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Operation of Isolated Power Systems under High Shares of Renewables

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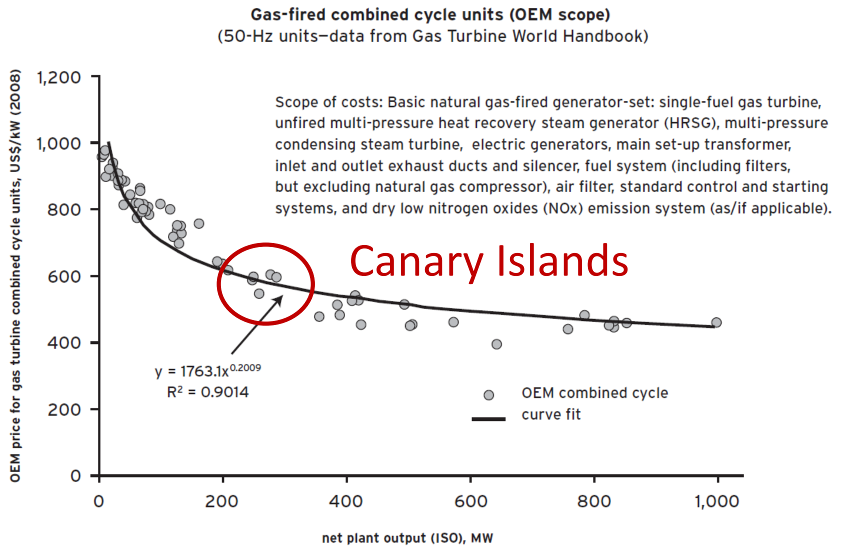
- Economic operation
- Technical operation
- Conclusions

Introduction (i)

- Several thousand island power systems exist worldwide.

- Island power system differ from interconnected ones by:
  - the lack of support from neighboring systems
  - the lack of economy of scales
  - additional logistic costs of fuels



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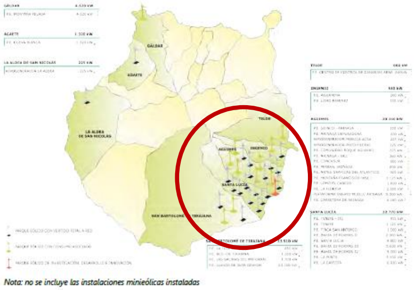
Introduction (ii)

- Further,
  - every generation unit represents a substantial portion of the total demand.
  - generation outage leads to a significant power deficit.
  - the number of spinning generating units is relatively small.
  - system inertia is smaller than interconnected systems.

- Finally, many isolated system are geographically small.
  - Variable Renewable Energy Resources (VRES) might be concentrated spatially.
  - This concentration reduces portfolio effect of VRES and VRES production varies rather simultaneously.



Introduction (iii)

- These characteristics pose some challenges to island power systems.

System operation costs	High operation costs Relatively large reserve requirements VRE variability
Frequency stability and protection	Smaller system inertia Slower reserve deployment times Sensitive to power deficit (gen outages,…)

- Renewables might solve some of the challenges but also accentuate others.

Introduction (iv)

- As seen previously, spinning reserves play a dominant role in island power systems.

- Spinning reserves must cover the largest expected variations.

- They are assigned to individual units in function of marginal costs and technical characteristics.

- Spinning reserves and their requirements affect thus both:
  - Economic operation
  - Stability

Economic operation (i)

- Spanish island systems are operated under a centralized scheme
  - Generating units are programmed according to dispatch rules taking into account security of supply issues

- Operation planning is carried out for three time horizons.

Weekly	• Start-up and shut-down of generating units • Published every Thursday: Saturday 0:00 to Friday 24:00
Daily	• Fine tuning of start-up and shut-down decision for day D till at least D+1 • Published every day
Real time	• Balance expected deviation in generation and demand with regard to the programmed generation and demand • Solve technical restrictions of the network

Economic operation (ii)

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- A unit commitment (UC) determines the hourly program of generating units for a given horizon (e.g., weekly UC):
  - Generation set points
  - Start-up and shut-downs

- The UC minimizes variables operation costs by satisfying demand, technical operation constraints of the units and reserve constraints.

- Renewables affect the UC by reducing the effective net demand, reducing thus costs.

Economic operation (iii)

- Renewables might affect reserve requirements and ramping capacity of generating units.

- Up and down spinning reserve requirements in the Spanish island systems:
  - Total up reserve
    - largest unit or
    - demand increase or
    - interconnection loss or
    - most probable RES variation
  - Down reserve is at least 50% of the up reserve

Economic operation (iv)

