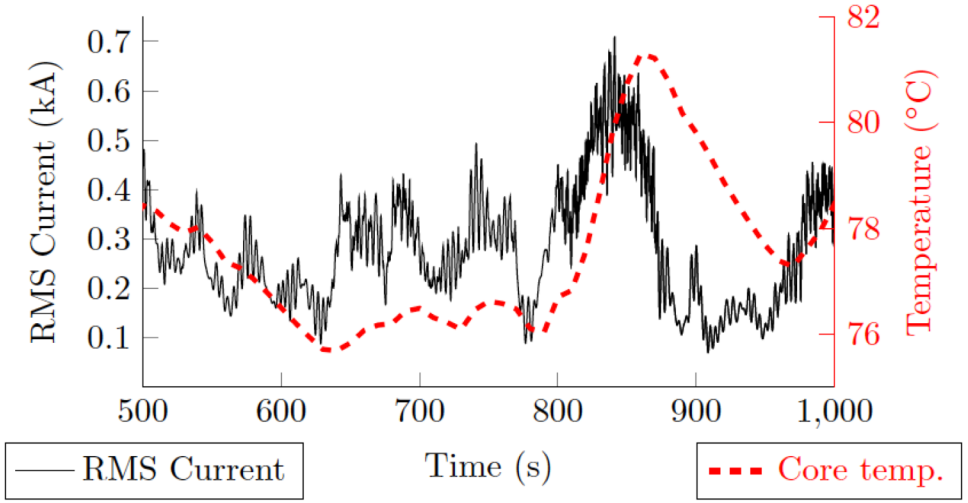


Credits: Hmarcollo

INTRODUCTION

- Static rating → highly conservative
  - Fixed ampacity=worst case thermal conditions (e.g. max solar irradiance, min wind speed, etc.)

- Dynamic rating: operating the offshore export cable **closer to its physical limits** → **thermal inertia**



QUESTIONS

- Q1: How much more current could be injected in the cable than the steady-state rating?
- Q2: How precise should the model be to be included in energy management studies? (trade-off between computing time and precision)
- Q3: If the test site were converted into a small-scale commercial site, would it be economically feasible to add WECs to a wave farm at a 2nd stage?

MODELLING: INSTALLATION

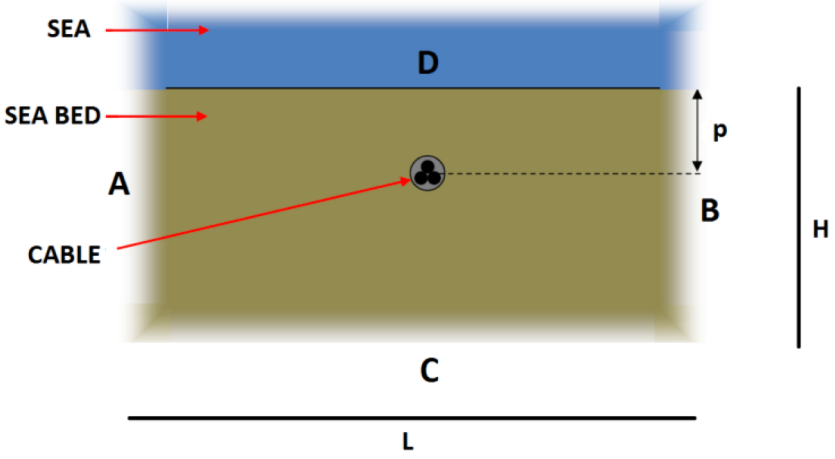
- SEM-REV open sea test site*
  - Located near Le Croisic (west FR)
  - Managed by Ecole Centrale de Nantes
  - Buried 24 km export cable
    - 20kV-8MVA

