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63° Congreso Internacional de Ingeniería Naval e Industria Marítima
Madrid, 24-26 abril, 2024
TRANSFORMANDO LOS OCÉANOS: INNOVACIÓN e ingeniería naval para un mundo CONECTADO y SOSTENIBLE

FAST RESPONSE ENERGY STORAGE SYSTEM FOR MARINE APPLICATIONS

Basilio Puente Varela

Head of Conceptual & Basic Design, Techno Pro Hispania

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CONSORTIUM

(7) antec — Reliability is a must. Design and manufacture state-of-the-art magnetic systems and components for all types of applications.

(8) CERN — Providing a unique range of particle accelerator facilities to researchers.

(9) DAMEN — Providing maritime solutions through design, shipbuilding, ship repair and related services.

(10) EFESTO — Designs and development of hybrid and full electric power trains and power units.

(11) OCEM — Design and manufacture of complex electronic power systems.

The consortium is made up of 11 partners from 5 EU Member States

(1) TECHNO PRO HISPANIA — A naval & industrial engineering company.

(2) CTN centro tecnológico naval y del mar — Development of innovative solutions based on the latest technologies in engineering.

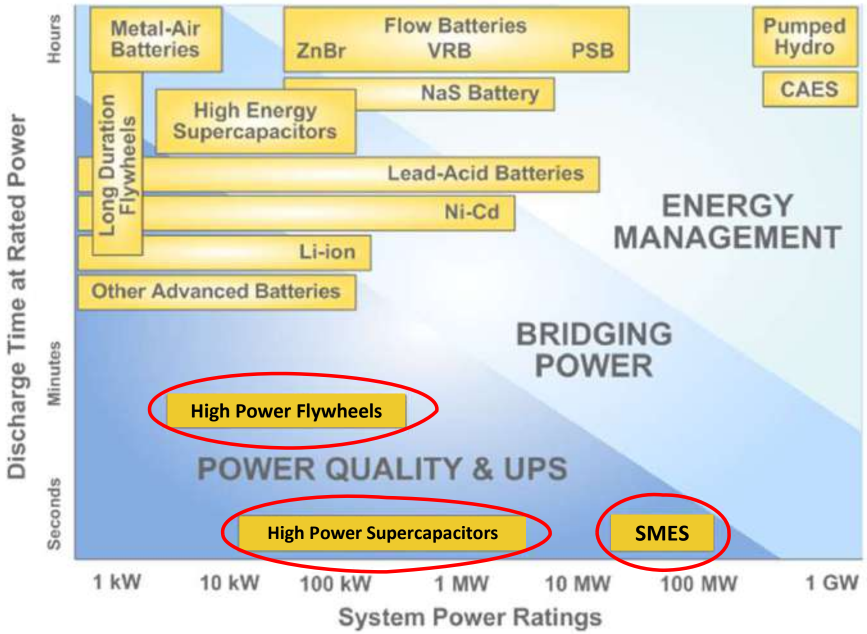
(3) BALEARIA — Leading shipping group in Spain, with 25 years of history in maritime transport.

(4) Ciemat — Public Research Organization focused on the fields of energy and the environment, and the technological fields related to both.

(5) POLITÉCNICA — University works from its Institutes and Research and Innovation Centers.

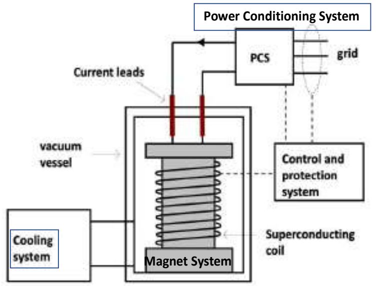
(6) CYCLOMED — Main activity is to act as a compact particle accelerator for precision nuclear medicine applications.

OVERVIEW OF ESS

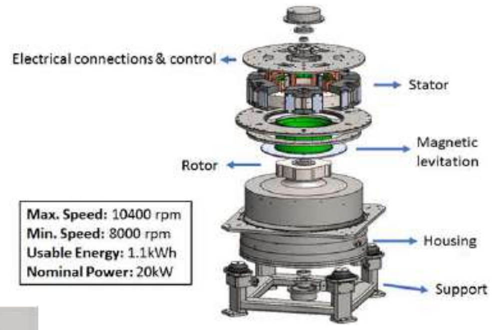


Energy storage technologies capacities

"Energy Storage Technologies for Electric Applications." http://www.sc.ehu.es/sbweb/energias-renovables/temas/almacenamiento/almacenamiento.html (accessed Jun. 12, 2023).



SMES



High Power Flywheels

High Power Supercapacitors

TECHNICAL DEVELOPMENT & MARINIZATION

Ship type	C-rate	Cycles	Energy	FRESS potential
Ferry	Very high	Very high	Nominal	High
OSV	Very high	Very low	Nominal	Medium
Cruise	Low	Likely high	Very high	Medium
Offshore drilling unit	Very high	Variable	Low	High
Fishing vessel	Nominal	Nominal	Nominal	Medium
Fish farm vessel	Nominal	Nominal	Nominal	Medium
Shuttle tanker	Very high	Very low	Nominal	Medium
Short sea shipping	Highly variable	Highly variable	Highly variable	Medium
Deep sea vessels	Highly variable	Highly variable	Highly variable	Medium
Bulk vessels with cranes	High	High	Low	High
Tug boats	Highly variable	Highly variable	High min. space)	Medium
Yachts	Low	Low	High	Low
High speed ferry	High	High	High	High
Wind farm support vessels	Very high	Very low	Nominal	Medium

Summary table of typical values for ESS technology requirements & FRESS potential integration

EMSA European Maritime Safety Agency, "STUDY ON ELECTRICAL ENERGY STORAGE FOR SHIPS," 2019.

