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Hierarchical Large-scale Distribution Grid Simulation Across Multiple Voltage Levels Using Smart Metering Data

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Introduction

The existing grid planning tools do not feature time-series load flow simulations combined with synthesis of load profiles for accurate state estimation. The Adaptricity.Sim of Secure Switzerland performs time-series simulations using smart meter measurements and synthetic time-series for missing data. The platform also allows the simulation of both Medium Voltage (MV) and low voltage (LV) grids in a single computation considering the impact of distributed energy resources installed at both voltage levels.

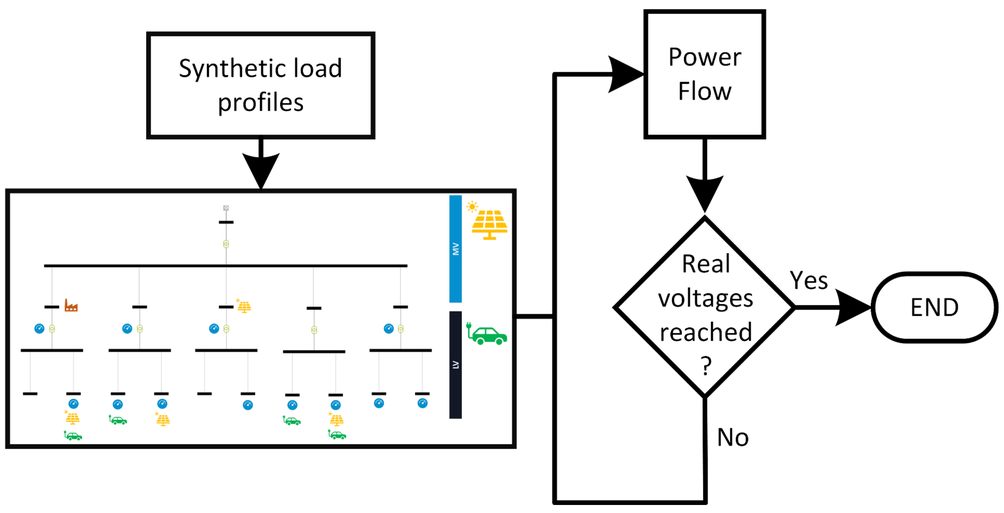

Figure 1 – Flowchart of the hierarchical simulation for both MV and LV grids including the synthesis of load profiles.

Base Case Simulation

A large-scale hierarchical simulation is performed for a Swedish distribution grid considering a 9-days period. Prioritized lists indicate which LV feeders encounter violations of voltage statutory limits or overloading of transformers and lines.

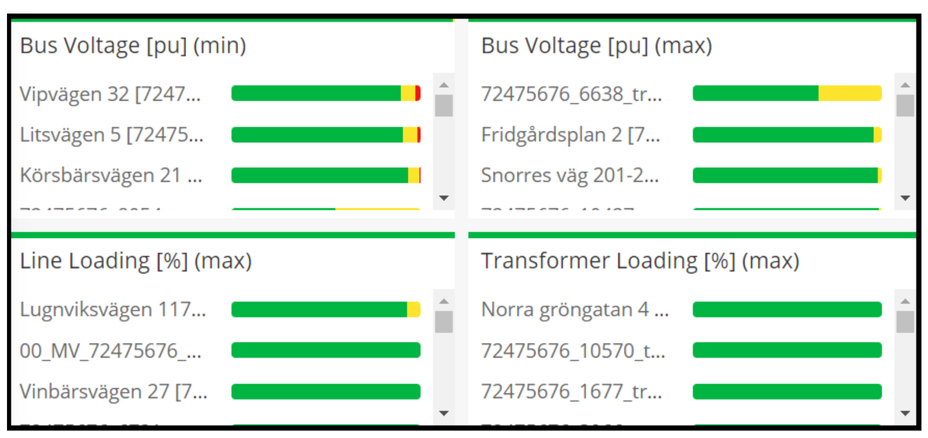

Figure 2 – Prioritized list of MV and LV grids for min/max bus voltages and loadings of transformers.

While the lists give only an overview of the feeders' status, histograms for the bus voltages, transformer and line loadings can provide further information.