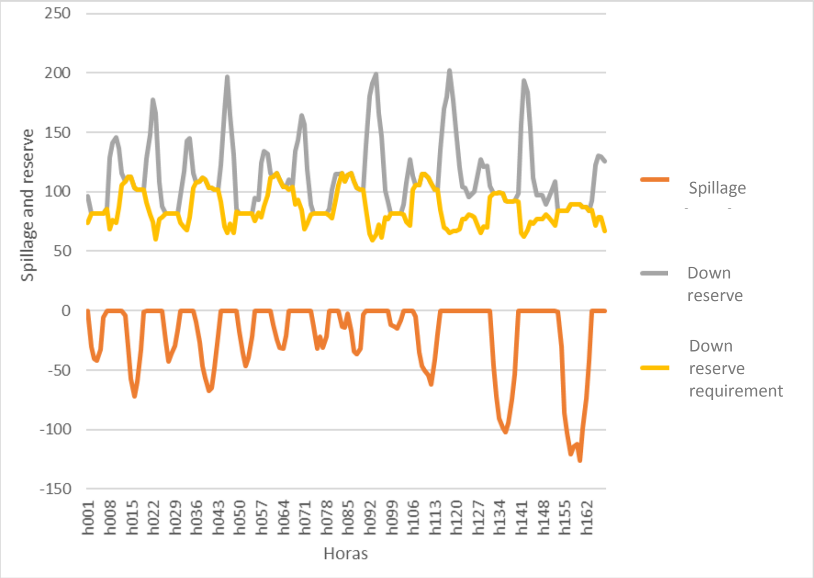
- Impact of RES penetration on the system operation costs of Tenerife in 2020 have been analyzed.

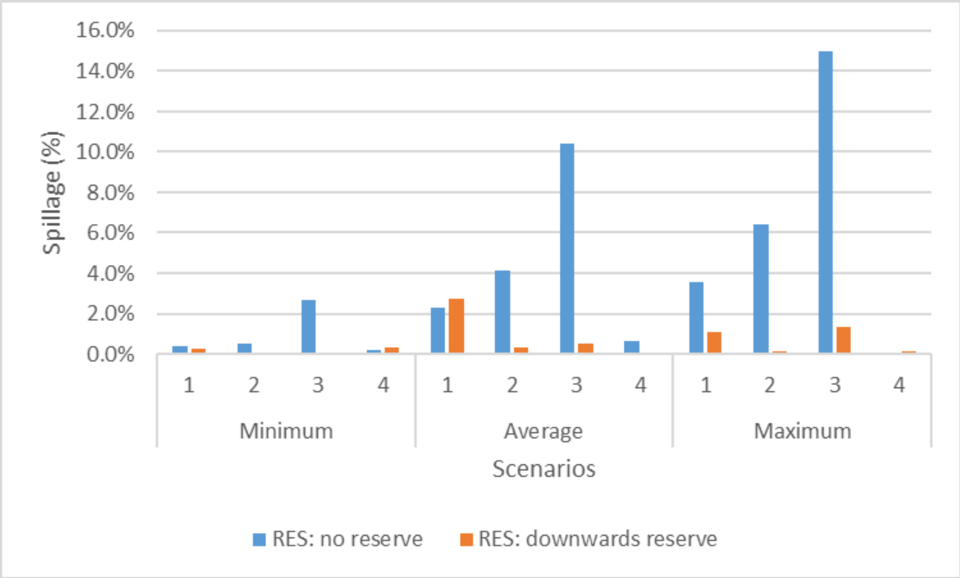
- Three scenarios of wind and PV penetration levels (according to the actual implementation of the tenders) have been studied for four weeks to determine wind spillage.

Scenario	Installed wind power (MW)	Installed PV (MW)
Minimum	133	112
Average	196	112
Maximum	222	112

Economic operation (v)

- Provision of downward reserves by RES reduces spillage.

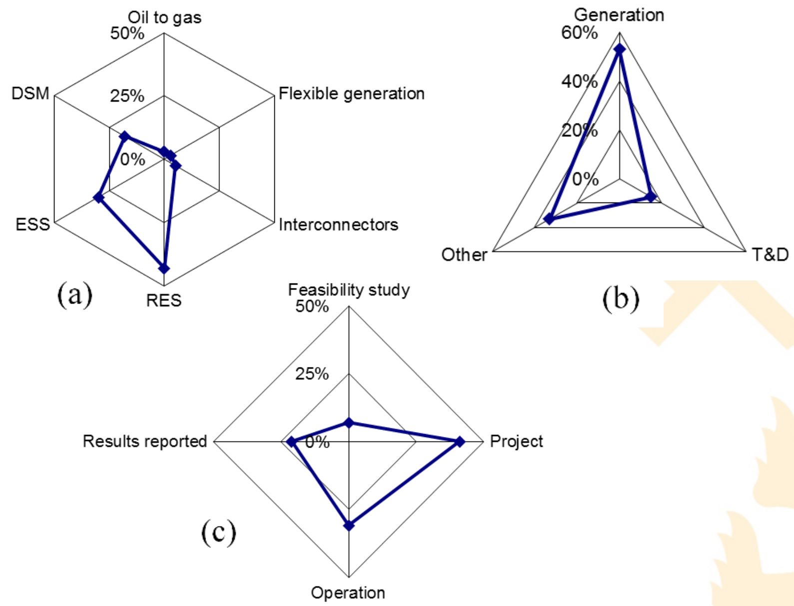




Economic operation (vi)

