Impact of Stochastic Security on Smart Grid Operation

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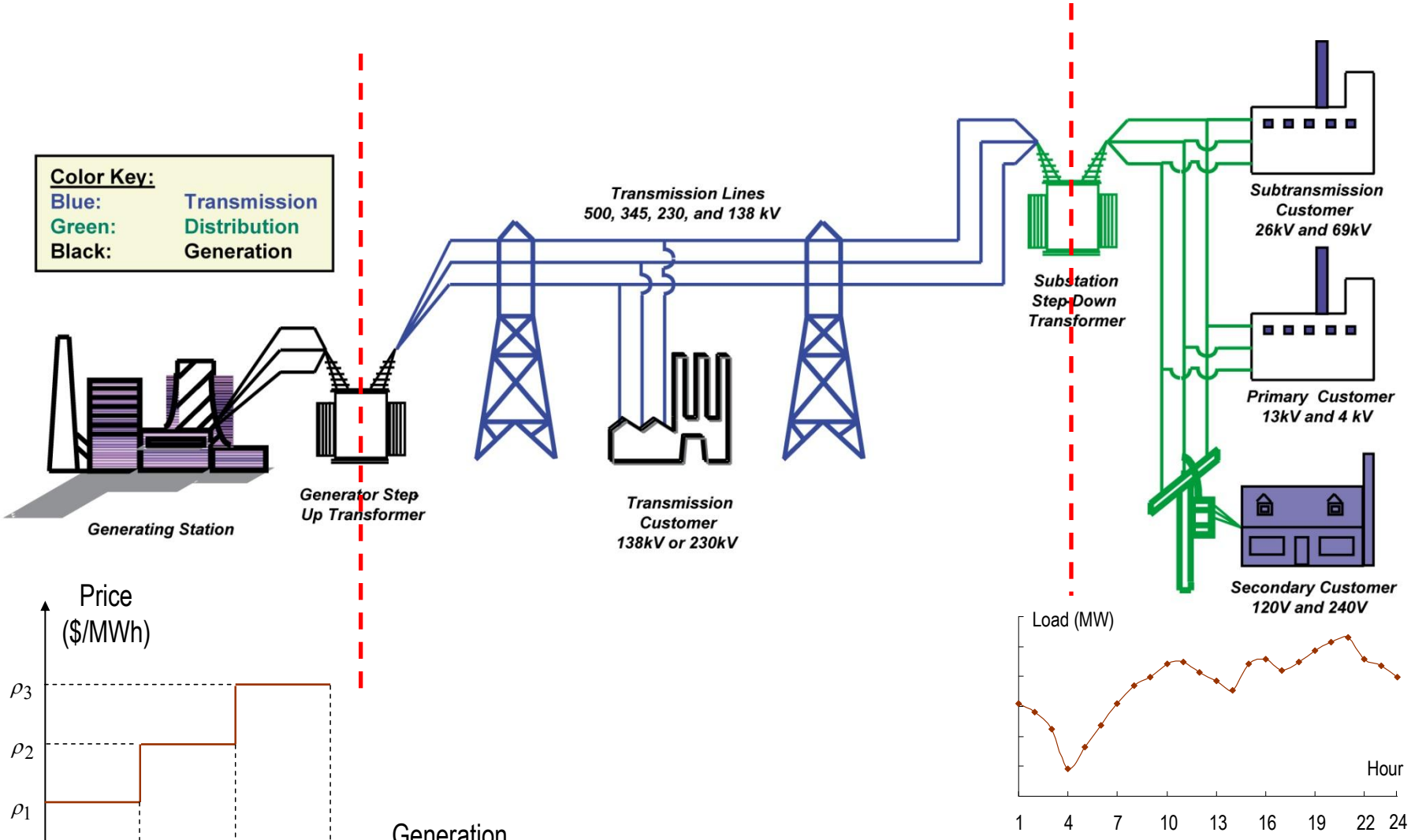
Outline

