THE POTENTIAL OF USING GENERATED TIME SERIES IN THE DISTRIBUTION GRID PLANNING PROCESS

Jan KAYS
TU Dortmund University – Germany
jan.kays@tu-dortmund.de

André SEACK
TU Dortmund University – Germany
andre.seack@tu-dortmund.de

Ulf HÄGER
TU Dortmund University – Germany
ulf.haeger@tu-dortmund.de

ABSTRACT

The conventional distribution grid planning process has difficulties to consider innovative operational concepts and grid users adequately. Thus, new planning methods are necessary for a future-oriented planning and operation of distribution grids. The utilisation of time series is a recommendation to take into account dependencies.

In this paper, a multi-agent system is utilised, which generates time series for distribution grids, considering innovative grid users and control concepts. The arising potential by using the time series is outlined and evaluated on the basis of an exemplary test system.

INTRODUCTION

The requirements concerning the distribution grid planning have become more challenging in recent years. While the development of the load growth has been the most relevant uncertainty in the past, the distribution system operators (DSO) have to face several new aspects when planning a distribution grid. Besides the increasing amount of distributed generation units on the basis of renewable energy sources, new loads, that can be controllable and intelligent, influence the loading situation in the grids. Although both aspects may raise the necessity of grid extension, the DSOs are requested by the regulatory agencies to operate and plan demand-oriented and efficient grids. Additionally, the decreasing acceptance in the population for grid extensions like new overhead lines forces the DSOs to evaluate the determined grid extensions necessities thoroughly.

However, the conventional and still practised planning process has its difficulties in finding an efficient solution to face the present challenges in the distribution grids. The consideration of extreme scenarios to evaluate the grid performance has some significant disadvantages. Being very dependent on this assumption, the generation of appropriate input parameters for the occurring extreme scenarios is already a challenging task. Moreover, the information about probabilities of occurrence for certain loading situations are usually not considered in the planning process. With an increasing amount of storage systems and demand-side management systems in the distribution grid, the complexity of the performance evaluation raises and demands for the consideration of the dependencies amongst the grid users and their environment.

Consequently, the planning process requires a new method to include the intelligence and dependencies of the grid users [1]. Actually, the applied input parameters within the planning process and planning optimisation tools have to be improved. Therefore, a new simulation environment on the basis of the concept of multi-agent systems has been developed at the TU Dortmund University. The system's objective is the generation of realistic time series of the grid users' behaviours as well as the occurring loading situations in the distribution grid. Within the system, every grid user is represented by an agent on its own, guaranteeing a high level of detail for the characteristic of individual grid users. Especially the dependencies of the grid users on environmental parameters (e.g. weather data or market price) as well as interdependencies amongst them can be respected with this modelling approach. The step-wise simulation within a given time period results in time series for all relevant input parameters in the distribution grid planning process. The resulting potential of these generated time series is presented in this paper and demonstrated for a given supply task. A variation of scenarios, which takes into account different innovative controlling algorithms of grid users, is analysed subsequently. With the analysis of the realistic time series of nodal voltages and asset loadings, the impact of upcoming grid users (storage systems, electric vehicles) and control algorithms on the loading is evaluable holistically. Therefore, alternatives to conventional grid extension measures can be valued economically and the DSO benefits from an improved knowledge of the time variant grid loading.

The paper is structured as follows. At first, the conventional distribution grid planning is analysed. Then, the developed multi-agent system is briefly introduced to demonstrate the available simulation possibilities. On the basis of a defined supply task, the resulting loading situations in the test case are outlined and evaluated. The paper closes with a conclusion.

CONVENTIONAL DISTRIBUTION GRID PLANNING

In the past, the distribution grids had to supply the customers with electric power. The customers themselves had behaviours, which were rather simple to forecast. The most relevant uncertainty for the DSO has been an adequate estimation of the load growth over the years. Besides this, the financial and operational effort for a complete monitoring has been too high. Therefore, the distribution grids have rather simple topologies in comparison to transmission grids. This has also an impact on the planning of distribution grids. With the medium and low voltage grids being hardly monitored, measured values are rare, wherefore the DSO assume defined extreme scenarios. They are the basis for dimensioning the grids in the planning process. With the increased amount of distributed generation units (DGU) in the distribution grids, two extreme situations are typically considered in today's distribution grid planning. These situations are assumed to cover all occurring loading situations in the distribution grid. The reconciled situations in the medium (MV) and low voltage (LV) grids of the dena distribution grid study [2] are given in Table 1. One situation, the peak-load situation, represents the conventional loading situation with maximum load and no renewable feed-in. The feed-in situation, which causes the severe problems in the recent past, defines a situation with maximum feed-in and the minimum occurring load.