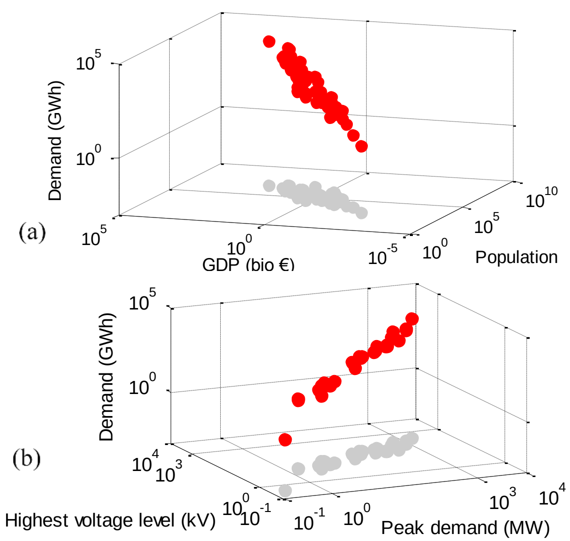
- In general terms, initiatives that transform island systems into sustainable island systems have been assessed.

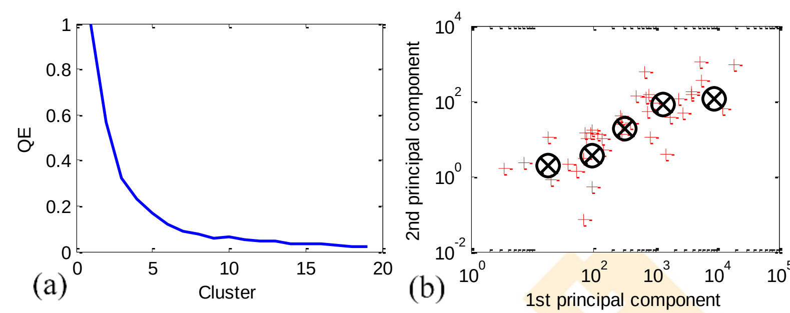
- Initiatives consist in applying one or several of the following actions:
  - RES
  - Storage
  - Demand side response
  - Electric vehicle



Economic operation (vii)

- The assessment has been carried out for five representative (out of 60) island systems

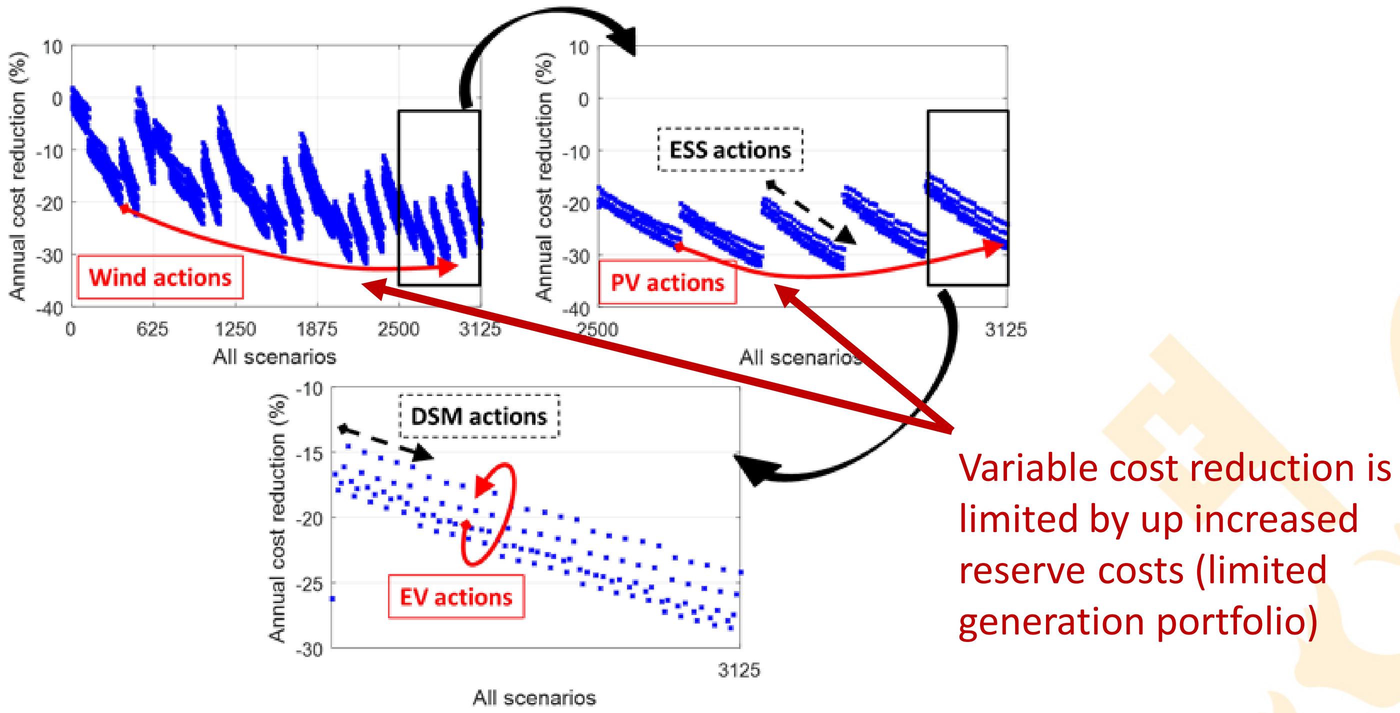




Prototype	1	2	3	4	5
D_{Energy} (GWh)	10627	1446.7	309.8	90.5	16.6
P_{gen} (MW)	2802.7	457.4	99.2	26.7	6.2
V_{TDmax} (kV)	220	66	66	32	32
n_{pop} (in thousands)	2550	244	88	33	5.5
C_{ave} (€/MWh)	81	118	101	146	140

