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Data-Driven Methods for Voltage Regulator Identification and Tap Estimation

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Outline

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Motivation

- Distribution utilities' traditional models are prone to errors and may contain outdated information as grid components are changed or upgraded over time.

- Accurate models of voltage regulating devices are required to address the operational and planning challenges.

- Assessing the tap changing activities in real-time by the voltage regulators can be very helpful.

- Improving voltage regulator model fidelity and assisting the utilities in monitoring their regulator and load tap changer (LTC) performance in real-time is necessary.

Voltage Regulator Controls and State

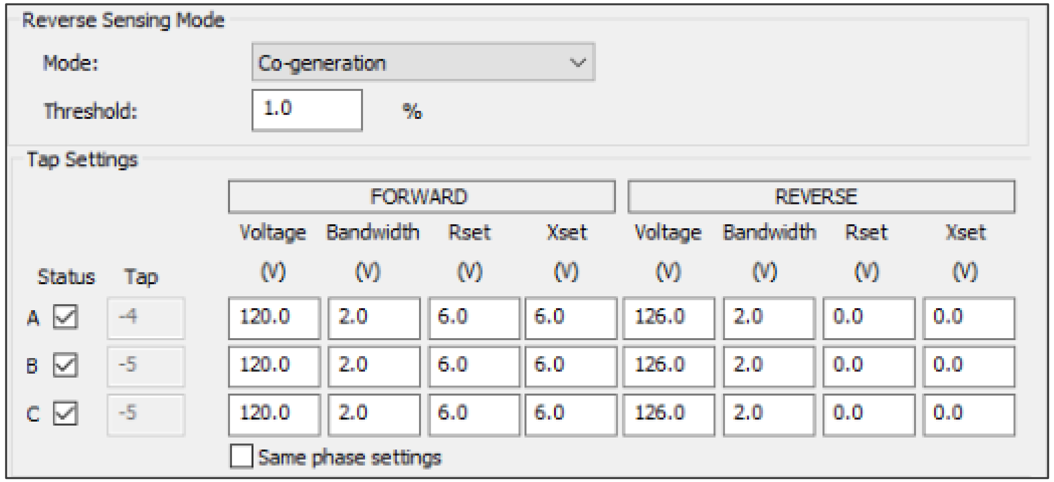
Background: Voltage regulating transformers control the voltage by switching onload taps up or down to keep the voltage in band

Problem:

- Most voltage regulators do not have remote login capabilities, so verifying their settings in planning models requires sending a crew to the device.
- For state estimation or power flow results, knowing which tap the voltage regulator is on is required, but this information is often not available in historical data

Objective: Use Machine Learning and Big Data from grid edge measurements to identify the 1) voltage regulator settings, and 2) the tap position of the regulator at a given time

Determining the Settings of the Voltage Regulator



Reverse Sensing Mode

Mode: Co-generation

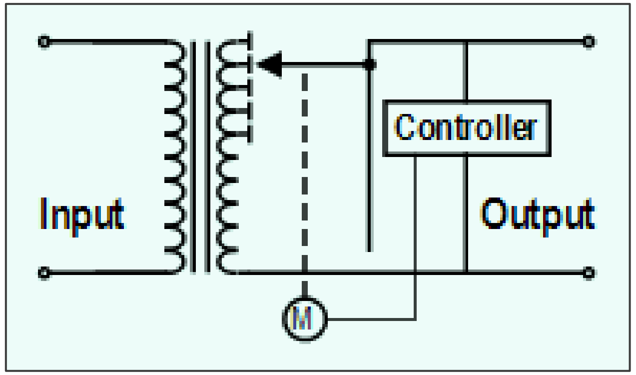
Threshold: 1.0 %

Tap Settings

		FORWARD				REVERSE			
Status	Tap	Voltage (V)	Bandwidth (V)	Rset (V)	Xset (V)	Voltage (V)	Bandwidth (V)	Rset (V)	Xset (V)
A ☑	-4	120.0	2.0	6.0	6.0	126.0	2.0	0.0	0.0
B ☑	-5	120.0	2.0	6.0	6.0	126.0	2.0	0.0	0.0
C ☑	-5	120.0	2.0	6.0	6.0	126.0	2.0	0.0	0.0

☐ Same phase settings

Determining the Tap Position



Utility Datasets

- 2019 data from two actual utility feeders.
- Voltage measurements at 15-minute intervals were available at each recloser
- Feeder A : 5.42 km and 859 customers.
- Feeder B: 12.91 km and 1,281 customers.

