Fast Frequency Response on a Low-inertia Power Systems

Sizing and Impact Analysis of FFR Reserve

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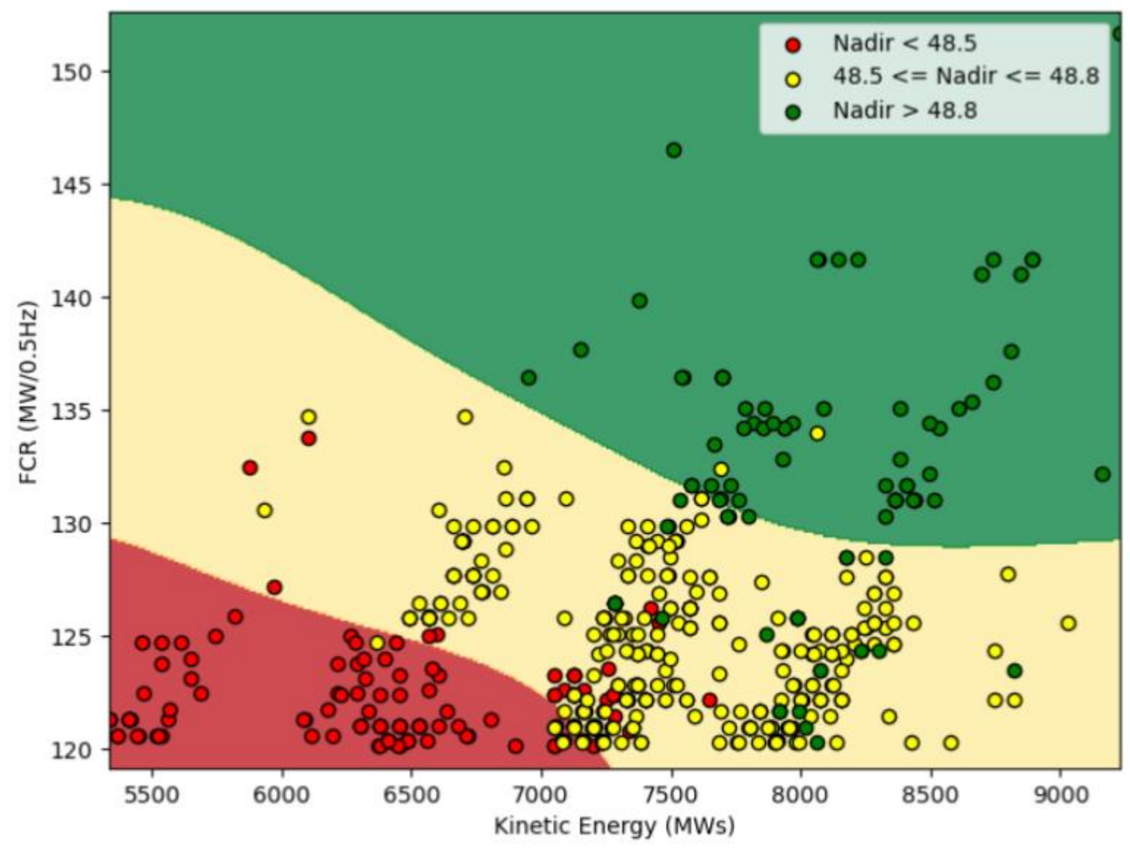
Introduction

System operators in low-inertia power systems often curtail RES generation to maintain system inertia and frequency support. Moreover, at a significance disturbance, UFLS schemes are activated to stabilize frequency. This research examines the interaction between inertia, FCR, and Nadir. It, furthermore, analyses the use of FFR for reducing UFLS activation and the requirements for kinetic energy and FCR. Finally, a methodology for proper sizing required FFR for each operating scenario is proposed.

