Weather Forecasting &
The Renewable-Heavy Power Grid

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Weather and the Power Grid

Marriage of Physics and Economics

• The “Grid” effectively has no storage
  • Nothing of sizable consequence at least
  • This means that supply must match demand minute-to-minute, to high precision

• Slight mismatches can be handled
  • Turbines/Generators can flex their rotational inertia
  • Load shedding deals with large consumers
  • BUT beyond very slight mismatches, damage to equipment and blackouts result

• Some of the detailed tuning can be accomplished by peaking power plants whose output can be fine-tuned minute by minute
  • Think of a jet engine with a throttle
  • When there is excess capacity other generators can be brought on line BUT these get $$$

• It’s much more cost-effective to schedule generation using a forecast of needed power
Demand and supply don’t have to match *exactly* in each of these regions, since they can exchange power across borders (BPA and CAISO have a particularly efficient High Voltage Direct Current connection)

**BUT**

Imports and exports are limited and have to be arranged in advance, so we really do have many functionally independent grids that need to be kept in balance.
Installed/Potential Wind Capacity

Q4 2016 Installed Wind Power Capacity (MW)

Total Installed Wind Capacity: 82,171 MW
Source: American Wind Energy Association Q4 2016 Market Report

U.S Potential Wind Capacity in Megawatts (MW) at 80 Meters

Total Potential Wind Capacity: 10,640,080 MW
Source: AMI Truepower, NREL

Renewables are a Significant & Growing Part of the Generation Stack

SPP Generation Mix


PJM Generation Mix


ERCOT Generation Mix

Data courtesy of ERCOT, MDA figure.
Renewables are a Significant & Growing Part of the Generation Stack

California Electrical Generation Mix March 8, 2011

California Electrical Generation Mix March 8, 2017

We can simulate the weather-dependent part of electrical demand using forecast temperature data (weighted by population) and actual demand data.

Data courtesy of ERCOT.

 Scatter driven by time of day, day of week, industrials, commercials, etc.
Forecasting Electrical Load using Numerical Weather Prediction (NWP) Models

The map at left shows a forecast field of temperature (bluer=colder), with population centers labeled by their forecast temperature in degrees Fahrenheit.

To forecast demand, we need to interpolate the forecast of temperature to the location of each population center, and then calculate the power that city would require at the forecasted temperature. Of course, we also need to bear in mind the human variability of electrical demand, such as weekday/weekend changes in behavior, day/night changes in lighting needs and activities.
Keeping track of our past forecast errors, and using a large number of weather forecast models allows us to estimate the uncertainty in our forecast, which is helpful to grid operators trying minimize blackout risk and to energy traders trying to understand their own level of financial risk.
Schematic of Wind Generation Forecasting

Locations and Properties of Wind Farms

Wind Turbine Power Curves

Past NWP forecasts of wind

Observed Wind Generation Data

Tuned wind generation model

Wind Generation Model

Numerical Weather Prediction Models

Dynamical Wind Generation Prediction
Wind Farm Locations & Properties

We use a parametric power curve that allows for the actual values of the cut-in, rated and cut-out wind speeds for each turbine type at each wind farm in each RTO.

Farm locations and generation capacity are indicated by dots, scaled by size (largest is 444 MW).
We can use archived model forecasts of past weather (these are done retrospectively as new models are introduced, resulting in a simulation of past weather called a “reanalysis”).

This allows us to explore what kind of variability should be expected over the life of a wind farm, or to see how a renewable-heavy grid would function.

Seasonal variability is pronounced, but different in ERCOT and MISO. In ERCOT, springtime stands out as consistently windier than other seasons, while in MISO, summer stands out as consistently calmer.
Forecasting Wind Speeds
Numerical Weather Prediction (NWP) Models

The map at left shows a forecast field of wind speed (bluer=faster), with direction indicated by arrows, and wind farm locations by black dots.

To forecast wind generation, we need to interpolate the forecast of wind speed to the location of each wind farm, and then calculate the power that farm would generate at the forecasted wind speed.
Forecasting Wind and Solar Generation using Numerical Weather Prediction (NWP) Models
Schematic of Electrical Load Forecasting

Population and infrastructure density maps/data

Past NWP forecasts of “weather”

Observed Electrical Demand Data

Tuned Load Model

Load Model (Net Load)

Dynamical Load Prediction

Numerical Weather Prediction Models

Demand

Supply

Numerical Weather Prediction Models
Conclusions

- Weather forecasts are a crucial input to a well functioning power grid
  - Demand and Supply

- Increases in weather predictability/skill has allowed much better prediction of demand & supply
  - Encourages more integration and development of “renewables”
  - Results in increased challenges AND/BUT increased benefits

Other Moving Targets (Challenges)

- Efficiencies, New Fuel(s), Storage, Transmission/Distribution, Demand Management, the Economy, the Unknown-Unknowns
Q & A

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