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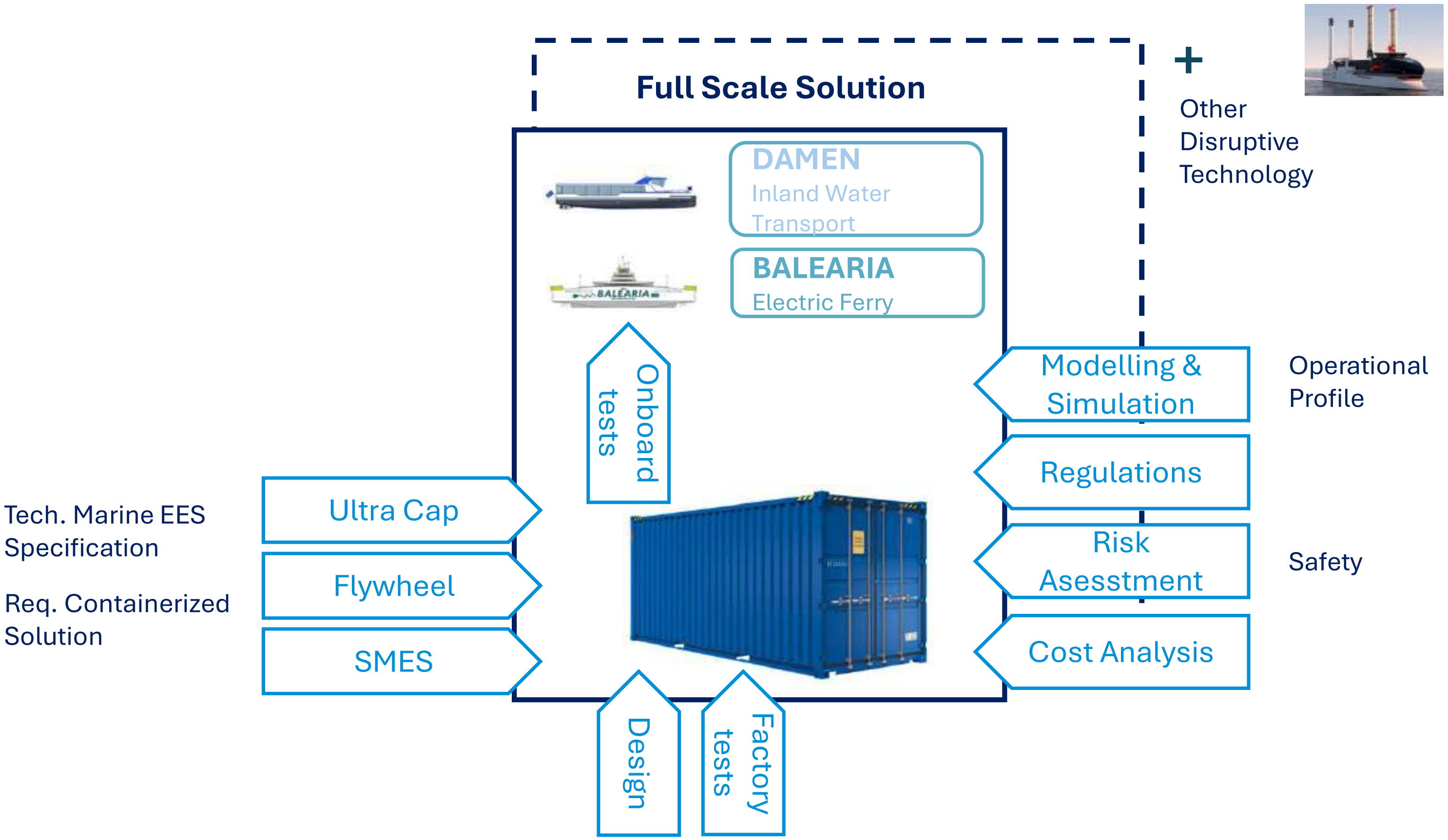
MAIN OBJECTIVES



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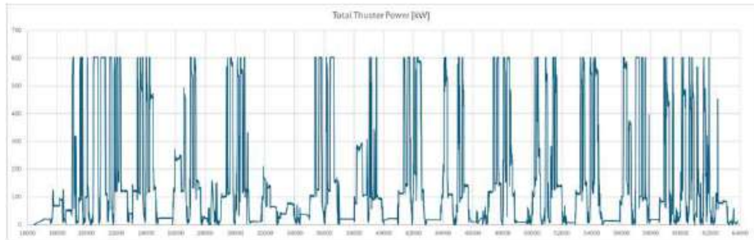
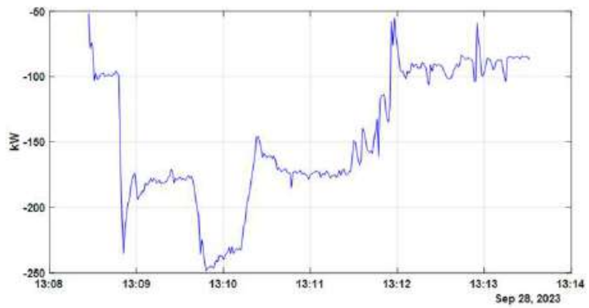
OPERATIONAL PROFILES

BALEARIA
Electric Ferry

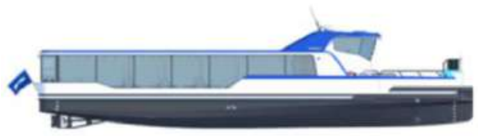


Port approach manoeuvre



Port departure manoeuvre

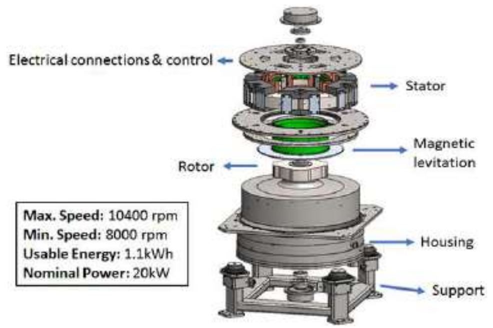
DAMEN
Inland Water Transport



12 trips per day – 500 kW peak – 10 kWh per approach & departure operation

TECHNICAL DEVELOPMENT & MARINIZATION

High Power Flywheels (KESS)



$$E = {}^{1}/_{2} \cdot J \cdot w^{2}$$

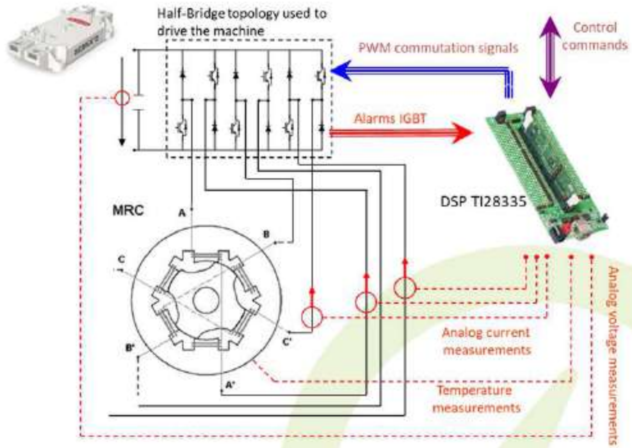
Design power = 20 kW
Speed range = 8000-10400 rpm
Useful energy = 3.96 MJ (1.1 kWh)

