DETERMINATION OF RELEVANT NETWORK PLANNING CASES

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ABSTRACT

Despite rising challenges in distribution system planning, caused by the rising share of distributed renewable energy sources and new possibilities due to innovative network operating equipment and concepts, the methods to determine network planning cases (NPC) have hardly been adjusted. Still based on simplified planning rules, which are independent of the examined grid, worst case NPC are derived by the network planner. However, changing simultaneities between customers and the necessity to assess new planning degrees of freedom require a reconsidering of the classic approach.

This paper proposes a method to determine relevant NPC based on time series for customer behaviour that are derived from synthetic time series modelling due to lack of comprehensive measurements at distribution level. Relevant planning cases are categorized dependent on their application in dimensioning NPC and representative NPC. The results show that still a small number of NPC is sufficient in network planning, but that the grid type influences the determination.

MOTIVATION

The rising share of distributed renewable energy sources (DRES) often leads to grid extension measures. To decide which measures are necessary so called network planning cases (NPC) are used in network planning, estimating the expected network loading. Traditionally two worst cases are used in planning medium and low voltage grids – a high generation and a high load case. The assumptions modelling these cases are based on known simultaneities of producers and consumers, derived from experiences of the network planner.

With new consumers, for example e-mobility, heat pumps and electric storages, and a further rise of DRES these formally known simultaneities change, causing a higher difficulty to estimate the dimensioning network cases. Studies have shown that the determination of the NPC can have a big influence on the network costs, therefore an accurate estimation is important [1].

Additionally, new grid operating equipment such as the On-Load-Tap-Changer (OLTC) or the Static Synchronous Compensator (STATCOM) and new grid operation concepts such as feed-in-management or the provision of reactive power by DRES units expand the amount of degrees of freedom of the network planner and can be a cost efficient substitution of conventional network expansion [2–4]. To assess these new solutions, the consideration of worst case NPC is not sufficient. Therefore a new set of NPC, which has different requirements than the classic worst cases, is needed.

An approach to tackle this issue is the usage of time series in network planning. Different national guidelines and standards define which customers must provide measurements to the DSO. In Germany, pv producers with an installed capacity of 30kW must provide this data [5]. Consumers with an annual demand of more than 100MWh must send measured data in a ¼-h-resolution [6]. Therefore, measured time series don´t exist for most of the customers connected to distribution networks. Additionally to the missing data, the simulation and assessment of time series is linked to a significant rise of effort compared to nowadays network planning process.

Therefore, this paper presents a new approach of the determination of relevant NPC based on synthetic time series. This concept tackles the problems of non-existent customer data and bypasses the tremendous effort for time series calculation by reducing them to relevant cases.

METHOD

An overview of the implemented method is given in Figure 1.

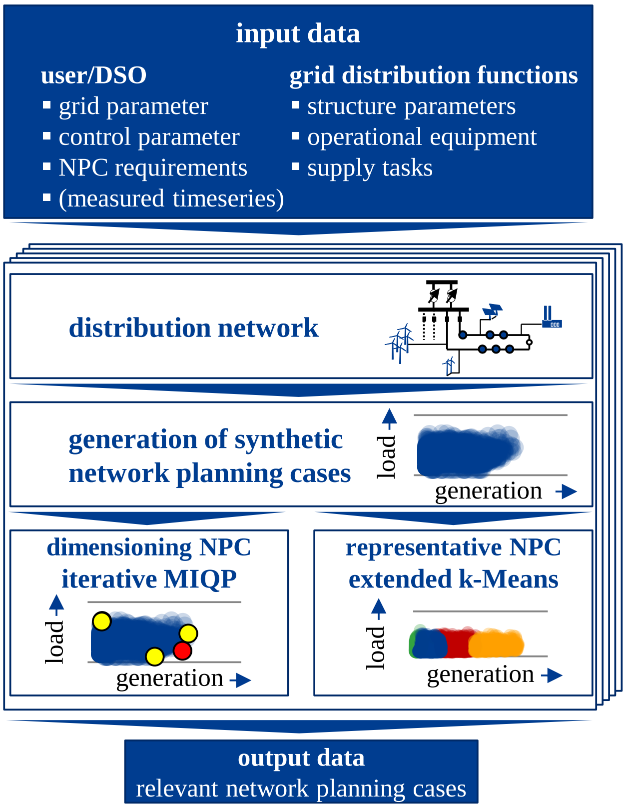


Figure 1: Overview of developed method

Distribution Network

The starting point is a model of the distribution grid, for which the relevant NPC should be determined. A real grid can function as input. The grid model must provide network operating equipment parameters, such as lines and transformers, but also information about the connected customers.
In addition to the application of the method on real networks a distribution network generator (based on [7]) was developed to derive general conclusions for the determination of NPC. This generator uses distribution functions for supply task, grid structure or electric parameters to model the varying heterogeneous German distribution grids.

