20-Renewable Energy Integration

ECEGR 4530

Renewable Energy Systems

Overview

- Introduction
- Generation
- Load
- Generator Commitment

Introduction

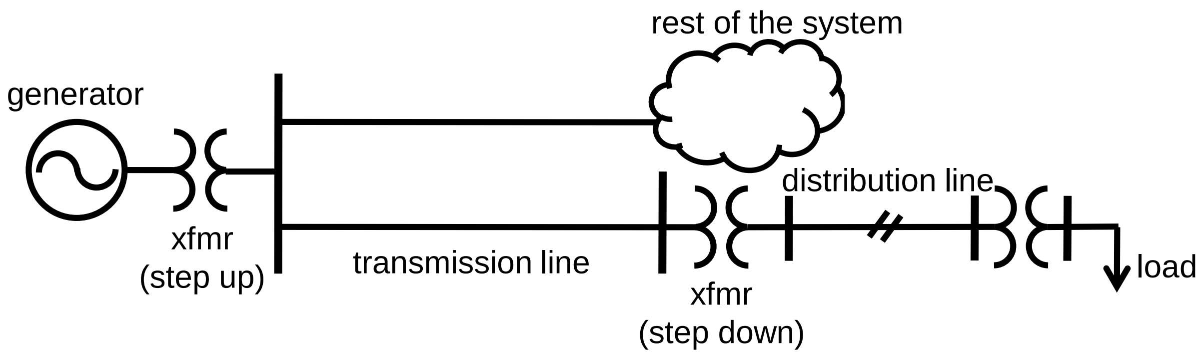
- The power system is NOT “plug-and-play”
- Renewable resources are not always good citizens
  - intermittent availability
  - variable power output
  - difficult to predict (in many cases)
  - reactive power consumers (if induction generators are used)

Introduction

- A level of accommodation is necessary to integrate renewable resources
- What determines how ease/difficult it is to integrate?
  - characteristic of renewable resource
  - characteristics of the power system

Introduction

- Recall that power systems are comprised of three classifications of components
  - generation
  - transmission
  - load



Generation (2015 Data)

- Total number and capacity of generators in U.S.: 20,068
  - Natural Gas: 5,774; 503,936 MW
  - Hydro: 4,020; 78,956 MW
  - Petroleum: 3,550; 42,321 MW
  - Coal: 968; 304,789 MW
  - Wind: 1098; 73,393 MW
  - Solar PV: 1633; 11,983 MW
  - Solar Thermal: 19, 1,774 MW
  - Geothermal: 197; 3,811 MW
  - Nuclear: 99; 103,860 MW
- Total nameplate capacity: 1,167,365 MW

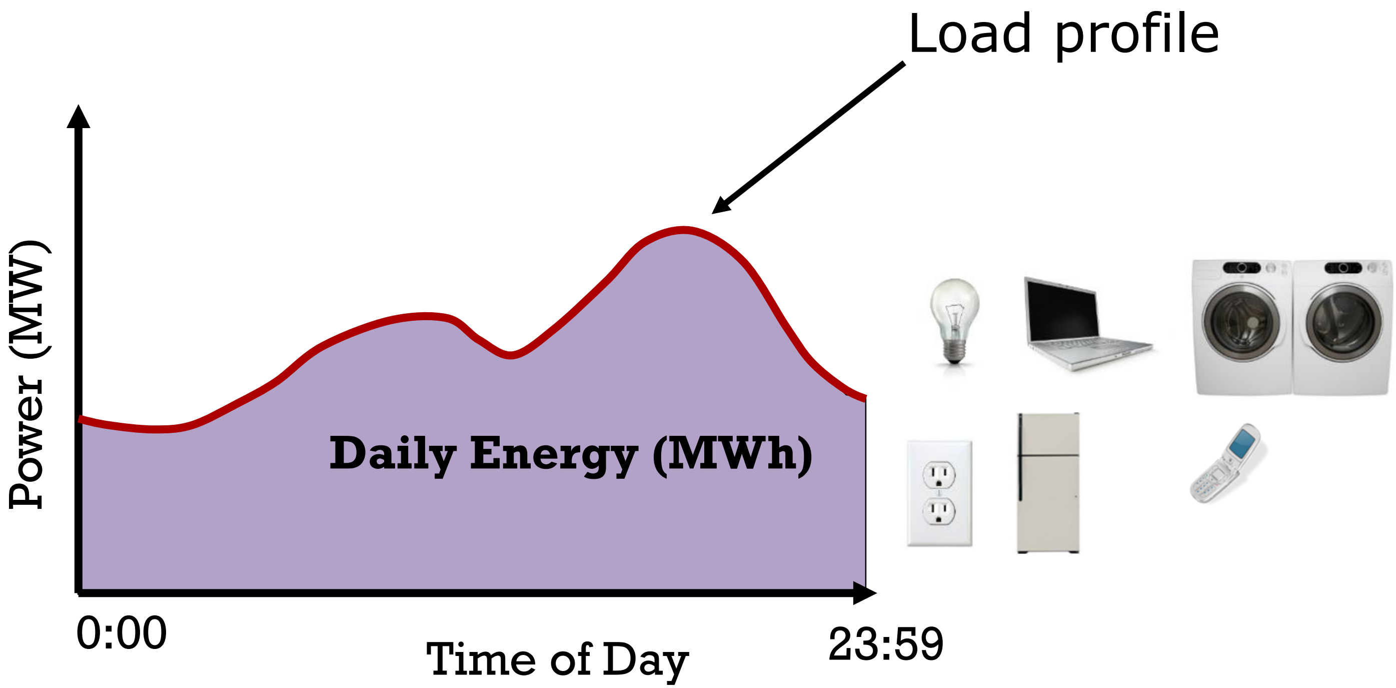
A single power plant may have more than one generator.

Generation-Load Balance

- Power generated must equal load (plus losses) at any instant
- If load exceeds generation, kinetic energy is extracted from the rotors, slowing down their rotational speed
  - System frequency decreases
- If generation exceeds load, kinetic energy is added to the rotors, increasing their rotational speed
  - System frequency increases

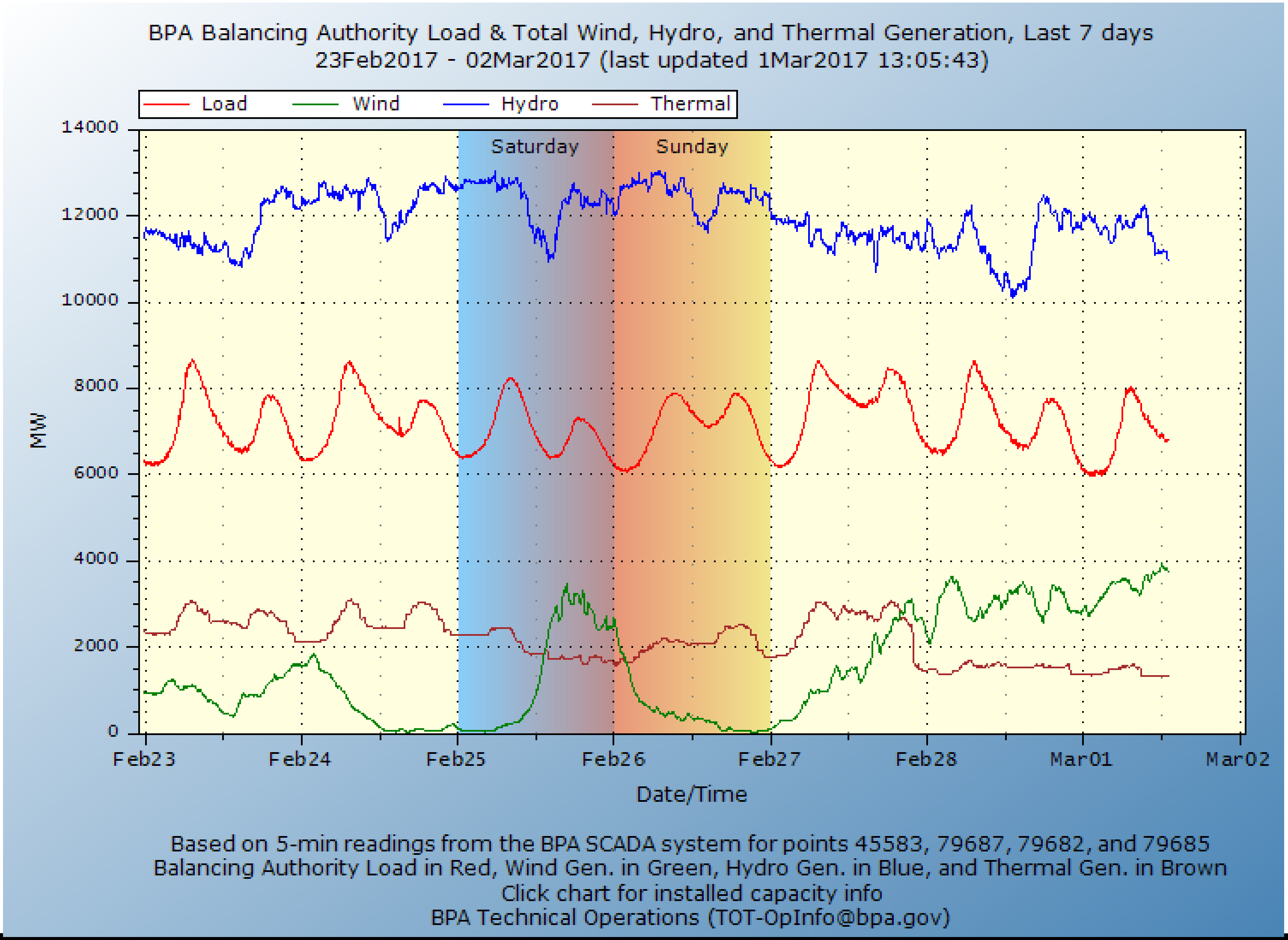
Generation-Load Balance

- Rotating machines provide the inertia that buffer against moment-to-moment mismatches in generation and load
- If load increases for a prolonged period, the generation must also increase or the system frequency will eventually decay to zero
  - But the generators will have tripped off-line before this happens


Load profile
Power (MW)
Daily Energy (MWh)
0:00
Time of Day
23:59

Load Profiles

- Load profiles are influenced by:
  - Time of day
  - Day of week
  - Season
  - Special events (e.g. Super Bowl)
  - Weather (primarily temperature)
- Customer size and make up (commercial, industry, business, etc.)


