THE UNIVERSITY OF HONG KONG

Department of Electrical & Electronic Engineering

Centre for Electrical Energy Systems

5th Carnegie Mellon Conference on Electricity Industry:

Smart Grids

Risk-limiting Dispatch of Smart Grids

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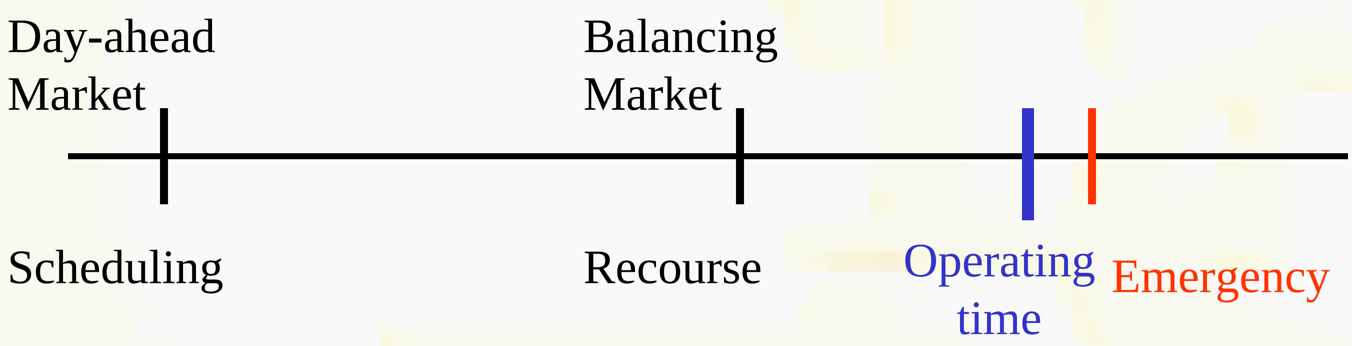
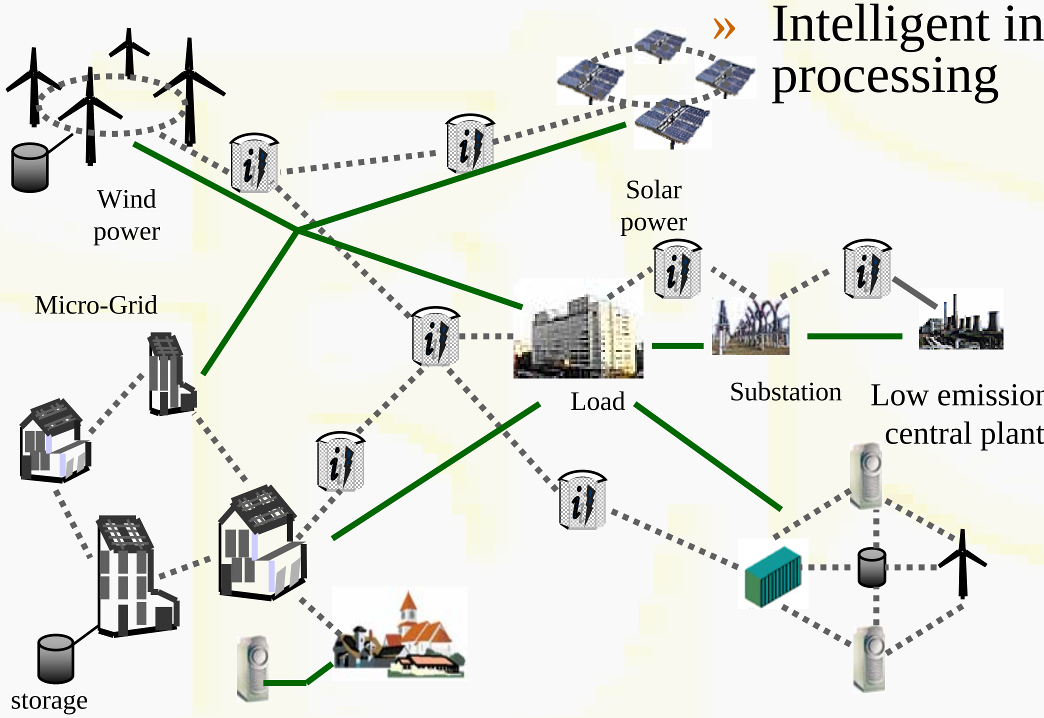
Worst-case Dispatch



- Constraints
  - Power balance
  - Operating limits
  - (N-1) Contingencies
- Objective
  - Min cost
- Uncertainty
  - Load demand
  - Forced outage of equipment
- Recourse
- Emergency
  - Load shedding

Future Energy Delivery System

- Renewables
  - » Wind
  - » Solar
  - » Storage
  - » Microgrid
- Smart grid
  - » Smart meters, sensors
  - » Intelligent appliances
  - » Customer choice
  - » Communication networks
  - » Intelligent information processing



Operating Smart Grid

- Reliability of the system: not be compromised.
- Benefit of renewable resources: be fully utilized.
- Risk of intermittent and stochastic renewable resources: properly accounted for.
- Capability of the smart grid: intelligently designed.
- A new operating paradigm is needed to take advantage of new technologies and new opportunity.

