Optimal Capacitor Planning for Large-Scale Electric Utility Distribution Systems

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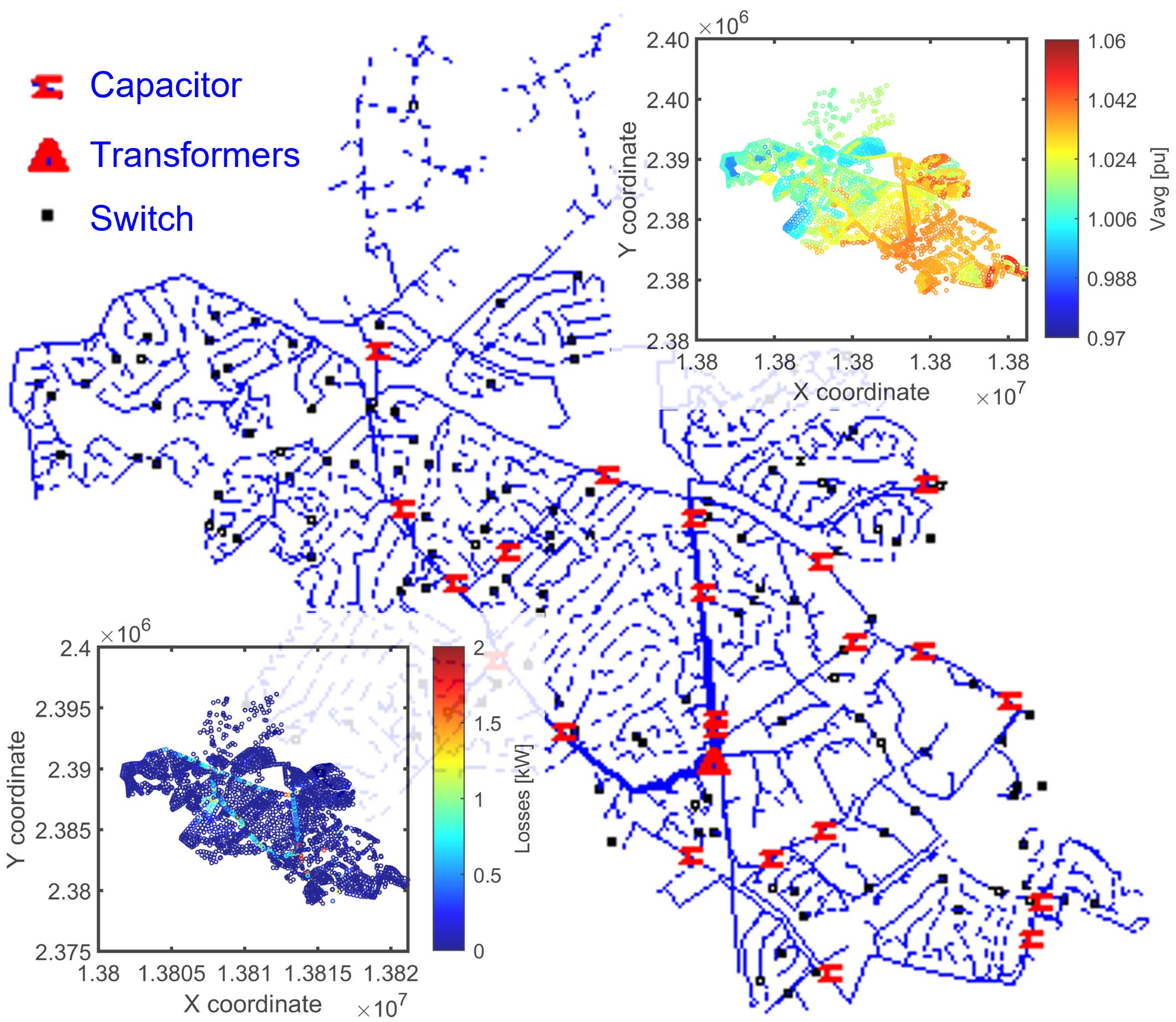
Introduction and Major Contributions

- Multi-step simulation procedure for distribution systems is in development for the purposes of optimal capacitor planning (OCP) and the virtual implementation of conservation voltage reduction (CVR) and volt-var optimization (VVO)
- This work illustrates OCP on a large electric utility circuit with the objectives of minimizing investment, active power line losses, and bus voltage deviation, while also considering voltage violations
- OCP capabilities on large utility systems to be employed for CVR case studies and time series simulation employing feeder-level and AMI load data for VVO with control of single- and three- phase capacitors and other devices which may be utilized to maintain system voltage.