BPA Balancing Authority Load & Total Wind, Hydro, and Thermal Generation, Last 7 days
23Feb2017 - 02Mar2017 (last updated 1Mar2017 13:05:43)
Load
Wind
Hydro
Thermal
Saturday
Sunday
14000
12000
10000
8000
6000
4000
2000
0
MW
Feb23
Feb24
Feb25
Feb26
Feb27
Feb28
Mar01
Mar02
Date/Time
Based on 5-min readings from the BPA SCADA system for points 45583, 79687, 79682, and 79685
Balancing Authority Load in Red, Wind Gen. in Green, Hydro Gen. in Blue, and Thermal Gen. in Brown
Click chart for installed capacity info
BPA Technical Operations (TOT-OpInfo@bpa.gov)

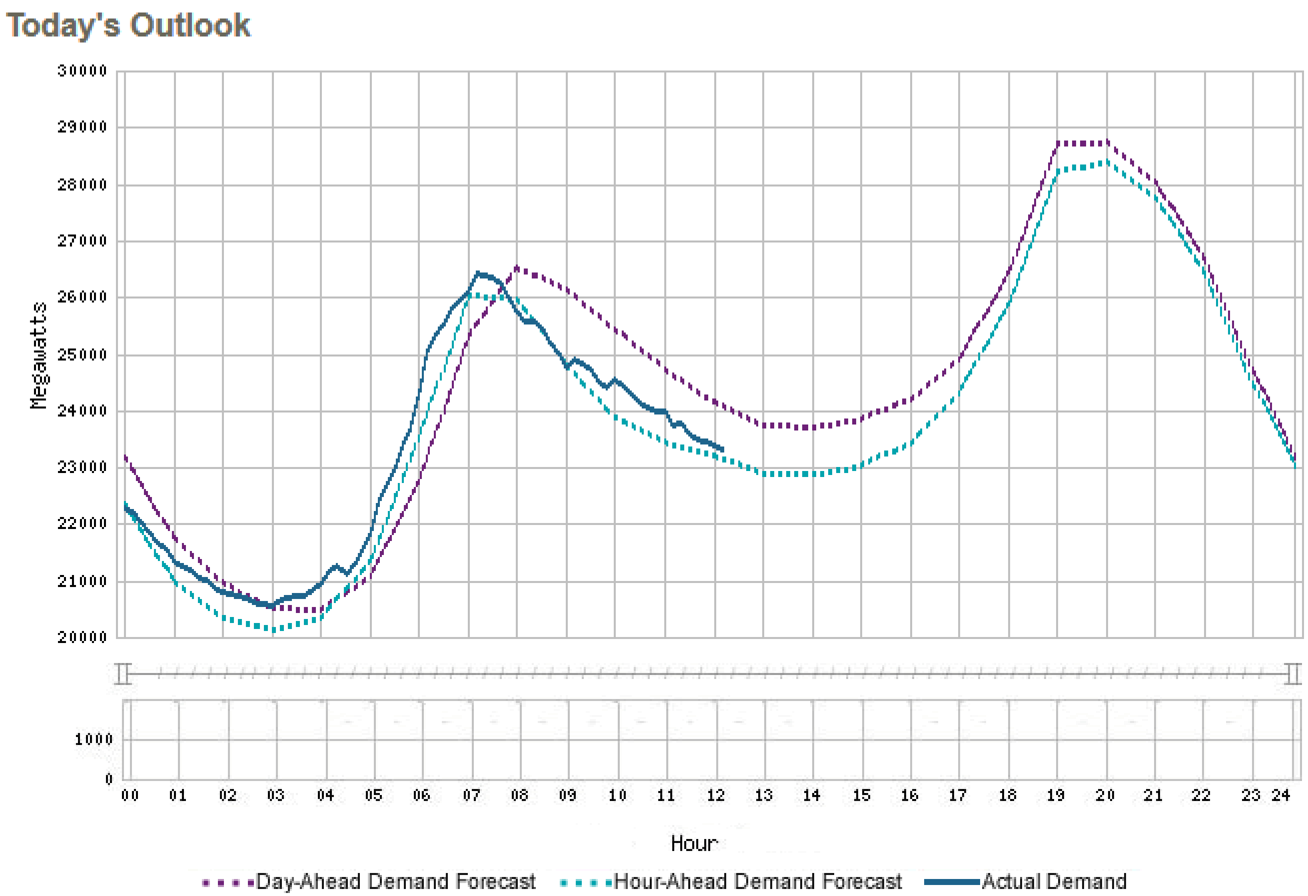
Generator Commitment & Dispatch

- System operators attempt to dispatch and commit generators to match supply and demand, plus a safety margin in case of a contingency
  - Contingencies typically include: loss of generator(s), transmission line(s)
- Forecasting load, and control of generators are important in maintaining system reliability

Load Forecasting

- Load profiles can generally be accurately predicted
  - Utilities have long historical records
  - Models account for day of week, temperature, season, etc.
- As forecast horizon (amount of time in the future the forecast is for) increases, accuracy decreases
- Utilities make forecasts with different horizons and durations
  - Hour ahead (or even less)
  - Day ahead

- Day-ahead forecast matches actual shape
- Hour-ahead forecast has greater accuracy