Table 1 - Assumed situations in distribution grid planning [2]

	Peak-load situation	Feed-in situation
Load	100%	10 % (LV) 15 % (MV)
Renewable feed-in		
• Wind power	0 %	100 %
• Photovoltaic	0 %	85 %

The defined situations can easily be analysed in standard network analysis software. Additionally, the scenarios cover all loading situations that occur in reality. However, the probability of occurrence of these situations is unknown, yet these scenarios may never appear in this constellation. This implies that grids, planned on the basis of extreme scenarios are not optimally adapted to the reality. Indeed, grids with a high amount of DGU tend to be overdimensioned when planned with extreme scenarios [3].

There have been many different approaches in the past to optimise the planning of distribution grids. A brief but detailed overview of algorithms and approaches is given in [4] and [5]. However, most of the methods aim to optimise the timing and positioning of assets in a grid, considering extreme scenarios. Besides the consideration of the probability of occurrence of certain loading situations, this conventional distribution grid planning has difficulties to take into account dependencies amongst the grid users and their environment. As a consequence, new and innovative measures like demand side management or other active grid users cannot be analysed and integrated in the traditional distribution grid planning. This is yet required for the satisfactory realisation of active distribution systems as proposed in [1].

The utilisation of time series for the determination of the occurring loading situations in the distribution grid is a proposal in [1]. In this context, an adequate representation of the new active grid users is necessary for the analysis of their influence on the system. Anyhow, up to now, time series, especially with consideration of interdependencies, are rarely utilised in the planning process.

AGENT-BASED SIMULATION ENVIRONMENT

The required time series that include interactions of the users and dependencies of external parameters are generated with a developed multi-agent simulation environment. This system is briefly explained in this section on the basis of [6].

Within the developed system, every grid user is represented by an agent, which is an autonomous piece of software, keeping individual properties and characteristics of the grid user. All relevant external environmental information, which influences the behaviour of any grid user, is also provided by dedicated service agents. This includes for example the market price or the local weather. Additionally, the grid and thus possible control structures coordinated by the DSO are also represented by an agent to integrate control methods and algorithms into the system. At the current state of the simulation environment, the following elements are available for being simulated in distribution systems:

- Electric loads (domestic, heat pumps, industry)
- Distributed generation units (photovoltaic, wind energy and bio mass units)
- Innovative grid users like electric vehicles
- Storage systems
- Controllable transformer as well as other control strategies

Because of every element being represented by one agent, the elements can be individually parameterised. Besides the assignment of device dependent parameter, different objective function for the assumed behaviour can be given to the agents. For example, the objective functions of storage systems could be either grid-friendly, self-consumption-oriented or market-oriented, resulting in a different impact on the grid loading situation [6].

The interaction of all agents is simulated for every time step in a given time interval. The general process, which is principally similar in every time step, is depicted in Figure 1. The chosen modular construction of the system allows for interaction on different levels in the simulation to pattern the real interaction as good as possible. After the allocation of global services, the agents that represent grid users determine their behaviours. Devices like storage systems are able to interact on a nodal level for the attainment of their objective functions. If DGU or storage systems have implemented voltage control algorithms or power flow control mechanisms, their agents react on the grid agent's calculation results. So, negotiations and control algorithms are also feasible on a grid level. Principally possible, the resulting power balance in the analysed grid can influence the market price for electric energy in the market agent. This influence causes a new determination of the nodal elements' behaviour, etc. Therefore, depending on the implementation, the feedback to the market agent can lead to a negotiation of the market price between the market agent on a global level and the consumers and producers on a nodal level.