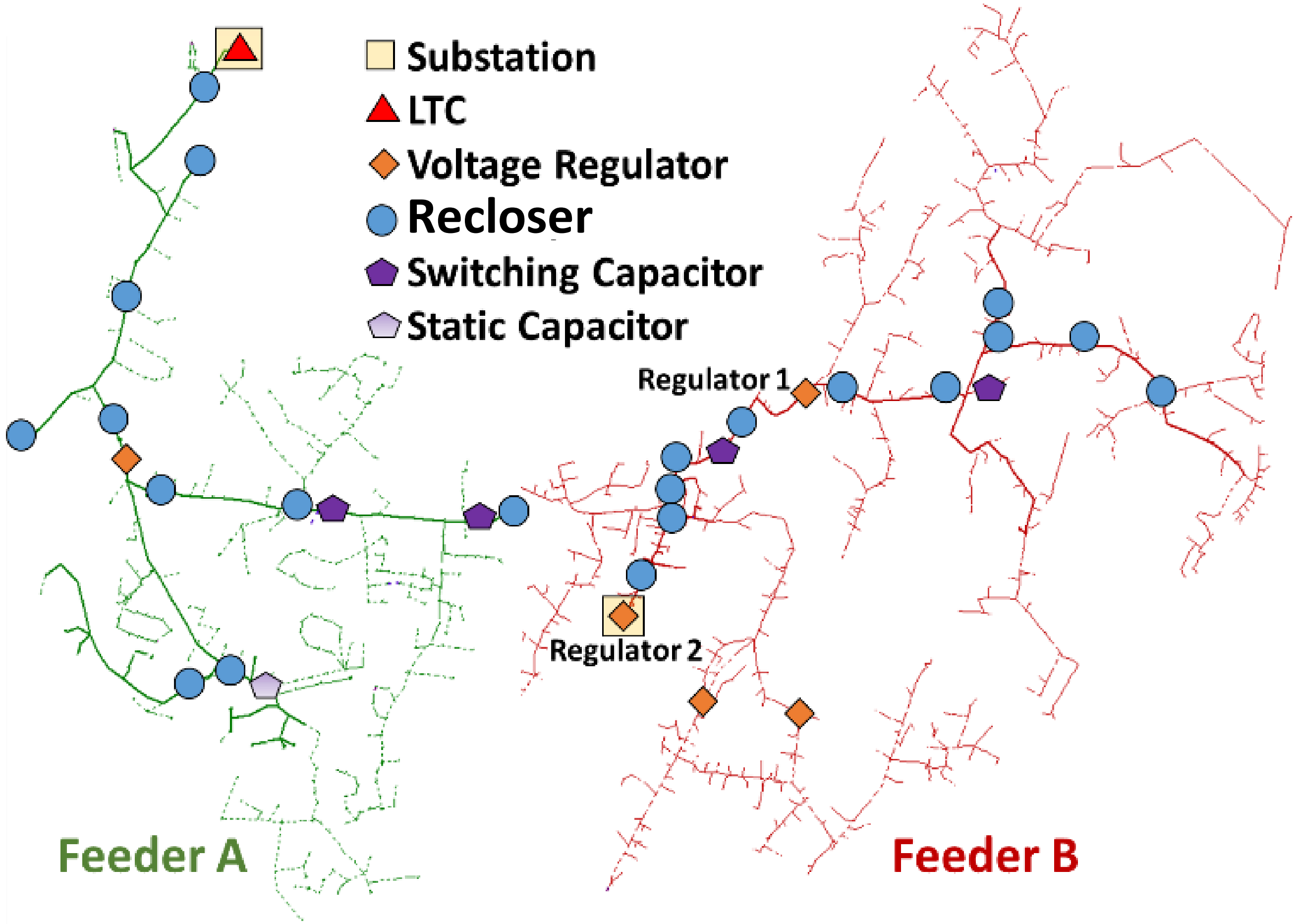


Fig. 1 Simplified circuit diagrams of the two utility feeder models

Identifying the Device and Controlled Phase

- The length and position of the tails of the voltage distributions are needed.