Switched Reluctance Machine:

- Lower losses in absence of torque
- No demagnetization issues at high temperatures
- More robust in aggressive environments
- Not depends on rare earths

Power and Control System:

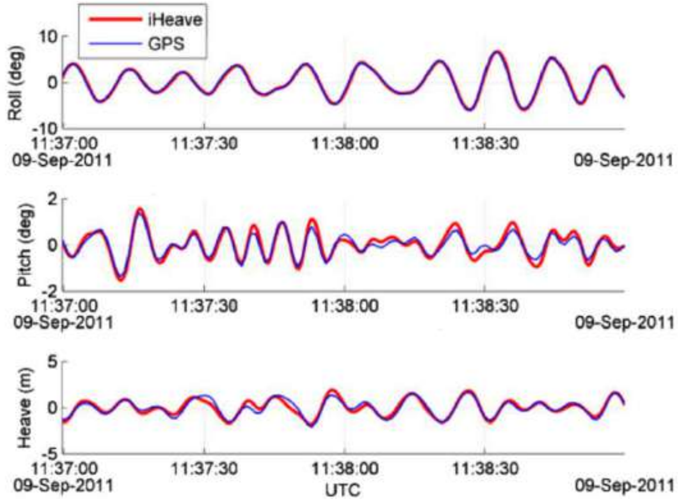
- H-bridge topology
- Control of torque through phase current regualtion
- Bidirectional Power



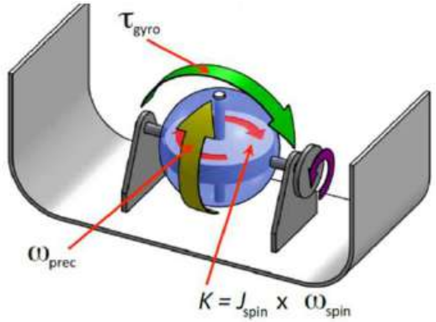
KESS DESIGN CHALLENGES

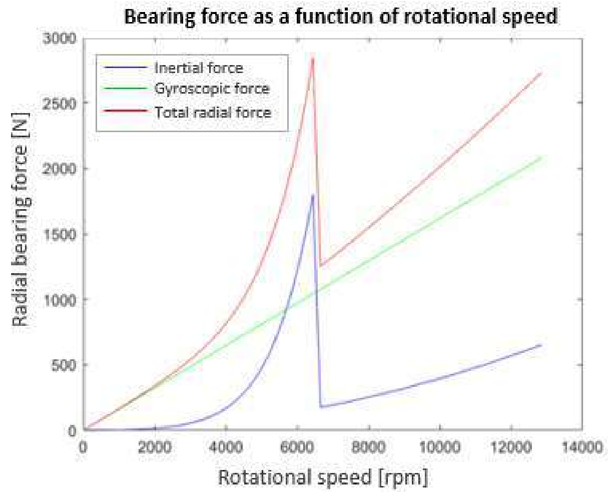
Design of KEES bearing for waterbone conditions

* Medium to big size boat
* Calm sea → close to the coast → Small waves



Roll ≈ 1-2 deg/s
Heave < 0,5 m/s^2

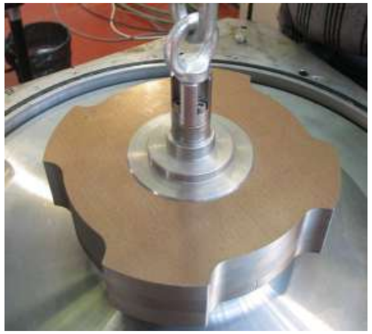




- Gyroscopic forces are **4 times higher** than inertial forces at operational speed
- This forces are only representatives for small waves and calm sea → **2 deg/s**
- **Double bearing configuration** allows to support extra forces in the flywheel, with an operation range of **8000-10400 rpm**

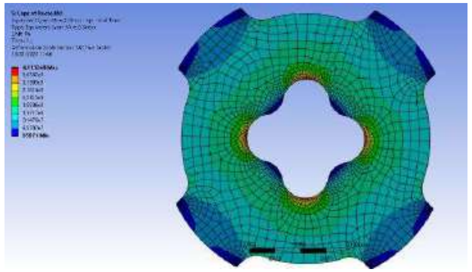
KESS DESIGN CHALLENGES

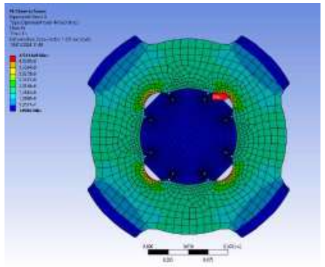
Sliding of rotor over the flywheel

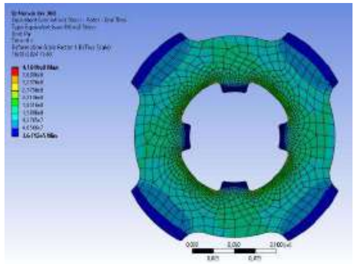


Three approaches are being done:

- **Models:** Complete 3D model including anisotropy of materials, parameter sensibility study and transient thermal effects
- **Testing:** Check material properties, compare to datasheets Dummy Rotor and flywheel (fatigue and temperature effects)
- **Calculation:** Interference between rotor and flywheel and joint definition





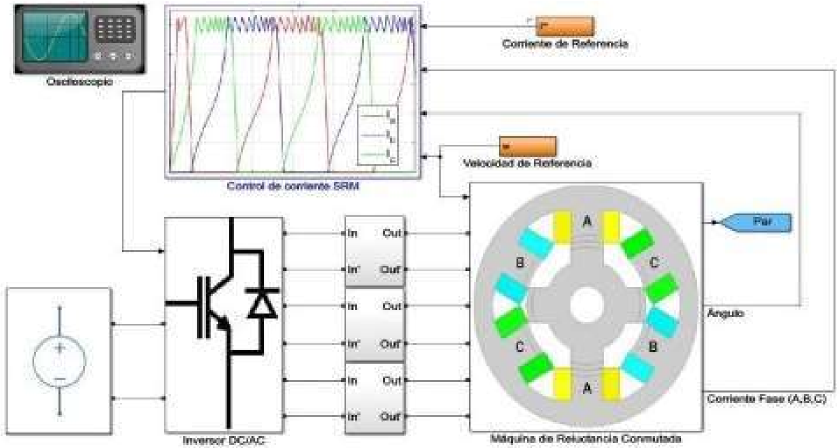


KESS SIMULATION MODEL

High Power Flywheels (KESS)

CIEMAT has developed models for flywheel in:

- MATLAB Simulink (electric model)
- ANSYS (Vibrations)



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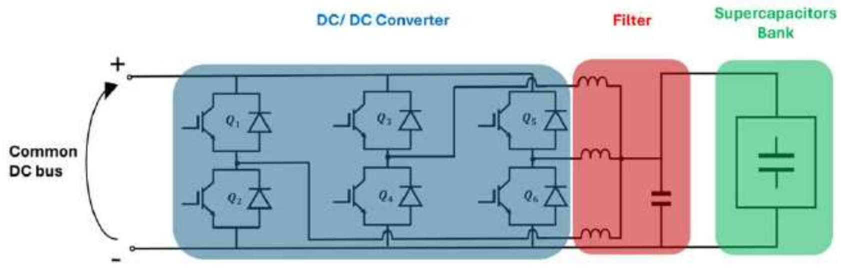
TECHNICAL DEVELOPMENT & MARINIZATION

Supercapacitors (EESS)

OCEM POWER ELECTRONICS

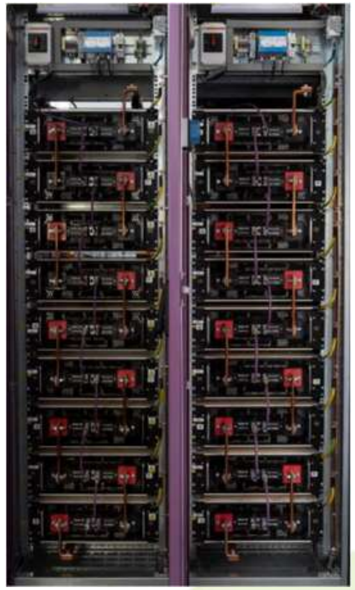


$$E = {}^{1}/_{2} \cdot C \cdot V^2$$

Design power = 120 kW
Voltage range = 750 – 300 V
Useful energy = 3 MJ (0.83 kWh)
(84% of the total energy stored)

Power and Control System:

- DC/DC converter to maintain main busbar voltage constant
- Diagnostic and protection
- Emergency discharge through ceramic disk resistor



Series connection of SC modules

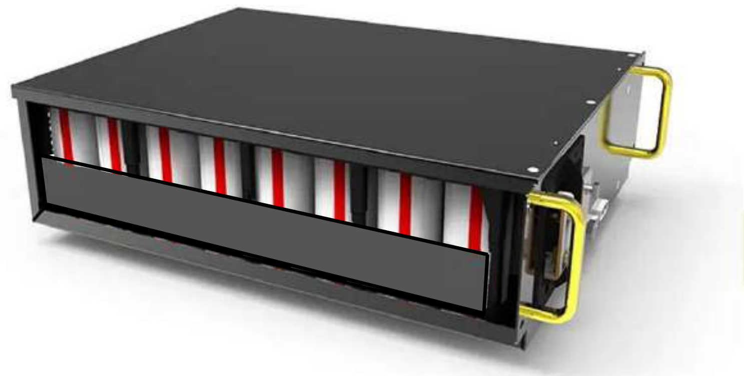
MAIN CHALLENGES FOR THE EESS

Supercapacitors (EESS)

OCEM POWER ELECTRONICS

The main challenges in designing the EESS, based on supercapacitors, concern the marinization of the storage system.

The EESS storage bank is made of a series connection of Supercapacitors cells stacked into Supercapacitors modules. At the current technology state, there is not a Supercapacitor module with a certification for marine application available on the market, furthermore, the Supercapacitor cells use flammable solvents, such as acetonitrile (C_2H_3N), then some safety actions have to be taken in order to be possible to carry the EESS on board.



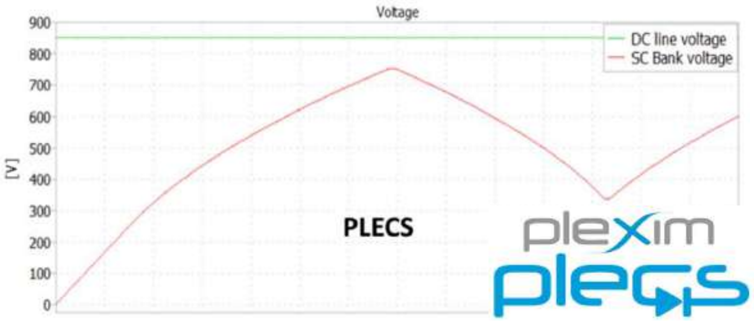
ElectrostaticEnergyStorageSystem (EESS) SIMULATION MODEL

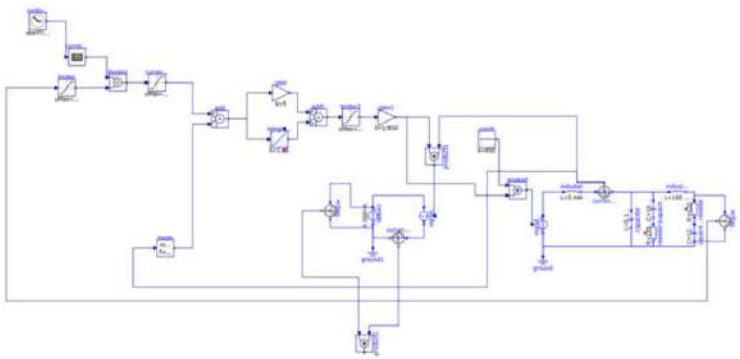
Supercapacitors (EESS)

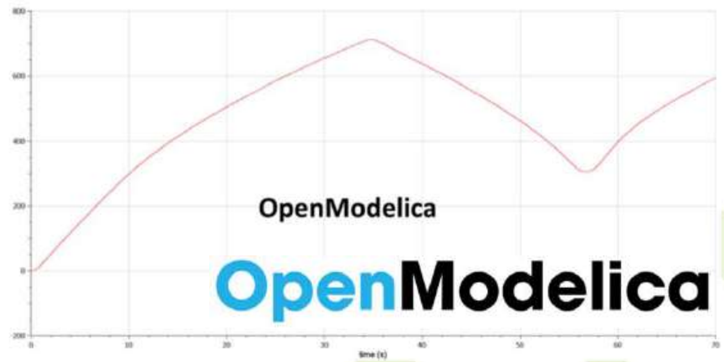
OCEM POWER ELECTRONICS

LabVIEW

OCEM built simulation models of the EESS exploiting two well known software tools for power electronics simulation: PLECS (for designing the system and sizing the components, making thermal evaluations also) and OpenModelica (based on average values, to integrate the EESS model into the overall system model)