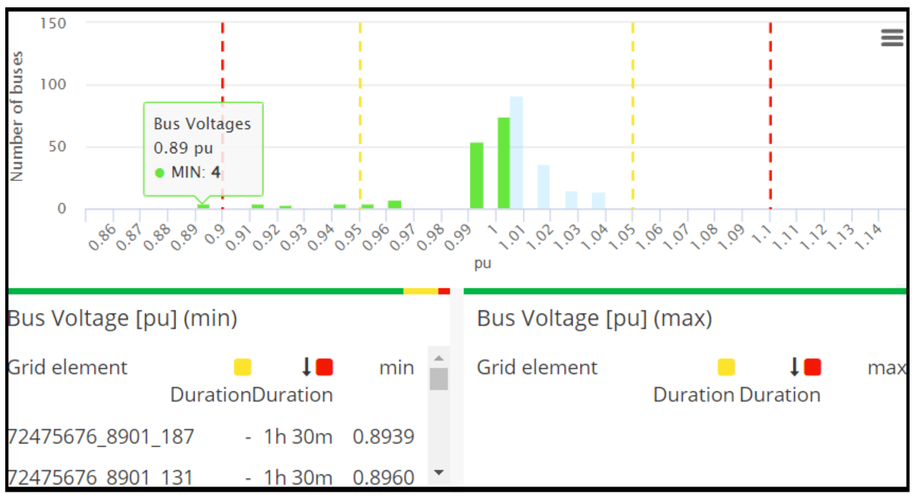

Figure 3 – Histogram for the bus voltages.

Simulation of Future Scenario

Future scenarios of different penetration levels for Photovoltaics (PVs) and electric vehicles (EVs) into the MV and LV grids, are also examined.

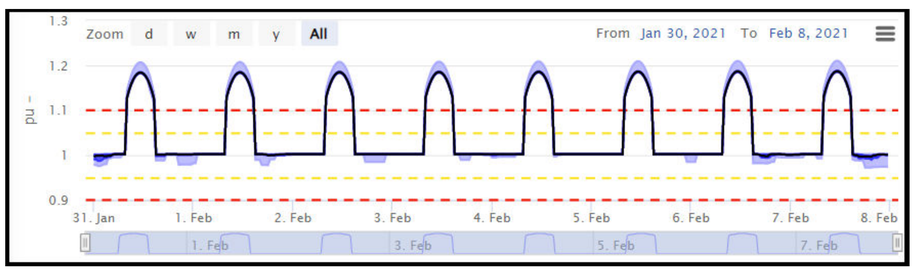

Figure 4 – Display of voltage time-series of all nodes in the LV feeder with most violations of max voltage limit.

Voltage curves can be generated showing that the PVs installed in MV nodes can cause overvoltages not only at the MV, but also at the LV level.

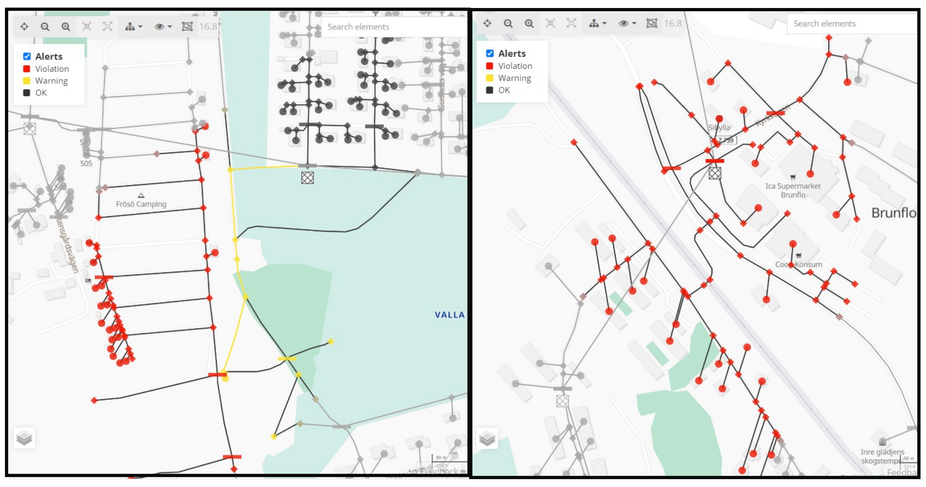

Figure 5 – In-depth illustration of two LV feeders

The in-depth illustration of each LV feeder indicates parts of the grid that face bottlenecks and may need to be reinforced in the future.

