Enhanced Flexible Ramping Product: Design and Analysis

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Overview of the presentation

- **Motivation**
- **Part I:** Enhancement of day-ahead flexible ramping products (FRPs)
- **Part II:** A data-driven FRP policy design for addressing the deliverability issue in real-time markets

Research motivation

Evolving grids → Evolving markets ← Evolving resources

↓

Research objective

To investigate flexibility procurement: flexible ramping product requirement and deliverability

Increased need for ramping capability

Increased intermittency due to variable energy resources (wind, solar), both bulk and distributed resources:

- Ramping shortage
- Generation-demand imbalance, need for out-of-market corrections
- Market inefficiency

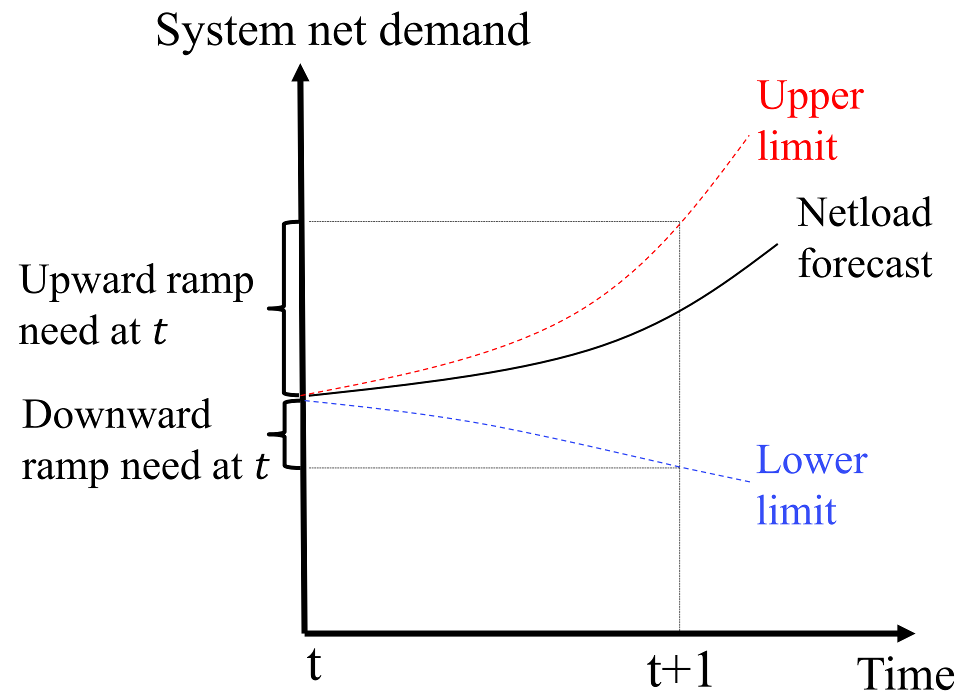
- **ISO-NE**: ***Flexibility needs will likely increase with distributed renewable energy penetration due to steeper and longer ramps*** **[1]**

- **CAISO**: ***The ISO needs ramping capability that can be utilized to meet the sharp changes in electricity net load*** **[2]**

[1] ISO-NE, "Flexibility Procurement and Reimbursement," June. 2017.
[2] CAISO, "Flexible Ramping Product FAQs," Fall 2016.

What is flexible ramping products (FRPs)?

- Reserved upward and downward ramping capacity procured at t to meet the net demand forecast plus upward and downward uncertainty at $t+1$.



Upward ramp need at t [1]: $\mathrm{FRup}_t = \max\{NetLoad_{t+1}^{max} - NetLoad_t, 0\}$

Downward ramp need at t [1]: $\mathrm{FRdown}_t = \max\{NetLoad_t - NetLoad_{t+1}^{min}, 0\}$

[1] CAISO, "Flexible Ramping Products," October 2012.

Motivation: CAISO's market enhancement

- **Day-ahead market enhancement [1]** ⟵ Focus of Part I
  - Add FRPs to CAISO day-ahead market.
  - Propose a framework to ensure that hourly day-ahead schedules can meet 15-min ramping needs.

