DOE ARPA-E Grid Workshop

December 13, 2010

The Electric Grid
Smart and Getting Smarter

Ken Huber
Applied Solutions
PJM Interconnection

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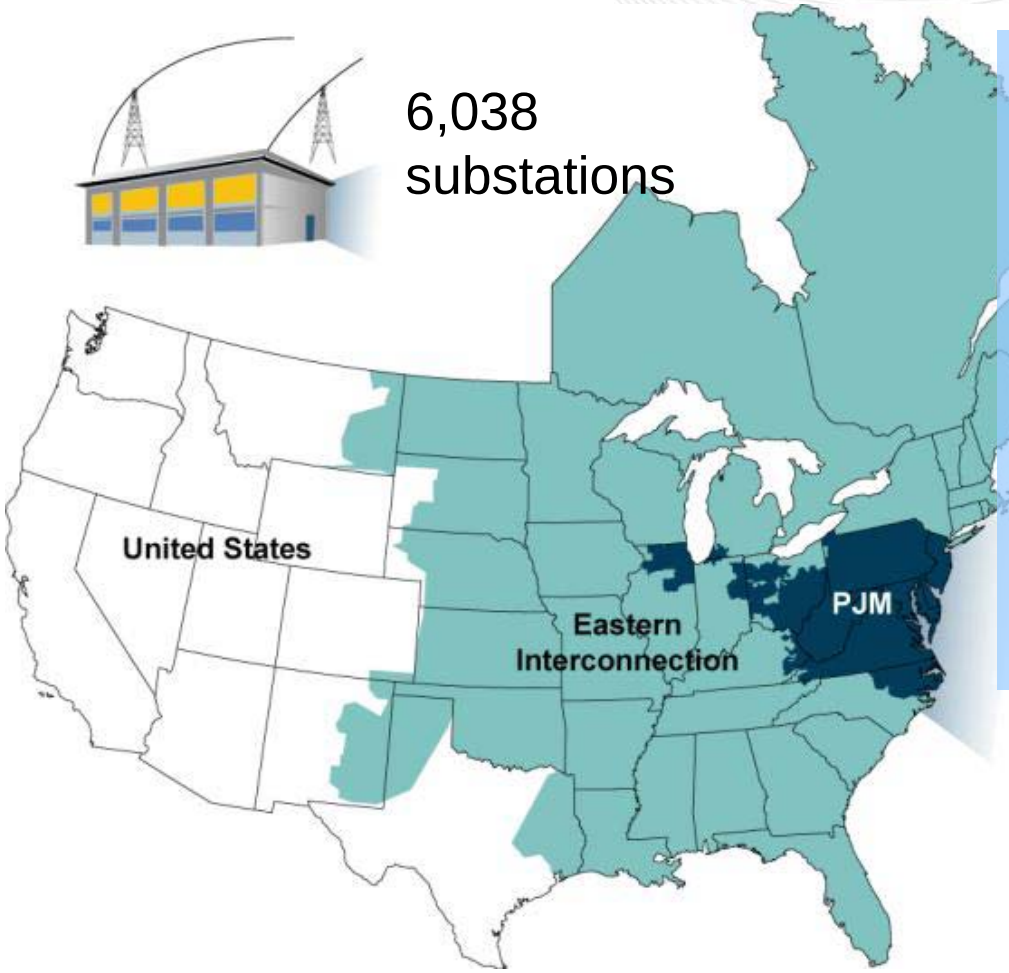
PJM as Part of the Eastern Interconnection

6,038 substations



KEY STATISTICS	
PJM member companies	600+
millions of people served	51
peak load in megawatts	144,644
MWs of generating capacity	164,905
miles of transmission lines	56,250
GWh of annual energy	729,000
generation sources	1,310
square miles of territory	164,260
area served	13 states + DC
Internal/external tie lines	250

- 26% of generation in Eastern Interconnection
- 23% of load in Eastern Interconnection
- 19% of transmission assets in Eastern Interconnection

19% of U.S. GDP produced in PJM

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Today's Grid

- **Greatest Engineering Achievement of the 20th century – National Academy of Engineering**

- **40% of Energy Consumption for Electricity**

- **164000 circuit miles – about 500 transmission owners & about 3000 load serving entities**

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Today's Grid – What Does It Provide

- **Energy on demand**
  - **No busy circuits**
  - **Rarely dropped service (99.97% reliable)**
  - **Many temporary faults cleared & lines restored in less than a second**

- **Voltages regulated to within 5%**

- **Frequency very close to 60 Hz**
  - **Continuous 'Load Following'**
  - **Optimal Security Constrained Generation Scheduling**

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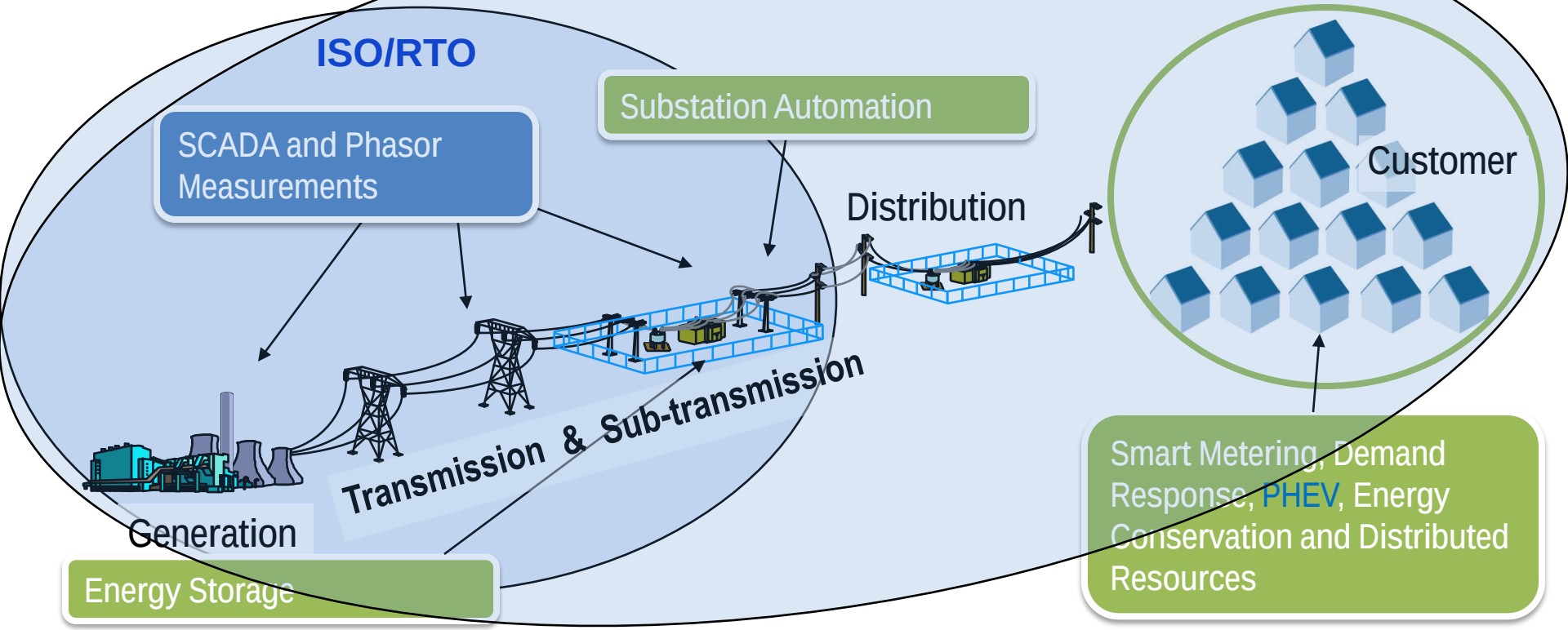
PJM's Role in the Smarter (Robust) Grid

A smart grid is the electricity delivery system (from point of generation to point of consumption) integrated with communications and information technology for enhanced grid operations, customer services, and environmental benefits*

Two-Way Communication and Control

*DOE: Funding for Smart Grid Activities presentation



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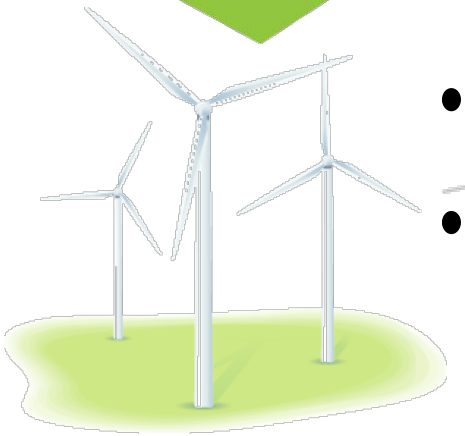
- If you like wind…
- If you like nuclear …
- If you like clean coal …



Bottom line….

