Supercapacitor Application for Reduction of Power Oscillations

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Division of Electric Engineering
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Ciemat

Brief introduction to CIEMAT

CIEMAT (Centre for Research on Energy, Environment and Technology) is a public research institute belonging to the Spanish Ministry of Economy, Industry and Competitiveness.

1300 engineers, researchers and administrative staff.
100 M€ of annual budget.

5 Scientific Departaments

- Department of Energy
- Department of Environment
- Department of Basic Physics
- Fusion National Laboratory
- **Department of Technology** ⇒ Division of Electric Engineering

3 Management Departments

- General Secretary
- Institutional Relationships and Knowledge Transference
- Department of Facilities Improvement and Safety

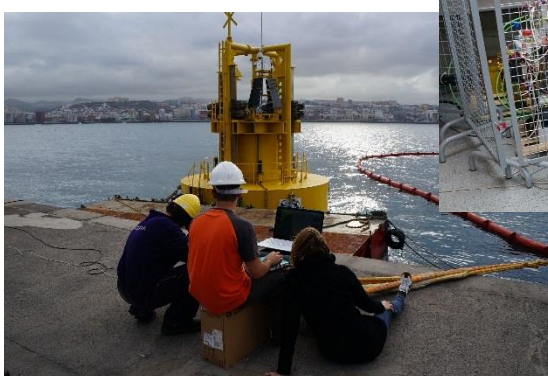
Brief introduction to CIEMAT. Division of Electric Engineering


Power electronics and electric drives


Validations with hardware-in-the-loop


Technologies for particle accelerators


Supercapacitors


Wave Energy Converters


Flywheels

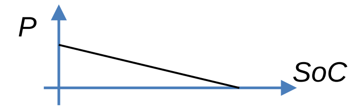

Medical applications of the electromagnetism (cyclotron)

1. Supercapacitors: Defining the right application

Let's start with an example ….

E= 765 kJ (213Wh) ⟶ E_{useful}= 574 kJ (159 Wh) 75% for ½ V

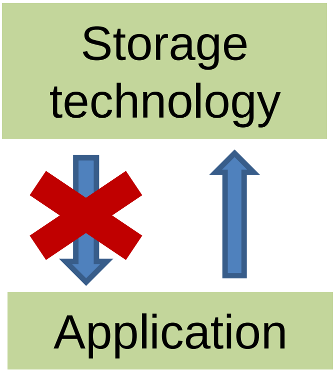
P= 85 kW ⟶ P_{max}< 85 kW



How much do the devices loose their capacity during the operation? (number of cycles, current levels, temperature, etc.)

- Selection of a storage technology must be done correctly, depending on the application.

- Each technology of energy storage has their advantages to be used in a particular application. Once defined the best application, the technology could be readjusted.



2. Supercapacitors: Applications

TRANSPORT

- Electric buses
- Starting of heavy vehicles (automobiles, trucks, heavy machinery and maritime systems)
- Use of regenerative braking and assistance to consume peaks

HIGH ENERGY PHYSICS

- Fusion reactors
- Particle accelerators

(reduction of power peaks and recuperation of the magnets energy)

POWER SYSTEMS (GENETION AND ELECTRIC GRIDS)

- Voltage and frequency regulation
- Compensation of power oscillations (power quality) and peak saving
- Spinning reserve in renewables
- Firming and ramp rate control in PV solar plants
- Backup power for wind pitch control systems
- Microgrids – distributed energy storage

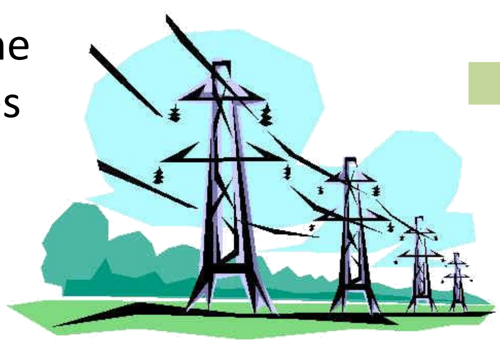
INDUSTRIAL APPLICATIONS

- Elevators and cranes
- Uninterrupted Power Systems (UPS)
- Hybridisation with batteries

2.1. Introduction: Renewable energy penetration

- This type of electric generation is likely to deteriorate significantly the power quality
- Its has been already documented and/or discussed for some interconnected electric power systems
  - Western, Texas and Eastern interconnections in US *(Miller et al., 2011;)*
  - Hawaii *(Kaneshiro, 2013)*
  - Ireland *(Iswadi et al., 2015)*
  - Nordic power system *(Yang et al., 2016; Storli and Nielsen, 2014)*
  - Continental Europe *(Wang et al., 2016)*

- The problem comes from the fact that renewable energies can not be managed, affecting to the **Grid Codes.**

