Risk-limiting dispatch for the smart grid: some research problems

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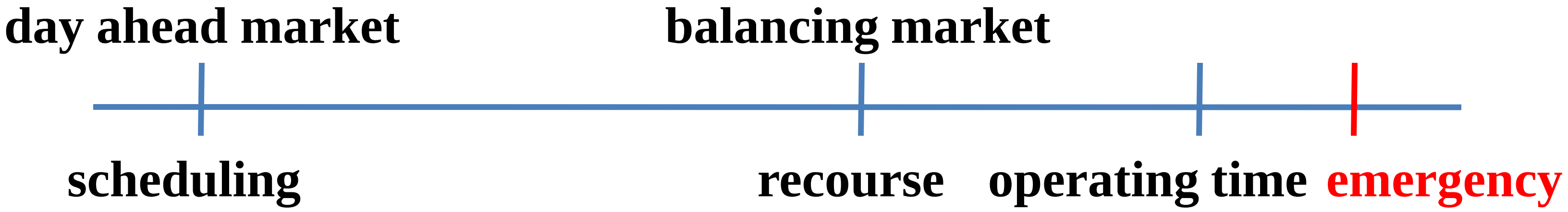
Outline

1. Current system operations: worst-case dispatch
2. Future electric power system: smart grid
3. Renewables and demand response increase uncertainty
4. Smart grid increases information and control
5. Risk-limiting dispatch
6. Preserving the interface: bundling unreliable supply/demand
7. Preserving the interface: unreliable energy transactions

Current electric power system operations



day ahead market **balancing market**

scheduling **recourse** **operating time** **emergency**

- ISO schedules generators/loads s.t. constraints are met:
  - Power balance
  - Operating limits
  - (N-1) contingencies
- Objective
  - Min cost

    s.t. constraints

- Uncertainty
  - Peak load demand
  - Forced outage (fault)
- Recourse
  - Balance
- Emergency
  - Load shedding

Operating risk and worst-case dispatch

- Operating risk
  - Not meeting constraints
- Constraints
  - Power balance

    $$g(\mathbf{x}(t), u) = 0$$

  - Operating limits

    $$h(\mathbf{x}(t), u) \leq 0$$

- u is such that for each contingency $x(t)$ is stable

- Stochastic uncertainty
  - Outage, peak demand
- (N-1) contingencies
- Dispatch **reliable power**

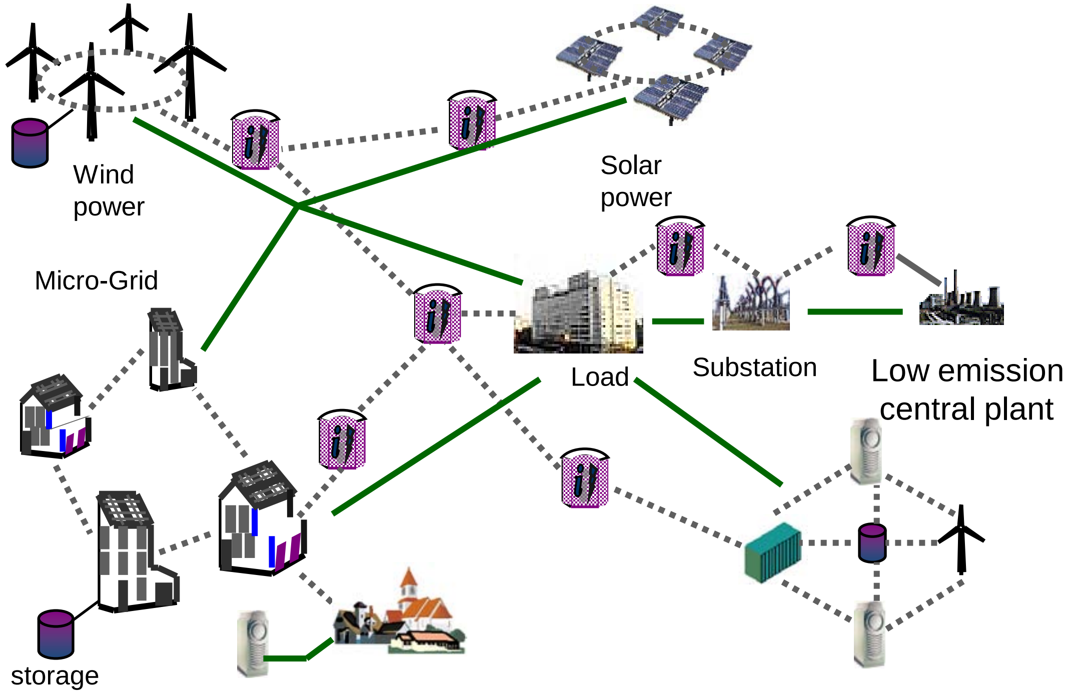
  $$\sum S_i \geq (1+r)D$$

  - $r \sim 0.05$ = reserve margin
  - D = peak demand
- Reserve margin increases capacity cost and carbon emissions

