

Role of the Smart Grid in Facilitating the Integration of Renewables

Invited Lecture

Shanghai Jiaotong University

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What is a Smart Grid

"**Smart grid**" is a concept with many elements where monitoring and control of each element in the chain of **generation, transmission, distribution and end-use** allow the electricity delivery and use to be more efficient.

Electric Power Grid



Source: www.sxc.hu



Motivation for a Smart Grid

Desire to make the grid smarter, safer, reliable and more cost-effective using advanced sensors, communication technologies and distributed computing.

Difference Between a Normal Grid And a Smart Grid



Normal Phone



Smart Phone

Starting and End Points of a Smart Grid

From Generator to Refrigerator



Power Plant



Transmission



Distribution

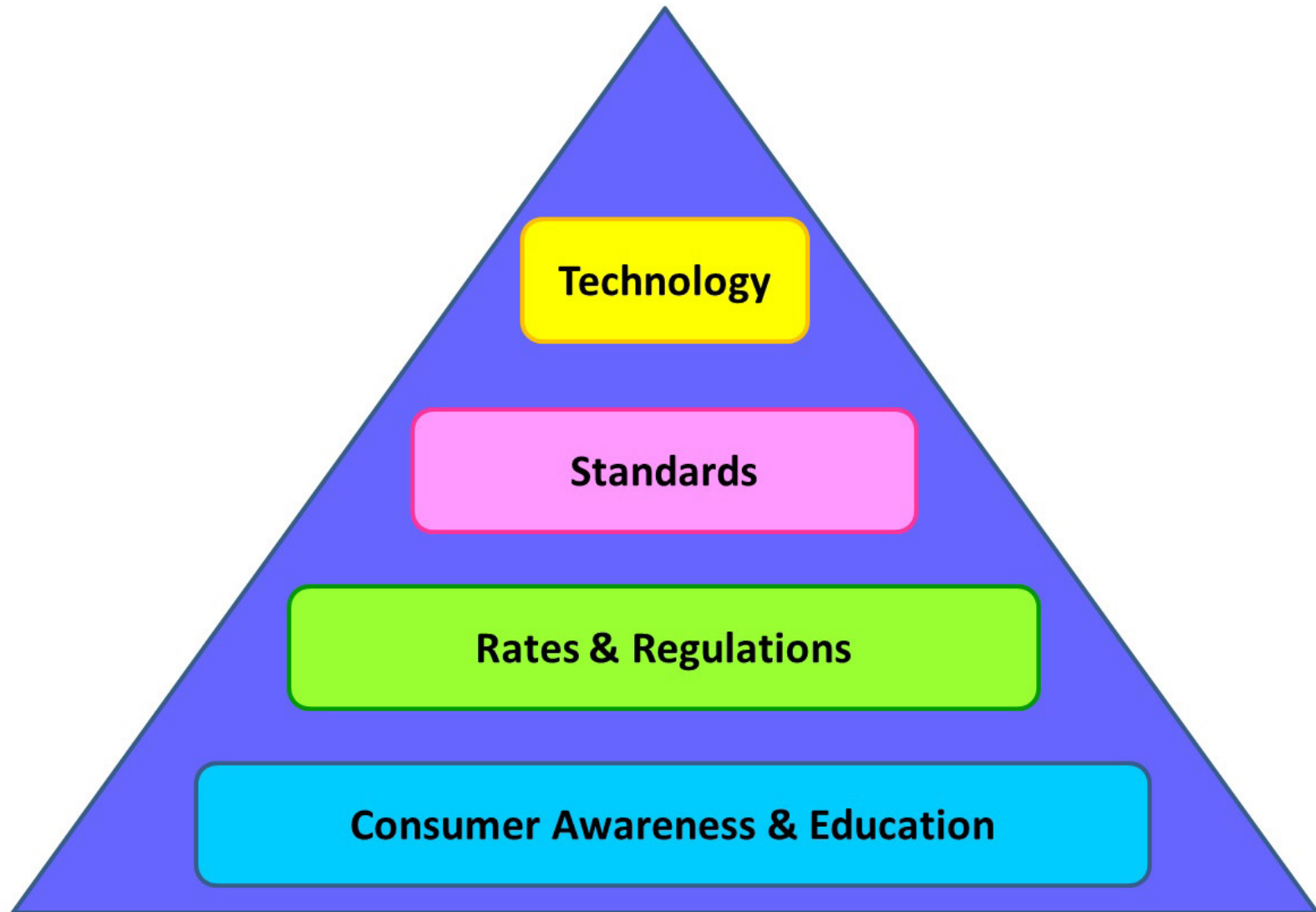


Home
Business



End-use
Appliances

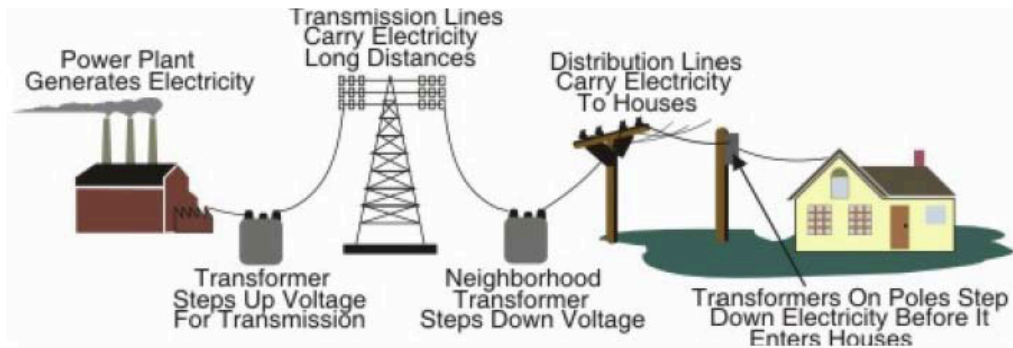
Smart Grid Building Blocks



Evolution of the Grid

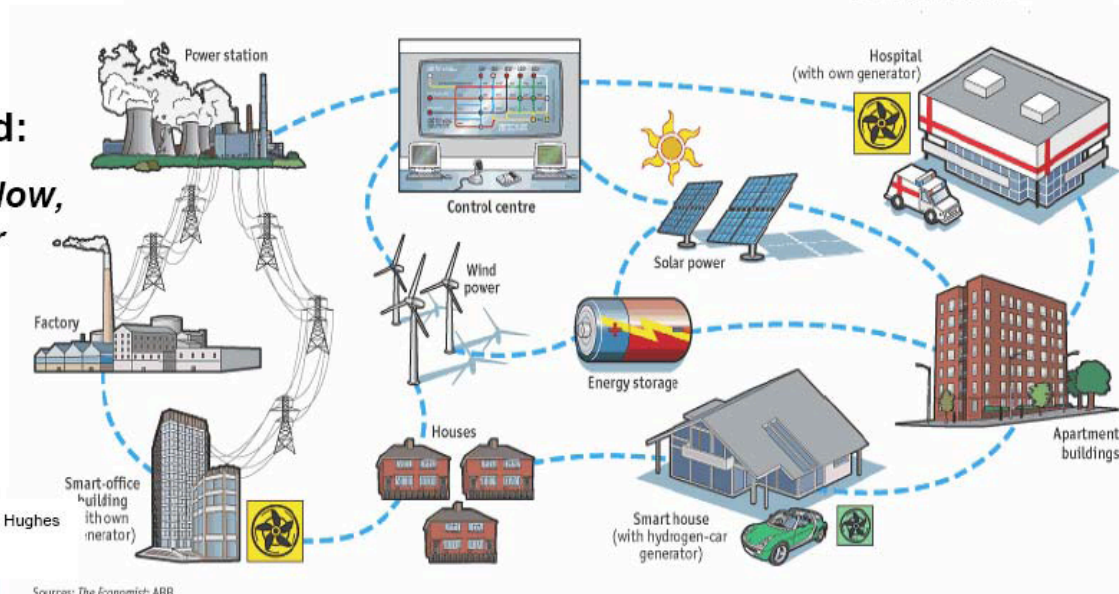
Before Smart Grid:

*One-way power flow,
simple interactions*



After Smart Grid:

*Two-way power flow,
multi-stakeholder
interactions*



Adapted from EPRI Presentation by Joe Hughes
NIST Standards Workshop
April 28, 2008