Operating Risk

- Operating risk
  - » Not meeting the constraints
- Operating constraints
  - » Power balance

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

  - » Operating limits

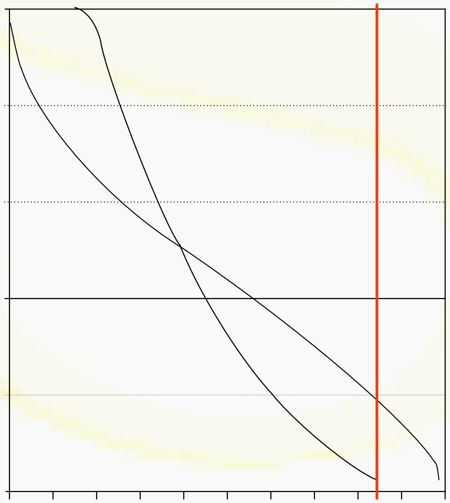
    $$h(\mathbf{x}(t), u) \le 0$$

  - » Risk-limiting: risk < (1-p*)

$$\Pr\{g(\mathbf{x}(t), u) = 0, h(\mathbf{x}(t), u) \le 0 \,|\, \mathbf{y}_{t-T}\} \ge p^*$$

  - » $\mathbf{x}(t|\mathbf{y}_{t-T})$ state $\mathbf{y}_{t-T}$ measurements

- Stochastic variables
  - » Conventional (Load demand, equipment outage)
  - » Renewable generation



  - » Demand response

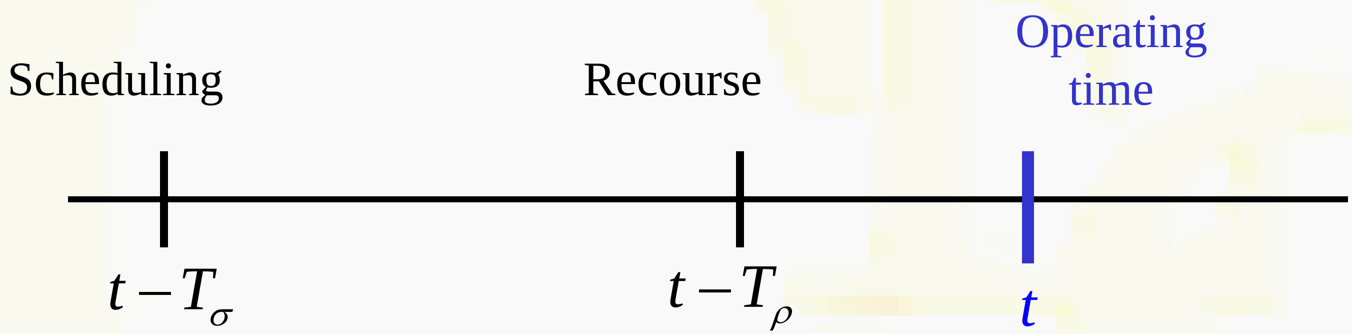
Risk-limiting Dispatch

- Scheduling
  - Decision u_σ : Generation
  - Max objective such that the risk of not meeting operating constraints is less than (1-*p**) based on available information at the time of scheduling.

$$\max \textit{objective} \text{ (e.g., min cost)}$$

$$s.t. \quad \Pr\{g(\mathbf{x}(t), u_\sigma) = 0, h(\mathbf{x}(t), u_\sigma) \leq 0 \,|\, \mathbf{y}_{t-T_\sigma}\} \geq p^*$$