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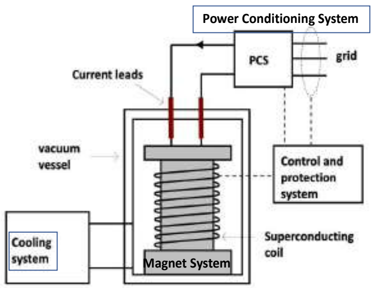
TECHNICAL DEVELOPMENT & MARINIZATION

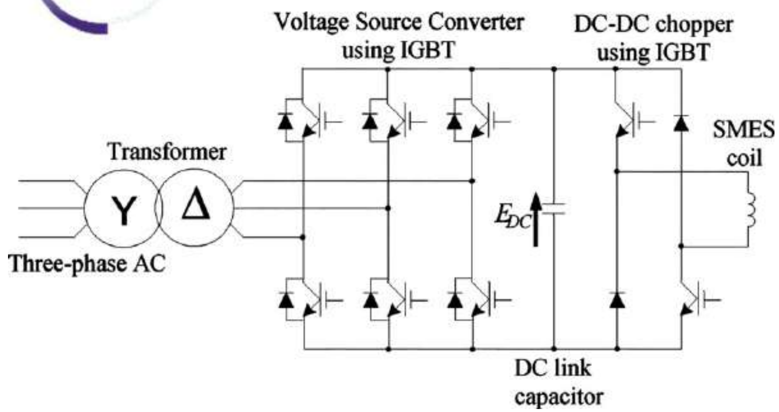
SMES (Superconducting Magnetic Energy Storage)



Optimized through COMSOL model
Forced convection of helium:
Autonomous function, cost-effective, compact design, local heat dissipation

$$E = {}^{1}/_{2} \cdot L \cdot I^2$$

Superconducting coil – cryogenic cooling (helium)
Nominal current = 475A @ 4.2K / 220A @ 20K
Energy = 275 kJ @ 4.2K (0.08 kWh)
(84% of the total energy stored)



Power and Control System:

- IGBTs Grid Side Inverter + DC-DC chopper

SMES MAIN CHALLENGES

SMES (Superconducting Magnetic Energy Storage)

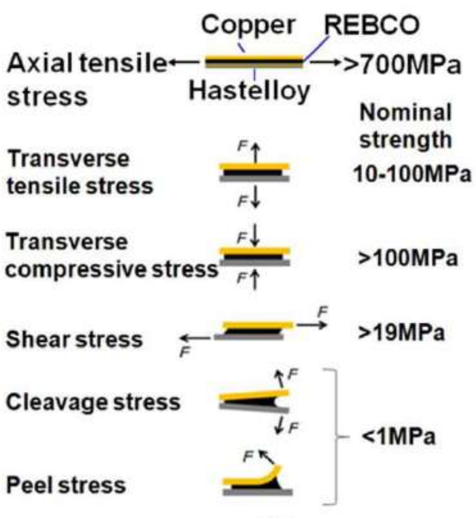
Mechanical degradation

Mechanical disturbances, frictional conductor motion, due to stress accumulation: 1) cool down and 2) coil charging, can cause mechanical degradation to HTS magnets.

Causes: the anisotropy of the mechanical properties of HTS tapes → tensile strength in the transverse direction (10-100MPa) and **cleavage and peel strength** (1 MPa) are typically the limiting factors

Solutions: a) Improvement in the mechanical strength of REBCO conductors, b) Suitable selection of impregnants, c) Improvement of the interface condition between tape and epoxy resin.

REBCO conductor



(a)

SMES MAIN CHALLENGES

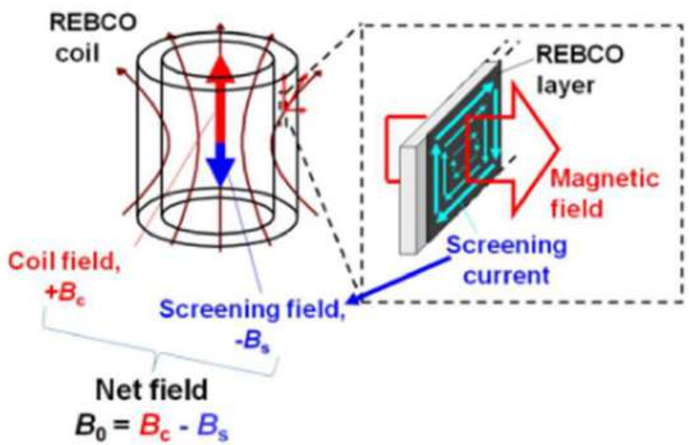
SMES (Superconducting Magnetic Energy Storage)

Screening currents

When an HTS magnet is energized, the radial component of the magnetic field penetrates a wide area of an HTS tape conductor, inducing a screening current

Magnetic field: The screening-current generates a negative magnetic field, −Bs, at the coil center as seen in Fig. 1 when the coil is firstly charged; therefore the net central magnetic field intensity equals to Bc−Bs. A **15% reduction in center field** can be observed

Mechanical stress: Screening currents have a significant impact in the mechanical design. Lorentz forces distribution differ significantly if SC are taken into account. **Peak of Lorentz forces** when taken into account SC can be **3-4 times larges than if SC** are not accounted for.



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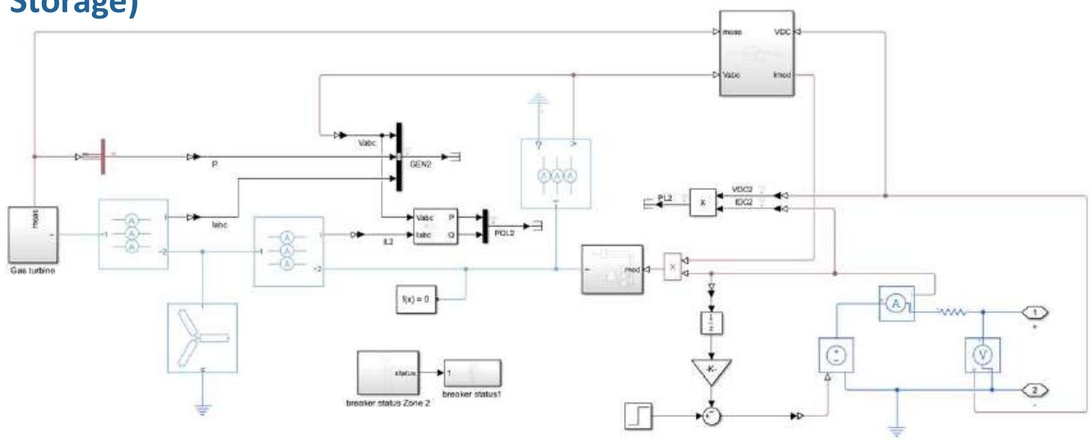
SMES SIMULATION MODEL