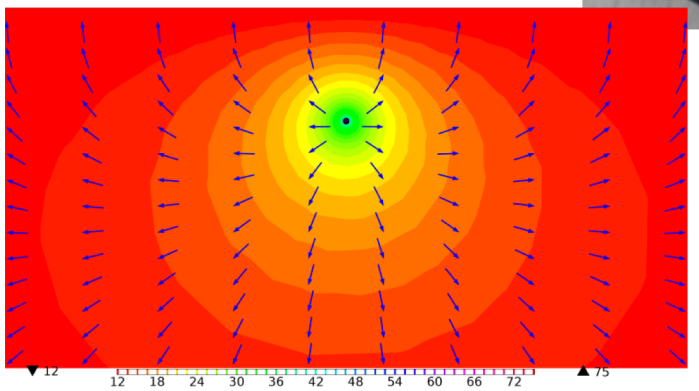
Figure modified, courtesy of Ecole Centrale de Nantes*

* Ecole Centrale de Nantes. (2021) The SEM-REV website. [Online]. Available: https://sem-rev.ec-nantes.fr/english-version/

Q1: HOW MUCH MORE CURRENT COULD BE INJECTED IN THE CABLE THAN THE STEADY-STATE RATING?

- COMSOL finite element method model validated against experimental data





Q1: HOW MUCH MORE CURRENT COULD BE INJECTED IN THE CABLE THAN THE STEADY-STATE RATING?

- 4 case studies
- Wave Farm
  - Up to 25 point absorbers (1 MVA each)
  - passively controlled
  - optimal damping for each sea-state
  - Aggregation effect: time delay

Case	Sea-state characteristics		Device number
	H_s (m)	T_p (s)	
1	3	9	15
2	6	9	15
3	6	9	20
4	6	9	25

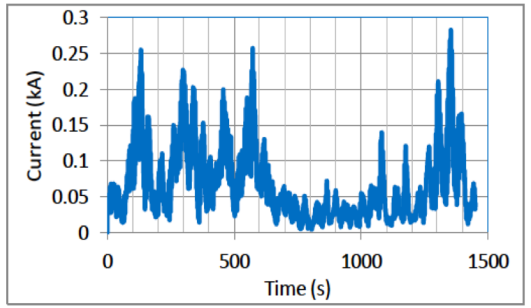


Fig. 4 Current profile flowing through the cable (Case 1)

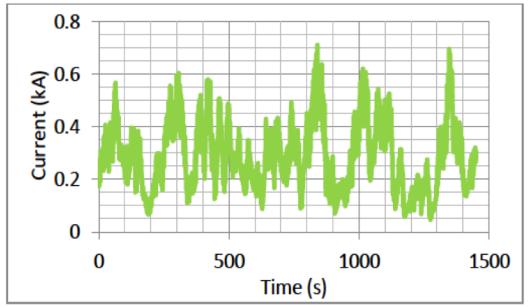


Fig. 6 Current profile flowing through the cable (Case 3)

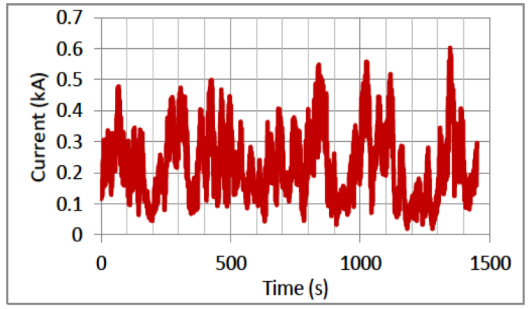


Fig. 5 Current profile flowing through the cable (Case 2)

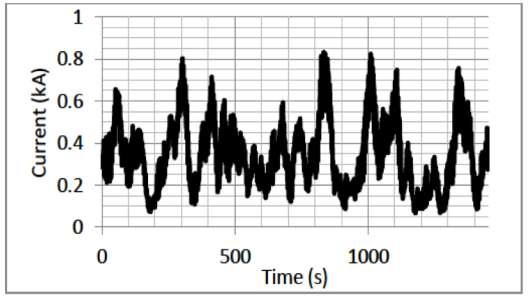


Fig. 7 Current profile flowing through the cable (Case 4)

Q1: HOW MUCH MORE CURRENT COULD BE INJECTED IN THE CABLE THAN THE STEADY-STATE RATING?

