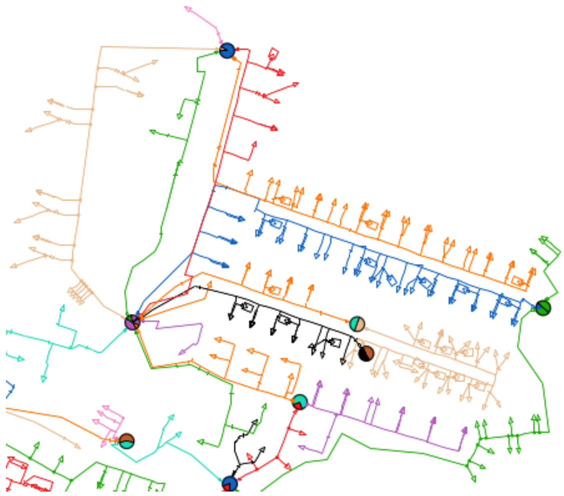
Analysis of Low Voltage Networks

In the past, most distribution system operators did not need detailed models and simulations of their low voltage networks. Now, due to the increase in recent years of distributed generation in low voltage networks and the use of electrical vehicles and heat pumps, analysis of low voltage networks has become increasingly complex and more important.

PowerFactory offers various tools for analysing critical voltages and loading of edge elements in low voltage networks. In this paper, we discuss different approaches for the network analysis and compare their pros and cons.



1 Analysis Methods

Worst-Case Scenario Load Flow

In some low voltage networks, the user might not have any knowledge of the actual load characteristic but only knows the maximum power of each load and generation unit. In this case, the Worst-Case Scenario Load Flow can be used to obtain a basic understanding of the network.

In this method, the maximum load for each load element is assumed. If generation units are to be considered, the user may wish to carry out a separate analysis in order to differentiate between a high load, low infeed scenario and a low load, high infeed scenario.

Using this approach, it is assumed that all loads are at their peak at the same time, which is rather unrealistic and leads to very high thermal loadings of edge elements and critical voltages, which in reality will probably never occur.

- \+ No detailed knowledge of the load characteristics required
- \- Results are very conservative; a second analysis is required if the user wants to take the effects of generation into account

Time Series Analysis

The most accurate way to analyse a low voltage network is to model and calculate the behaviour in the time domain. In order to do this, time-varying load and generation profiles are needed. This data can be obtained from smart meters. Alternatively standard profiles can be used. With *PowerFactory's* Quasi-Dynamic Simulation, a series of load flow calculations over a predefined period of time can be executed.

The results of the calculation, such as loading of a line at each time step, will be recorded in result files. Plots can then be created to visualise the results. This helps the user to get a better understanding of the situation in the network by showing not only if a certain value, e.g. thermal limit of a line, is exceeded but also how often and for how long it is exceeded. Additionally, statistical values such as the maximum, minimum and average of a certain variable can be calculated.

+ Most accurate approach; time dependent results offer a better understanding of the actual state of the network

- Time-varying load and generation profiles required; long calculation times; post-processing of results required

