EXTENDED MODELLING OF ELECTRICAL LOADS FOR DISTRIBUTION NETWORKS FOR AN INCREASED USE OF EXISTING RESOURCES WITH REGARD TO A DEREGULATED ENERGY MARKET

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INTRODUCTION

Due to the forthcoming liberalization of the german energy market a more intensive and effective utilization of existing ressources of distribution networks has to be taken into consideration. The evaluation of retail wheeling and network system services requires manageable tools for an extended modelling of electrical loads and analysis of extensive and critical network operating conditions. This paper presents the method and principles of an integrated planning tool based on innovative scientific methods like bus load modelling and cluster analysis.

MOTIVATION

Concerning the reliable planning as well as the economical and secure operation of eletrical distribution networks the knowledge of load behaviour is of great importance. The maximum and minimum load value as well as their duration, frequency and simultaneity are necessary valuation criteria for the determination of network operating conditions. For example, these informations lead to the decision whether a new customer supply may effect merely a higher loading of existing operational equipment or entails a cost-intensive expansion of the distribution network.

The previous planning practice was characterized by the forecast certainty of the load development. Therefore electrical distribution networks were designed to be very robust and long-lasting. There was a long-term planning horizon allowing large investment steps. This safety led to a high demand on reliabilty of operational equipment and electrical networks. The technical network design was characterized by the worst-case-assessment of the maximum load distribution without regard to the duration or freqency of this condition.

The deregulated energy market leads to new planning criteria. The competition and the retail wheeling require a flexible but also robust distribution network. The uncertain load development leads to a short-term planning horizon. The reliablity of customer supply is no longer a constant value but depends on the individual customer demand. The reliablity, voltage quality, etc. are now new characteristics of the product „electrical energy".

This surrounding field leads to the introduction of new planning tools like reliabilty analysis and extended modelling of electrical loads.

Existing approaches for load modelling consider the electrical customer behaviour [1]. The ideas of this modelling have been further developed in [2] using a fuzzy approach. Other methods of load modelling use statistical algorithms ([3], [4]). The disadvantage of these methods is the large input-data based on extensive measurements as well as the difficulty to obtain consumer information.

PROCEDURE OF EXTENDED MODELLING

The „Extended modelling" of electrical loads describes the determination of load curves at the operational equipment of the network. These main load curves are a superposition of different load curves belonging to the customer groups that are connected to this operational equipment.

According to the different behaviour of the electrical customers in distribution networks the load curve modelling will be done in three steps divided into the determination of:

- Typical tariff customer load curves
- Representative special tariff customer load curves
- Temperature-dependent ripple controlled load curves.

External influences, e. g. temperature or day type, are further parameters of these models. The process of modelling yields load curves for different season and day types. Referring to [5] a divison into the four seasons as

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well as the day types „working day“, „saturday“ and „holiday/sunday“ will be done.

Principle method

The principle method of the „Extended load modelling“ is shown in figure 1. Based on the mathematical methods bus load modelling [5] and cluster analysis [6] the determination of typical load curves for tariff customer groups and normalized load curves for special tariff customers is processed. These scientific methods are described in detail below. Additionally ripple controlled loads are modelled and assigned to the substations of a distribution network. The knowledge of customer group combination of all secondary substations belonging to the same distribution network leads to the determination of the required main load curves. The summary of these load curves leads to the temporary loading of the superposed transformer substation. A cyclic load flow calculation yields information about critical conditions of all operational equipment classified by duration and frequency.