Sources: *The Economist*; ABB

Source: Altalink, Alberta, Canada

Intelligent Interconnected Microgrids

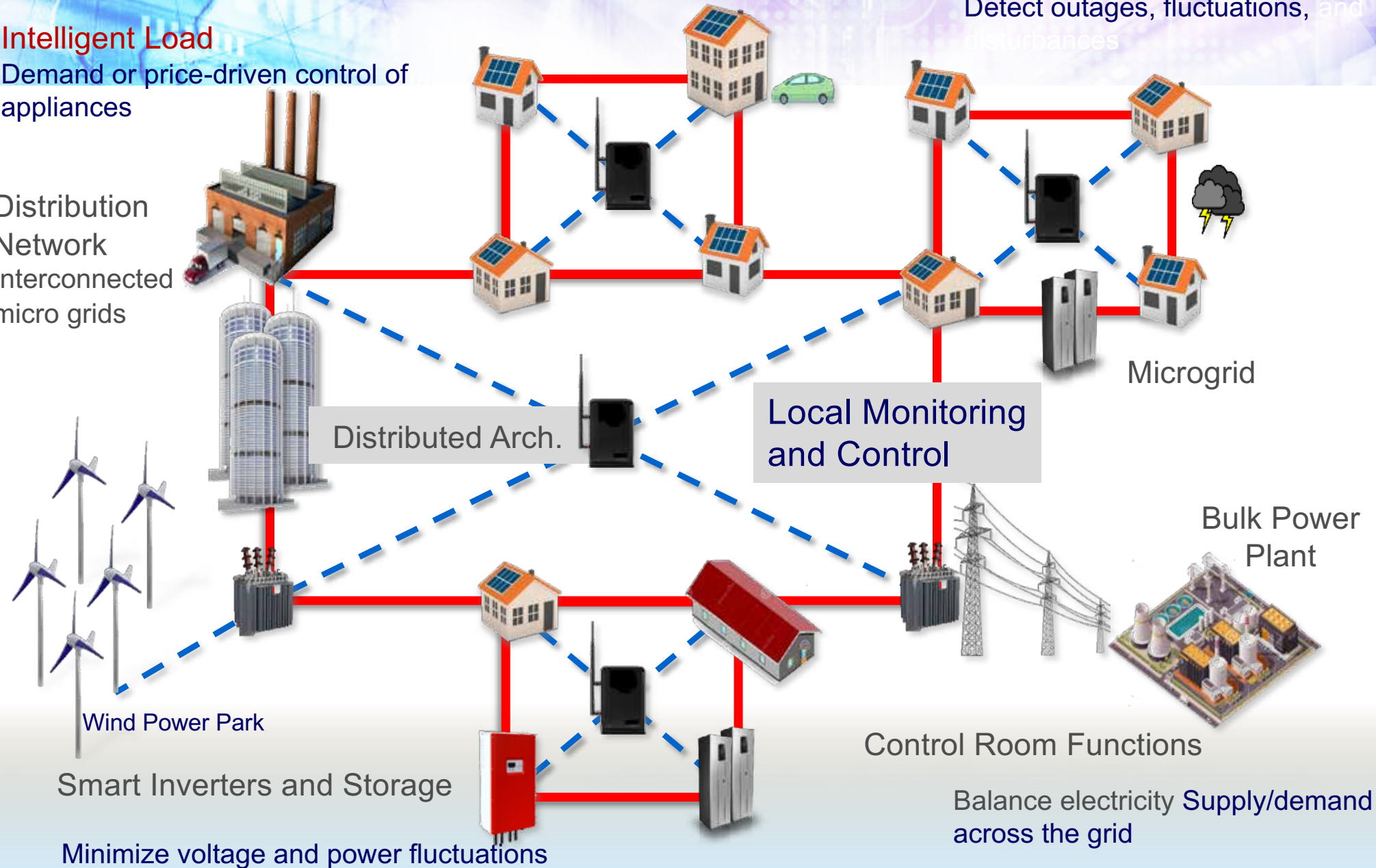
Intelligent Load

Demand or price-driven control of appliances

Distribution Network
Interconnected micro grids

Sensors

Detect outages, fluctuations, and disturbances



Distributed Arch.

Local Monitoring and Control

Microgrid

Bulk Power Plant

Wind Power Park

Smart Inverters and Storage

Minimize voltage and power fluctuations

Control Room Functions

Balance electricity Supply/demand across the grid

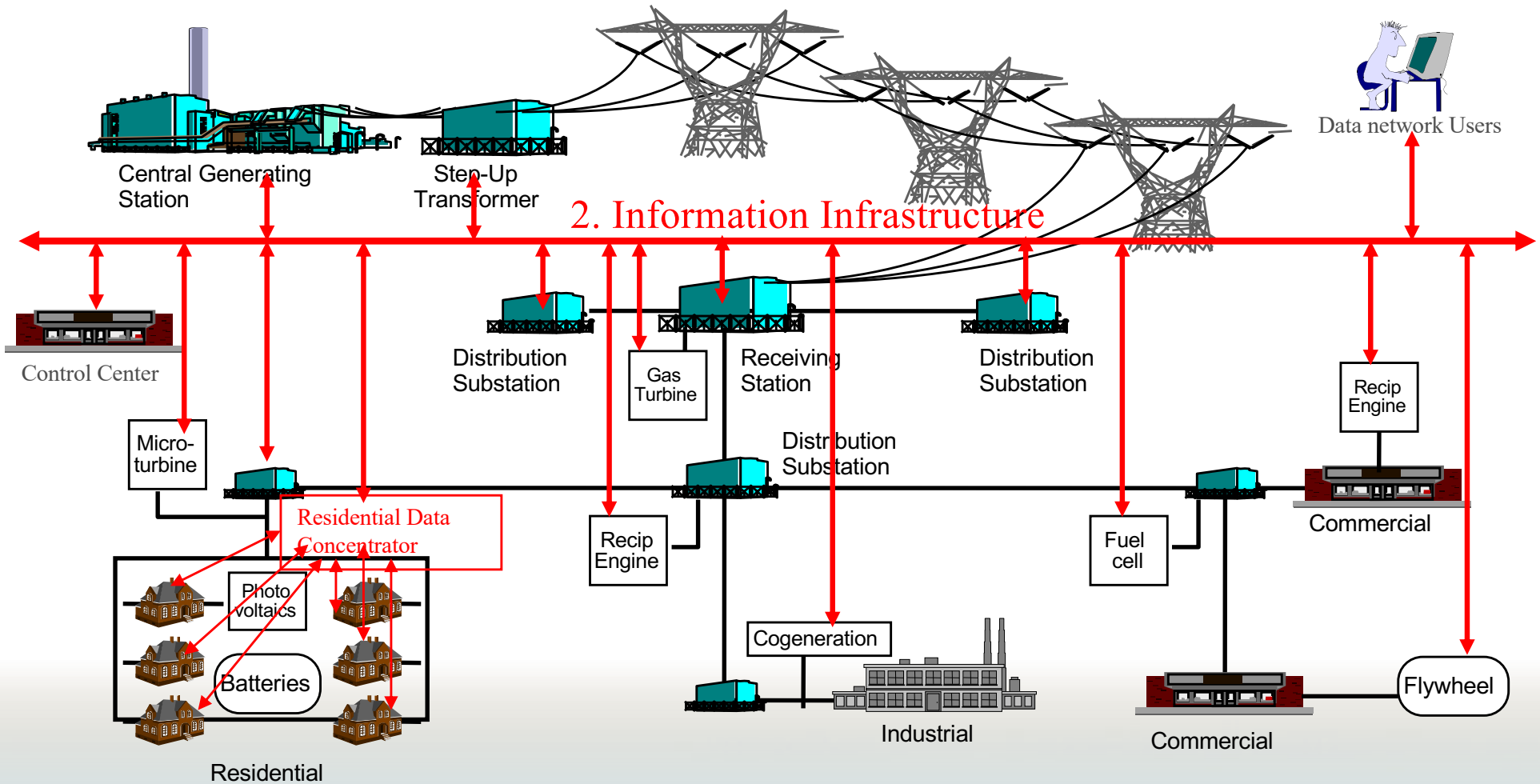


Merging Power Flow with Information Flow:

Integrated Communications

Electric Power & Communication Infrastructures

1. Power Infrastructure



Changing Landscape for the Electric Utility





Issues with Distributed Generation

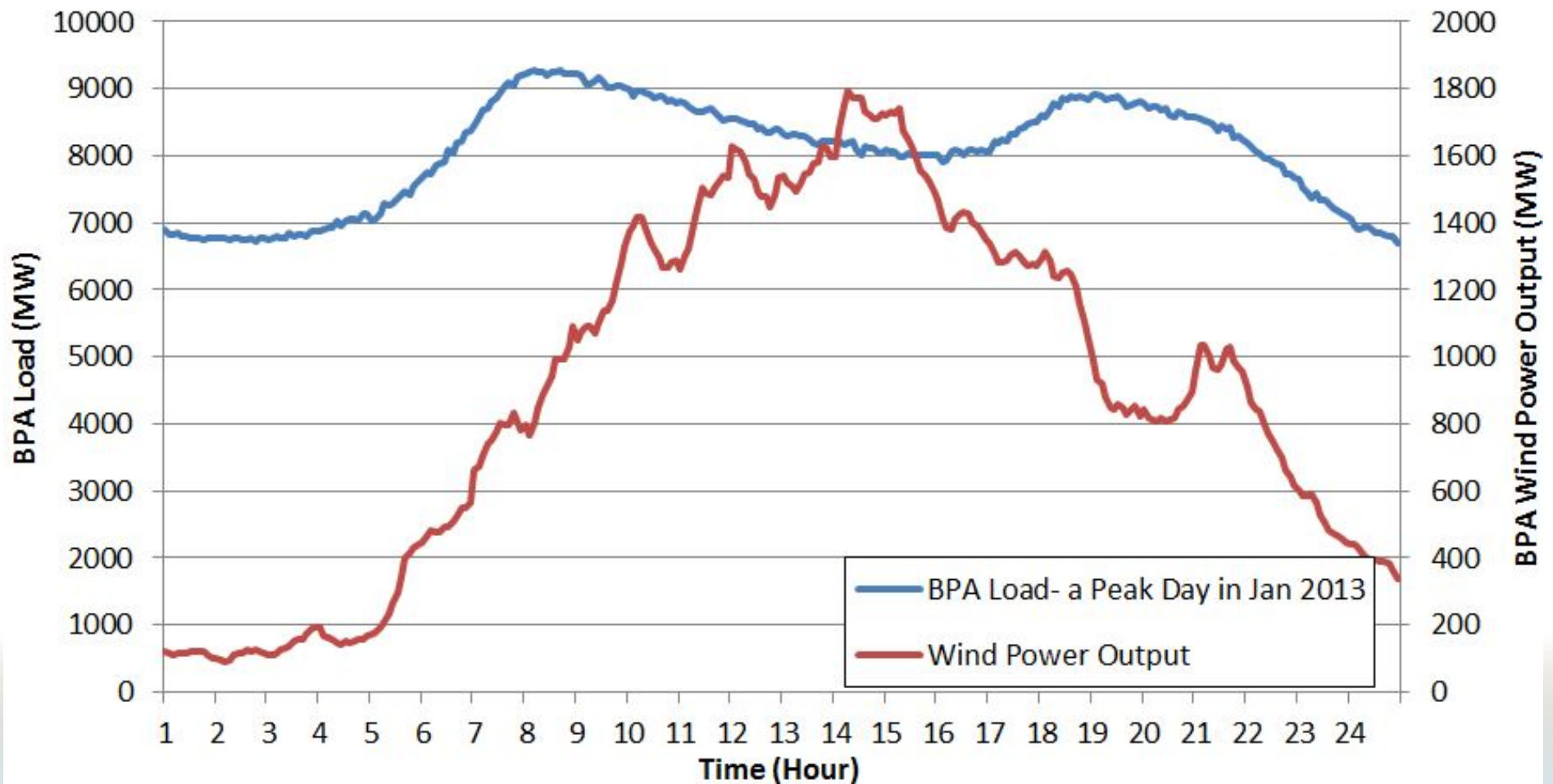
- Wind and solar are intermittent
- Hydro is space limited
- Resource is free but not always usable



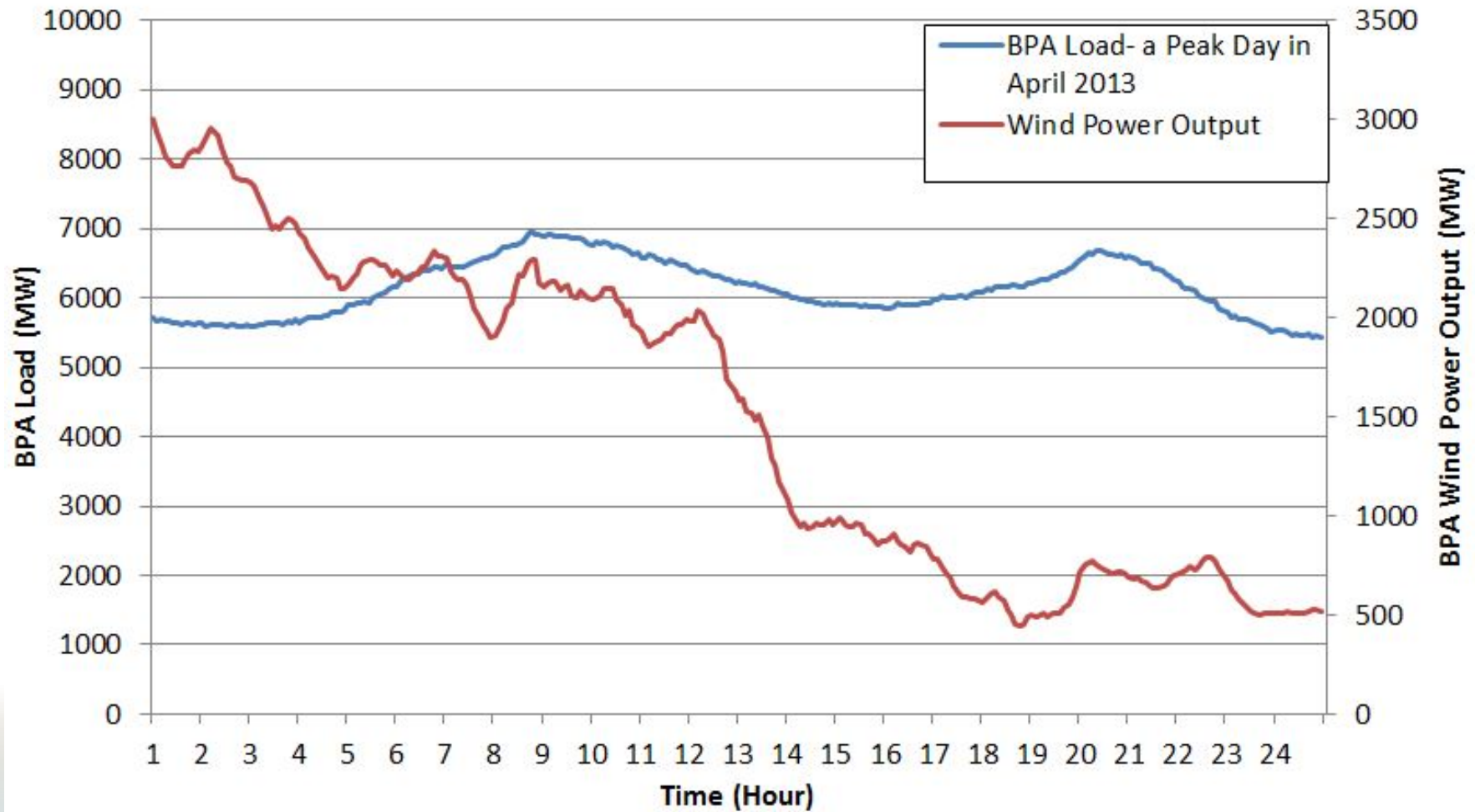
Wind Energy

Off-shore Wind turbines, Blyth, U.K.