Synthetic NPC generation

As next step, synthetic time series, modelling the network loading in a precise manner by considering dependencies between customers and their demand and generation, are created. This step is based on the analysis of real time series, composed of measurements of wind and pv power plants, households and commerce, trade, services and industry customers. Stochastic interdependencies (linear and non-linear) were derived and used to model realistic time series for all customers connected to the distribution system. The result is a time series, modelling the NPC in an 8760-h-pattern.

Determination of relevant NPC

Because the simulation of time series for electrical networks is linked to high effort for calculation and interpretation of results, these time series are reduced to relevant NPC. These are categorized in two different sets: "Dimensioning NPC", used for the design and rating of the grid, and "Representative NPC", used for the calculation of annual curtailed energy or losses. Figure 2 shows the difference between these categories.

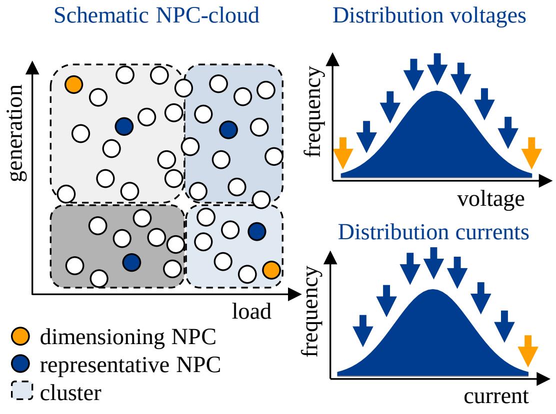


Figure 2: Categorization of relevant NPC

It can be seen, that the dimensioning NPC can be found at the edge of the NPC-cloud and therefore result in the highest network loading with the highest currents and the maximum or minimum voltages. In contrast, the representative NPC are a cross section of the whole time series, representing various network states.
This leads to different requirements for the NPC, which results in different methods for the derivation. The two methods are described in the following.

Determination of Dimensioning NPC

To derive the NPC with the maximum network loading, used for the dimensioning of the grid, first an estimation of the whole time series is performed. Using a simplified load-flow-calculation, based on a forward-backward-sweep ([8]) and on linear sensitivities, expressing the influence of a customer on the lines, for each line the maximum occurring current and for each node the maximum and minimum voltage is estimated. These limits form the constraints of an optimization problem, which is set up guaranteeing that the highest network loadings, caused by the time series, are also reached by the small number of dimensioning planning cases.
The degrees of freedom are the number and parametrization of dimensioning synthetic NPC, which are composed of the feed-in and demand of the connected customers. Synthetic in this context means, that the NPC aren't selected from the time series, but rather can be composed of demand and feed-in of each customer between their minimum and maximum power. The objective function of the implemented algorithm guarantees that the difference between the maximum network loading (limits for each line and node) of the simulation of the time series and simulation of the determined dimensioning NPC is as small as possible. For a detailed explanation of the formulation of the optimization problem see [9].
By solving the described formulation the time series is reduced to a predefined number of NPC. Constraints and objective function are formulated based on the aforementioned linear sensitivities to be able to use exact procedures instead of heuristic ones. Iterative mixed integer quadratic programming (MIQP) is used for solving, which means that the problem is solved repetitively and after each solving of the optimization problem the linear sensitivities are updated based on the voltages calculated with the found solution.

Determination of Representative NPC

The requirements for the representative NPC are different than the ones described for the dimensioning NPC. For these, similarity structures in the time series must be identified to group the NPC in clusters which lead to similar network states. A lot of so called cluster algorithms exist in literature [10, 11]. Based on some test clustering the k-Means algorithm, an iterative, partitioning algorithm was applied and extended for this research issue.
The drawback of the standard algorithm is the negligence of grid parameters in the clustering and the assumption, that each NPC should be represented with the same quality, independent of his contribution to the time-related values, such as annual losses or feed-in-

management. Therefore three modifications were implemented:

1. A distance metric considering the grid structure
2. Additional parameters to enforce heterogeneous cluster quality
3. Optimization of cluster representatives after completion of the clustering

By using these modifications the time series can be reduced to a small amount of representative NPC, significantly lowering the effort for a simulation of the time series and the assessment of time dependent values such as losses or feed-in-management.

