Frequency fluctuations in the Balearic grid before and after coal closure

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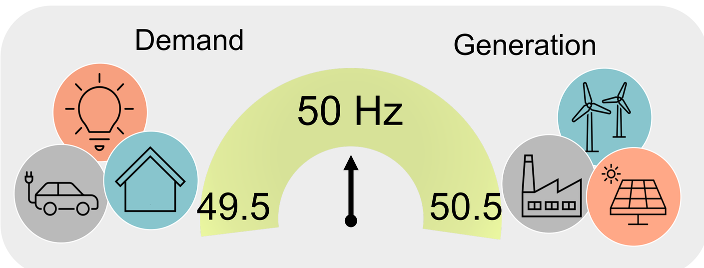
Abstract

In 2019, the most polluting power station in the Balearic Islands, was partially closed down, marking the end of coal as the main energy source in the territory. The goal was to decrease emissions, a first step step towards decarbonization. In [1], we analyze the effect of the close down in the frequency fluctuations, a good proxy for generation-demand balance and grid stability.



Data analysis

Before / After

We analyze 1-second frequency data from [2] and 10-minute power data from [3].

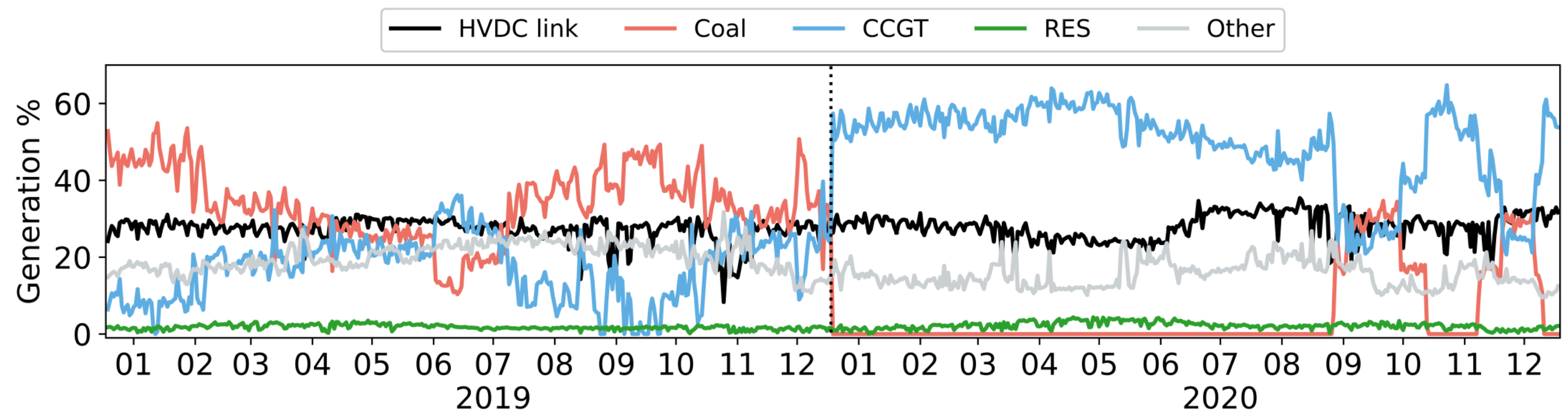


Figure 1: Daily generation percentage in the Balearic Islands throughout the years 2019 and 2020. CCGT stands for Combined Cycle Gas Turbine. HVDC stands for High Voltage Direct Current.

