Renewable Energy and the Smart Grid

Sujet de stage M2

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Context: Why is the Smart Grid interesting today and tomorrow?

Consider the situation today in the United States: The gas industry claims that at current demand, there is enough natural gas from "fracking" (Hydraulic fracturing) to last one hundred years. However, with the reduced cost of natural gas, its use has doubled, which means that there will be nothing left in just 50 years. Most European countries are fighting against fracking because of the real danger of pollution, especially the destruction of underground water supplies. Without action, there will be no energy infrastructure in one or two generations. There is of course also the problem of global warming. Energy research is of incredible social importance, and there is a need for fundamental research to create a sustainable future.

Coping with volatility. The deployment of renewable resources presents major challenges in system operations. Wind and solar energy are intermittent — volatile on short and long time-scales. Even if their output was perfectly predictable, managing this volatility would not be a simple task. The main difficulty comes from very limited possibilities of power storage; power production and demand must be matched as close as possible at any time.

Fig. 1 shows typical data from the Bonneville Power Administration. The four plots are explained as follows: green is energy from wind, red is load, blue is hydro-generation, and brown is called "thermal", meaning traditional gas-turbine and coal (mainly natural gas). Typically there is lots of hydro power, so the extra is sold to Canada.

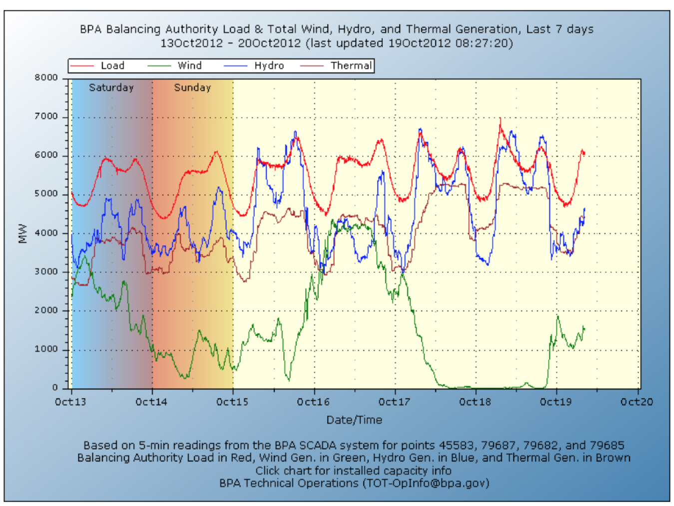

Figure 1: A fall day in the U.S. North-West

Variability of wind generation is much greater than variability in demand (load). The variability seen in hydro- and thermal-generation is a result of *control* required to mitigate volatility in demand and in supply of electricity from wind. Resources that help to cope with volatility are called *ancillary services*. Ancillary services are needed on a range of time scales.

The high frequency regulation needs are broadcast by the power authority in charge of the grid. Fig. 2 shows this signal for one week in the fall of 2012. Note the dramatic spike of $\pm$ one gigawatt of electricity during the afternoon of October 31.

Volatility like this will increase as more and more renewable energy is brought on-line.

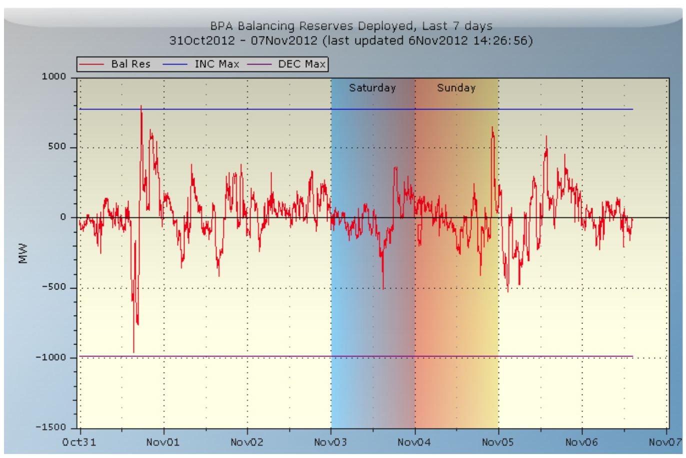

Figure 2: Regulation needs at BPA

Objetives

The objective of this internship is to propose a basic model for distributed energy production taking into account its volatility, and investigate the possibilities of different resources for control (responsive generators, energy storage, controlable demand).

A Basic Question. How do we deal with so much volatility in a large network?

Some may say, *build a large enough transmission grid, and it will all cancel out.* There are two difficulties with this response. First, there is huge correlation in wind over a large geographic area. Second, a large grid has dynamics – like a large interconnected set of masses and springs. There are stability issues that must be addressed.

We need resources to deal with these fluctuations in supply. This is in part a network architecture question since we need resources, and we need to know where to place them to maximize their value.

Below is a partial list of sources of ancillary service:

(i) Traditional generation (coal is slow, gas is faster)

(ii) Capacitors and batteries

(iii) Demand response. Examples are pool pumps, plug in electric vehicles, and air conditioning and heating (HVAC) for both residences and commercial buildings. Note that Google is a huge consumer of energy for cooling their servers - the cooling is very flexible because big buildings have lots of inertia (see [2]).

(iv) *Flexible manufacturing* will grow in importance – this is already important today. This includes actually manufacturing such as the manufacture of aluminum, and also flexibility in some operations such as pumping water over the mountains.

Once we have these resources in place, we need approaches to control. Control is a bit tricky because of a) politics, and b) we don't want centralized control. That is, an operator in Madrid shouldn't be controlling a pool pump in Nice. The control could be autonomous, based on local measurements (phase and frequency of power), and perhaps a global signal from "Madrid" that provides an indication of the needs of the grid, such as the regulation signal shown in Fig. 2. There are also state estimation issues – the operator in Madrid wants to know the percentage of pool pumps that might respond to a signal, and adjust the signal accordingly.

Reading

A beautiful introduction to this problem can be found in [1]. See also [3] and [4].

Prerequisites. Basic knowledge of probability theory is required. Some prior experience with programming (C, C++ or Matlab) is strongly recommended.

Other. Co-advised by Sean Meyn (University of Florida). There is a possibility to continue with a PhD.

References

[1] D.S. Callaway and I.A. Hiskens. Achieving controllability of electric loads. *Proceedings of the IEEE*, 99(1):184 –199, jan. 2011.

[2] H. Hao, P. Barooah, T. Middelkoop, and S. Meyn. How demand response from commercial buildings can provide the regulation needs of the grid. In *Proc. of the 50th Annual Allerton Conference on Communication, Control, and Computing*, 2012.

[3] S. Koch, J. Mathieu, and D. Callaway. Modeling and control of aggregated heterogeneous thermostatically controlled loads for ancillary services. In *Proc. PSCC*, pages 1–7, 2011.

[4] J.L. Mathieu. *Modeling, Analysis, and Control of Demand Response Resources.* PhD thesis, 2012.