Improving system resilience through formal verification of transactive energy controls

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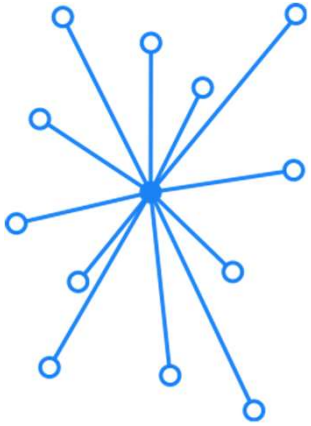
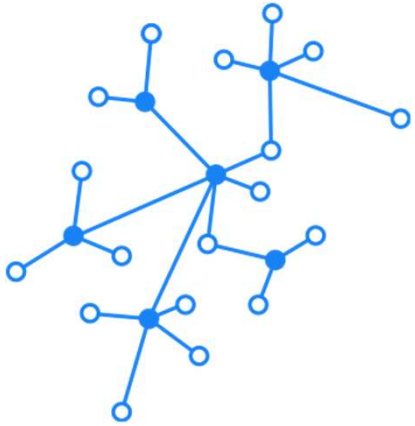
Decentralization enables more robust architectures, while introducing new challenges



Centralized

Radial Distribution Networks
Web 2.0



Decentralized

Peer-to-peer Distribution
Web 3.0

MITei Protocol Labs Research

Resilience in decentralized transactive power systems:

1) When the system works as intended, **is it robust**?
2) Does the system **work as intended**?
3) What **tools from Web 3.0** can help us build better control systems for transactive energy?

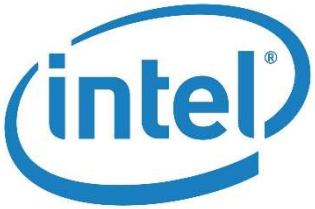
Formal verification of control algorithms can be used to discover and eliminate errors prior to implementation

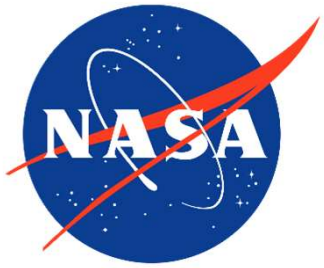
Prove that a control system specification is safe:

1. Produce formal model using TLA+

2. Define error states
   - Variable domains
   - Temporal properties
   - Deadlock

3. Model checking
   - Based on starting condition, evaluate reachable states
   - Model non-determinism by following all possible paths





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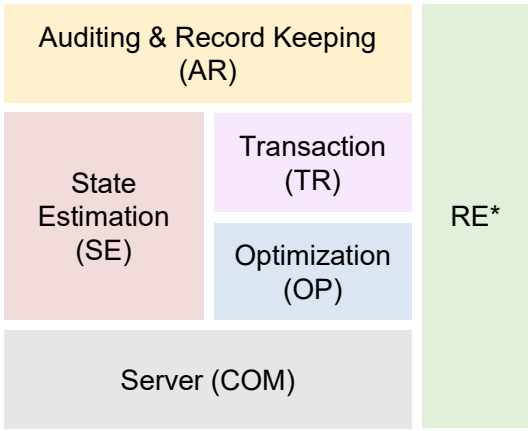
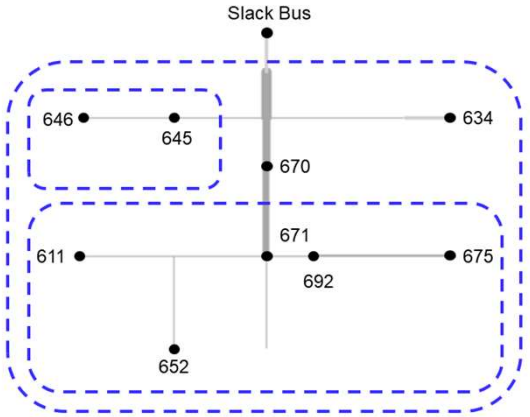
Functionally Defined Invariant Architecture (FDIA) using a Laminar Coordination Framework



* Regulation

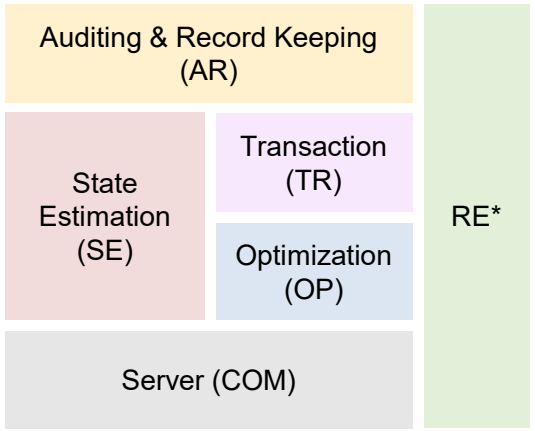
FDIA facilitates upgrades through functionally-defined modules