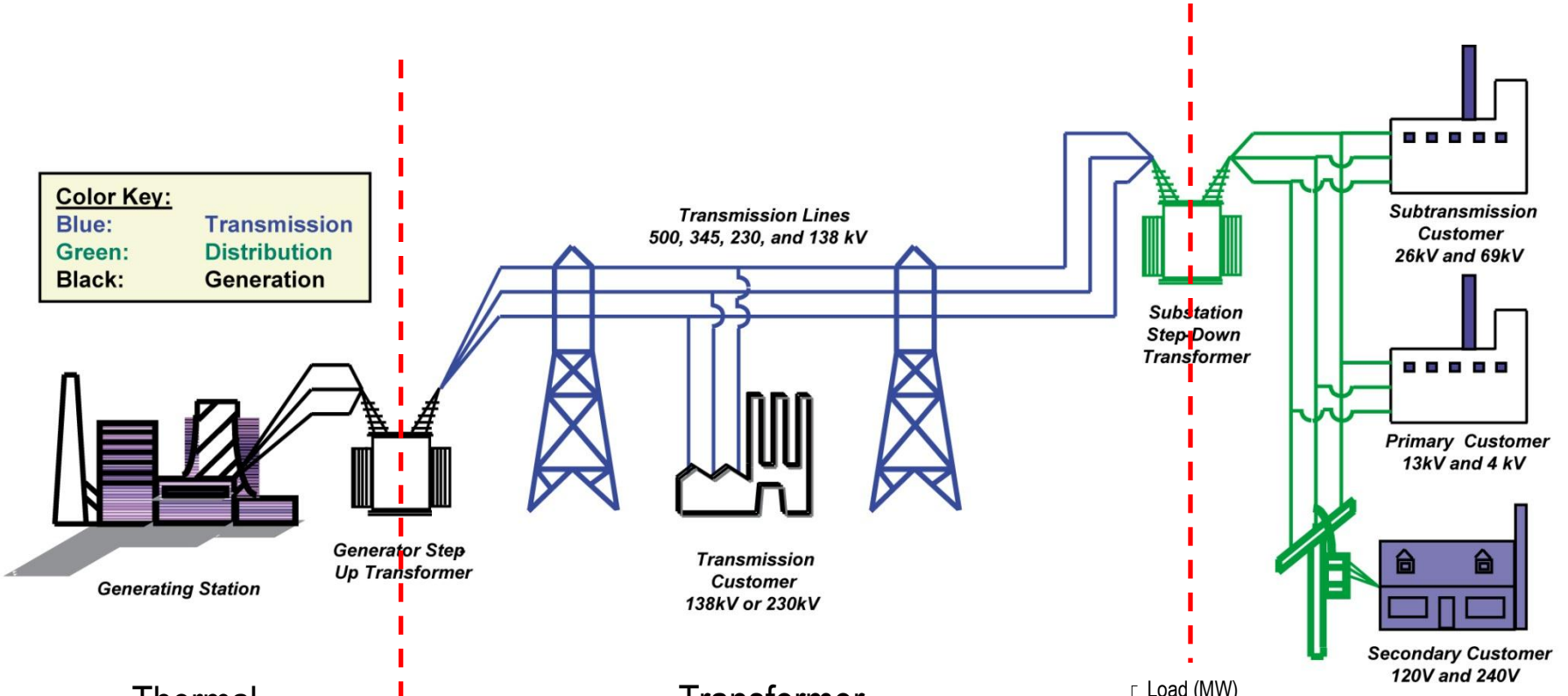
- Introduction to Electricity Grid Operation
- Smart Grid Today
- Stochastic Security-Constrained Unit Commitment
  - Challenges
  - Formulation
  - Applications