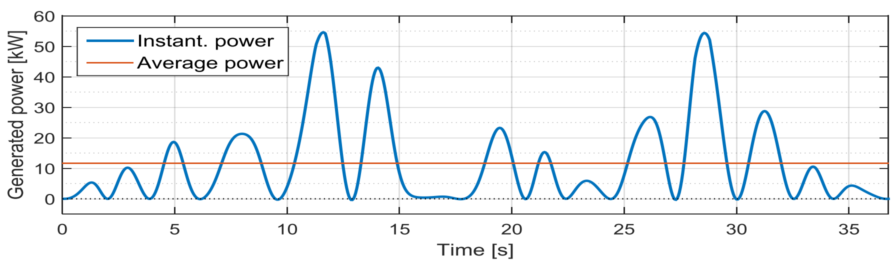


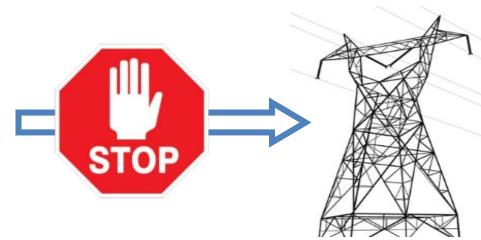
1. Voltage regulation
2. Reactive power supply
3. Response to system fault
4. Response to frequency changes
5. «ride through» short interruptions

2.2. Power oscillations to be integrated into the grid

Many times, the instantaneous power profile generated by a particular technology cannot be directly injected into the grid for quality and stability reasons.

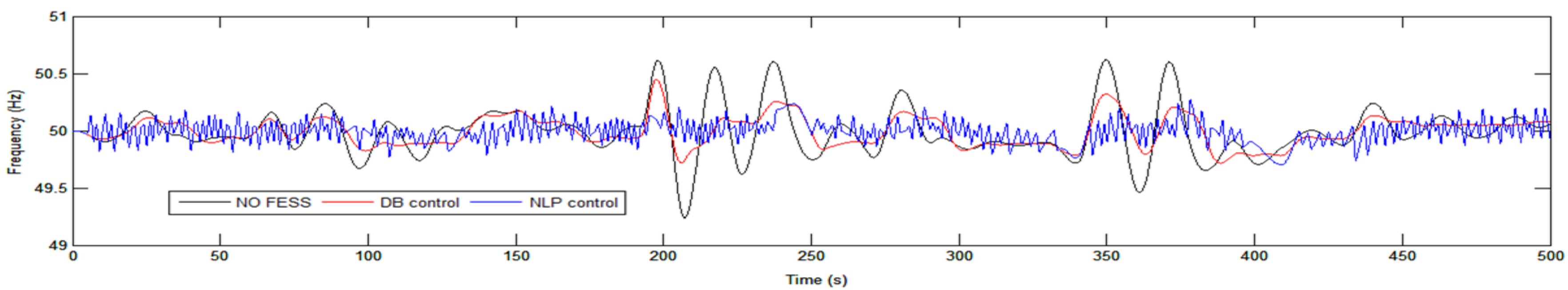
Example: Power generated by a single point absorber WEC under real wave conditions





Therefore, a power conditioning stage is required to smooth the instantaneous power profile, especially in weak grids

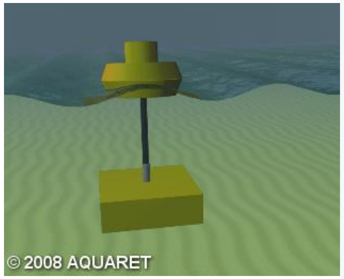
- -Sizing and locating of the generators
- -Control strategies
- -**Energy storage**

