Frequency fluctuations and stability of power grids with a large renewable penetration ratio

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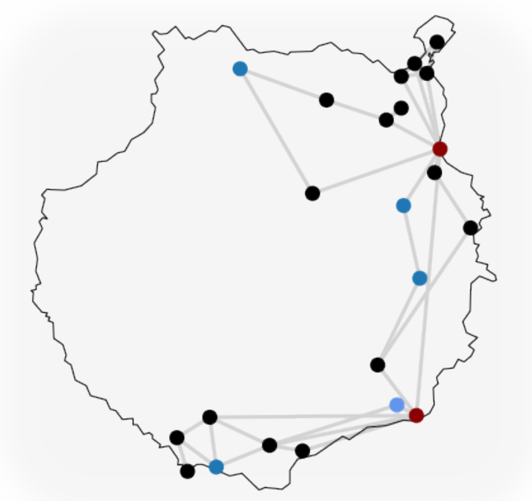
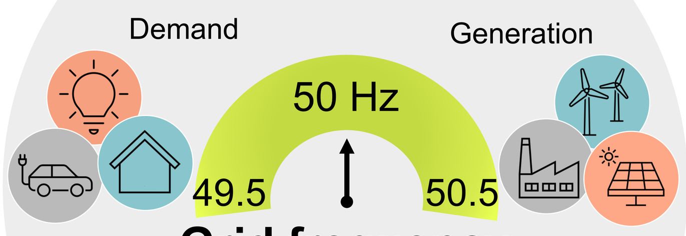
Abstract



High voltage grid of Gran Canaria

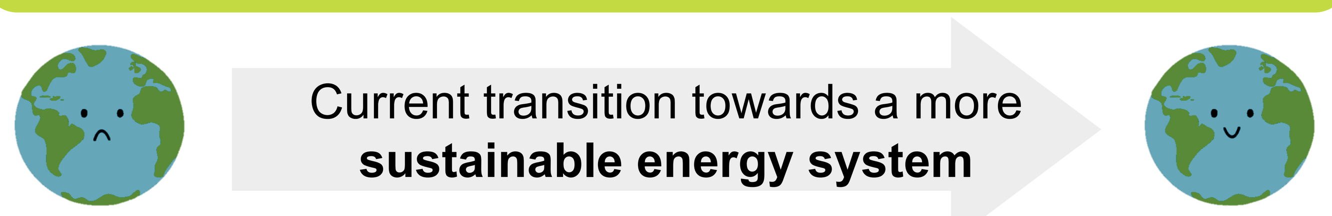
We propose a dynamical model to study power grid stability in scenarios of high renewable penetration. We consider the high voltage grid as a network of substations and power plants interacting via transmission lines. In particular, we present Gran Canaria as a case study.



Grid frequency

is a good indicator of the **generation-demand balance**.

Motivation



Integrating a **high share of renewable generation** in the power grid is a challenging task [1].

- **Intermittent and unpredictable nature** of renewable energy sources adds fluctuations on the generation side
- **Reduced conventional control capacity**
- **Loss of rotational inertia** increases frequency fluctuations

Model

- **Conventional generation** nodes [2, 3]:

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

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

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

Secondary control $$\dot{P}_i^s = -\kappa_i \frac{\omega_i}{\omega_R} - \underbrace{\lambda_i \left(P_i^s - P_i^{ref}\right)}_{\text{dispatch}}$$