Electricity Grid Overview



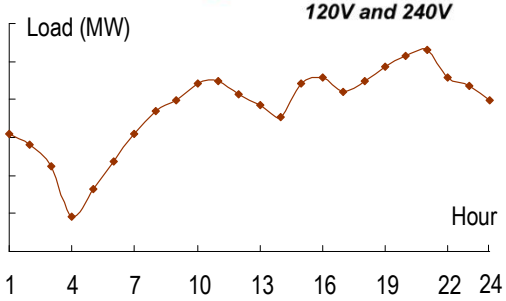
Source: Department Of Energy Report

Electricity Grid Overview



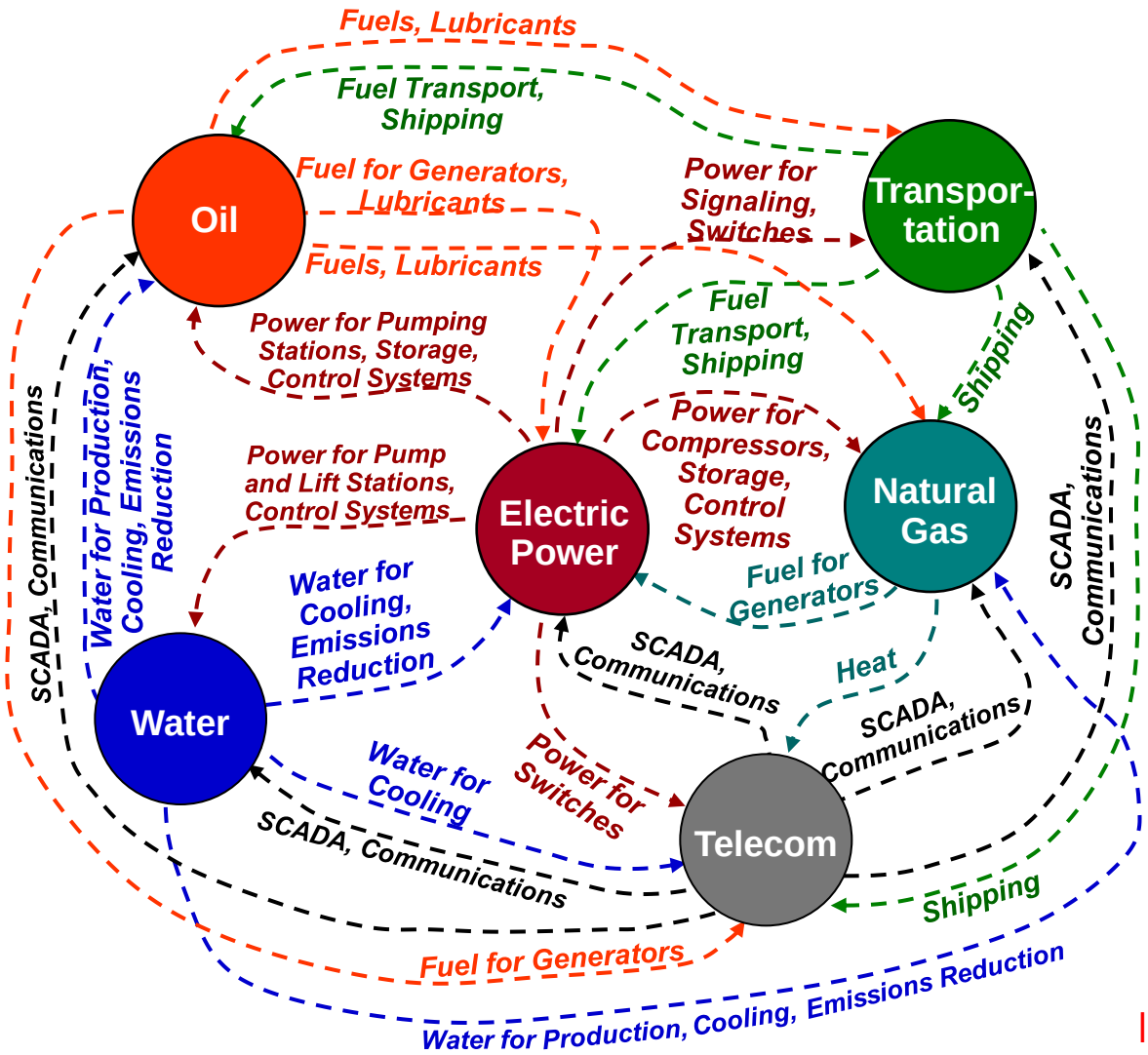
- Thermal
- Combined-cycle
- Hydro
- Pumped-storage
- Wind
- PV-battery

- Transformer
- Phase shifter
- Capacitor
- AC line
- HVDC line



Source: Department Of Energy Report

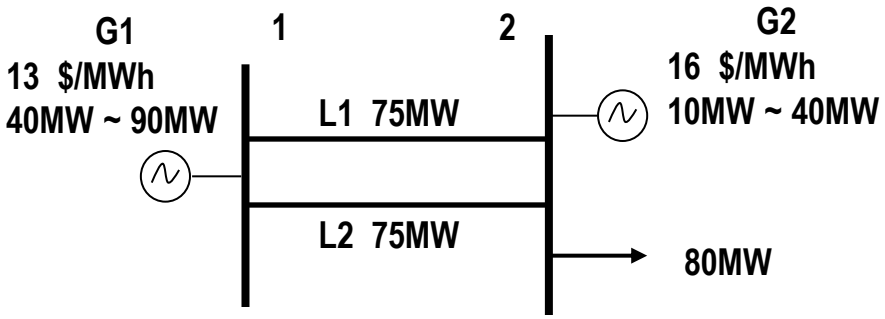
Interdependent Infrastructures



Source: Heller, M, Interdependencies in Civil Infrastructure Systems. *The Bridge*, Vol. 31, No. 4, 2001.

Secure and Economic Operation

- ISO uses SCUC to determine a secure and economic operation.
  - SCUC determines optimal unit commitment decisions (ON/OFF) and generation dispatches (MW) with least cost.
  - SCUC satisfies prevailing system and unit constraints for the base case and contingencies.
  - Several ISOs have started implementing SCUC (e.g. New York ISO, PJM interconnection, Midwest ISO, and ISO-New England).



	G1 (MW)	G2 (MW)
Base Case	80	0

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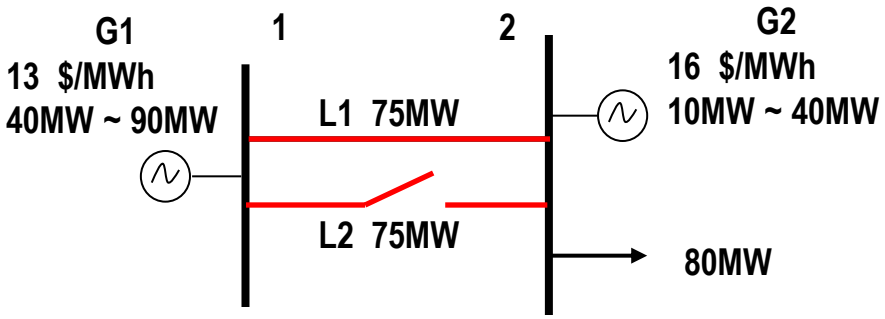