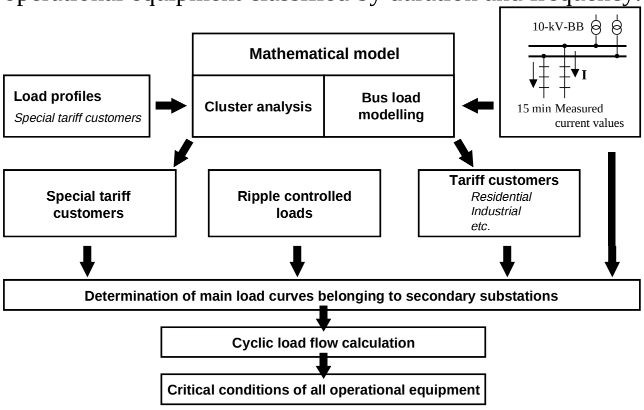


Fig. 1: Principle method of „Extended load modelling“

Bus load modelling

Due to the multitude of existing operational equipment in low voltage and middle voltage distribution networks it is not possible to detect typical load curves by continuous measurements. Instead of this procedure typical load curves (TLC) are determined by the help of a statical estimation method using selected and easily to obtain measurements.

On condition that individual consumers with similar load behaviour can be combined in special groups, typical load curves can be determined for each of these groups.

Input parameters for this determination procedure are the time-dependent active power values calculated by the measured busbar feeder currents, the annual energy consumption and the consumer group combination of all secondary substations. The last mentioned parameter is illustrated in fig. 2 using an open operated middle voltage ring network with 5 substations as example. The left line supplies 2 substations. The consumers supplied by the first substation are divided into two groups: 50% industrial consumers and 50% commercial consumers. The consumer combination of the second substation consists of 50% residential, 25% industrial and 25% commercial consumers. These informations can easily be obtained by the customer database of power supply companies.

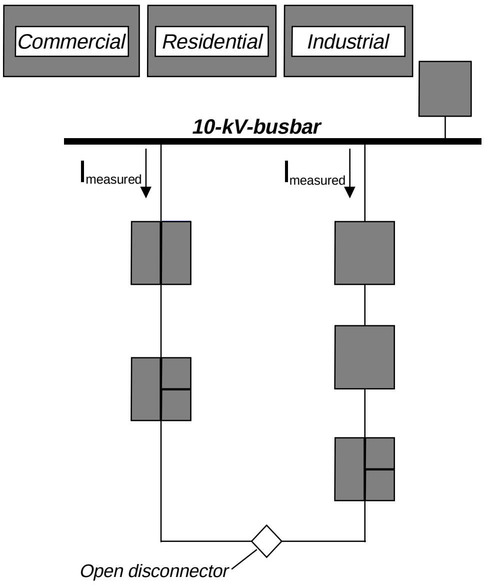


Fig. 2: Consumer group combination at different secondary substations

The mathematical model is based on a linear approach:

$$\boldsymbol{z} = \boldsymbol{H} \cdot \boldsymbol{x} + \boldsymbol{v} \qquad \text{(Eq. 1)}$$

The measured busbar feeder active power values **z** are combined with the typical load curves ***x*** of all consumer groups by a system matrix ***H*** (see also fig. 3).

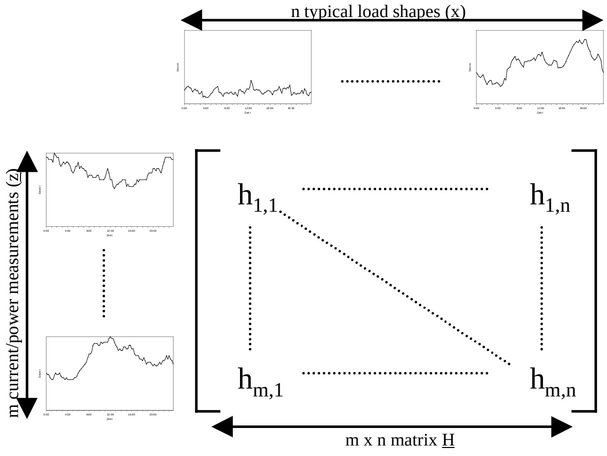


Fig. 3: Mathematical model of bus load modelling

The additional fault vector ***v*** represents measuring inaccuracies, load noise of the individual measurements as well as systematic faults of the model. The condition vector ***x*** is calculated by the help of a static estimation method which is based on the interior-point-method [7]. The elements h_{ij} of the system matrix ***H*** represent average annual power values. These characteristic values are derived form the annual energy consumption and the consumer group combination of the investigated operational equipment.