You have to love Transmission & Storage

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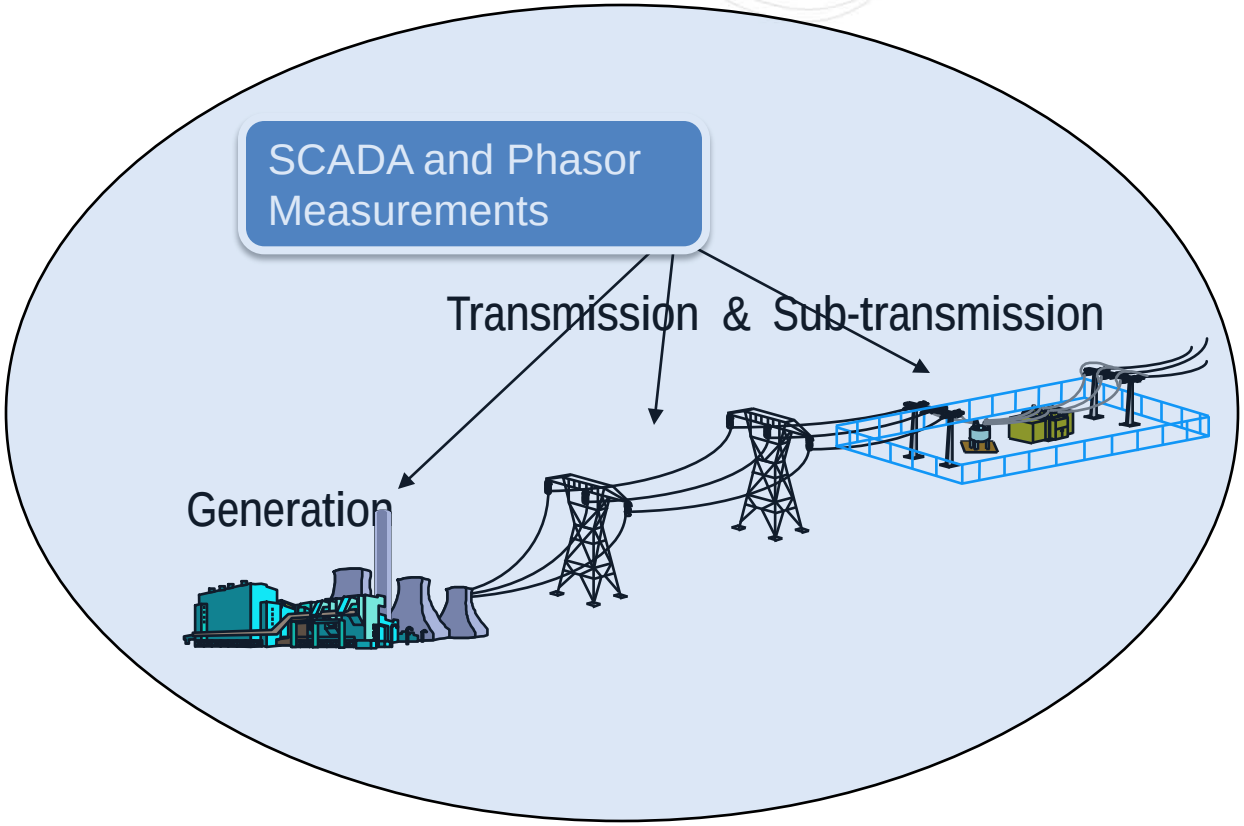
Phasor Measurement



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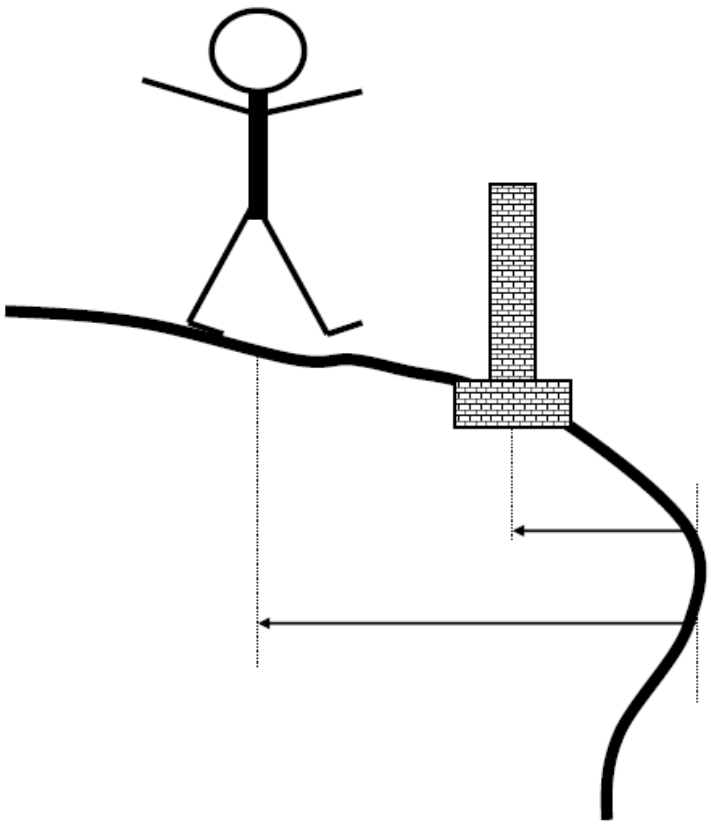
Wide-area situational awareness



Measurements give us current system states:

For true situation awareness we need to know;

- **Where the edge is**
- **How close to the edge we can safely (reliably) operate**

8
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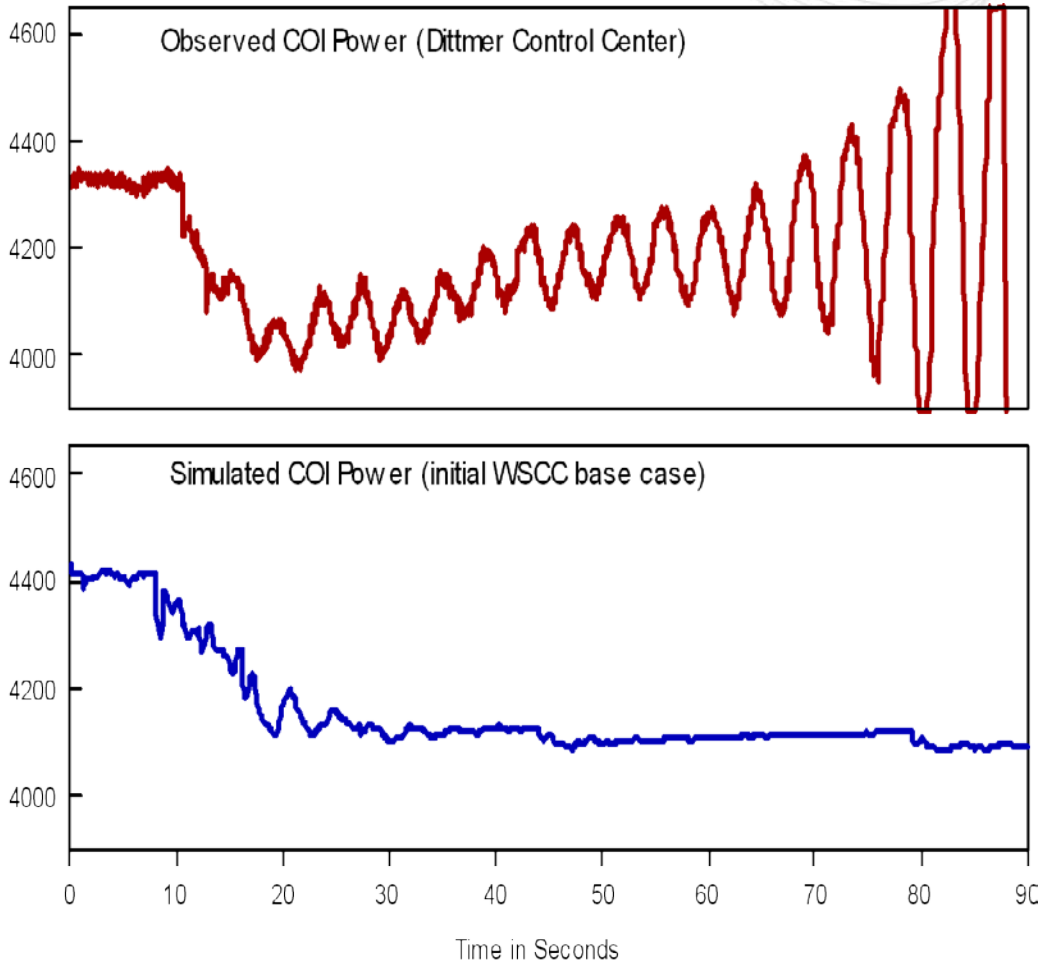
Off-line Applications