	G1 (MW)	G2 (MW)
Base Case	80	0
SCUC	70	10

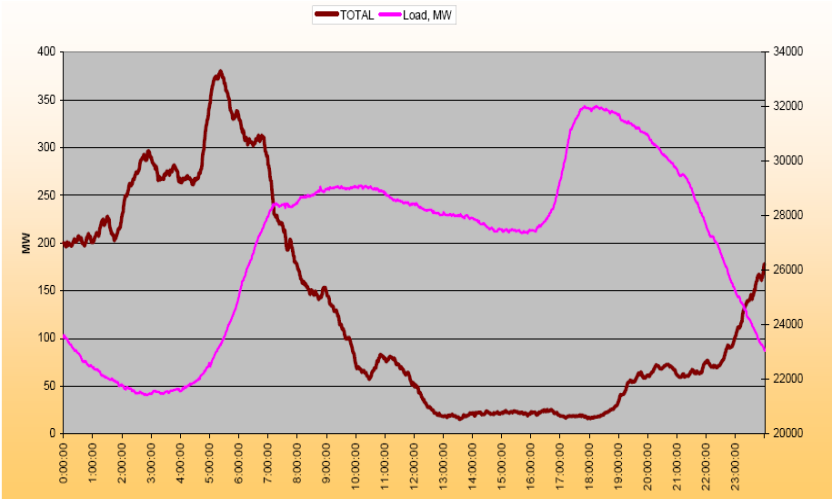
Smart Grid Today

- There is growing evidence that the aging electricity grid subjects us to more frequent system failures today, which will no longer be acceptable.

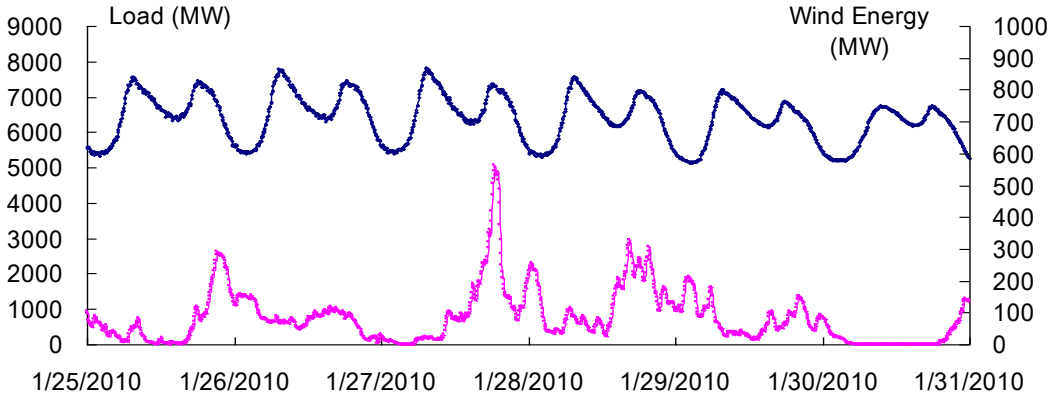
- Smart grid is a response to economic, security, and environmental mandates placed on energy supply and delivery.
  - Accommodates all generation and storage options
  - Enables active participation by consumers
  - Enables new products, services and markets
  - Provides power quality for the range of needs in a digital economy
  - Optimizes asset utilization and operating efficiency
  - Anticipates and responds to system disturbances in a self-healing manner
  - Operates resiliently against physical and cyber attacks, and natural disasters