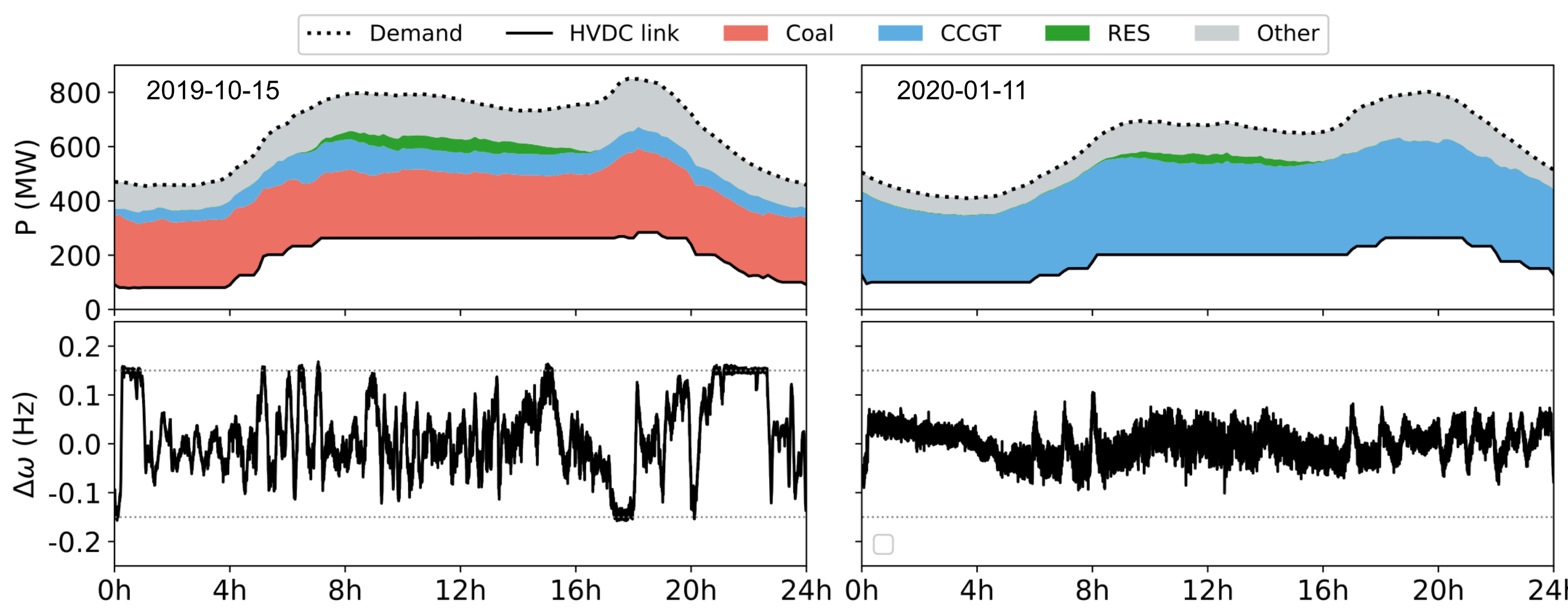


Figure 2: Time series of the demand, generation and frequency deviations from a typical day when the main generation source was: (left) coal, (right) natural gas. Dotted lines in frequency plots indicate the statutory limits ±0.15 Hz.

Before

- **Large frequency deviations despite large inertia** from coal plants.
- **Deviations reach the statutory limits** on several occasions.

After

- **Nowadays, natural gas** is the **main generation source**.
- **Smaller** frequency **deviations**.

- **Fast fluctuations** are **due to stochastic demand changes**. They are smaller at night (valley hours) and larger during the peak hours.
- **Large deterministic frequency variations due to step-like changes in HVDC link** power.

- Large frequency fluctuations clamp at ±0.15 Hz. This behavior is not observed in other power grids. [4].
- This comes from **threshold-like control provided by HVDC link**. While the link usually operates at a constant power, when the frequency reaches ±0.15 Hz, the control is activated and the power changes continuously in time.
- This control was **frequently triggered when coal was in operation**, while it is **occasionally triggered nowadays.**

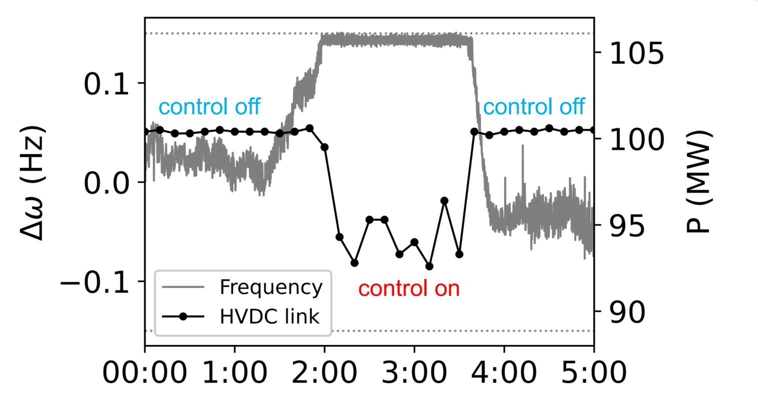


Figure 3: Grid frequency deviations and HVDC link power time series in 2020-01-30, a day without coal generation.

Model

- All nodes (consumers P_i^m=0):

$$\dot{\theta}_i = \omega_i$$

$$\dot{\omega}_i = \frac{\omega_R^2}{2H_i P_i^G(\omega_i+\omega_R)}\left[P_i^m - \left(1+D_i\frac{\omega_i}{\omega_R}\right)P_i^l - \sum_j K_{ij}\sin(\theta_i-\theta_j)\right]$$

generation load transmitted power

- Conventional generators: two additional eq. for primary and secondary control.

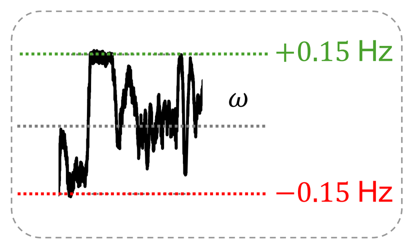
$$\dot{P}_i^m = \frac{1}{\tau_i}\left(P_i^s - P_i^m - \frac{P_i^c}{R_i}\frac{\omega_i}{\omega_R}\right) \qquad \dot{P}_i^s = -\kappa_i\frac{\omega_i}{\omega_R} - \lambda_i\left(P_i^s - P_i^{ref}\right)$$

dispatch

- Renewable generation: modelled as a negative load.
- HVDC link with threshold-like frequency control:

$$\dot{P}_{link} = \frac{P_{link}^{ref}-P_{link}}{\tau_{link}} - H(|\omega|-0.15)\kappa_{link}(\omega \mp 0.15)$$

