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Robust Network Control and Disjunctive Programming

The problems we consider are motivated by current issues on the safety and stability of power grids; however there are other critical infrastructure settings where very similar paradigms will arise. To explain our approach it is best to very quickly review the three-part mechanism that governs today's power grids. See [1, 2] for background.

1. First we have OPF, or "Optimal Power Flow," a computation performed periodically (roughly every five minutes) and whose main job is to set generator outputs over the next period, using estimates for demands over that period, and so as to minimize generation cost.

2. Demands will deviate from the estimates during the next period, in a noisy fashion, and sometimes indicating a trend. When demands (loads in the language of power engineering) do change, we have a generation vs demand mismatch, and frequency of the AC quantities (voltages in particular) will change in the opposite direction. This change, at the level of physics, guarantees that demands continue to be satisfied. If the change is very large, however, the network will collapse. The frequency change is termed primary response.

3. If a net demand change is somewhat permanent, the frequency shift will be noticed at a central location, and quite rapidly (perhaps in a matter of seconds) fast generators will be commanded to change their output so as to erase the mismatch between generation and loads. This is the secondary response.

This three-leg system has proved quite robust and effective in traditional grid operation, but is becoming less effective due to a number of reasons, including the large-scale introduction of renewables, with large real-time variance and complex correlations. Another issue, with increasing interest, is that of adversarial action that causes a large, instantaneous, mismatch and also possibly a correlated interference information flows. In both settings we obtain a variety of problems where fast, and accurate, optimization can play a very important role.

We discuss a number of problems and optimization techniques that can be used to address problems described above. In addition to mathematical techniques, modern grid operators will have access to an additional resource: storage (e.g., batteries). Storage gives an operator the ability to very quickly absorbe negative conditions and to react. Scheduling of storage introduces complexity because, for example, the behavior of batteries can be state-dependent and will reflect prior history. We will discuss the use of disjunctive programming in this context.

References

[1] A.R. Bergen and V. Vittal. Power Systems Analysis. Prentice-Hall (1999).

[2] D. Bienstock. Electrical Transmission System Cascades and Vulnerability: An Operations Research Viewpoint. SIAM-MOS Series on Optimization (2015).