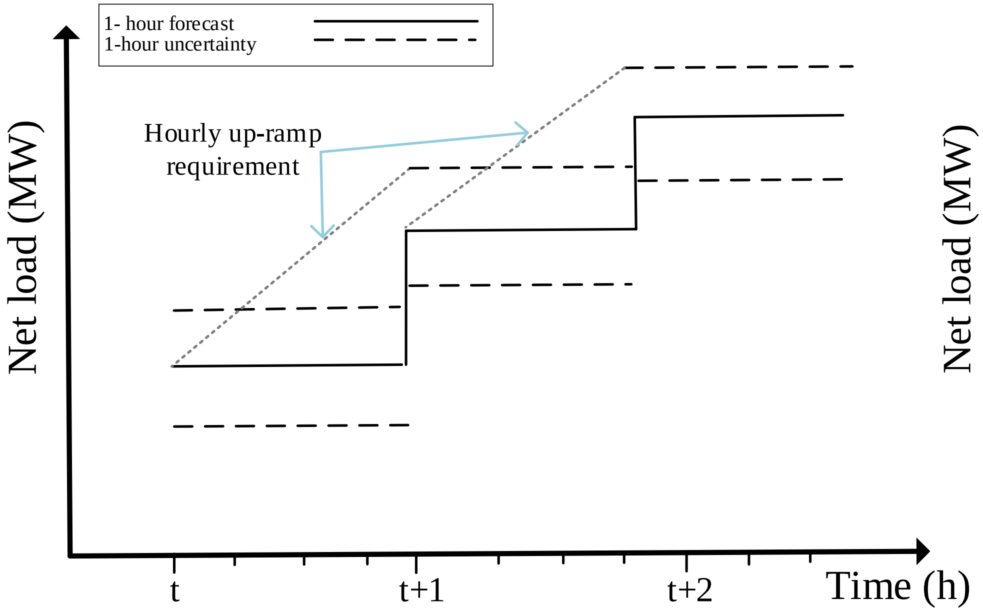
- **Real-time market enhancement [2]** ⟵ Focus of Part II
  - Deliverability of FRPs in real-time market.

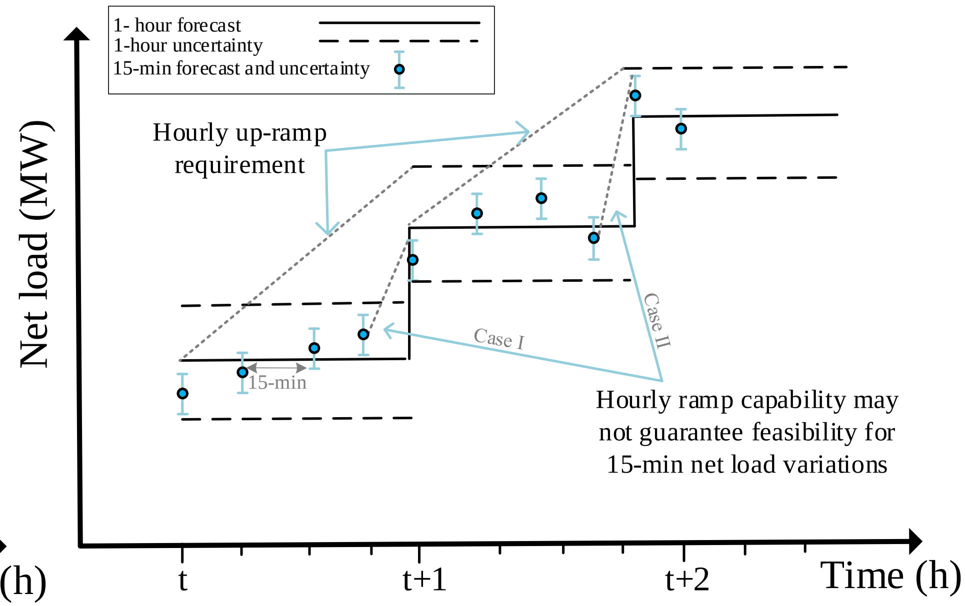
[1] CAISO, "2020 Draft Three-Year Policy Initiatives Roadmap and Annual Plan," Sep-2019. [Online]. Available: http://www.caiso.com/Documents/2020DraftPolicyInitiativesRoadmap.pdf.
[2] CAISO, "Flexible Ramping Product Refinements," November 2019. [Online]. Available: http://www.caiso.com/InitiativeDocuments/IssuePaper-StrawProposal-FlexibleRampingProductRefinements.pdf.

Part I: Enhancement of day-ahead flexible ramping products (FRPs)

Resource Scheduling with Enhanced Flexible Ramping Product: Design and Analysis

- **Feasibility of CAISO's DA FRPs design for intra-hour 15-minute variability and uncertainty**





Focus: *Enhance DA FRPs design to accommodate both hourly and intra-hour 15-minute variability and uncertainty*

Feasibility of hourly FRPs for intra-hour 15-minute variability and uncertainty

- **Hourly FRPs constraints**

  - Capacity constraints

$$p_{g,t} + \boldsymbol{ur}_{\mathbf{g,t}} \leq P_{g,t}^{max} u_{g,t}, \qquad \forall g, t$$

$ur_{g,t}$: Hourly ramp up provision of unit g at time t
$p_{g,t}$: Power generation of unit g at time t

  - Ramping constraints

$$\boldsymbol{ur}_{\mathbf{g,t}} \leq Ramp_g u_{g,t}, \qquad \forall g, t$$

$Ramp_g$: Hourly ramp rate of unit g

  - Hourly requirement constraints

$$\sum_g \boldsymbol{ur}_{g,t} \geq \mathrm{FRup}_t \,, \qquad \forall t$$

FRup_t: Hourly ramp up requirement at time t

* Above formulation is for the ramping up product; the ramping down product is symmetric.

