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Frequency constrained unit commitment in isolated power systems with high penetration of RES

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- Frequency constrained unit commitment (FCUC)
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Introduction

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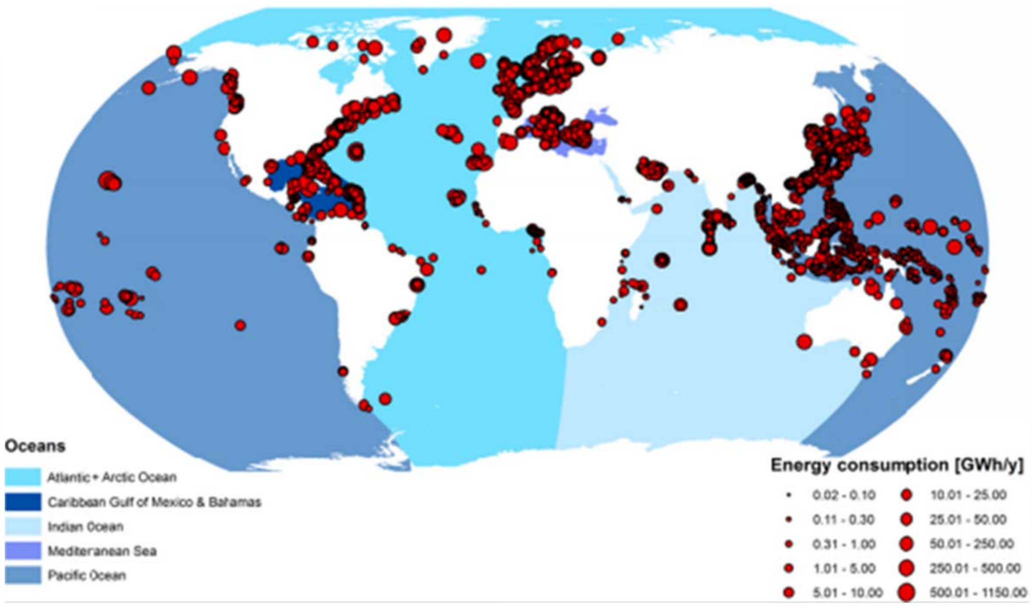
Introduction

- There are **thousands of isolated power systems** worldwide and their number is increasing (e.g., off-grid systems).



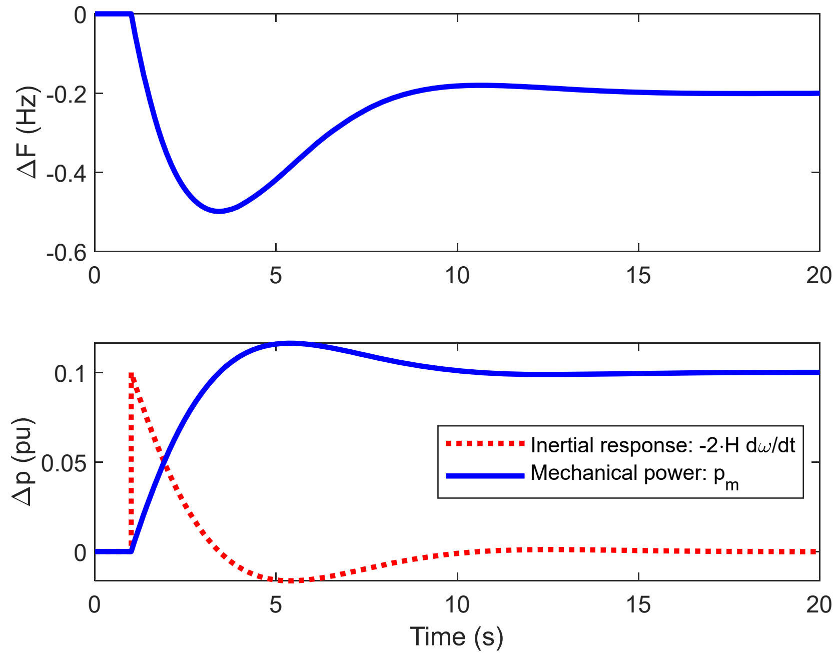
Source: P. Blechinger, R. Seguin, C. Cader, P. Bertheau, Ch. Breyer, Assessment of the Global Potential for Renewable Energy Storage Systems on Small Islands, Energy Procedia, Volume 46, 2014.

Introduction

- Isolated power systems are especially **sensitive to active power unbalances** due to their:
  - **isolated nature** (lack of supporting interconnections)
  - the **small number of committed generation units**, with relatively large individual generation levels and reserve requirements.
  - spatially concentrated variable RES
- They are thus per se low-inertia power systems.

Introduction

- Large active power unbalances (e.g., generation outages) lead to **frequency deviations**, confined by the **primary frequency control (PFC)** activating the spinning reserve.



$$\Delta p_e = \Delta p_m - 2H \cdot \frac{d\omega}{dt}$$

Introduction

- The **objective of operation planning** is to supply the electrical demand at minimum variable cost such that, among others, **security of supply** is guaranteed.