Power Distribution System Modeling and Simulation

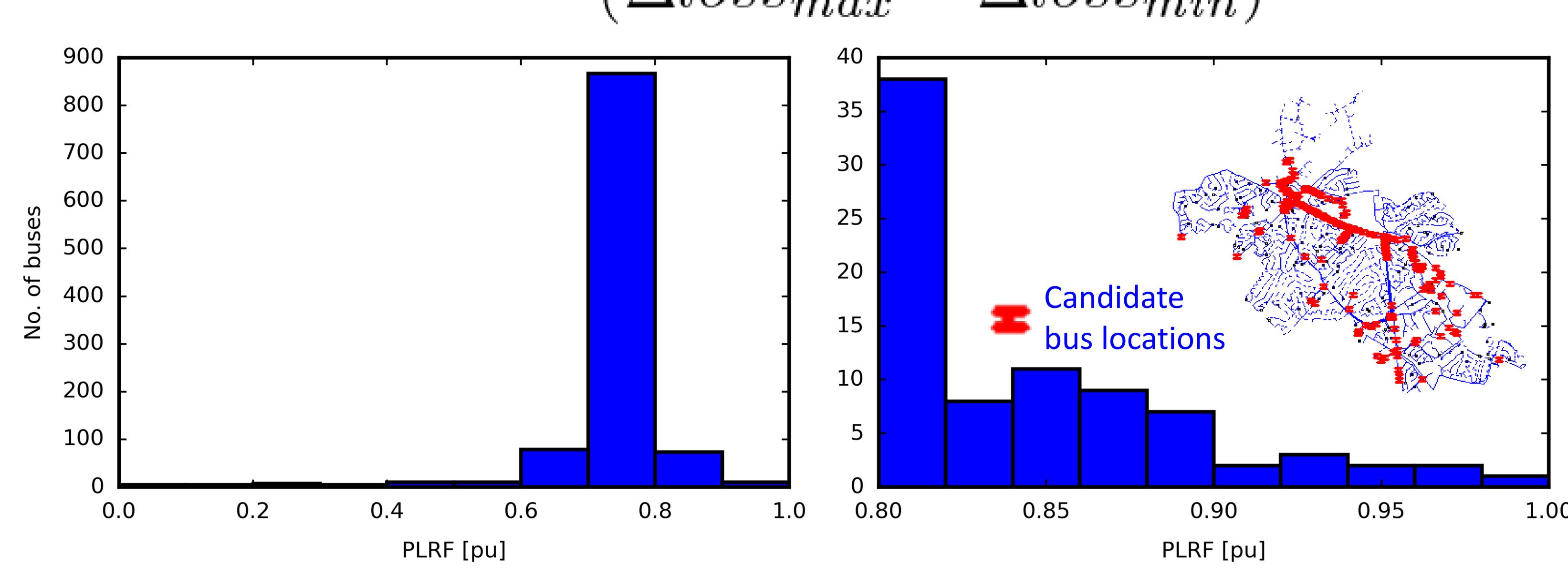
- Procedure to convert power distribution system models from Synergi, a utility software, to open-source OpenDSS, was developed and applied to actual power systems
- The circuit, henceforth referred to as **KUs1**, utilized in this work is a large **48MW, 9MVAr** distribution system with advanced metering infrastructure (AMI) and is a candidate for CVR and VVO
- The KUs1 circuit OpenDSS model is a full copy of its Synergi counterpart which includes the matching of line mapping, impedances, and power losses, spot load demand, active and reactive powerflow, and bus voltages.



Sensitivity Analysis through PLRF

- Sensitivity analysis through power loss reduction factor (PLRF) employed to determine bus locations for capacitor installation
- Calculations based on the difference in active power loss corresponding to each bus between a base case scenario and another scenario with voltage reduced by 5%
- One- and two-phase buses removed from candidate bus vector
- Procedure reduced candidates from ~4000 to as few as 300, which corresponds to number of decisions variables for optimization.

$$PLRF(n) = \frac{(\Delta loss_n - \Delta loss_{min})}{(\Delta loss_{max} - \Delta loss_{min})}$$