Renewable Energy Integration

- Integrated Operation Challenge



Source: California ISO integration of renewable resources report , August 2007

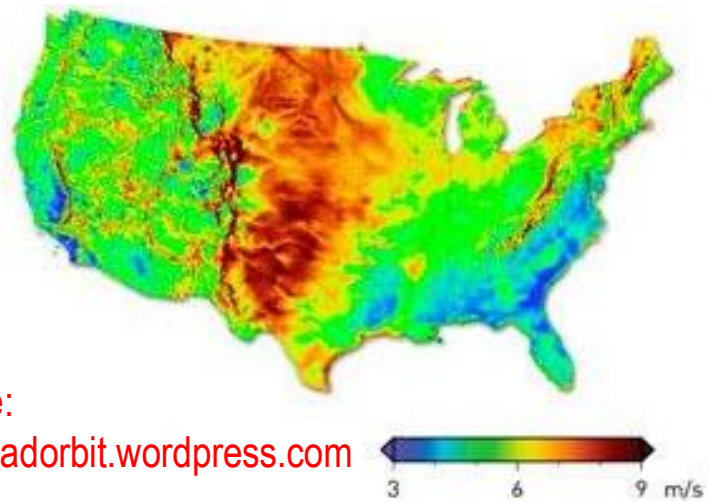


Source: http://www.bpa.gov, 2010

Renewable Energy Integration

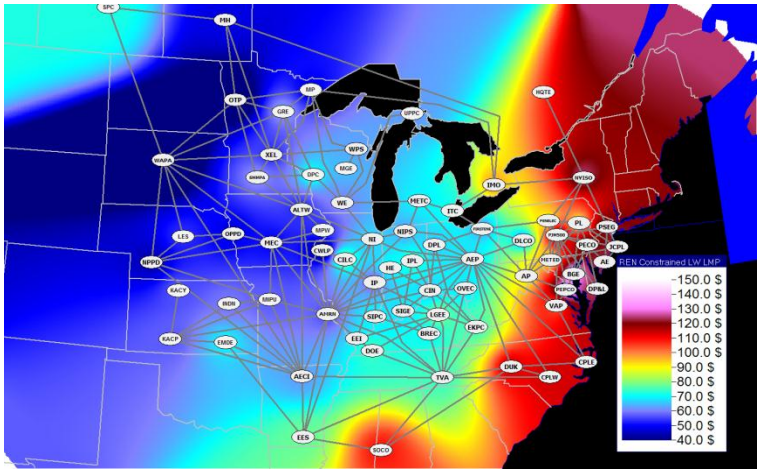
- Integrated Operation Challenge
- Transmission Challenge

Wind Resource Map



Source:
http://badorbit.wordpress.com

Annual Load Weighted LMP

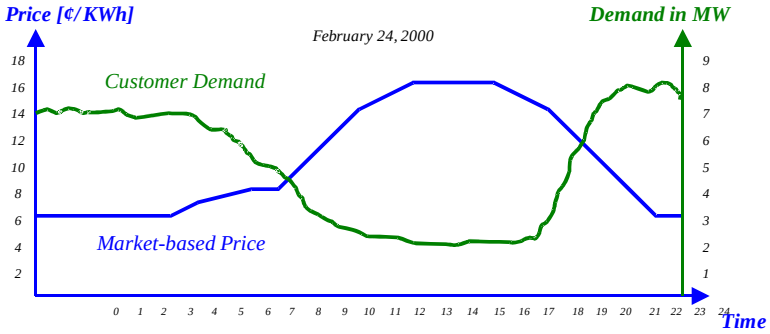


Source: Midwest ISO

Demand Response

- Most electricity consumers today act as price takers via flat rates, which do not reflect truly time-variant electricity supply costs.
- In smart grid, the electricity industry is in transition toward a demand-driven business. Demand response will help power markets set efficient market prices, mitigate market power, improve economic efficiency, and increase system security.

Behavior of a Demand in a Vertically Integrated Power Market



Response of a Demand to Price Signals

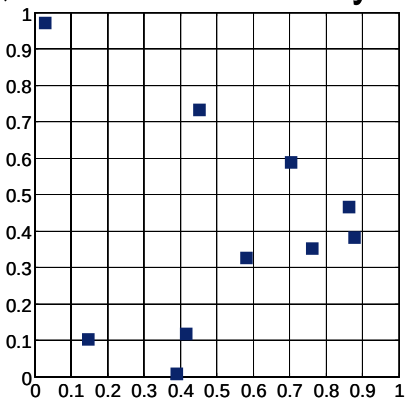
Stochastic SCUC - Motivation

Stochastic SCUC	SCUC
Minimize cost under the base case plus expected costs introduced by each scenario	Minimize operation cost under the base case
Use the Monte Carlo method to simulate uncertainty via multiple scenarios and check security evaluation for each scenario	Select credible contingencies and check security evaluation for each contingency

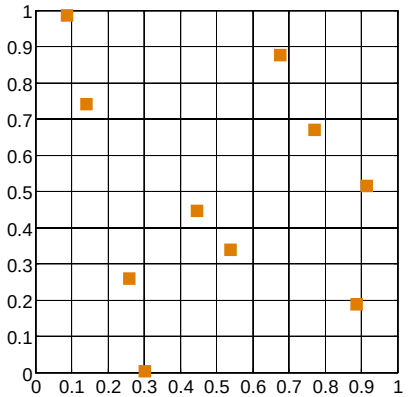
- Uncertainty Simulation
  - Random outages of system equipment
  - Load and wind forecast inaccuracy
  - Fuel price and availability
- Rigorous formulation for the hourly commitment of quick-start units in scenarios
- Efficient decomposition method for solving the stochastic SCUC problem, which is a NP-hard problem

Scenario Generation

- Outage simulation of a single generator
  - Generate a sample following the uniform distribution [0,1]
  - Compare it with the forced outage rate (FOR) of the generator
- Monte Carlo method based sampling
  - The advantage of the Monte Carlo method over other techniques (such as enumeration method) is more significant as uncertainty dimensions increase.
  - Simulation accuracy depends on the number of samples and the variance of sample estimates. Evenly distributed samples can reduce the variance of sample estimates, thus the efficiency of the Monte Carlo simulation is improved.