Feasibility of hourly FRPs for intra-hour 15-minute variability and uncertainty

- **Intra-hour 15-minute FRP constraints**

❑ Ramping constraints

$$\boldsymbol{ur_{g,t}^{ih}} \leq Ramp_g^{15} u_{g,t}\ , \qquad \forall g, t$$

$ur_{g,t}^{ih}$: 15-min ramp up provision of unit g at time t

$Ramp_g^{15}$: 15-min ramp rate of unit g

❑ Immunization of hourly ramp up product against 15-min variability and uncertainty

$$\boldsymbol{ur_{g,t}^{ih}} \leq \boldsymbol{ur_{g,t}}, \qquad \forall g, t$$

❑ 15-min requirement constraints

$$\sum_{\forall g} \boldsymbol{ur_{g,t}^{ih}} \geq \max\left(\mathrm{FRup}_{t_{0min}}^{ih}, \mathrm{FRup}_{t_{15min}}^{ih}, \mathrm{FRup}_{t_{30min}}^{ih}, \mathrm{FRup}_{t_{45min}}^{ih}\right), \forall t$$

$\mathrm{FRup}_{t_{0min}}^{ih}, \mathrm{FRup}_{t_{15min}}^{ih}, \mathrm{FRup}_{t_{30min}}^{ih}, \mathrm{FRup}_{t_{45min}}^{ih}$: Intra-hour 15-min ramp up requirements at time t

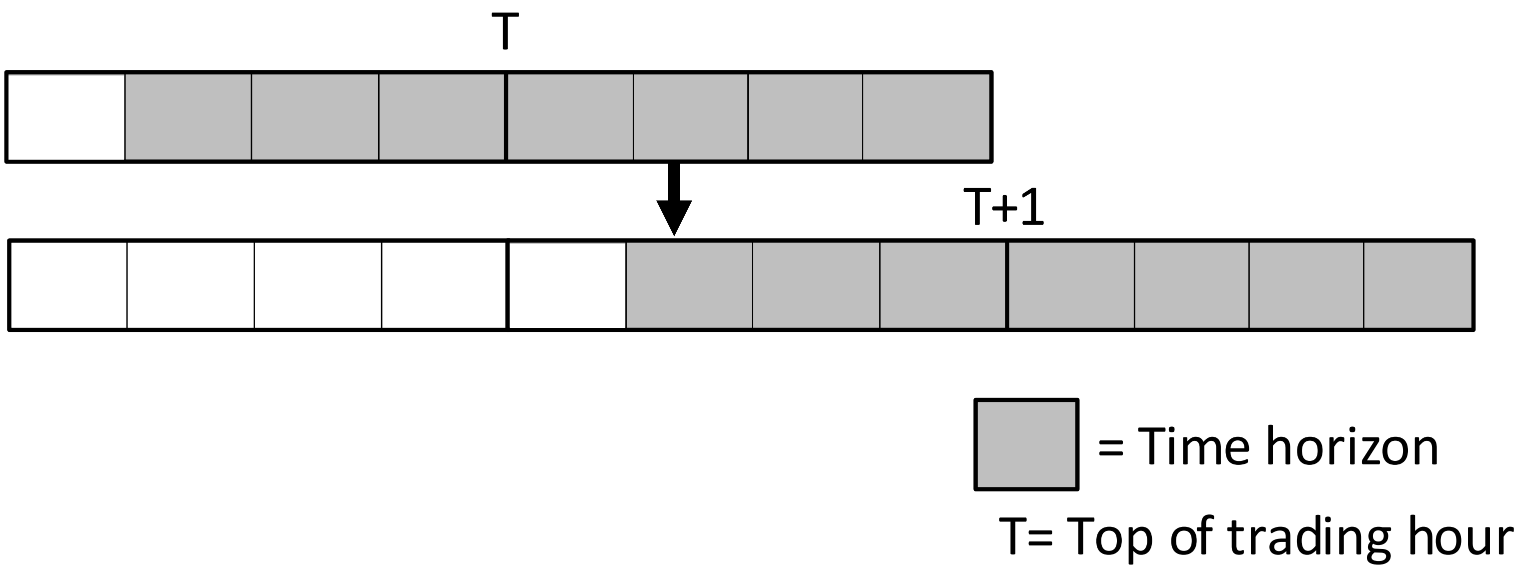
* Above formulation is for the ramping up product; the ramping down product is symmetric.