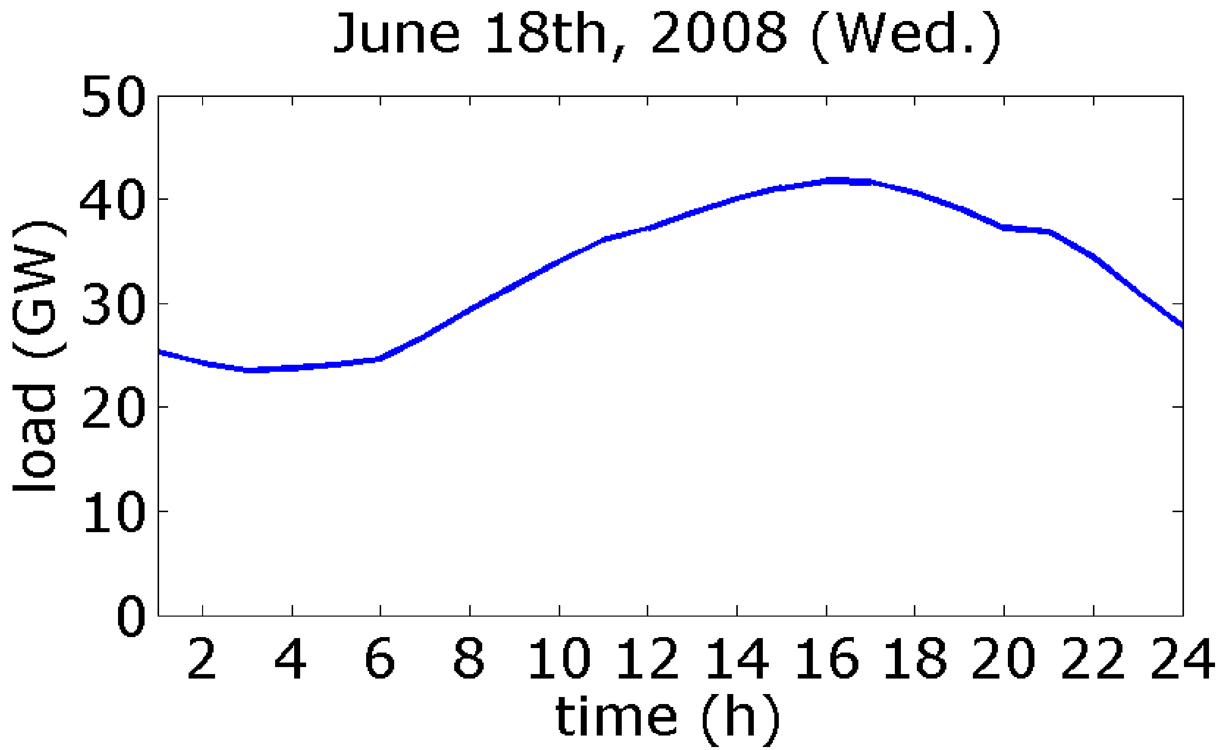
California ISO

Generator Commitment

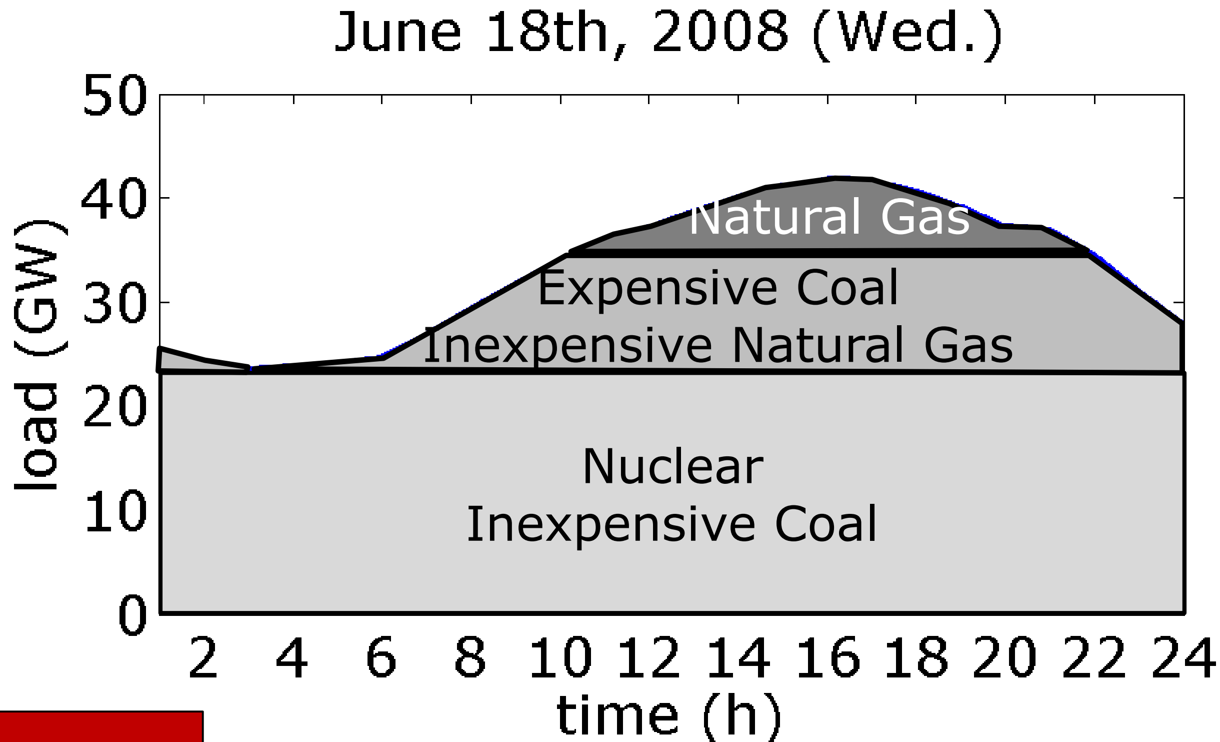
- Nuclear and Coal-fired power plants
  - Long start-up times from several hours to days
  - Slow ramp rates
  - Inexpensive
- Natural Gas power plants
  - Short start-up times
  - Fast ramp rates
  - Expensive

Generator Commitment

- How should power plants be dispatched to satisfy the load?



Generator Commitment

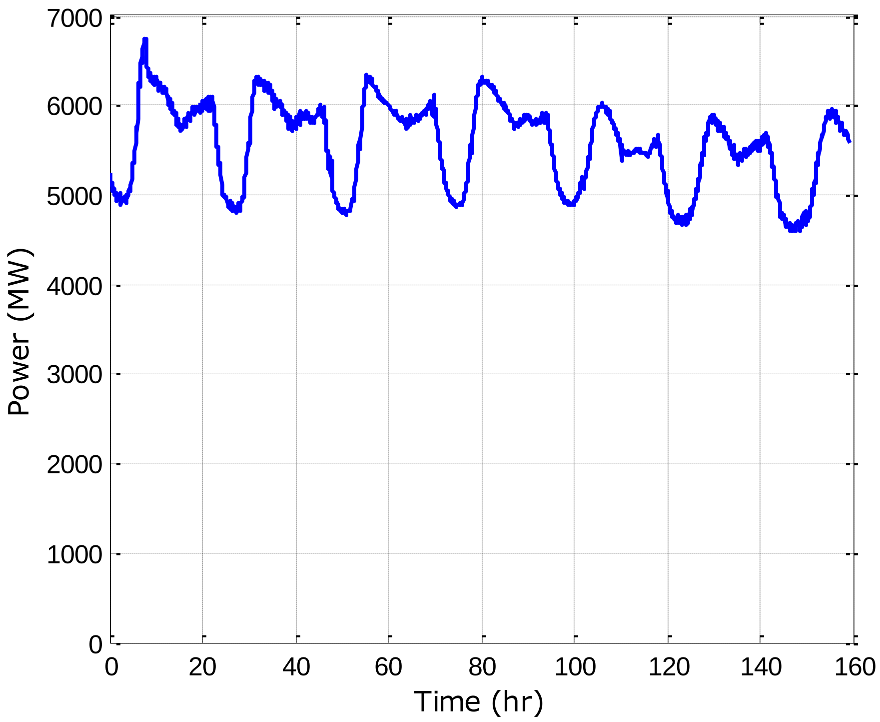


Natural gas is now displacing coal

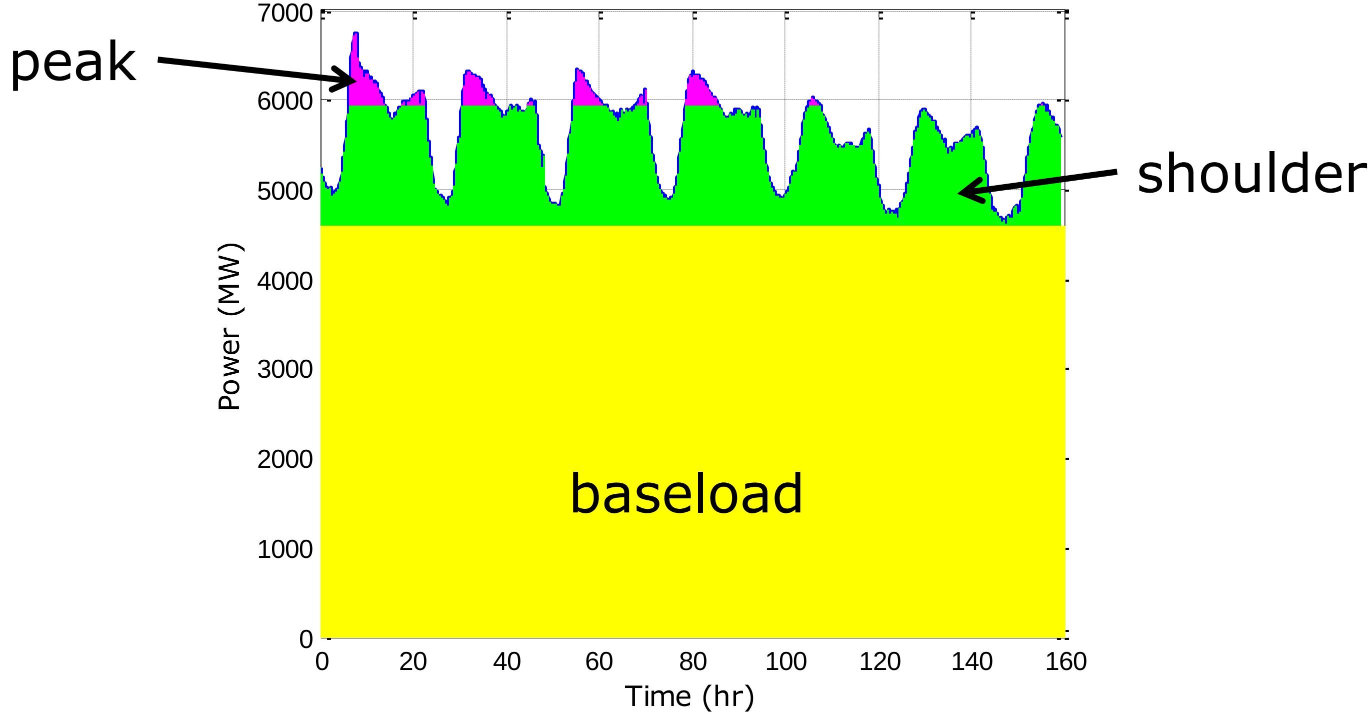
Integration of Renewable Resources

- How does the inclusion of uncontrollable renewable resources affect generator commitment?
  - We can control the resource to produce less power, but not more