The result of this calculation method is the vector ***x*** which represents the typical load curves of the individual consumer groups. These curves are normalized to the consumer group dependent average annual power $P_{a,i}$. This characteristic value is defined as:

$$P_{a,i} = \frac{A_i}{8760\,h} \tag{Eq. 2}$$

A_i: Annual energy consumption for consumer group i

The determination of typical load curves is carried out for different season types (represented by a set of different temperature ranges) and for different day types (see above for details). Among the average load curve the standard deviation is also calculated allowing an estimation of the load model quality.

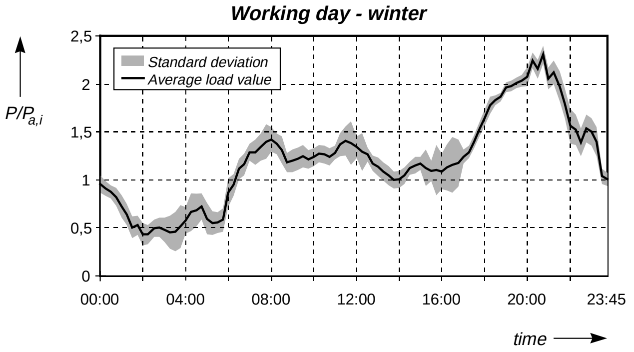


Fig. 4: Typical load curve
calculated for residential customers

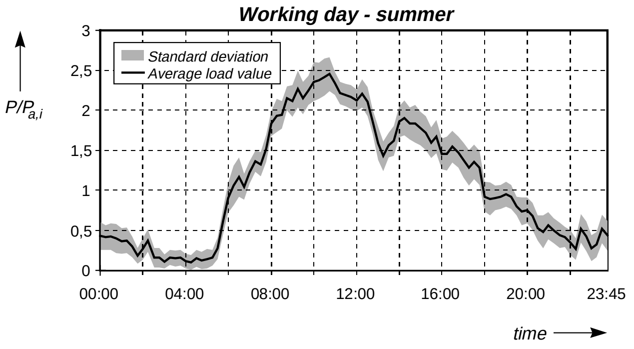


Fig. 5: Typical load curve
calculated for commercial customers

Fig. 4 and fig. 5 show calculated typical load curves for residential and commercial customers on a working day. The variation range stays within a 5-10 % band indicating a reasonable estimation.

Ripple controlled loads

Ripple controlled loads represent a special type of customer loads. The ripple control system of an utility company broadcasts high-frequent signals to all customer installations via the distribution network. These ripple-control signals cause the start and stop of fixed customer loads, e. g. electrical storage heating. The ripple control system is controlled by a special computer directly attached to the power system management. Consequently the ripple control enables possibilities for a direct load management.

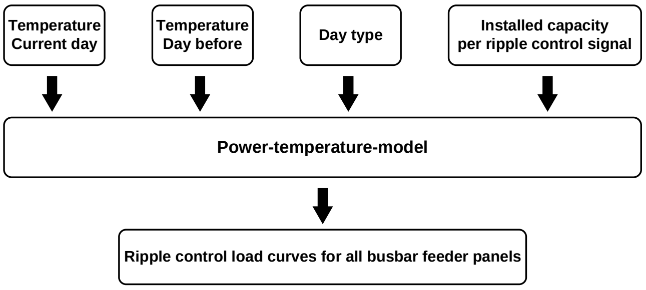


Fig. 6: Simulation model for ripple controlled customer loads

Fig. 6 presents the model for these ripple controlled customer loads. This model yields temperature-dependent load curves for all busbar feeder panels of a primary substation. Exemplary fig. 7 shows a typical set of ripple controlled load curves.