- Phases independently controlled: may not be any outliers and the length across the phases will be nearly equal.

- For substation LTC: outliers are present and the values of the tails will be higher for any of the two uncontrolled phases.

$$Higher\ tail = V_{max} + \{Q_3 + whisker \times (Q_3 - Q_1)\} \quad (1)$$

$$Lower\ tail = V_{min} - \{Q_3 - whisker \times (Q_3 - Q_1)\} \quad (2)$$

Estimating Tap Positions

- The per-phase voltage measurements of the reclosers are utilized.
- Finding the tap positions that are at minimal distances from the corresponding measurements.
- The cosine similarity metric is used as a distance metric.

Objective:

Maximize

$$\sum_{t=1}^{T} \max\{Cosine\ Similarity(x_t, c)\}$$

Constraints:

$$w = c_j - c_{j-1} \quad \text{when } j > 1 \qquad (3)$$

$$0.25 \leq w \leq 2 \qquad (4)$$

$$-32 \leq c_j \leq 32 \qquad (5)$$

Identifying Substation LTC

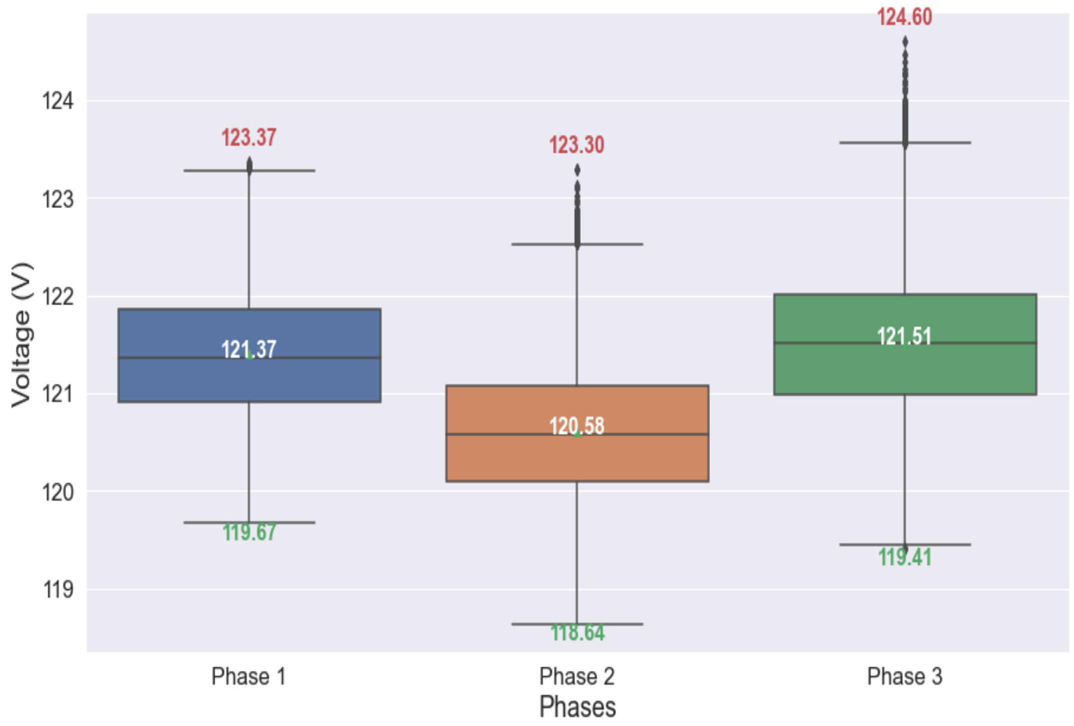


Fig. 2 Boxplots of all phases for the substation LTC average voltage measurements (Feeder A)

Phases	Higher Tail (V)	Lower Tail (V)
1	0.075	-0.175
2	0.775	0.005
3	1.02	0.01

Table I. Identifying Controlled Phase of The Substation LTC (Feeder A)