Conclusion and Outlook

The tool can be used for the evaluation of base case and future scenarios conducting large-scale time-series simulations for both MV and LV grids.

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Synthesis of Load Profiles

The matrix of the load profiles provided by the Load Profile Generator (LPG) tool is stretched or squeezed horizontally and vertically so as to fulfil the following requirements:

- Energy balance between the residual load and the sum target of energy consumptions.
- Non-negativity, since all values should be higher than or equal to zero.
- Peak power, as each profile should not exceed its defined peak power.

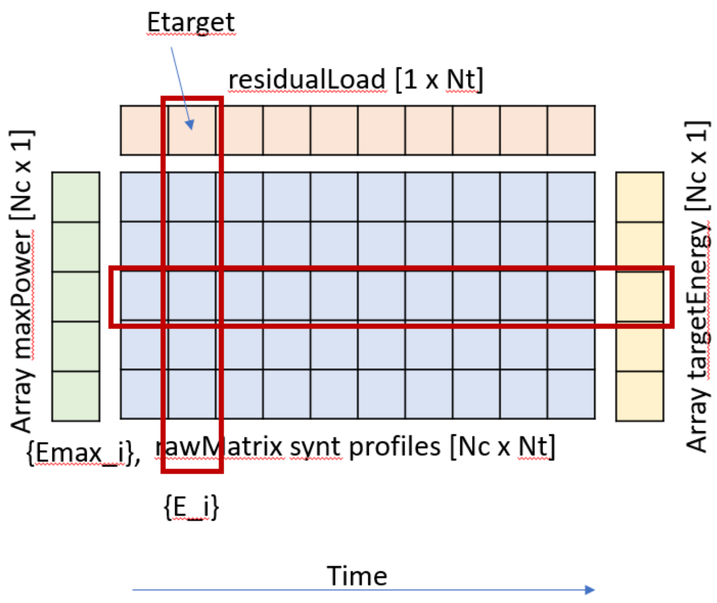

Figure 5 – Stretch and squeeze for synthesis of load profiles.

MV/LV Power Flow Simulation

Different methods, e.g., Newton-Raphson, are applied for the power flow calculation converging to the same numerical results. In each iteration, the measured voltages are compared to the calculated ones, and when the difference does not exceed the predefined value, the convergence requirement is met.

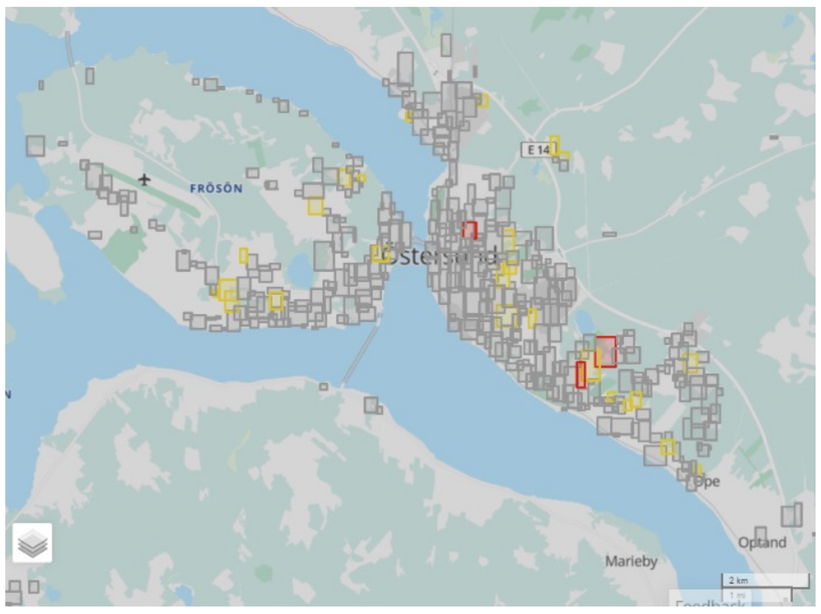

Figure 6 – Geospatial illustration of various 16 kV/0.4 kV grids represented with blocks for the region of Östersund.

Examined Grid

The examined grid of the Östersund region includes a MV grid topology of 16 kV comprising the substation to the upstream high voltage (HV) grid of 110 kV. 453 transformer substations 16 kV/0.4 kV and the grid topology for the LV feeders are considered.