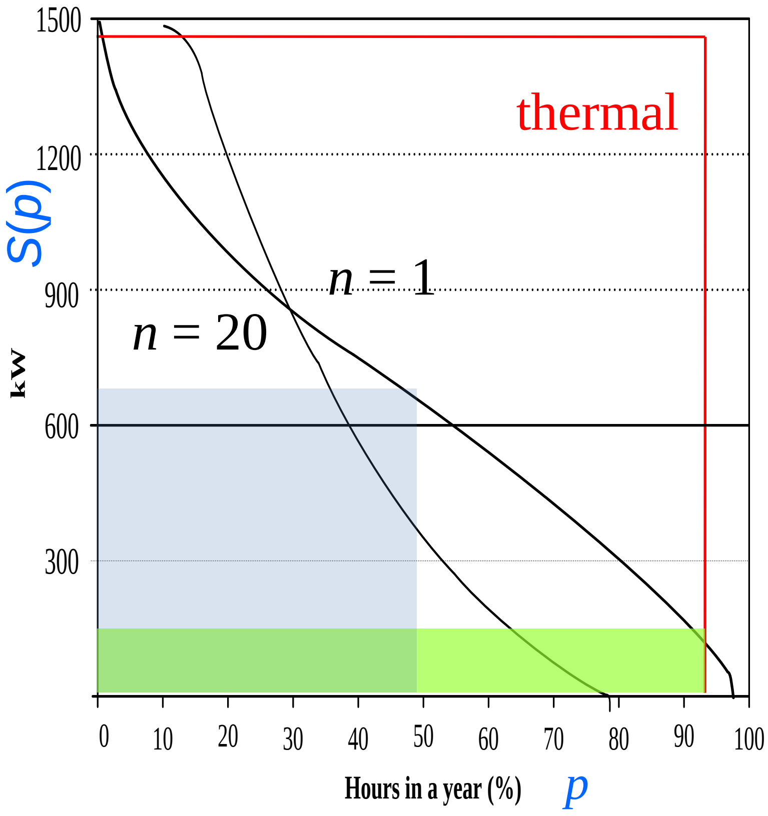
Future electric power system

- Renewables
  - Wind
  - Solar
  - Storage
  - microgrid

- Smart grid infrastructure
  - Smart meters, sensors
  - Intelligent appliances
  - Communication
  - Demand response



Renewable generation increases uncertainty



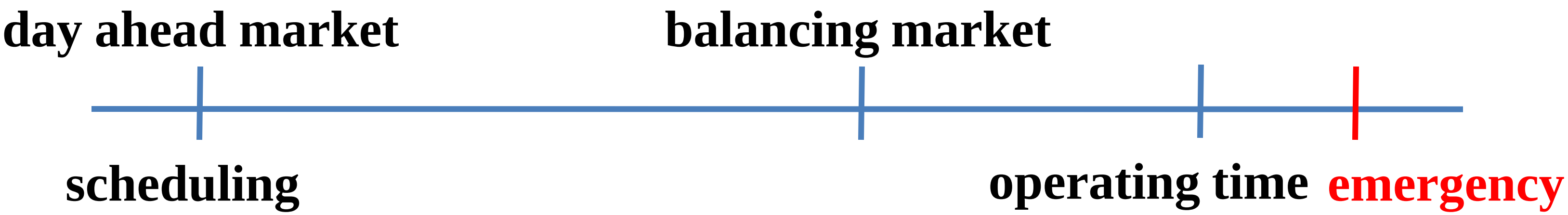
- Generation availability

$$S(p) = \max\{x \mid P(\tfrac{1}{n}\textstyle\sum_{i=1}^{n} S_i \geq x) \geq p\}$$

power supply exceeds $S(p)$ for p % hours/year

- Rated capacity = 1500KW
- Average capacity = 700KW
- Reliable capacity = 150KW (reliable capacity ~ thermal)