Identifying Regulator

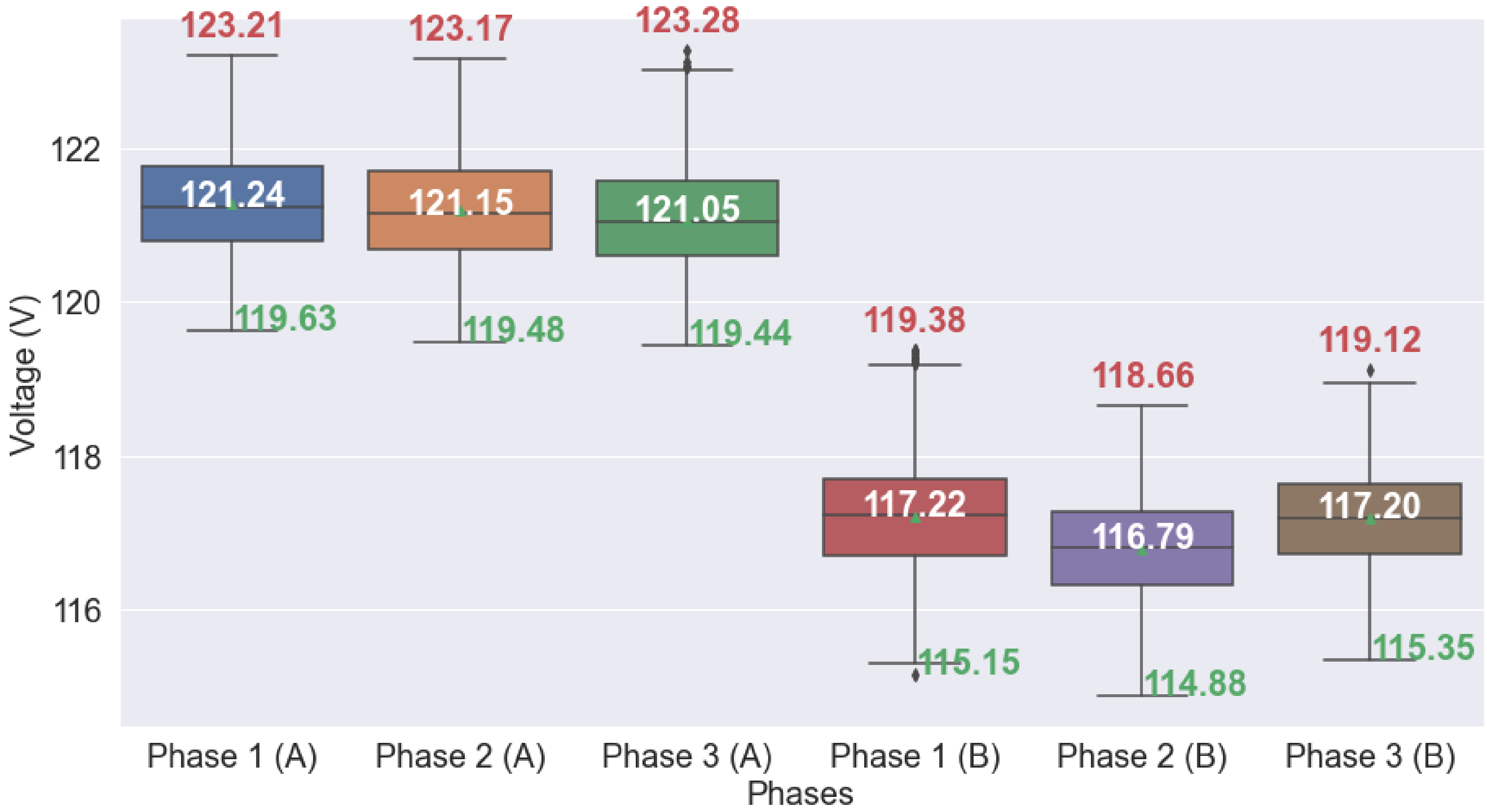


Fig. 3 Boxplots of all phases for the average measurements of the regulator in Feeder A and regulator 1 in Feeder B, respectively

