Frequency-adaptive load control of microgrids

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FAPER Concept

Many renewable energy sources are intermittent: the sun is not always shining, and the wind is not always blowing. Everyone wants renewable energy, but a massive amount of energy storage and/or backup generation is unappealing. If power generation does not equal load, the frequency of the power grid deviates, especially in small power grids known as microgrids. We modeled FAPERs[1] (Frequency Adaptive Power and Energy Rescheduler): on/off appliances such as refrigerators or electric hot water heaters that modify their behavior based on the frequency of the power grid. FAPERs help the grid by turning on when there is excess power ($f > 60$Hz) and off when there is a shortage of power ($f < 60$Hz).

The effect is energy storage: a surplus of power raises the grid frequency, which raises the temperature limits of heaters (and lowers the limits for refrigerators, freezers, and air conditioners), which turn on, effectively storing the energy as heat (or cold). Conversely, a shortage of power lowers the grid frequency, which changes temperature limits in the opposite direction, such that the appliances are likely to turn off.
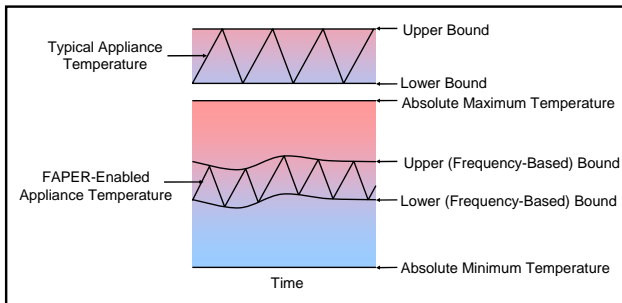

FIGURE 1: FAPERs are appliances such as refrigerators with temperature bounds that change with power grid frequency.

Simulation Model

Five hundred FAPER units were simulated on the microgrid in Figure 2. The simple microgrid is justified because heating and cooling loads are not especially inductive, and they are distributed, minimizing transmission line effects (which are already minimal in a microgrid setting). The simulated microgrid was comprised of:
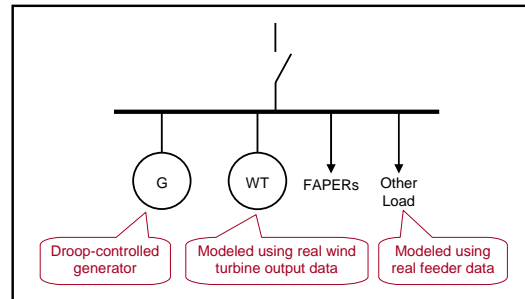- 25% Wind Power
- 10% FAPER load

FIGURE 2: An extremely simple microgrid was used in simulations

FAPER Control

In the control algorithm presented in [1] (and [2]), temperature limits vary directly with frequency. In our simulations, this caused three major problems:
- High gains cause instabilities. A rising in frequency causes FAPERs to turn on, which causes a drop in frequency, which causes FAPERs to turn off, which causes… etc.
- If a group of FAPERs turn off simultaneously, it can be problematic when they turn on again (simultaneously), causing unexpected spikes in total load.
- If the frequency swings up and down quickly for a short duration, then FAPERs as a group become unresponsive because the hottest units will already be cooling and the coldest units will already be heating. Slightly shifting the temperature bounds no longer has an effect.

The control algorithm presented in [3] discusses a temporally-distributed load-shedding tactic, in which case FAPERs turn on or off regardless of their current temperature.
- The response time of this tactic is less agile since large frequency swings do not cause an increase of FAPER responses over small swings.

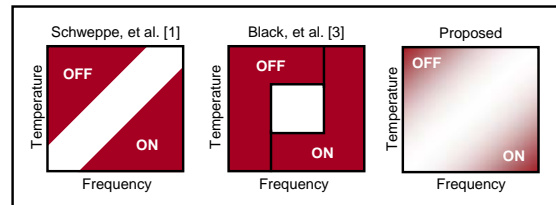A new control method is proposed in figure 3.

FIGURE 3: Visualization of FAPER control algorithms for heaters

We have tried a new approach involving probabilistic functions. The algorithm is similar to the original function described in [1], but instead of "hard" limits, the limits are probabilistic: there is a good chance that any given FAPER will respond, but it may wait. Since not all FAPERs respond immediately, all problems seen in [1] are mitigated. The algorithm is more effective than that in [3], however, because larger frequency swings cause more FAPERs to respond, yielding better control.

Results

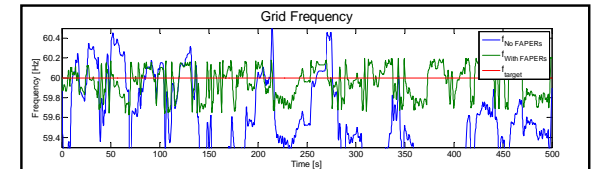Figure 4 is a sample of the simulation frequency output.

FIGURE 4: FAPERs help stabilize microgrid frequency

An optimization loop was used to determine the parameters of each control strategy. Figure 5 presents a "best case" of each strategy where parameters (such as frequency thresholds) were trained against the simulation.
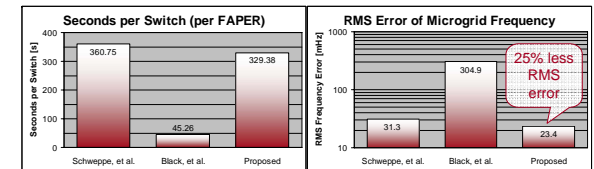

FIGURE 5: Comparison of algorithm effectiveness on a microgrid

Conclusions

We have found that a probabilistic control functions yield better FAPER results than previously explored control methods. Future experiments are needed in a more complete microgrid simulation setup to verify the effectiveness of FAPERs with more certainty. Explorations of more malleable control methods are also under way.

References

[1] Schweppe, F.C.; Tabors, R.D.; Kirtley, J.L.; Outhred, H.R.; Pickel, F.H.; Cox, A.J., "Homeostatic Utility Control," *IEEE Transactions on Power Apparatus and Systems* , vol.PAS-99, no.3, pp.1151-1163, May 1980

[2] Short, J.A.; Infield, D.G.; Freris, L.L., "Stabilization of Grid Frequency Through Dynamic Demand Control," *Power Systems, IEEE Transactions on* , vol.22, no.3, pp.1284-1293, Aug. 2007

[3] Black, J.W.; Ilic, M., "Demand-based frequency control for distributed generation," *Power Engineering Society Summer Meeting, 2002 IEEE* , vol.1, no., pp.427-432 vol.1, 25-25 July 2002