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XXXII Cycle

Advanced frequency modelling for grid stability studies

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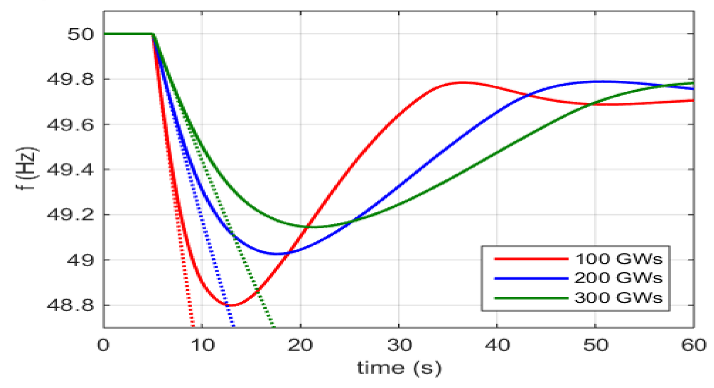
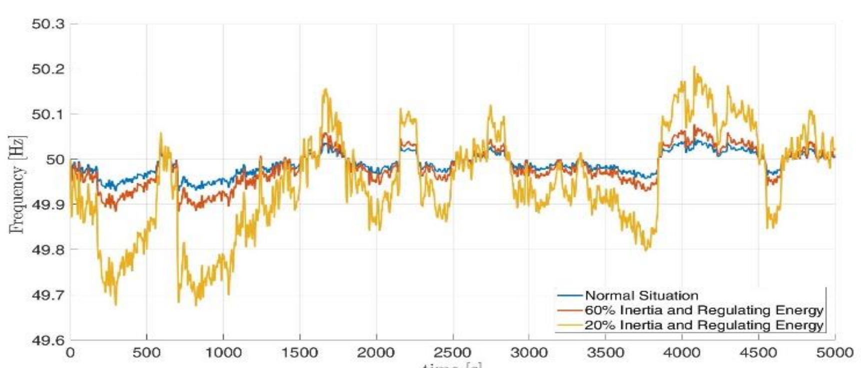
Research context and motivation

- In the future, Inertia of the electric grid will fall due to the decrease of Conventional Generation (CG). The frequency signal will change faster than today, and this willl endanger the stability of the power system both in the event of a contigency or under normal load variations (see Figure on the left for a contigency and on the right for normal operation: with lower CG installed the frequency will dangerously oscillate).





- In such a perspective, new resources like Battery Energy Storage Systems (BESSs) seem very well suited for primary frequency and RoCoF (rate of change of frequency) control.
- In literature Contingency analysis has been widely studied and the role of inertia has been identified as the most important especially in the first instants.
- However, BESSs impact on normal operations is usually studied in open loop without considering the effect on the grid. Quantifying this effect is a first crucial step in order to appropriately dimension new reserves and consider their techno-economical performance.

Addressed research questions/problems

Two are the main problems/questions addressed in my research:

1) How to construct a base case scenario where the grid frequency signal is realistically oscillating? The frequency signal is always oscillating around the nominal value due to the power deviations of all the elements of the grid. These deviations can be tipically divided in two broad families: stochastic frequency deviations due to the fast changing of loads (and renewable primary sources) and deterministic frequency deviations which are caused by the changing of production CG due to the market structure of the power system, where Energy and Balancing makes the schedule of TG change during the day. Clearly also the continuous presence of primary, secondary and tertiary control (if present) must be considered as they naturally react against frequency perturbations.

2) What is the impact of fast primary frequency control and RoCoF performed by new resources? First we have to correctly model the battery and the converter performances. Secondly we want to asses the performance both on the grid frequency signal and on the BESSs State of Charge (SoC). Different operational strategies and power band can used by the BESSs and this will have different impacts both on the SoC and on the frequency signal such that a trade off can be identified. Finally the performances of BESSs can be compared to different CGs resources.

Novel contributions

- Reconstruct, by using different methodologies, the grid frequency signal in a realistic way by reproducing the main phenomena which makes the grid deviate from the nominal value.
- Study the impact of new regulation strategies for frequency control in close loop, i.e. considering at the same time the impact of regulation both on the grid and on the new resources SoC perfoming these services.