Phasor data measures system dynamic behavior during disturbances that simulations can't yet accurately predict

9
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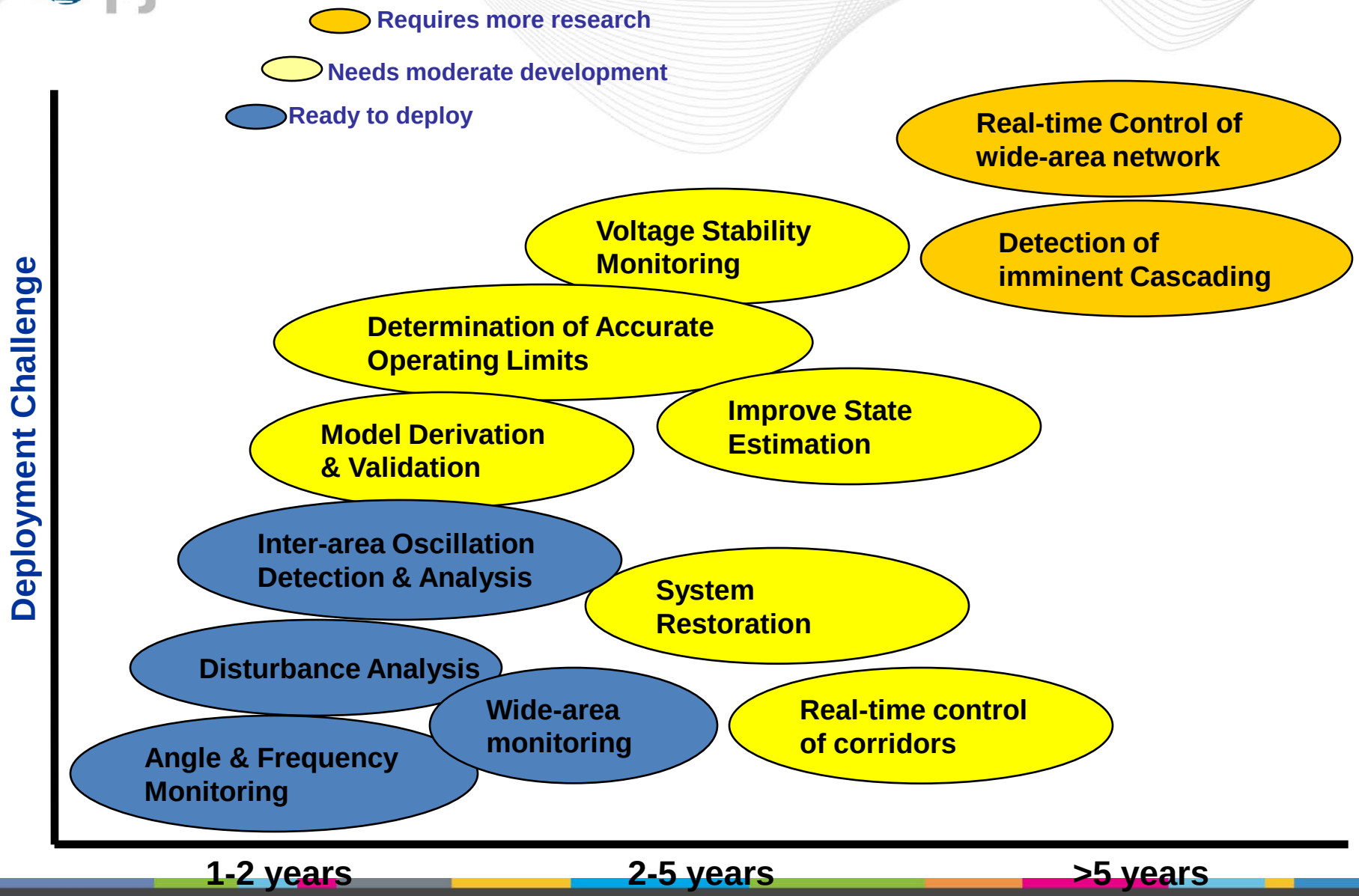
SynchroPhasor Applications



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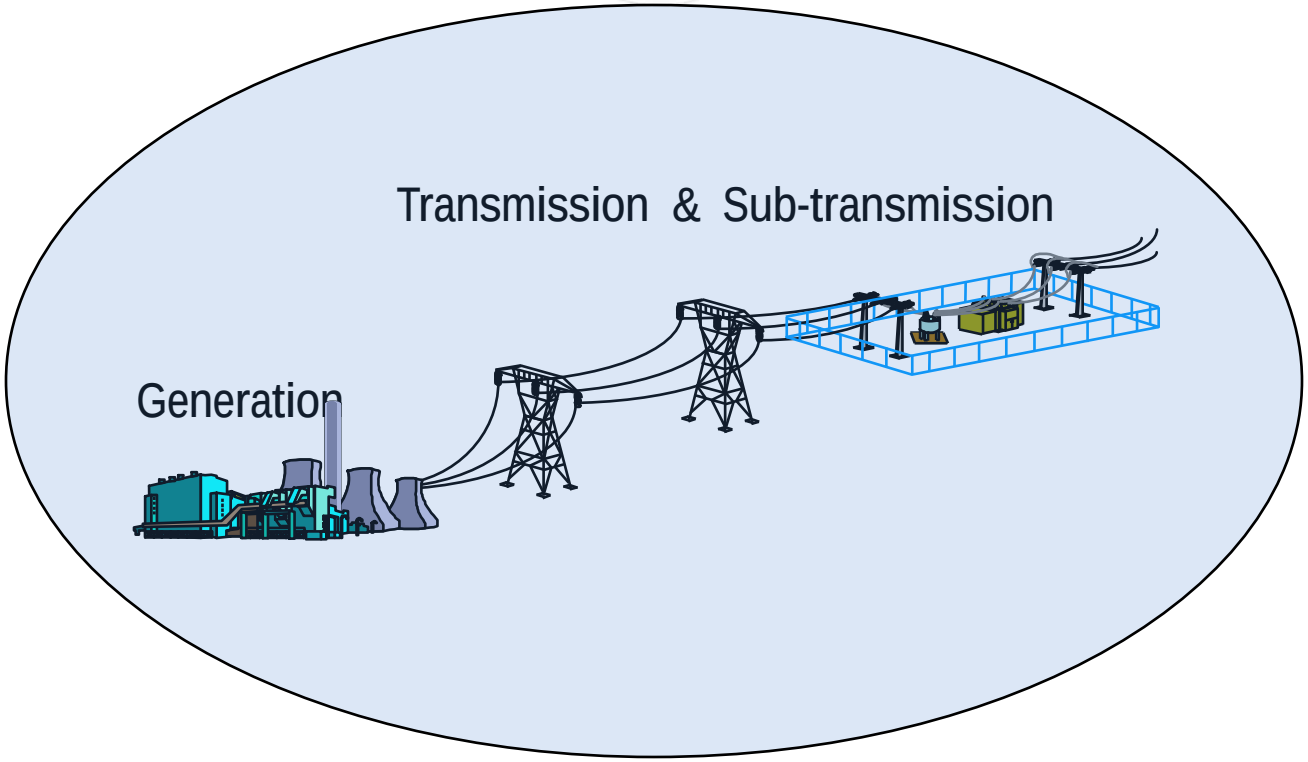
Grid Energy Storage