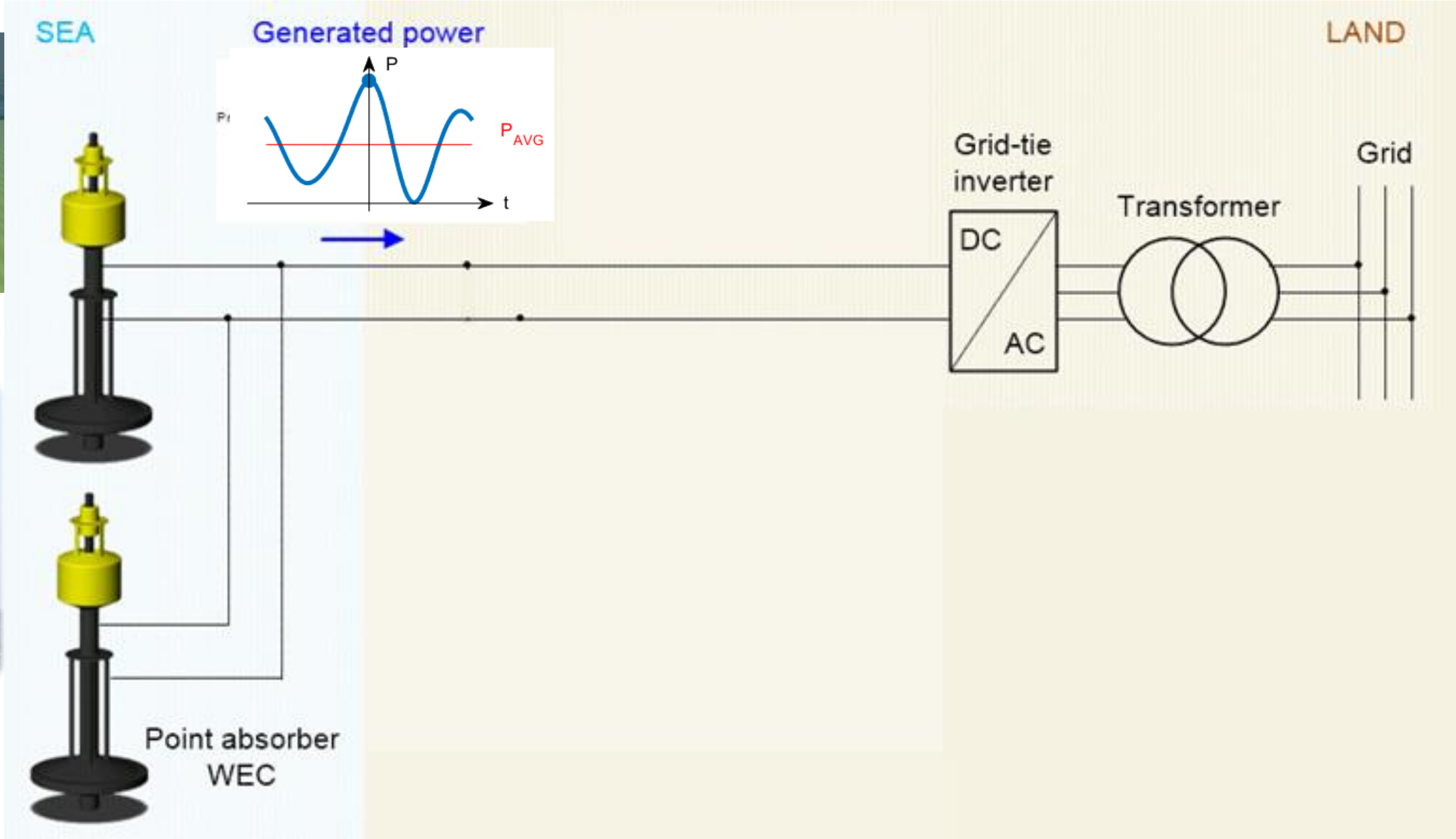


2.3. Applications: Compensation of power oscillations in wave energy generation

STUDY CASE 1

A heave point absorber type of wave energy converter.