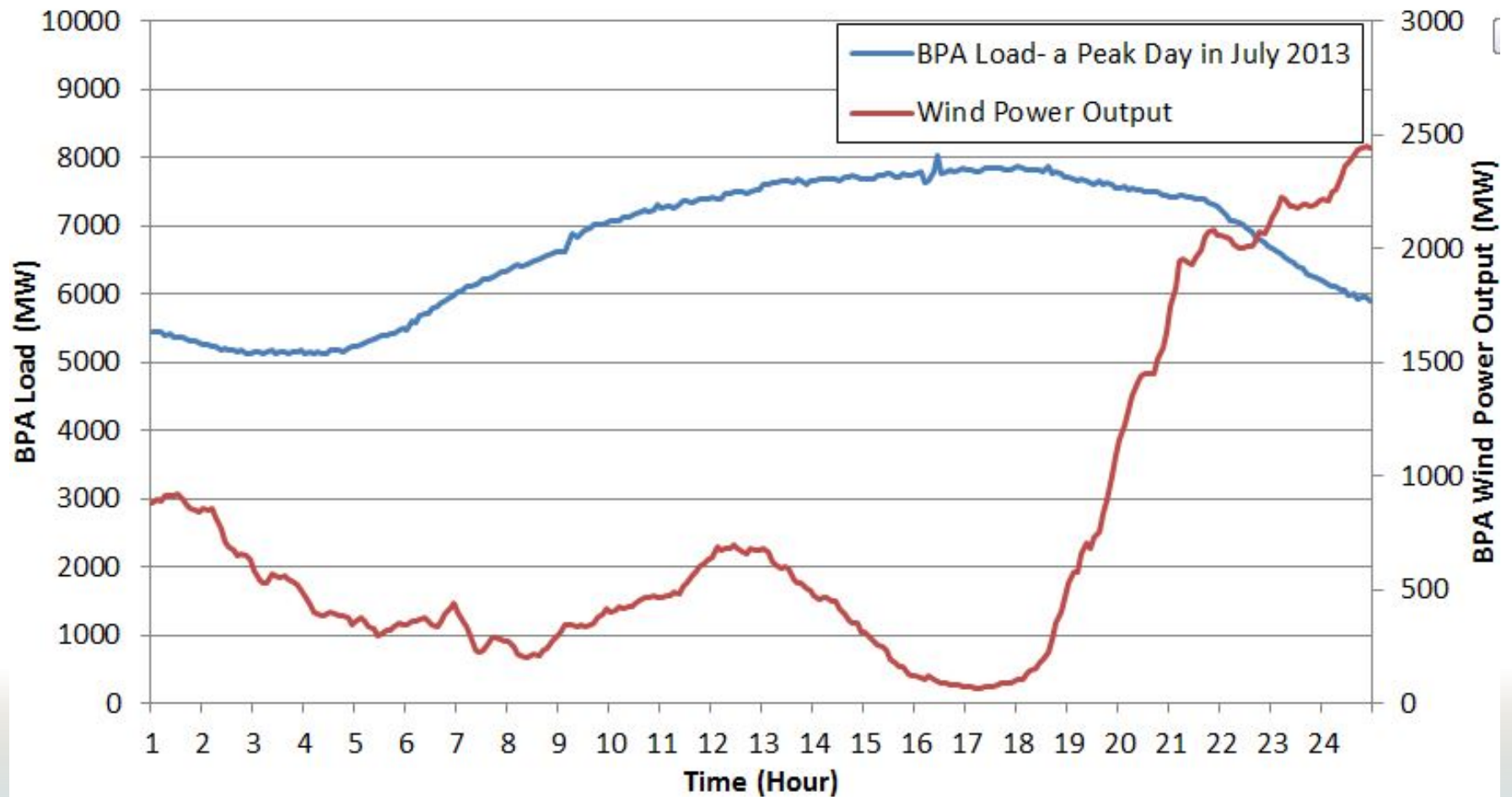
BPA Wind Output and Load Mismatch (January 2013)



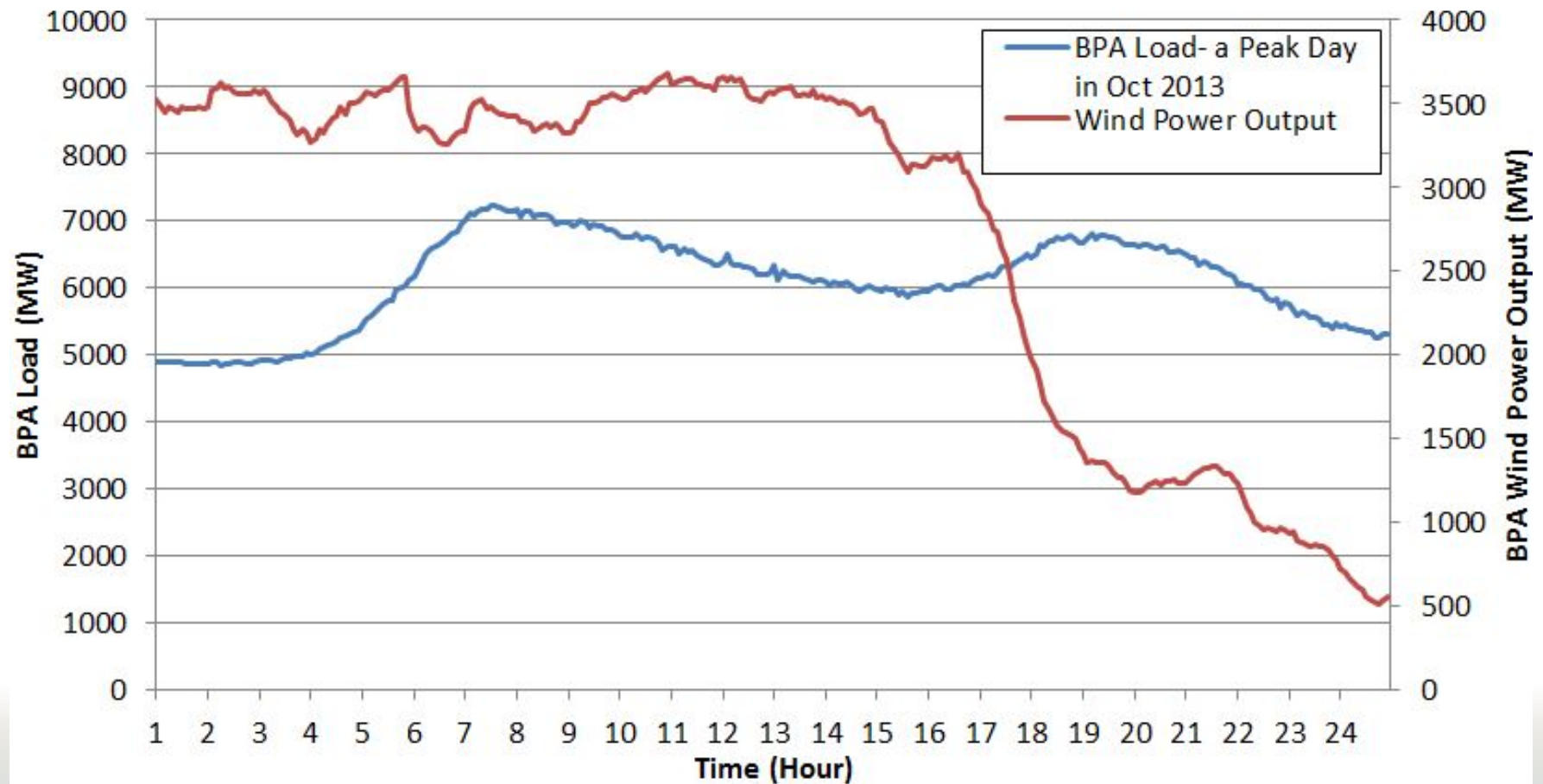
BPA Wind Output and Load Mismatch (April 2013)



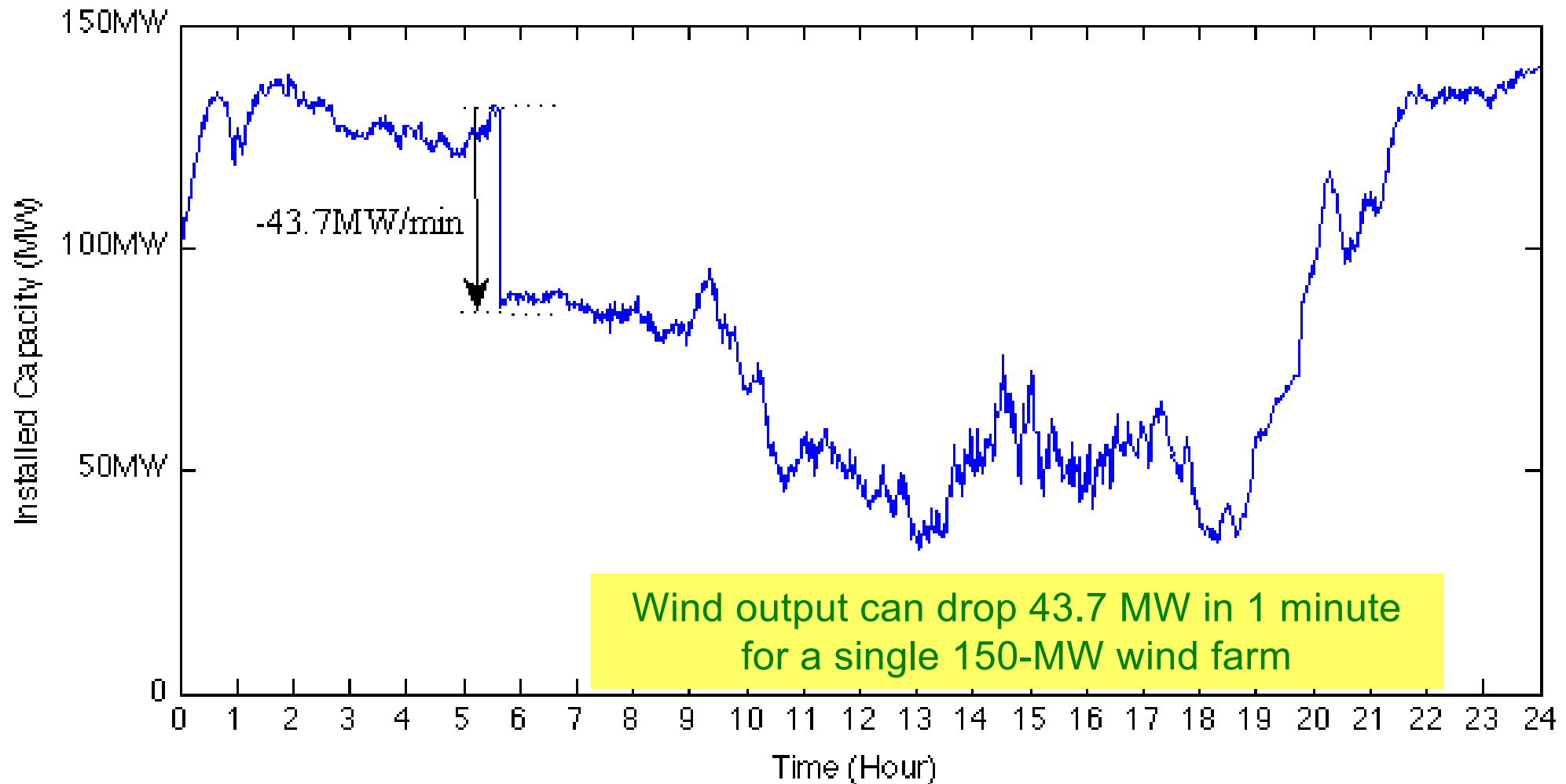
BPA Wind Output and Load Mismatch (July 2013)



