Flexibility Polytopes for Aggregated Energy Resources: Computation and Applications (AGSR_106)

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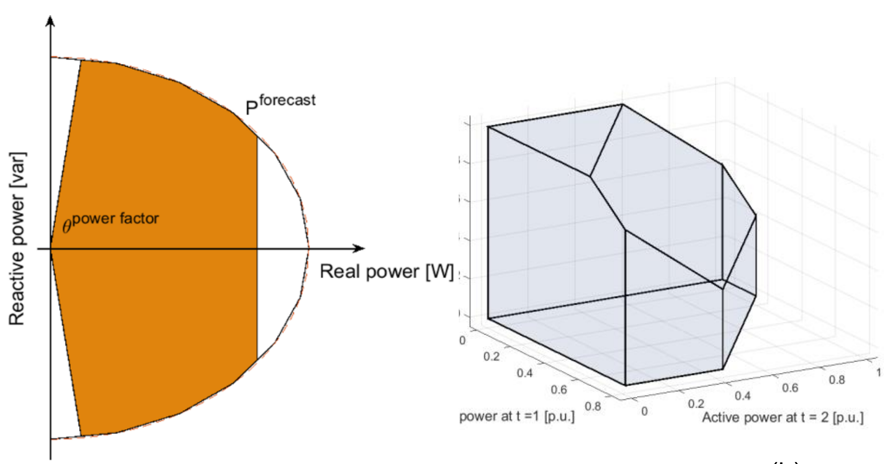
Power systems have been accommodating a significant amount of distributed energy resources (DERs), such as solar photo-voltaic (PV) systems, batteries, electric vehicles and controllable loads. The flexibility from DERs can be used to address many problems in the power grid. For example, PV inverter set-points can be optimized to provide reactive power support and efficiently deal with voltage issues. Controllable loads, such as air-conditioners and refrigerators, can balance fluctuations from renewables and reduce peak network demand by essentially acting as virtual batteries. Due to these, there has been increasing effort on characterizing the flexibility available from DERs and on the aggregation of such flexibility.

The flexibility polytope of a single PV inverter, as shown in the figure below, captures all feasible active and reactive power operating points. The flexibility polytope of a battery or a storage-like load extends to higher dimensions to capture the internal state of charge dynamics over several time-periods. The aggregate flexibility from a population of DERs can be obtained by computing the Minkowksi sum (M-sum) of the individual feasible sets. However, since M-sum represents the element-wise summation, the exact computation of M-sum is computationally very challenging, especially in higher dimensions (4-D and above) and for a large population.

In this work, we develop and compare algorithms to compute M-sum approximations of flexibility polytopes. Using a novel polytope decomposition and an interval summation technique, we show how the aggregate polytopes can be rapidly computed. Unlike many existing algorithms that work only in low dimensions, our algorithm extends efficiently to higher dimensions. Using our method, the approximation accuracy reached 95% in a 2-D case, within 20 seconds, and 70% in an 8-D case, in less than a minute. These aggregate flexibility polytopes are finally used in an optimal power flow problem to provide voltage support in a power distribution grid and to attain optimal charging schedules for a population of air-conditioners and electric vehicles.

Flexibility Polytopes for (a) a PV Inverter and (b) an Air-conditioner



(a) (b)