- Maximum temperature not exceeded in most cases, despite highly energetic conditions
- Maximum current almost 2.5 times greater than steady-state rating.

CURRENT RESULTS FOR DIFFERENT SEA STATES AND DEVICE NUMBERS

Case	Maximal current (A)	Percentage of steady-state current rating (%)
1	283	97
2	602	207
3	709	245
4	833	287

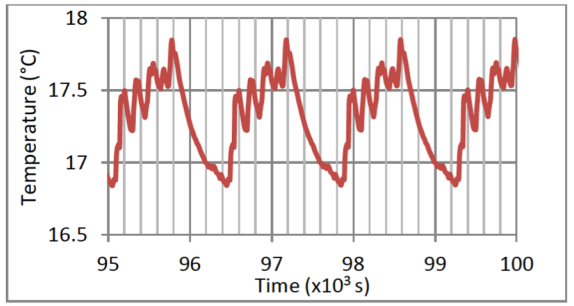


Fig.11 Cable temperature versus time (Case 1)

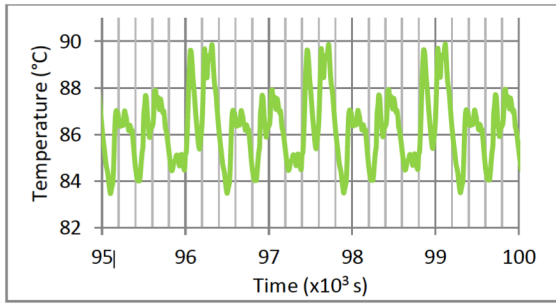


Fig.13 Cable temperature versus time (Case 3)

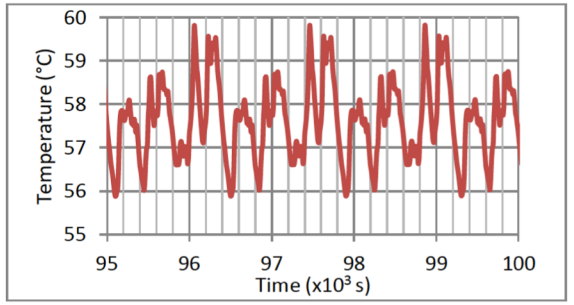


Fig. 12 Cable temperature versus time (Case 2)

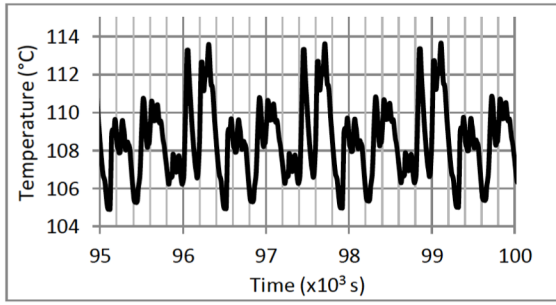
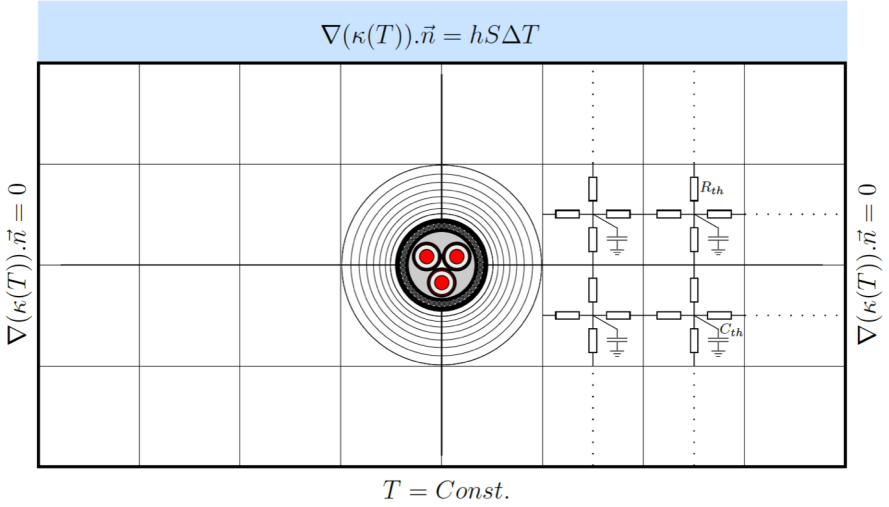