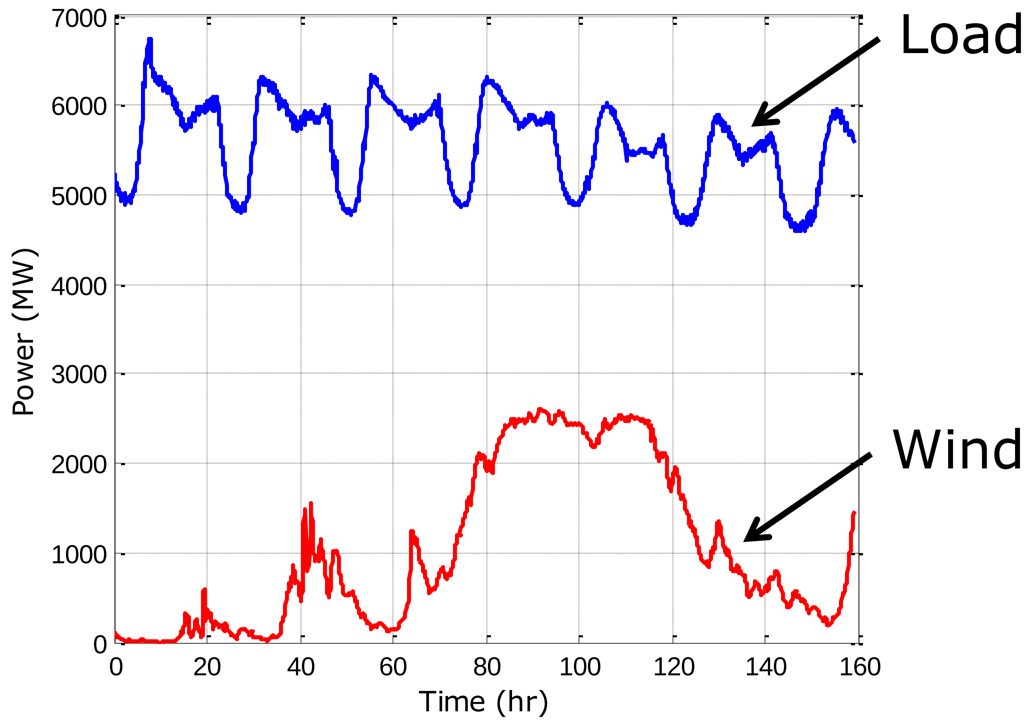
Integration of Renewable Resources



Integration of Renewable Resources

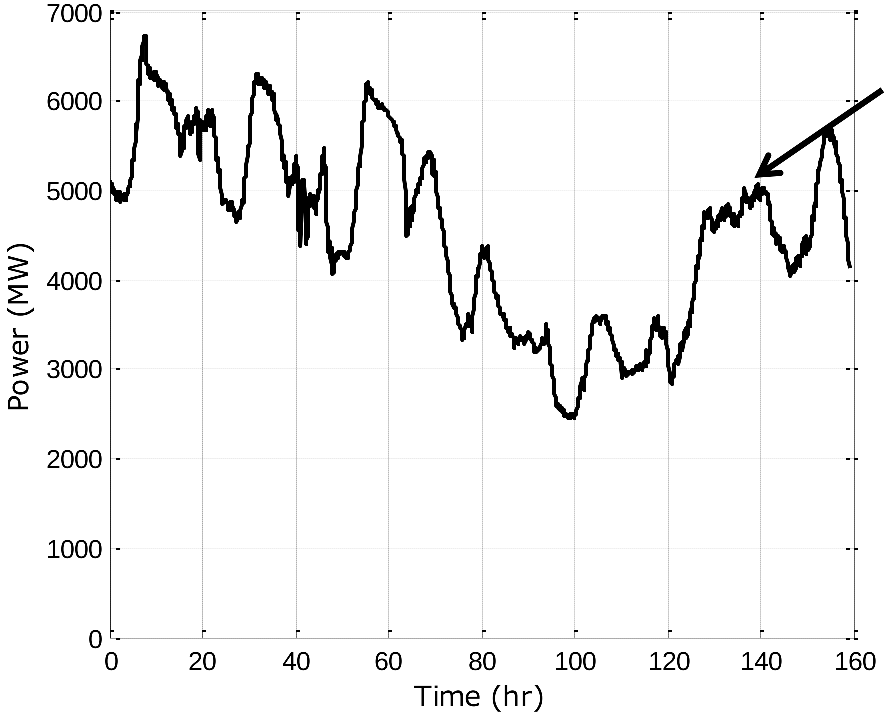


Integration of Renewable Resources



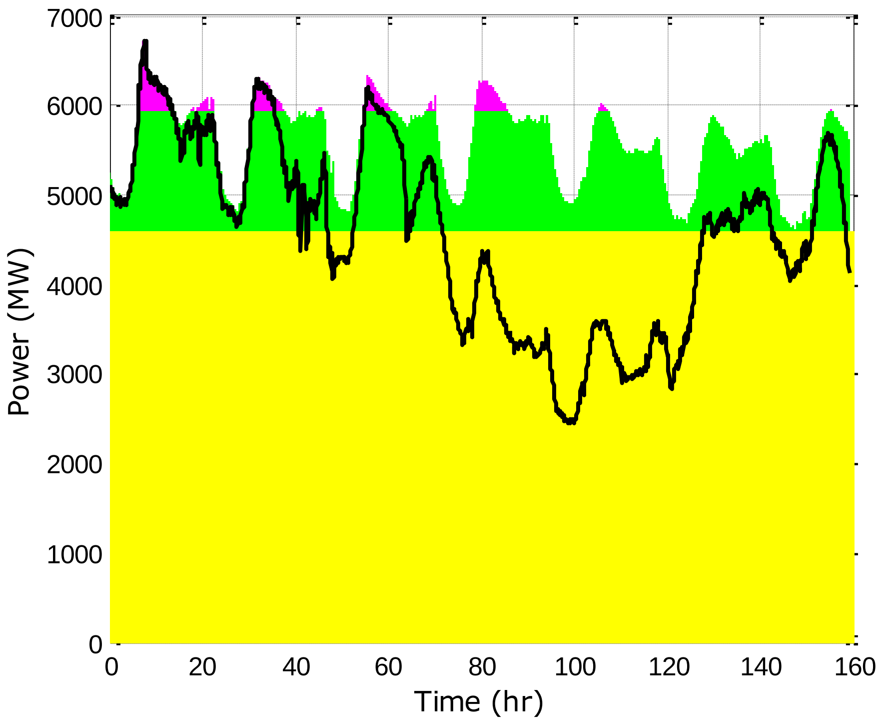
Note: Total Wind Plant Capacity is 2780 MW

Integration of Renewable Resources

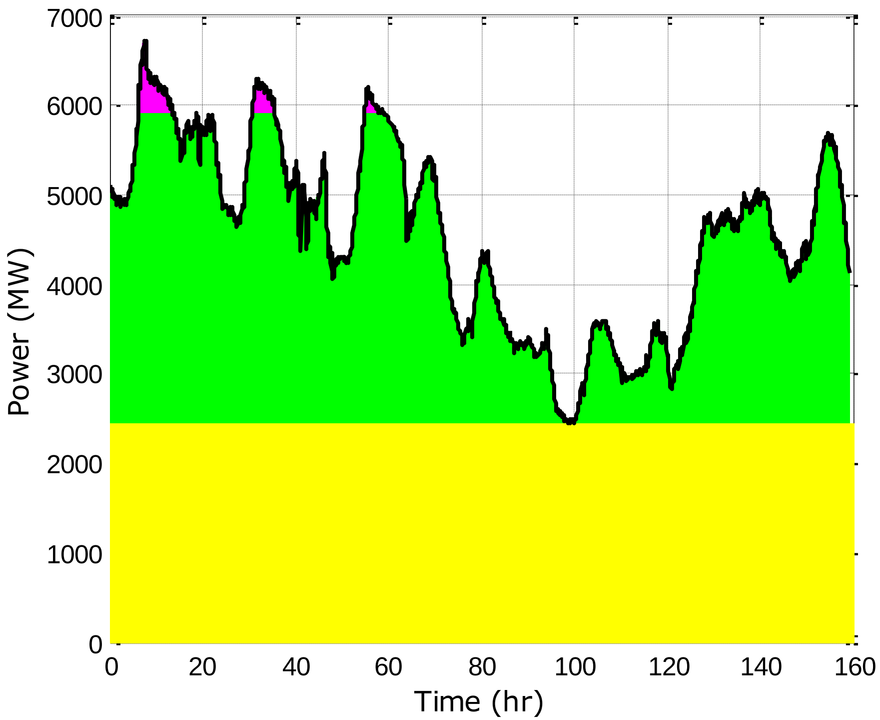


Net Load
(Load – Wind)