- **Consumer nodes:**

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

- **Renewable generation**: modelled as a negative load

Data assimilation

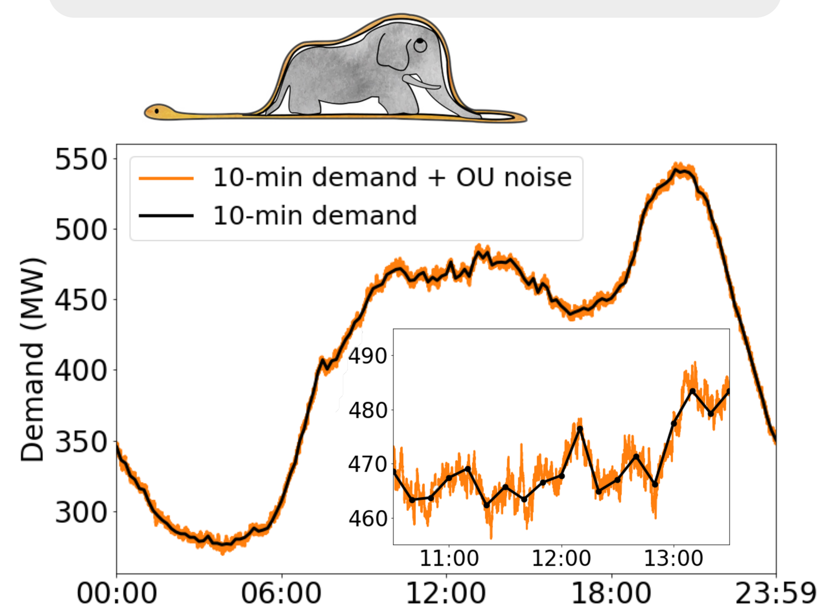
To combine the numerical model with observations we use 10-minute total demand and generation data from Red Eléctrica de España (https://demanda.ree.es/visiona/home)

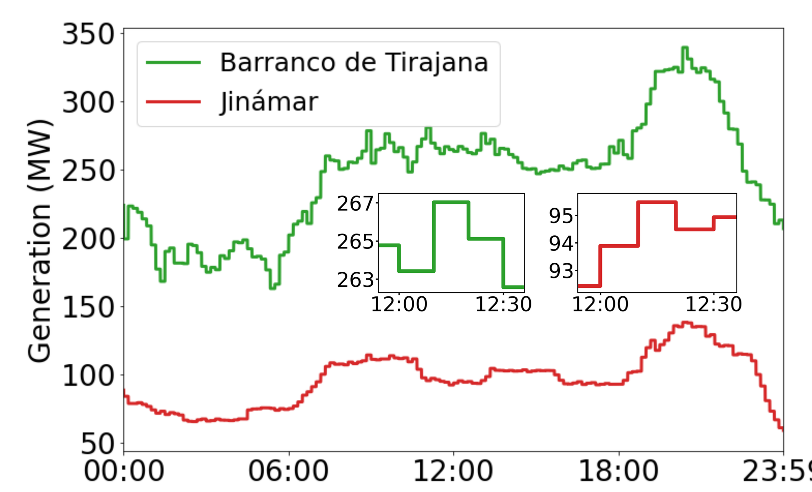
Demand distributed according to population of each node **+ fast fluctuations** (Ornstein-Uhlenbeck noise)

$$P_i^l = P_i^{REE} + \epsilon \xi_i^{OU}$$

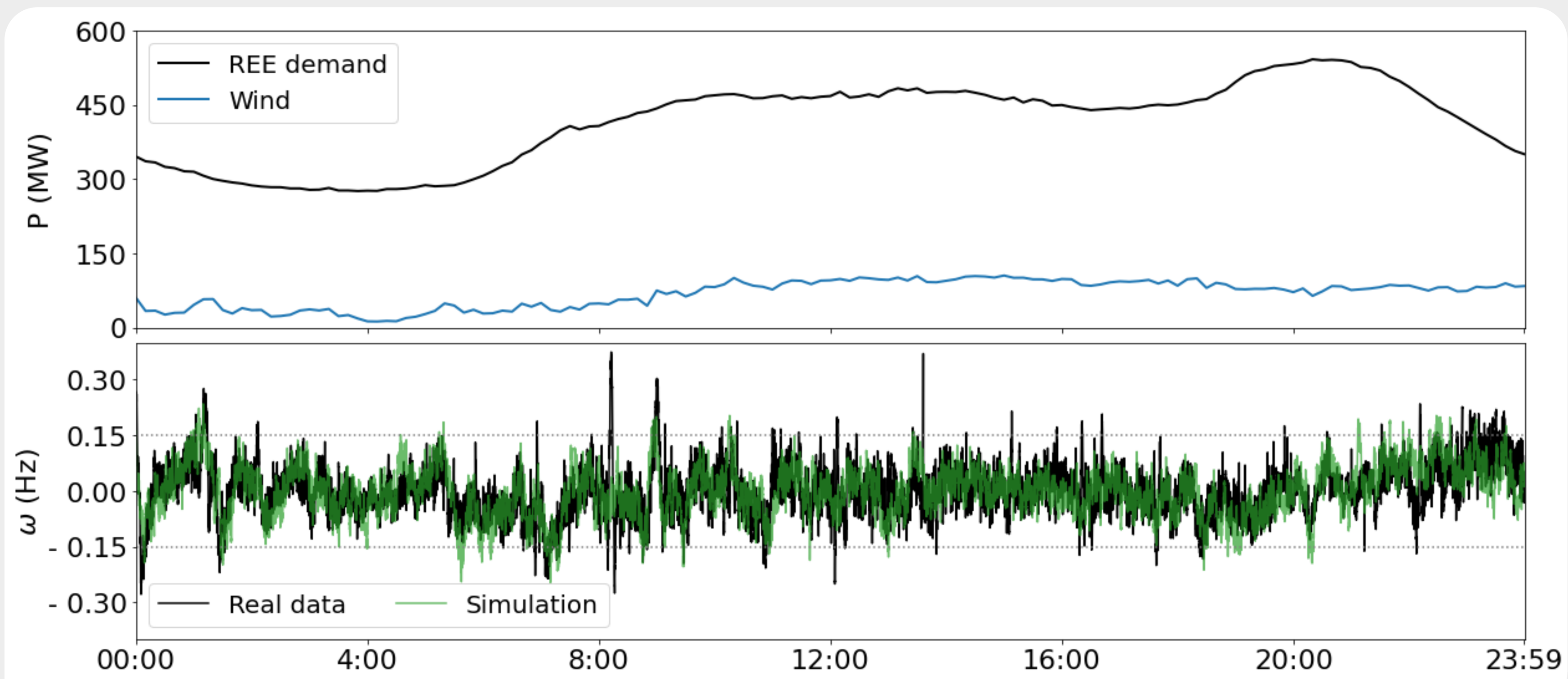
Generation distributed by technology in each generation node