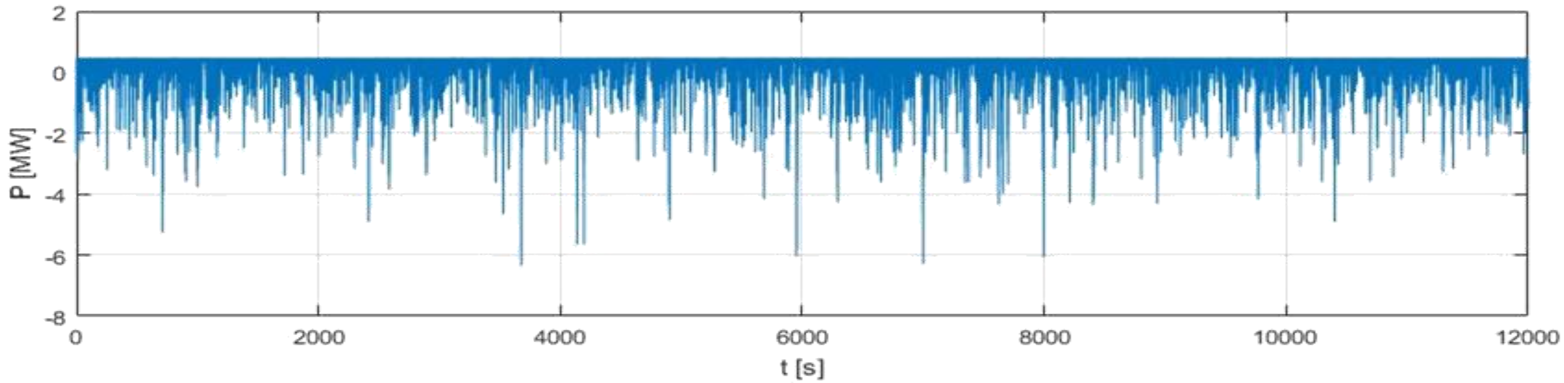


2.3. Applications: Compensation of power oscillations in wave energy generation

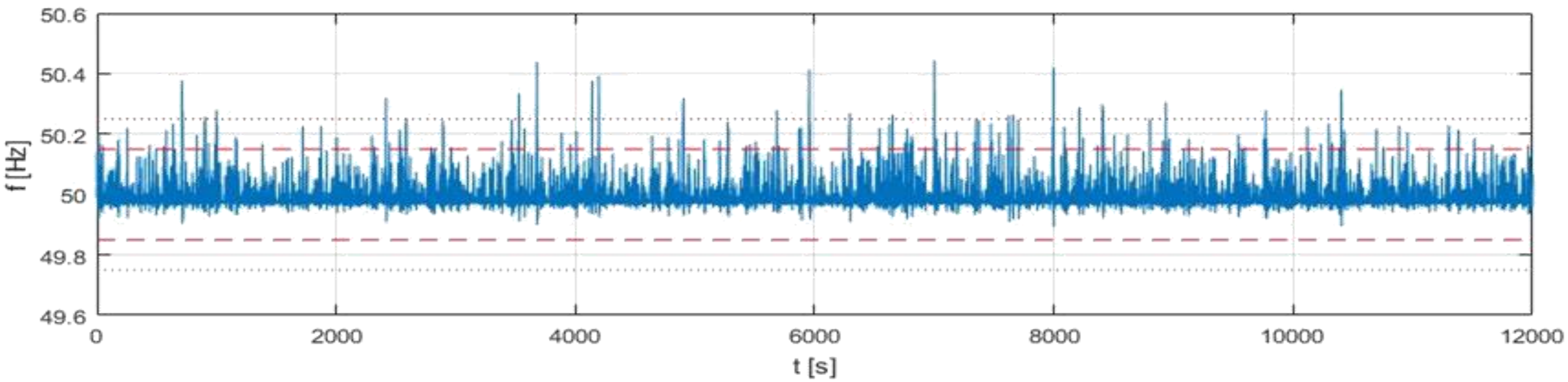
STUDY CASE 1

A heave point absorber type of wave energy converter.

Power supplied to the grid by a wave energy farm



Evolution of the grid frequency



Frequency might be not scape out of the limits

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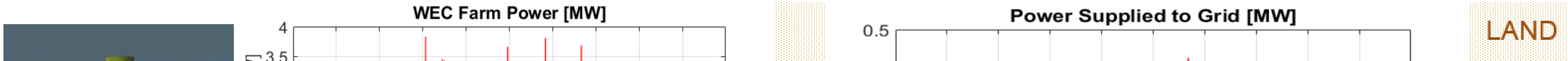
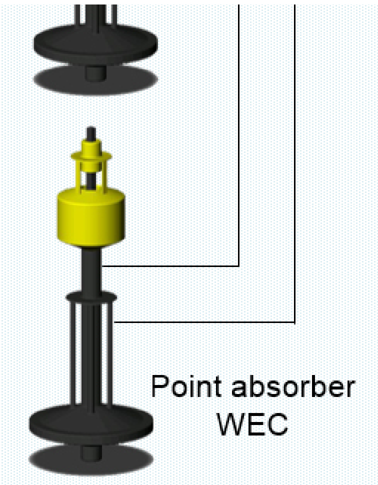
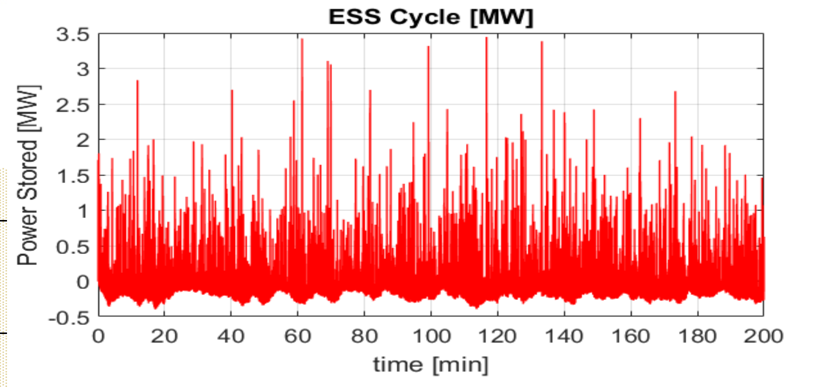


Selecting a module of 125kW, 0.5 kWh ⇨ $$n_{ESS} = \frac{E_{cycle}}{E_{ESS}} = \frac{7.35\ kWh}{0.5\ kWh} \sim 15$$

A constrain in the power is currently more restrictive when considering resource. ⇨ $$n_{ESS} = \frac{P_{\max\_cycle}}{P_{ESS}} = \frac{3.45\ MW}{125\ kW} \sim 27$$