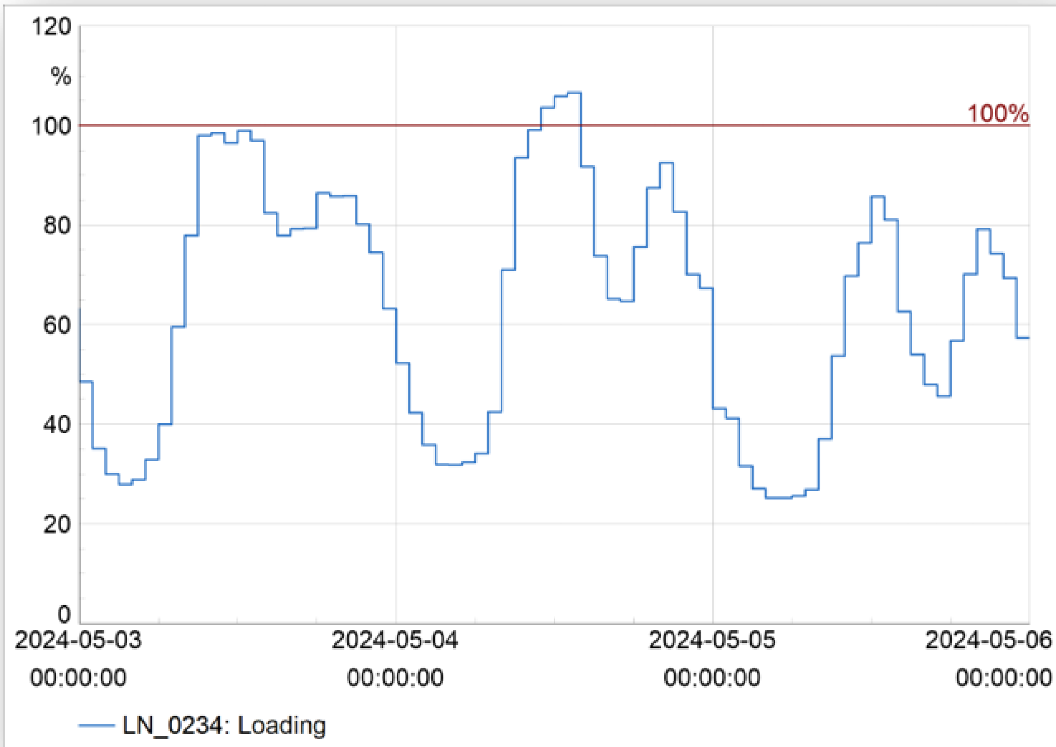


Figure 1: Quasi-Dynamic Simulation - Loading of a Line

Low Voltage Load Flow using Coincidence Curves

If we examine a low voltage network with, for example, 50 electric vehicles, it is very unlikely that all 50 electric vehicles will be charged at the same time. Detailed research on this behaviour has been done for different types of loads (e.g. electric vehicles, households and heat pumps). The results of these studies are so-called coincidence curves, which express the coincidence factor as a function of the number of consumers.

The *PowerFactory* Low Voltage Load Flow considers the number of consumers of a certain load type that are supplied by a branch and multiplies the coincidence factor for the respective number of units by the maximum power. This procedure is carried out for each branch and each load type. A sensitivity analysis is used to determine which loads have an impact on a specific branch flow. Therefore, the Low Voltage Load Flow can be used in both radial and meshed networks.

The results of the Low Voltage Load Flow have been compared with the peak load of a time series calculation (benchmark). This study has shown that the results of the Low Voltage Load Flow are very close to the benchmark. Thus, the Low Voltage Load Flow enables the calculation of realistic maximum loadings of branch elements such as lines and transformers, and minimum and maximum voltages at all nodes in a network, based on as little input data as possible.

+ Realistic results without a time domain calculation; time characteristics not required
- Coincidence curves are required

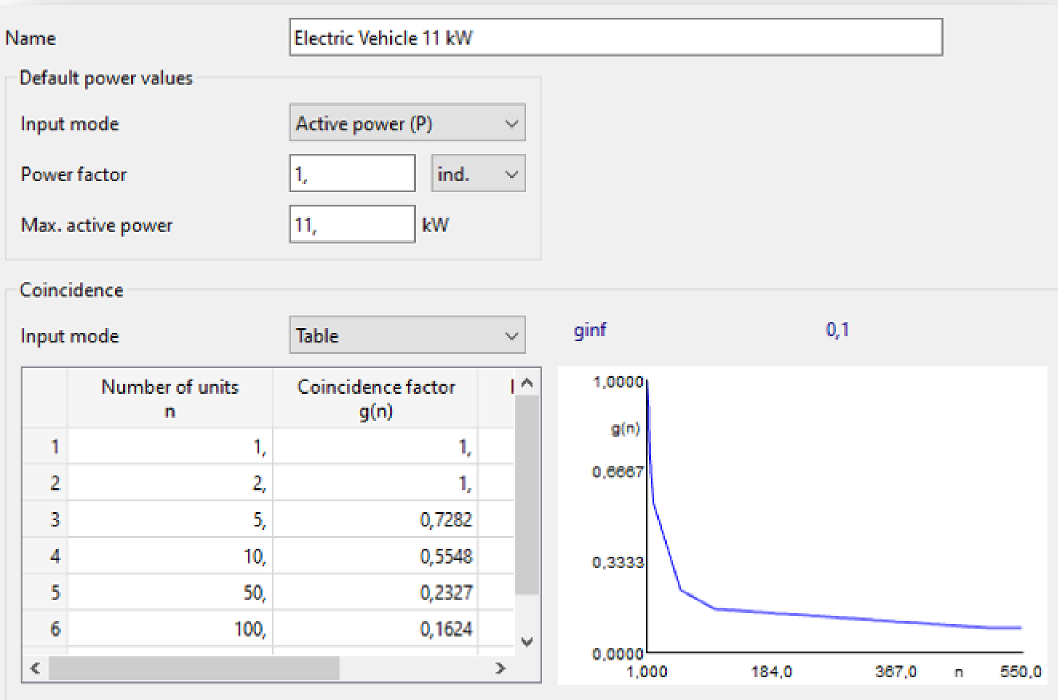


Figure 2: Coincidence Curves

Probabilistic Analysis

The Probabilistic Analysis allows network assessment based on probabilistic input data rather than assessment of individual operation scenarios or time series analysis.