- To guarantee security of supply, a certain **amount of spinning reserve** is hold back for the PFC and secondary frequency control.

- The amount of spinning reserve basically **follows a static N-1 criterion,** although frequency stability is of course a dynamic problem.

Introduction

- Currently, the spinning reserve is mainly **provided by synchronous generation** (e.g., thermal and hydro generation).

- The **growing penetration of RES generation** affects reserve provision and frequency stability by substituting synchronous generation,

  - **reducing** further the available **resources for spinning reserve**.

  - **reducing** further the available **inertia and PFC capacity**.

Introduction

- Questions arise such as:

  - What if **RES generation started providing spinning reserve**? Is it viable? Is it feasible?

  - What if the determination of the amount **of spinning reserves followed dynamic criteria**? What are these criteria? How can be frequency stability included into the planning problem? What formulations should be used to be efficient? Transparent?

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RES generation providing spinning reserve

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RES generation providing spinning reserve

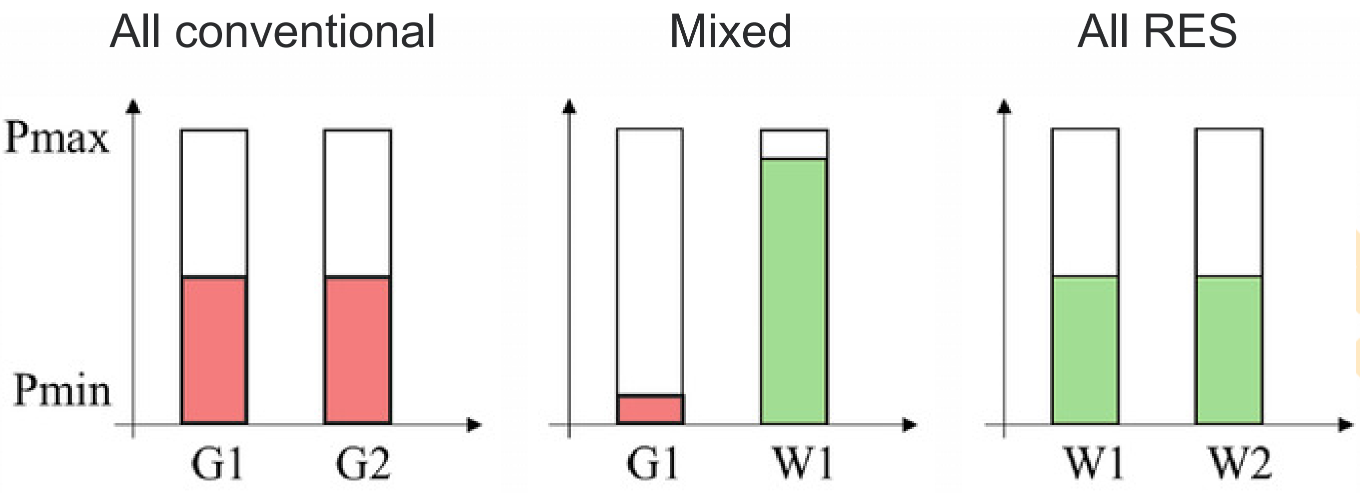
- Currently, RES generation does not provide down- or upwards spinning reserve.

- **Grid codes** require the ability to provide PFC, but this is **not tantamount to a mandatory and planned** provision of PFC.

- Providing spinning reserve could be **an option to further foster RES penetration** instead of simply spillingt it at high penetration levels.

RES generation providing spinning reserve

- The **idea is to avoid using conventional generation** that is just providing spinning reserve but making use of RES generation.



Source: Rajabdorri, M., et al.: Viability of providing spinning reserves by RES in Spanish Island power systems. IET Renew. Power Gener. 2021; 15: 2878– 2890.

RES generation providing spinning reserve

- The **unit commitment formulation**, minimizing variable operation costs, needs to be modified by considering a possible **deloaded operation**:

$$\min_{x,P} suc\left(x_{g,t}\right) + gc\left(P_{g,t}\right)$$

$$\sum_{g \in G} P_{g,t} = D_t$$

$$\underline{P}_{g,t} = \overline{P}_{g,t} = W_{g,t} \cdot x_{g,t} \quad \forall g \in W \subset G$$

$$\underline{P}_{g,t} \cdot x_{g,t} \le P_{g,t} \le \overline{P}_{g,t} \cdot x_{g,t}$$

$$\vdots$$

$$\sum_{g \in G \setminus W, g \neq gg} \left(\overline{P}_{g,t} - P_{g,t}\right) \ge L_{gg} \cdot P_{gg,t}$$