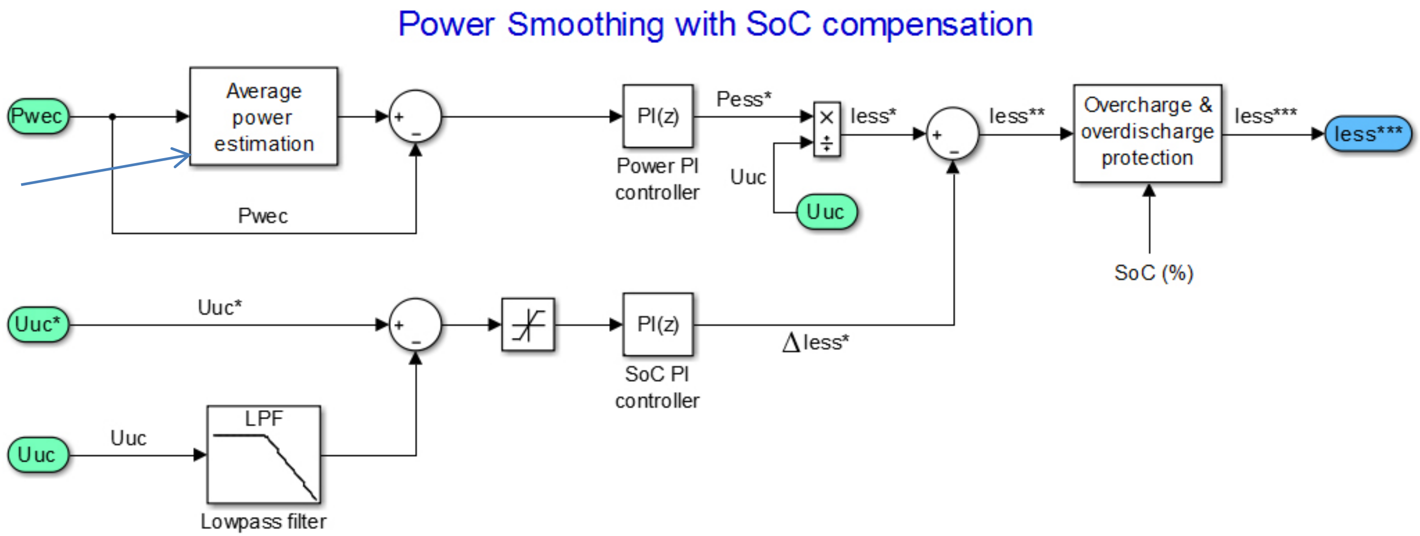
converter

2.3. Applications: Compensation of power oscillations in wave energy generation

STUDY CASE 1

- First task is to define the power to be supplied to the grid (or the load) and the power required by the storage.

Moving average window (MAW) algorithm



- A second regulation loop is required to compensate the long-term discharge (or charge) of the system. State Of Charge (SoC) compensator.

2.3. Applications: Compensation of power oscillations in wave energy generation

STUDY CASE 2

Project:
UNDIGEN MAS

2015-2017

Power supply of isolated power systems based on supercapacitors

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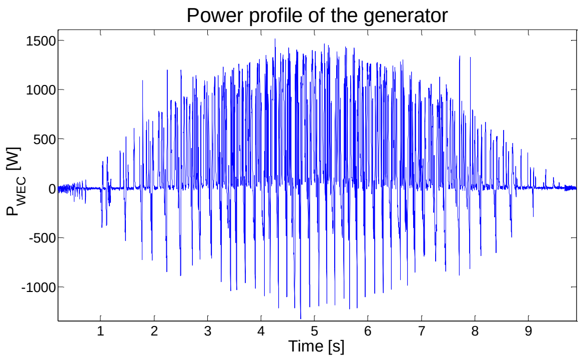
ELECTRÓNICA SUBMARINA SAES
GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
PLOCAN consorcio PLATAFORMA OCEÁNICA DE CANARIAS
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Gobierno de Canarias
Unión Europea Fondo Europeo de Desarrollo Regional

- Weather buoys supply
- Biomarine plants supply
- Submarine surveillance
- Marine communications

