Impact of High Photo-Voltaic Penetration on Distribution Systems

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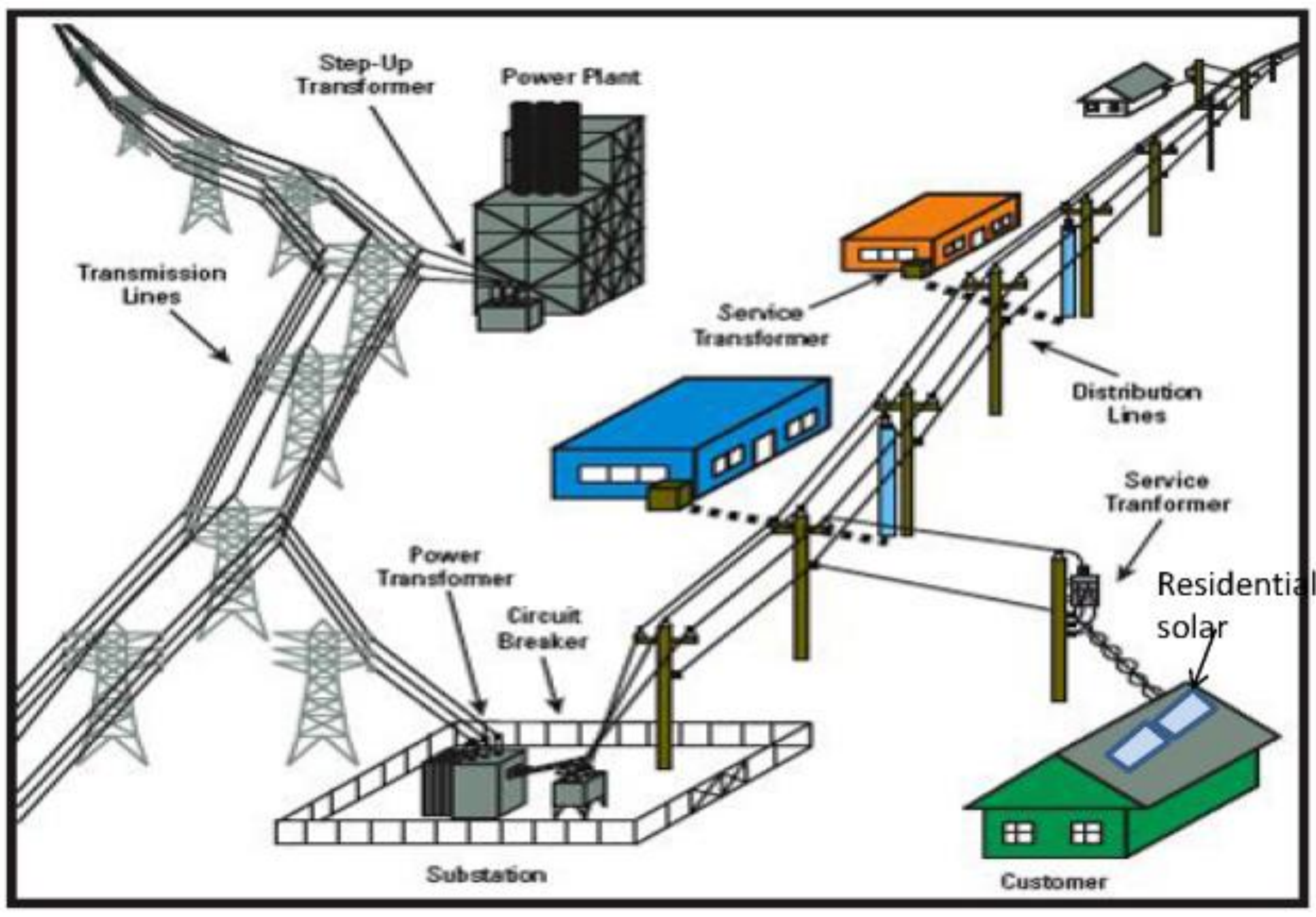
INTRODUCTION

Our project looks at the effects of large-scale implementation of PV within various distribution systems. The prevalence of PV within the last decade has made this topic important because of how different PV installations can affect certain aspects of distribution systems. Our goal is to model these different types of PV in multiple distribution systems and analyze the results so that recommendations can be given on optimal configuration and installation types.