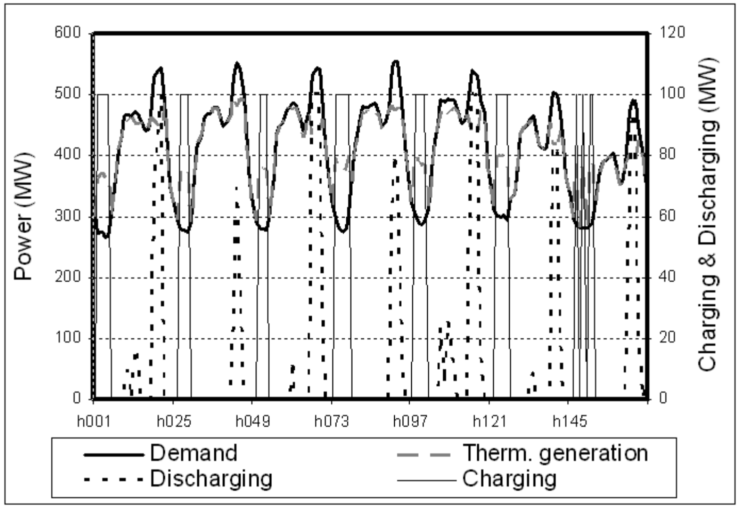
Economic operation (viii)

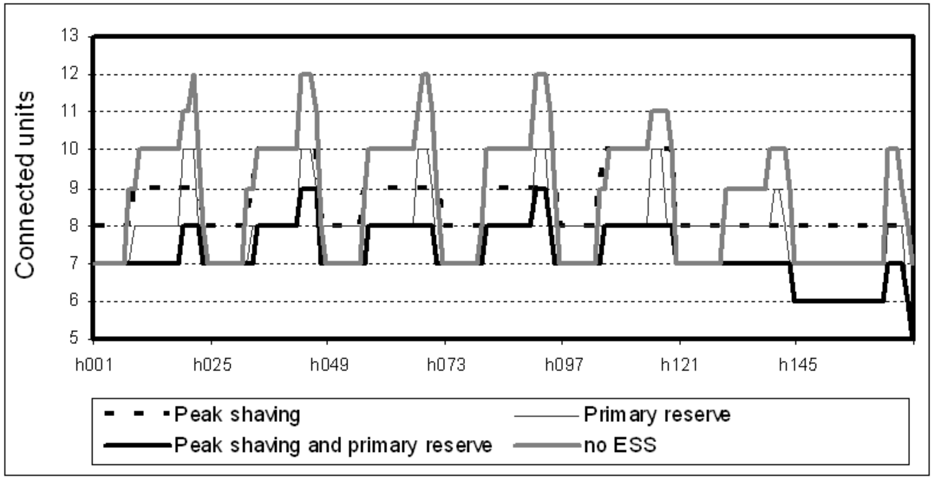
- Among others, it has been shown that costs decrease with increasing RES but cost reduction has a maximum.



Economic operation (ix)

- Energy storage systems improve system operation costs by providing spinning reserve and/or load shifting.



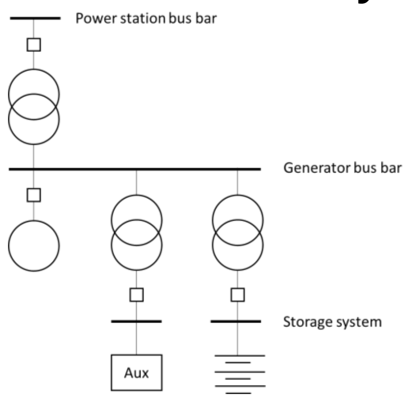


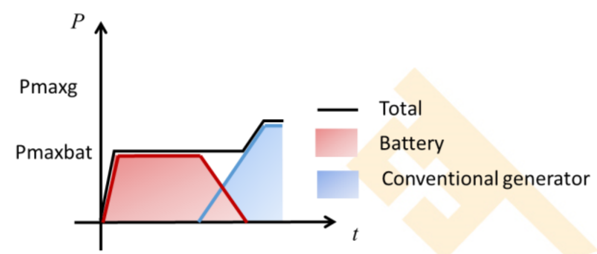
	System costs savings (%)				
	ESS 1	ESS 2	ESS 3	ESS 4	ESS 5
Primary reserve	0.00	1.48	2.75	3.80	4.67
Peak shaving	0.00	1.07	1.92	2.39	2.77
Primary reserve and peak shaving	0.00	1.79	3.61	5.25	6.58

Economic operation (x)

- Although energy storage system are beneficial, they are not considered in the current Spanish regulation (grid code and regulation on the economic operation of isolated systems).

- A possible alternative is to hybridize a conventional generator.





