

Simulation framework for distribution planning under uncertainty using OpenDSS

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Simulation framework for distribution planning under uncertainty using OpenDSS

Charline Leduc — August 2025

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Distribution System Operators are moving from predictable, one-way delivery to grids with high variability, driven by distributed energy resources and ongoing electrification of uses. This thesis builds a reproducible simulation-based methodology to identify how a representative medium-voltage feeder behaves under increasing photovoltaic (PV) penetration and higher electrical vehicle (EV) presence. Simple, deployable battery energy storage systems (BESS) and demand shaping are solutions that are explored to preserve voltage quality and reduce technical losses.

First, this thesis frames the shift from deterministic and traditional "worst case" specifications to data-aware, time-series planning. Then, two archetypal networks are defined, a "within limits" case and an intentionally overloaded variant. The quasi-static time-series setup in OpenDSS/Python is then described in detail, as well as the line voltage band of 0.95–1.05 chosen for planning decisions and the Monte-Carlo PV siting to produce realistic, non-uniform scenarios.

Thereafter, the model is used to first quantify the effects of photovoltaic panels alone. In the within-limits network, average daily losses reduce along the increase in PV penetration, to reach a drop of $\approx 28\%$ at 70% of PV penetration. All the while daily voltage maxima remain below 1.05 pu. In the overloaded feeder, losses still lessen remarkably ($\approx 30\%$ at 80 % of PV penetration) but several buses still exhibit daily minima below 0.95 pu across scenarios. The Monte-Carlo scenario spread peaks at intermediate penetrations ($\approx 40\text{--}60\%$), showing why single-snapshot planning can be misleading.

To further improve the state of the overloaded network, batteries were then integrated to the model. A fully local algorithm that charges when the local voltage exceeds 1.00 pu and discharge below 0.95 pu is implemented, while respecting the power limits of the batteries. This implementation allows to reduce the percentage of time the furthest bus spends in undervoltage from 15% to 2%. Furthermore, it yields additional loss cuts of around 24%. Using batteries with a lesser charge power shows a trade-off: it allows for late evening and night support as energy remains but slightly increases average losses due to longer operation.

The last feature to be added to the model is the effect of EV on the grid. With realistic residential, workplace and commercial usage, unmanaged evening charging shifts the daily voltage minima downwards relative to the no-EV case, even at high PV penetration. Two load management solutions were then presented: the Time Of Use method and the Peak Shaving method.

To conclude, this thesis has demonstrated that, in this realistic network, photovoltaic panels are absolutely beneficial to reduce losses but do not guarantee acceptable voltages on stressed networks. Local and voltage driven storage control is an effective and rapidly deployable lever to avoid this issue. EV charging must be managed to avoid minor under-voltage, but network reinforcement might be ultimately necessary.