BPA Wind Output and Load Mismatch (Oct 2013)

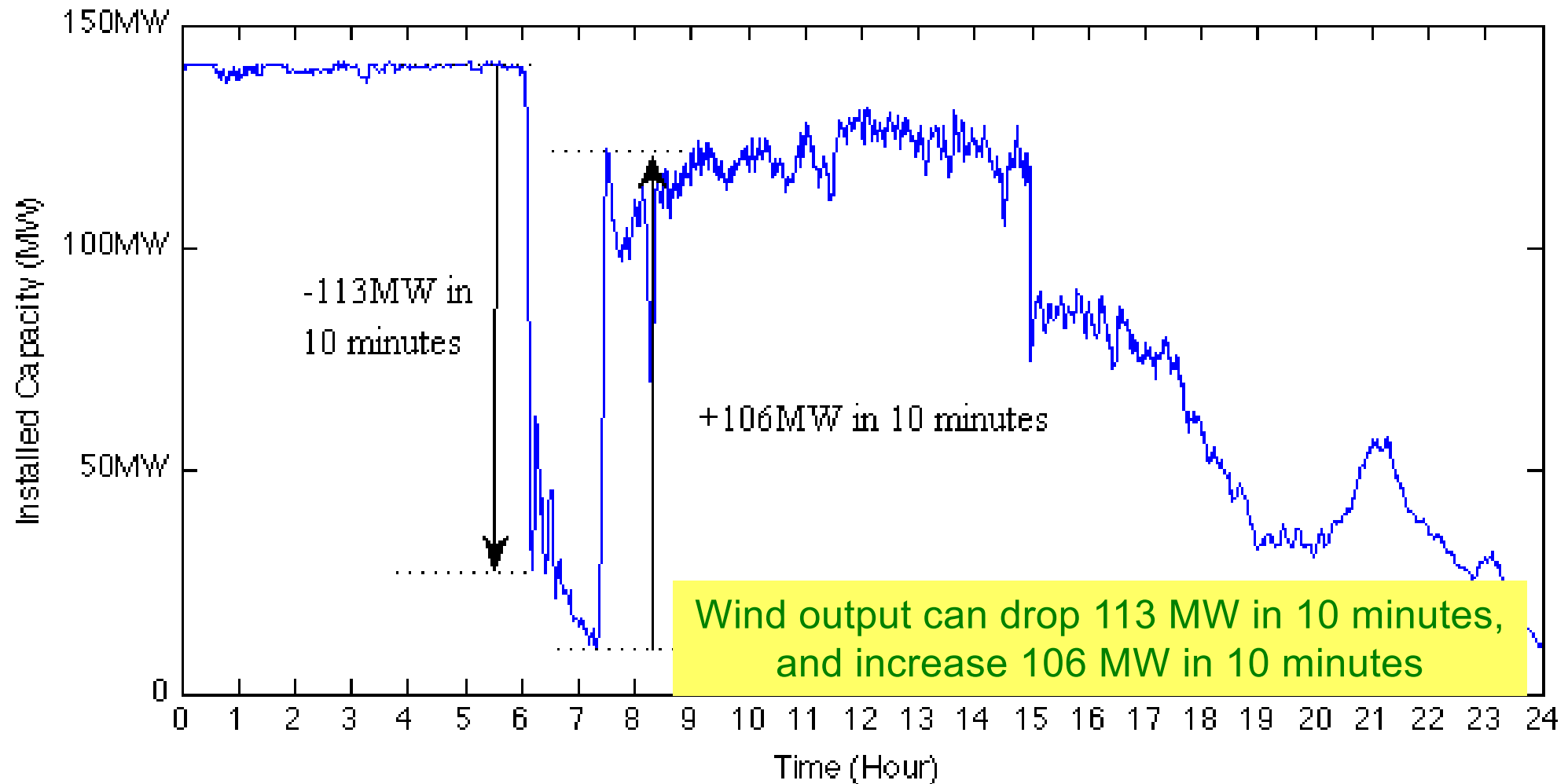


1-minute Variation of a 150MW Wind Farm Output in Texas



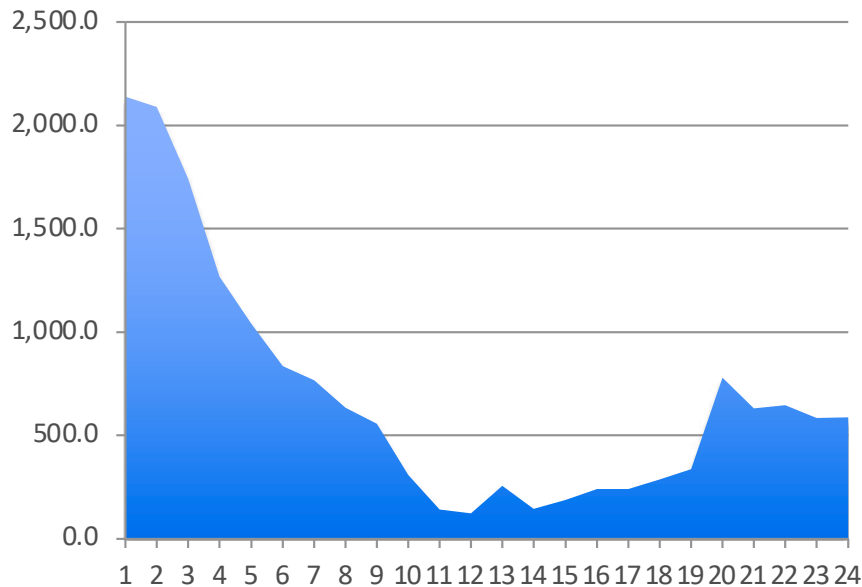
Source: NREL

10-min Variation of a 150MW Wind Farm Output in Texas

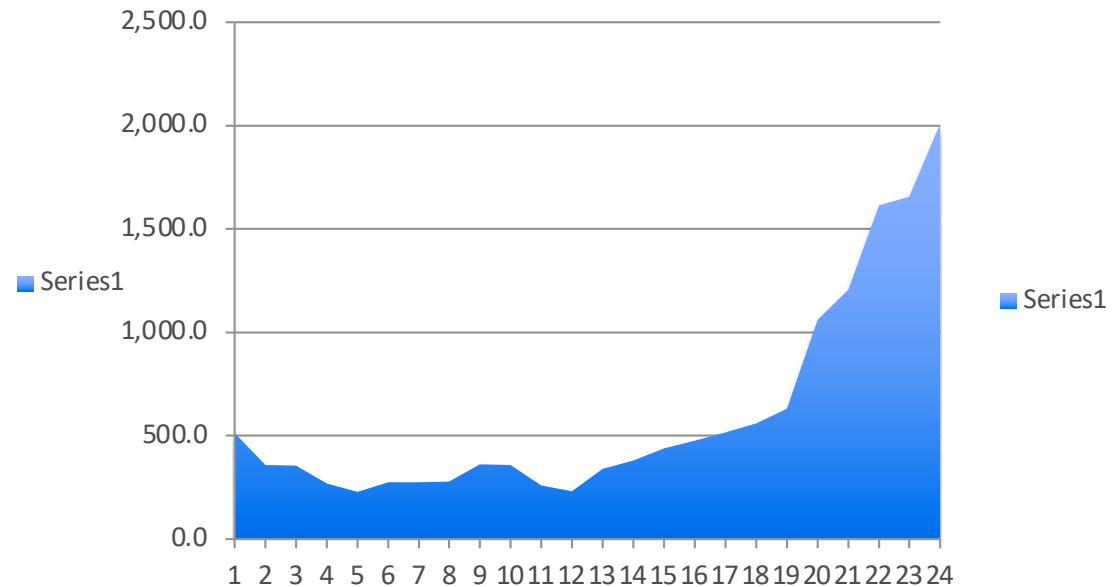


Source: NREL

Hourly wind power variation (MW) in Texas, USA (01 and 02 Jan)