- This avoids:
  - Administrative procedures to register the storage system for dispatch
  - Modifications of remuneration procedures

Economic operation (xi)

- Hybridization would however still require an adaption of the grid code.
- In fact, spinning reserves can only be provided by conventional generators if they are dispatched.
- The hybrid generator could by contrast provide reserve although if the conventional generator itself is not dispatched.

Technical operation (i)

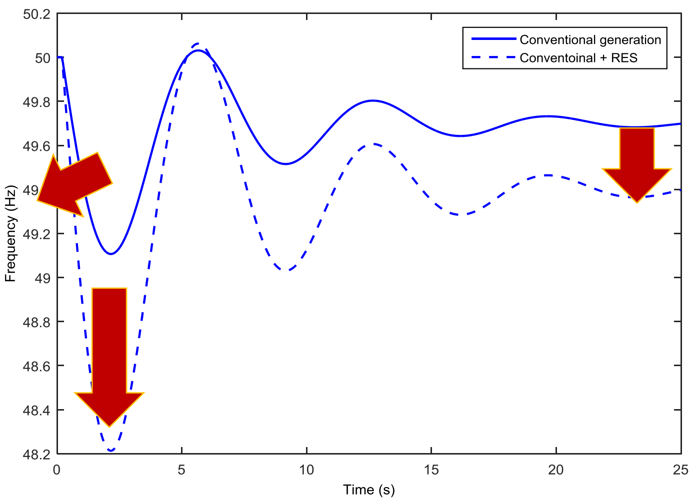
- Penetration of renewables might be affected or limited by:
  - System operation constraints (reserves, etc.)
  - Transmission network capacity
  - Stability constraints

- Substitution of conventional generation capacity through renewables does not necessarily occur at the same site.

- Geographic distribution of generation capacity affects power flow and voltage profile.

Technical operation (ii)

- Renewables affect frequency stability in two ways:
  - by reducing system inertia, and
  - by slowing down reserve deployment by substituting conventional generating units without providing reserve.



Island system usually limit the maximum amount of VRES supply (e.g., 30% of demand in Guadaloupe island):

- Due to increased reserve requirements
- Due to increased UFLS

Technical operation (iii)

- Although renewables reduce system inertia and reserve deployment speed, this does not happen linearly nor continuously (consequence of the UC).
  - At most as much reserve provided by conventional units as before if reserve criterion remains the same

- RES are technologically able to emulate inertia or to provide reserve through deloaded operation.

- Deloaded operation reduces RES benefits, although from a point of view of system costs might be beneficial.

Technical operation (iv)

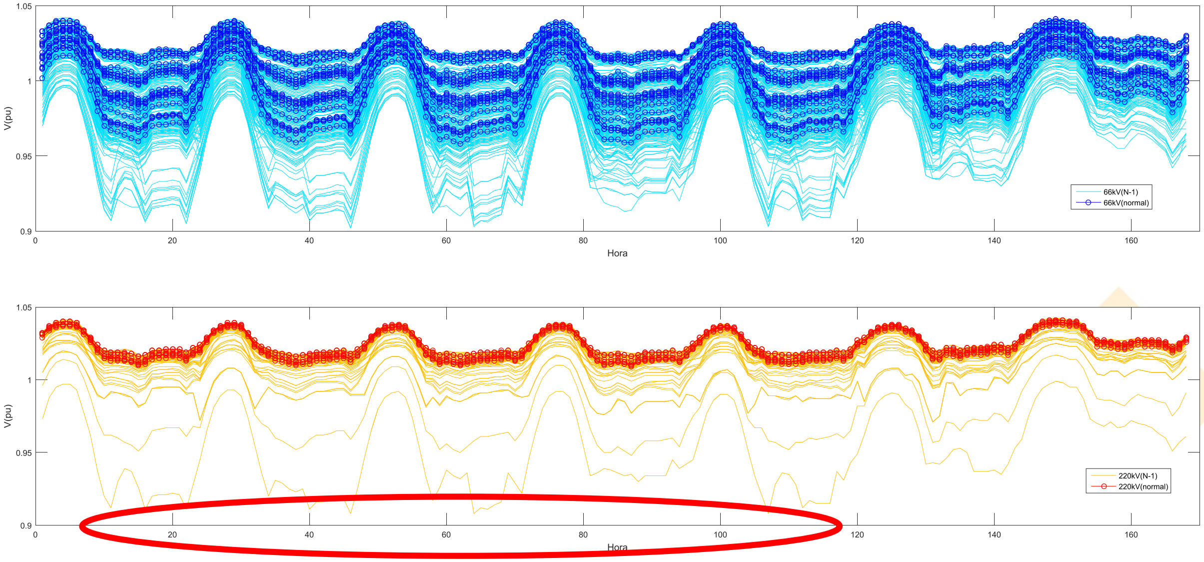
- The impact of RES penetration on the technical operation of Tenerife has been analyzed.

- In particular the following studies have been carried out:
  - Steady state operation under normal and N-1 operation
  - Frequency stability
  - Transient stability

- The current situation (2016) has been used as a reference.

Technical operation (v)

- The impact of RES penetration on voltage profile of transmission grid has been analyzed.