In the context of low voltage network analysis, the Probabilistic Analysis is used in conjunction with a load flow. This requires a distribution function for the input data i.e. load and generation. The distributions can be created either based on a standard distribution, e.g. Weibull distribution, or from existing characteristics, e.g. active power load characteristics.

The Probabilistic Analysis produces stochastic results, i.e. each result quantity will no longer be a fixed number but a distribution from which statistic quantities (e.g. mean values and maximum values) can be derived. Therefore, it is possible to determine the probability that a certain event will occur, e.g. that a certain line will be overloaded.

+ Stochastic results offer a more comprehensive understanding of the state of the network than single load flow calculations

- Distribution functions of loads and generation required; long calculation times; post-processing of results required

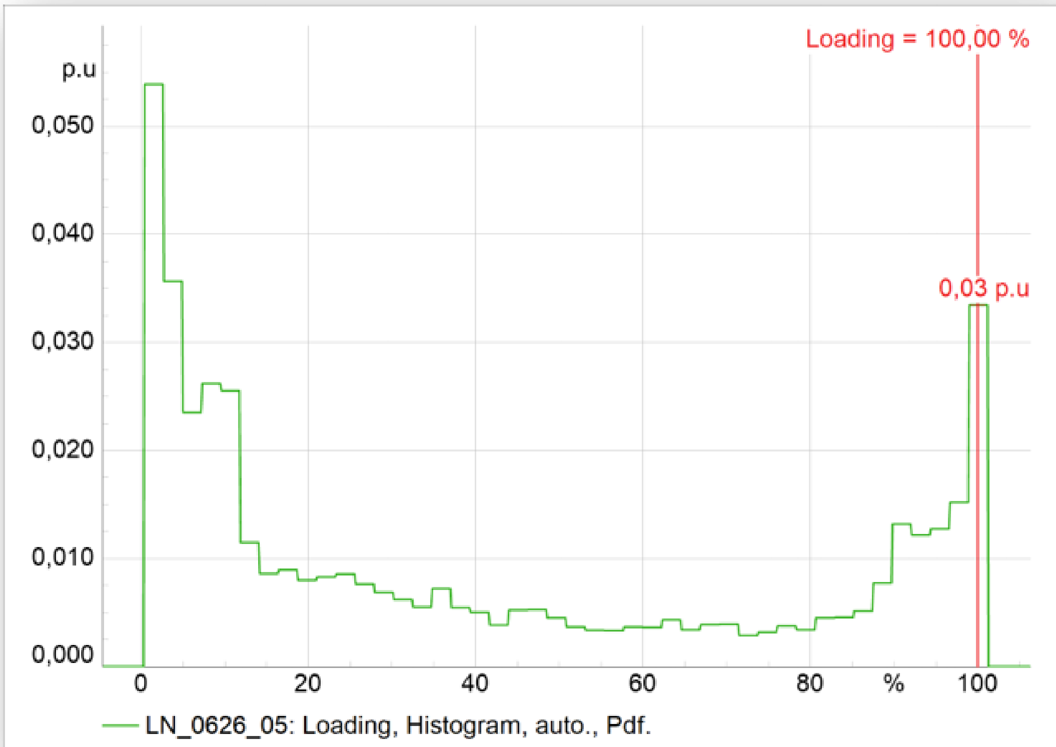


Figure 3: Probabilistic Analysis - Histogram of Line Loading

Load Scaling

In this method, the maximum measured power of the low voltage network or the feeder (usually measured by a maximum demand indicator at the MV/LV transformer) is distributed among the loads either according to the yearly energy consumption or the connection capacity.

The results are more realistic than the Worst-Case Scenario. In some cases, however, the voltage deviations, especially at the end of feeders, and the loading are underestimated.

The addition of new load elements is problematic with this method because values for the yearly energy of the new loads are not known and the existing value of the maximum demand indicator cannot be used because it was measured without the new loads. Furthermore, generation units are not considered. Therefore, this method is not recommended if there are any generation units in the network.

- \+ Results are less conservative and more realistic than the Worst-Case Scenario
- \- In some cases, thermal loading and voltage deviations are underestimated; maximum power of the low voltage network and the yearly energy consumption of each consumer need to be known; generation units are not considered

2 Executive Summary

Using the various tools available in *PowerFactory*, a range of different approaches to the analysis of low voltage networks is possible. The user can select the appropriate methods and tools according to the availability of input data, time constraints and the type of output that is required.

3 Licence Configuration

Depending on the methods to be used, additional licence modules are required:

- ✓ Distribution Network Tools (for Low Voltage Load Flow)
- ✓ Probabilistic Analysis
- ✓ Quasi-Dynamic Simulation (for Time Series Analysis)

The methods *Worst-Case Scenario Load Flow* and *Load Scaling* can be conducted with the *Base Package* without additional modules.

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