- Standard 13-Bus feeder with **coordination domains** in blue
- Nodes' consumption and generation stored as demand curves
- Modeled both **centralized** and **transactive** modes

Ransil et al. (Under Review)
J. D. Taft. PNNL-25480. (2016)

TLA+ Model Design



* Regulation

FDIA Model: specification of each module (COM, OP, TR, etc.) as a set of processes

Settings: pointer to feeder structure script, choose module versions, transmission conditions, and set Regulatory (RE) variables

Feeder Structure: describes hierarchical structure and node demand curves

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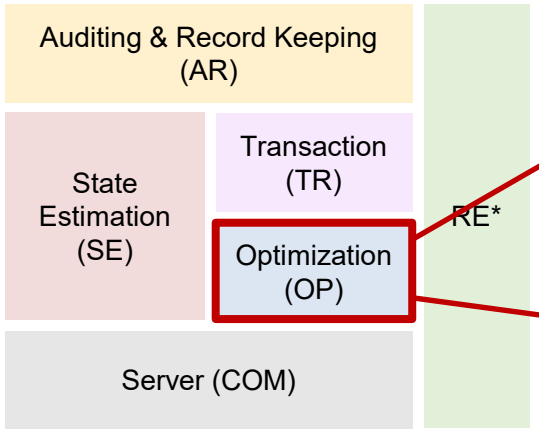
Effect of transmission outage

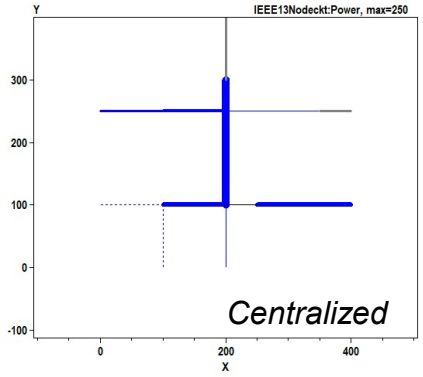


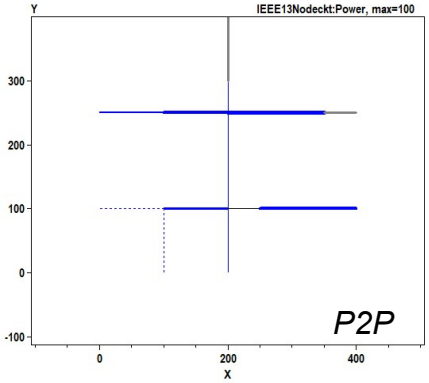
* Regulation

OP module determined based on `OP_SlackBusPower`:

(1) **Normal operating conditions**: flat rate determined by slack bus

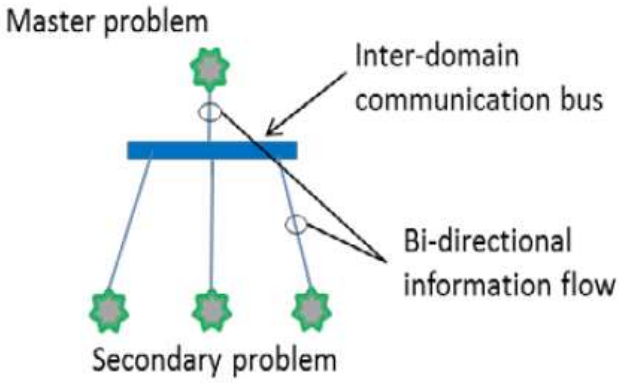
(2) **Peer-to-peer** sales optimized within and between coordination domains





Effect of latency

Laminar coordination frameworks rely on **coordination signals**:



J. D. Taft. PNNL-25480. (2016)

For each node, define `latency ∈ {SET}` and explore non-deterministically

On each iteration step, **track relevant variables for optimization** and check for repeated states to identify error states

Iteration	Price	Net Load	Step	Skipped
1	20	846	20	{“646n”, “671n”}
2	30	1581	10	None
3	19	1946	-11	{“646n”, “671n”}
4	48	-462	29	None
5	47	-309	-1	{“646n”, “671n”}
6	45	-120	-2	None
7	44	-120	-1	{“646n”, “671n”}
8	42	512	-2	None
9	43	512	1	{“646n”, “671n”}
10	45	-120	2	None
11	44	-120	-1	{“646n”, “671n”}

Get in touch!

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TLA+ Code: https://github.com/redransil/TLA-laminar