Feasibility of hourly FRPs for intra-hour 15-minute variability and uncertainty

- **Goal of the additional constraints:**
  - Improve quantity determination of FRP for next markets without adding too complexity to the problem
  - Enable more consistency between day-ahead and real-time scheduling frameworks

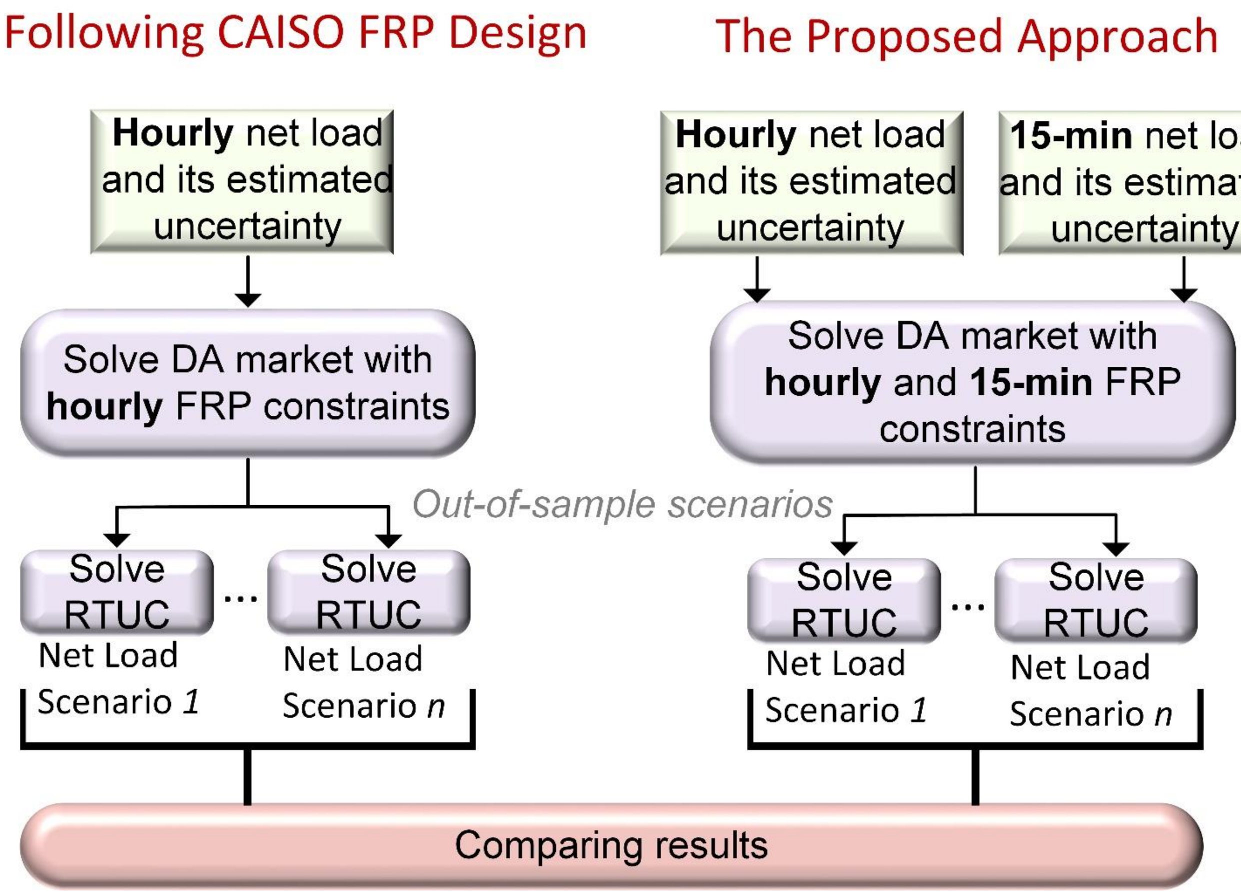
Validation methodology

- **To validate the proposed model:**
  - We developed a real-time unit commitment (RTUC) process similar to CAISO's model:



- Four binding intervals are considered for each trading hour.
- Commitments of long-start units are fixed
- Fast-start units can be committed to follow the realized net load

Feasibility of hourly FRPs for intra-hour 15-minute variability and uncertainty



The DA solutions are tested against different operational states (out-of-sample testing)

