PennState

ELECTRICAL ENGINEERING & COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN

CPS: Synergy: Collaborative Research:

Digital Control of Hybrid Systems via Simulation and Bisimulation

Ji-Woong Lee (PI) [1] Constantino Lagoa [1] Heath Hofmann [2]

[1]Pennsylvania State University, University Park
[2]University of Michigan, Ann Arbor

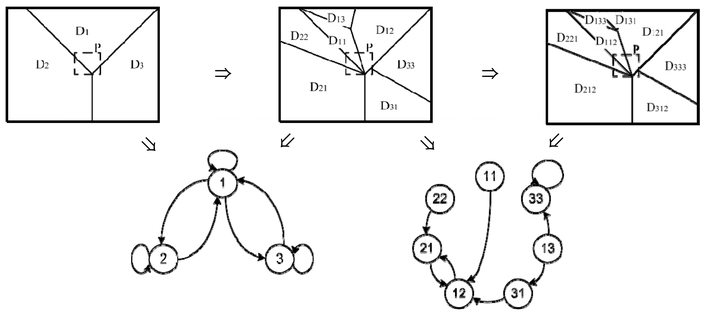
Project Goals

- **Unification:** Symbolic models and Lyapunov analysis
- **Scalability:** Increasing sequence of symbolic models
- **Convexity:** Linear matrix inequality conditions
- **Nonconservatism:** Symbolic models convergent to true model
- **Robustness and Risk:** Modeling error vs. computational complexity
- **Test Case:** Risk adjusted Optimal AC Power Flow

Cyber-Physical System (CPS) Approach

Analysis

Symbolic Model ⇒ Lyapunov Analysis ⇒
Updated Symbolic Model ⇒ Improved Lyapunov Analysis ⇒ ⋯



Control Design

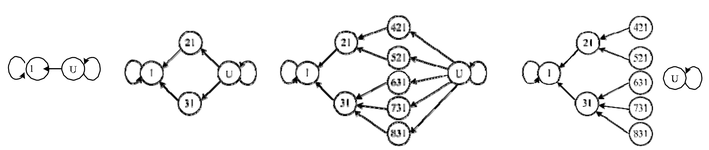
Control Objectives

- Stabilization
- Performance (i.e., relative stability) optimization
- Robustness against uncertainty
  (e.g., modeling error, externa; bounded perturbations)

A Synthesis Procedure

- Partition state-input space adapting to control objective. (Coarsest partitions do not work!)
- Obtain simulation (i.e., symbolic model) of plant.
- Achieve closed-loop bisimulation (e.g., optimal stability region).

Simulation → Updated Simulation → ⋯ → Closed-Loop Bisimulation



Handling Risk

Moments Approach

$$\max_{x} \text{Prob}_{\delta}\{\delta : g(x,\delta) \geq 0\}$$
$$\text{s.t. } f(x) \leq \gamma$$

$$\max_{\mu,\mu_x} \int d\mu$$
$$s.t.\ \mu \preccurlyeq \mu_x \times \mu_q$$
$$supp(\mu_x) \subseteq \{x : f(x \leq \gamma\}$$
$$supp\,(\mu) \subseteq \{(x,\delta), g(x,\delta) \geq 0\}$$

Moments representation of measures
Linear Matrix Inequality approximation

+ Asymptotically exact approximations
- Computational complexity increases "fast" with degree of approximation

Scenario Approach

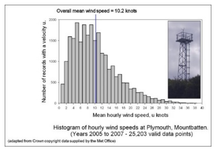
$$\min_{x} f(x)$$
$$\text{s.t. Prob}_{\delta}\{\delta : g(x,\delta) \geq 0\} \geq 1-\varepsilon$$

$$\min_{x} f(x)$$
$$\text{s.t. } g(x,\delta^{[i]}) \geq 0; i = 1,2,\dots,N$$

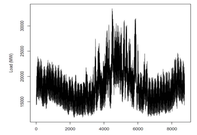
+ Easy setup
- Approximations to risk are "loose"
- May require non-convex solvers

AC Power Flow Under Uncertainty

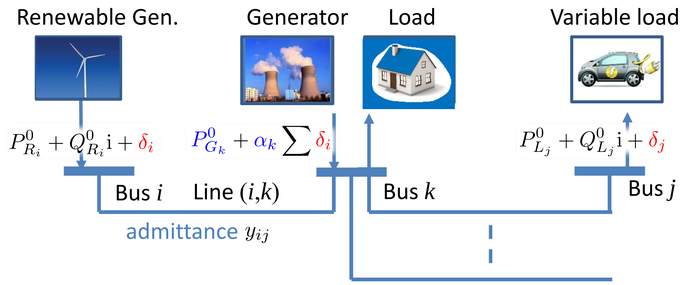
Electricity generated by a wind farm depends on the wind speed and location of installation



Loads can exhibit high variability

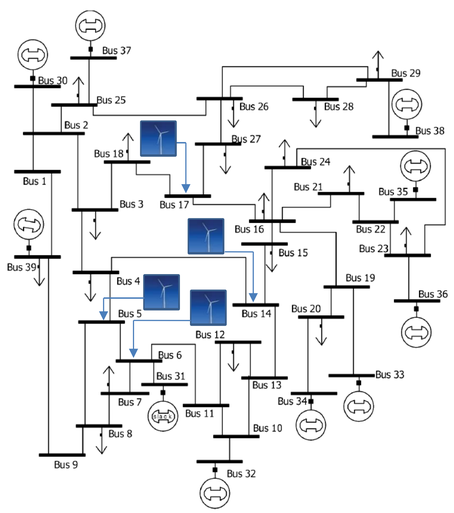


New York Independent System Operator (NYISO) hourly load for the year 2010, in MW



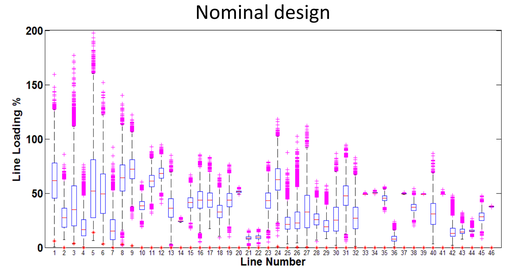
Simulation – England 39-bus

- 21 loads with a total demand of 6254 MW
- 46 trans-mission lines
- 11 tap changing transformers



- 10 order IV synchronous generators with max capacitance of 8404 MW
- TG and AVR control devices
- Individual cost parameters for every generator

Nominal design



Risk-adjusted design