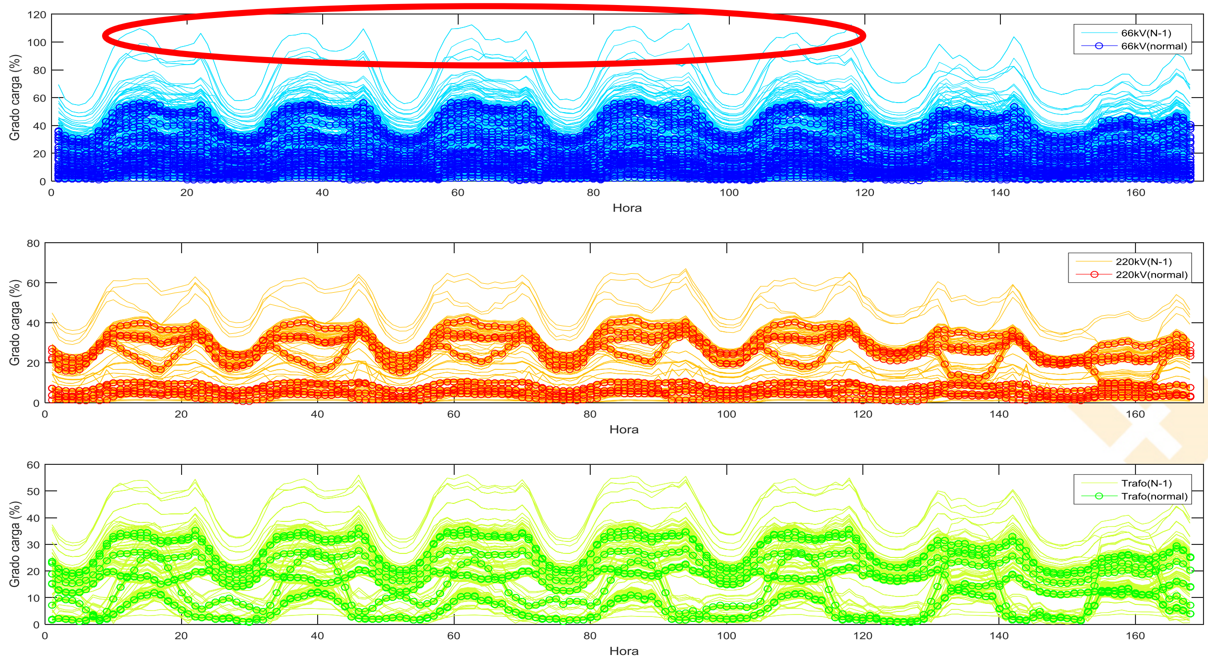


Voltage below 0.93 pu limit

Technical operation (vi)

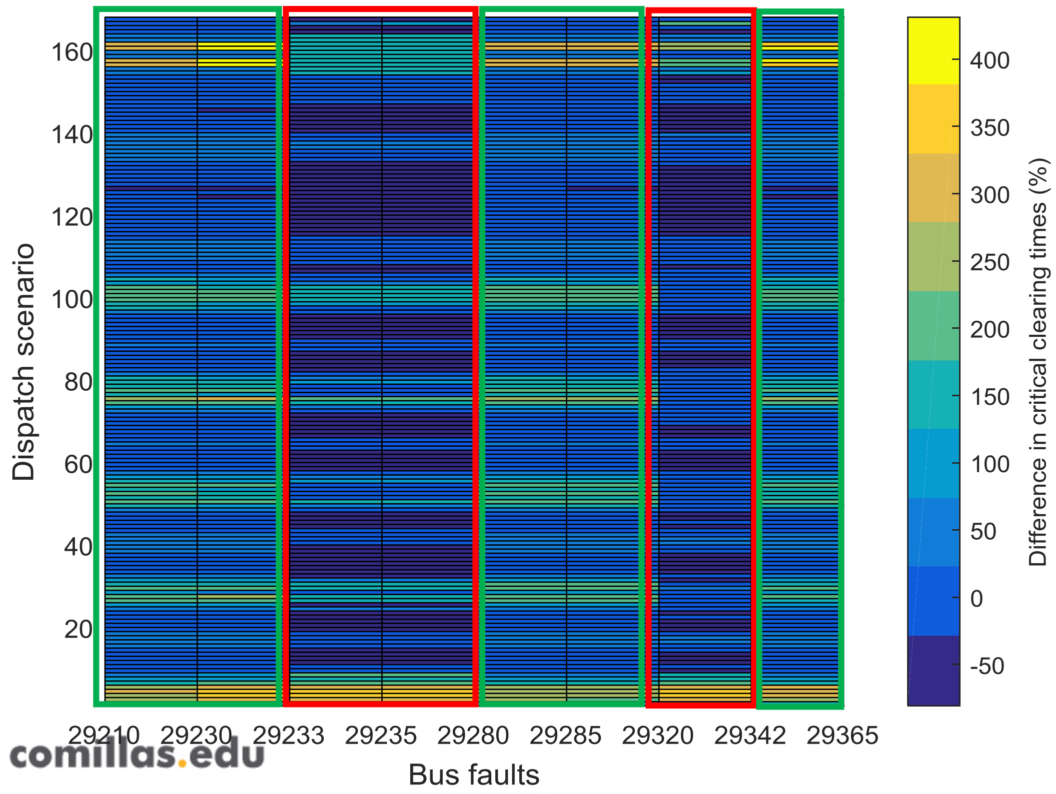
- The impact of RES penetration on branch flows within the transmission grid has been analyzed.