Submitted and published works

- **Assessment of primary frequency control through battery energy storage systems.** Arrigo, F., Bompard, E., Merlo, M., & Milano, F. (2020).. International Journal of Electrical Power & Energy Systems, 115, 105428. (Online from August 2019)
- **Mitigation of frequency stability issues in low inertia power systems using synchronous compensators and battery energy storage systems**. Mosca, C., Arrigo, F., Mazza, A., Bompard, E., Carpaneto, E., Chicco, G., & Cuccia, P. (2019).. IET Generation, Transmission & Distribution.
- **Agent-based Modelling to Evaluate the Impact of Plug-in Electric Vehicles on Distribution Systems.** Falco, M., Arrigo, F., Mazza, A., Bompard, E., Chicco, G.. (2019, September). In 2019 International Conference on Smart Energy Systems and technologies.
- **On the virtual inertia provision by BESS in low inertia power systems.** Toma, L., Sanduleac, M., Baltac, S. A., Arrigo, F., Mazza, A., Bompard, E., ... & Monti, A. (2018, June). In 2018 IEEE International Energy Conference (ENERGYCON) (pp. 1-6). IEEE.
- **Fourier transform based procedure for investigations on the grid frequency signal.** Arrigo, F., Merlo, M., & Parma, F. (2017, September). In 2017 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe) (pp. 1-6). IEEE.
- **Dynamic phasors to enable distributed real-time simulation**. Mirz, M., Estebsari, A., Arrigo, F., Bompard, E., & Monti, A. (2017, June). In 2017 6th International Conference on Clean Electrical Power (ICCEP) (pp. 139-144). IEEE
- **(submitted). Forecast-based V2G Aggregation model for Day-Ahead and Real-time operations.** Giordano, F., Arrigo, F., Diaz-Londono, C., Spertino, F., Ruiz,F. submitted to 2020 PES Innovative Smart Grid Technologies Conference (ISGT-USA)

Adopted methodologies

Three different methodologies to emulate the frequency signal and several indices were used to assess the impact of BESSs

(1) Simulink Model based on the Swing Equation (SE)

SE, under certain hypothesis, well describe the grid frequency dynamics. Reverse and Forward model are based on the Swing Equation and can reproduce entire days:

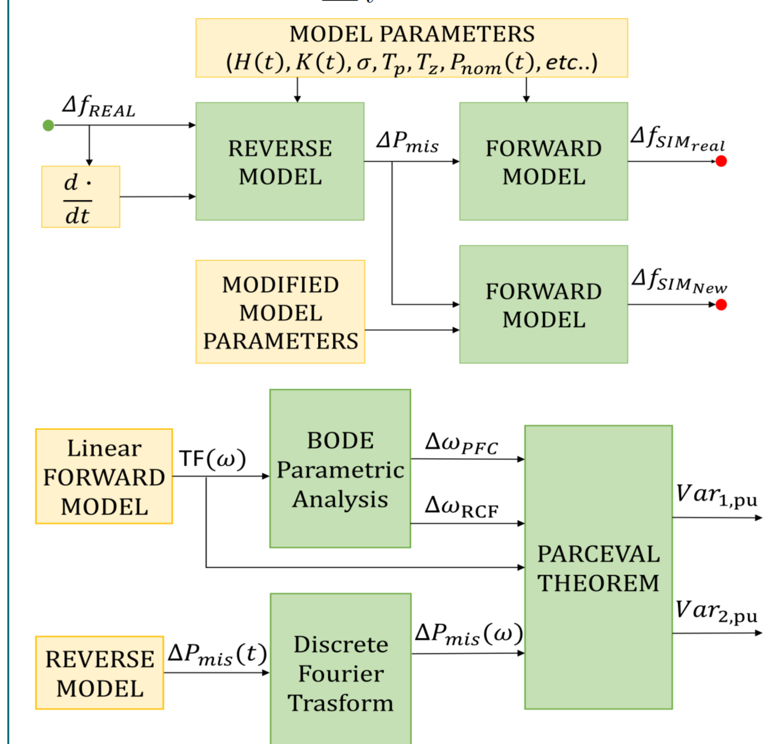
$$\frac{2H}{\mathrm{f_{nom}}} \cdot \frac{df}{dt} = \Delta P_m - \Delta P_e \,, \qquad (1)$$

$$H = \frac{\sum_i H_i \cdot S_i}{\sum_i S_i} \,, \qquad (2)$$

$$\Delta P_m = \Delta P_{\mathrm{PRI}}(\Delta f) + \Delta P_{\mathrm{SEC}} \,, \qquad (3)$$

$$\Delta P_e = \Delta P_{\mathrm{mis}} + \Delta P_{\mathrm{con}} + \Delta P_{\mathrm{LOAD}}(f) \,, \qquad (4)$$