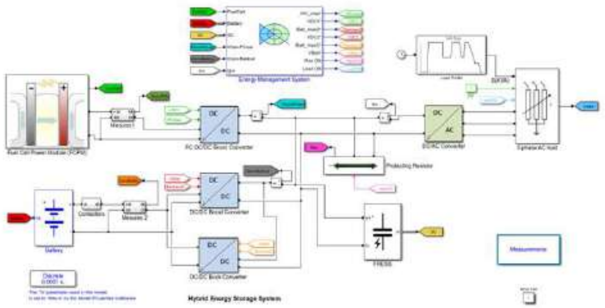
SMES (Superconducting Magnetic Energy Storage)

CYCLOMED

- AC basic grid
- EES with var. load
- MVDC grid

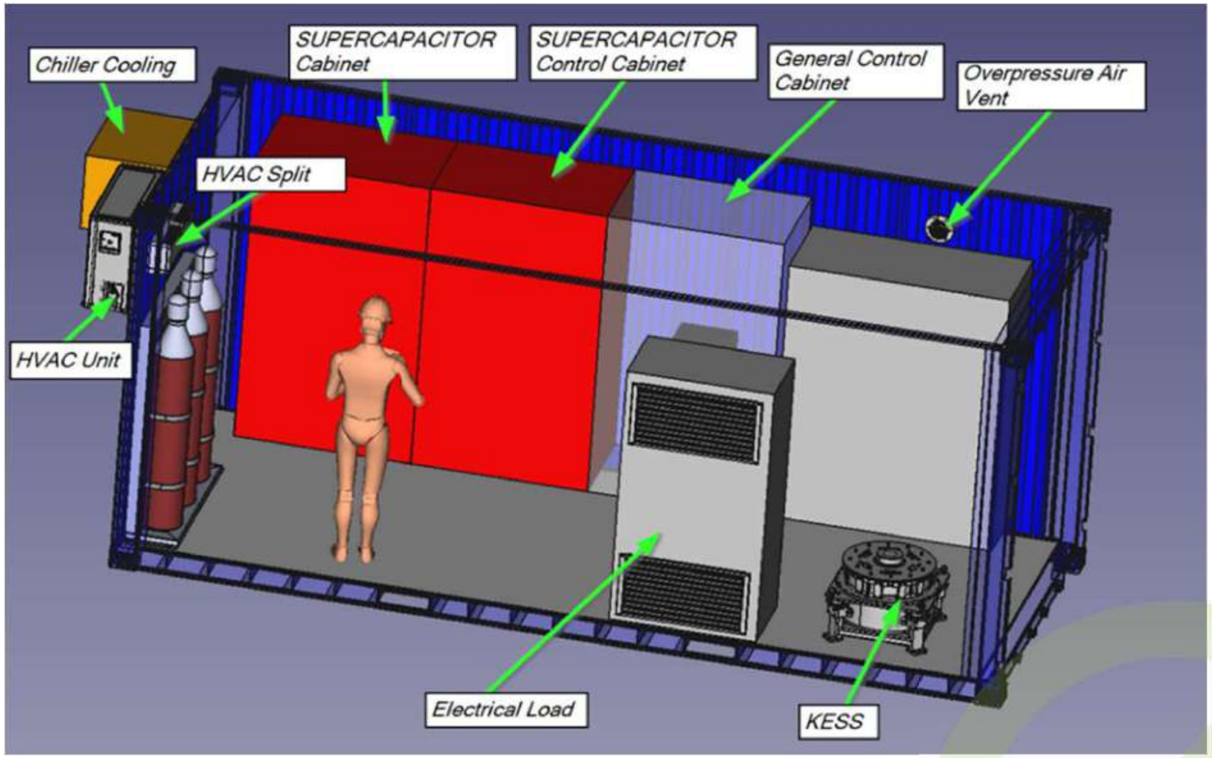


Cyclomed has developed models for SMES in MATLAB



MATLAB SIMULINK

CONTAINER INTEGRATION



SIMULATION MODEL WORKFLOW

OpenModelica
plexim plecs
MATLAB SIMULINK
LabVIEW

{ FRESS Submodels }

Export to FMU →

fmi Functional Mock-up Interface

Import from FMU →

- *Define variables of interest for each model*
- *Reduce/simplify model complexity*
    - *Remove unwanted physics*
    - *Use simplified solutions*
    - *ROM models?*
- *Validate against complex/full model*

Mechanical model (Ship movements)