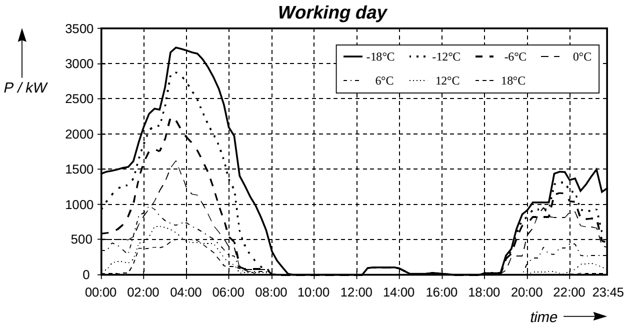


Fig. 7: Typical set of ripple controlled load curves

Cluster analysis

The determination of typical load curves for special tariff customers fails due to the non-uniform load behaviour of this consumer group. Therefore a subdivision of the special tariff customers into classes with similar load behaviour is required. To determine these classes the mathematical method of cluster analysis is introduced.

The objective of a cluster analysis is forming a data volume into a defined number of clusters in such way that the behaviour of this data is homogeneous within the cluster and heterogeneous between the clusters.

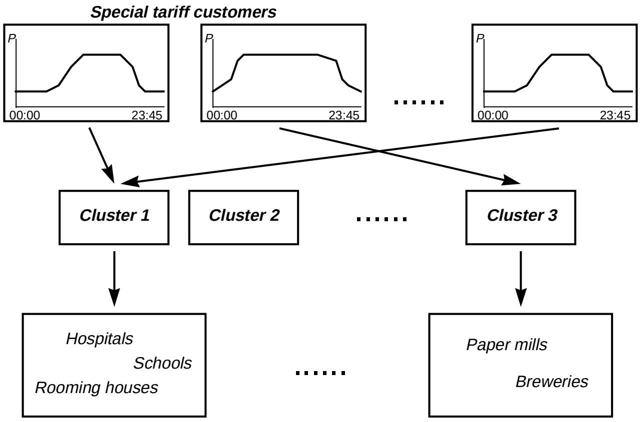


Fig. 8: Method of cluster analysis

Fig. 8 presents the method of classification in a schematic description. The measured load curves are compared by the cluster analysis algorithm. As a result these curves are grouped into the corresponding classes. The average values of all load curves belonging to the same cluster form the representative load curve of this cluster. Therefore this load curve shows the typical load behaviour of this cluster. The optimum number n of classes has to be determined by the comparison of different solutions. A typical number of classes for special tariff customers is between 6 and 10.

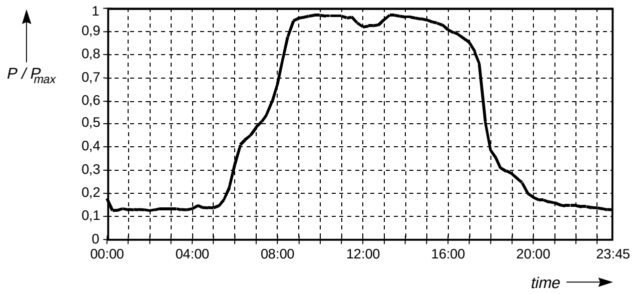


Fig. 9: Typical load behaviour
of the cluster „Large stores and shops“

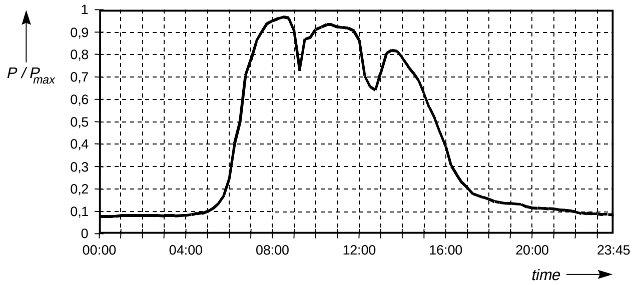


Fig. 10: Typical load behaviour
of the cluster „Middle-class industrial companies“

Typical load curves for different special tariff customer groups are presented in fig. 9 and 10. The class of large stores and shops show the maximum load between 08.00 a. m. and 18:00 p. m. corresponding to the hours of business in germany. The cluster of middle-class industrial companies with a large part of manual activities (e. g. furniture plants, sawmills, ...) is determined by two load dips as a result of the morning and lunch break.