Fig.14 Cable temperature versus time (Case 4)

Q2: TRADE-OFF PRECISION/COMPUTING TIME FOR THE THERMAL MODEL ?

- How precise should the model be to be included in energy management studies?
  - COMSOL (FEM)
  - RC model
    - Model 1: non-linear thermal characteristics
    - Model 2: linear thermal characteristics
    - Model 3: ibid. Model 2 but input time series = RMS value of current amplitude
  - IEC standards
    - 60287 (static rating)
    - 60853 (cycling load, hourly time step)

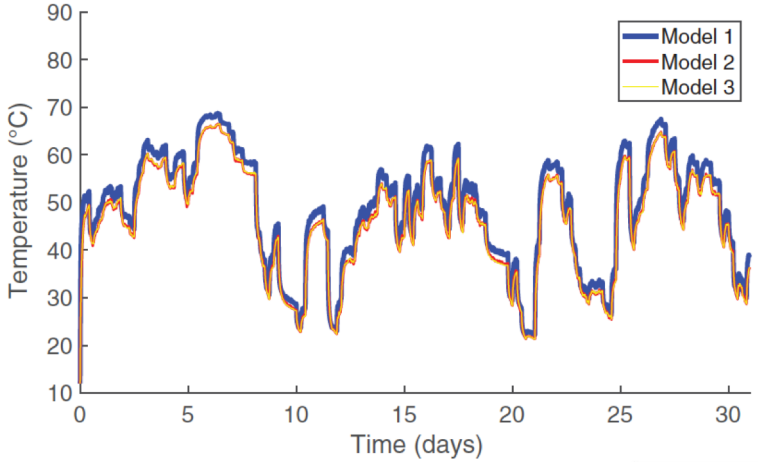


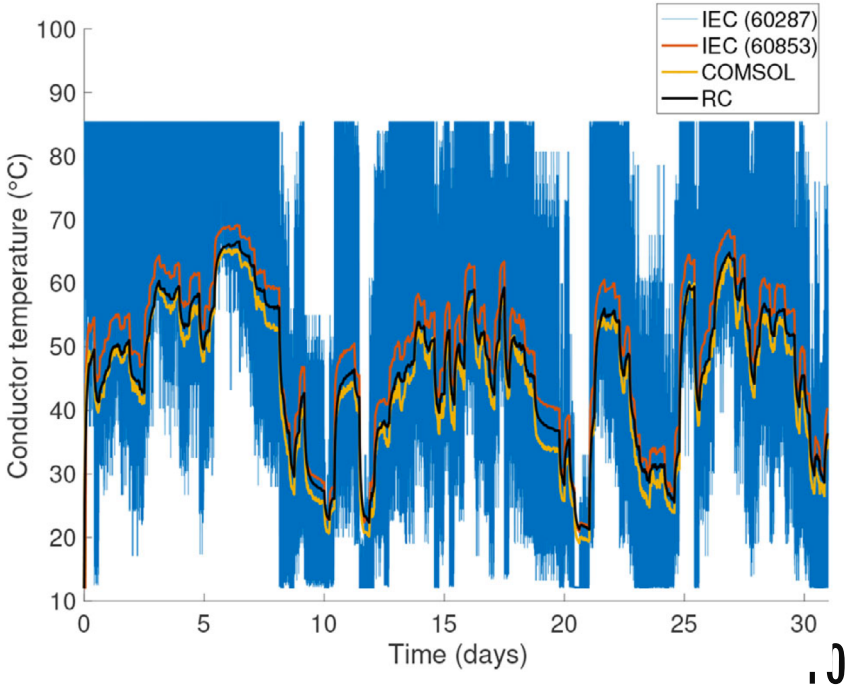
Q2: TRADE-OFF PRECISION/COMPUTING TIME FOR THE THERMAL MODEL ?

