Assessing the Technical Potential of Fast Frequency Response in Grid-Supportive Loads

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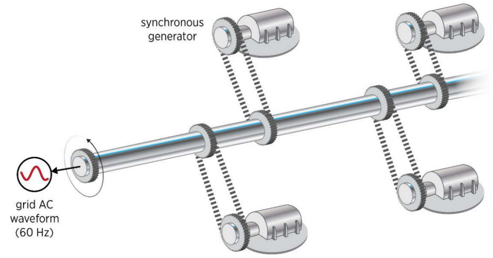
Motivation

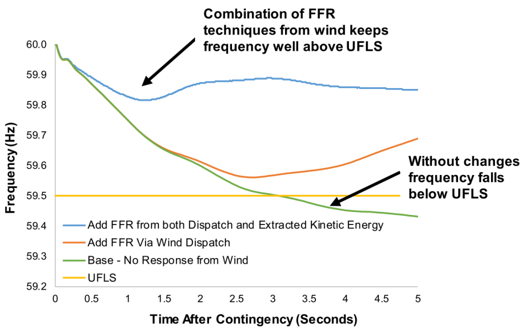
- The current electric grid relies on synchronous machines to provide system inertia and help maintain the grid frequency of 60 Hz [1].



- **Inverter-based resources (IBR) are replacing synchronous generators and loads**, which reduces system inertia and increases grid frequency fluctuations.

	Synchronous Machines	Inverter-based Resources
Generators	Fossil Fuel Hydro Nuclear	Solar PV Wind Batteries
Loads	Synchronous Motors Induction Motors	EV Chargers Power Electronic Loads Variable Frequency Drives (VFDs)

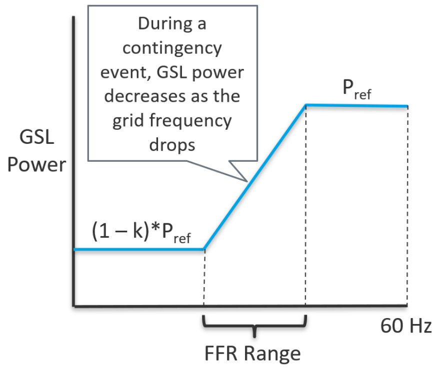
- **IBR generators can provide fast frequency response (FFR)** to mitigate the issues of low inertia, for example under frequency load shedding (UFLS) [1].



- While solar PV and wind must be curtailed to provide up-regulation FFR, IBR loads can supply FFR with minimal impact on the device or end user [2].

Grid-Supportive Loads

- A Grid-Supportive Load (GSL) is a power electronics-based device that can **autonomously adjust its power consumption based on grid measurements**, for example grid frequency or voltage [2].



- Because they do not require communication, **GSLs respond very fast and are resilient to cyber attacks** when compared to traditional demand-side management.

Technical Potential Model

- The technical potential of GSLs to deliver FFR services for a given end use depends on three parameters:

$$Potential(t) = P(t) f_{GSL} k$$

- $P(t)$: The total power consumed by the end use at time t. The load profile could depend on time of day and season, as well as on the number of end use devices installed in the given region.
- f_{GSL}: The fraction of devices that can incorporate GSL technologies, for example devices with VFDs or other power electronic interfaces.
- k: A control parameter defining the minimum level of power for the device (see figure above). Larger values could impact the end use service or device degradation.

- For example, residential refrigerators use about 400 MW in the ERCOT system on average [3]. If f_{GSL}=0.5 and k=0.5, then **refrigeration can provide about 100 MW of FFR in the ERCOT system**.

End Use Analysis

- Multiple factors impact the FFR potential for different end uses:

	P(t)		f_{GSL}		k
End Use	Total Energy	Smooth Load Profile	GSL Market Share	Diffusion Rate/ Turnover	Control Flexibility
EV Charging	●	◐	●	●	●
HVAC	●	○	◐	◐	○
Water Heating	◐	◐	○	◐	◐
Refrigeration	◐	●	◐	◐	◐
Laundry	○	◐	○	◐	○
Other Pumps	○	●	◐	◐	●

● = High potential; ◐ = Medium potential; ○ = Low potential

- **EV charging** load is expected to grow significantly, and Level 2 and 3 chargers are capable of GSL functions. Power can be shut off (k=1) for short durations with minimal impact on charge time.
- **HVAC** has very high energy consumption, but seasonal and diurnal load changes could limit the value of GSL, and short power fluctuations could impact occupant comfort.
- **Refrigerators** have a very smooth load profile and have higher energy consumption and VFD rates than other appliances.
- **Other pumps** (for pools, hot tubs, and wells) have a high potential for flexibility, but relatively low energy consumption.

Future Work

- An economic analysis of GSL is in progress that compares the cost of implementation with the value of FFR as a grid service.
- Based on the technical potential analysis, we recommend EV charging and refrigeration as promising end uses for GSL services.
- More research is required to better predict future load profiles, technology adoption, and FFR requirements for low-inertia grids.

[1] P. Denholm, T. Mai, R. W. Kenyon, B. Kroposki, and M. O'Malley, "Inertia and the Power Grid: A Guide Without the Spin," 2020. https://www.nrel.gov/docs/fy20osti/73856.pdf

[2] H. Jain, B. Mather, A. K. Jain and S. F. Baldwin, "Grid-Supportive Loads—A New Approach to Increasing Renewable Energy in Power Systems," in IEEE Transactions on Smart Grid, vol. 13, no. 4, pp. 2959-2972, July 2022, doi: 10.1109/TSG.2022.3153230.

[3] End-Use Load Profiles for the U.S. Building Stock. https://www.nrel.gov/buildings/end-use-load-profiles.html

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