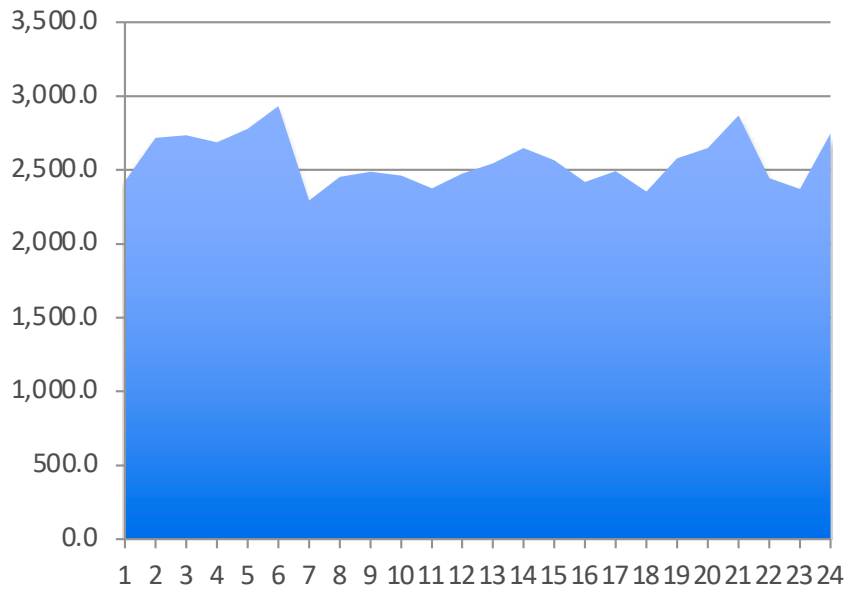
01 Jan 2008



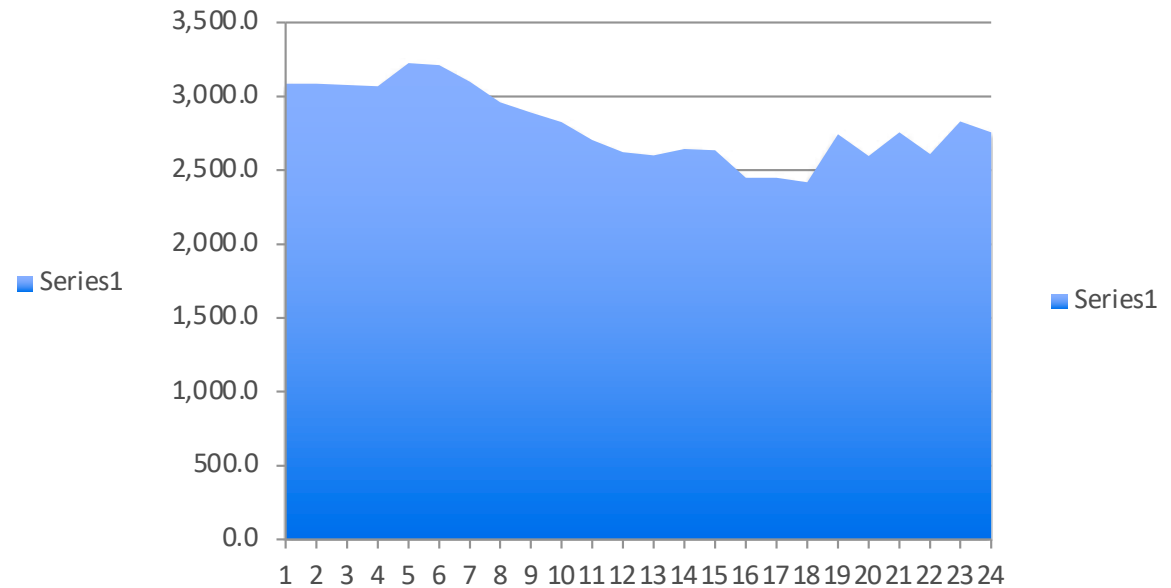
02 Jan 2008

Installed Capacity 4,541 MW

Hourly wind power variation (MW) in Texas, USA (03 and 04 Jan)



