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Primary Frequency Response Reserve Products for Inverter-Based Resources

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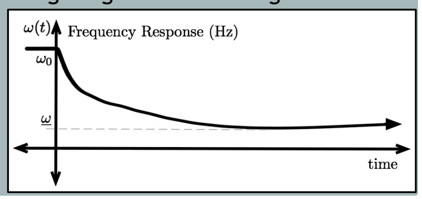
Introduction

We suggest introducing new ancillary service products into the electricity market that provide incentive for Inverter-Based Resources (IBRs) to contribute to primary frequency control and take advantage of their fast-acting capabilities. We propose four such products: Primary Frequency Response (PFR) reserve, Fast Frequency Response (FFR) reserve, Virtual Inertia (VI) reserve, and inertia products. We formulate a real-time co-optimization problem, derive prices for each product, and analyze the incentives provided to IBRs.

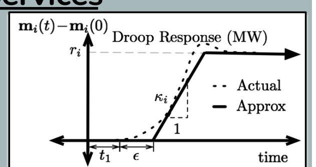
Primary Frequency Response Requirements

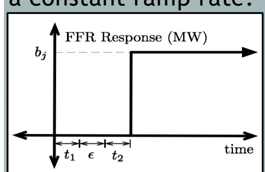
Primary frequency response intends to arrest frequency decline in response to the largest generator outage. Frequency dynamics are modeled by the swing equation. Reserve requirement from [2,3] ensures frequency stays above $\underline{\omega}$.



Ancillary Services

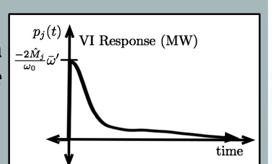
<u>Primary Frequency Response (PFR) Reserve:</u> Accommodates droop control. Droop control is modeled as having a time delay followed by a constant ramp rate.





<u>Fast Frequency Response Reserve (FFR)</u>
Triggered at a lower frequency than PFR reserve. Exhibits a step response and has a discontinuous trajectory. Only provided by fast acting resources.

<u>Virtual Inertia (VI) Reserve</u>
Emulation of the swing equation with a proportional response to the derivative of frequency. Temporary response that decays quickly after an outage. Only provided by fast acting resources.



<u>Synchronous Inertia</u>
Reduces Rate-of-Change of Frequency, giving PFR reserve more time to respond. Appears in swing equation.

Profit Maximizing Market Participants

Demand is assumed fixed.

<u>Inverter-based Resources (IBRs)</u>
Products Provided:
Electric generation, FFR reserve, VI reserve.

Private Constraints:
1) Power capacity with reserve headroom.
2) Energy capacity with reserve headroom.

Model captures IB storage.

<u>Synchronous Generators</u>
Products Provided:
Electric generation, PFR reserve, synchronous inertia.

Private Constraints:
1) Power capacity with reserve headroom.
2) PFR reserve limit set by independent system operator.

Real-time Co-Optimization

Determines dispatch and prices in the real-time market. Minimizes total system costs. No time horizon considered. Commitment statuses and inertia levels are fixed. Non-convex but easily solved to a local minimum. The constraints are as follows:

- <u>Transmission Constraints</u>: DC transmission limits.
- <u>Reserve Requirements</u>: Requirements extend those from [2,3] by incorporating VI reserve. Causes non-convexity.
- <u>Synchronous Generator Private Constraints</u>: PFR reserve limit is imposed by the ISO and is considered constant from the perspective of the generator.
- <u>IBR Private Constraints</u>: Power and energy reserve for VI response are derived in the paper. Energy reserve for FFR response is proportional to the ISO required deployment time Δt.

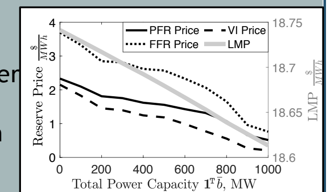
Incentive Alignment Result

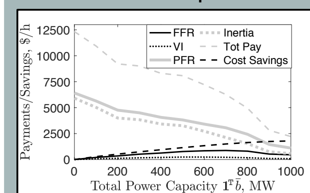
Assume a local minimum is identified that solves the KKT conditions (mild assumption). Define product prices by the Lagrange multipliers as in [1]. Assume market participants are price-takers. **The locally optimal dispatch maximizes profits for all IBRs and generators.**

Numerical Results

<u>Numerical Results Setting</u>
ACTIVSg2000 Texas test case from [4]. Increase number of IBRs from 0 to 1000. Each IBR has 1 MW of power capacity and energy capacity uniformly randomly sampled from 100 to 1000 MW-s. IBRs only provide VI and FFR reserve.

<u>Product Prices:</u>
Prices drop as total IBR power capacity increases. The PFR reserve price is smaller than the FFR reserve price.



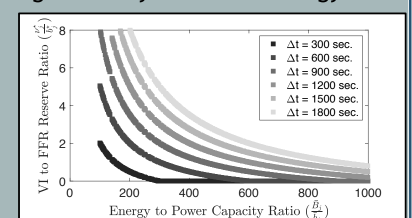


<u>Payments/Cost Savings:</u>
Total ancillary service payments and total costs decrease as the total IBR power capacity increases.

<u>IBR Incentives:</u> Energy and power capacity constraints are typically both binding. This does not happen if only considering VI or FFR reserve. This happens because VI and FFR reserve have significantly different energy requirements.

Optimal VI reserve increases with power capacity.

Optimal FFR reserve increases with energy capacity.



Conclusions

We propose inertia along with PFR, FFR, and VI reserve market products. Introducing both VI and FFR reserve incentivizes IBRs to fully utilize their energy and power capacities. Introducing VI and FFR reserve decreases total reserve payments and production costs. Proposed prices align ISO and market participant incentives.

References

[1] Manuel Garcia, Ross Baldick, and Felipe Wilches-Bernal. "Primary Frequency Response Reserve Products for Inverter-Based Resources". In: Proceedings of the 55th Hawaii International Conference on System Sciences. 2022.
[2] Manuel Garcia and Ross Baldick. "Real-time co-optimization: Interdependent reserve types for primary frequency response". In: Proceedings of the Tenth ACM International Conference on Future Energy Systems. 2019, pp. 550–555.
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[4] Adam B Birchfield et al. "Grid structural characteristics as validation criteria for synthetic networks". In: IEEE Transactions on power systems 32.4 (2017), pp. 3258–3265.

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