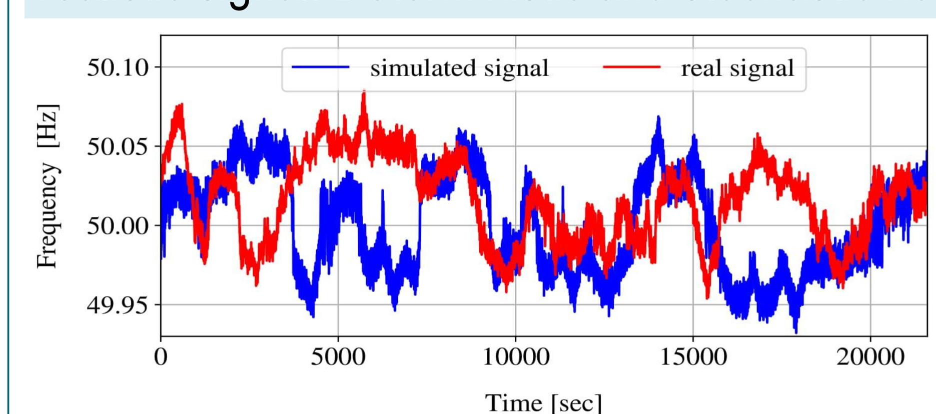
$$\Delta P_{\mathrm{mis}} = \Delta P_{LOAD} + \Delta P_{RES} - \Delta P_{\mathrm{CG}} \,. \qquad (5)$$

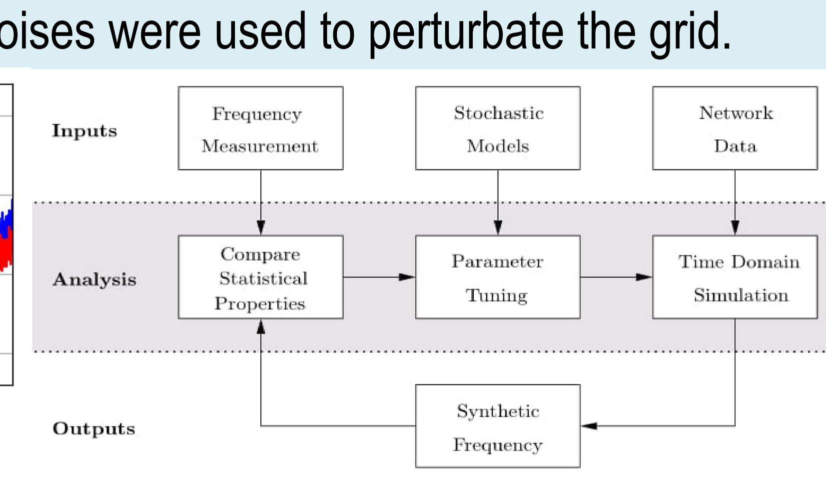


Starting from the real frequency, the REVERSE model is used to get the ΔP_{mis} and then it is inserted into the FORWARD model to obtain a new frequency variation. The Forward model support the change on inertia levels and frequency Reserves during the day. Explicit Time domain simulation will be performed and a linearized version of this models was used to perform a **Frequency Domain Analysis** in order to discover the root causes of the BESSs impact

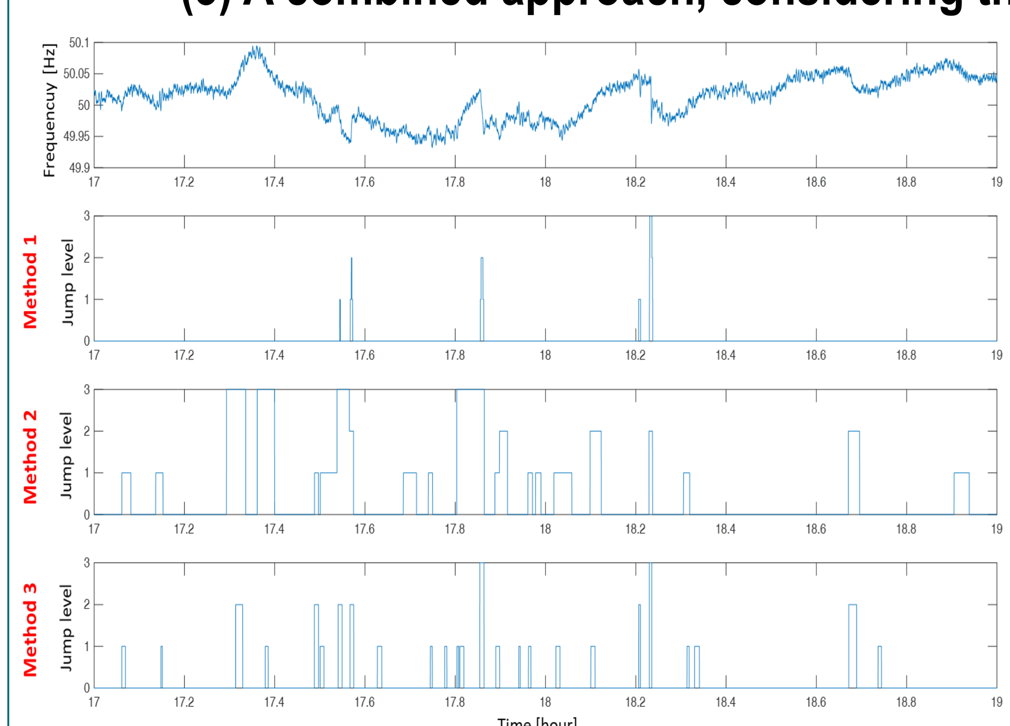
(2) Dome Software procedure based on Fourier Transform