DA: Day-ahead RTUC: Real-time unit commitment

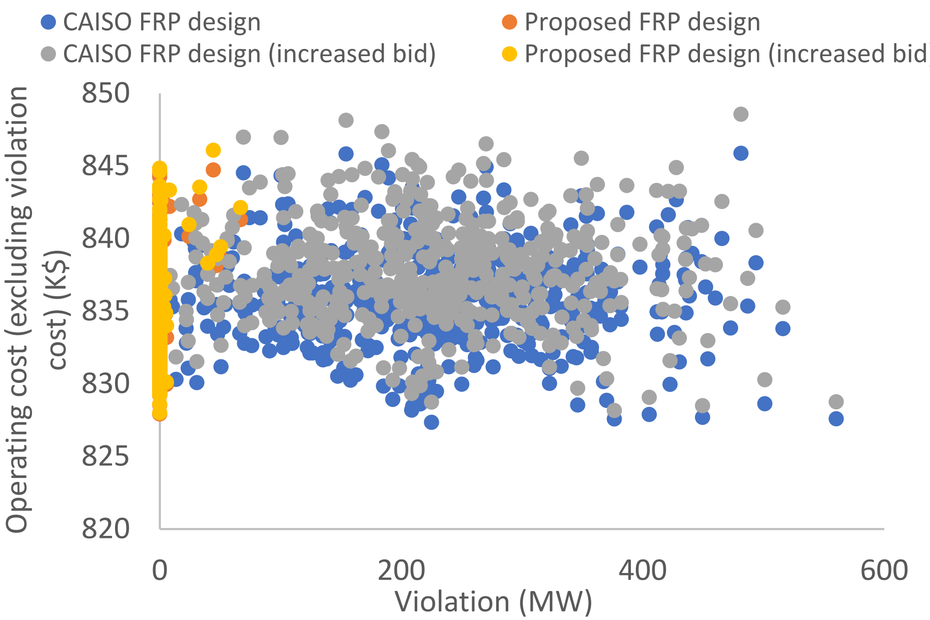
Results: Test case & assumptions

- **Test case**: IEEE 118-Bus System
- **Confidence level:** 95% for hourly and 15-min requirements
- **500 out-of-sample scenarios**:
  - Based on 15-min net load uncertainty
  - Each scenario includes net load for 96 intervals
- Violation in the form of load shedding was allowed: VOLL: $10000/MW
- Two bids for generation units in RTUC:
  - Same as day-ahead
  - %15 increase compared to day-ahead