Integration of Renewable Resources

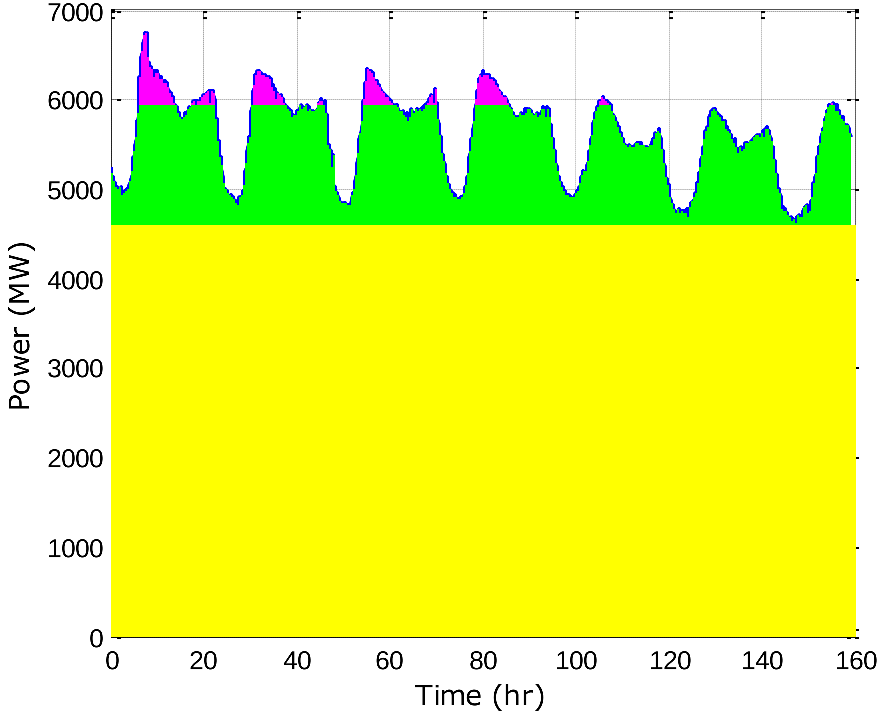


Integration of Renewable Resources

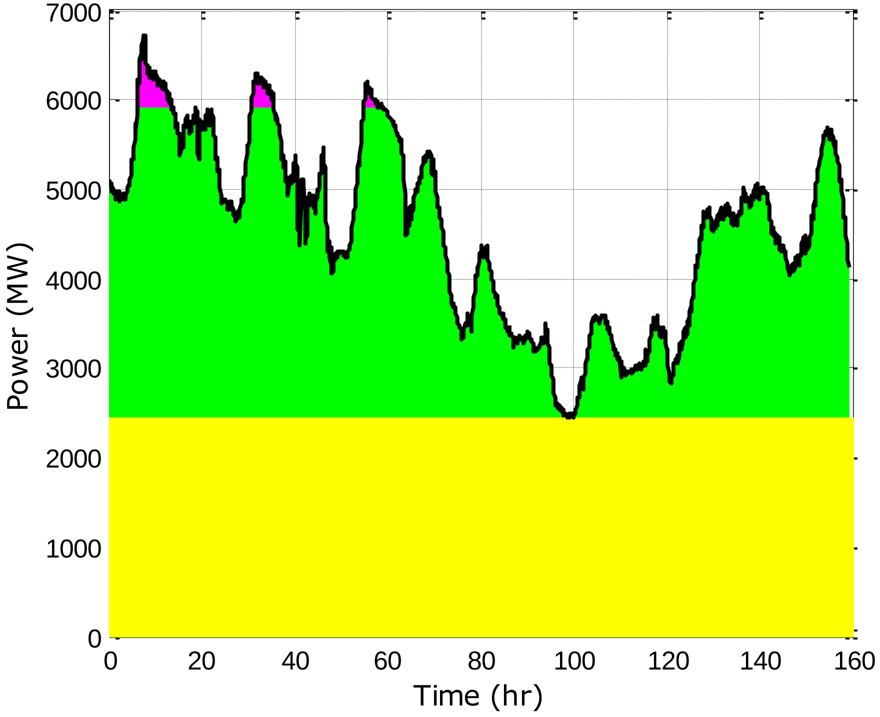


Integration of Renewable Resources

Without Wind



With Wind



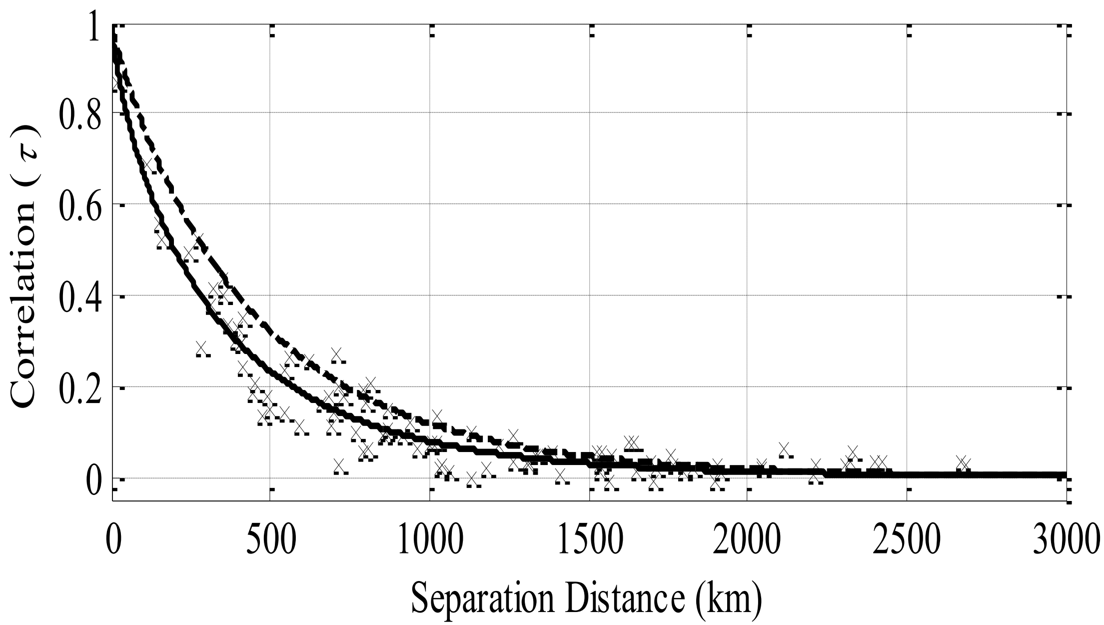
Integration of Renewable Resources

- Presence of wind plants disrupts the "natural" commitment of generators
- Assuming integration is done into an existing system (i.e. non-renewable generators are already built)
  - Baseload units may not run continuously
  - Shoulder units may start-up, shut down and ramp more frequently
  - Peaking units may or may not be used more often
- All of the above threaten reliability and economy of the power system

Integration of Renewable Resources

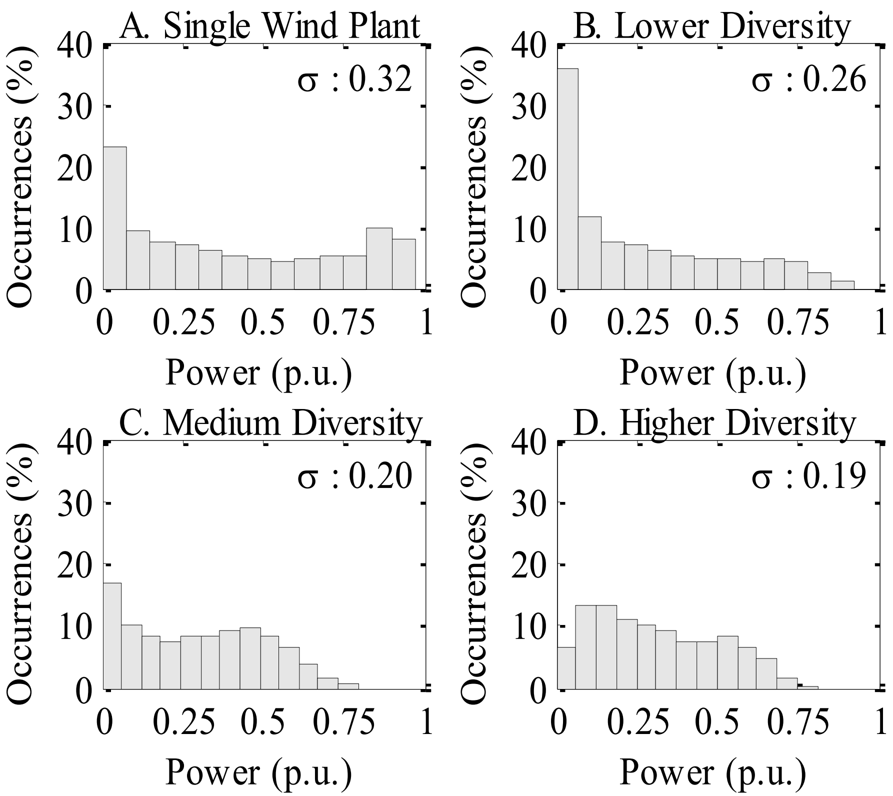
- Factors affecting integration of renewable resources:
  - Capacity
  - Resource characteristic
    - Correlation with load
    - Variability
    - Uncertainty
  - Transmission
  - Generation Resource Mix (flexibility of the system)

Geographic Diversity



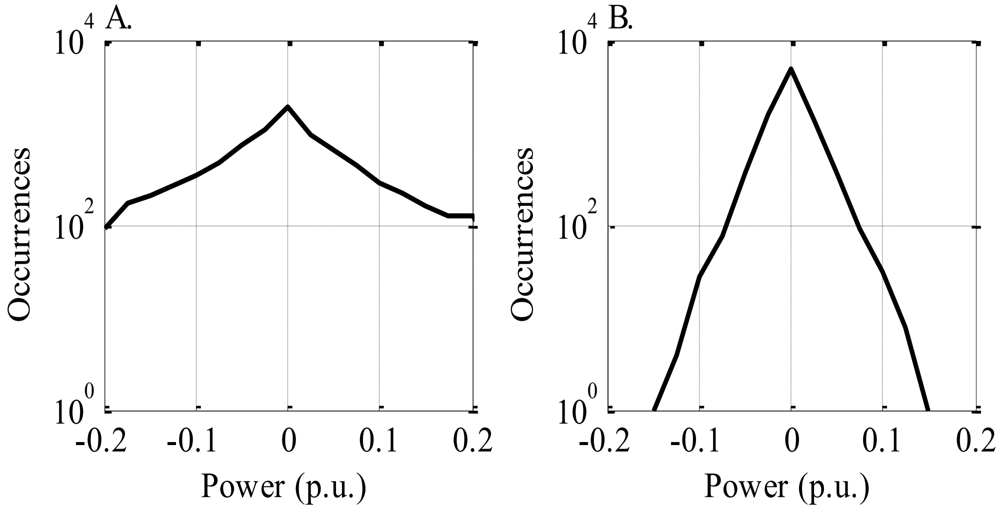
Correlation of wind power decreases as separation of wind plants increases

Geographic Diversity



PDF tends toward a Normal distribution as diversity increases.