Wind power and worst-case dispatch

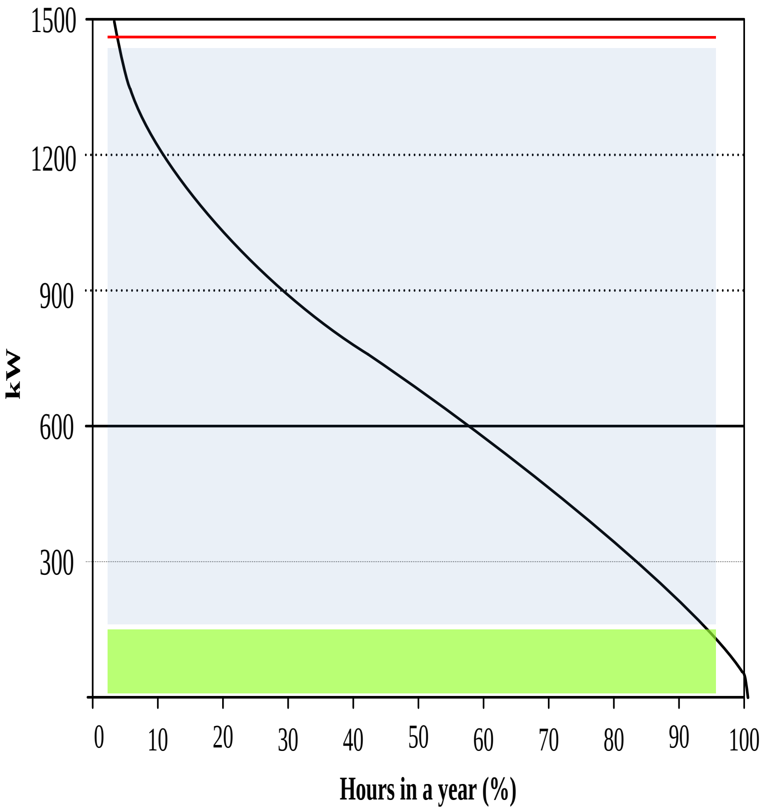


day ahead market

balancing market

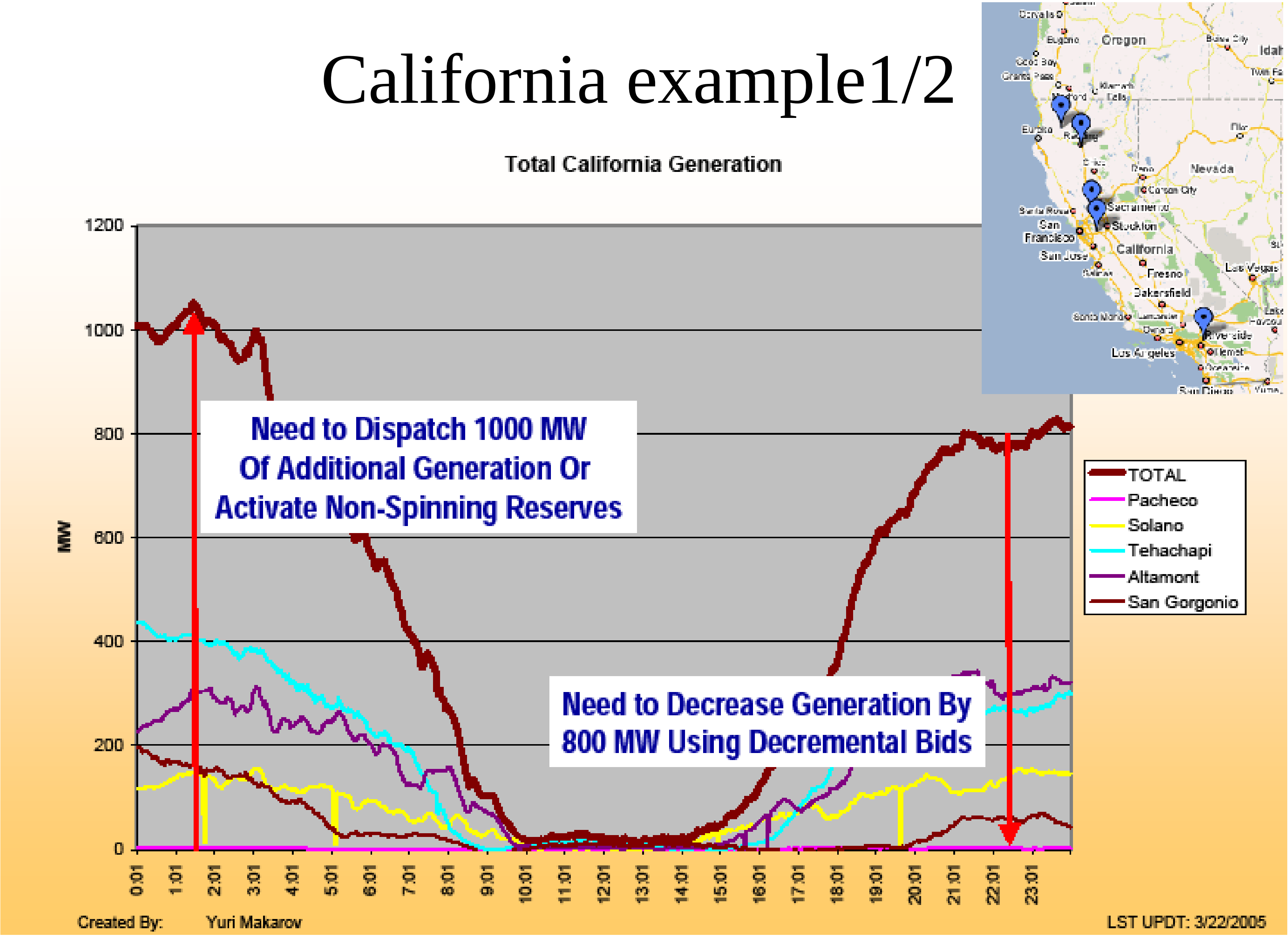
scheduling

operating time **emergency**



- Rated capacity = M
- Reliable capacity = 0.1-0.2M
- **If M is scheduled need reserve capacity of 0.8M**
- **If 0.2M is scheduled it should displace 0.8M of thermal power, which becomes reserve**