RESULTS

With the distribution grid generator, three different grids were created to demonstrate the proposed method and quantify the influence of the grid type on the determination of relevant NPC. The three examined networks were:

1. rural PV and household-dominated grid
2. rural Wind-dominated grid
3. urban commerce, trade and service dominated grid

First, the developed time series model was applied to generate synthetic NPC in an 8760-h-resolution for each customer. These NPC-clouds, aggregated for generation and load in the entire grid, can be seen in Figure 3.
The results show, that depending on the customers connected to the grid different shapes of NPC-clouds appear. This can be explained by different generation and load profiles of the customers, but also by the varying interdependencies and simultaneities between the customers.
In the next step, the dimensioning NPC were derived using the developed iterative MIQP. These can be seen as pale blue circles. To compare these with the classic approach of using general NPC, the NPC using classic assumptions (based on [3]) are marked as black circles. It can be seen, that the derived dimensioning NPC appear closer to the cloud than the NPC derived by the classic approach. This could be an indicator that the classic worst cases overestimate network loading and could lead to an oversized network. Inversely this also means, that general, identical assumptions for all kinds of grids are not appropriate, moreover it is necessary to consider the type of grid and connected customers. In the examined networks, two NPC were sufficient to represent the time series in an appropriate way. Further simulations point out, that dependent on grid structure three NPC could be necessary to accurately represent the time series.

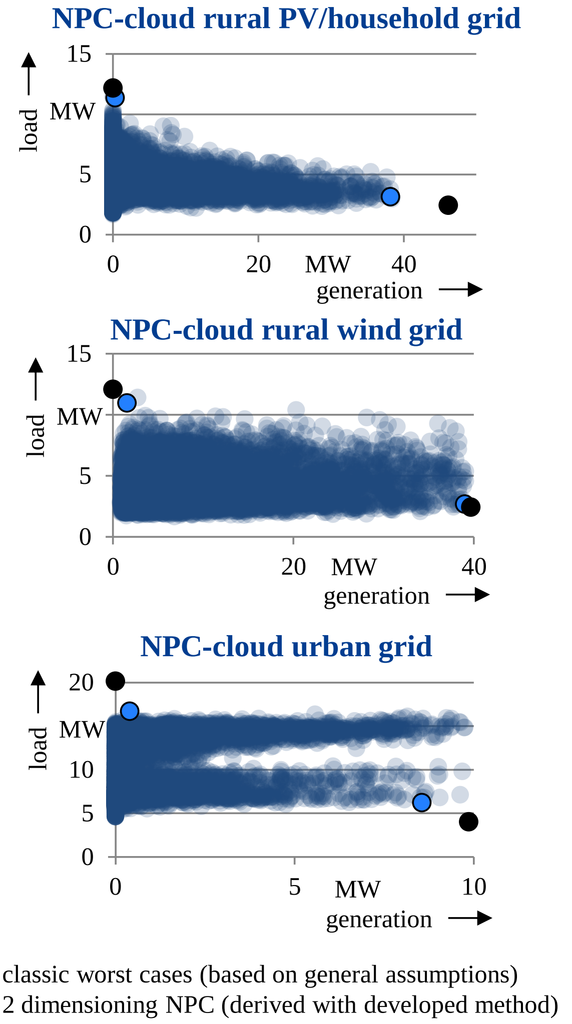
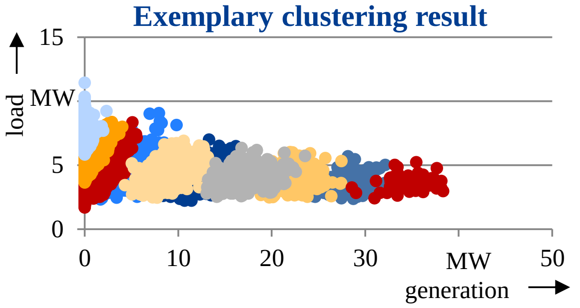


Figure 3: Results of NPC generation and determination of dimensioning NPC

To determinate the representative NPC, the extended k-Means-algorithm was deployed on the three grids. The results can be seen in Figure 4. In the upper figure, an exemplary clustering result is shown, displaying the different assigned clusters when reducing the time series to ten representatives. It is evident that cluster cuttings strive to proceed in lines with similar residual loads, which leads to NPC resulting in similar network loadings grouped together. This is a direct result of the newly developed distance metric.
The reduction to a varying number of representatives and the accuracy of this reduction can be seen in the lower chart of Figure 4. To assess the quality of the clustering yearly network losses and necessary feed-in-management to stay in the network boundaries were calculated based on the derived representatives and compared to the values calculated with the whole time series. As can be seen with 30 representatives the deviations of the values in all grids are under 3%, which can be referred to as a precise estimation.
It can also be determined that the grid type influences the

number of representatives needed – in the urban network, consisting of not so volatile customers, a lower number is sufficient than in the rural networks with highly volatile customers. This leads to the conclusion that the type of network influences the sufficient amount of representatives.



