Scalable and Safe Control Synthesis for Systems with Symmetries

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Motivation

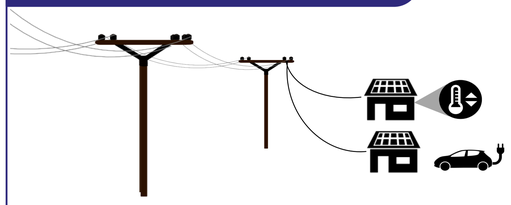

Figure 1: Electrical loads at one node of a distribution network.

Problem and Objective

- Problem: Many complex engineered systems require scalable methods for ensuring safe operation (e.g., Internet of Things, transportation networks, and electrical power systems)
- Objective: Develop scalable method for controlling very **large collections** of subsystems to achieve **common objectives** while ensuring **safety constraints**

Application – Electric Power Systems

- **Large collection**: Thousands of electrical loads (e.g., electric vehicles and air conditioners)
- **Common objective**: Collective power consumption is coordinated to help balance supply and demand of energy on transmission network
- **Safety constraints**:
  - Each load has constraints (e.g., temperature)
  - Groups of loads have collective constraints that ensure safe operation of distribution network

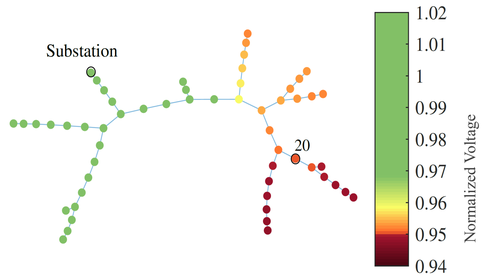

Figure 2: Distribution network experiencing unsafe operation due to loads that are not satisfying collective safety constraints.

Scientific Impacts

- *Applicability:* Methods apply to CPS that consist of large numbers of dynamically decoupled subsystems with symmetries.
- *Formal Safety Guarantees:* The developed control algorithm guarantees the recursive safety and feasibility.
- *Scalability:* Solution achieves scalability by exploiting subsystem symmetries from homogeneity. Moreover, the computational burden from invariant set computation is avoided in proposed algorithm.

Broader Impacts

Education

- Current graduate student researcher: Sunho Jang (co-advised by PIs)

Industry

- Collaboration with Michigan utility DTE Energy

Proposed Solutions

- Improve the grid's ability to host higher percentages of renewable energy generation
- Support third-party aggregators' and residential customers' ability to participate in wholesale electricity markets

Recent Work

System and Safety Setting

- System is composed of homogeneous subsystems with a safe set of states.
- The number of subsystems in each mode is constrained.

Bisimilar Abstract System

- Construct a bisimilar abstraction of the aggregation.
- Any controller safe for the abstract system is also safe for the original system.

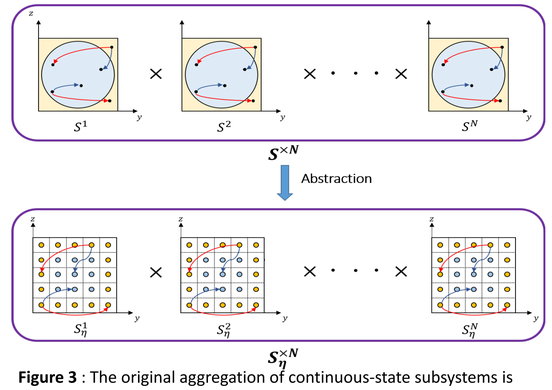

Figure 3 : The original aggregation of continuous-state subsystems is abstracted to an aggregation of bisimilar discrete-state subsystems.

Invariant Set Construction

- An invariant set construction method has been developed that ensures states stay inside the safe set under a periodic input.
- The developed method provides an implicit representation of an invariant set, which is utilized by the proposed control algorithm.

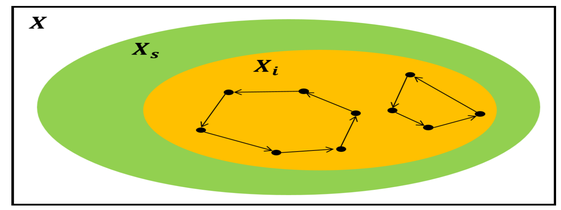

Figure 4 : The constructed invariant set X_i includes states that have a periodic trajectory inside the safe set X_S.

Invariant-set Driven MPC

- Using the invariant set, this MPC-based algorithm keeps the state inside the maximal controlled invariant set.
- Recursive safety and feasibility are guaranteed.
- Computation complexity is independent of the number of subsystems.

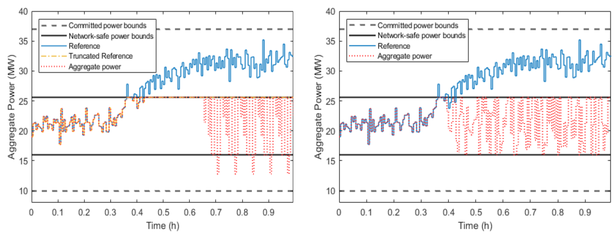

Figure 5 : Reference signal tracking of MPC with truncated reference signal (left) and Invariant-set driven MPC (right) given safety bounds on aggregate power

Publications from the last year

S. Jang, N. Ozay, and J.L. Mathieu. "Large-scale invariant sets for safe coordination of thermostatic loads." In: Proceedings of the American Control Conference. May 2021.

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