2.3. Applications: Compensation of power oscillations in wave energy generation

STUDY CASE 2



Project:
UNDIGEN MAS
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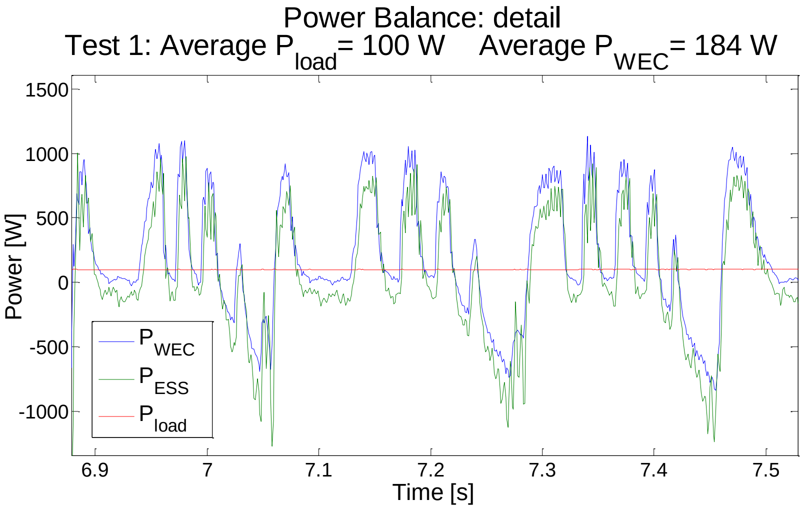
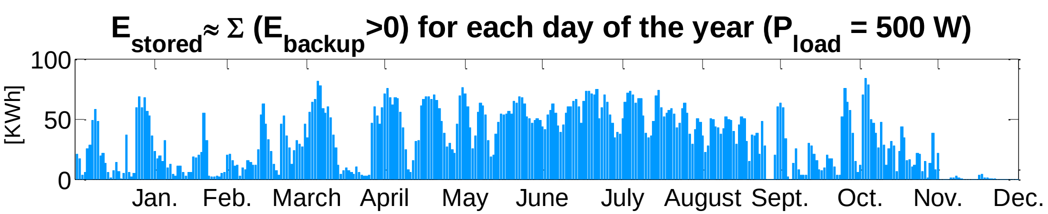
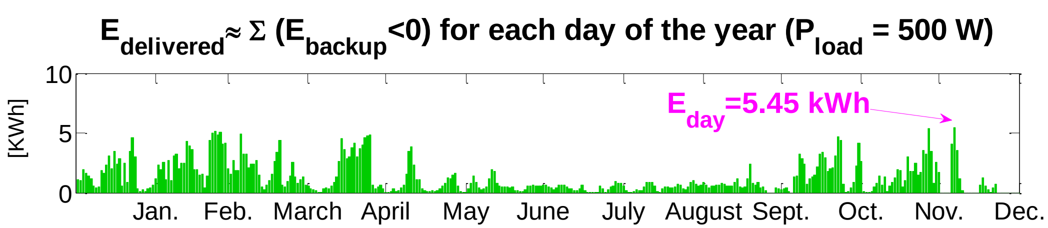
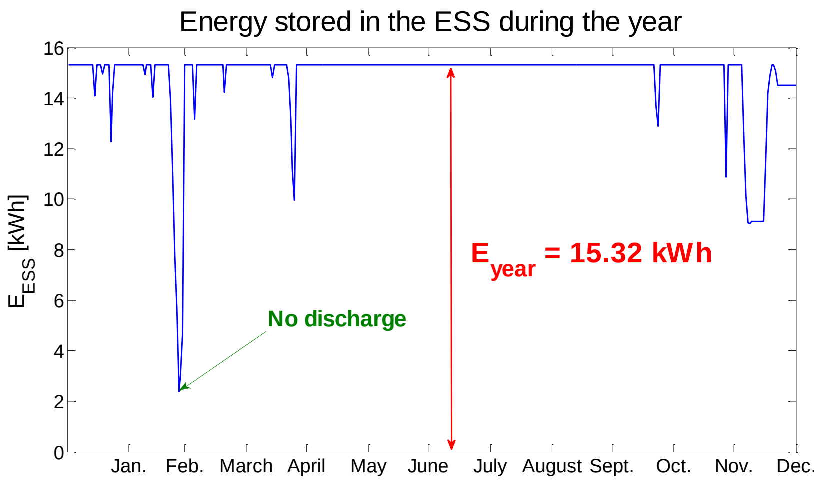