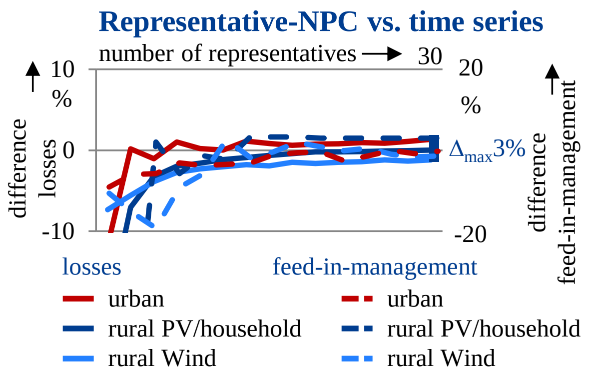


Figure 4: Results of determination of representative NPC

CONCLUSIONS

The two developed methods to reduce the time series to a few relevant NPC, categorized in dimensioning NPC and representative NPC, can help reduce the calculation and assessment effort of a time series. The exemplary application on three different networks shows that

1. the time series can be reduced up to two or three NPC for the dimensioning of the grid.
2. roughly 30 NPC for the calculation of annual values such as losses or feed-in-management are needed.
3. grid type and connected customers influence the determination of relevant NPC.

These scientific findings show that a modification of the classic approach in distribution grid planning of selecting a few worst cases based on identical assumptions for all networks should be modified. The proposed approach presents a model to tackle this issue, in addition the absence of sufficient real time measurements are circumvented by introducing a procedure to generate synthetic NPC considering dependencies between customers.

In further research it is planned to derive practicable simple planning rules for the determination of NPC based on the detailed method proposed in this paper. The developed procedure to generate synthetic distribution networks enables the derivation of robust rules, suitable for different grid structures, parameters and supply tasks.

REFERENCES

[1] S. Patzack, N. Erle, H. Vennegeerts, A. Moser, 2016, “Einfluss von auslegungsrelevanten Netznutzungsfällen auf die Netzdimensionierung”, 14. Symposium Graz

[2] Deutsche Energie-Agentur GmbH (dena), 2012, “dena-Verteilnetzstudie: Ausbau- und Innovationsbedarf der Stromverteilnetze in Deutschland bis 2030”

[3] E-Bridge, IAEW, OFFIS, 2014, “Moderne Verteilernetze für Deutschland: Verteilernetzstudie”

[4] Stawag et. al., 2016, “smart area aachen - Fachbericht: Innovative Lösungen und Betriebsmittel für das Verteilnetz der Zukunft”

[5] Deutscher Bundestag, 2016, "Gesetz für den Ausbau erneuerbarer Energien: Erneuerbare Energien Gesetz - EEG 2017"

[6] Deutscher Bundestag, 2016, "Verordnung über den Zugang zu Elektrizitätsversorgungsnetzen: Stromnetzzugangsverordnung - StromNZV"

[7] M. Jäkel et al., 2015, “Modular Probabilistic Approach for Modeling Distribution Grids and its Application”, International ETG-Congress 2015

[8] G. W. Chang, S. Y. Chu, and H. L. Wang, 201 07, “An Improved Backward/Forward Sweep Load Flow Algorithm for Radial Distribution Systems”, IEEE Trans. Power Syst., vol. 22, no. 2, pp. 882–884

[9] RWTH, FGH, INPG, 2015, “evolvDSO - Development of methodologies and tools for new and evolving DSO roles for efficient DRES integration in distribution networks: Deliverable 3.1”

[10] M. Ester, H.-P. Kriegel, J. Sander, and X. Xu, 1996, “A Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noises”, 2nd International Conference on Knowledge Discovery and Data Mining

[11] T. Hastie, R. Tibshirani, and J. H. Friedman, 2009, "The elements of statistical learning: Data mining, inference, and prediction”