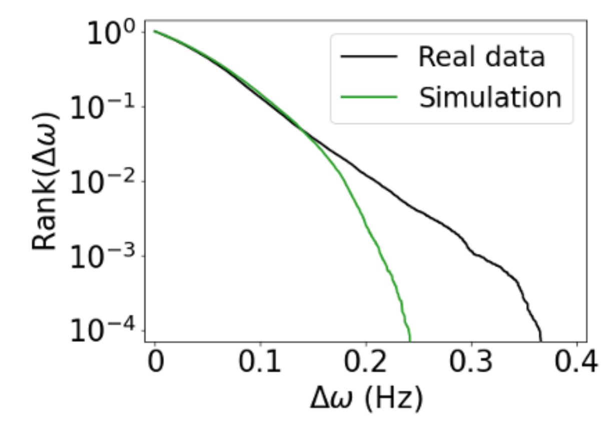
$$\lambda_i, P_i^{ref}$$

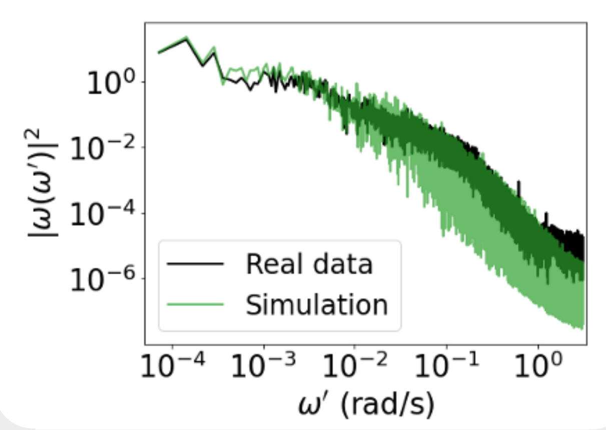




Model validation







Frequency data: *https://osf.io/by5hu/*

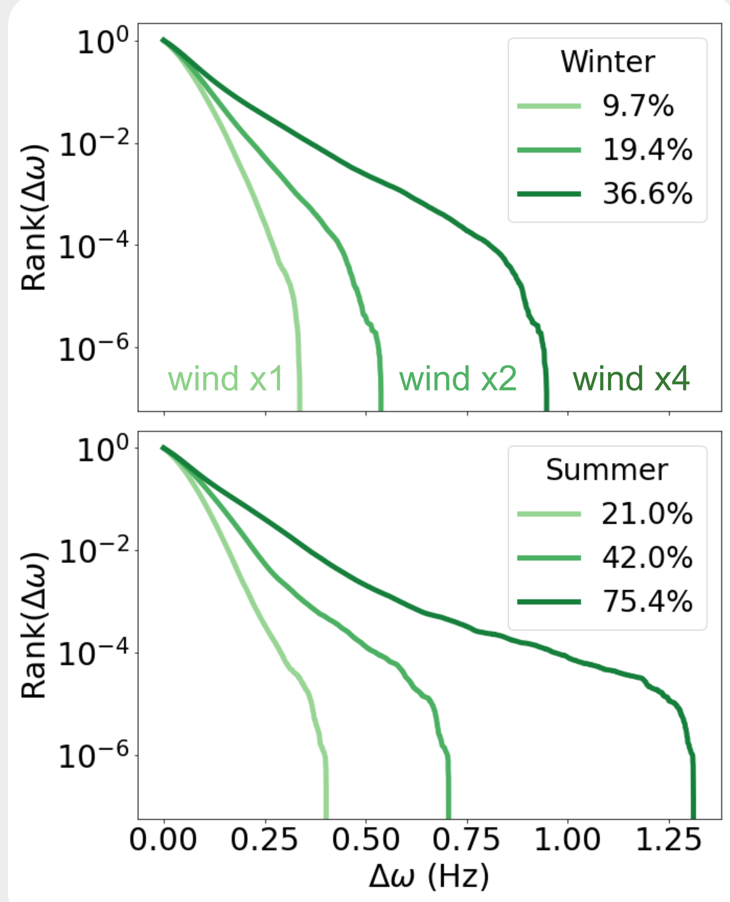
- The **model reproduces the statistics of real data**, and it captures the frequency peaks associated to renewable generation variability.
- In the rank distribution, we see that the model works best for the smaller frequency deviations.
  - Large fluctuations are associated with **deterministic events which the model cannot predict unless they are recorded in the 10-minute data** (model input).
- The slope in the power spectrum indicates that **frequency fluctuations are correlated**, and the Ornstein-Uhlenbeck noise is a good choice to model fast power variations.

Future scenarios

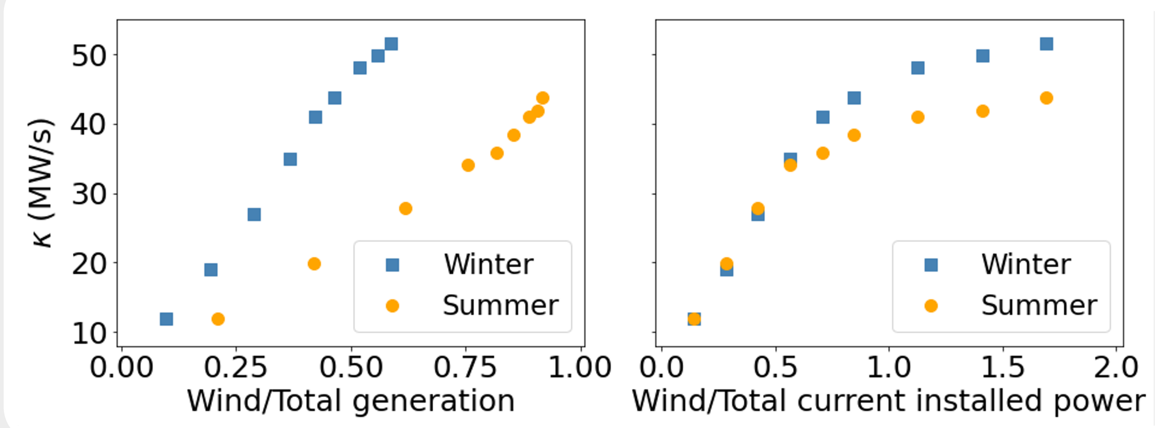
- We plot the rank distribution of frequency fluctuations for
  - current installed wind power
  - 2 and 4 times the current installed wind power

The legend displays the fraction of the total generated energy provided by wind.

- As expected, we observe that **higher wind penetration leads to larger frequency fluctuations**.
- We also see that for the same installed wind power, there is roughly twice as much wind generation in summer than in winter. This is because **trade winds** prevail all year in Gran Canaria, but they are **most intense during spring and summer**.



- To avoid **large frequency fluctuations** that **threaten grid stability** as wind penetration increases, we consider **additional control capability** in conventional power plants.
- We plot the amount of secondary control needed to reduce the probability of frequency deviations larger than ± 0.2 Hz to that of the current case.



Acknowledgements

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QR code

References

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