Power supply of isolated power systems based on supercapacitors



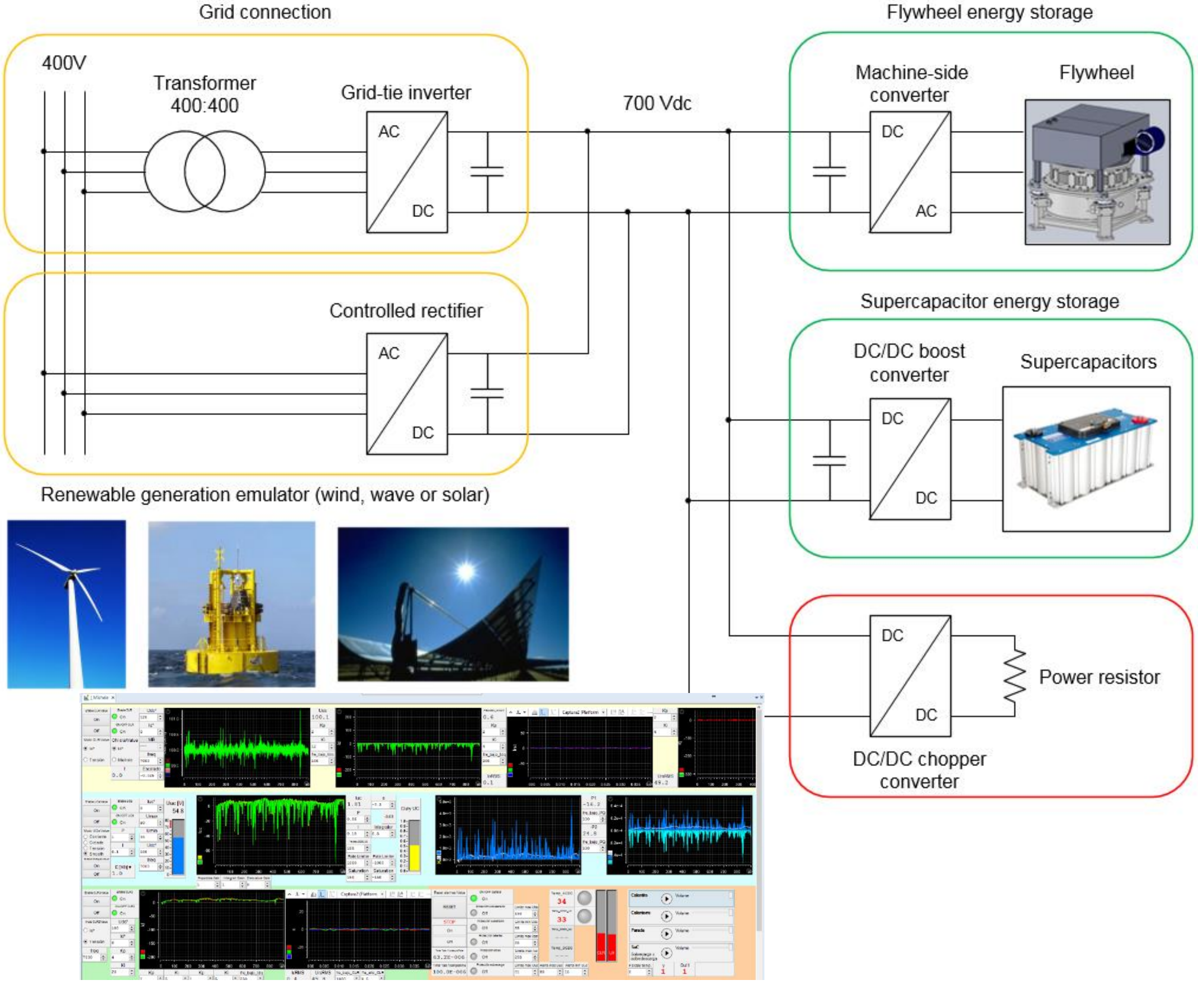




2.3. Applications: Compensation of power oscillations in wave energy generation

STUDY CASE 2

A **multiporpose test bench** based on power electronics allow testing the system emulating the real application.



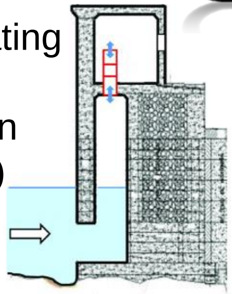
2.3. Applications: Compensation of power oscillations in wave energy generation

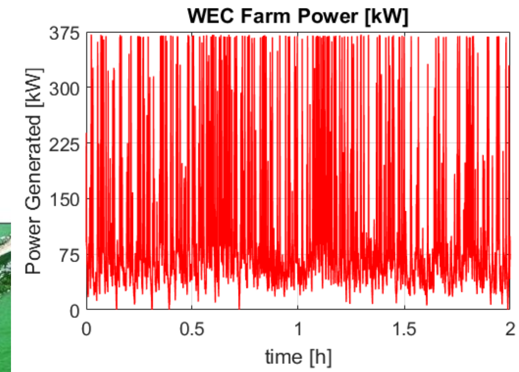
STUDY CASE 3

Ciemat EVE

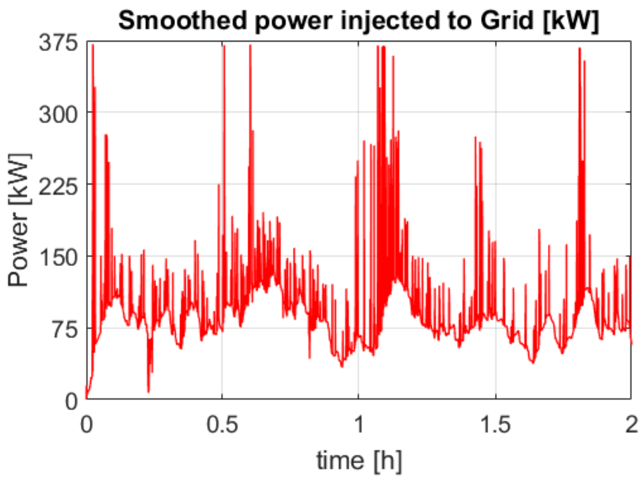
2017-2018

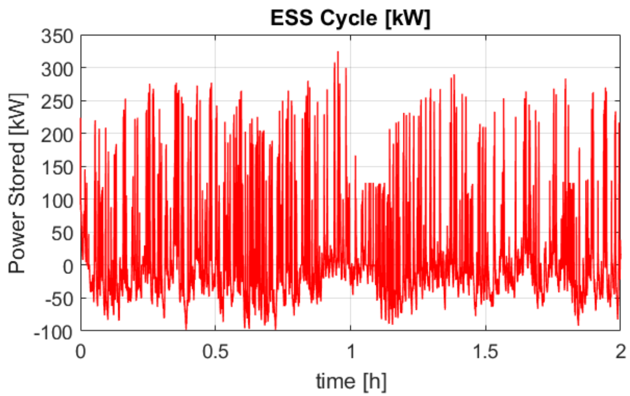
Oscillating Water Column (OWC)