ENGINEERING STANDARDS & DESIGN PRACTICES

- Bus Voltage maintained within 0.95-1.05 per unit.
- Line Currents not exceeding ampacity of the line.
- Real power must not be injected from the distribution system to transmission. system via the substation transformer
- Transformer KVA ratings not exceeded.
- Adherence to IEEE Std 1547™-2018 for inverter capacity reserved for KVAR injection.



DISCUSSION

34-Node

- Modeled after a real-world distribution system in Arizona.
- Selected by IEEE to be used to test power-flow algorithms for solving unbalanced three phase systems.
- Has a nominal voltage of 24.9 kV. The length between nodes is long and the loading is relatively light.
- There are two regulators, two capacitor banks (300 KVAR @ node 844 and 450 KVAR at node 848) and one transformer to step down to 4.16kV.

This is the first system we used to analyze power-flow solutions and PV implementation. We tested different PV installations (spot and distributed) and inverter control nodes to see how voltage profile was affected.

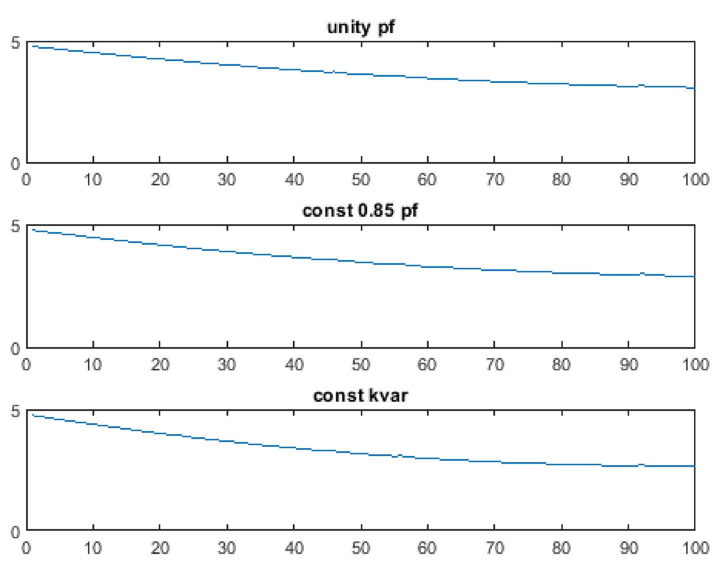
123-Node

•4.16kV unbalanced 3 phases system characterized by low loading at each node and relatively short lines.
•Contains a mix of single, two, and three phase overhead lines, and 3 phase underground lines.
•Low voltage results in higher losses for a system of its size.
•Unregulated voltage is between 0.941 and 0.999 p.u., outside the 0.95-1.05 band used for distribution systems.
•Total system power is 3.326 MVA at 0.92 lagging power factor, with ~5 MVAR-hour losses and 2.5 MWh losses per day.
•Goal is to provide voltage regulation via KVAR injection from the inverters.
•44% of inverter capacity is reserved for KVAR injection per IEEE Std 1547™-2018
•Determination is made of minimum %PV penetration is needed for voltage control.
•Recommendation made for solar inverter operation based on minimizing losses until voltage control via solar is possible, then maximizing real power injection while maintaining voltage profile.

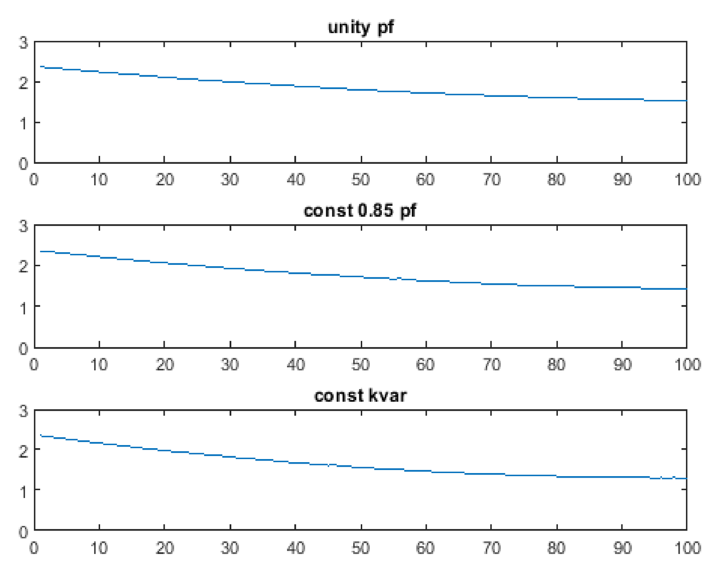
Additional Notes

- 34 Node System Optimized for losses, and 123 Node analyzed for voltage profile.
- 123 Node exhibited loss reduction at all %PV penetration in the recommended control scheme.
- 34 Node was optimized for real losses but exhibited a 59.6% reduction in MVAR-hour losses.