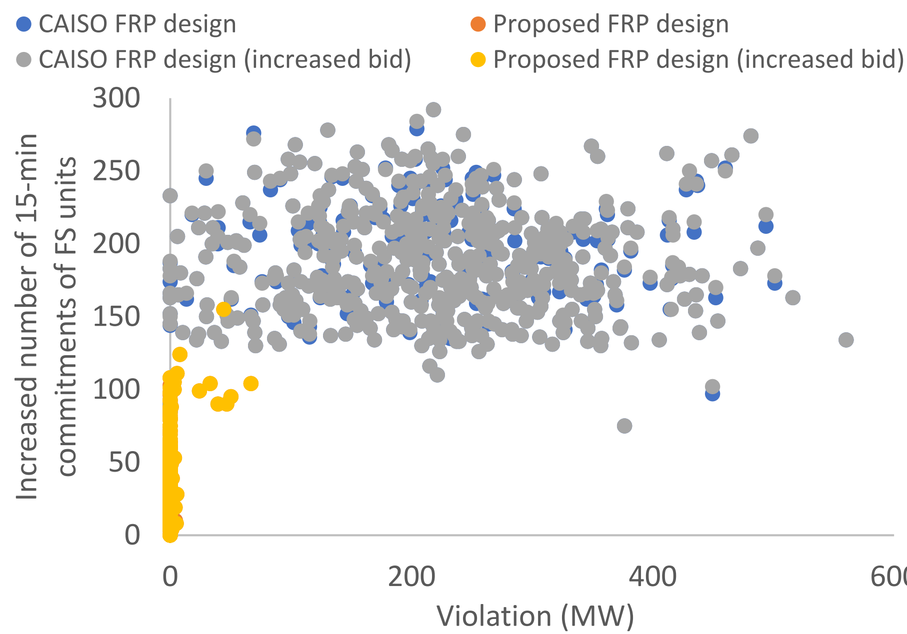
VOLL: Value-of-loss load

Results: 118-Bus System

RTUC cost versus violation



Increased commitment number of fast-start units versus violation

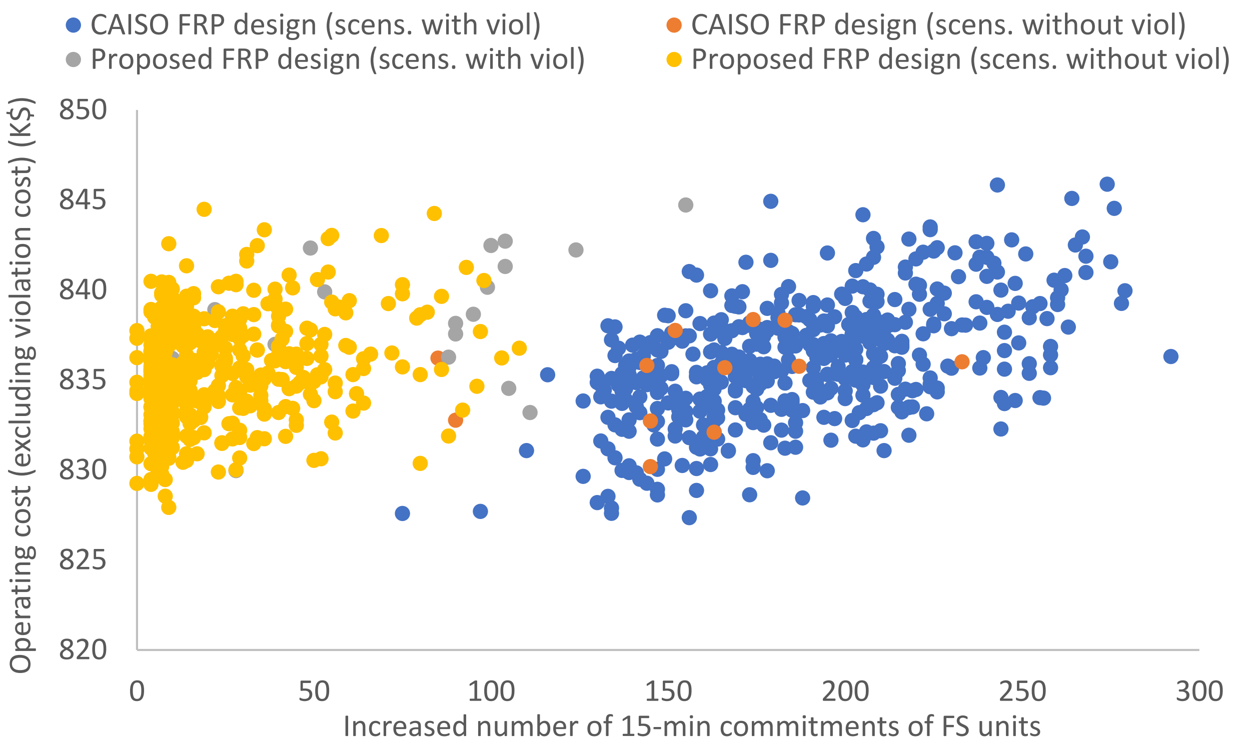


FS: Fast start

In 99.8% of scenarios the proposed method provides pareto optimal solutions with respect to cost and violation

Results: 118-Bus System

- Operating cost versus Increased number of 15-min commitments of FS units in RTUC



Scens. With viol- Scenarios with occurrence of violation

Scens. Without viol- Scenarios without occurrence of violation

FS: Fast start

Concluding Remarks: part I

- **The proposed model enhances the quantity allocation of FRPs with minimal disruption to existing day-ahead market models**

- **The proposed approach leads to:**
  - ❑ Less expected final operating cost in the fifteen-minute market
  - ❑ Decreasing the potential violation in real-time operation (need for less out-of-market corrections)
  - ❑ Less need for committing fast-start units in real-time operations

Part II: A data-driven FRP policy design for addressing the deliverability issue in real-time markets

State-of-art approaches for ramping needs

- Contemporary market structure: assign FRP awards based on system-wide or proxy ramping requirements
  - Cons: awarded FRPs my not be deliverable

$$\sum_{g \in G} ur_{g,t} \geq FRup_t$$

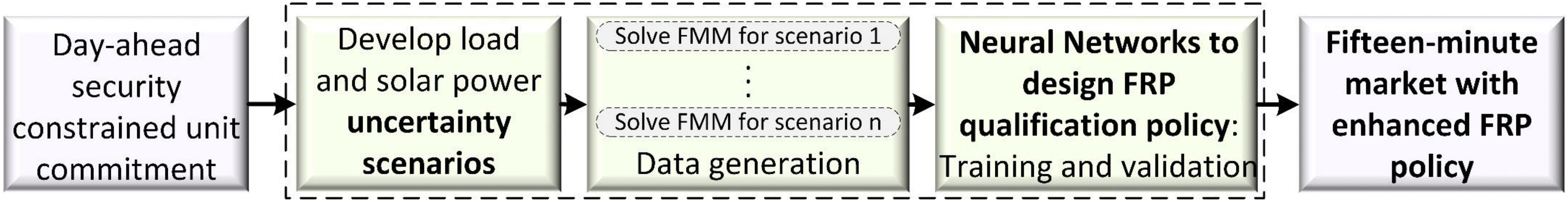
$$FRup_t = max\{NetLoad_{t+1}^{max} - NetLoad_t, 0\}$$

$FRup_t$: system-wide or proxy ramping requirements

- Two-stage stochastic programs: Improves operations by optimizing system response, e.g., ramping activation
  - Pros: explicitly checks to see if the ramping capability awards are deliverable for each scenario
  - Cons: computational burden and market implications

Proposed data-driven FRP design:

- Goal: Enhanced FRP design policy by:
  - Predicting flexible resource responses to ramping events considering their deliverability
  - Assigning deployable FRP awards to responsive resources (e.g., not located behind transmission bottlenecks)



FMM: Fifteen-minute market

Data-driven stage: general structure of the machine learning algorithm

Goal: *To assess deployability of FRP of various generation resources and to allocate FRP effectively*

- **Data mining algorithm:** Neural network regression function
- Determine ζ_{gts} that approximates response of a unit due to net-load changes
  - Target: Per unit dispatch change of each generator at each time interval due to flexibility provision
  - Features: Net-loads and net-load changes
  - Instances: 15-min net load scenarios