Tap Estimation Results

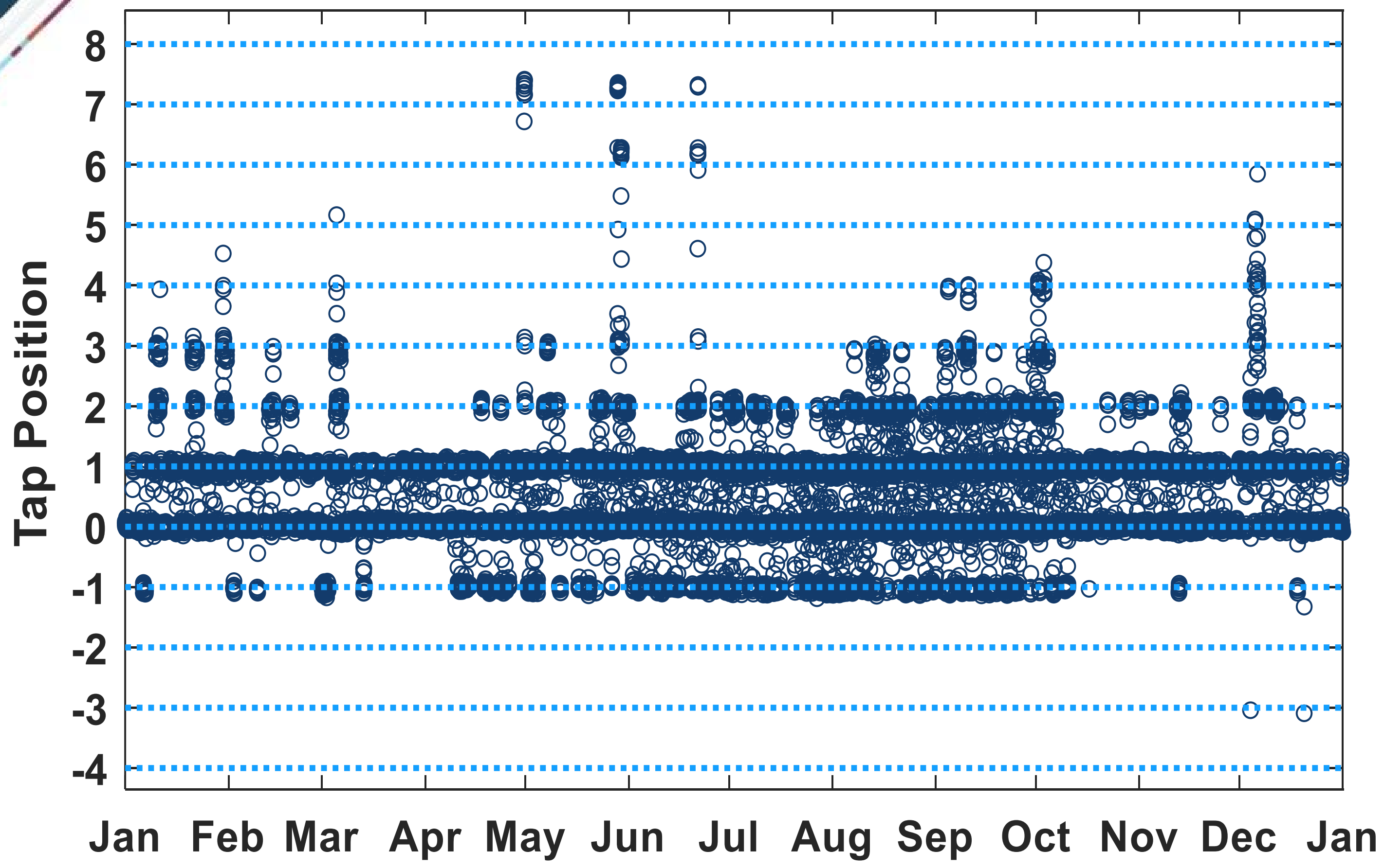


Fig. 4 Estimating the tap positions using averaged voltage measurements of phase 1. (Feeder A)

Feeder	Voltage Regulator	Difference between consecutive taps (V)	Total No. of unique taps
A	Regulator	0.7	10
B	Regulator 1	0.6	8

Table II. Tap Estimation Results for Phase 1

Types of Measurements

- Tap position estimation : Instantaneous measurements are more suitable
- Differentiating between the per-phase regulator and LTCs : Averaged measurements are more suitable