Measured-value acquisition

The measured current values of the busbar feeder panels are used to determine the absolute load curves of all secondary substations belonging to the same distribution network. Fig. 11 shows exemplary the measuring points of these characteristic values inside a primary substation. For further steps in the modelling process only those measured current values are usable that are determined under the condition of the normal network state. In case of a power transfer from line 3 to line 2 due to a cable failure in line 3 the measured current values of both lines have to be marked as not useable for the time period of the transfer.

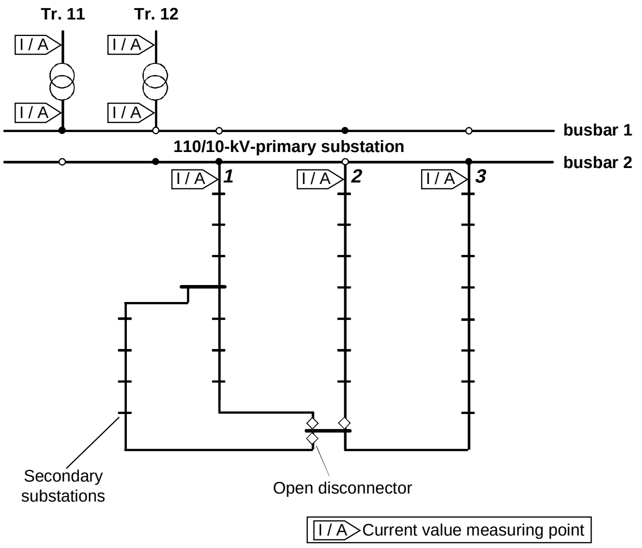


Fig. 11: Current measured-value acquisition

Fig. 12 presents the measured current values of line 2 in case of the normal network state and in case of a power transfer from line 3. The normal network state leads to maximum current values of about 80 A. A power transfer from line 3 leads to temporary increased current values of more than 160 A. The further utilization of these increased values would cause non-realistic load curves of the secondary substations due to the fact that as a result of the switching operation the constant assumed consumer matrix $\boldsymbol{H}$ changes.

Referring to the described mathematical model these measured current values have to be converted into active power values assuming a constant power factor and a constant operating voltage of the busbar.

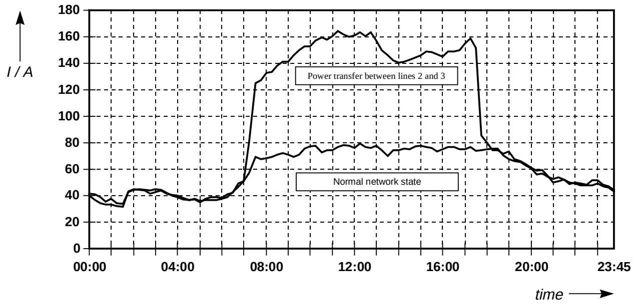


Fig. 12: Measured current values for different network states

Load curve determination

The normalized typical load curves for tariff customers, the normalized cluster load curves for special tariff customers and the temperature-dependent ripple controlled load curves are weighted and scaled for each secondary substation using the annual energy consumption values (see fig. 13). The sum represents a set of temperature-dependent absolute load curves for this substation.