Ordinary Monte Carlo



Latin Hypercube

Stochastic SCUC Formulation

- A two-stage stochastic programming
  - First-stage: optimal operation decisions for base case
  - Second-stage: viability and optimality of the first stage decision in each scenario
- Objective: Minimize operation costs for base case + expected costs introduced by each scenario
  - First-stage constraints (Base Case)
    - System constraints
    - Unit commitment constraints
    - Demand response constraints
    - Network constraints
  - Second-stage constraints (Scenarios)
    - System constraints
    - Unit commitment constraints
      - Power generation (restricted by the base case solution)
      - Hourly unit commitment of quick-start generators
    - Fast demand response decisions
    - Network constraints

Stochastic SCUC Solution

- Original Problem

$$\text{Min} \quad c \cdot x + \sum_s p^s \cdot d^s \cdot y^s \qquad \text{Objective}$$

$$\text{S.t.} \quad A \cdot x \le b \qquad \text{First-stage Constraints}$$

$$E^1 \cdot x + F^1 \cdot y^1 \le h^1 \qquad \text{Second-stage Constraints}$$

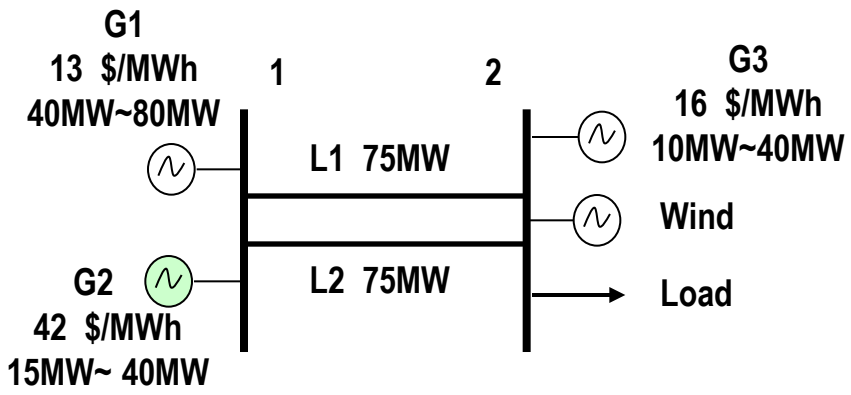
$$E^2 \cdot x + F^2 \cdot y^2 \le h^2$$

$$\vdots$$

$$E^s \cdot x + F^s \cdot y^s \le h^s$$

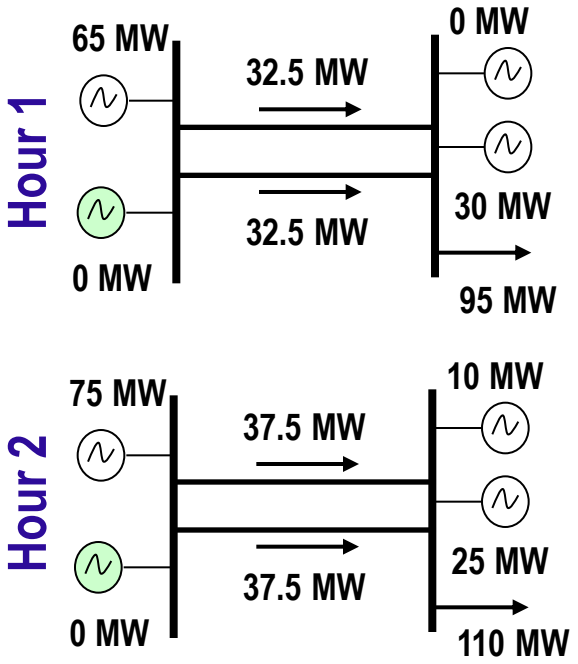
$$x \in R^{m1} \cdot \{0,1\}^{n1} \qquad y^s \in R^{m2} \cdot \{0,1\}^{n2}$$

Stochastic Short-term SCUC

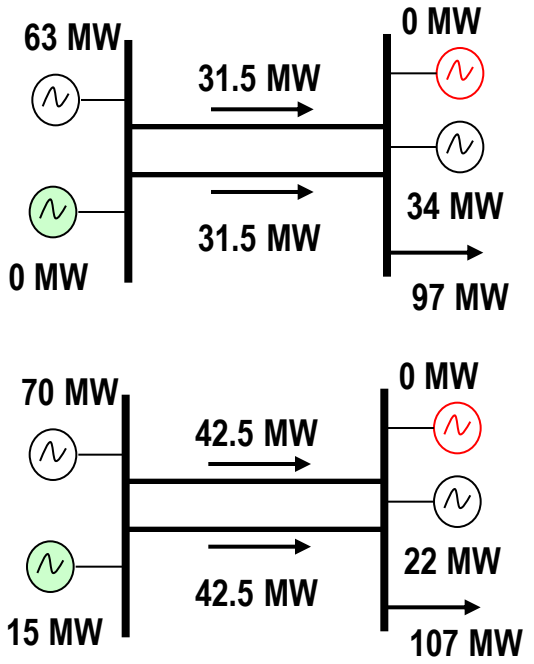


	Outage	Wind (MW)		Load (MW)		Probability
		H1	H2	H1	H2	
Base Case	-	30	25	95	110	0.82
Scenario 1	G3	34	22	97	107	0.09
Scenario 2	L2	23	32	91	112	0.09