→

$$\min_{x,P} suc\left(x_{g,t}\right) + gc\left(P_{g,t}\right)$$

$$\sum_{g \in G} P_{g,t} = D_t$$

$$\overline{P}_{g,t} = W_{g,t} \quad \forall g \in W \subset G$$

$$\underline{P}_{g,t} \cdot x_{g,t} \le P_{g,t} \le \overline{P}_{g,t} \cdot x_{g,t}$$

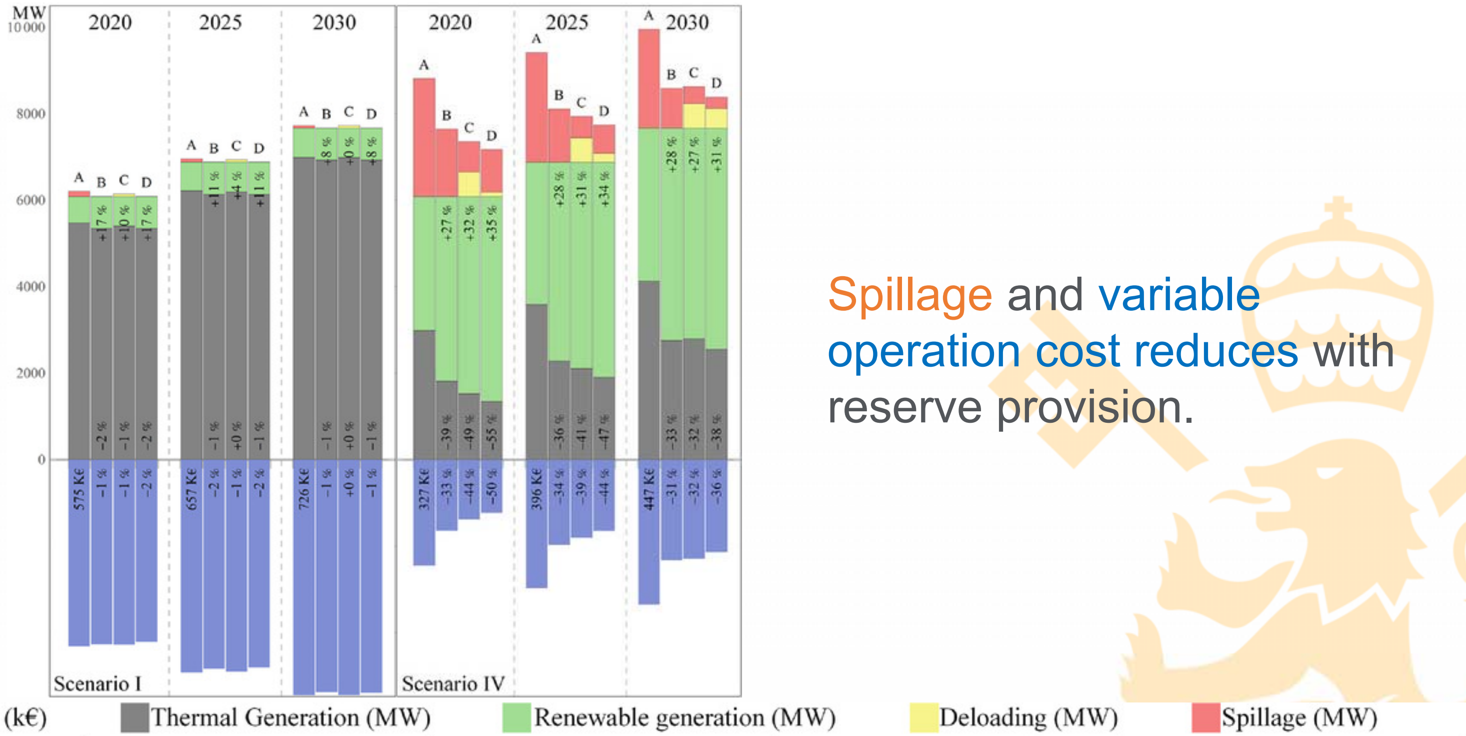
$$\vdots$$

$$\sum_{g \in G, g \neq gg} \left(\overline{P}_{g,t} - P_{g,t}\right) = L_{gg} \cdot P_{gg,t}$$

RES generation providing spinning reserve

- Impact of providing down- and upwards reserve on variable operation costs, and RES generation spillage:

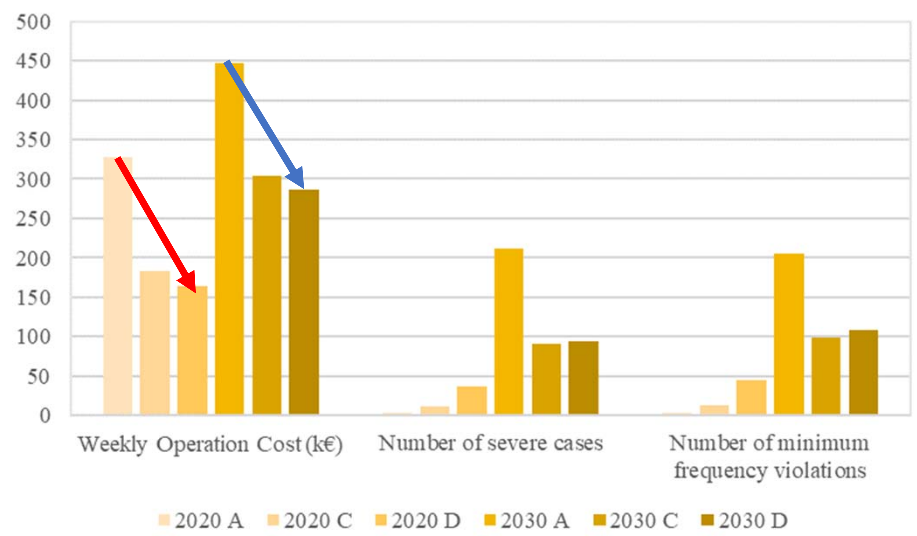
A: no reserve
B: downward reserve only
C: down and fix upwards reserve
D: down and variable upwards reserve

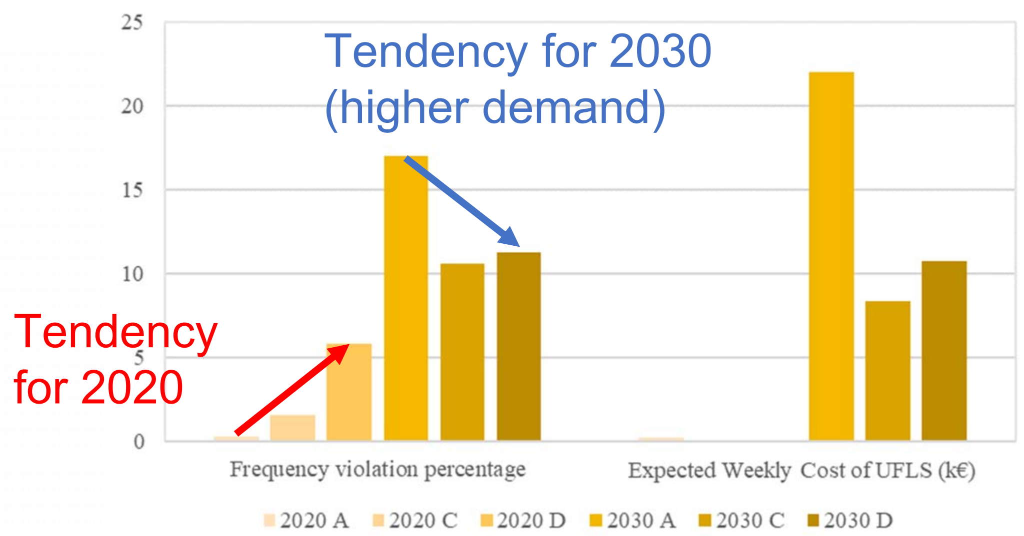


Spillage and variable operation cost reduces with reserve provision.

RES generation providing spinning reserve

- Impact of high-RES generation scenario providing spinning reserve on frequency stability:





D. Fuentes Pascual, M. Rajabdorri, L. Sigrist, E. Lobato, Technical impacts of providing frequency regulation by wind turbines in Spanish island power systems, November 2022.

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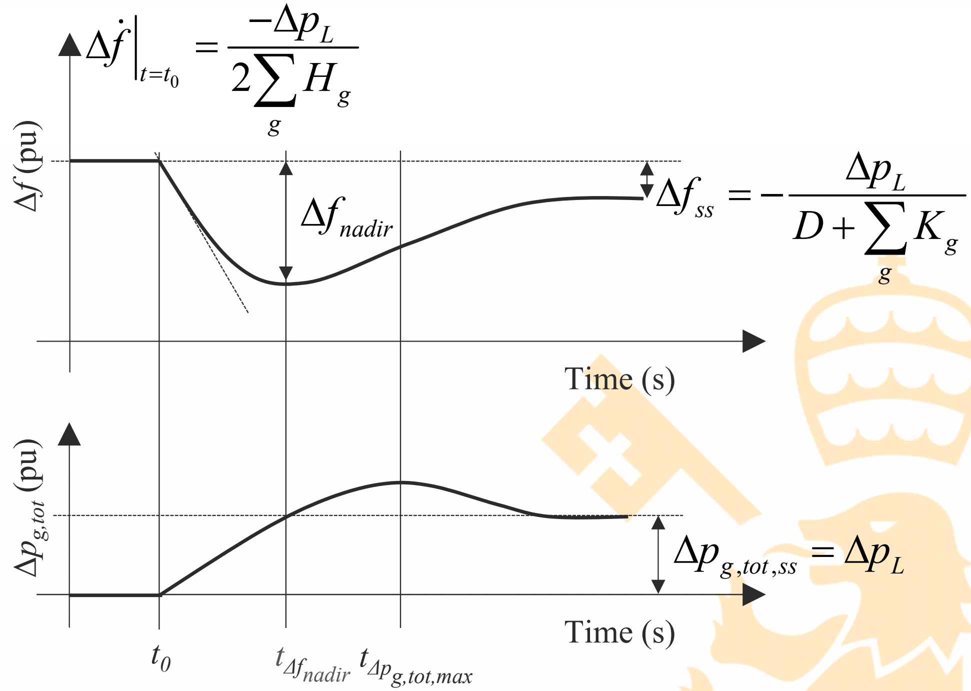
Frequency constrained unit commitment (FCUC)