MVARh losses as a function of PV percent penetration



MWh losses as a function of PV percent penetration



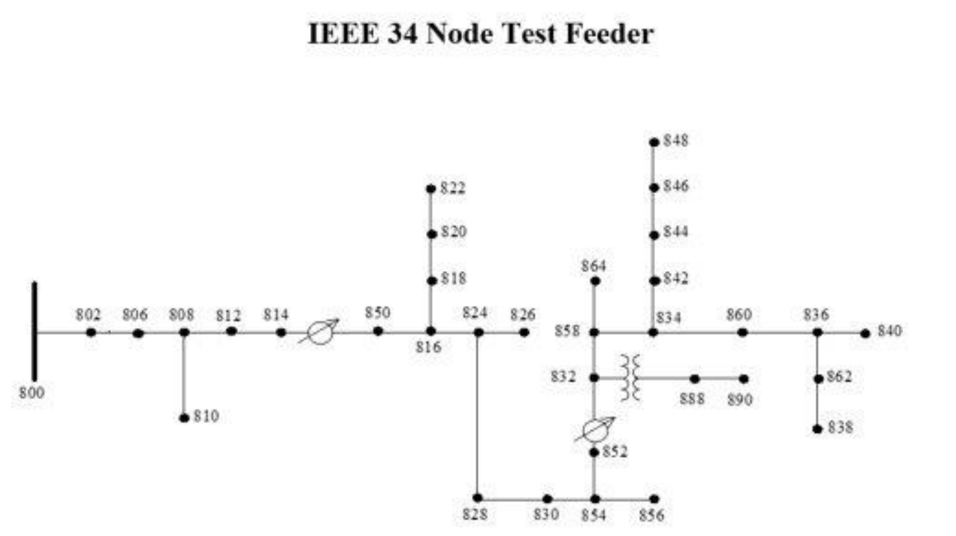
Optimization

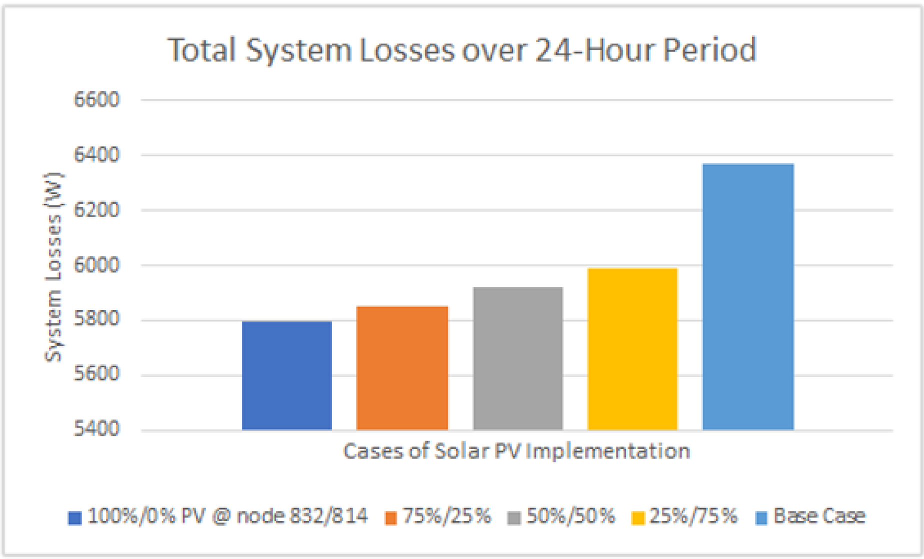
- The purpose of optimization is to maximize the efficiency of PV implementation in the 34-node distribution system.
- We chose to use the power-flow method to optimize the 34-node system. Specifically, we aimed to minimize losses by implementation of spot-load PV systems (community owned solar farms) with a constant 0.85 lagging power factor.
- Using [3] to define our power-flow system and [2] for multi-PV sizing and setting, we found two critical nodes to implement our solar farms.
- Node 832 was the primary node due to lowest system losses.
- Node 814 was the secondary node due to lowest system voltage.
- We tested different iterations of PV size of our critical nodes in order to optimize both their size and placement within the system.