California example1/2

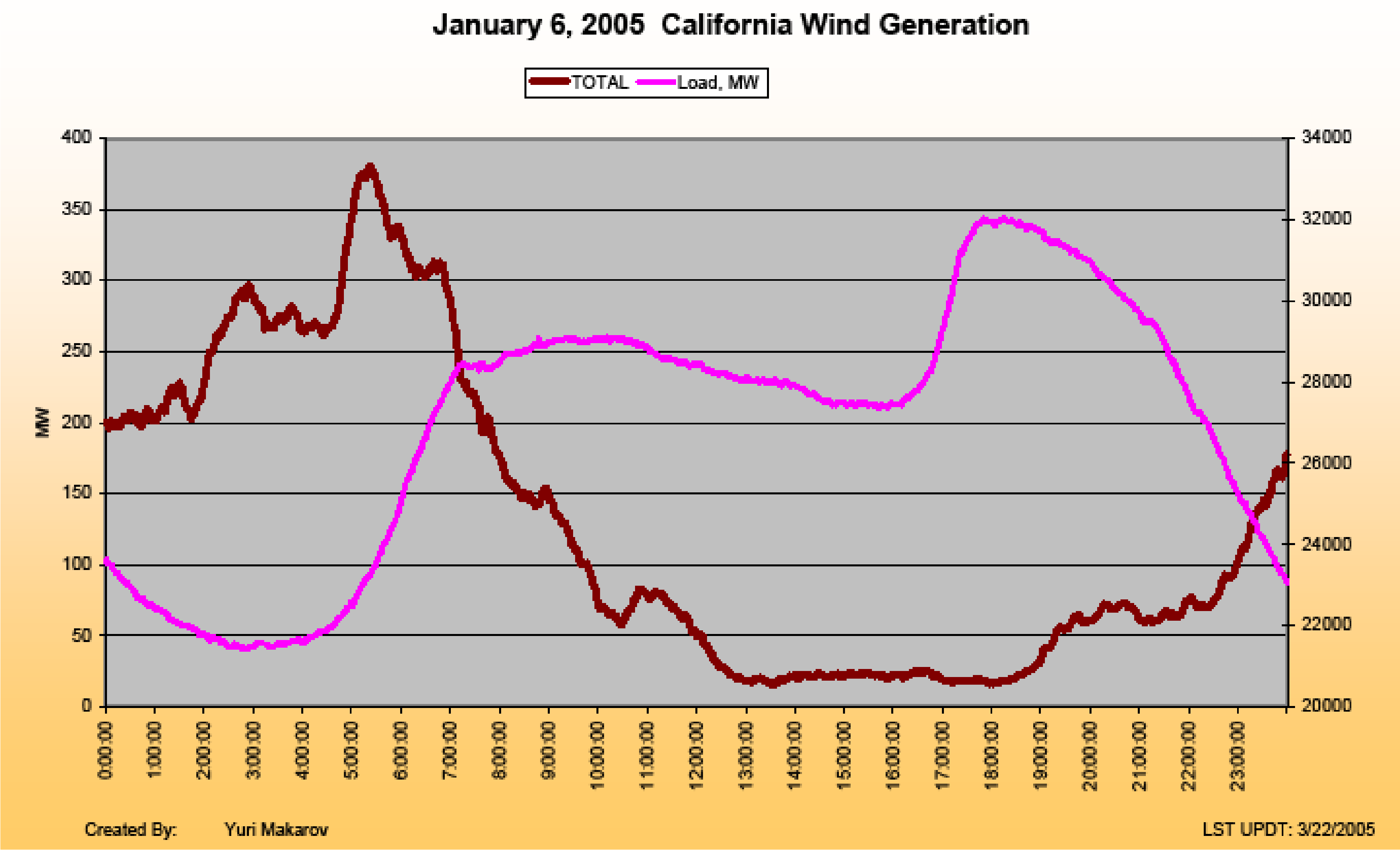


Need to Dispatch 1000 MW Of Additional Generation Or Activate Non-Spinning Reserves

Need to Decrease Generation By 800 MW Using Decremental Bids

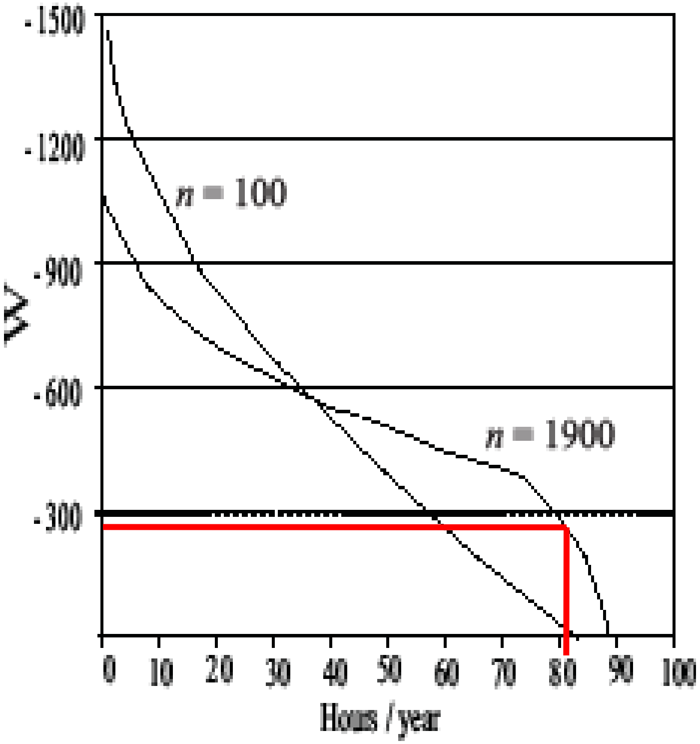
Source: Y. Makarov and D. Hawkins, CALISO

California example2/2



Source: Y. Makarov and D. Hawkins, CALISO

Demand response increases uncertainty



- Demand response

$$D(h) = \min\{x \mid \mu(\tfrac{1}{n}\textstyle\sum_{i=1}^{n} \Delta_i \le x) \ge h\}$$

Demand reduced by |*D*(*h*)| for at least *h* hours/year

D(80) = - 300W

- **Worse-case dispatch cannot use demand response to reduce reserves**

Case against worst-case dispatch

- Worst-case dispatch designed for system with reliable power transactions in which
  - Generators have 0-1 failure characteristic
  - Short-term peak demand is predictable
  - Information is scarce and decisions cannot be refined
- Wind power generation and demand response are highly uncertain
- Consequently, renewable generation and demand response are unfairly treated by worst-case dispatch

Greater information and control

- More accurate information
  - Smart meters, sensors
- More refined control
  - Intelligent appliances
  - Demand response
- Tighter feedback
  - Communication
- Enable risk-limiting (vs. worst-case) dispatch