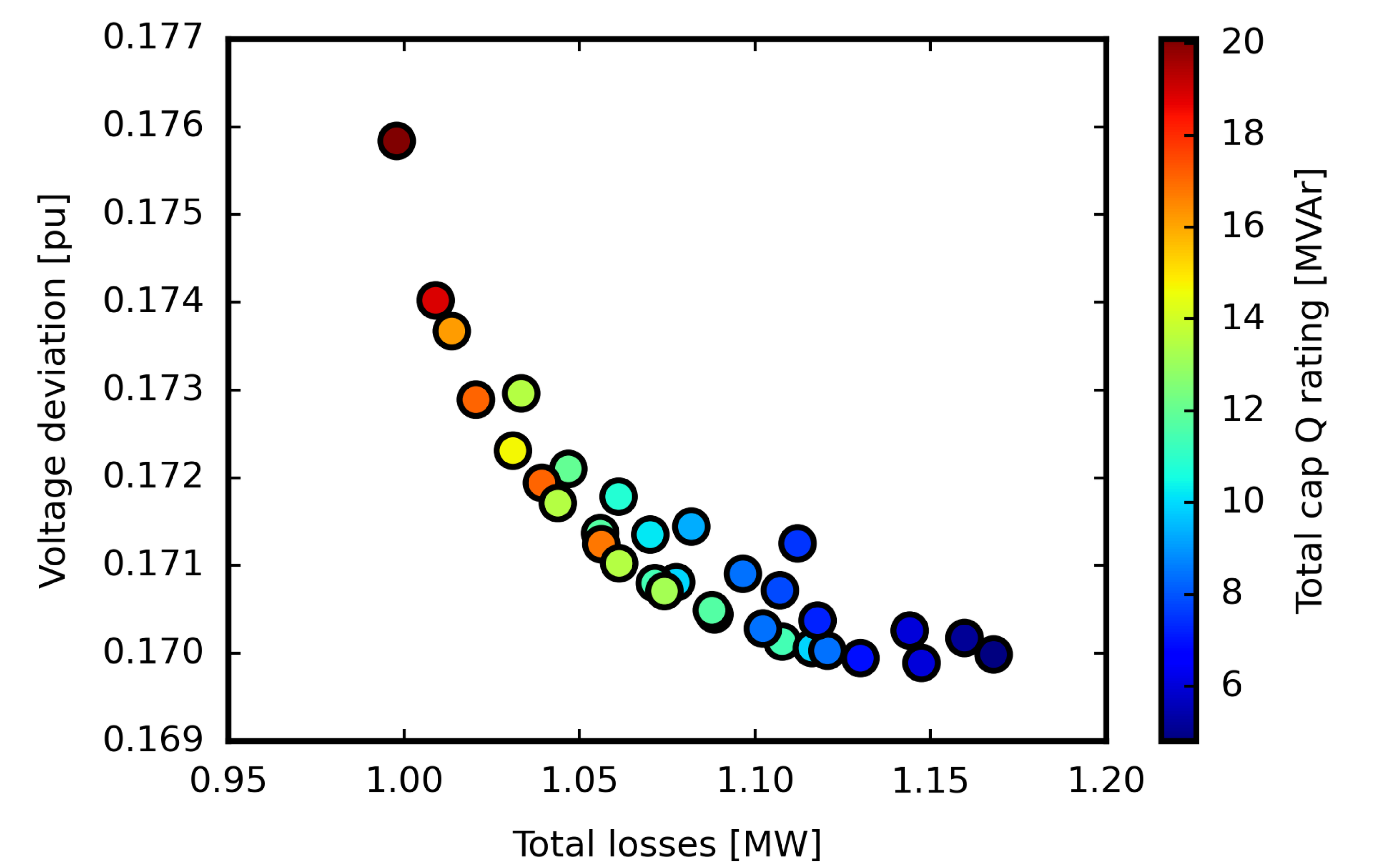
Multi-objective Optimization for Capacitor Planning

- Tools for optimal capacitor planning (OCP) have been developed with Python which interfaces with the OpenDSS open-source software
- **Multi-objective optimization** through the non-dominated sorting genetic algorithms (NSGA) II and III is employed with the objectives of minimizing total installed capacitor kVAr rating (representing investment), total active power losses, and voltage deviation, where the reference voltage is 1.0pu
- **Decision variables** are the installed capacitor kVAr ratings for the candidate bus locations, which were determined through an initial sensitivity analysist
- These kVAr ratings are selected from a **discrete range** of 0 to 1200kVAr in increments of 300, which corresponds to typically **available capacitor sizes** at the distribution system level
- It should be noted that only three-phase buses were considered according to typical utility practices.

$$VD = \sqrt{\left(\frac{1}{N_{bus}}\right) * \sum_{n=1}^{N_{bus}} (v_n - v_{ref})^2}$$

Conclusions

- Multi-objective optimization for capacitor placement in KUs1 at its peak load is achieved by producing a Pareto of best designs
- Total system losses is reduced as capacitors are added to the system, and voltage deviation increases after a total installed capacitor Q rating of approx. 8MVAr is reached
- The increase in voltage deviation is likely due to this case's high voltage operation of the source bus
- The "best" design may be selected depending on the weights provided for each parameter.



Ongoing and Future Work

- CVR implementation and analysis has been performed for the example system with the multi-step simulation procedure over time series simulation based on feeder-level load data
- Case studies to determine how OCP may support CVR are underway by allowing reduction of total system voltage and preventing voltage violations for buses at further distances
- Time series simulation of VVO is in progress with the prospect of employing local AMI data for enhanced granularity
- This VVO simulation is to utilize the OCP capabilities as well as three-phase and single-phase control of capacitors.

Acknowledgement

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