RESULTS

34-Node Optimization

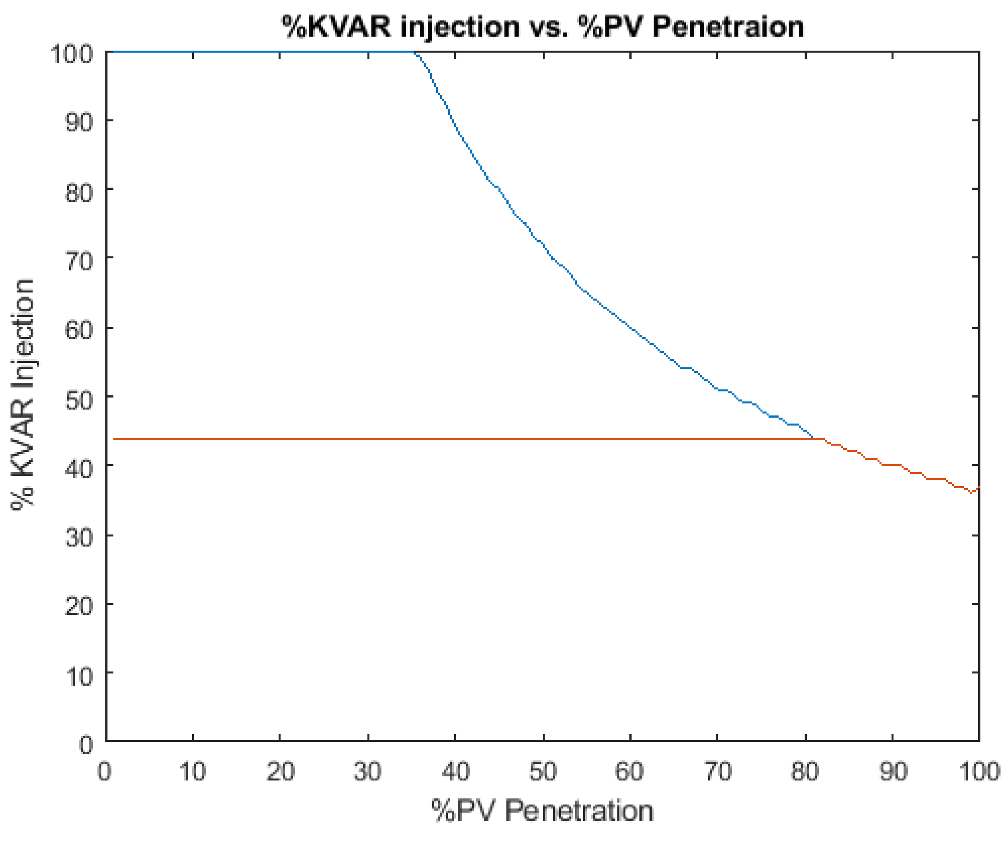
•Most beneficial to have all PV in the system located at the 832 node for the control type that was utilized.
•The figure below represents the total losses of the system when PV is injected into nodes 832 and 814 at the percentages listed with 100% being 316kw.
•Results show a 9.01% reduction of real power loss. Also, we noted a 59.6% reduction of reactive power loss.





123-Node

•Operation in the region above and to the right of the blue curve represents areas where voltage control is possible solely by inverter operation.
•The orange curve is the recommended operation of the inverters, based on the requirement for 44% of inverter capacity reserved for KVAR injection.
•Prior to the intersection of the curve at 81% PV penetration, traditional voltage regulators are required to maintain voltage profile.



PROGRAMS AND RESOURCES

[1] was used to guide us in our initial research on power-flow solutions.
MATLAB and OpenDSS were utilized for all simulation requirements.

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[2] K. Seepromting, R. Chatthaworn, P. Khunkitti, A. Kruesubthaworn, A. Siritaratiwat and C. Surawanitkun, "Optimal Grid-Connected with Multi-Solar PV Placement and Sizing for Power Loss Reduction and Voltage Profile Improvement," *2018 18th International Symposium on Communications and Information Technologies (ISCIT)*, Bangkok, 2018, pp. 479-483.

[3] D. Q. Hung, N. Mithulananthan and K. Y. Lee, "Determining PV Penetration for Distribution Systems With Time-Varying Load Models," in *IEEE Transactions on Power Systems*, vol. 29, no. 6, pp. 3048-3057, Nov. 2014.