In time domain, the frequency signals have very different behaviours, while the signal spectra are very similar and therefore the spectrum can be used in order to obtain a realistic signal. Deterministic and stochastic noises were used to perturbate the grid.





(3) A combined approach, considering the presence of frequency jumps



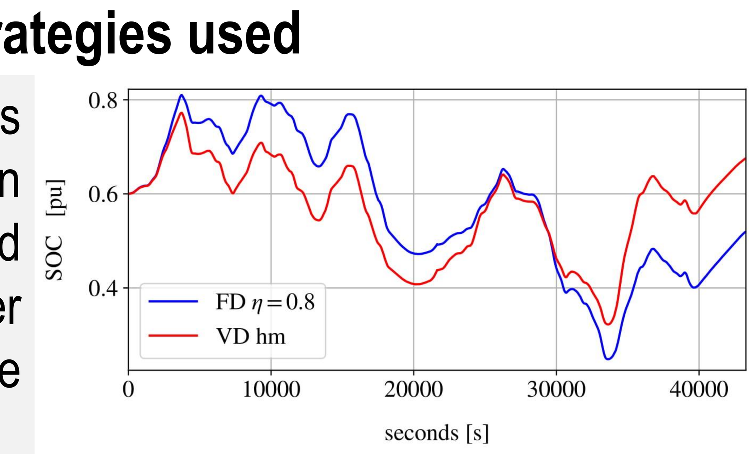
Particular countries (especially smaller ones) are characterized by sudden and big frequency jumps. In order to reproduce and investigate these jumps, the frequency profile must be analyzed. Special indicators were built in order to automatically find the presence and the characteristics of a jumps (Δf, ΔP, starting and closing time, etc.).

(4) Indices and BESSs strategies used

(A) Complementary and Overlapping power bands were used to asses the differences between primary and RoCof control. Fixed droop and Variable droop strategies were also used in order to stabilize the grid while at the same time managing the SoC.

(B) Indicators such as mean, standard deviation, swekness of freq. and SoC profiles were studied

(C) Efficacy index is used in order to asses the difference between BESS and CG



$$e_k = \frac{\left| E_k^+ + |E_k^-| - \left(E_{o,k}^+ + |E_{o,k}^-|\right) \right|}{E_k^{\mathrm{ref}}}$$

$$E_k^{\mathrm{ref}} = \int_o^T \frac{P_{\mathrm{nom,k}}}{R_k(r)} \left|\Delta f(r)\right| dr$$

List of attended classes

- 01RJLRV – Advanced control in electrical energy conversion: a practical approach to real-time implementation (17/02/2017, 4)
- 03LCLRV – Epistemologia della macchina (5/4/2017, 4)
- 01RQXRV – Pattern recognition and neural networks (didattica di eccellenza) (5/5/2017, 8)
- 01NKVNC - Sistemi elettrici di Potenza (14/7/2018, 10)
- 01RRPRV – Lean startup e lean business for l'innovation management (31/7/2017, 4)
- 01QSNRV – Energy security in EU: Methodological approaches and policy making (27/9/2017, 3)
- 01SFGRW – Metodi di ottimizzazione con octave e matlab(7/2/2018, 3)
- 01SWJRV – Control and optimization in Smart Grids (didattica di eccellenza vp)(31/05/2018, 4)