Smoothing Effect

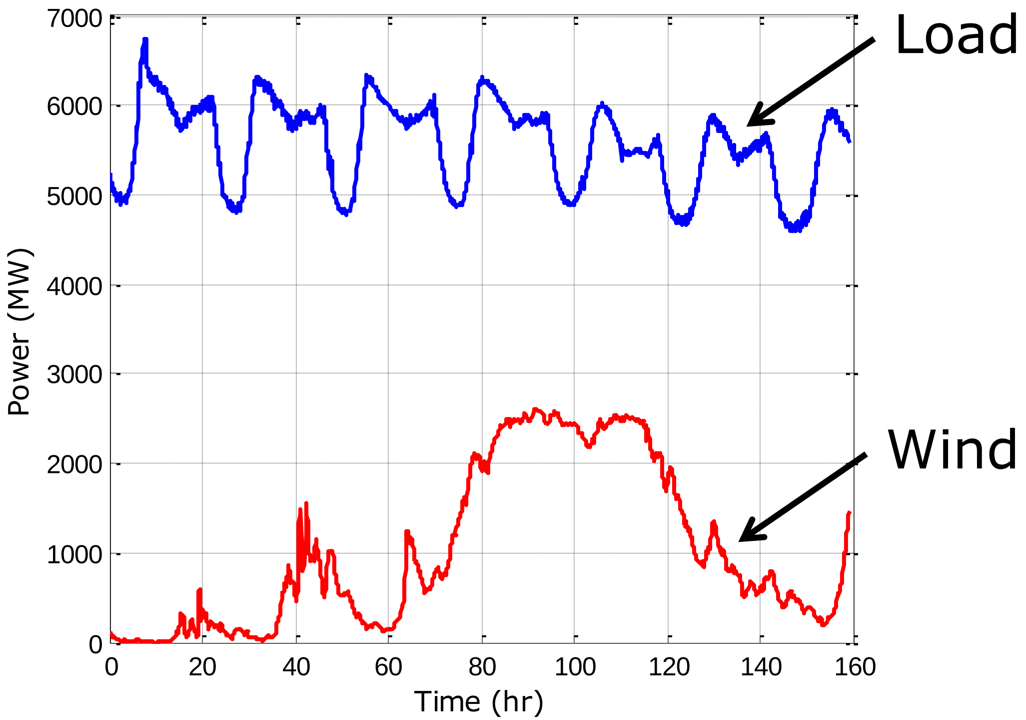


Variation is larger for single wind plant (A) than a large system (B)

Renewable Resource Penetration

- Penetration by Energy: ratio of energy from renewable resource to energy consumed by load over a given period
- Penetration by Capacity: ratio of total wind plant capacity to peak load (annual or given period)

Renewable Resource Penetration

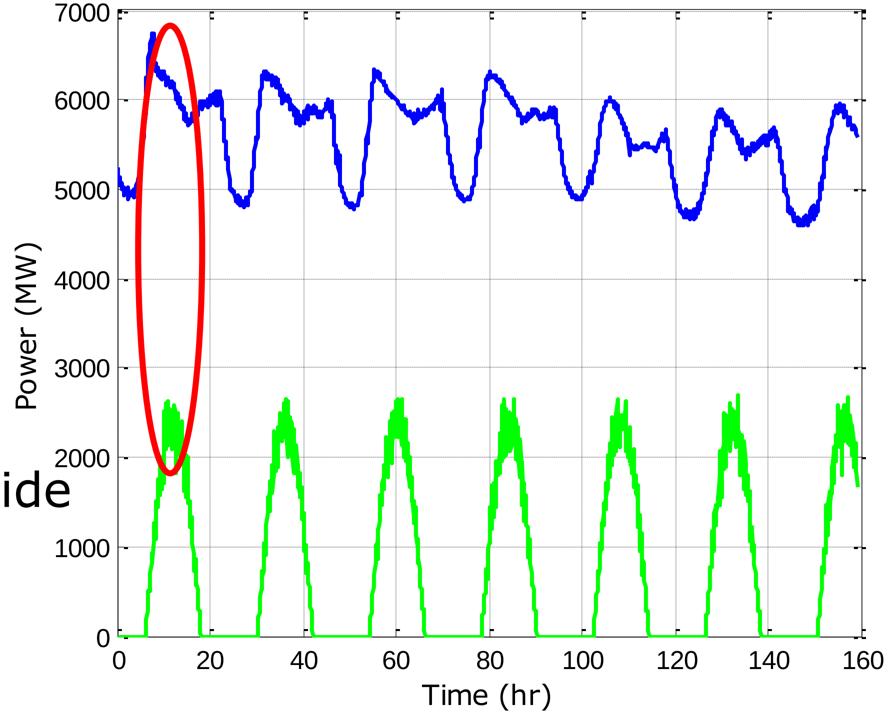


Renewable Resource Penetration

- Penetration by Energy: 18%
- Penetration by Capacity: 42%

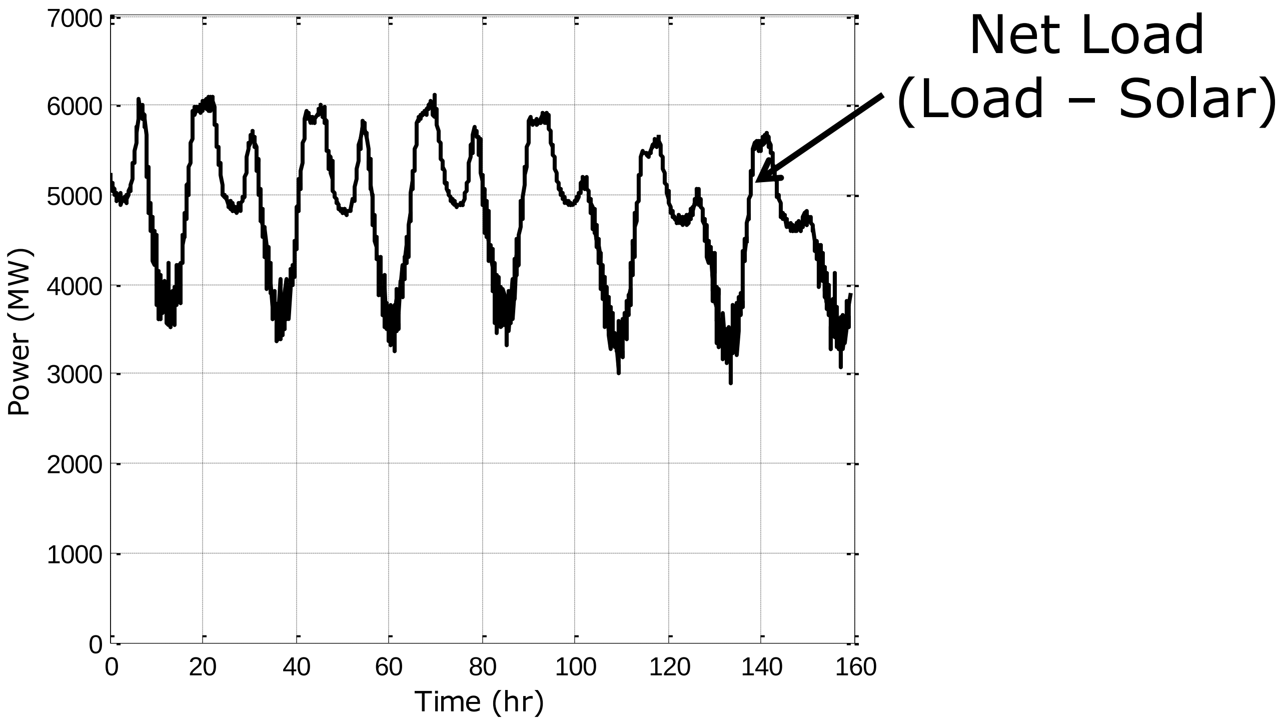
Integration of Renewable Resources

- Assume that instead of wind plants, the renewable resources is PV plants (2,780 MW)