Close to but below the limit of 115%



Technical operation (vii)

- The impact on transient stability has been quantified by means of variations of the critical clearing time for faults at 220kV buses.



CCTs of faults with previously large CCTs reduce.
CCTs of faults with previously smaller CCTs increase.

CCTs remain above 230 ms.

Technical operation (viii)

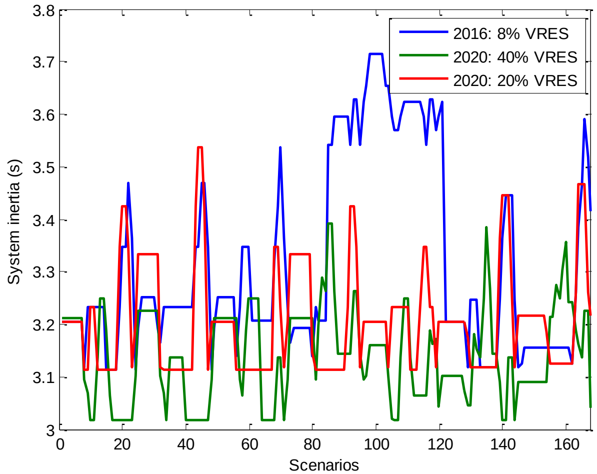
- Finally, the impact of RES penetration on frequency stability has been studied.

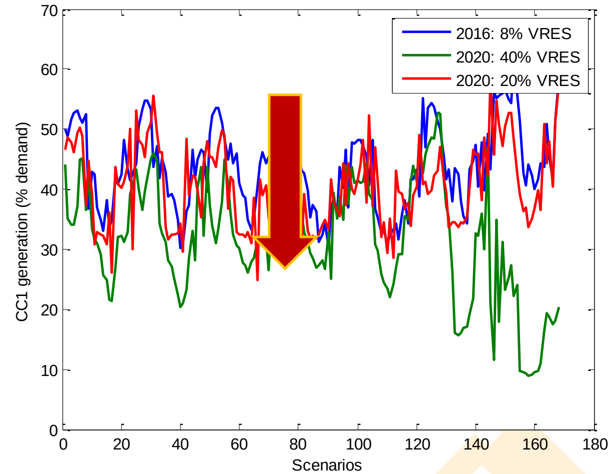
- The impact of tripping the largest unit on system response is analyzed.
  - Frequency deviations
  - Underfrequency load shedding

Technical operation (ix)

- Global results

Participation of CCPP in demand shrinks with increasing VRES

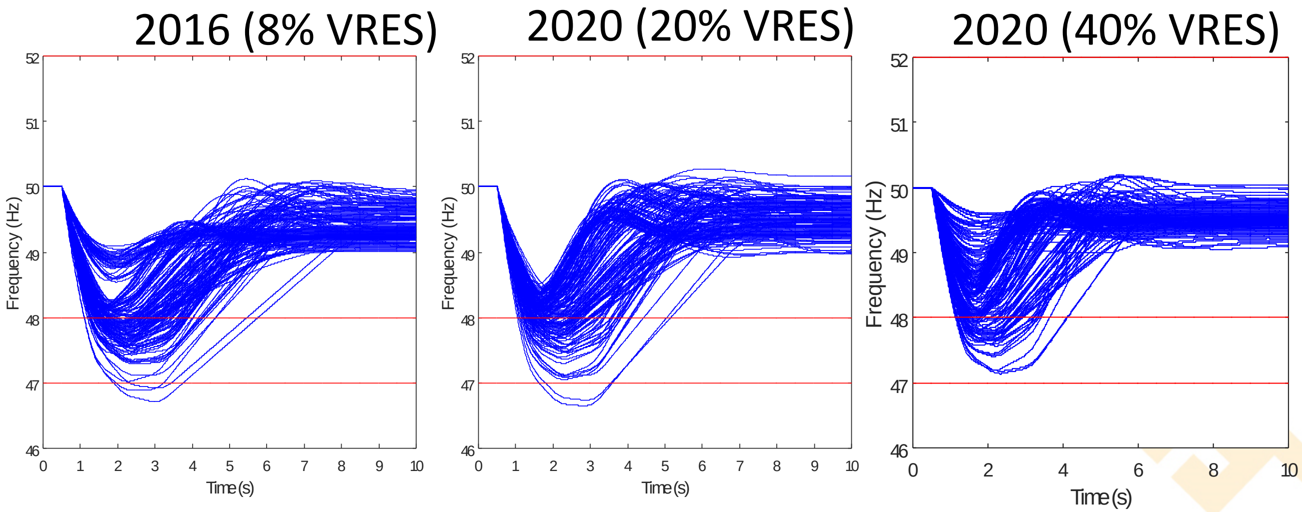




	2016 (8% VRES)	2020 (20% VRES)	2020 (40% VRES)
H_{equ} (s)	3.3	3.2	3.1
K_{equ} (pu)	13.1	12.9	12.2
Pshed (% demand)	27%	28%	20%
Σf_{min}	329.37	337.29	260.97

Technical operation (x)

- Responses in terms of frequency to all possible outages



Technical operation (xi)

- Finally, energy storage systems are able to improve system response thanks to their ability to emulate inertia and provide droop control.