Risk-limiting dispatch: scheduling

scheduling

operating time

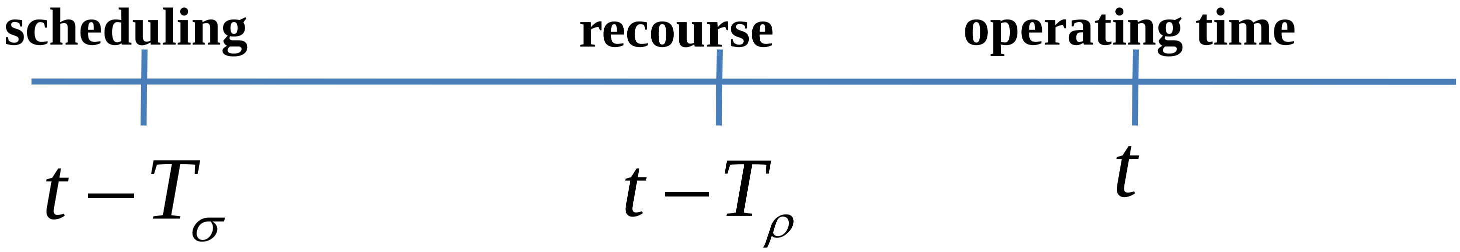
$t-T_\sigma$

t

- Scheduling
  - Decision u_σ: Generation/demand
  - Max objective such that the risk of not meeting operating constraints is less than (1-*p**) based on information y_{t-T_σ} at scheduling time

$$\min\ \mathrm{E}(\mathrm{cost})$$
$$\Pr\{g(x(t),u_\sigma)=0, h(x(t),u_\sigma)\leq 0|y_{t-T_\sigma}\}\geq p^*$$

Risk-limiting dispatch: recourse

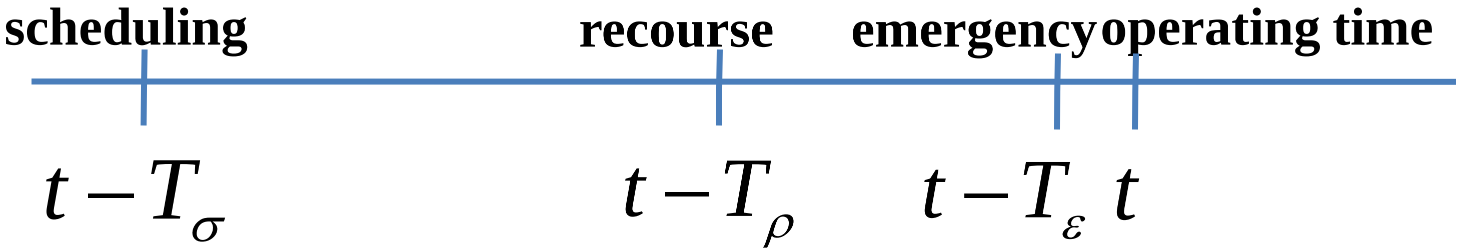

scheduling **recourse** **operating time**

$t - T_\sigma$ $t - T_\rho$ t

- Recourse
  - Decision u_ρ : Generation, demand response
  - Max objective such that the risk of not meeting operating constraints is less than (1-*p**) based on information y_{t-T_ρ} at recourse time

$$\min \ \mathrm{E}(\mathrm{cost})$$
$$\Pr\{g(x(t), u_\sigma, u_\rho) = 0, h(x(t), u_\sigma, u_\rho) \leq 0 | y_{t-T_\rho}\} \geq p^*$$

Risk-limiting dispatch: emergency



scheduling **recourse** **emergency** **operating time**

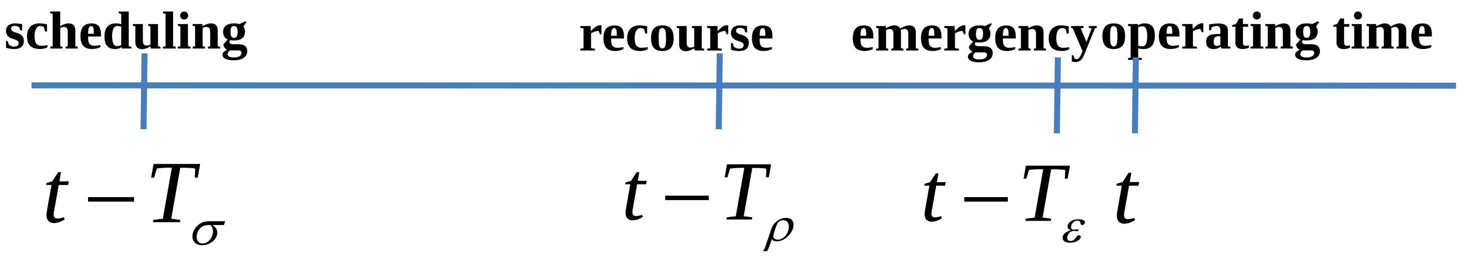
$t - T_\sigma$ $t - T_\rho$ $t - T_\varepsilon$ t

- Emergency
  - – Decision u_ε : Generation, interruptible load
  - – operating constraints must be satisfied based on information y_{t-T_ε} at emergency time

$$\min\ \mathrm{E}(\text{cost})$$

$$\Pr\{g(x(t), u_\sigma, u_\rho, u_\epsilon) = 0, h(x(t), u_\sigma, u_\rho, u_\epsilon) \leq 0 | y_{t-T_\rho}\} = 1$$

Risk-limiting dispatch: summary



scheduling **recourse** **emergency** **operating time**

$t - T_\sigma$ $t - T_\rho$ $t - T_\varepsilon$ t

- Optimization for system operation:

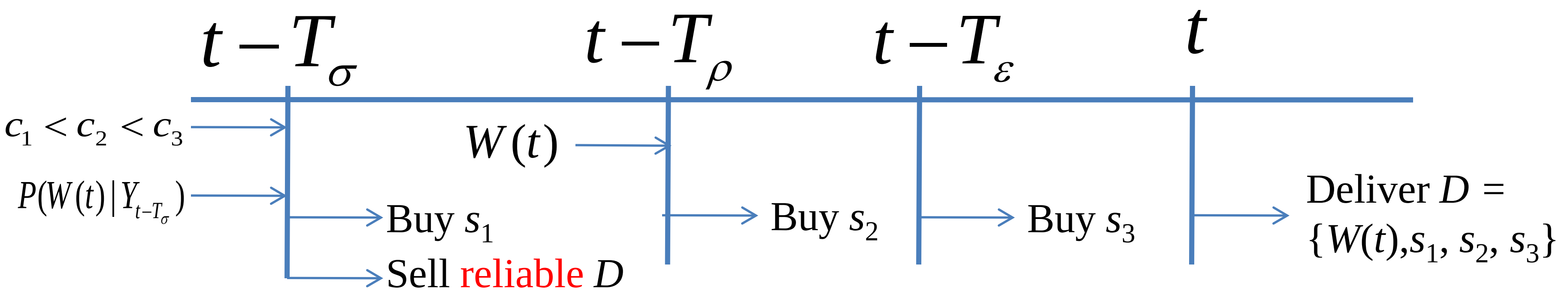
$$\min E f(x(t), u_\sigma, u_\rho, u_\epsilon)$$

$$\begin{array}{lll} P\{g(x(t), u_\sigma) = 0, & h(x(t), u_\sigma) \leq 0 & |y_{t-T_\sigma}\} \geq p^* \\ P\{g(x(t), u_\sigma, u_\rho) = 0, & h(x(t), u_\sigma, u_\rho) \leq 0 & |y_{t-T_\rho}\} \geq p^* \\ P\{g(x(t), u_\sigma, u_\rho, u_\epsilon) = 0, & h(x(t), u_\sigma, u_\rho, u_\epsilon) \leq 0 & |y_{t-T_\epsilon}\} = 1 \end{array}$$

- **Impossible stochastic sequential dispatch problem**

* See: Bouffard and Galliana, *Trans Power Syst*, 2008; Morales et al. *Trans Power Syst*, 2009