Base Case Simulation

Apart from the variations of node voltages at each timestep, the hierarchical simulation provides the number of alerts, such as the warnings and violations of voltage statutory limits.

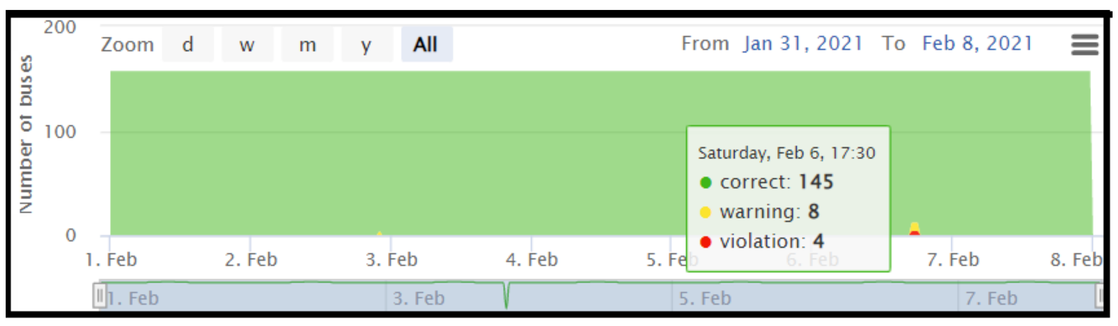

Figure 7 – Display of warnings and violations for each timestep.

Simulation of Future Scenarios

The histograms show for the future scenarios carried out what percentage of the grid elements operate normally or can cause warnings and violations.

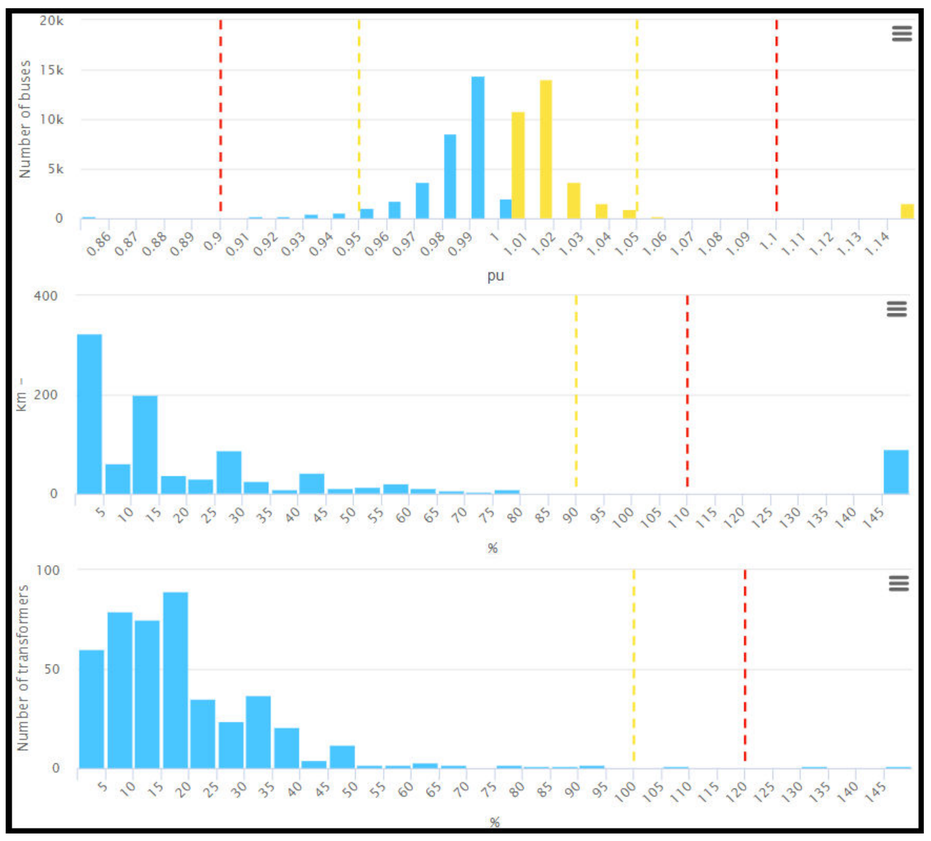

Figure 8 – Histograms of bus voltages, transformer and line loadings for the future scenario of the examined grid.