- Different storage technologies are currently in place or investigated:
  - Ultracapacitor
  - Li-Ion battery systems
  - Pump storage

Technical operation (xii)

- Sizing of the power capacity of the energy storage system can be done in function of a desired máximum frequency deviation.

- Frequency deviation can be estimated by simple, but quite effective equation:

$$\Delta\omega_{min} = -\frac{p_{lost}}{\sqrt{2H\sum_{i=1}^{n}\frac{k_i}{T_i}}}$$

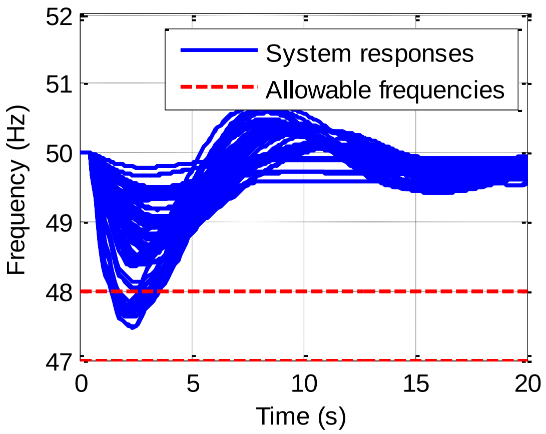
- Then, power capacity can be estimated by:

$$p_{BESS} = p_{lost,max} - p_{lost,c}$$

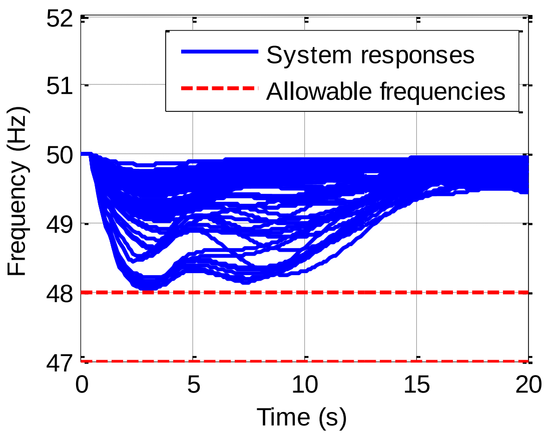
Technical operation (xii)

- Impact on UFLS for many different disturbances with and without ultracapacitor of the island system of La Palma

Without UC



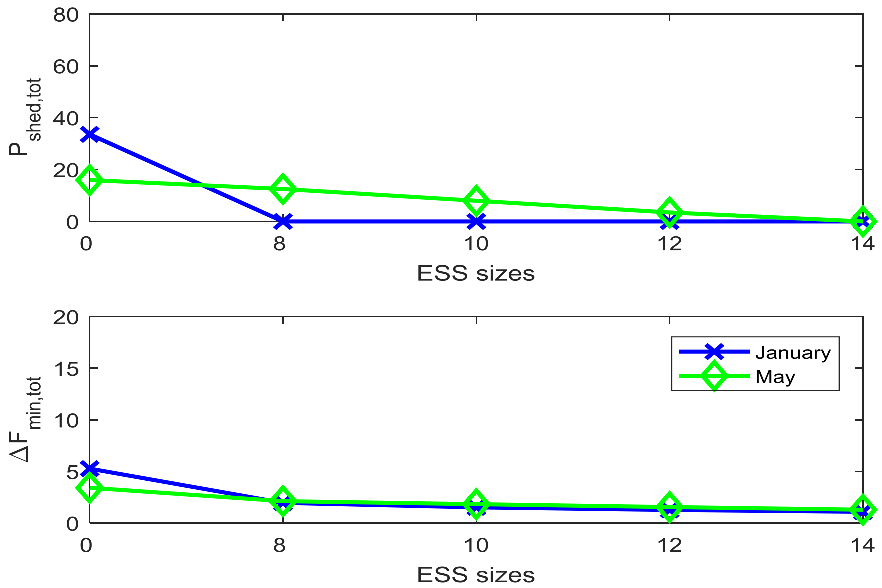
With UC



	Totally shed load (MW)
Without UC	274.31
With UC	35.72

Technical operation (xii)

- Impact on UFLS of a battery storage system for different disturbances under two different scenarios of the island system of Menorca



The previous sizing method led to a power capacity between 7.2 and 12.2 MW, depending on the scenario.

Conclusions (i)

- Island power system present some particular challenges for operation costs and stability.
- Spinning reserves play a dominant role in island power systems.
- Renewables can reduce operation costs, but only to a certain penetration level. Beyond this, additional actions are needed.
- Energy storage can effectively and viably provide spinning reserve.

Conclusions (ii)

- Renewables might affect inertia and reserve deployment speed, but the impact on stability cannot be studied without taking into account their impact on the generation schedule.

- Up to some penetration levels, it seems that increasing RES penetration does not necessariliy lead to a less stable system.

- In either case, advanced devices such as energy storage systems are able to improve frequency stability effectively.