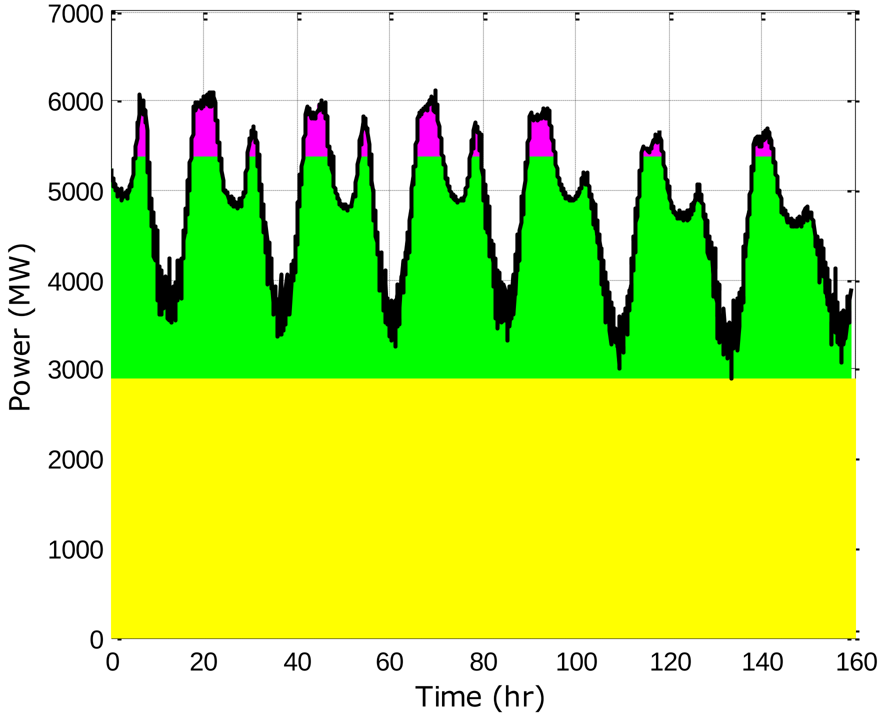
Solar tends to coincide with peak load

Integration of Renewable Resources

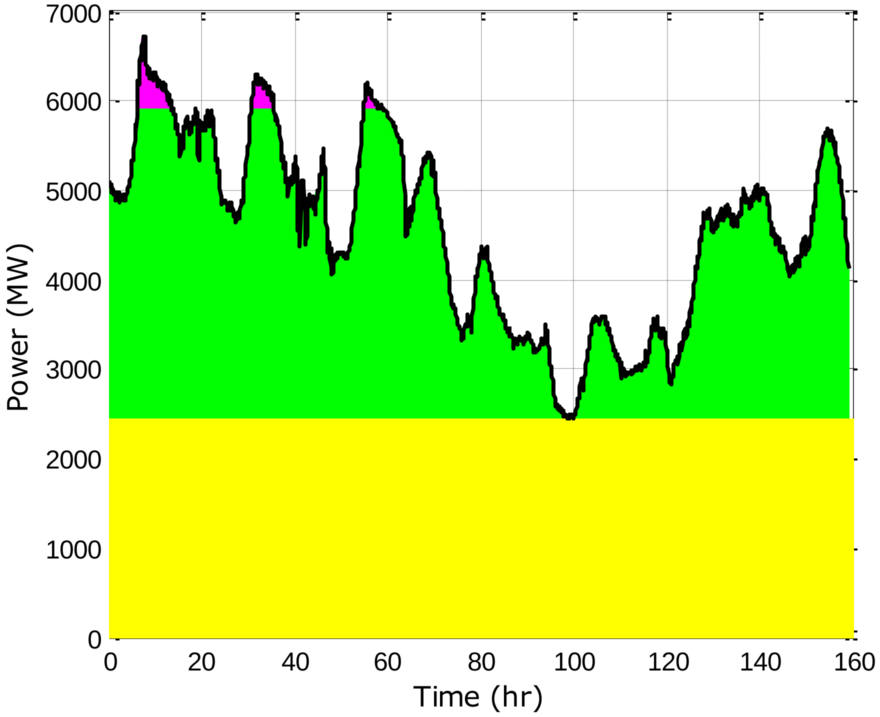


Integration of Renewable Resources

With Solar



With Wind



Integration of Renewable Resources

- Integration of solar power tends to be easier than with wind power
  - Easier to forecast
  - Coincides with peak load
    - Beneficial to offset air conditioning load in hot climates
- As solar penetration increases, fast-ramping generators are needed near sun set hours

Integration of Renewable Resources

- Solutions:
  - Curtail renewable resources
  - Add energy storage
  - Include forecasting
  - Demand Response

What happens when there is too much wind?

- Net load: load – wind power
  - Wind power potential > load late at night
- Hydro systems can be constrained due to environmental concerns
- Solution:
  - Curtail wind power production
- Result:
  - Lawsuits!

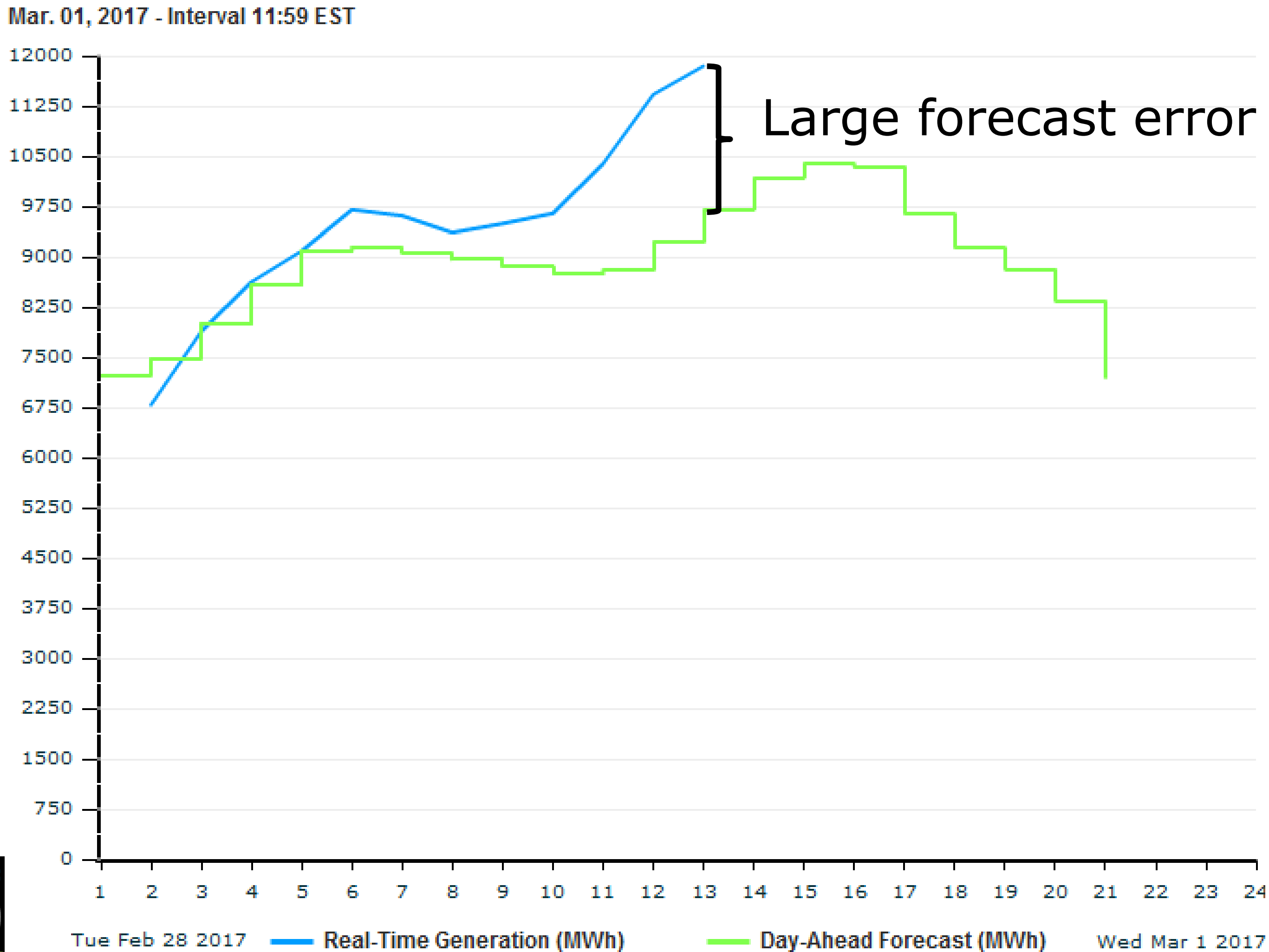
Forecasting Renewables

- Integration of renewables becomes easier if the wind, solar, etc. can be accurately forecasted
- More challenging than forecasting load, but accuracy is improving
- Geographic diversity improves forecast accuracy

Forecasting Techniques

- Approaches to forecasting depend on time scale
- Short term
  - "persistence"
  - neural networks
  - time-series models
- Long term (1-2 days)
  - Numerical weather prediction models
- Longer term
  - Climatology (historical averages)

Many new approaches being researched


Mar. 01, 2017 - Interval 11:59 EST
12000
11250
10500
9750
9000
8250
7500
6750
6000
5250
4500
3750
3000
2250
1500
750
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Large forecast error
Tue Feb 28 2017
Real-Time Generation (MWh)
Day-Ahead Forecast (MWh)
Wed Mar 1 2017

Renewable Energy Credits

- Value of renewable energy can be split into two commodities:
  - Energy
  - “green-ness”
- Renewable Energy Credit (REC): value associated with the green-ness with 1 MWh of energy produced from a qualifying renewable resource

Renewable Energy Credits

- Just like energy, RECs can be sold by the owner of the renewable energy plant
- Who might purchase a REC?
  - Carbon-offset companies
  - Utilities that are in states with Renewable Portfolio Standards (buy REC instead of build a renewable power plant)
  - Companies/individuals wanting to reduce their carbon footprint
- REC purchase can be entirely independent of energy purchase

Renewable Energy Credits

- RECs can be bought and sold in markets
- RECs can be differentiated by generation source (Solar RECs)
- Prices vary:
  - Typically range from $10 to $50 per MWh

Example

- A Wind Plant produces 100 MWh of electricity
- Electricity is sold on the spot market for \$30/MWh
- RECs are sold at the market rate of \$10/MWh
- The Wind Plant receives 100 x 30 + 100 x 10 = \$400
- The Wind Plant could sell less than 100 MWh of RECs, but not more