Power generated



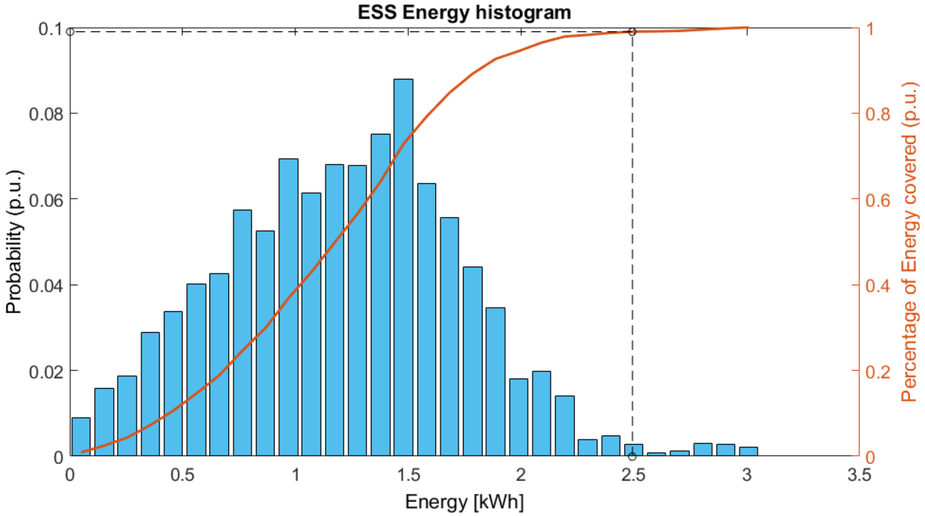


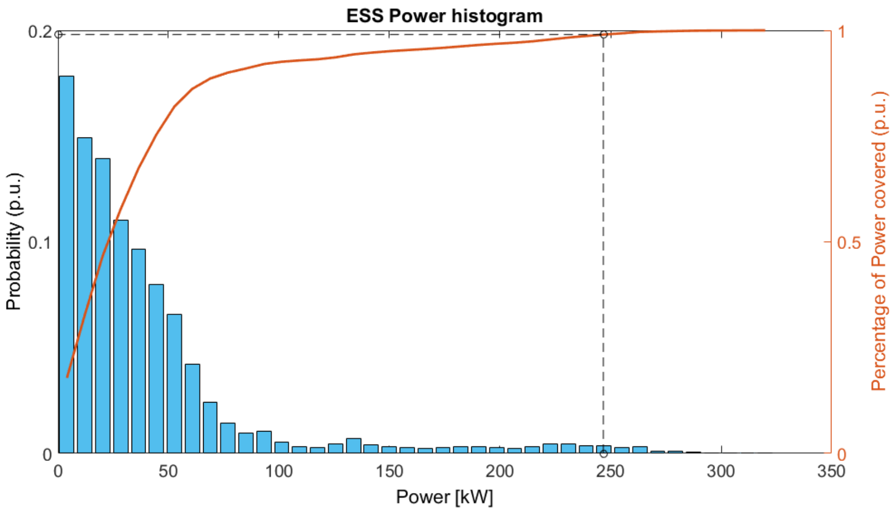
Once considered a control strategy for the ESS a time profile of **power required** is obtained.

2.3. Applications: Compensation of power oscillations in wave energy generation

STUDY CASE 3

Energy and power Histograms allow to define the energy and power as a function of the probability to cover the requirements.





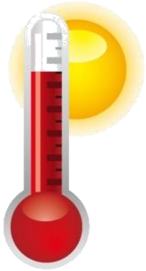
How necessary is to cover all the power oscillations?

2.5 kWh cover 99% of the energy requried

200 kW cover 80% of power demand, 250 kW cover 99%

3. Lessons learnt from the experimental use of Supercapacitors

- It is not convinient to operate at the maximum voltage for a long time for not to have a reduction of capacitance (2.6 V for a 2.7 V cell). The real energy available is lower.
- There is tendence to the unbalance of the cells voltage when connected in series. That is higher with higher currents and higher temperature.
- 60ºC is a limit recommended not to overpass.
- Internal resistance (ESR) produces not only a lost of efficiency but to increase the cooling requirements
- It is necessary to do a temperature control in the cells, at different points.



4. Technological challenges of Supercapacitors

Our three … or more wishes for the performance of supercapacitors from the point of view of applications.

- More voltage level per cell
- Characteristics appropriated in particular for my application (power and energy levels, DoD, etc.)
- Better isolation voltage in order to increase the voltage level
- Reduce the internal resistance (ESR)
- Reduce the balancing requirements
- Improve the temperature range performance to reduce the lost of capacity.
- Reduce costs to be more competitive at the energy markets

Course in CIEMAT. Madrid. 19-23 November 2018.

Applications of Energy Storage in Electric Power Systems

- Technologies and applications
- Experts from different research institutes and Universities (CSIC, UPM, UAM, CNH2, IMDEA, etc.)
- Use of the unique experimental laboratories of CIEMAT to provide 25% of the time in experimental tests with prototypes, computer simulations and visit to pumped-hydro plant.

More information:

www.ciemat.es search for *energy storage*

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THANK YOU FOR YOUR INTEREST

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