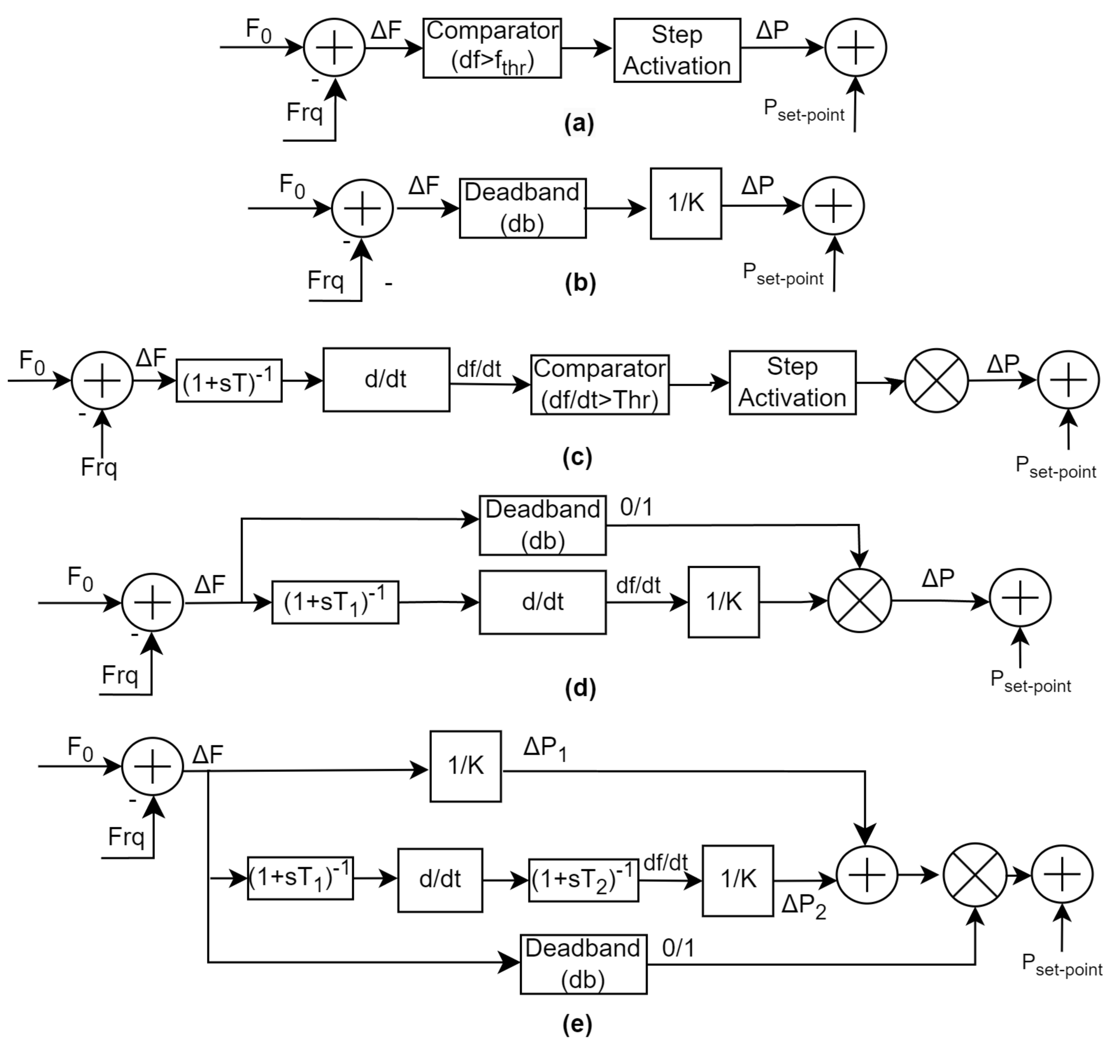
Correlation of FCR and KE with Nadir

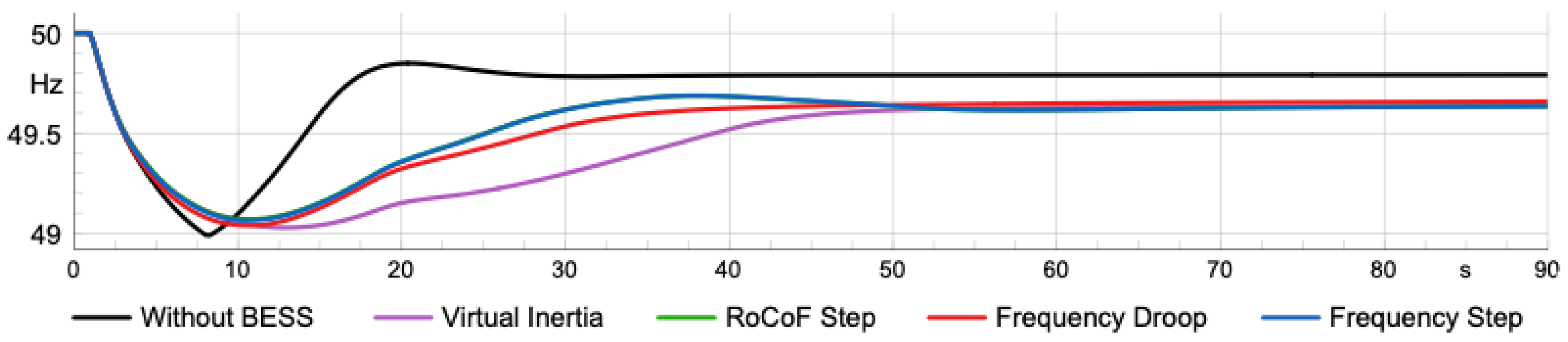
A frequency analysis of an isolated power network (Cyprus) at various operating points reveals that: low RES leads to high Nadir (green area), increasing RES lowers Nadir (yellow area), and peak RES causes prohibited Nadir (red area). It should be noted that FCR response time is critical, prompting varied allocations for identical reserve capacities [1].