FCUC

- Currently, the reserve criterion is a static one, although related frequency stability is a dynamic problem.
- **FCUC** formulations explicitly consider **frequency stability constraints**.
- Different approaches exist, but they coincide **in estimating certain indexes** related to the underlying frequency dynamics.

FCUC

- Commonly, three indexes are considered:
  - Initial rate-of-change of frequency (RoCoF)
  - Steady-state frequency, f_{ss}
  - Frequency nadir, f_{nadir}



FCUC

- FCUC approaches can be broadly grouped into analytical or data-driven approaches:
  - **Analytical approaches** include **explicit expressions** for RoCoF, nadir and steady-state frequency
  - **Data-driven approaches** estimate them through **functions deduced from a large training set**.

Analytical FCUC

- In a analytical approach, the standard UC formulations **is extended** by adding the following terms (here, for generation outages):

$$\Delta\dot{f}\Big|_{t=t_0} \geq \Delta\dot{F}_{ini} \qquad 2\cdot\left(\sum_{g,g\neq gg} H_g \cdot x_{g,t}\right)\cdot\Delta\dot{F}_{ini} \leq -p_{gg,t}$$

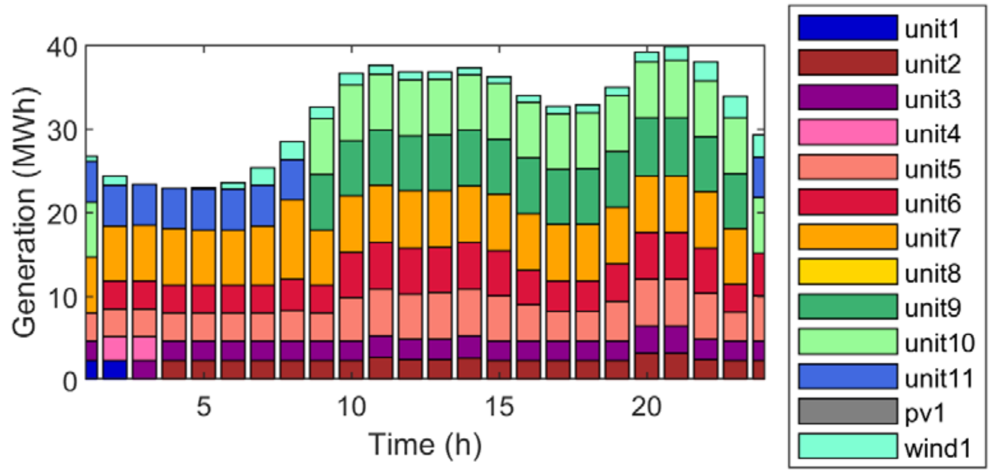
$$\Delta f\Big|_{t=\infty} \geq \Delta F_{ss} \qquad \left(\sum_{g,g\neq gg} K_g \cdot x_{g,t}\right)\cdot\Delta F_{ss} \leq -p_{gg,t}$$