Production Tax Credit

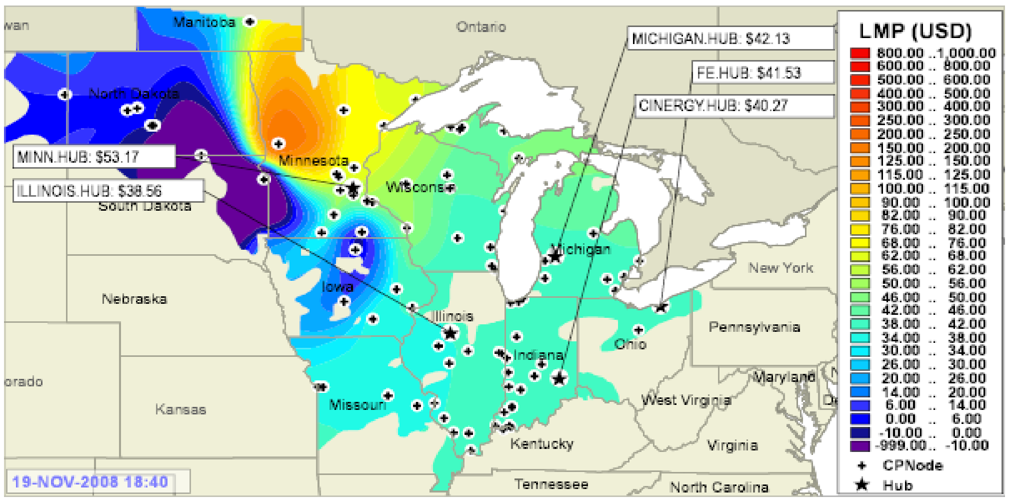
- U.S. government has supported renewable energy through Production Tax Credit (PTC)
- For every MWh of generation, the owner is awarded a tax credit
  - Amount varies, and is inflation-adjusted
  - ~$23/MWh
- PTC requires renewal by Congress
  - Has lapsed several times, creating volatility in the construction of wind plants
- Tax credits can be sold to other companies

Midwest ISO - Market Information - Windows Internet Explorer

http://www.midwestiso.org/page/LMP%20Contour%20Map%20&%20Data

The LMP Contour map below provides a real-time map of the MISO footprint showing selected Commercial Pnodes, with their respective LMP values. Each Commercial Pnode is represented as a circle with the regional color dependent on the price. The map and the table will automatically refresh every 5 minutes to show the updated information.

Interactive LMP map below requires free SVG 3.0 plug-in. Please install the plug-in if you do not see the LMP map.



Location	Hourly Day Ahead			5-Minute Real Time			Delta			Last Hour Estimated		
	HE 19			18:40						HE 18		
	LMP	MLC	MCC	LMP	MLC	MCC	LMP	MLC	MCC	LMP	MLC	MCC
AEC	84.28	-2.55	-0.74	39.34	-1.53	-3.29	44.94	-1.02	2.55	44.73	-1.65	-0.85
AECI	80.39	-4.62	-2.56	38.06	-2.81	-3.29	42.33	-1.81	0.73	35.85	-3.61	-7.77
AEP	83.9	-0.77	-2.9	40.47	-0.4	-3.29	43.43	-0.37	0.39	53.06	0.14	5.70
ALTE.ALTE	87.47	1.17	-1.27	41.23	0.35	-3.28	46.24	0.82	2.01	29.64	0.44	-18.02
ALTE.COLUMBAL1	85.04	-1.79	-0.74	39.6	-1.27	-3.29	45.44	-0.52	2.55	27.95	-0.86	-18.41
ALTE.EDGG5G5	79.83	-0.97	-6.77	39.84	-1.03	-3.29	39.99	0.06	-3.48	27.80	-0.67	-18.75
ALTW.ALTW	84.51	-2.15	-0.91	30.66	-1.87	-11.63	53.85	-0.28	10.72	29.16	-2.77	-15.30
ALTW.DAEC	82.09	-4.74	-0.74	37.77	-3.1	-3.29	44.32	-1.64	2.55	30.15	-3.95	-13.12
ALTW.EMERY31	86.28	-0.55	-0.74	-84.76	-3.66	-125.26	171.04	3.11	124.52	12.15	-4.61	-30.46
ALTW.FPL_DAEC	82.09	-4.74	-0.74	37.77	-3.1	-3.29	44.32	-1.64	2.55	30.15	-3.95	-13.12
ALTW.OTTUMW1	80.14	-6.69	-0.74	37.11	-3.76	-3.29	43.03	-2.93	2.55	25.42	-4.66	-17.14
AMIL.BALDWI52	77.85	-5.73	-3.99	37.91	-2.96	-3.29	39.94	-2.77	-0.7	35.16	-3.51	-8.55
AMIL.CLINTO51	77.08	-5.3	-5.19	38.2	-2.67	-3.29	38.88	-2.63	-1.9	22.17	-2.70	-22.35
AMIL.HAVANA86	84.64	-2.19	-0.74	37.08	-3.79	-3.29	47.56	1.6	2.55	27.26	-3.89	-16.08
AMIL.HENNEPN81	85.62	-1.21	-0.74	39.24	-1.63	-3.29	46.38	0.42	2.55	27.71	-1.45	-18.06
AMIL.TILTNCC1	87.65	-2.86	2.94	39.38	-1.49	-3.29	48.27	-1.37	6.23	53.25	-1.66	7.68
AMIL.VERMILN83	86.69	-3.12	2.24	39.51	-1.36	-3.29	47.18	-1.76	5.53	51.61	-1.70	6.09

Done

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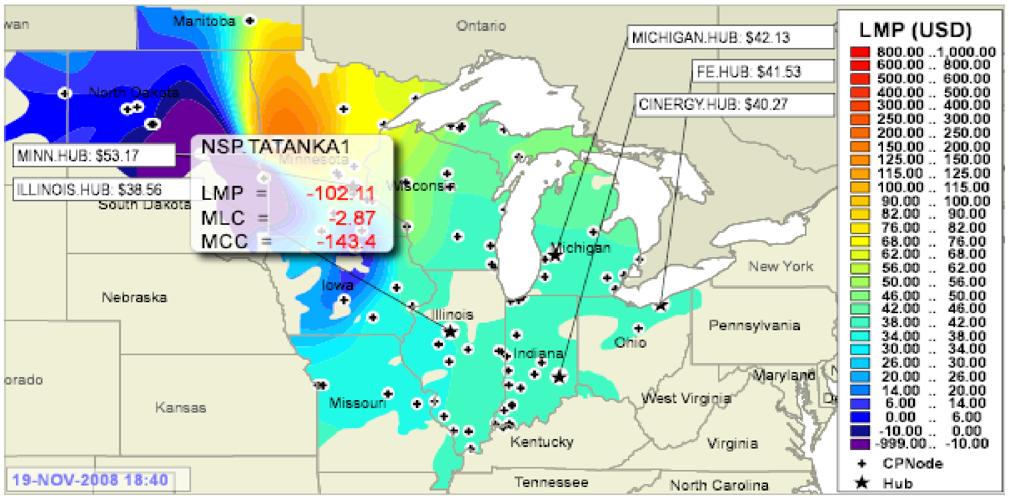

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AECI	80.39	-4.62	-2.56	38.06	-2.81	-3.29	42.33	-1.81	0.73	35.85	-3.61	-7.77
AEP	83.9	-0.77	-2.9	40.47	-0.4	-3.29	43.43	-0.37	0.39	53.06	0.14	5.70
ALTE.ALTE	87.47	1.17	-1.27	41.23	0.35	-3.28	46.24	0.82	2.01	29.64	0.44	-18.02
ALTE.COLUMBAL1	85.04	-1.79	-0.74	39.6	-1.27	-3.29	45.44	-0.52	2.55	27.95	-0.86	-18.41
ALTE.EDGG5G5	79.83	-0.97	-6.77	39.84	-1.03	-3.29	39.99	0.06	-3.48	27.80	-0.67	-18.75
ALTW.ALTW	84.51	-2.15	-0.91	30.66	-1.87	-11.63	53.85	-0.28	10.72	29.16	-2.77	-15.30
ALTW.DAEC	82.09	-4.74	-0.74	37.77	-3.1	-3.29	44.32	-1.64	2.55	30.15	-3.95	-13.12
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AMIL.CLINTO51	77.08	-5.3	-5.19	38.2	-2.67	-3.29	38.88	-2.63	-1.9	22.17	-2.70	-22.35
AMIL.HAVANA86	84.64	-2.19	-0.74	37.08	-3.79	-3.29	47.56	1.6	2.55	27.26	-3.89	-16.08
AMIL.HENNEPN81	85.62	-1.21	-0.74	39.24	-1.63	-3.29	46.38	0.42	2.55	27.71	-1.45	-18.06
AMIL.TILTNCC1	87.65	-2.86	2.94	39.38	-1.49	-3.29	48.27	-1.37	6.23	53.25	-1.66	7.68
AMIL.VERMILN83	86.69	-3.12	2.24	39.51	-1.36	-3.29	47.18	-1.76	5.53	51.61	-1.70	6.09

RECs and PTCs

- RECs and PTCs provide revenue streams to renewable power plants external to the energy market
- Renewable power plants can bid zero or negative prices into electricity markets and still profit

Example

- Let the PTC be \$23/MWh and the REC price be \$15/MWh
- A renewable energy power plant can offer

-\$27/MWh for energy and make \$1 profit (ignoring their variable costs)

- In other words, they will <u>pay</u> \$27 to produce

1 MWh of electricity but make \$28 in RECs and PTCs