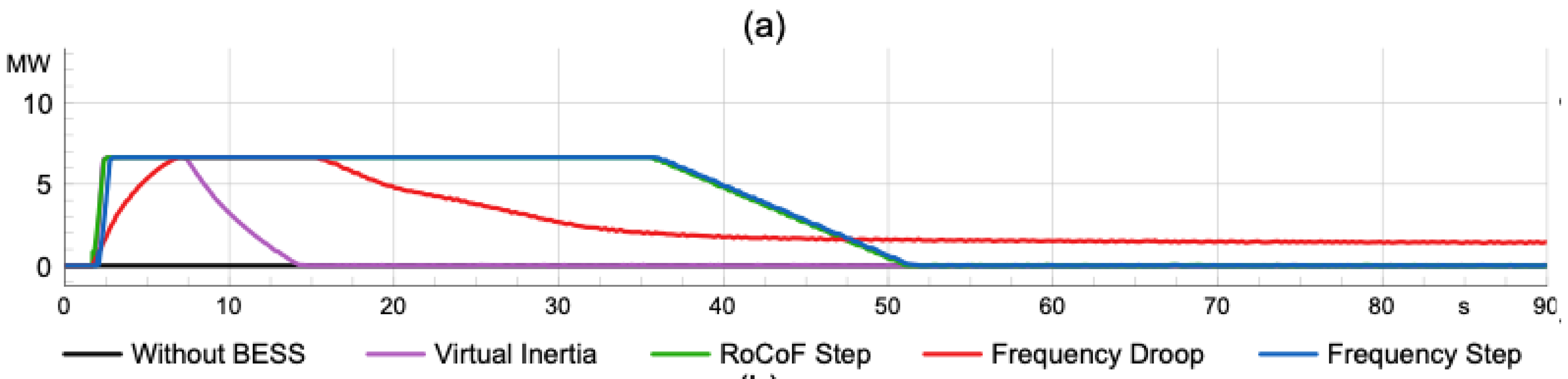
FFR Controllers Implementation

Several controllers implementations have been proposed [2]. The most widely used is the step response (a). When the frequency decreases beyond a limit, the controller immediately activates the FFR power injection. After a period of time, the FFR controller gradually decreases the power output. Moreover, frequency proportional response (b), RoCoF step response (c), Virtual inertia (d), and Frequency-RoCoF proportional (e) controllers proposed.





(a)