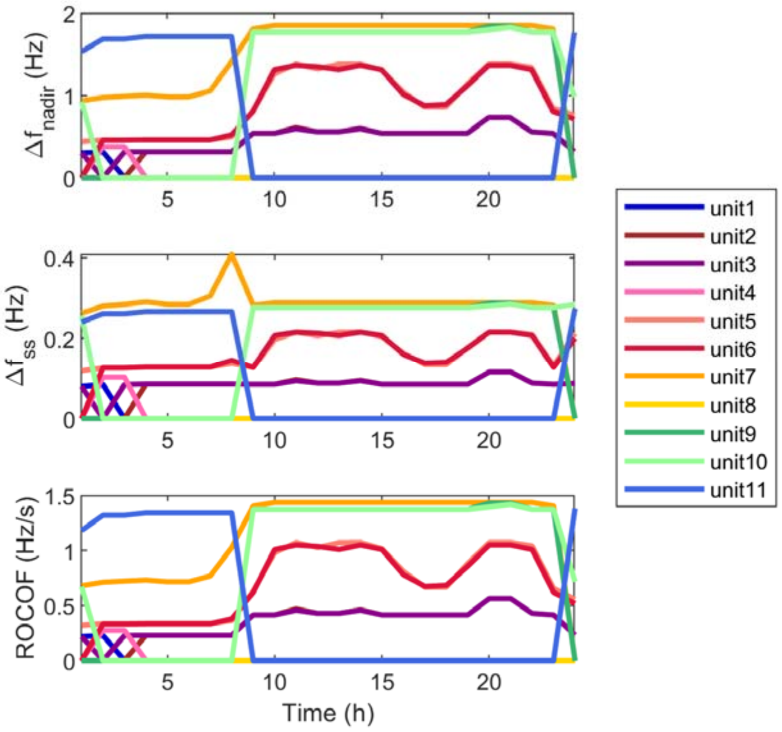
$$\Delta f(t) \geq \Delta F_{nadir} \qquad \left(\Delta F_{nadir}\right)^2\left[2\cdot\left(\sum_{g,g\neq gg}\frac{K_g}{T_g}\cdot x_{g,t}\right)\cdot\left(\sum_{g,g\neq gg} H_g \cdot x_{g,t}\right)\right] \leq {p_{gg,t}}^2$$

A. Rouco, M. Rajabdorri, E. Lobato, L. Sigrist, Analytical frequency-constrained UC for island power systems, 15th IEEE PowerTech Conference - PowerTech 2023, Belgrade (Serbia). 25-29 June 2023.