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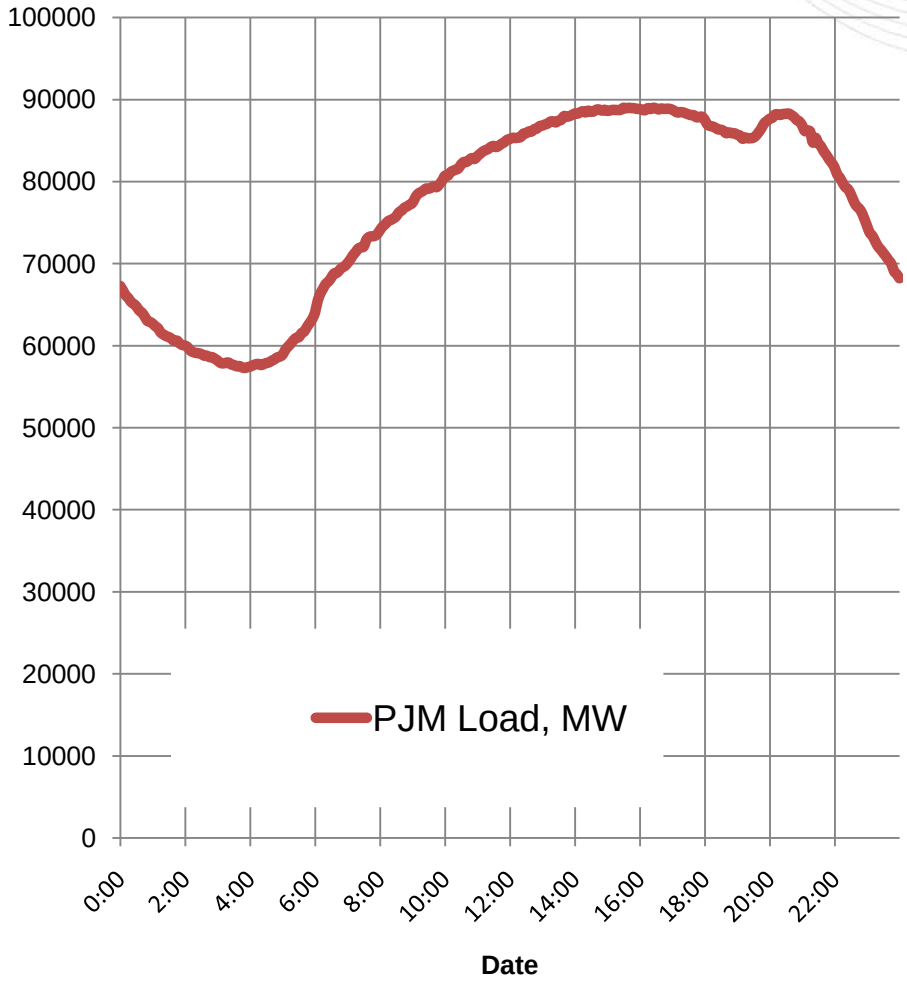
PJM Load and Total Wind on April 7, 2010



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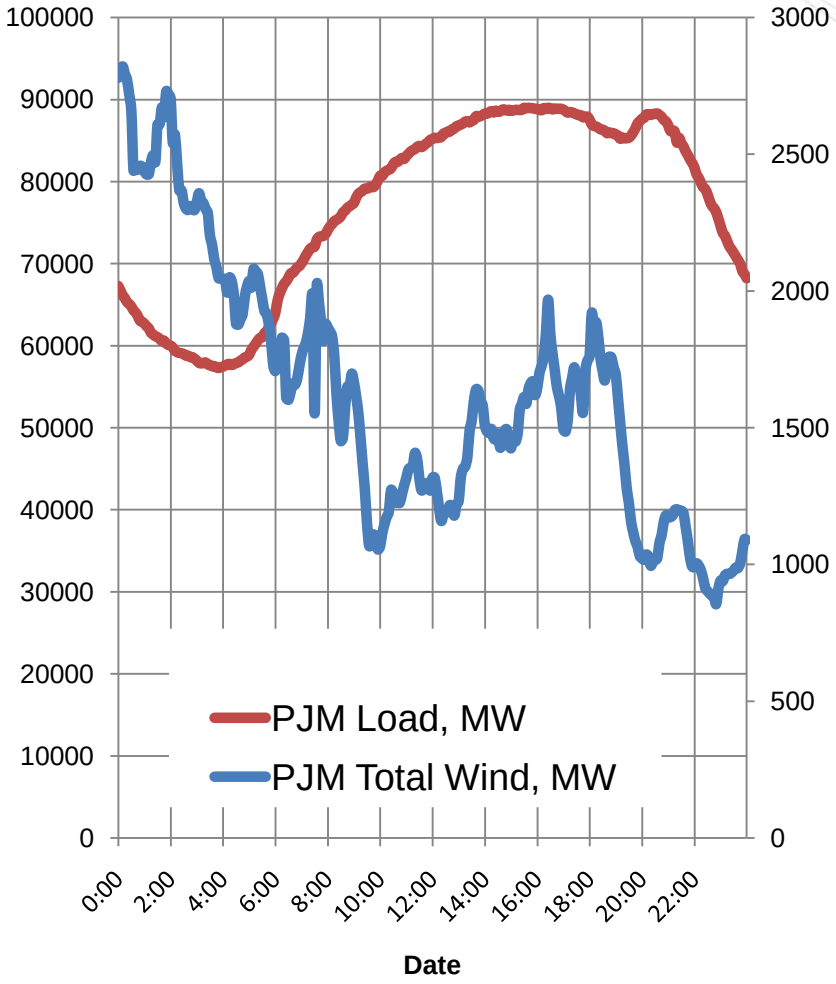

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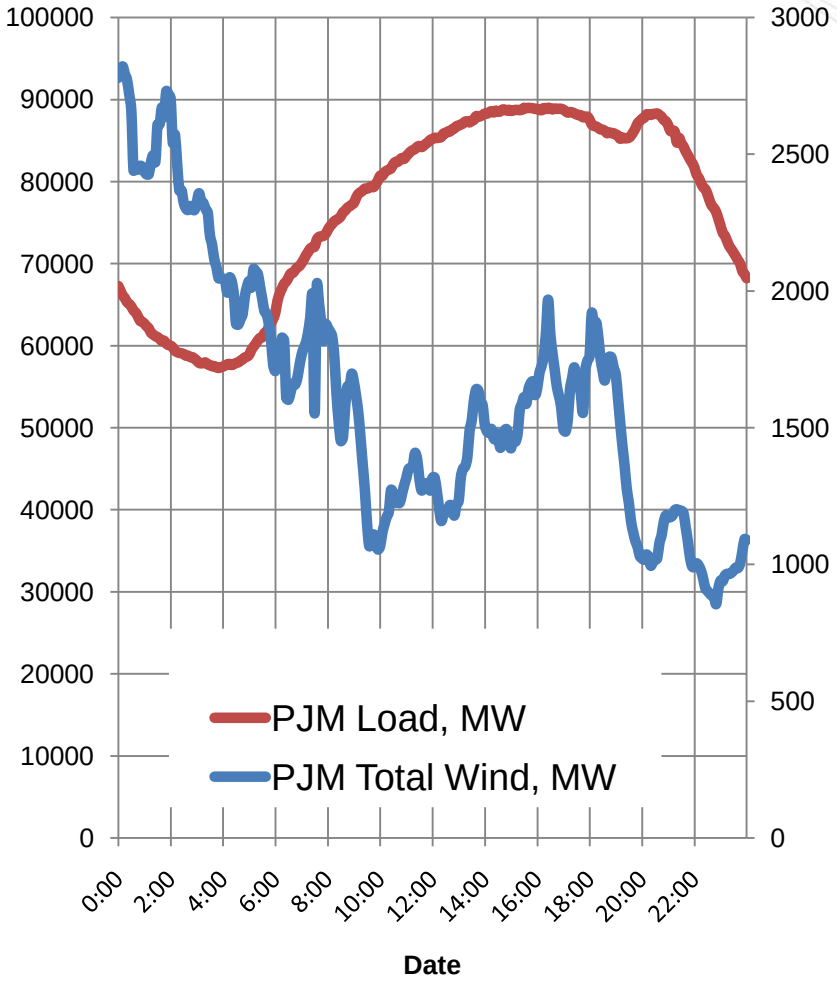
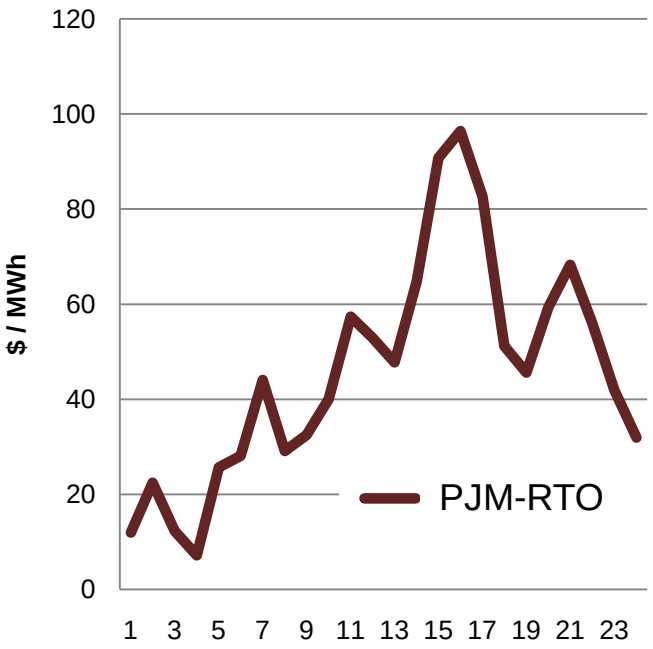