03 Jan 2008



04 Jan 2008

Installed Capacity 4,541 MW

Roof-top Solar Photovoltaics in Virginia

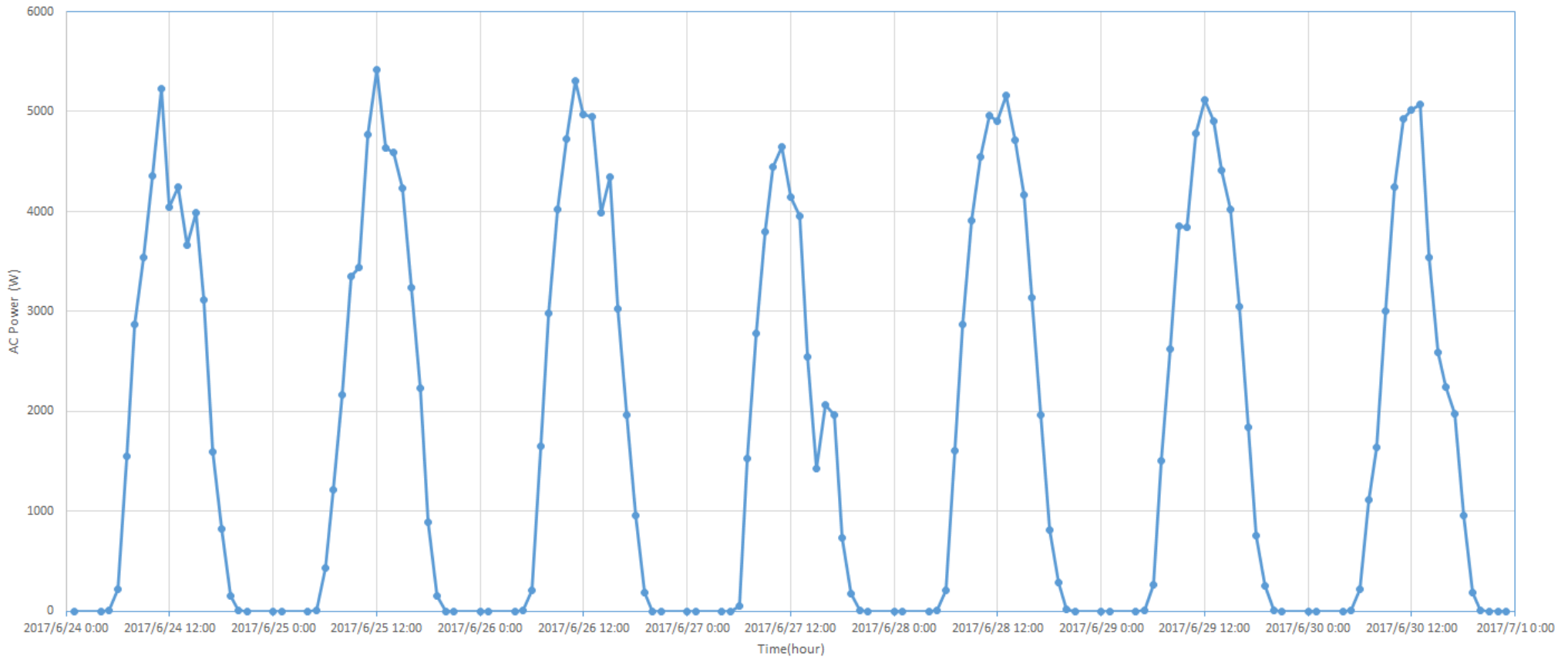


Solar Panels in Winter



7-Day Solar PV Output

PV AC Power Output During One Sunny Week



Day 1

Day 2

Day 3

Day 4

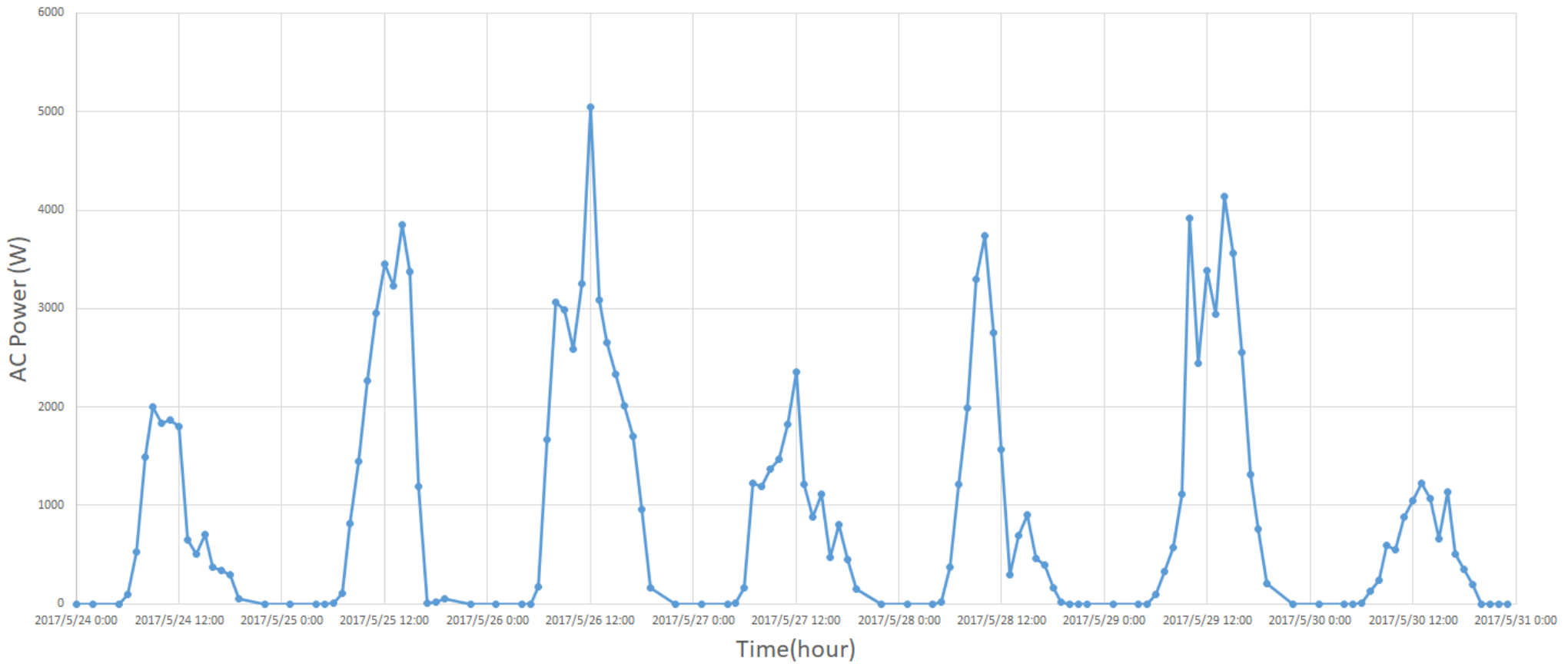
Day 5

Day 6

Day 7

7-Day Solar PV Output (intermittent)