Analytical FCUC

- Application of the FCUC to a Spanish isolated power system

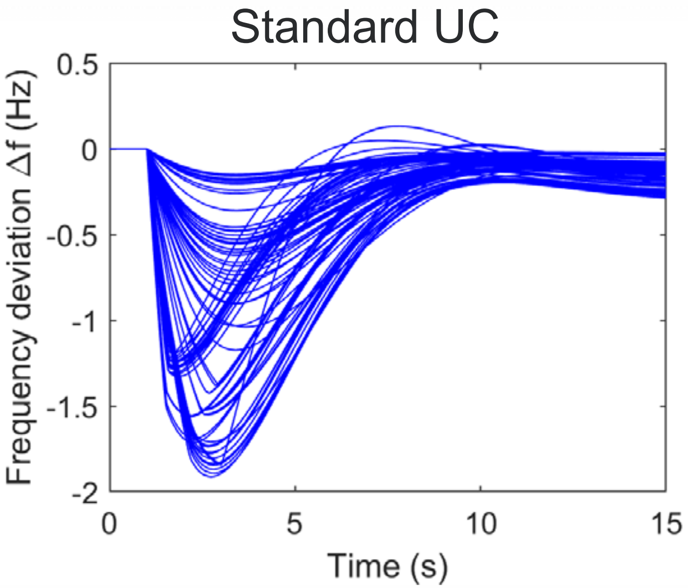


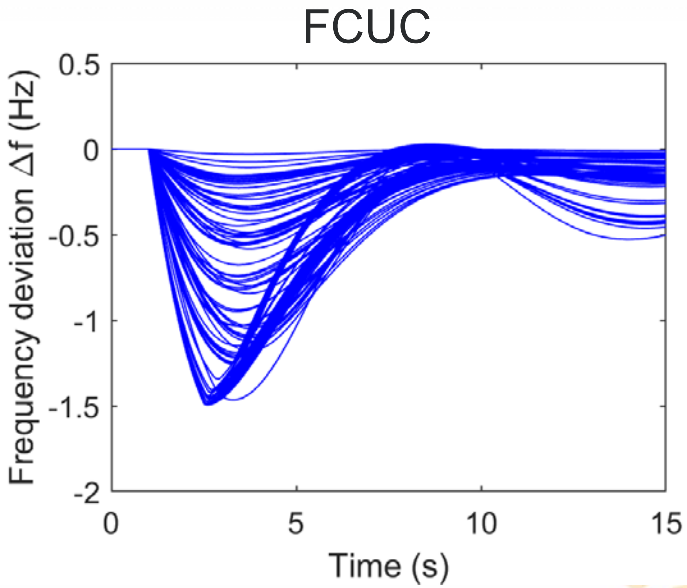


Analytical FCUC

- Comparison with standard UC

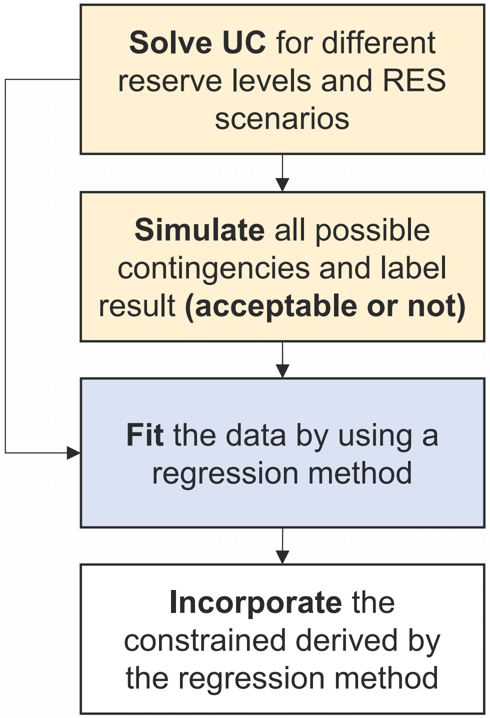
	Cost (k€)	Spillage (MWh)	Average Δf_{nadir} (Hz)	Average shed load (MW)
FCUC	156	14.1	-0.88	0.8
standard UC	141	2.8	-0.93	1.2





Data-driven FCUC

- In a data-driven approach, a three-step approach can be used:



Creation of the **training set** by considering all large amount of scenarios and contingencies.

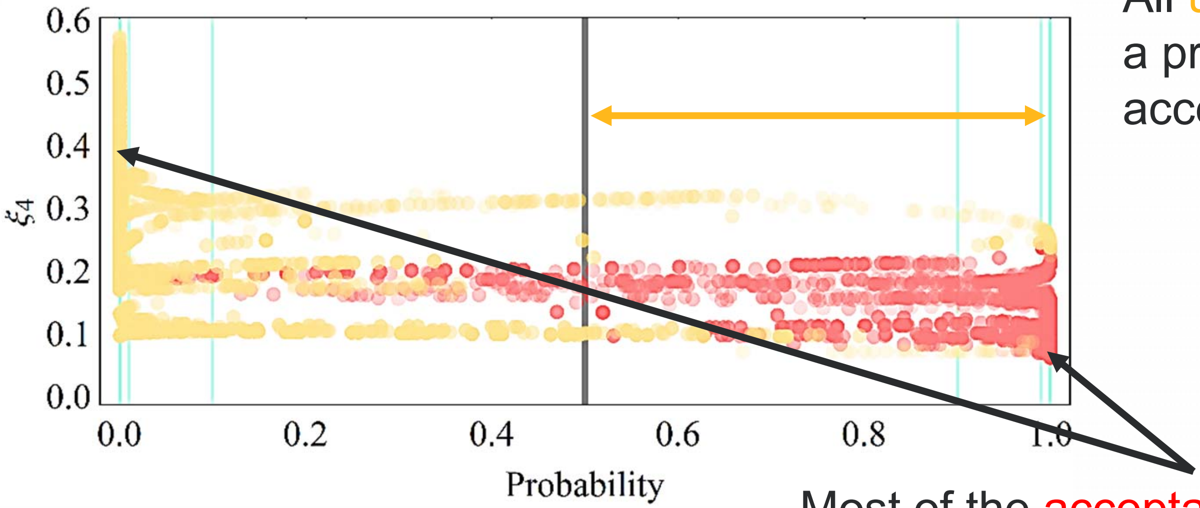
Since the results are in **dichotomous form, Logistic Regression (LR)** can be used.

Explanatory variables, ξ, available within UC are: the inertia, the relative power loss, the reserve, etc.

$$c_0 + c_1\xi_{1,gg} + c_2\xi_{2,gg} + \cdots + c_m\xi_{m,gg} \geq \psi$$

Data-driven FCUC

- Logistic regression (LR) **predicts the probability of a result of being acceptable or not** in terms of the explanatory variables, ξ_i.



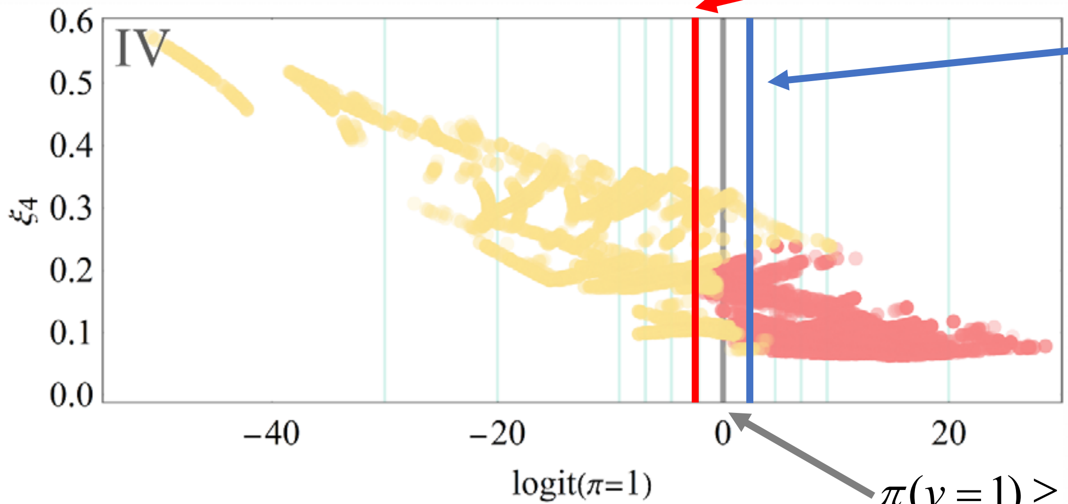
All unacceptable results herein have a probability being classified as acceptable, π(v=1), above 0.5

Most of the acceptable/unacceptable results are classified as such.