Wind power offer in reliable-power-only market



$t-T_\sigma$ $t-T_\rho$ $t-T_\varepsilon$ t

$c_1 < c_2 < c_3$

$P(W(t)|Y_{t-T_\sigma})$

$W(t)$

Buy s_1

Sell reliable D

Buy s_2

Buy s_3

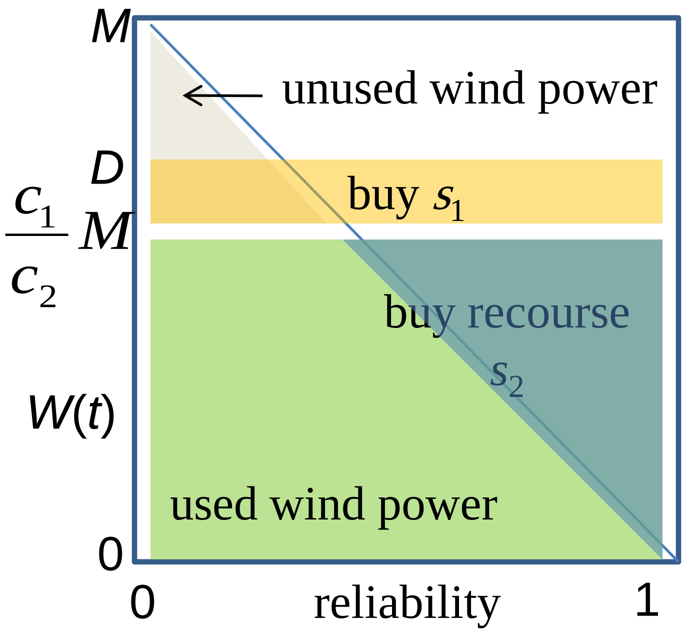
Deliver D = $\{W(t), s_1, s_2, s_3\}$

Assume $P(W(t) > x \,|\, Y_{t-T_\sigma}) = 1 - \frac{x}{M}$

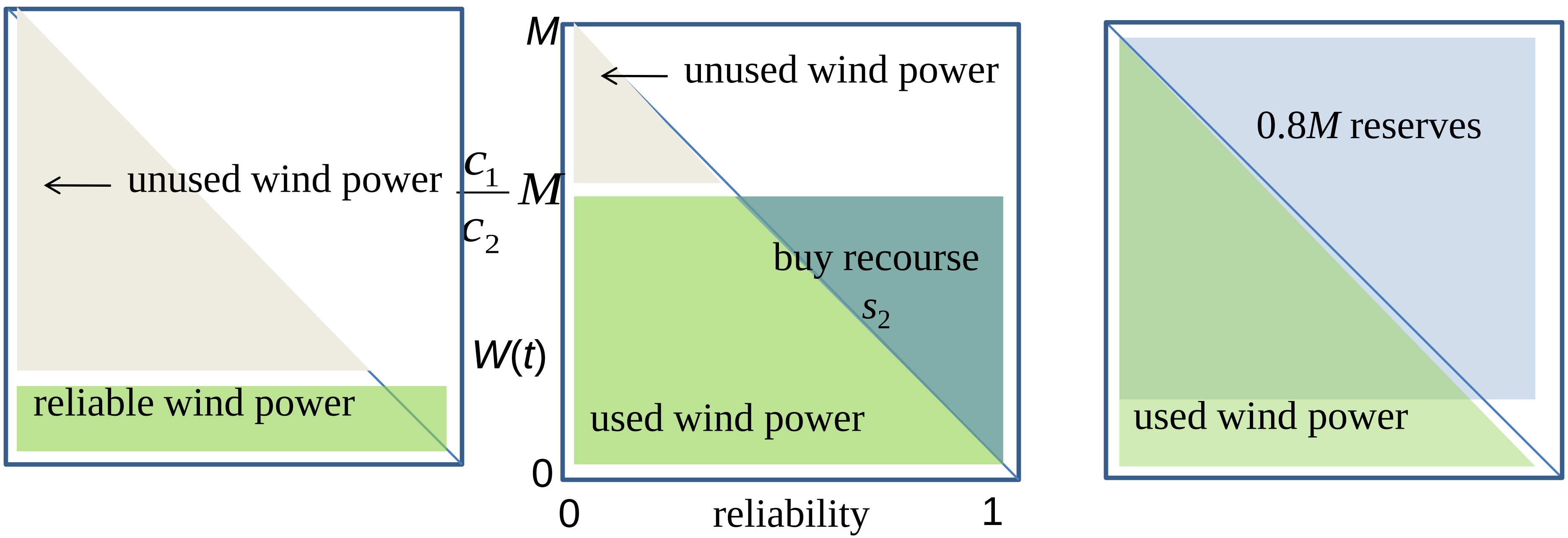
Max $E\{c_1 D - c_1 s_1 - c_2 s_2 - c_3 s_3 \,|\, D, s_1, s_2, s_3\}$

$D \geq \frac{c_1}{c_2} M$ $\quad s_1 = D - \frac{c_1}{c_2} M$

$s_2 = [D - s_1 - W(t)]_+ \quad s_3 = 0$



Comparisons $c_1 < c_2$



Worst-case dispatch

Revenue = $c_1 \quad 0.2M$

Reliable-equivalent dispatch

Net revenue = $1/2 \quad c_1^2/\, c_2 \quad M$

PIRP dispatch

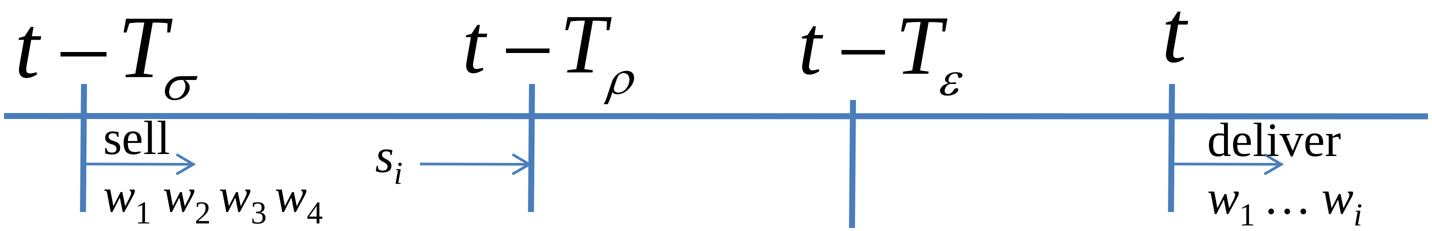
Revenue = $1/2 \quad c_1 \quad M$

Subsidy = $1/2 \quad c_1 \quad 0.8M$

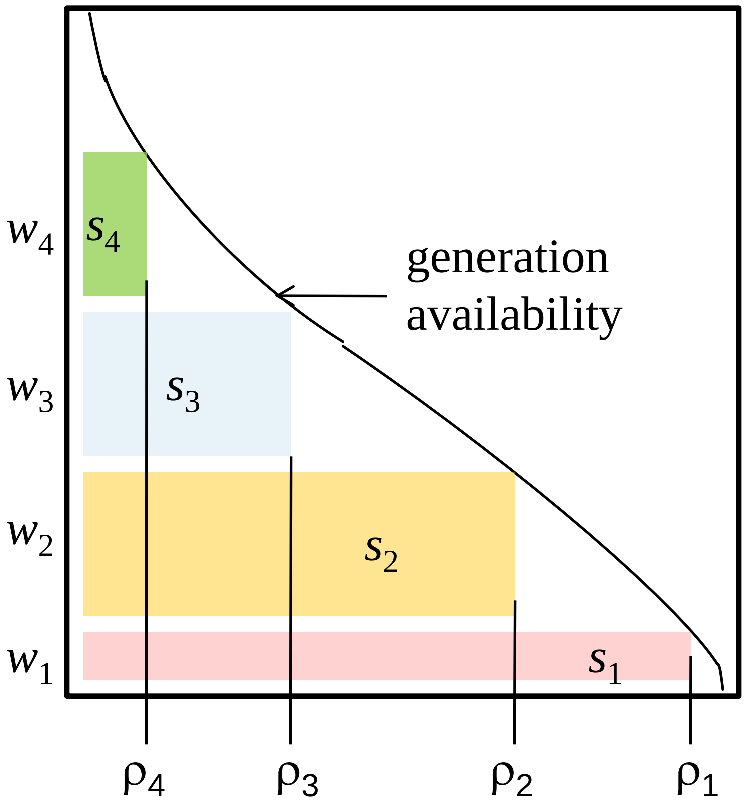
Interruptible power transactions

- Interruptible power contracts parameterized by (c, ρ) with per MW price c delivers power with probability ρ, and no power with probability (1- ρ)
- Suppose market creates contracts (c_1, ρ_1), …, (c_k, ρ_k) with $1 = \rho_1 > \ldots > \rho_k$ and $c_1 > \ldots > c_k$
- Note ρ_1 is reliable power
- How will wind generator react? Take $k = 4$

