EE 292K Project Proposal: Optimal Tradeoffs between Demand Response and Storage with Variable Renewables

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1 Motivation

In the analysis and optimization of traditional power systems, one key binding constraint is the "instantaneous balance" between power supply and demand. However, recently, fueled by the advances in technologies, two key techniques in the smart grid vision, demand response and energy storage, can be implemented to relax this constraint by effectively shifting the supply or demand of the power system in the time horizon.

It is well known that deploying such techniques can potentially improve the "social utility" of the power system. Many recent literatures are dedicated to analyzing the role of demand response or energy storage in the smart grid (see [1]). However, to the best of our knowledge, currently there is no existent work that has explicitly studied the trade-offs between these two techniques. The main objective of this project is to fill in this gap.

In addition to demand response and energy storage, the third key component of the smart grid is the renewable generation, which presents significant challenges in power system operations due to the stochastic nature of the energy derived from wind, sun and tides. In this project, we consider power systems incorporating renewable generation, demand response and energy storage, and our main goal is to explicitly characterize the tradeoffs between demand response and energy storage in such power systems.

2 Project Plan

In our tentative plan, this project proceeds as follows:

- First, we motivate and propose the "central planner" assumption, which assumes that the whole power system is controlled by a "central planner" who aims to optimize the social utility of the power system. The main motivation for this assumption is that according to the second theorem of welfare economics, once the optimal scheduling strategy of the central planner is available, a competitive equilibrium (CE) obtaining the optimal social welfare can be easily derived.

- Second, motivated by the small prediction errors of the renewable generation and consumer requests, we show that at each time step, the whole power system can be partitioned into one bulk power system and (possibly multiple) residual power systems. Table 1 summarizes the comparisons between a bulk power system and a residual power system. The timeline in each time period is summarized in Figure 1. Many recent literatures have been dedicated to solving the OPF problem associated with the bulk power system. In this project, we focus on solving the stochastic control problem associated with a residual power system, and analyze the optimal tradeoffs between demand response and storage in a residual power system.

A single-bus residual power system is illustrated in Figure 2, where the components inside the dotted frame are controlled by the central planner.

- Third, we formulate the social utility optimization problem in a residual power system as an average-cost stochastic control problem, and present how to solve this problem based on dynamic programming (DP). Although we cannot derive a closed-form solution for this stochastic control problem, however, since the residual power system is single-bus, we will show that it is computationally tractable to solve this problem numerically. Furthermore, we will present some preliminary analytical results about the average cost and the cost-to-go function. For example, we will prove that the optimal average cost is monotone in some design parameters.
- Finally, we will demonstrate a realistic numerical example.

References

[1] Han-I Su and Abbas El Gamal, "Modeling and Analysis of the Role of Fast-Response Energy Storage in the Smart Grid", working paper.

	Bulk Power System	Residual Power System
Power Flow	AC power flow	DC power flow
Number of Buses	multiple buses	single bus
System Dynamics	time-varying deterministic	time-invariant stochastic
Optimization Techniques	traditional OPF	stochastic control
Decision Time	before observing the prediction errors	after observing the prediction errors

Table 1: Comparison between bulk and residual power systems

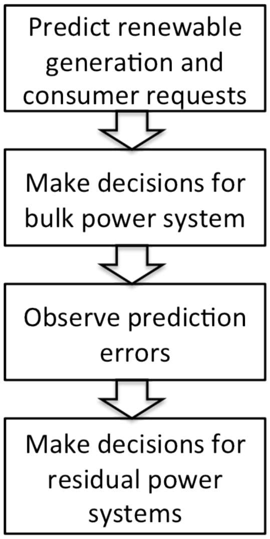

Figure 1: Timeline at each time period

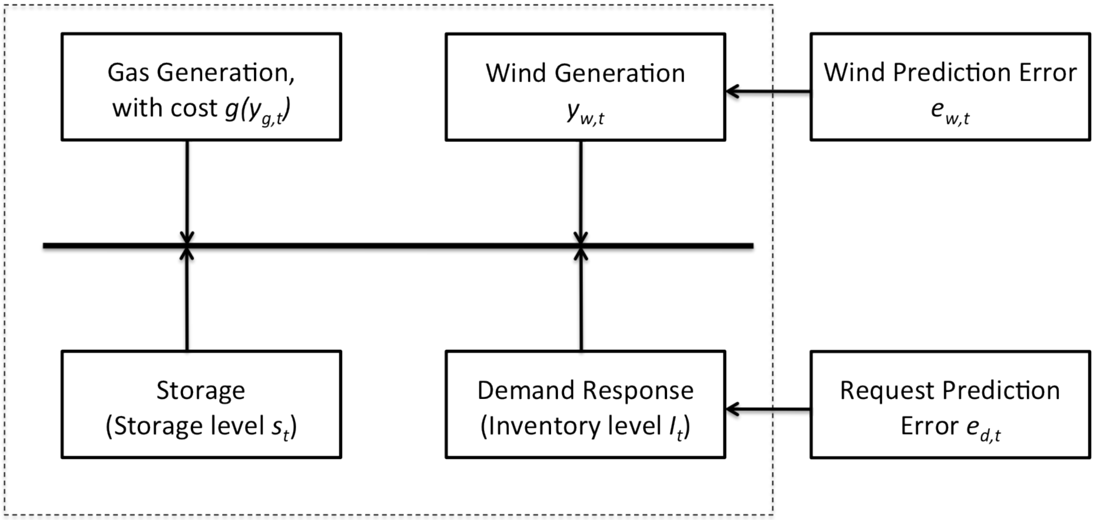

Figure 2: A single-bus residual power system