- RC models: negligble error for Models 2 and 3
- Drastic computing time decrease for RC Models 2 and 3 for a acceptable precision loss
- IEC 60853
  - relatively precise despite non-cycling, highly varying load (6% error max)
  - safe assumption (temperature overestimation) and reduced computing time

Model	Computing time
FEM COMSOL	26 h 44 m
Model 1	8 h 46 m
Models 2 and 3 (RC models)	28 m 40 s
IEC 60853	16 m 57 s

7 days, 10 s time step

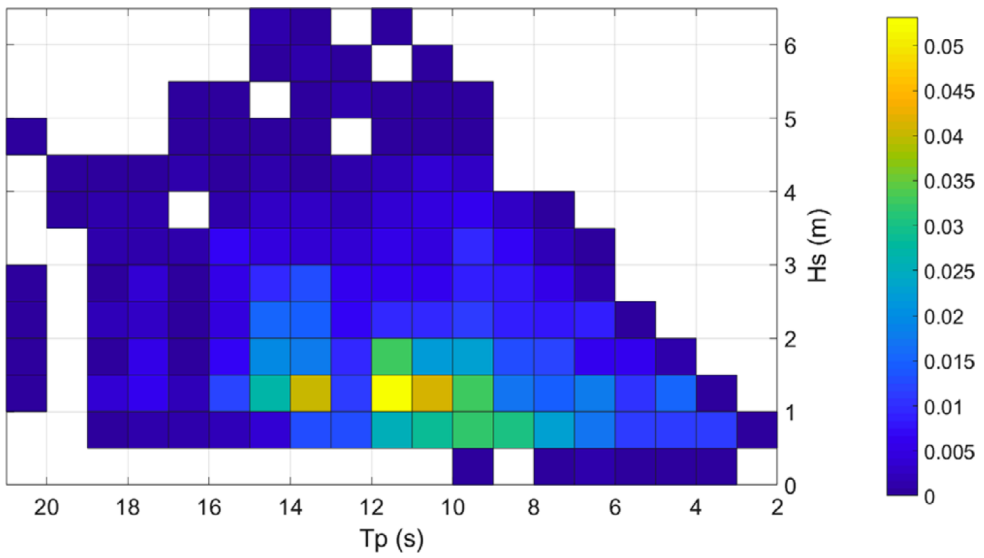




Q3: ECONOMIC FEASIBILITY?

- Deployment of dynamic rating at a 2nd stage?
  - Dynamic rating allowed in the future (insurance, etc.), after installation of the farm

  → adding some WECs
  - SEM-REV sea-states
  - Aggregation effect: hydrodynamic modelling



WEC number	Curtailment allowed (Y/N)	Add. AEP per add. WEC (MWh)	Ratio max $(I(t))/I_r$	Max. temperature (°C)
11	N	0	0.96	68.5
12	N	3667	1.05	81.8
11 to 13	Y	3536	1.14	90
11 to 14	Y	3091	1.22	90
11 to 15	Y	2435	1.31	90
11 to 16	Y	1923	1.40	90
11 to 36	Y	771	2.87	90

Q3: ECONOMIC FEASIBILITY?

- Would it be economically feasible to increase the maximum allowed rated power (8 MW) of the existing SEM-REV test site for a fictitious wave farm at a 2nd stage?
- Revenue per additional WEC R_{WEC}:

$$R_{WEC} = R_A + AE$$

where R_A : additional revenue per WEC $R_A = \frac{AEP*FIT}{N_{WEC}}$

AE : annual expenses per WEC

V. S. Neary, M. Lawson, M. Previsic, et al.. Report SAND2014-9040 : "Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies," Sandia National Lab.(SNLNM), Albuquerque, NM (United States), 2014.

Q3: ECONOMIC FEASIBILITY?