Wind generator example



- At scheduling time, supplier sells w_i units of ρ_i reliability power
- Assume availability state s_i is known at recourse time
- At time t deliver contracts $\rho_1 \dots \rho_i$
- Revenue of $\sum c_i w_i$ with no subsidy



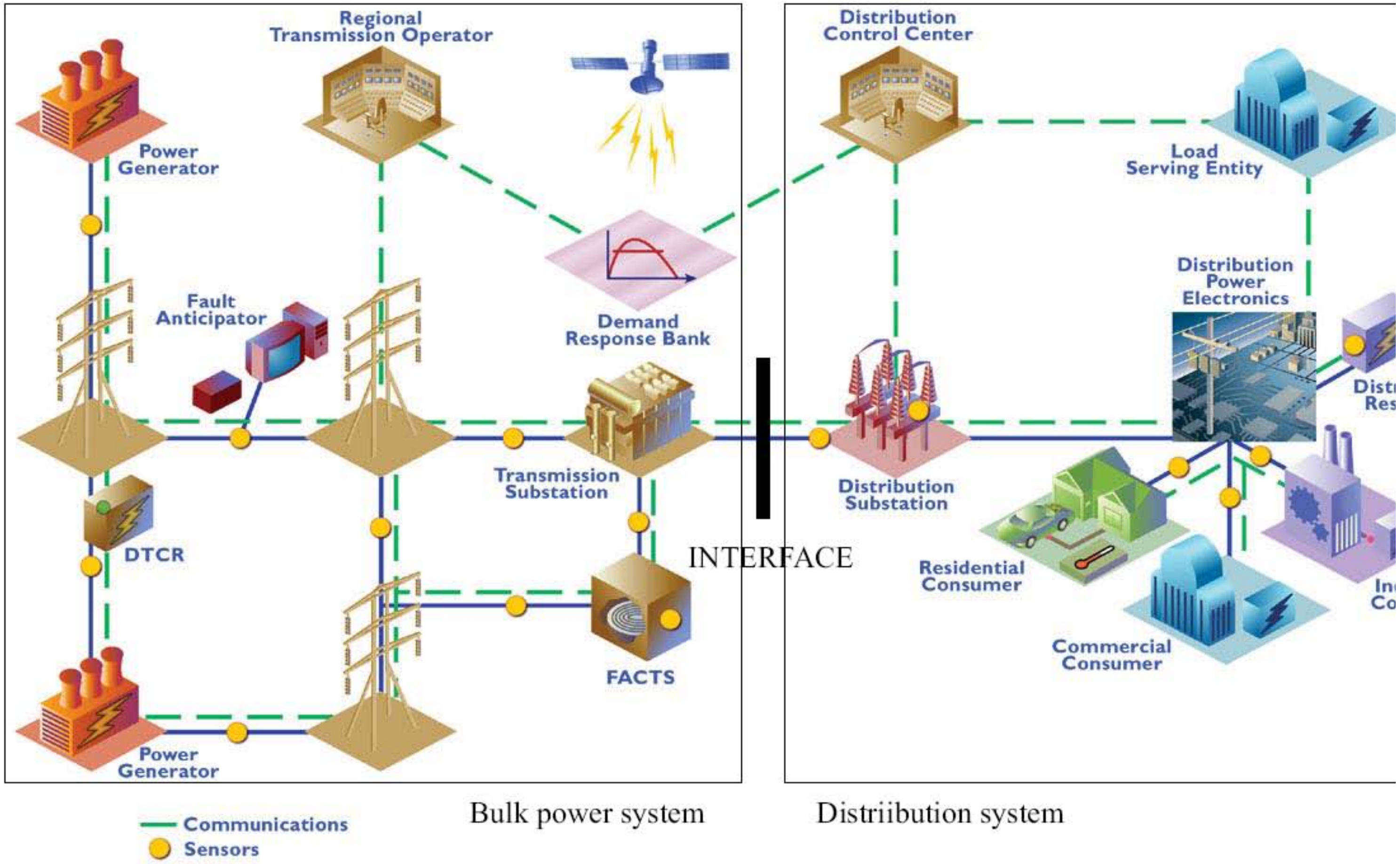
How will customers behave

- Recall that less reliable power is cheaper: $c_1 > \ldots > c_k$
- Customers may select bundle to

$$\text{Max } \sum_i \left[\rho_i U(D_i) - (1-\rho_i) L(D_i) - c_i D_i \right]$$

  - $U(D)$ is utility of consuming D
  - $L(D)$ is loss of not consuming D

Incremental deployment



- Permit interruptible power in distribution system and reliable power in bulk power system

Conclusion

- Federal programs are deploying smart grid elements on large scale
- Current practice of worst-case dispatch requires subsidies for renewable sources and demand response
- More accurate and timely information and more refined control suggest shift to risk-limiting dispatch, which does not require subsidies
- Risk-limiting dispatch can be introduced incrementally in distribution system