Data-driven FCUC

- If we look at the logarithm of the corresponding odds **of being acceptable or not** in terms of the explanatory variables, ξ_i:

$$\pi(v=1) \geq 0.1 \leftrightarrow \psi = \text{logit}\left(\pi(v=1)\right) \geq -2.12$$



$$\pi(v=1) \geq 0.9 \leftrightarrow \psi = \text{logit}\left(\pi(v=1)\right) \geq 2.12$$

Very conservative, but many acceptable considered as unacceptable.

$$\pi(v=1) \geq 0.5 \leftrightarrow \psi = \text{logit}\left(\pi(v=1)\right) \geq 0$$

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M. Rajabdorri, E. Lobato, L. Sigrist. Robust frequency constrained uc using data driven logistic regression for island power systems. IET Generation Transmission & Distribution. Vol. 16, nº. 24, pp. 5069 - 5083, December 2022.

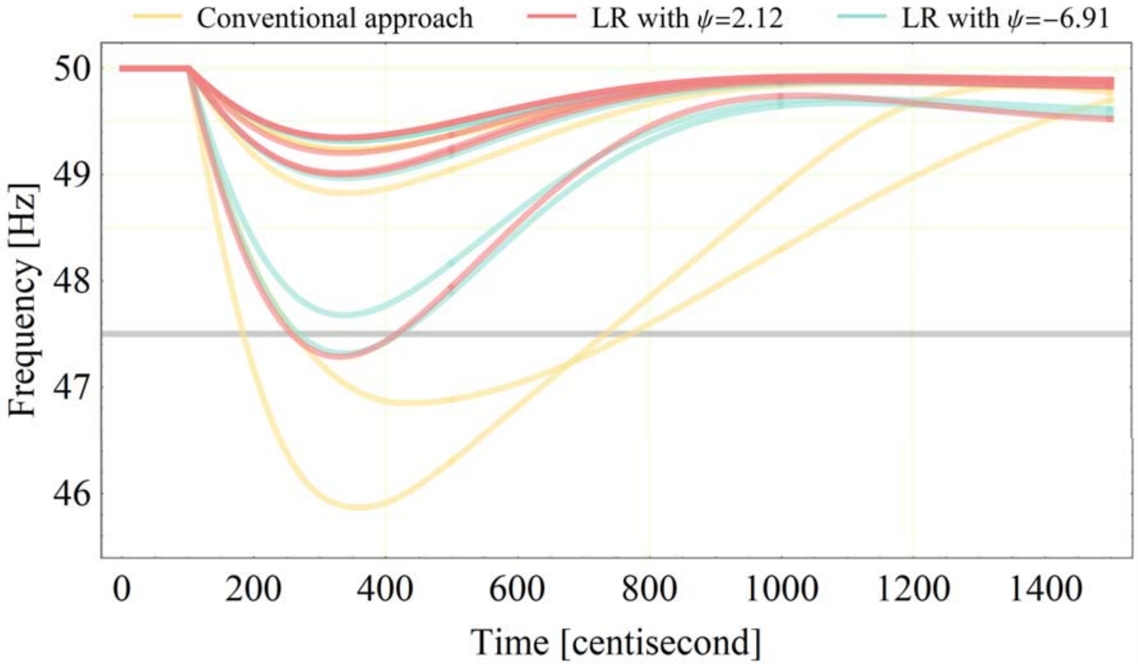
Data-driven FCUC

- Application of the data-driven FCUC to a Spanish isolated power system and comparison with the standard UC

	HQFR (%)	LQFR (%)	average F_{nadir} (Hz)	Average shed load (MW)	Operation cost (k€)
standard UC	68	32	48.29	2.3	141
FCUC ψ = 0	81	19	48.77	1.2	144
FCUC ψ = -2.12	79	21	48.68	1.5	143
FCUC ψ = -6.91	77	23	48.52	2.1	140

Data-driven FCUC

- Impact on frequency dynamics



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Concluding remarks

Concluding remarks

- Currently, the amount of spinning reserve follows a static N-1 criterion although the underlying problem is dynamic.
- RES generation does not provide upwards spinning reserve.
- It has been shown that providing reserve by RES generation is beneficial from the technical and economic point of view (although the economic impact is more straightforward).
- It has been shown the a dynamic criterion can be set up by using either analytical or data-driven approaches. The more conservative the approach, the costlier the operation.