Risk-limiting Dispatch

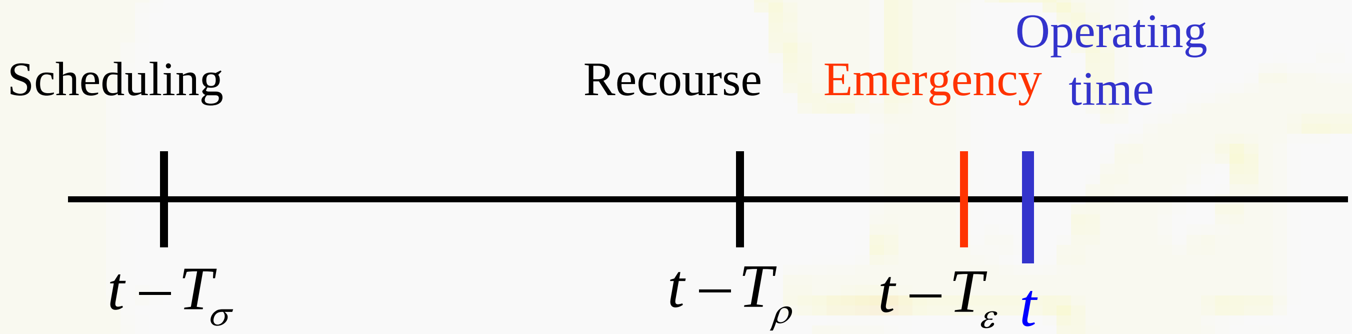


- Recourse
  - » Decision u_ρ : Generation, intelligent appliances
  - » Max objective such that the risk of not meeting operating constraints is less than (1-p*) based on available information at the time of recourse.

$$\max \textit{objective} \text{ (e.g., min cost)}$$

$$s.t. \quad \Pr\{g(\mathbf{x}(t), u_\rho) = 0, h(\mathbf{x}(t), u_\rho) \leq 0 \,|\, \mathbf{y}_{t-T_\rho}\} \geq p^*$$

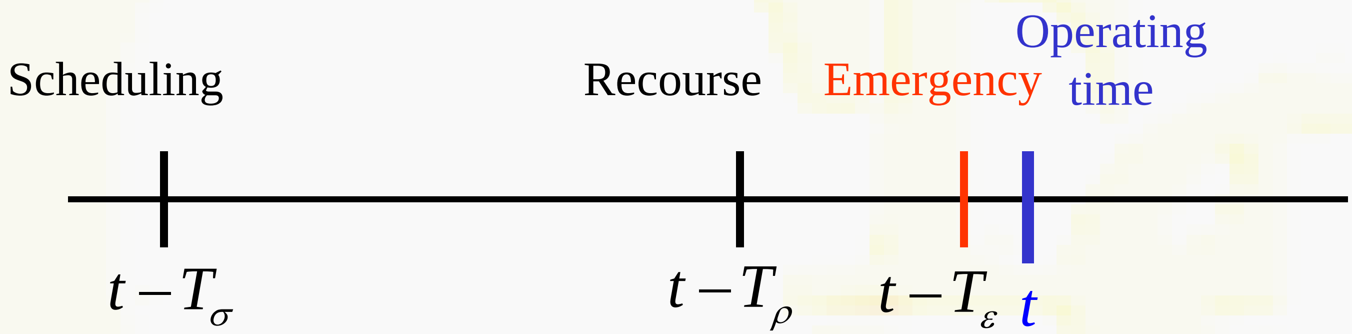
Risk-limiting Dispatch



- Emergency
  - » Decision u_ε: Generation, interruptible load
  - » The operating constraints must be satisfied.

$$\Pr\{g(\mathbf{x}(t), u_\varepsilon) = 0, h(\mathbf{x}(t), u_\varepsilon) \le 0 \,|\, \mathbf{y}_{t-T_\varepsilon}\} = 1$$

Optimal Dispatch



- The overall optimization problem for system operation:

$$\max \quad f(\mathbf{x}(t), u_\sigma, u_\rho, u_\varepsilon)$$

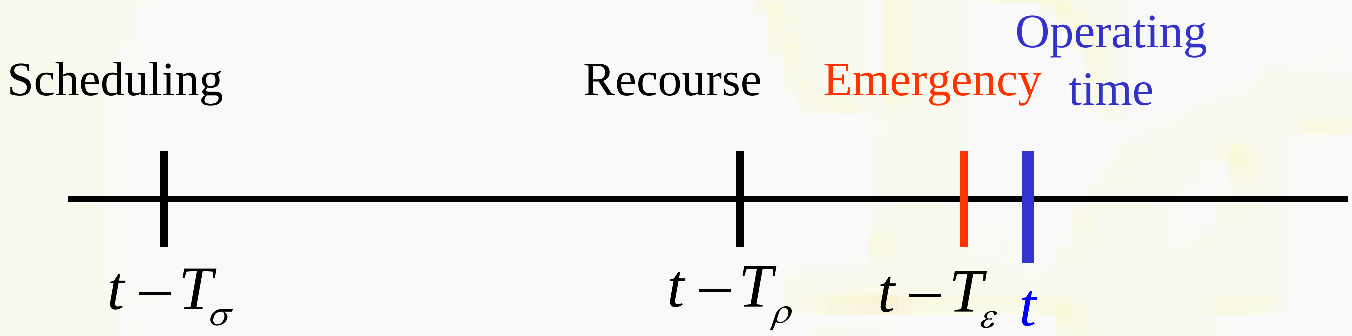
$$s.t. \quad \Pr\{g(\mathbf{x}(t), u_\sigma) = 0, h(\mathbf{x}(t), u_\sigma) \le 0 \,|\, \mathbf{y}_{t-T_\sigma}\} \ge p^*$$