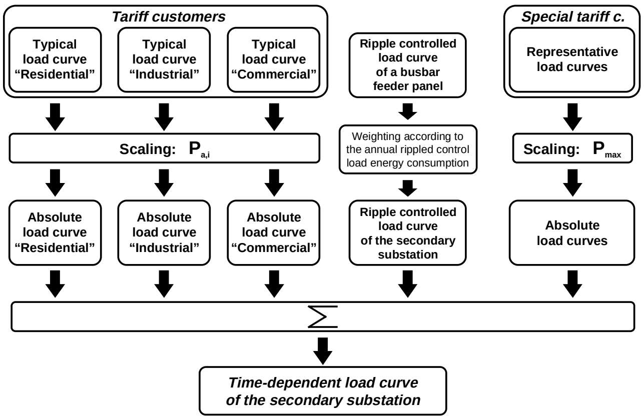


Fig. 13: Determination of secondary substation load curves

This determination process is implemented in an integrated program structure (fig. 14). The user chooses a defined distribution network area, the network state (normal switch state, additional new customer supply, etc.) and the considered load situation based on the presented method for load modelling. These informations are given to an external load flow calculation program.

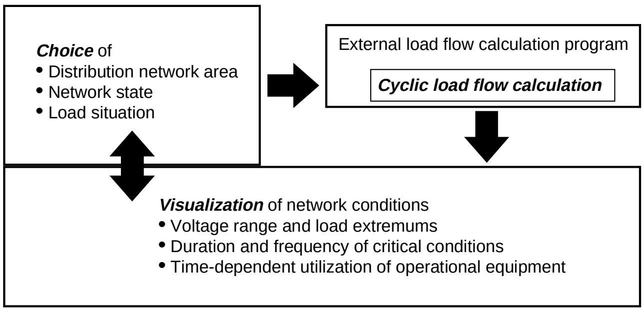


Fig. 14: Integrated program structure

The results of the cyclic load flow calculation are visualized in the integrated program yielding informations about duration and frequency of critical network conditions or the time-dependent utilization of the operational equipment.

RESULTS FOR A PRACTICAL NETWORK

In this part of the paper a comparison between measured and modelled current values for a rural distribution power system will be presented. Additionally a network calculation will be done for a selected outgoing feeder. The topology of the regarded 10-kV distribution network is presented in fig. 15.

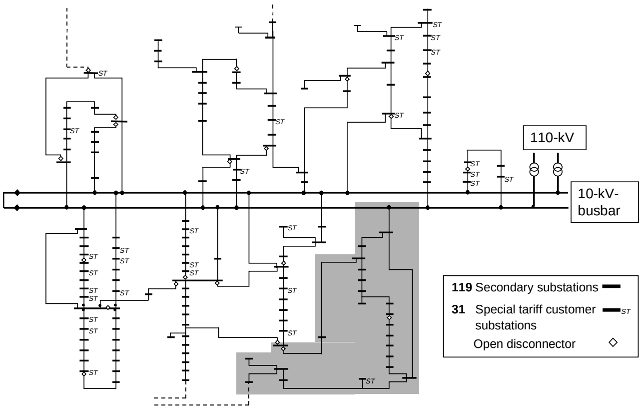
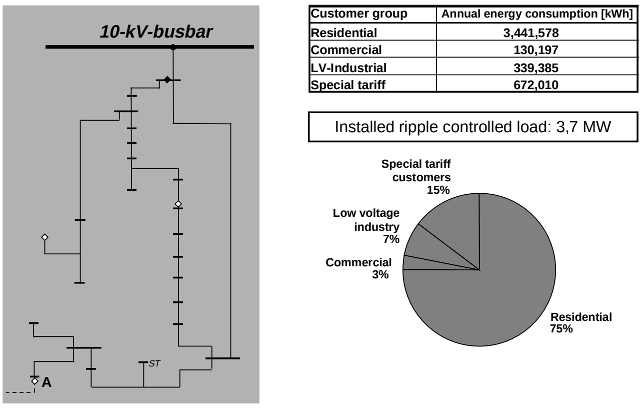


Fig. 15: Practical distribution network

The selected outgoing feeder for network calculation is marked with a gray shaded area. The consumer structure of this outgoing feeder is described in fig. 16. The structure is characterized by a strong part of residential customers combined with a strong existence of ripple controlled loads.