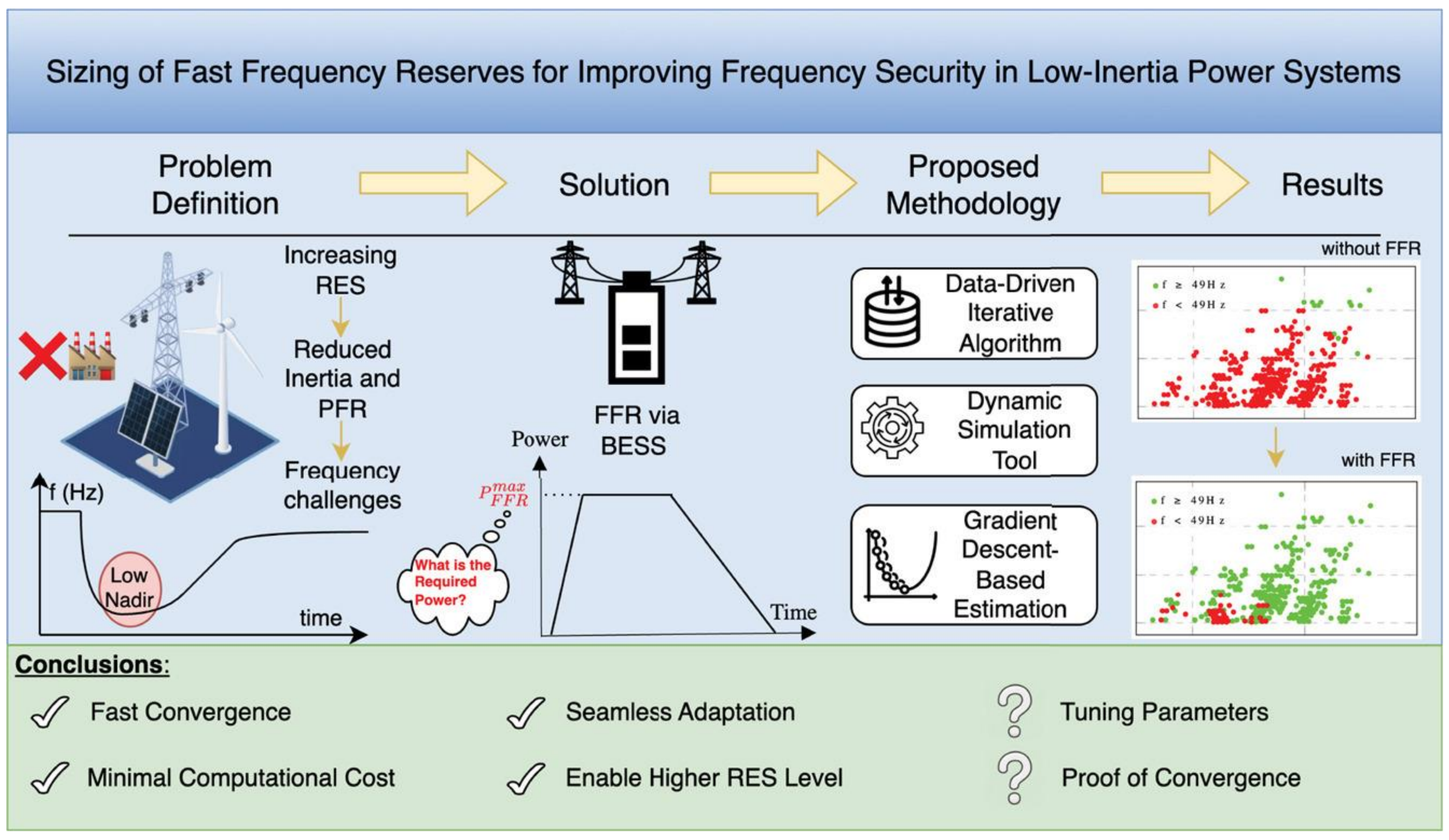


(b)