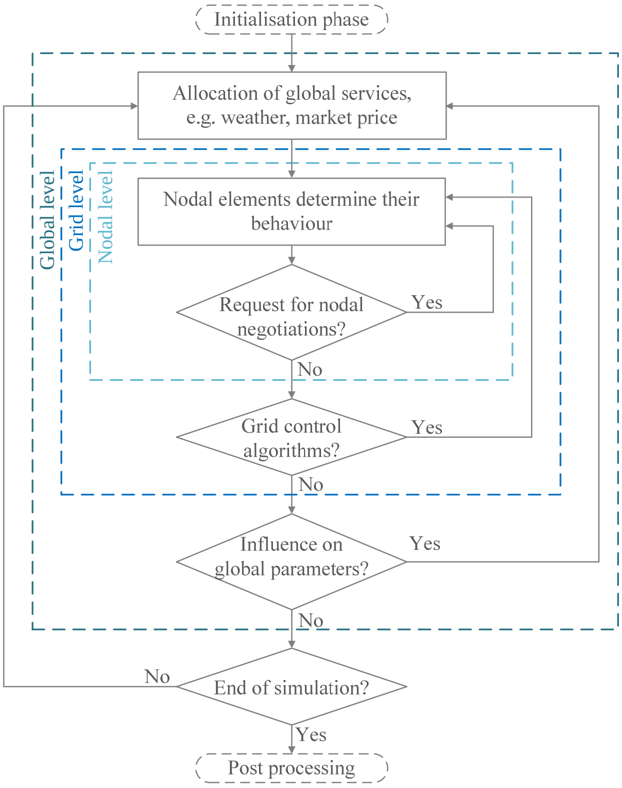

Figure 1 - General concept of the simulation environment

For the first time, the chosen simulation system design allows for a maximum of flexibility in the implementation of negotiations, control algorithms and dependencies of the grid users within and between the different identified levels. The utilisation of the simulation results, time series for all relevant parameter, in the planning process enables the determination of relevant loading situations in dependency of the assumed interactions between the grid users. Additionally, the simulation results can be aggregated and applied in the analysis of higher voltage levels. As a consequence of the modular construction of the system and its elements, any level of detail can be analysed in the post processing of the simulation. The significance of the results is only influenced by the modelling approach of the elements. Consequently, for example, if the relevant data is available, the residential loads can be further decomposed to single domestic loads like washing machines, which can still negotiate the price for electric energy with the market agent on the global level.

DEFINITION OF A SUPPLY TASK

The potential of the generated time series of the agent-based simulation environment is demonstrated in a low voltage test grid in comparison to the conventional analysis of the distribution grid. The grid and the defined scenarios of the supply task are outlined in the following.
The applied model grid is a German rural low voltage grid, with an already high installed capacity of photovoltaic (PV) units in the *initial scenario*. The four feeders (F1-F4) differ in length and type (two different cable types and an overhead line). The *future scenario* includes the additional installation of several new PV units. The grid is illustrated in Figure 2.

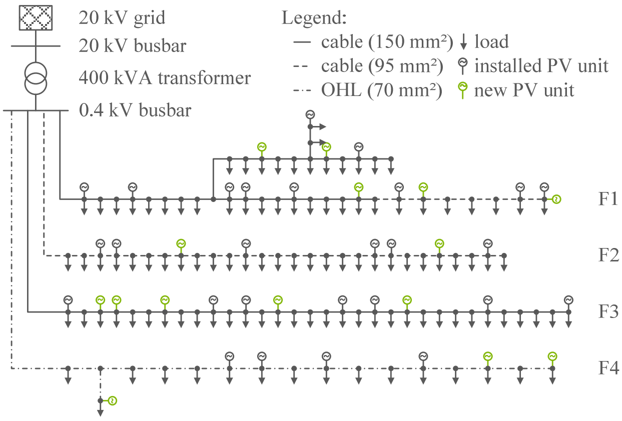

Figure 2 - Simulated low voltage test grid

The performance of the test grid will be analysed for the *initial* and the *future scenario* with the agent-based simulation system. Additionally, the following different supply tasks in the future scenario are introduced and evaluated in the next section:

- Assuming that 10 % of all households own an electric vehicle (EV), additional EVs are connected to the grid. (*EV scenario*)
- Every PV unit gets a battery storage system, which follows different target functions:
  - Grid-friendly behaviour (*BSS-G scenario*)
  - Self-consumption optimisation (*BSS-S scenario*)
  - Market-oriented behaviour (*BSS-M scenario*)

These defined supply tasks are examples for the possible supply task variations that can be considered in the agent-based simulation environment. Furthermore, principally all assumptions are also combinable.