Heaviside step function



Simulation results

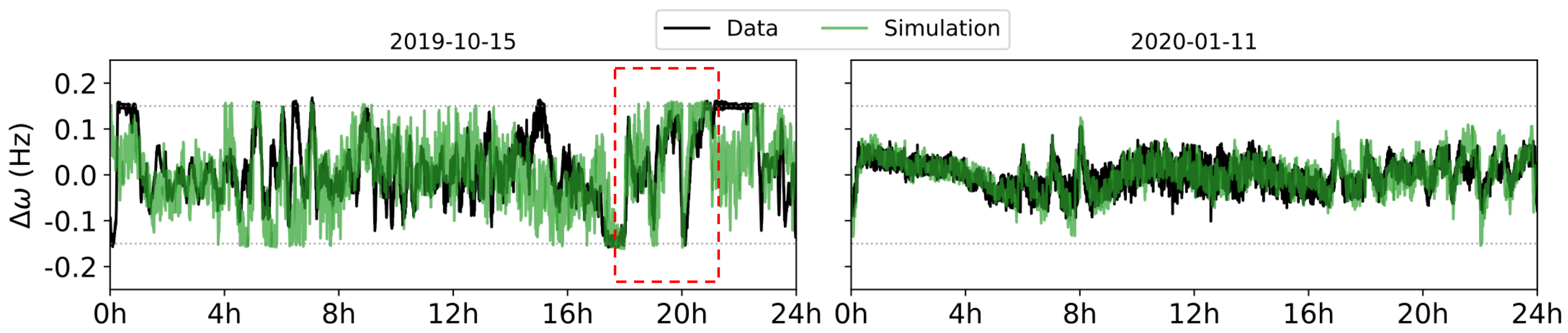
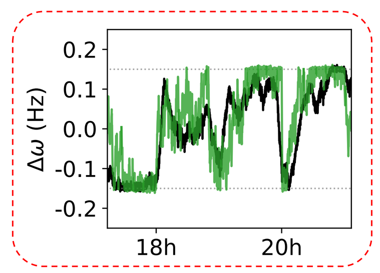


Figure 4: Daily time series of frequency deviations. Comparison between simulations and data for a typical day when the main generation source was: (left) coal, (right) natural gas. Same days as Figure 2.



- The model reproduces frequency fluctuations to good extent.
- It also **captures fast stochastic changes**, modelled as a correlated noise, **and deterministic peaks** from the HVDC link.
- It **reproduces the threshold-like frequency control effect**.

- Rank size distribution measures the probability to have a fluctuation of size larger than |Δω|.
- On days when **threshold-like control is activated**, we observe a **sharp decay** in the distribution. This feature is also adequately **captured by the model**.
- Other days frequency deviations decay smoothly. Numerical results show larger excursions probably due to **not** having **enough secondary control** capacity **in the model**.

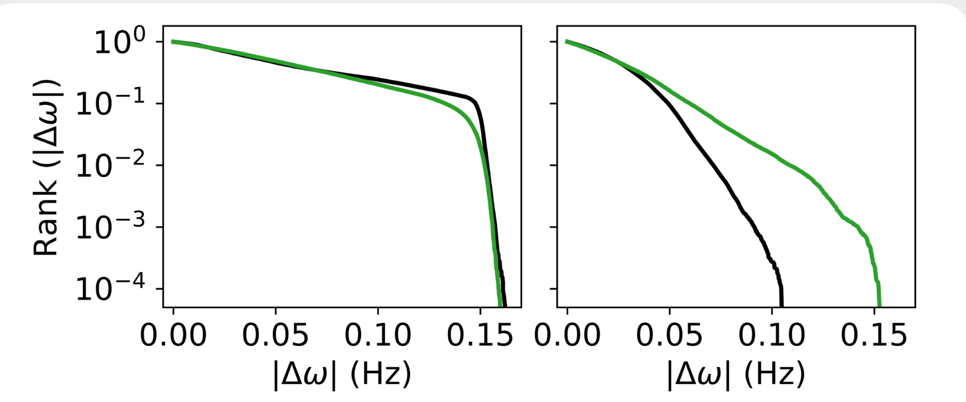


Figure 5: Rank size distribution of frequency deviations from the same days as Figure 4. Comparison between simulations and data.

Conclusions

- Upon the introduction of variable renewable sources, the data analysis shows that **inertia is not as relevant for grid stability as having a fast flexible control**.
- We propose a **model** that **reproduces frequency deviations from input power data**.
- Discrepancies between simulations and data are probably mainly due to :
  - **Variable control capacity** throughout the day, but we consider it constant.
  - 10-minute input data is **missing** power **changes happening at faster timescales**.

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Short video explanation

Check out our paper [1]

References

[1] M. Martínez-Barbeito, D. Gomila, P. Colet. (2021). *ENERGY 2021*, 13-18.

[2] Power grid frequency database *https://power-grid-frequency.org*

[3] Red Eléctrica de España *https://demanda.ree.es/visiona/home*

[4] L. Rydin Gorjão et al. (2020). *Nature communications*, 11(1), 1-11.