Locational Marginal Prices

April 7, 2010



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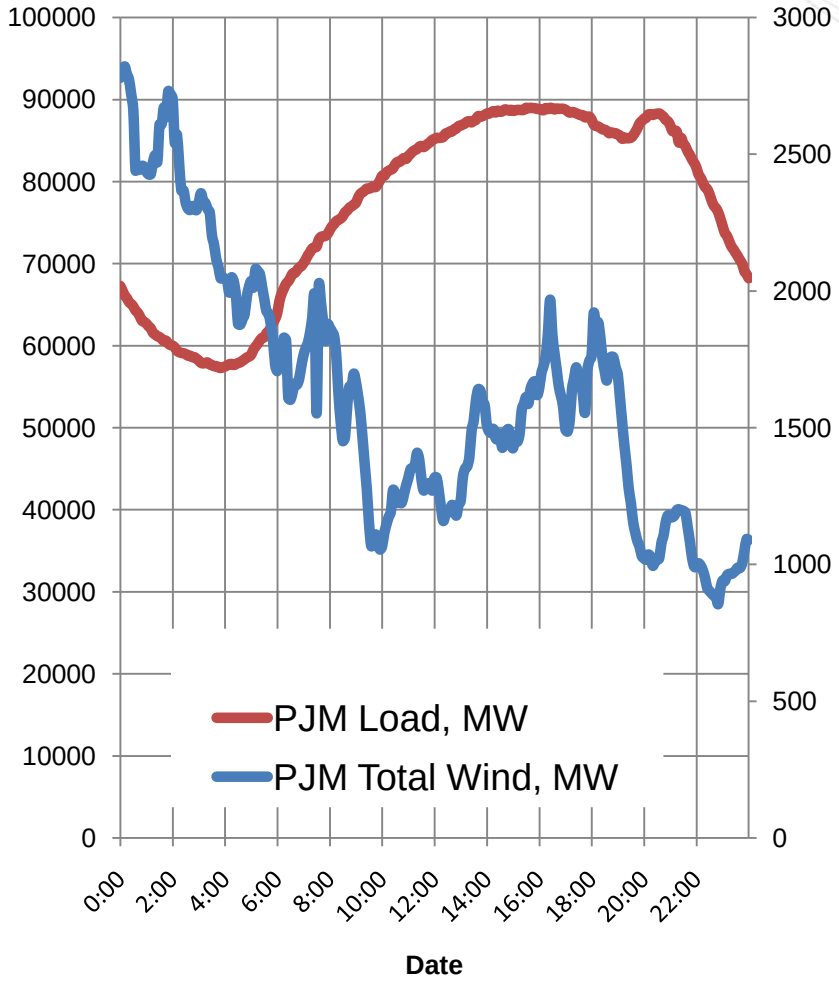

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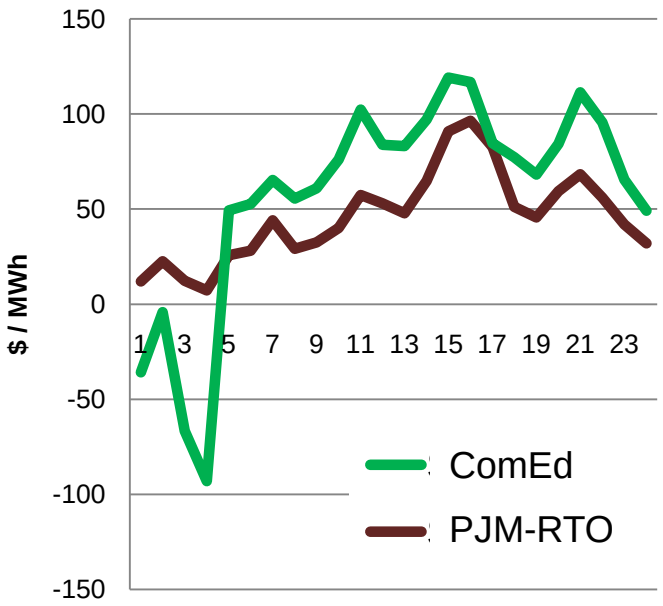

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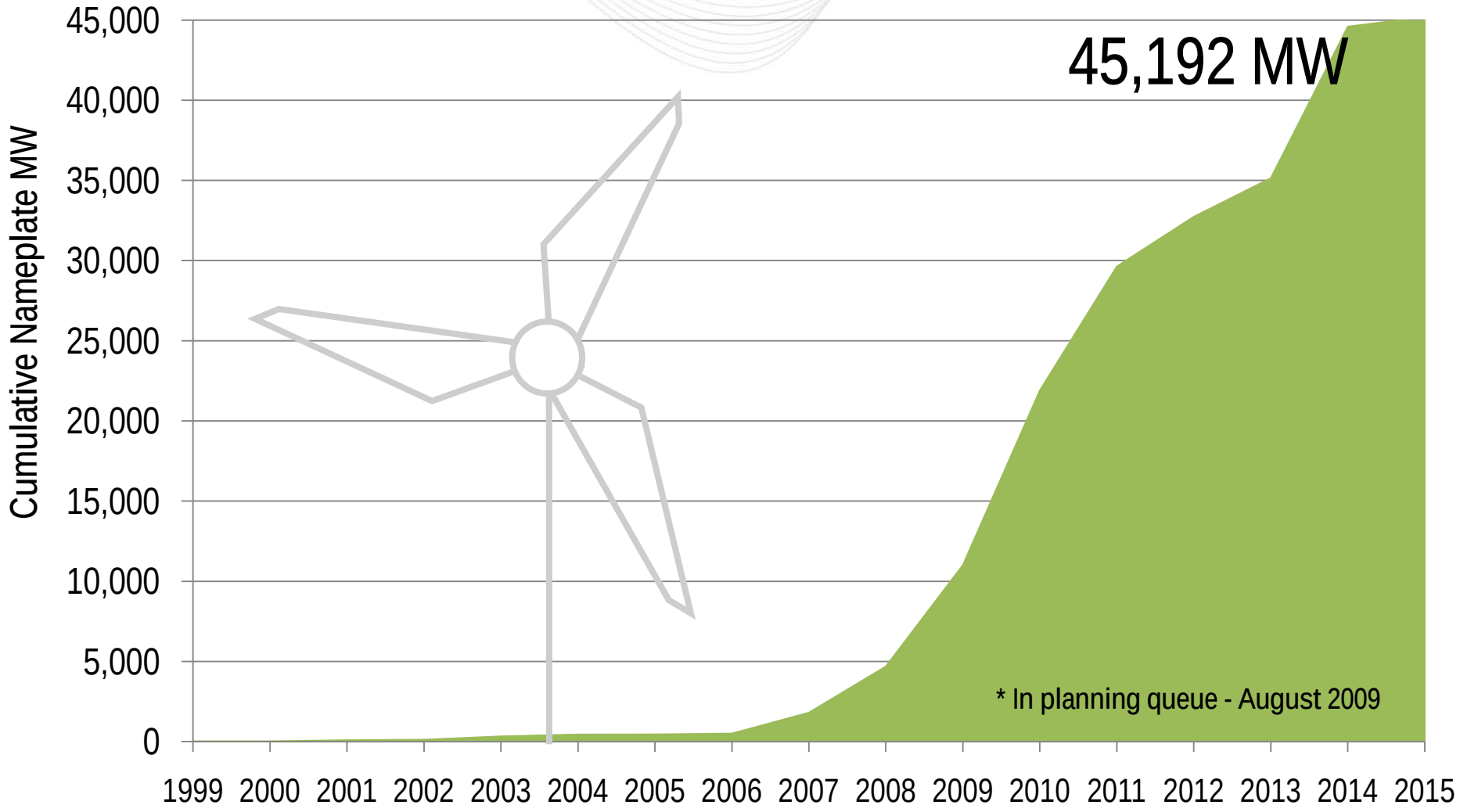
Wind Generation in PJM - Operational and Proposed



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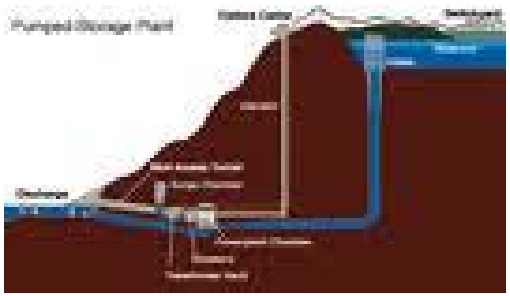
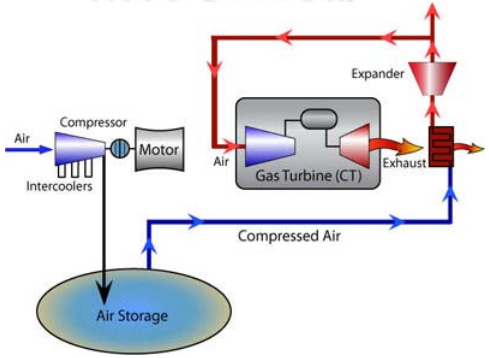
Grid Storage Types and Availability