Data-driven stage: Inputs to Neural Network algorithm

- Features used by neural network algorithm: *net-load* and *net load changes*

No		Feature	Inputs	mathematical notation
1	Netload information	Netload	1	NL(t)
2		Netload (1 15-min before)	1	NL(t-1)
3		Netload (2 15-min before)	1	NL(t-2)
4		Netload (3 15-min before)	1	NL(t-3)
5		Netload (1 15-min after)	1	NL(t+1)
6		Netload (2 15-min after)	1	NL(t+2)
7		Netload (3 15-min after)	1	NL(t+3)
8	Change in netload information	Delta netload	1	ΔNL(t)
9		Delta netload (1 15-min before)	1	ΔNL(t-1)
10		Delta netload (2 15-min before)	1	ΔNL(t-2)
11		Delta netload (3 15-min before)	1	ΔNL(t-3)
12		Delta netload (1 15-min after)	1	ΔNL(t+1)
13		Delta netload (2 15-min after)	1	ΔNL(t+2)
14		Delta netload (3 15-min after)	1	ΔNL(t+3)

Proposed data-driven FRP design:

- Deliverability: Enhanced FRP design policy that employ ramping <u>*response factor sets*</u> ($\zeta_{\mathrm{gts}}^{\mathrm{fru}}$)

  - **Capacity and ramp constraints:**

$$fru_{gt}^{s} \leq ur_{g,t}$$

$$fru_{gt}^{s} \geq \zeta_{gts}^{fru} RR_{g}^{15min}$$

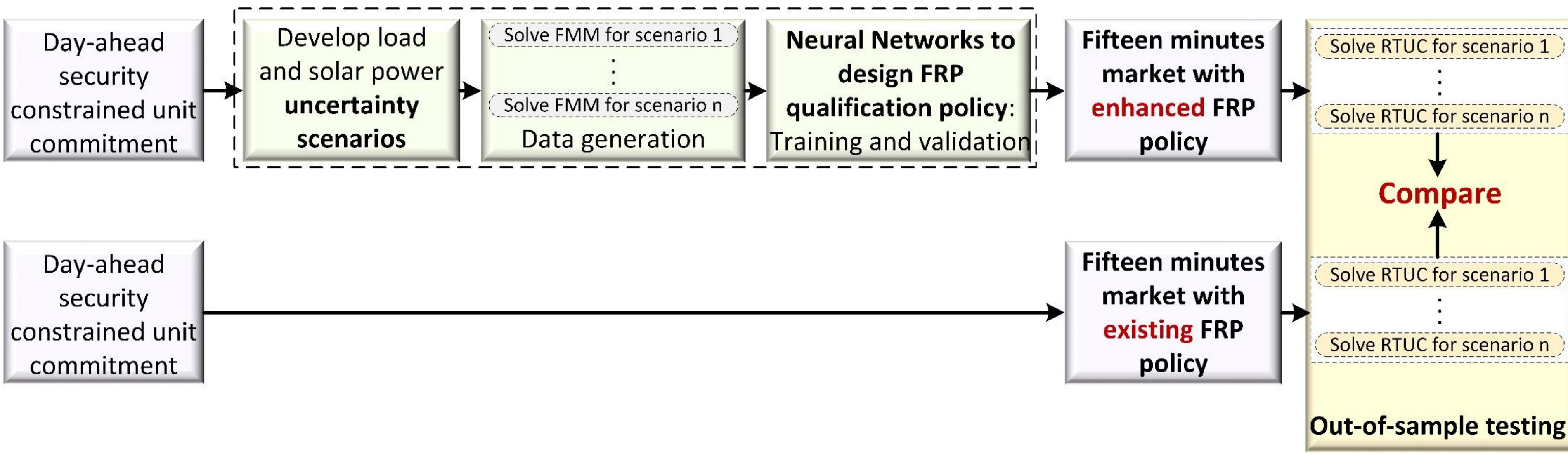
$$\sum_{g \in G} fru_{gt}^{s} \geq \Delta NL_{nts}$$

  - **Transmission line constraint for post-deployment upward FRP:**

$$-P_k^{max} \leq \underbrace{\sum_{n} P_{nt}^{inj} PTDF_{nk}}_{\text{Pre-activation flow on line } k} + \underbrace{\sum_{g:g \in G^n} fru_{gt}^{s} PTDF_{n_g k}}_{\text{Change in flow due to up FRP activation}} + \underbrace{\sum_{gs:gs \in GS^n} (P_{gs,t+1} - P_{gs,t}) PTDF_{n_g k}}_{\text{Change in flow due to solar generation change}} - \underbrace{\sum_{n} \Delta L_{nts} PTDF_{nk}}_{\text{Change in flow due to load changes}} \leq P_k^{max}$$

- *Set of constraints for downward FRP is symmetric*

Process flowchart for the proposed data-driven FRP design



RTUC: Real-time unit commitment   FMM: Fifteen-minute market

Results: Enhanced FRP allocation (quantity and location)

