

Innovation, from concept to reality: a novel linear switched reluctance generator for wave energy conversion

Miguel Santos-Herran¹, Jorge Torres, Luis García-Tabarés, Marcos Blanco, Gustavo Navarro, Jorge Nájera, Álvaro Santiago, Marcos Lafoz
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Madrid (Spain)

¹ miguel.santos@ciemat.es

Background: PTOs in Ocean Energy

2050 European targets of **80-95% reduction** in greenhouse **emissions**.

Potential deployment of **300 GW** of **wave & tidal** farms worldwide by 2050.

Power Take-Offs (PTOs) as a **key** enabler to attain this challenging target:

- EU's "Declaration of Intent for Ocean Energy" aims at **reducing** levelised cost of electricity (LCOE) by **50%** by 2025.
- PTOs represent **20-22% of lifetime costs**, with room for cost reduction thanks to learning by doing, learning by research and economies of volume and scale.
- PTOs are a challenge area and **priority topic** in R&D roadmaps (e.g., Strategic Research and Innovation Agenda for Ocean Energy 2020).

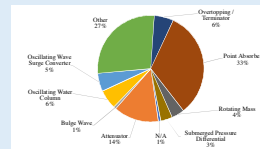
Background: heaving point absorbers

One third of existing wave energy devices are **point absorbers**.

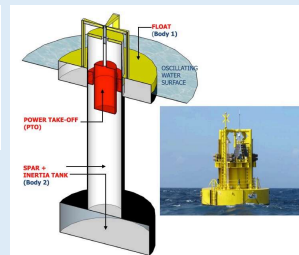
Linear generators are particularly suitable for heaving point absorbers, converting mechanical energy into electricity in a single stage (**direct drives**).

+ Linear electrical machines can control PTO force and modulus

- Smaller force capacity and density than hydraulic counterparts



SEA-TITAN will develop a **new configuration of Linear Switched Reluctance Machine** aimed at achieving higher specific forces and efficiencies



The SEA-TITAN project

EU-funded (H2020) - 3-year project (*N.B. extended to 3.5 years because of CoVID-19*) - €3.9M.

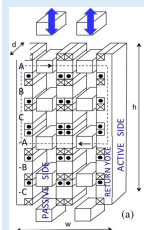
Consortium: **11 partners**, 4 wave energy technology developers.



AIM: a **step change** in the sector by designing, building, testing and validating a crosscutting and **innovative Direct Drive PTO** compatible with multiple types of WEC.

The Azimuthal Multi-Translator Switched Reluctance Machine (AMSRM)

The AMSRM concept



Based on the previously-developed concept of **multi-translator** (i.e., adding stators to increase the machine force at a higher rate than its weight) **switched reluctance machine** introduced and patented by Wedge Global.

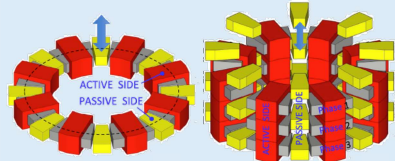
However, the old design still needs two lateral heavy stators with return yoke.

ADVANTAGES OVER THE PREVIOUS MACHINE:

- No lateral stators: **minimum** amount of **iron**, increasing the specific force
- Smaller leakage flux** than the rectangular configuration
- Circular arrangement that suits standard cylindrical spar shapes

SOLUTION:
arranging the stator coils (active side) and the translator poles (passive side) in a toroidal geometry.

(Patent application WO202040064A1)



AMSRM design

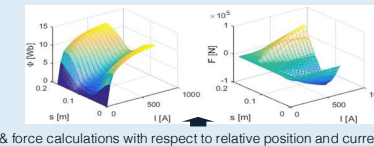
Magnetic analysis is the basis for subsequent electrical, mechanical and thermal calculations.

Calculation methodology

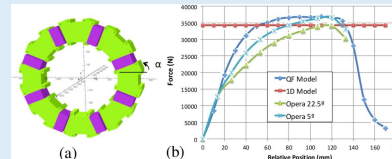
1-D Analytical Model
• Definition of a Benchmark case considering the saturation effects
• Forces are calculated using the co-energy and the filament approach

2-D FEM Simulation (QUICKFIELD)
• Magnetic field changes along the pole position
• Correcting coefficients for the 1-D model

3-D FEM Simulation (OPERA & MAXWELL)
• Correcting coefficients for the 2-D model considering end effects and the magnetic field variation on the Z-axis



Flux & force calculations with respect to relative position and current



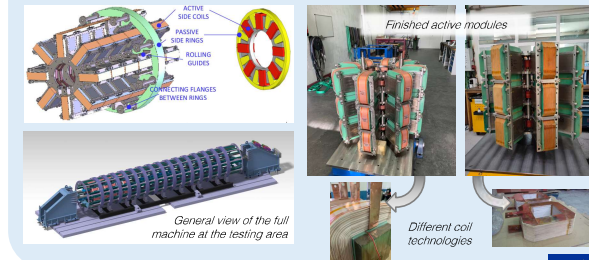
AMSRM PROTOTYPE CHARACTERISTICS

Parameter	Value	Units	Parameter	Value	Units
No. phases	3	mm	Max. force	70	kN
No. coils per phase	8	-	Operational current	350	A
Outer diameter	1000	mm	DC link voltage	1000	V
Inner diameter	440	mm	Pole ratio	6:4	
Stroke	3000	mm			
Max. speed	3	m/s			

AMSRM fabrication

The machine is **currently being manufactured**. The moving and shorter active side will slide along the longer passive part, inside of it.

The machine will be tested in a **back-to-back configuration** with 2 active modules: 1 working as actuator, 1 working as generator. Two different coil technologies (single pancake & welded plate) will be studied.



The SEA-TITAN project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement no. 764014