Pumped Hydro

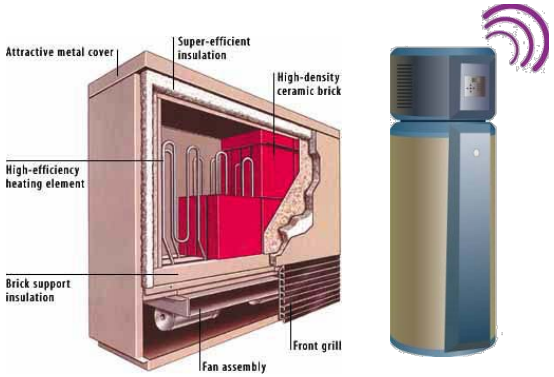


Compressed Air

Flywheels

Stationary Battery

Mobile Batteries



Thermal Storage

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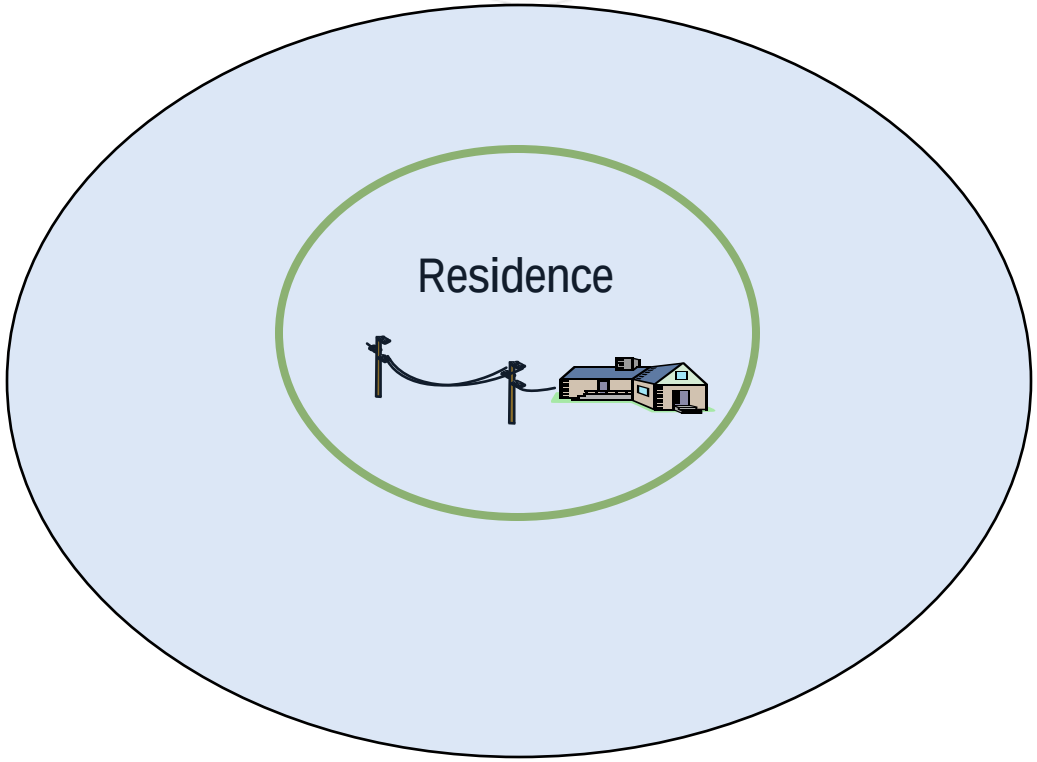
The Smart Home



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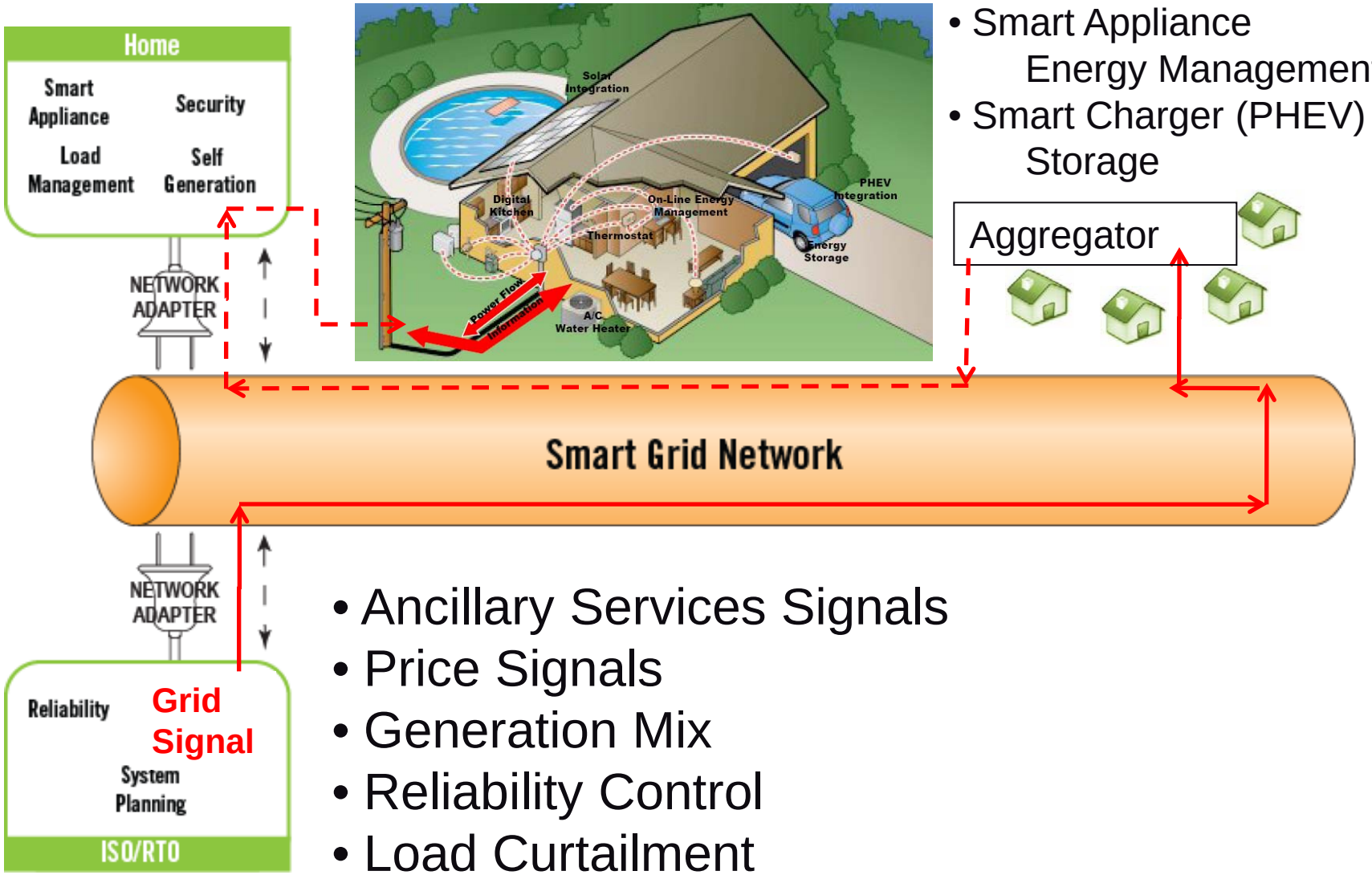
Smarter Grid Network – Smart Home



- Smart Appliance Energy Management
- Smart Charger (PHEV) Storage

- Ancillary Services Signals
- Price Signals
- Generation Mix
- Reliability Control
- Load Curtailment

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PHEV: Grid Benefits

It's really going to happen.