- Results for FMM market and real-time operation over all time intervals

Approach	Contemporary policy	Proposed policy
FMM operating cost (K$)	1171	1175
Real-time operating costs		
Ave (K$)	2328	2199
Standard deviation (K$)	812	754
Max (K$)	6134	6126

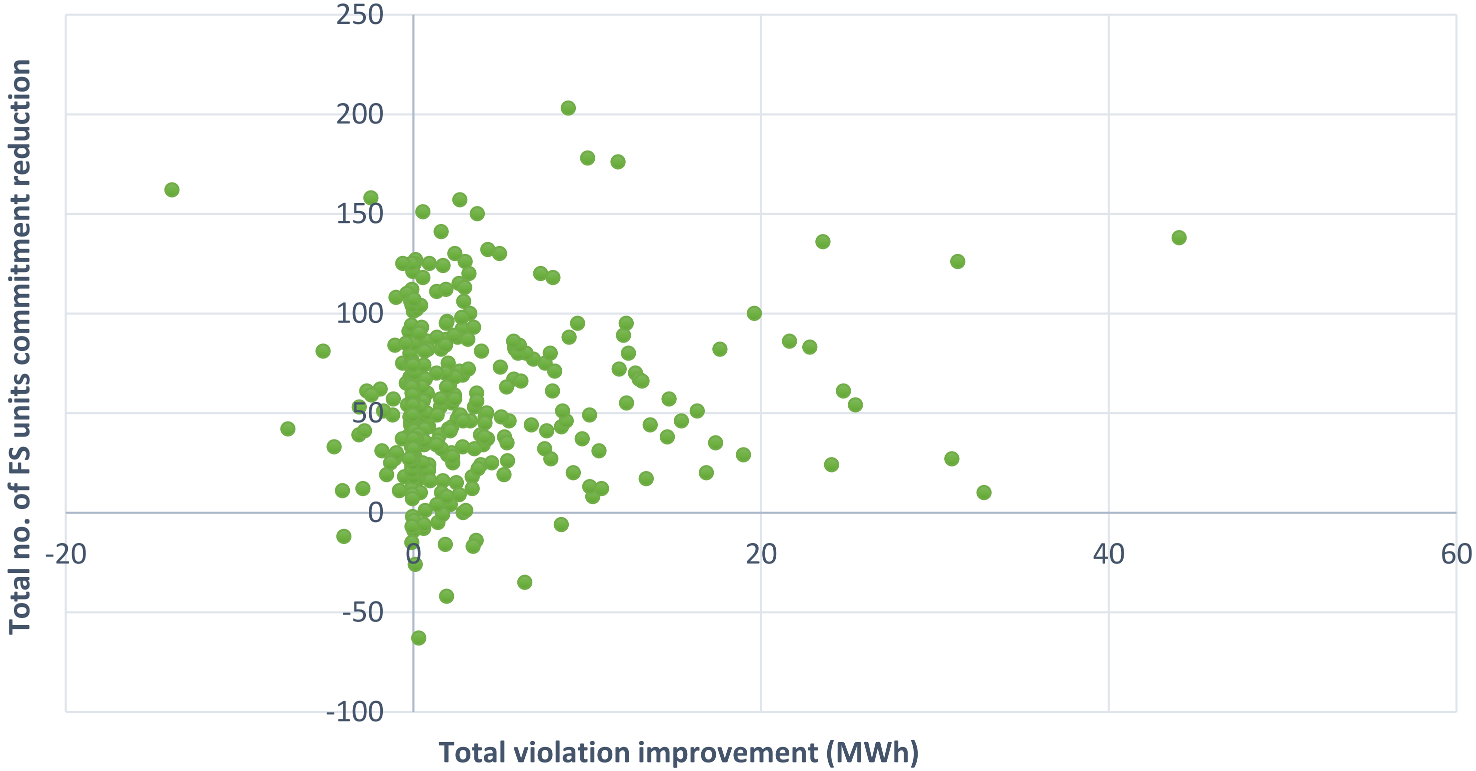
- Number of scenarios with improvement over all time intervals in real-time operation (total number of scenarios = 350)

Metric	
# Scenarios with cost (excluding violation cost) improvement	**350**
# Scenarios with total violation improvement	**233**
# Scenarios with reduction in total commitment of FS units	**331**

FMM: Fifteen-minute market   FS: Fast-start

Results: Enhanced FRP allocation (quantity and location)

- Reduction in number of additional commitment of fast start units versus total violation improvement for 350 scenarios



FMM: Fifteen-minute market FS: Fast-start

Concluding Remarks (part I and II)

- **The Enhanced FRP policy improves the quantity allocation and deployability of FRPs with minimal disruption to existing day-ahead and real-time market models**

- **The proposed approach leads to:**
  - Less operating cost in real-time operation
  - Less number of potential violation in real-time operation and less need for out-of-market correction
  - Less need for committing fast-start units in real-time operations

Thank you!