Customer group	Annual energy consumption [kWh]
Residential	3,441,578
Commercial	130,197
LV-Industrial	339,385
Special tariff	672,010

Installed ripple controlled load: 3,7 MW

Fig. 16: Consumer structure of the selected outgoing feeder

Fig. 17 shows the comparison between the measured and modelled current values in the regarded outgoing feeder panel. The maximum and minimum current value curves represent the extreme measured values in the considered time period (one season). The modelling has been carried out for two different temperatures.

The deepest temperature in the considered season was about - 6 °C. The comparison between the modelled load curve (- 6 °C) with the maximum measured load curve in the season shows that the maximum load demand caused by ripple controlled loads in the night will be reached at the same time with the same value.

The average temperature in the considered season was 0 °C. The comparison between the modelled load curve (0 °C) with the average measured current shows a satisfying correspondance.

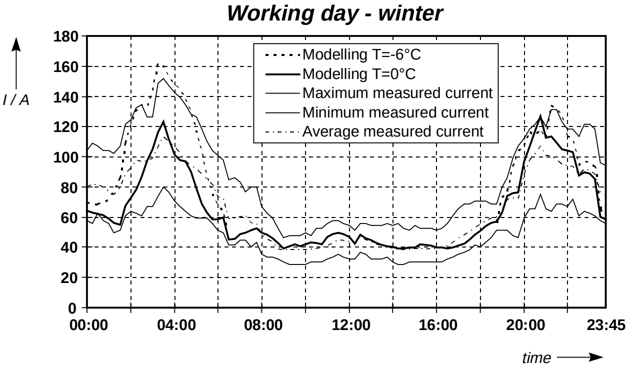


Fig. 17: Comparison between measured and modelled current values of the regarded outgoing feeder panel

Increase of the load demand in distribution networks will normally lead to a violation of the voltage restriction before thermal restrictions will be reached. Hence the minimal voltage will be considered for the above presented maximum load situation in the following.

Fig. 18 presents the minimal calculated time-dependent voltage at substation A which represents the end of the selected outgoing feeder (see fig. 16).

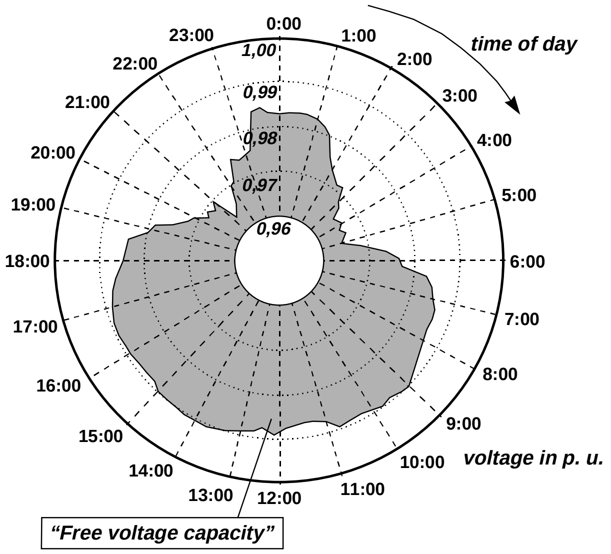


Fig. 18: Minimal calculated time-dependent voltage at substation A

The difference between the calculated voltage and the minimal allowed voltage of 9.6 kV in this network represents the time-dependent free distribution capacity. This free distribution capacity of the whole outgoing feeder can be converted to a time-dependent load demand increase for every secondary substation. Hence the integration of additional customers can be analysed and evaluated.

CONCLUSIONS

The presented approach for load modelling in distribution networks is an efficient planning tool for the determination of free distribution capacities. With the resulting knowledge about the time-dependent voltages at the secondary substations for different typical load situations the integration of additional customers can be evaluated.

Especially under the influence of the deregulation process in Europe the extended modelling of electrical loads is an essential method for an increased and efficient use of existing network ressources and therefore very important for planning and operation of these networks.

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