Photo: EPRI

PHEVs: The Momentum Builds

Battery Electric Vehicles
2010 Coda Automotive Sedan
2010 Mitsubishi iMiEV BEV
2010 Nissan LEAF
2010 Ford Battery Electric Van
2010 Tesla Roadster Sport EV
2011 Peugeot Urban EV*
2011 Renault Kangoo Z.E.
2011 Renault Fluence Z.E.
2011 Tesla Model S
2011 BYD e6 Electric Vehicle
2011 Ford Battery Electric Small Car
2011 Opel Ampera Extended Range BEV*
2012 Fiat 500 minicar

1902 Lohner-Porsche PHEV

2009 BWM MINI E

Battery Electric Vehicles
2012 Renault City Car*
2012 Renault Urban EV*
2012 Audi e-tron
2013 Volkswagen E-Up*
2016 Tesla EV

Extended Range Electric Vehicles
2010 Chevy Volt Extended Range

Plug-in Hybrid Vehicles
Fisker Karma S Plug-in Hybrid
2010 Toyota Plug-in Hybrid
2011 BYD F3DM Plug-in Hybrid
2012 Bright Automotive IDEA Plug-in Hybrid
2012 Ford Plug-in Hybrid
2012 Volvo Plug-in Hybrid

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Vehicle Economic Charging

Assumptions

- 1,000,000 PEV Vehicles by 2015
- ~18% of U. S. Population is within the PJM territory
- ~ 180,000 PEV Vehicles in the PJM Territory
- ~ 33** Miles traveled per vehicle per day
- ~ Average vehicle fuel usage: 22** mpg
- ~ No tax compensation

Daily cost per PEV Vehicle

Gasoline: 33 miles/day * $3.00 /gal // 22 miles/gal = $4.50

Electric: 33 miles/day * $.07 / kWh // 4 miles/kWh = $0.60

Annual cost/savings

Cost:

Gasoline: 365 days * $4.50 /day = $1650

Electric: 365 days * $0.60 /day = $220

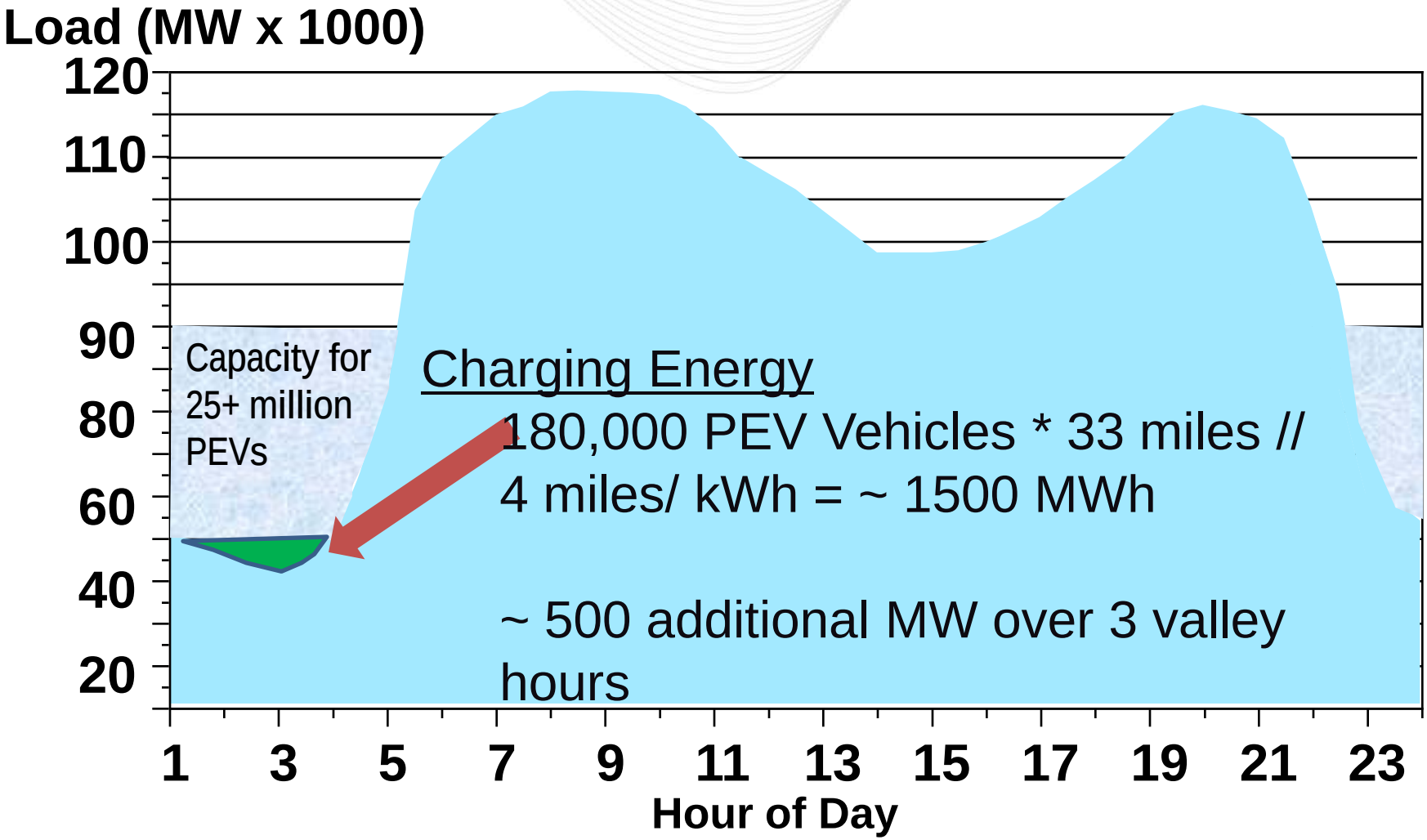
Savings:

~ $1400 annually per vehicle

180,000 vehicles (within PJM) = ~ $250,000,000 annual

** U.S. Bureau of Transportation Statistics

Vehicle Charging Impact on PJM



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Fleet Vehicles

Fleets are of particular interest

- Typically well established, consistent routes
- Return to same location for long term parking
  - Controlled infrastructure costs
  - Parked for 10-12 hours in low electric load periods
- Electric vehicle promotion

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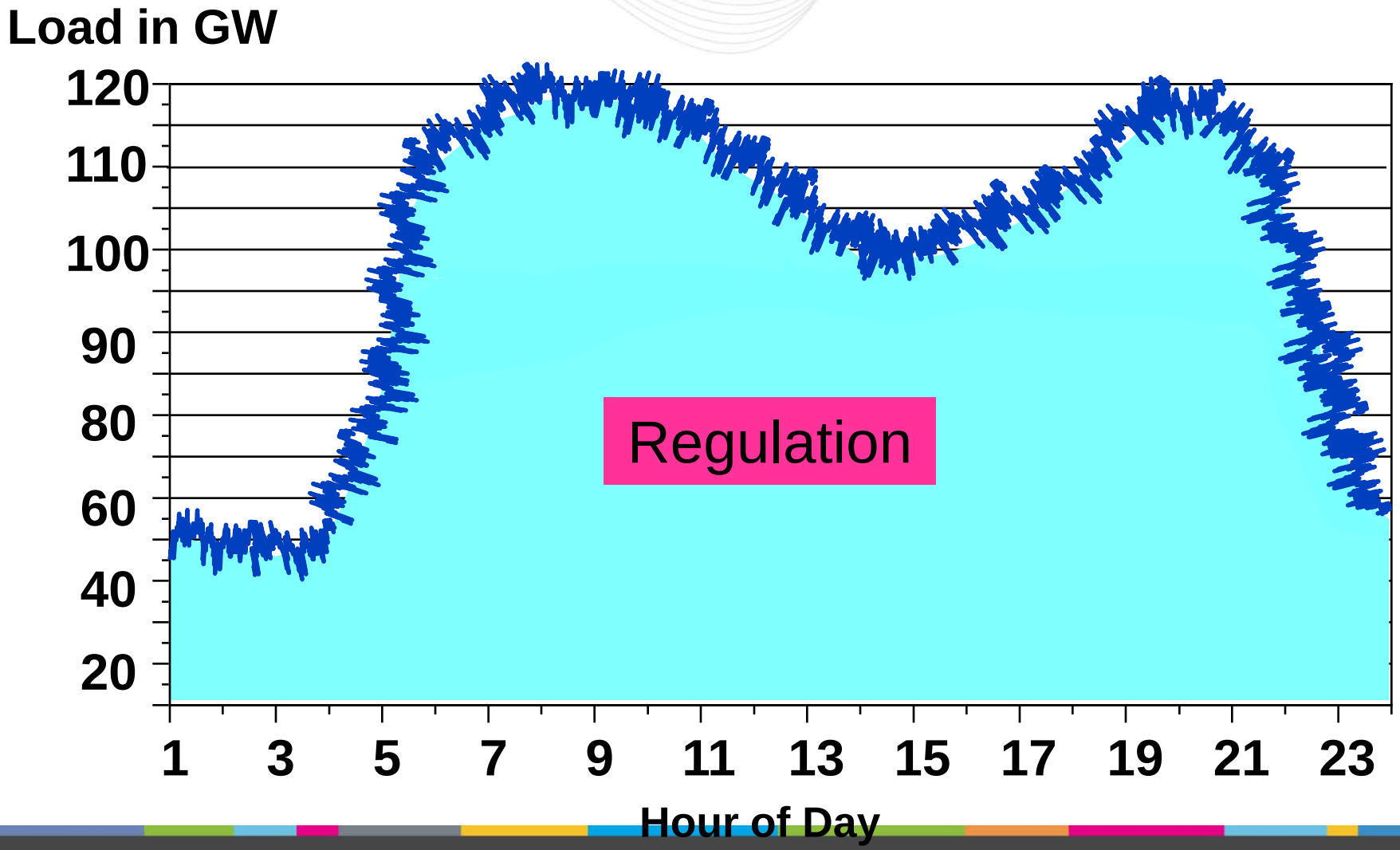
Grid Benefits – Frequency Regulation