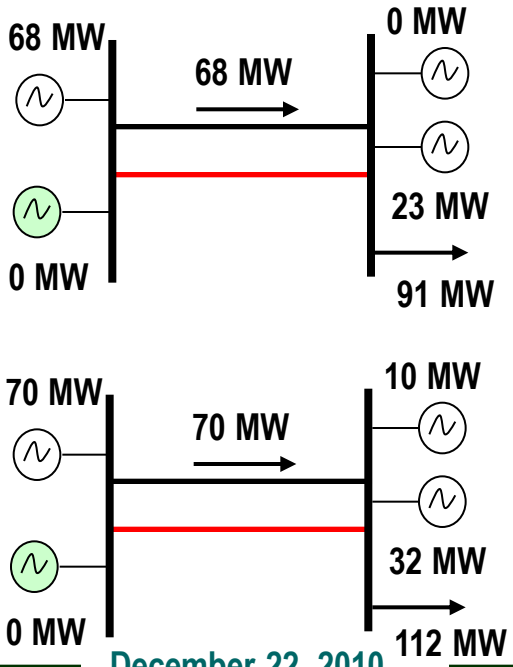
Base Case



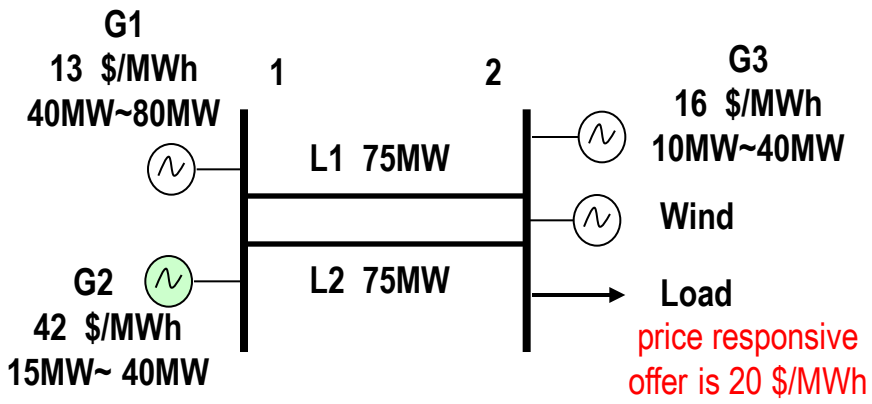
Scenario 1



Scenario 2



Stochastic Short-term SCUC



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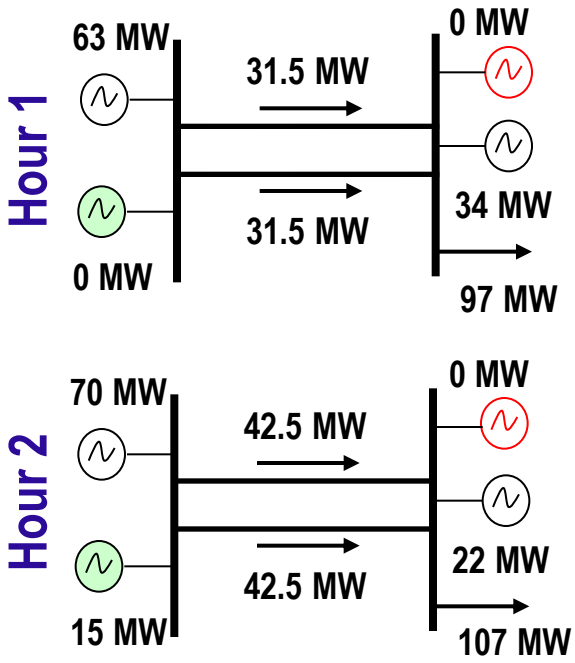
Price Insensitive



