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

<table>
<thead>
<tr>
<th>Regressor</th>
<th>MAE (10^{-3} pu)</th>
<th>RMSE (10^{-3} pu)</th>
<th>Max. error (10^{-3} pu)</th>
<th>%Best</th>
</tr>
</thead>
<tbody>
<tr>
<td>ElasticNet</td>
<td>1.560</td>
<td>1.984</td>
<td>10.83</td>
<td>8.38</td>
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<tr>
<td>Bayesian ridge</td>
<td>1.563</td>
<td>1.986</td>
<td>10.66</td>
<td>7.22</td>
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<tr>
<td>Linear regression</td>
<td>1.563</td>
<td>1.986</td>
<td>10.65</td>
<td>8.78</td>
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<tr>
<td>Lasso-Lars</td>
<td>1.661</td>
<td>2.161</td>
<td>13.53</td>
<td>22.44</td>
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<td>Gradient boosting</td>
<td>1.788</td>
<td>2.246</td>
<td>11.43</td>
<td>26.94</td>
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<td>Extra-trees</td>
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<td>AdaBoost</td>
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</tbody>
</table>

**MAE**: mean absolute error  
**RMSE**: root mean square error  
**%Best**: proportion of test samples where this estimator is the most accurate

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 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).

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