- AE : annual expenses per WEC

$$AE = M_{struct} + M_{PCC} + M_{moor} + DI + OMM$$

M_{struct}: manufacturing cost of WEC structure

M_{PCC}: cost of the power conversion chain

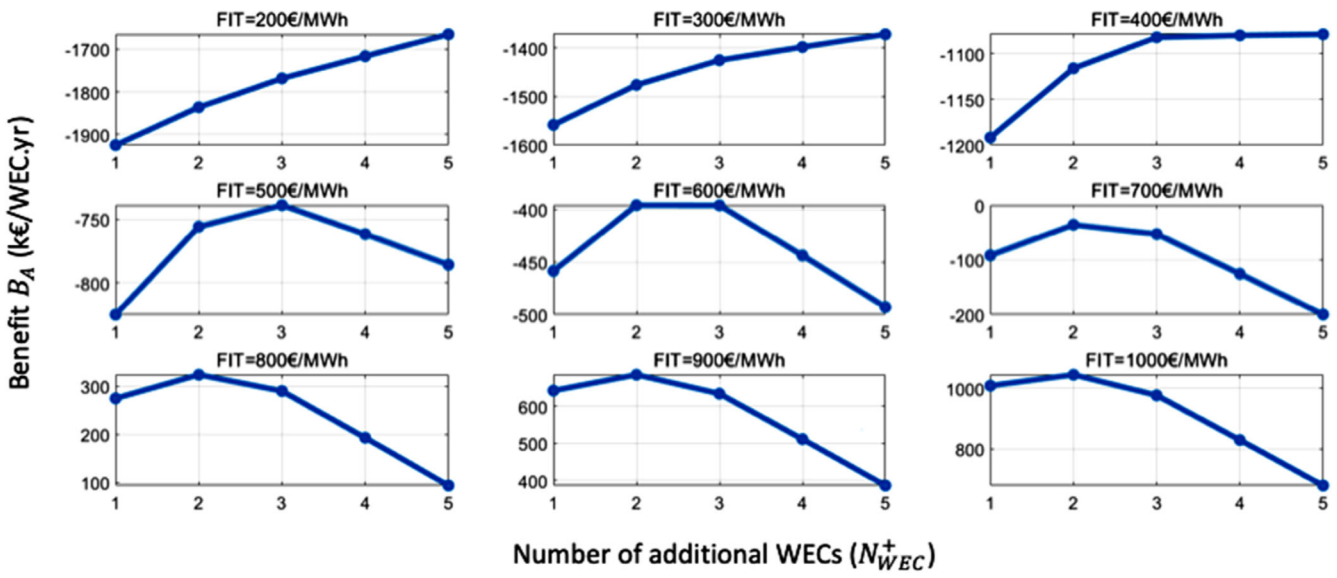
M_{moor}: cost of the moorings

DI: deployment and installation costs

OMM: operating, maintenance and monitoring costs

V. S. Neary, M. Lawson, M. Previsic, et al.. Report SAND2014-9040 : "Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies," Sandia National Lab.(SNLNM), Albuquerque, NM (United States), 2014.

Q3: ECONOMIC FEASIBILITY?



➔ Hardly economically viable to install WECs at a 2nd stage to exploit dynamic rating at the SEM-REV test site but:

- very mild climate (→ Portugal, Ireland?)
- small extension → high cost of transport per WEC
- still high LCOE for wave energy

➔ Need to consider dynamic rating at the design phase of the wave farm

Thank you for your attention. Any questions?

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- Papers
  - « Modeling of a wave farm export cable for electro-thermal sizing studies », Charles-Henri Bonnard, Anne Blavette, Salvy Bourguet, Adrien Charmetant, *Renewable Energy, Elsevier*, 147, 2020
  - « Upgrading wave energy test sites by including overplanting: a techno-economic analysis », Anne Blavette, Charles-Henri Bonnard, Ildar Daminov, Salvy Bourguet, Thomas Soulard, *IET Renewable Power Generation*, May 2021