ANALYSIS OF THE SIMULATION RESULTS

To start with, the performance of the test grid is analysed with the conventional planning with extreme scenarios. These are taken from Table 1. Based on [2], the allowed limit for asset loading is 100 % of the rated appearing power and the maximum voltage deviation from the nominal voltage U_N is ±6 %. If any necessity for grid reinforcements occurs, like overloading of assets or nodal voltage interval violations, the assumed measures are also taken from [2].

Because of the grid being designed in the past for the peak-load situation without any limit violations, only the performance of the feed-in situation is documented. Table 2 reveals that no problems occur in the *initial scenario*. However, in the *future scenario* the transformer is overloaded and the highest appearing nodal voltage exceeds the allowed upper limit significantly.

Table 2 - Result summary for the conventional grid analysis

	initial scenario	*future scenario*
transformer loading	62 %	115 %
max. line loading	40 %	82 %
highest nodal voltage	1.05 pu	1.09 pu
number of nodes with U > 1.06 pu	-	22
lowest nodal voltage	0.99 pu	0.99 pu

Therefore, the local transformer has to be upgraded and all four feeders have to be reinforced. Considering the given investment costs in [2], the transformer upgrade results in 10,000 €, the necessary 1,450 m of new 150 mm² cable results in 87,000 €. The determined necessary investment sums up to 97,000 € due to the conventional approach.

Results of the multi agent system

The results of the agent-based simulation environment are time series for all parameters that are relevant for the evaluation of the grid performance. The simulation is performed for the time period from 1st January 2011 to 31st December 2011, covering all 8760 h of the year. The resulting line loading for the first segment of the feeder F3 in the *initial* and *future scenario* is depicted in Figure 3.

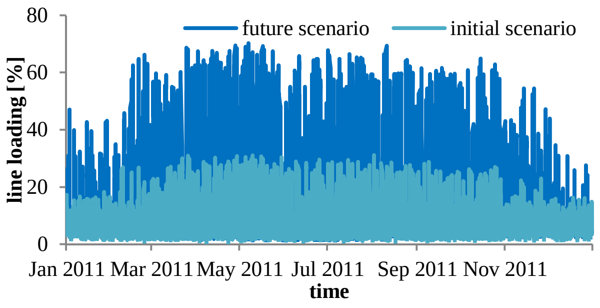

Figure 3 - Loading time series of the first segment of F3 in the scenarios

However, it remains difficult to analyse the generated time series holistically. Therefore, those are sorted to duration curves that facilitate the determination of impermissible loading situations and nodal voltages. Some assets like transformers allow for an overloading within a certain period without shortening the asset's life-time, if no extreme thermal situations occur as well as sufficient time for cooling is available subsequently. This aspect can also be considered in the analysis of the time series in duration curves, by using average loading values of several simulation time steps. The duration curves of the local transformer loading in the scenarios for different regarded time-periods are given in Figure 4. Additionally, the determined loading of the transformer in the extreme scenario based evaluation is drawn.

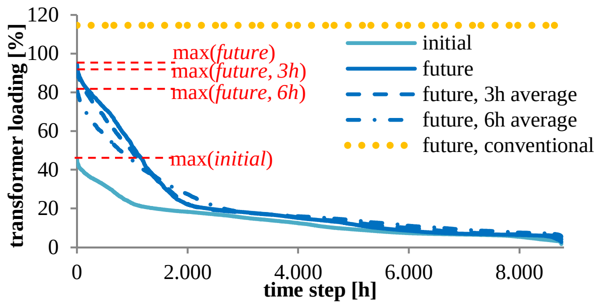

Figure 4 - Transformer loading duration curves for the scenarios

Processing the time series to histograms and the consequential cumulative distribution functions is especially supportive in the analysis of the appearing nodal voltages. The distribution of the nodal voltage of the last node in feeder F4 is given in Figure 5. The curve progression of the cumulative distribution function in the *future scenario* reveals a reinforcement necessity in feeder F4. Nevertheless, this reinforcement is the only determined measure in the grid on the basis of the time series. The required additional cable with a length of 360 m induces investments of 21,600 €, which is about a 77 % cost benefit in comparison to the extreme-scenario based grid evaluation of the *future scenario*.

