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Machine Learning-Based Prediction of Distribution Network Voltage and Sensor Allocation

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Motivation

Background:

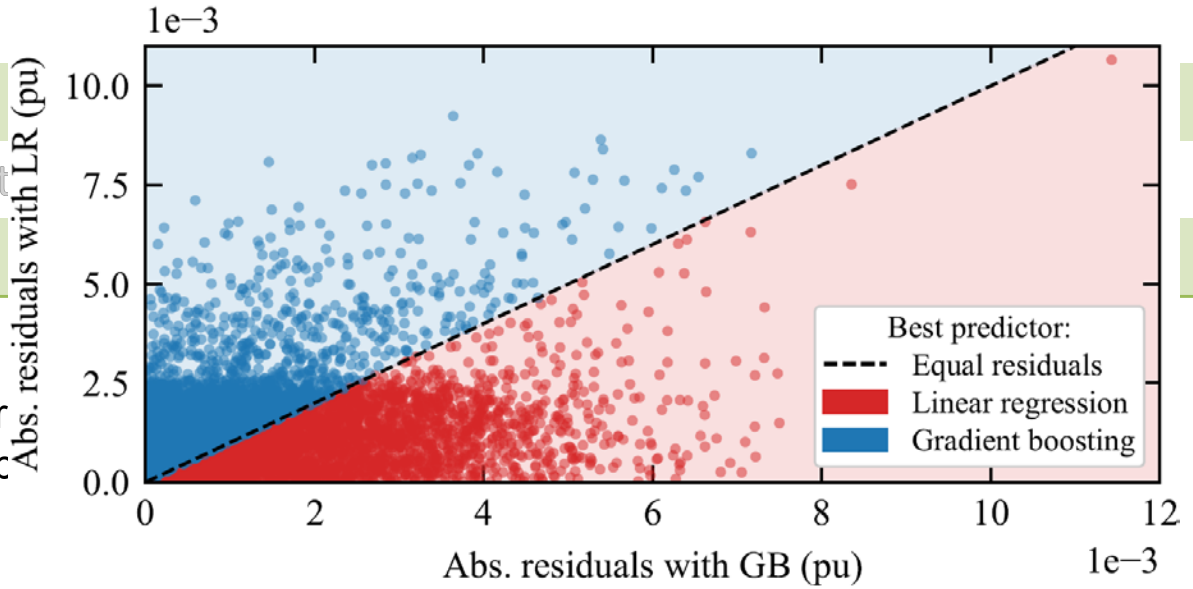
- Large photovoltaic integration at the distribution level challenges the traditional voltage control techniques.
- Distribution networks are usually not fully monitored and state estimation is less developed in distribution systems than in transmission systems.
- Large-scale deployment of smart meters increases visibility into distribution networks.

Objectives:

- Predict bus voltages through historical data and load/generation forecast.
  - ✓ Learn a mapping function between load sizes and bus voltages without full knowledge of the circuit topology.
  - ✓ Identify strategic buses for monitoring to achieve high prediction accuracy.

Voltage Prediction: Single Regressors

Regressor	MAE (10^{-3} pu)	RMSE (10^{-3} pu)	Max. error (10^{-3} pu)	%Best
ElasticNet	1.560	1.984	10.83	8.38
Bayesian ridge	1.563	1.986	10.66	7.22
Linear regression	1.563	1.986	10.65	8.78
Lasso-Lars	1.661	2.161	13.53	22.44
Gradient boosting	1.788	2.246	11.43	26.94
Extra-trees				8.48
Bagging				5.58
Random forest				5.82
AdaBoost				



MAE: mean absolute error
RMSE: root mean square error
%Best: proportion of test samp

Ensemble regressor:

- MAE decreased by 26%.
- Maximum error still larger than 0.01 p.u.

Voltage Prediction: Two-Step Regressor

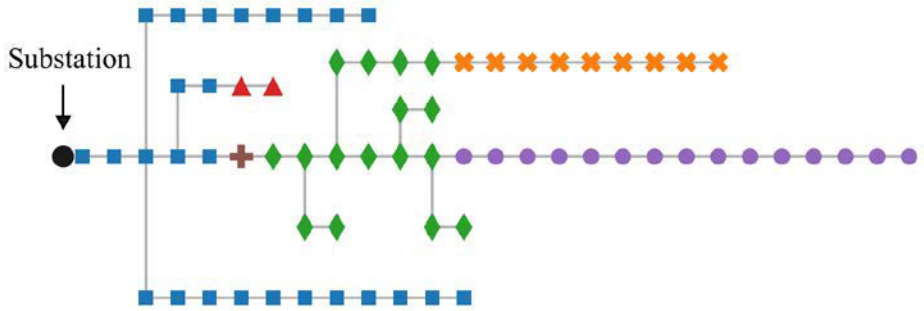
- Proposed two-step regressor:
  - ✓ Split the range of target values into three subranges: less than $(1-\tau)$ pu (submodel **A**), between $(1-\tau)$ and $(1+\tau)$ pu (submodel **B**), and greater than $(1+\tau)$ pu (submodel **C**).
  - ✓ Fit a separate model for each subrange.

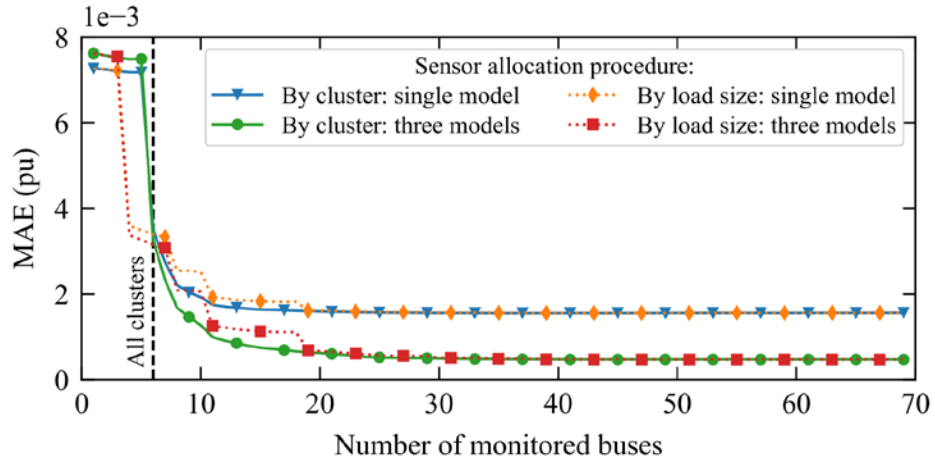
Two-step regressor:
- MAE decreased by 69%.
- Maximum error decreased to 0.0034 p.u.

- Two-step voltage prediction:
  - ✓ Predict voltage using a global regressor (single model).
  - ✓ Based on the initial prediction, select the corresponding local regressor (submodel **A**, **B**, or **C**) and perform the voltage prediction again (refinement).

Sensor Allocation

- Trade-off between fewer measurements at strategic locations and network observability.
- Similar buses are identified through agglomerative hierarchical clustering.
- Proposed approach:
  - ✓ Select the most important bus from each cluster for monitoring.
  - ✓ Add more buses (in descending order of importance) to the predictor until the desired accuracy is achieved or there is no further improvement in the prediction error.





Conclusions/Recommendations

- Accuracy of voltage prediction in distribution networks can be significantly improved by modifying and combining simple estimation techniques.
- High network observability can be achieved by selecting only a few strategic buses for monitoring.
- This data-driven estimation approach can be updated periodically to reflect changes in the network.