PERSPECTIVES FOR EACH CONTROLLER TYPE

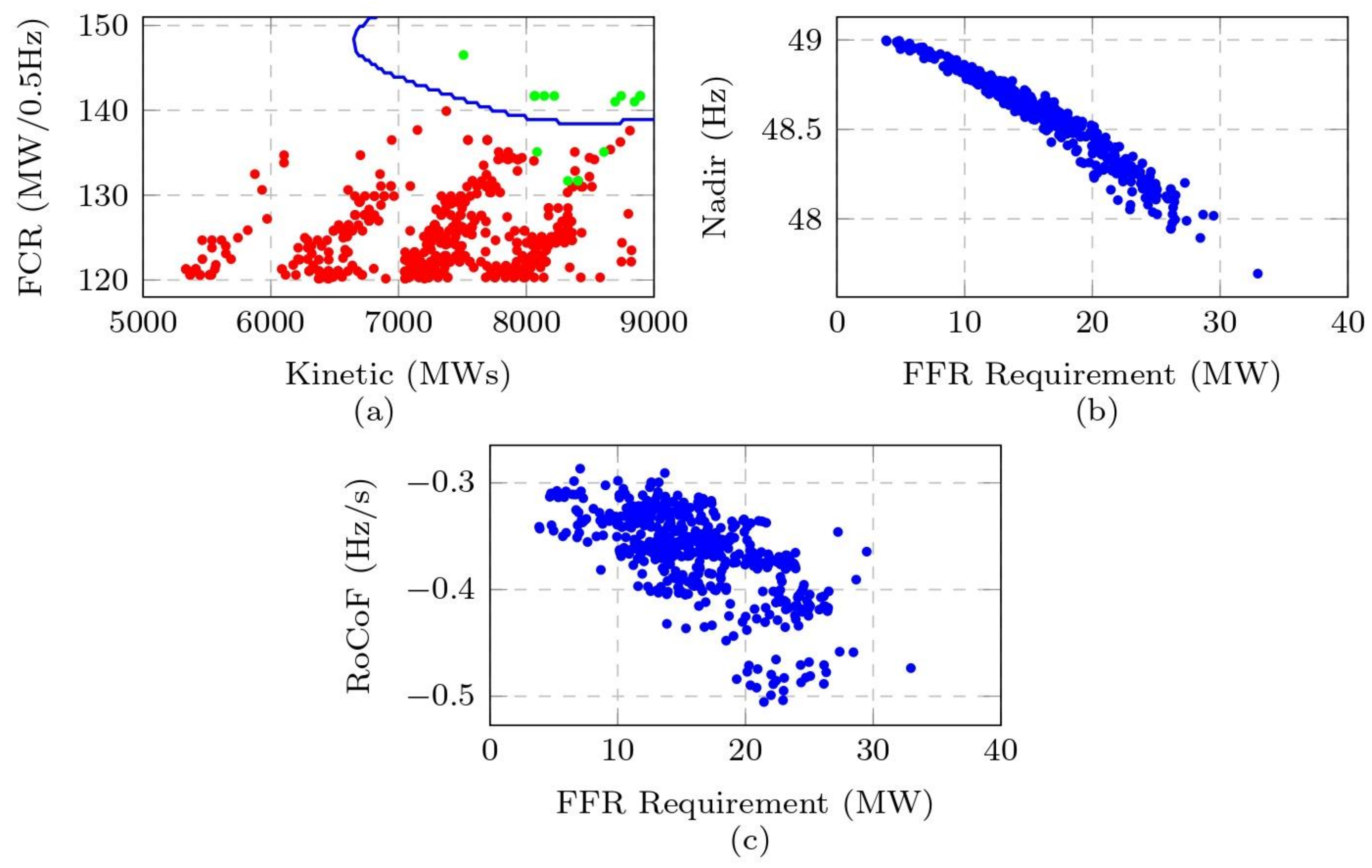
Control Mode	Frequency Proportional (P-f)	Frequency Step	Virtual Inertia (P-df/dt)	RoCoF Step	Frequency-RoCoF Proportional (P-f,df/dt)
Improved Nadir	✓✓	✓✓✓	✓	✓✓✓	✓✓✓
Improved Initial RoCoF	Low	Low	Low	Low	Low
Improved Steady State	✓✓	✗	✗	✗	✓✓
Adaptive Response	✓	✗	✓	✗	✓
Energy Consumption	Moderate	High	Low	High	High
Symmetric Operation	✓	✗	✓	✗	✓

Sizing Methodology [3]



The proposed methodology iteratively computed the required FFR capacity (for step response controller) to achieve a frequency Nadir close to the target value. It integrates DSA to calculate the deviation of the Nadir from the target and employs a gradient descent-based linear prediction method to estimate the necessary FFR reserves in each iteration. The linear estimator is inspired by the swing equation

Results



- All scenarios converge in four iterations
- There is an almost linear correlation between initial frequency Nadir and FFR requirements.
- Due to varying FCR response times and FCR capacities a significant dispersion exists between RoCoF and FFR requirements

Key Insights / Conclusions

- Without FFR, as the RES penetration increases the UFLS after disturbances and the PV curtailment increases.
- RoCoF and post-fault frequency steady state are not affected by the addition of FFR therefore FFR cannot replace the minimum FCR and KE requirements.

FFR schemes bridge the speed of response between KE and FCR, allowing for higher values of Nadir with lower KE and FCR requirements and consequently lower RES curtailments and fewer UFLS activations.

Future Work

- Develop **optimal operation strategies** for coordinated control of **Electric Vehicles (EVs)** and **Heat Pumps (HPs)** in active distribution networks.
- Investigate **flexibility activation** from EVs and HPs to provide **ancillary services** to the **transmission system**.
- **Integrate the developed flexibility solutions into long-term planning tools** to support investment decisions

[1] S. Panagi, A. Lazari, V. Koutsoloukas, and P. Aristidou, "Impact of fast frequency response on renewable energy source curtailment and load shedding," IET Conf. Proc., vol. 2024, no. 5, 2024

[2] A. Argyrou, S. Panagi, and P. Aristidou, "Comparison of Fast Frequency Response Methods in the Low-Inertia Grid of Cyprus," in *Proc. SyNERGY MED*, Limassol, Cyprus, Oct. 2024.

[3] S. Panagi and P. Aristidou, "Sizing of fast frequency response reserves for improving frequency security in low-inertia power systems," *Sustain. Energy, Grids Netw.*, Jun. 2025