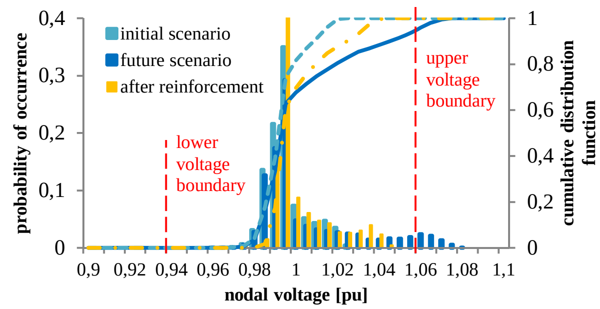

Figure 5 - Histogram and distribution function of the nodal voltage at the last node of F4

The impact of the electric vehicles and the battery storage systems with different objective functions on the nodal voltage in feeder F4 in the further scenarios is depicted in Figure 6. Obviously, the different assumptions of the scenarios have an influence on the distribution of appearing nodal voltages at the node. In comparison to the future scenario, the additional EV or the self-consumption oriented battery storage systems do not lower the maximum appearing voltage at the node. Just as these scenarios (*EV* and *BSS-S scenario*), the *BSS-G scenario* keeps the necessity for the feeder reinforcement. In contrast, the *BSS-M scenario* with the market-oriented behaving storage systems deteriorates the situation in the grid. The assumed behaviour of the storage systems superimposes already challenging loading situations and results in violations of the upper as well as the lower voltage boundary. Anyway, the DSO is able to analyse the probability of occurrence of these situations with the generated time series. The resulting variation of the maximum transformer loading is listed in Table 3. Except for the BSS-M scenario, the transformer loading is always below the maximum allowed loading in the simulations with the multi agent system (MAS). In contrast, the transformer loading in the conventionally analysed *future scenario* exceeds the permitted maximum loading.

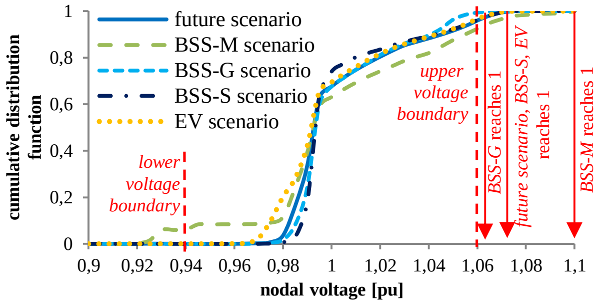

Figure 6 - Cumulative distribution functions of the voltage at the last node in F4

Table 3 - Comparison of the maximum transformer loading

	Transformer loading
future scenario (conventional)	115 %
MAS *future scenario*	94 %
MAS *future scenario*, 3 h average	92 %
MAS *future scenario*, 6 h average	81 %
MAS *EV scenario*	93 %
MAS *BSS-M scenario*	135 %
MAS *BSS-S scenario*	94 %
MAS *BSS-G scenario*	87 %

Analysing the different scenarios with varying complexity and rate of interaction enables the DSO to determine a realistic setting of input parameters for further steps in the distribution grid planning. The time series allow for a realistic consideration of the innovative grid users and existing time-dependencies for e.g. storage systems that are hardly to be taken into account in the analysis of two extreme scenarios in the conventional distribution grid planning.

CONCLUSION

The increasing amount of volatile renewable energy sources, intelligent loads or innovative control algorithms requires an adaption of the traditional distribution grid planning process. Up to now, the grids are mainly planned on assumed extreme scenarios, which can neither consider the volatile characteristics of the DGU nor time dependencies and interdependencies between the grid users. However, the often discussed interactions of active distribution systems have to be respected in the distribution grid planning process, too [1], to determine their impact on the grid.

Therefore, the developed simulation environment on the basis of a multi agent system faces these challenges by generating realistic time series of the most probable grid user behaviours, taking into account existing interdependencies. With these time series, the DSO is enabled to conclude the rising challenges, if many new devices in the grid appear. Additionally, the DSO can detect the probability of occurrence for certain critical situations. In dependency of the frequency, alternative innovative measures can be economically evaluated in comparison to traditional grid reinforcement measures. The more detailed analysis of grid regions might also allow for a reduction in the determined reinforcement necessity. A holistic evaluation and comparison of the time series results to the extreme scenario based results might be also taken for an adaption of the established planning guidelines. With a better knowledge of the occurring loading situations, the up to now necessary operational reserve can be reduced.

In any case, the time series that are generated by the developed multi agent simulation environment support the development of an efficient and future-oriented distribution grid planning, which is more adapted to the expected supply tasks.

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