HVAC model

AMESIM

Heat transfer model

{ Container Global Model }

GLOBAL SIMULATION MODEL - *Thermal Example*

TEMPERATURE MODEL INSIDE THE CONTAINER

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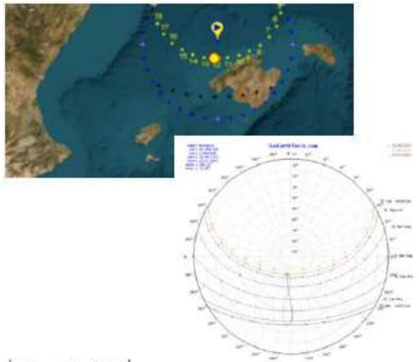
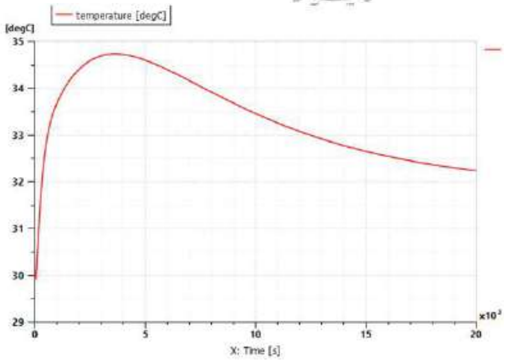
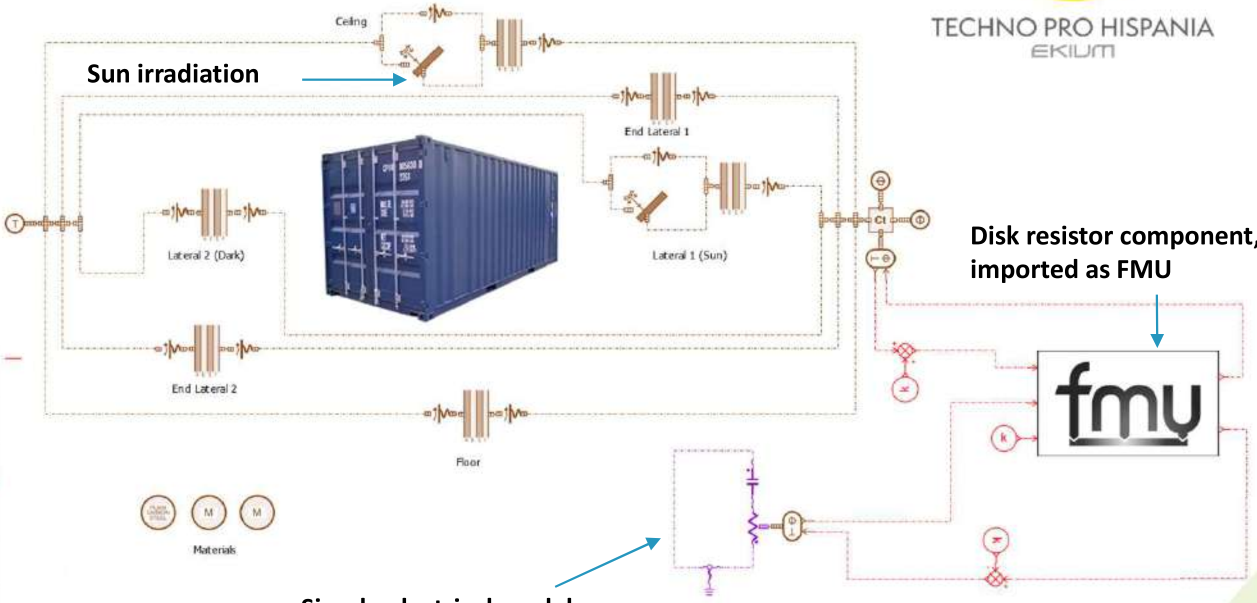
AMESIM





Sun irradiation



Disk resistor component, imported as FMU

Simple electrical model (to be substituted by OCEM FMU)

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DEVELOPING NEW COMPONENTS

VALIDATION OF CERAMIC DISK RESISTOR

Disk Resistor Component:

- Absorb energy by an increase of temperature using Joule effect
- After a quick temperature increase (1-2 min) a very slow heat transfer by radiation and convection heat transfer starts until the cylinder reach equilibrium temperature (>8 hours).

Why to model this?

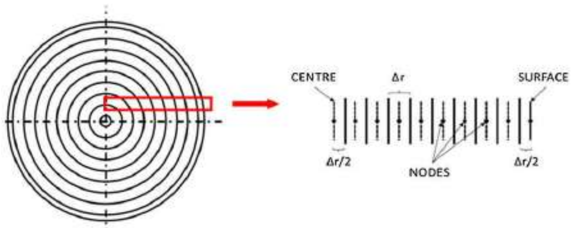
- Manufacturer only provide a simple heat transfer coefficient for:

Radiation and Convection $W_a = 0.00026(\ T)^{1.4}$

  - Average cylinder temperature (<u>not surface temperature</u>)
  - Calibrated only at 25º C
  - Natural convection only (<u>forced convection is expected</u>)

Discrete Cylinder Transient model:

- Customizable number of discrete volume elements of the cylinder
- Efficient Modelica code! Only 18 functional lines of code!
- Accept the input of a homogeneous heat load (electrical Joule effect)
- Validated results against literature (Heisler charts)



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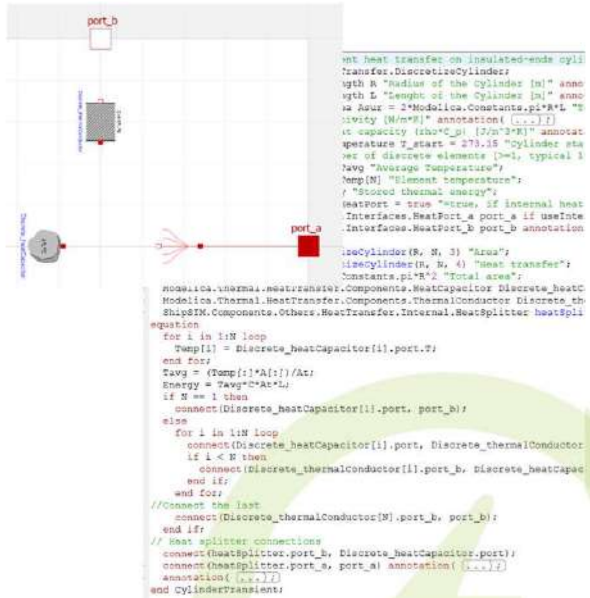
Modelica Language



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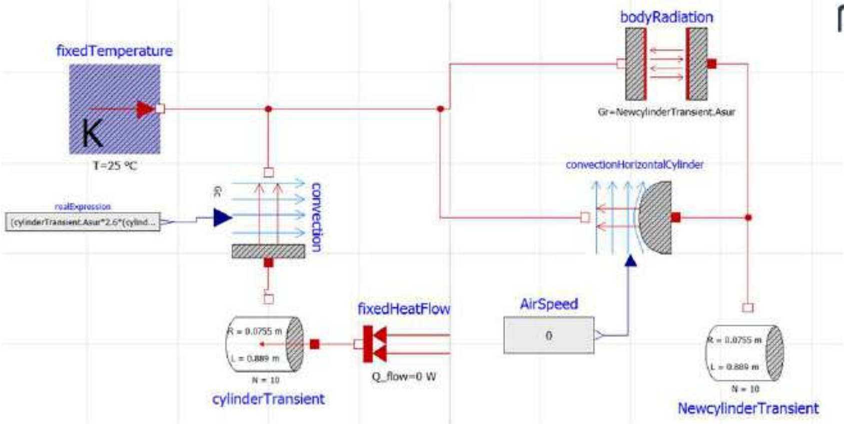
VALIDATION NEW COMPONENTS

VALIDATION OF CERAMIC DISK RESISTOR



Modelica Language
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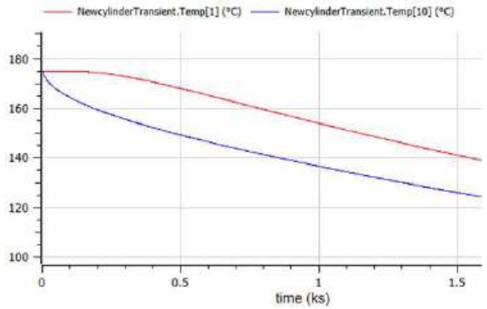