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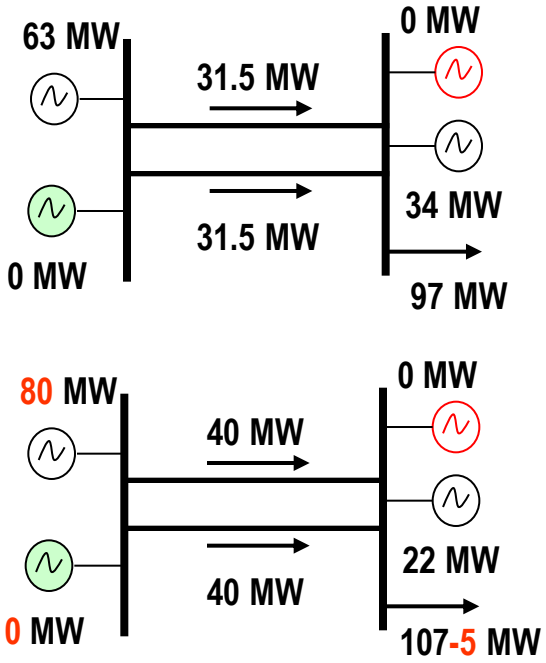
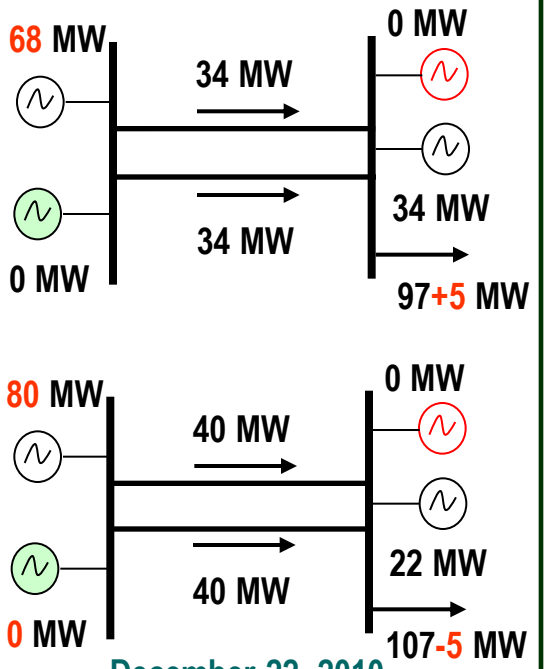
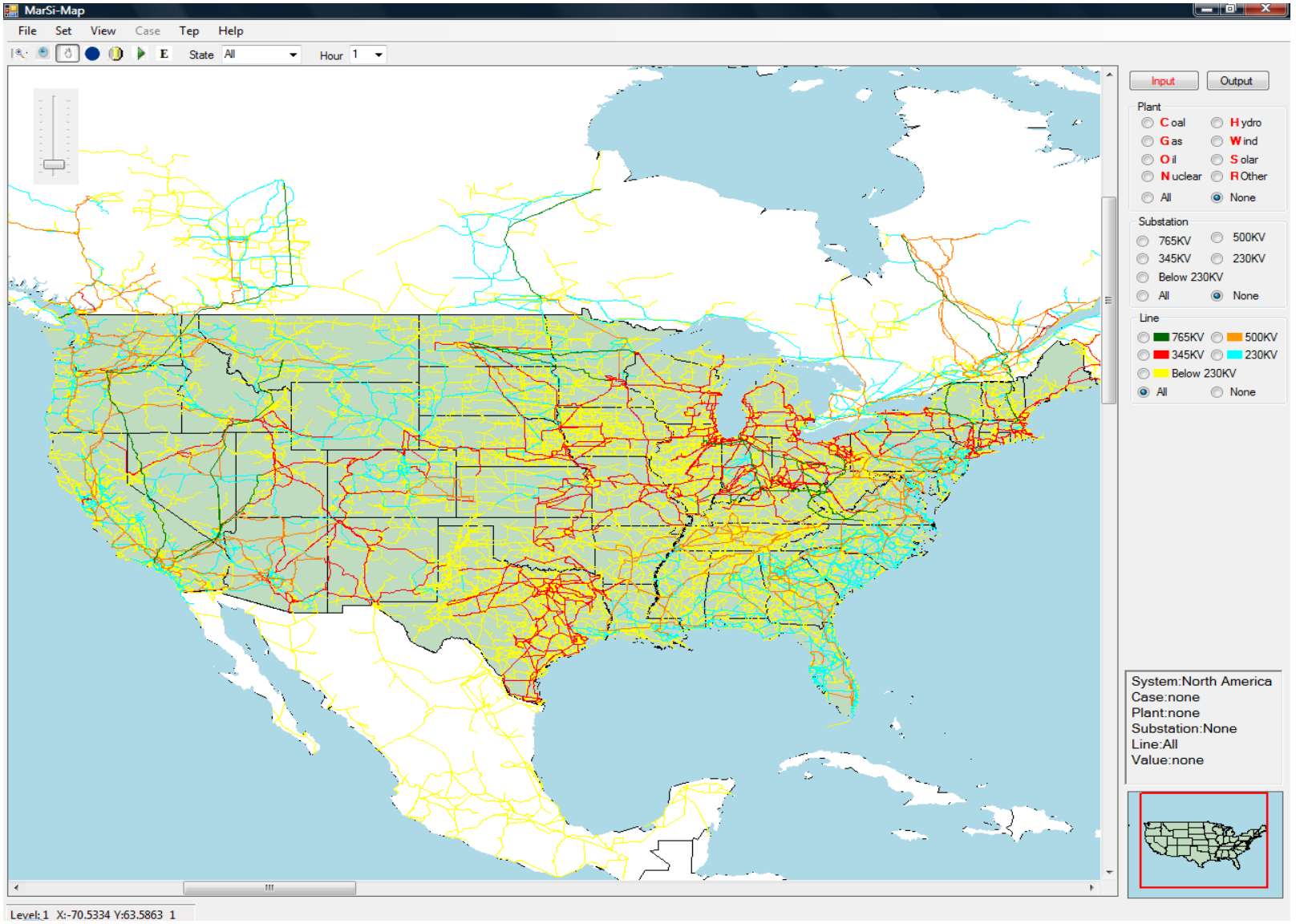


Shiftable



Visualization of Electricity Grid



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