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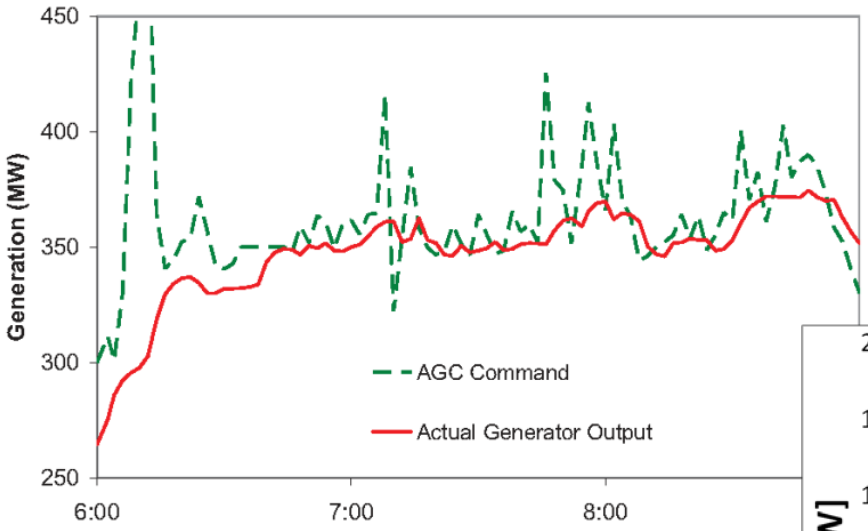
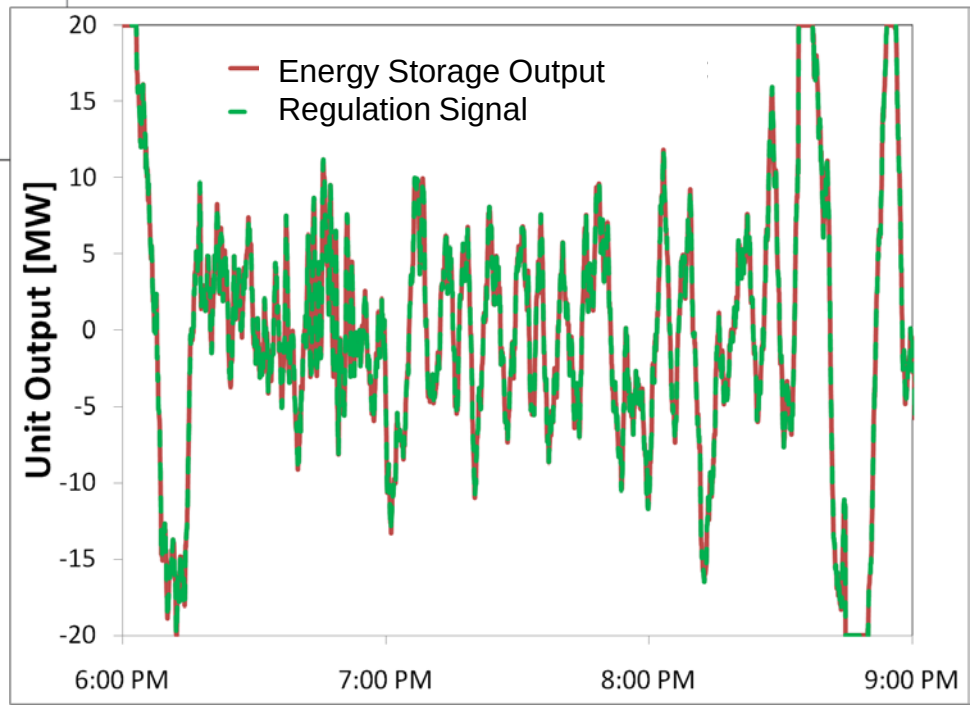
Fast Regulation: Speed Matters…



A fossil power plant following a regulation command signal

Energy Storage (batteries / flywheels) accurately following a regulation command signal



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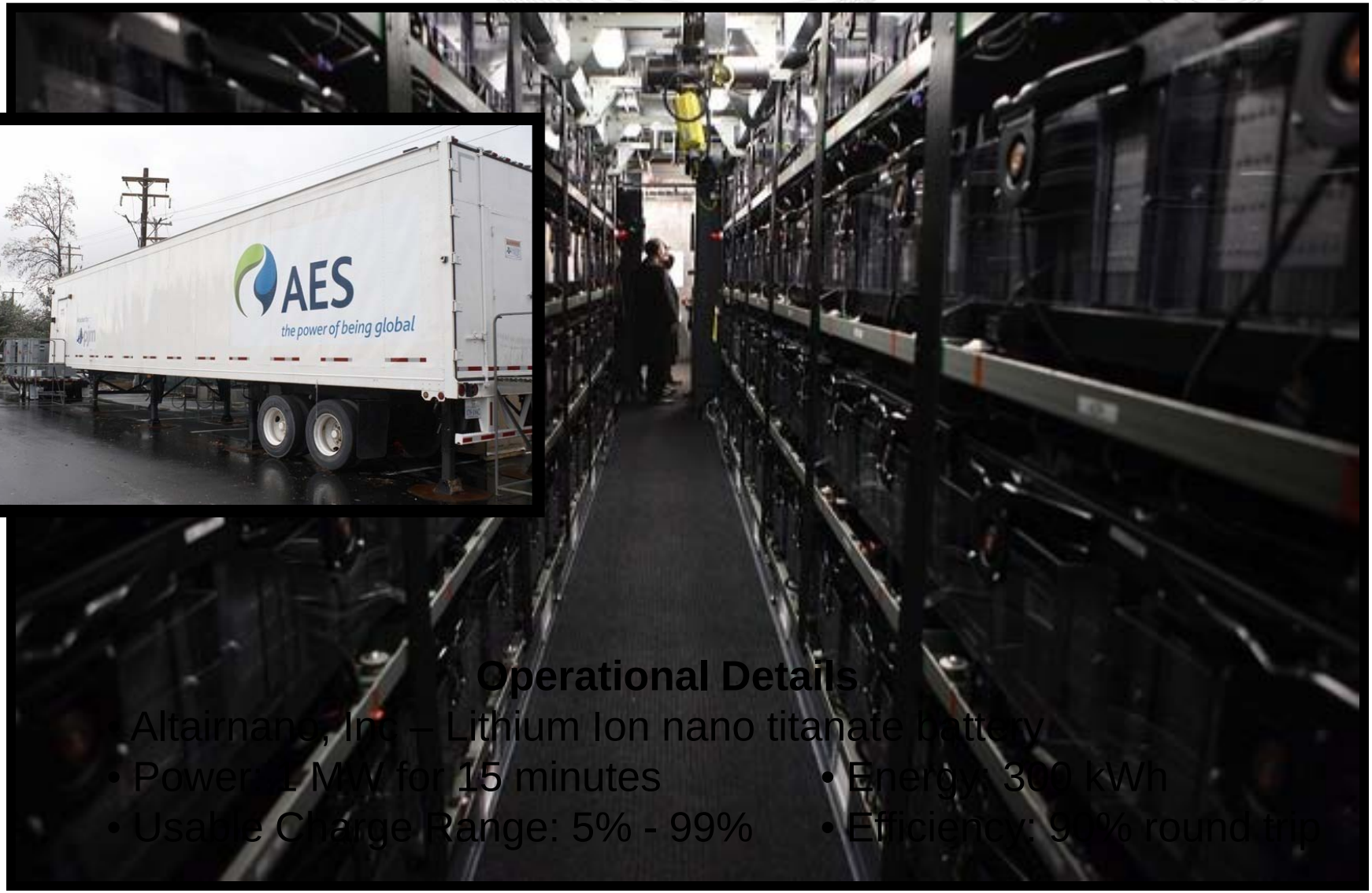
AES Grid-Scale Energy Storage System



Operational Details

- Altairnano, Inc – Lithium Ion nano titanate battery
- Power: 1 MW for 15 minutes
- Usable Charge Range: 5% - 99%
- Energy: 300 kWh
- Efficiency: 9[illegible]% round trip

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Frequency Regulation – "Cash Back" for Vehicles

$700/day
1 MW

Aggregator

$30/day
0.075 MW

1.075 MW

Grid Signal

Frequency Regulation Signal