PV AC Power Output During One Cloudy Week



Day 1

Day 2

Day 3

Day 4

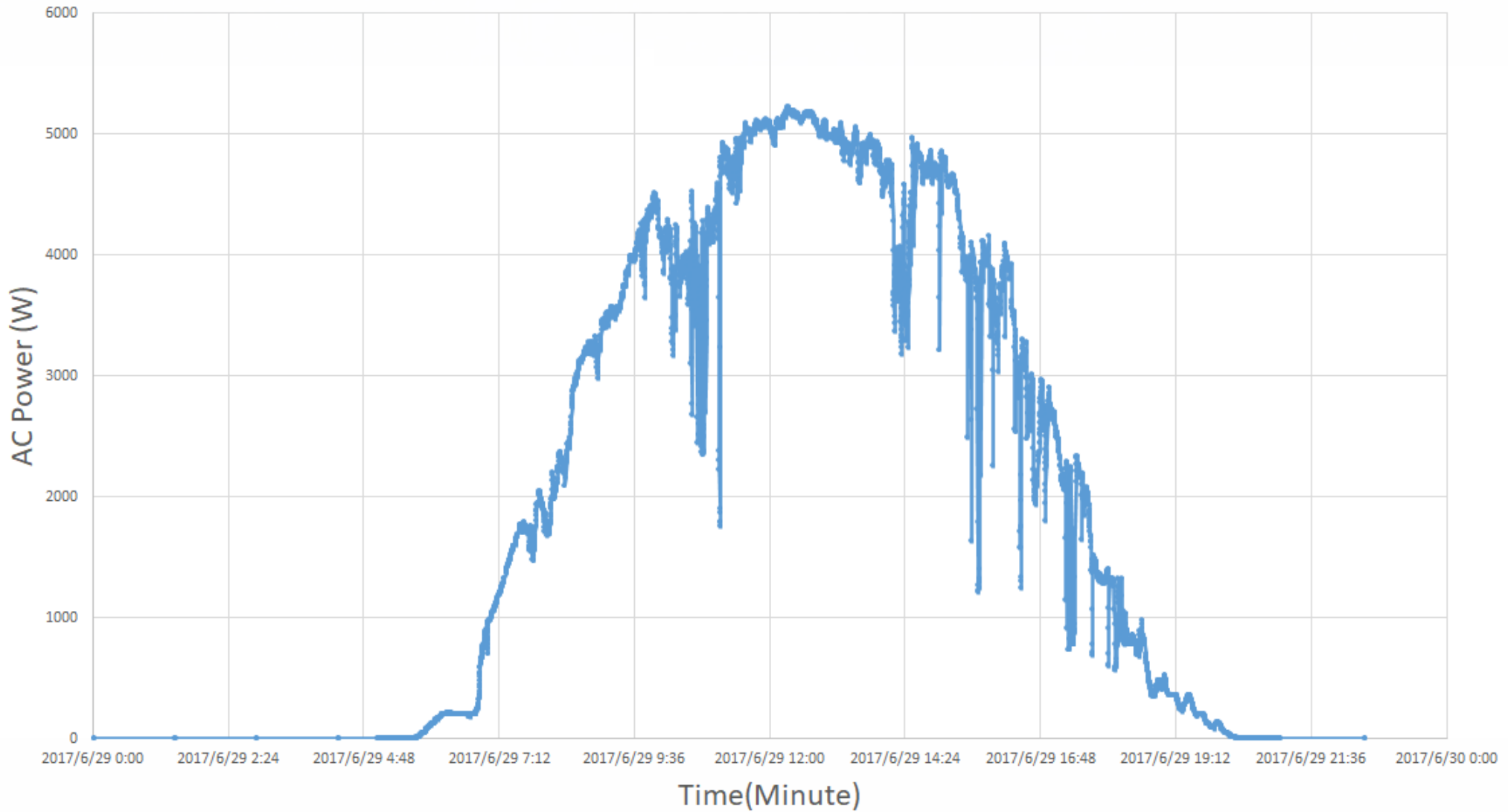
Day 5

Day 6

Day 7

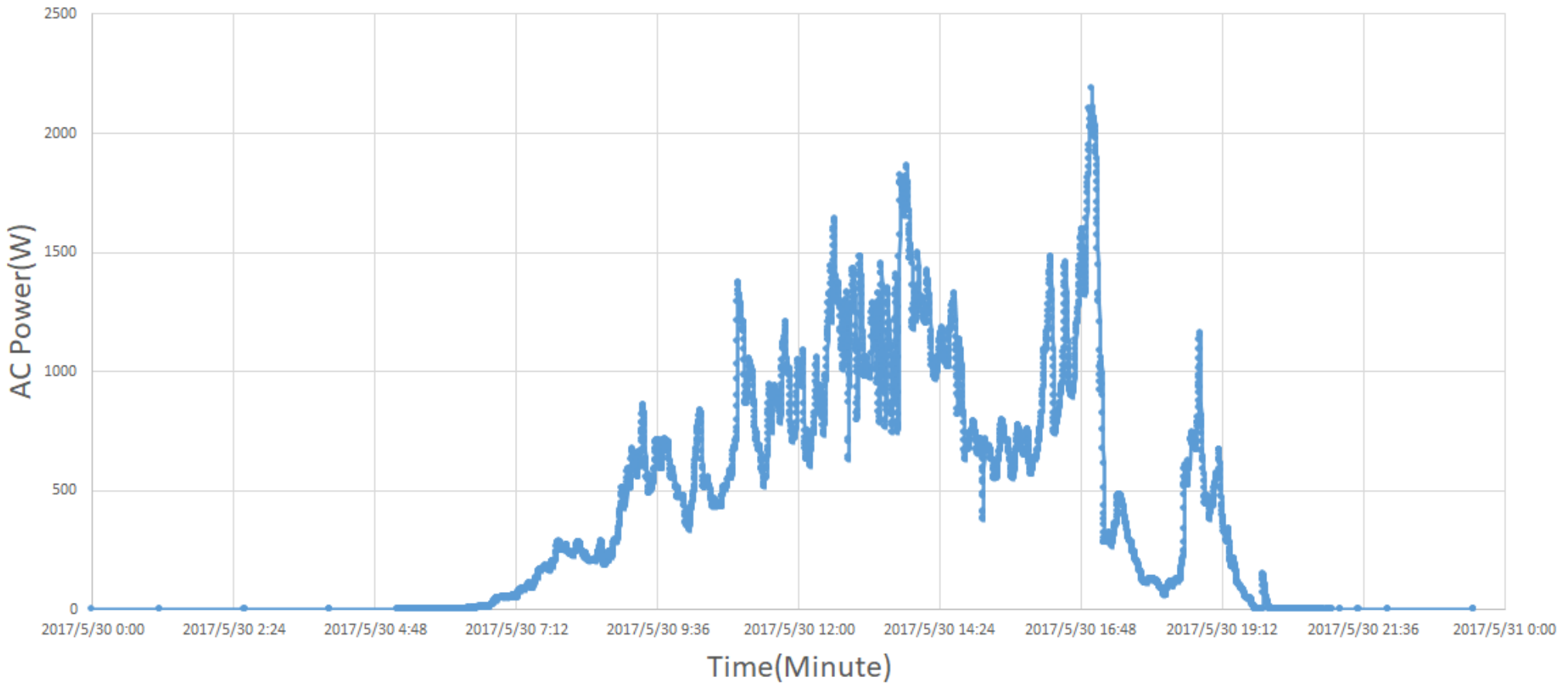
Daily PV Output

PV AC Power Output During One Sunny Day



Daily PV Output (intermittent)

PV AC Power Output During One Cloudy Day



Can the Intermittency be Absorbed by the Network?

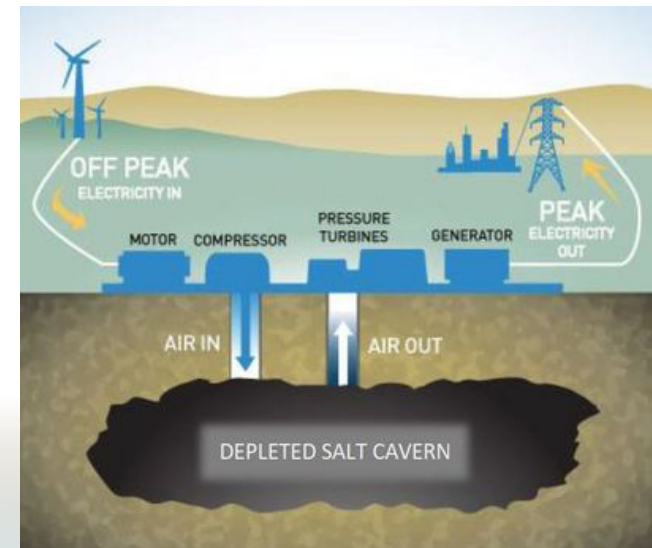


Battery storage



Pumped Storage

Compressed Air Storage





Demand Response

Demand Response is a customer action to control load to meet a certain target. Here the customer chooses what load to control and for how long.

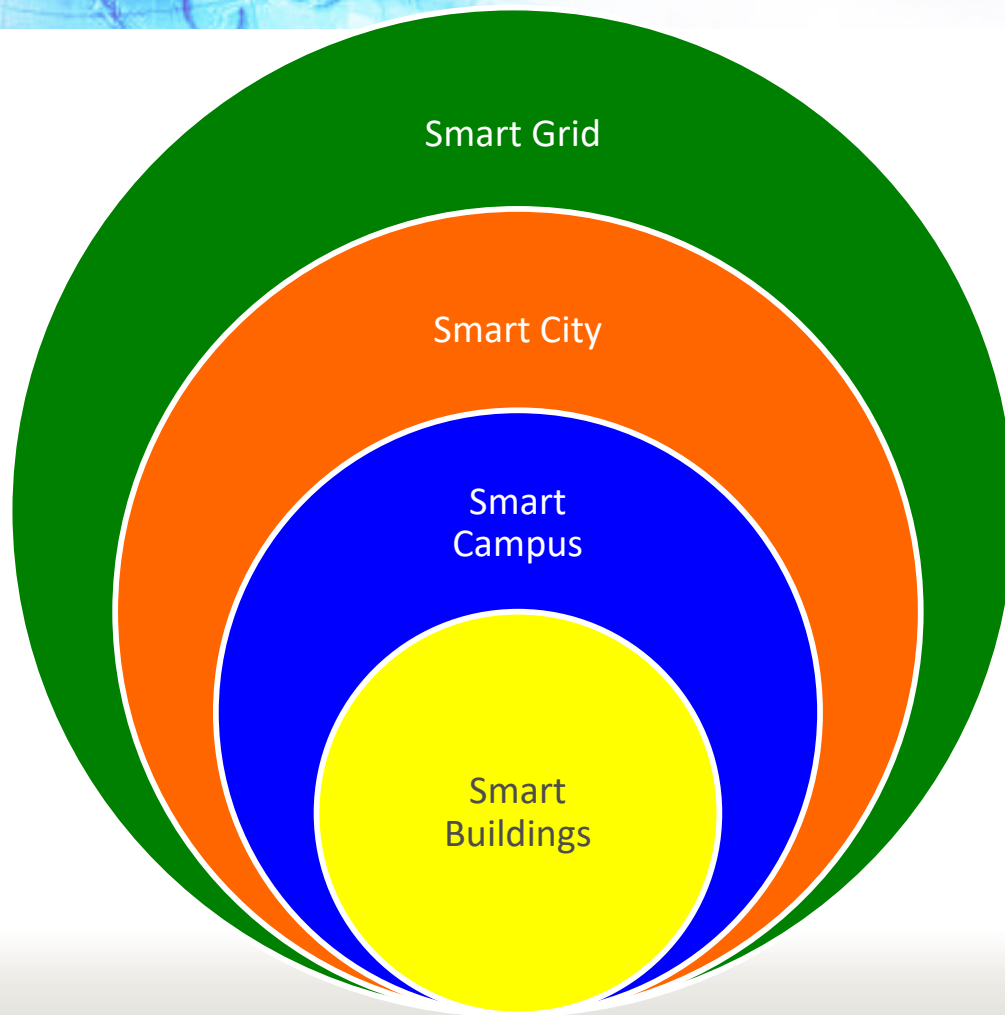


New Paradigm for the Power System

- Historically: Demand driven supply
(supply responds to demand)
- New Reality: Supply driven demand
(demand needs to adjust to meet
fluctuating supply with help from storage)

THE SMART GRID ECOSYSTEM

THE SMART GRID ECOSYSTEM



Smart grid: Bi-directional flows of energy, remote control/automation of power, integrated distributed energy...

Smart city: Complex system of interconnected infrastructures and services...

Smart Campus: A collection of buildings managed by the same facility manager...

Smart buildings: Intelligent building automation systems, smart devices, productive users, grid integration...

← Supported by ICT and distributed networks of intelligent sensors, data centers/clouds →

What makes a Building Smart



A single platform for monitoring and control of HVAC, lighting, water supply, sensor networks, security camera & fire emergency



Cumulative Benefits of Building Load Control

- A large number of buildings can be controlled to absorb large fluctuations of supply in the short term
- Minimal storage is required
- Investment is for monitoring and control

Addressing the Intermittency in Renewable Generation

- Smart vs. not-so-smart load control
(adjust temperature set points in an air conditioner or water heater vs. turning the unit off)
- Size the storage to take advantage of demand dynamics
- Control the renewable generation to avoid instability (output control from PV inverters)

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