$$\Pr\{g(\mathbf{x}(t), u_\rho) = 0, h(\mathbf{x}(t), u_\rho) \le 0 \,|\, \mathbf{y}_{t-T_\rho}\} \ge p^*$$

$$\Pr\{g(\mathbf{x}(t), u_\varepsilon) = 0, h(\mathbf{x}(t), u_\varepsilon) \le 0 \,|\, \mathbf{y}_{t-T_\varepsilon}\} = 1$$

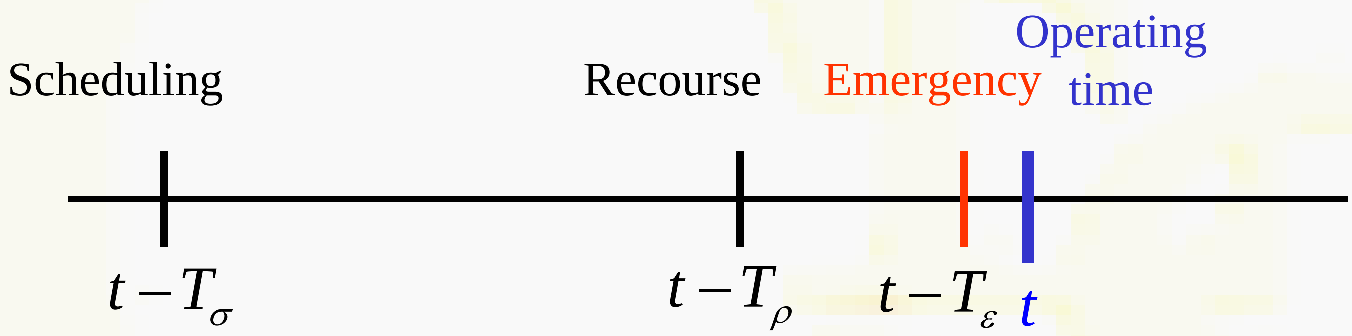
- Suppose that the costs of generation for different periods (scheduling, recourse, emergency) are known, for a simpler model, the optimal dispatch has been derived in terms of nested conditional probabilities.
- We believe that the result can be generalized.

Optimal Bidding of Renewable Generators



- Suppose that the market for energy scheduling is a conventional deterministic forward market.
- A renewable resource, say a wind generator, is required to submit a binding bid and he bundles it with contracts for recourse and emergence powers.
- The optimal *certainty-equivalent* bid has been derived and can be used to study incentives in different pricing schemes for renewable generation.

Cost/Benefit Assessment of Smart Grids

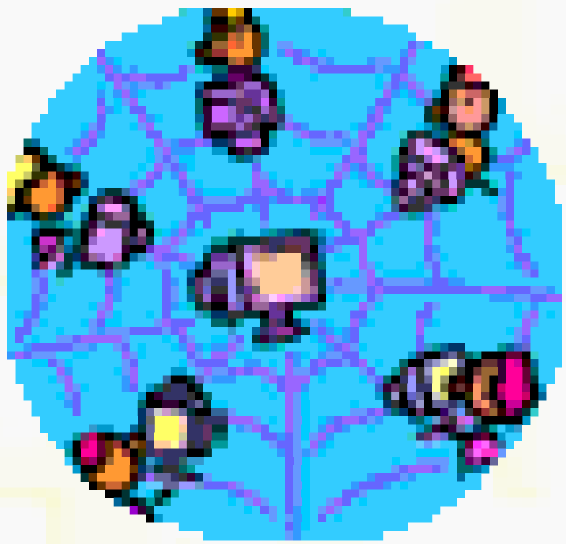


- Different costs of decisions u_σ u_ρ u_ε and their consequences.
- Decisions are based on available information $\mathbf{y}_{t-T_\sigma}$ $\mathbf{y}_{t-T_\rho}$ $\mathbf{y}_{t-T_\varepsilon}$ which depends on how smart is the grid.
- Cost/benefit assessment of smart grids
  - » Cost reduction of recourse (or emergency) due to better information.

Summary

- Future electric energy systems will consists of
  - significant intermittent and stochastic renewable resources,
  - customer choice,
  - intelligent sensors, devices, and appliances
  - smart grid.
- To fully realized their functions, a new operating paradigm is needed.
- A risk-limiting dispatch approach to system operation is proposed.
- Optimal dispatch of generation may be derived which may be used to study bidding and pricing strategies.
- It may be used as a framework for assessing benefit of smart grids.

Thank You



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