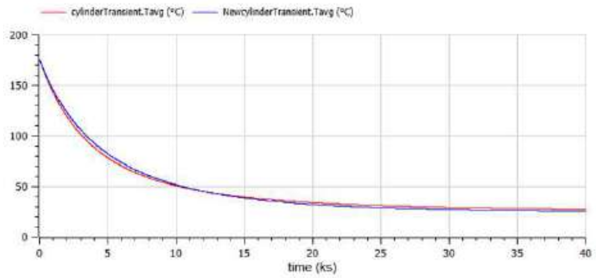

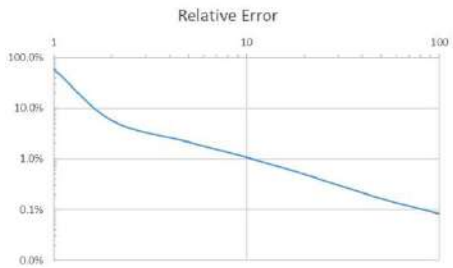

With this model we obtain:

- Heat transfer and cooling with forced convection
- External cylinder temperature and radiation heat to other equipment
- Real heat transfer and temperature distribution that can be used in partial discharges, cycle loads, etc...

Validation against literature:

- Excellent results with low number of discrete elements (about 1% error with 10 elements)
- Increase elements with Biot number!

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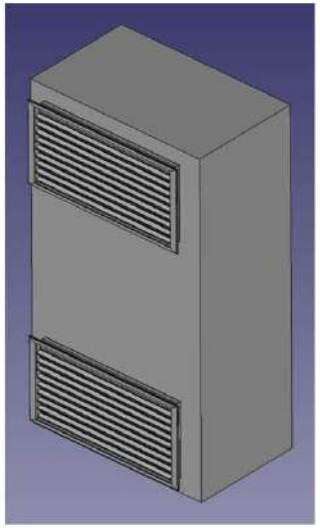
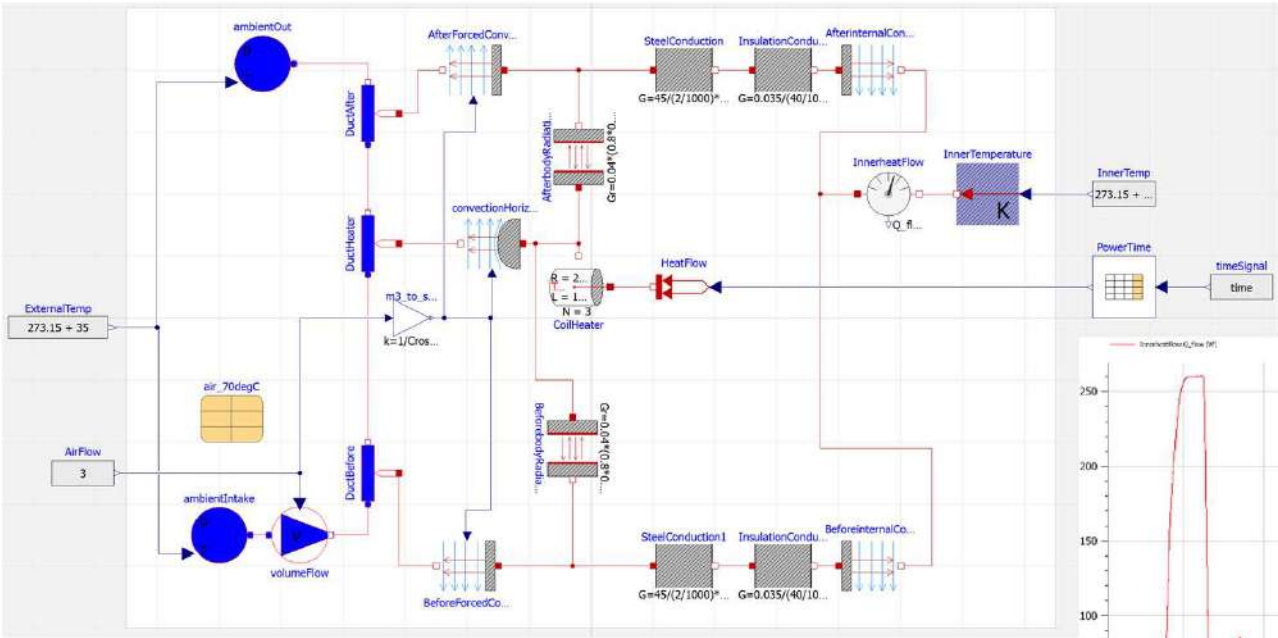
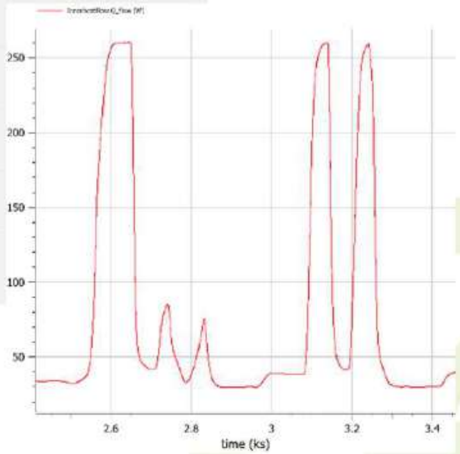
DEVELOPING A MORE COMPLEX SUBSYSTEM

LOAD RESISTOR MODEL & HEAT GAIN IN THE CONTAINER

Modelica Language







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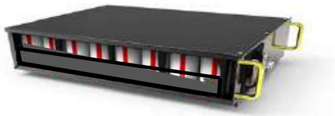
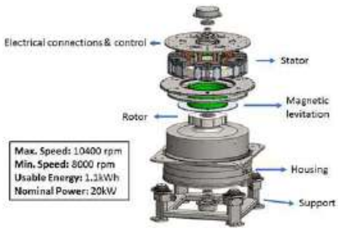
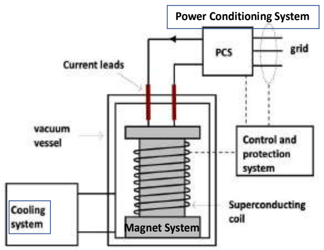
NEXT STEPS

- PROGRESS ON SIMULATIONS
- EVALUATE SAFETY ASPECTS OF THE DESIGN
- COST ANALYSIS
- CONTAINER DETAIL DESIGN







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63° Congreso Internacional de Ingeniería Naval e Industria Marítima

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Thank you for your attention!

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Basilio Puente Varela

Head of Conceptual & Basic Design, Techno Pro Hispania S.L.

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