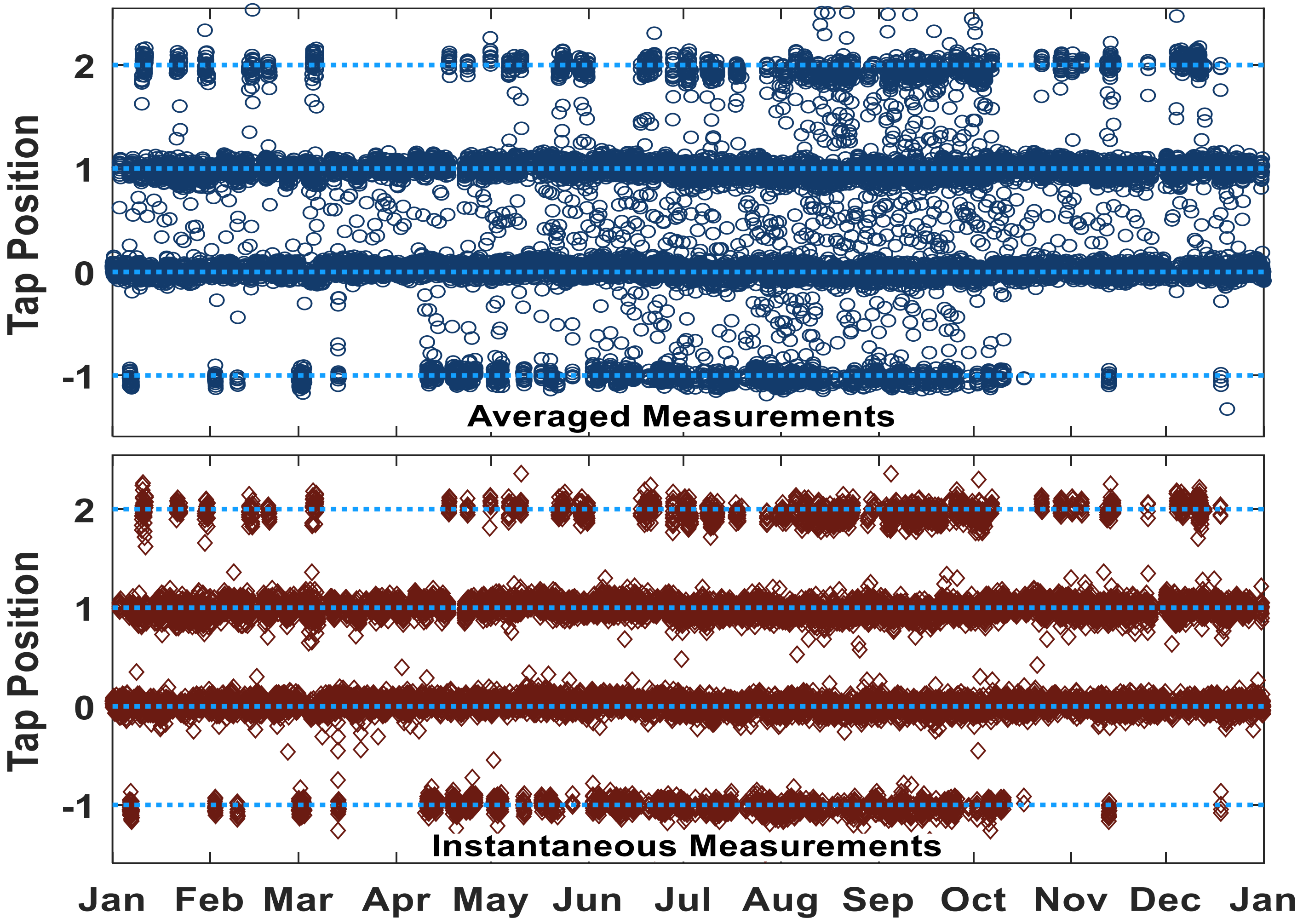


Fig. 5 Tap position estimation results using averaged measurements and instantaneous measurements for the same voltage regulator in Fig. 4

Limitations

- Enough measurement points (reclosers in this case) are needed
- Data needs to be less noisy
- Measurements must be available at a few distinct points in the feeder
- Tap position estimation: measurements are needed on either side of a voltage regulator
- Measurement points need to be closer to each other

Conclusion

- Methods to distinguish voltage regulators from LTCs.
- An optimization-based approach for identifying historical tap position states of voltage regulators and LTCs, useful for analysis tasks and state estimation.
- Developing innovative data-driven approaches that can be deployed using voltage measurements only.
- A practical toolset for verifying the accuracy of voltage regulator tap changing operations
- Easily implementable to help reduce the erroneous operations and track events such as CVR

Thanks.
For any questions

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