Metastudy

Use of controllable local network transformers in MV and LV networks

In addition to the expansion of photovoltaic systems, future demands on medium and low-voltage networks will increasingly result from the integration of charging infrastructure for electric vehicles and electric heat pumps. The resulting violations of the voltage band within the distribution networks according to DIN EN 50160 can be controlled to a large extent by using controllable local network transformers. They thus represent an essential component of strategic network planning.

The current trend towards the expansion of photovoltaic systems, charging infrastructure for electromobility and electric heat pumps is continuing. This results in an increased load on the medium and low-voltage grids (MV and LV grids). If limit violations are identified in the course of strategic network planning by means of analyses of various scenarios, these are to be remedied with suitable measures. In the case of voltage band violations, the controllable local network transformer (rONT) is a suitable and innovative means of eliminating these limit violations. There are already studies that explicitly recommend the use of controllable local network transformers (**Table 1**).

The aim of this paper is to use a metastudy of 56 distribution networks, divided into 10 MV and 46 LV networks, with a total of 244 network plans, to considerably increase the data basis for general recommendations for action and, based on this, to make further statements on the use of controllable local network transformers.

Methodical approach

The distribution networks analyzed are first divided into the area types "rural" and "urban" on the basis of their characteristics, and then additionally into the network structures "rural" and "suburban",
"urban" and "inner-city" cate- gorized. This offers the advantage that more precise statements can be made about distribution networks depending on their location within a network area or supply area. For the analyses, additional network structure parameters such as

- Mains cable length
- Transformer rating apparent power
- Number of house connections respectively points of delivery
- Number or power of charging points/ heat pumps/ photovoltaic systems
- Base load

and evaluated in a statistical analysis. Furthermore, the costs of both conventional and innovative network planning with controllable local network transformers are compared.
to realize the potential for cost savings.
to be able to determine the network. Conventional network planning represents the reference variant. For distribution grids of the urban area type, an alternative evaluation model is also evaluated, which shows how innovative grid planning with controllable local network transformers can be evaluated on the basis of other criteria beyond a pure cost consideration. Based on the analyses and results carried out, general findings are then derived on the basis of the meta-study.

Use of controllable local network transformers	
Principle/Recommendation for action	Source
In rural distribution grids, the use of innovative operating equipment (especially controllable local grid transformers) should be examined as an economic option.	[1]
Use of controllable local network transformers after economic testing.	[2]
If voltage band violations occur despite reactive power management or static feed-in management, the use of voltage regulators (rONT or NSESR[1]) should be examined.	[3]
As an overall strategy, an on-demand combination of static feed-in management with a controllable local grid transformer is recommended.	[3]
The use of voltage regulators (rONT, MSESR[2]) is often the most cost-effective solution, especially in MV systems without line overloads. If only voltage-reducing measures are used If the local network transformer is required in both the MV level and the LV level, it is preferable to use the adjustable local network transformer.	[3]
[1] NSESR: low-voltage single-phase controller;[2] MSESR: medium-voltage single-phase controller	

Table 1: Examples of existing principles and recommendations for the use of controllable local network transformers

Results on the basic application potential

First, irrespective of the supply task, it is considered when a controllable local network transformer is generally more economical than conventional network expansion with line transformers.

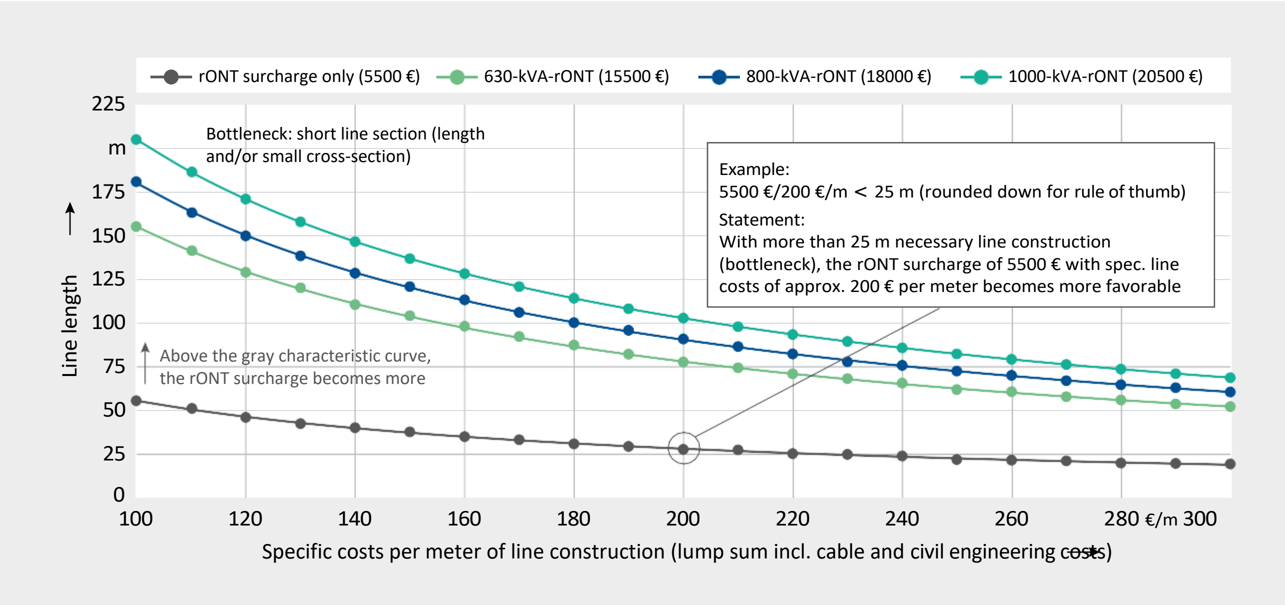

Fig. 1. application potential as a function of cable costs (bottleneck).

measures. In **Fig. 1**, it is analyzed for four different cost assumptions from which line length and specific line costs the use of a controllable local network transformer is more cost-effective. The gray curve (only rONT surcharge) only considers the cost difference of an extension of an existing transformer by a control unit to a controllable local network transformer, if a replacement of the transformer was already planned in advance.

The difference of €5,500 corresponds to the sum of the list price of the tap changer of €3,950 at the time of the meta- study and an assumed additional cost in terms of construction and installation of the transformer compared with a conventional, unregulated transformer. In contrast, for the other characteristic curves, a complete transfor- mator replacement not planned in advance with a new re- gelable local network transformer in ver-

The different power classes are taken into account. It can be seen that with more than 25 m of necessary line construction of, for example, a trunk line (line from a local network station to the first end consumer), the rONT extension is more economical than the purely conventional network extension with specific line costs of about 200 €/m. If the costs of a complete rONT are used, e.g. for the event-driven deployment of a rONT, the example with a line cost of 200 €/m is calculated.

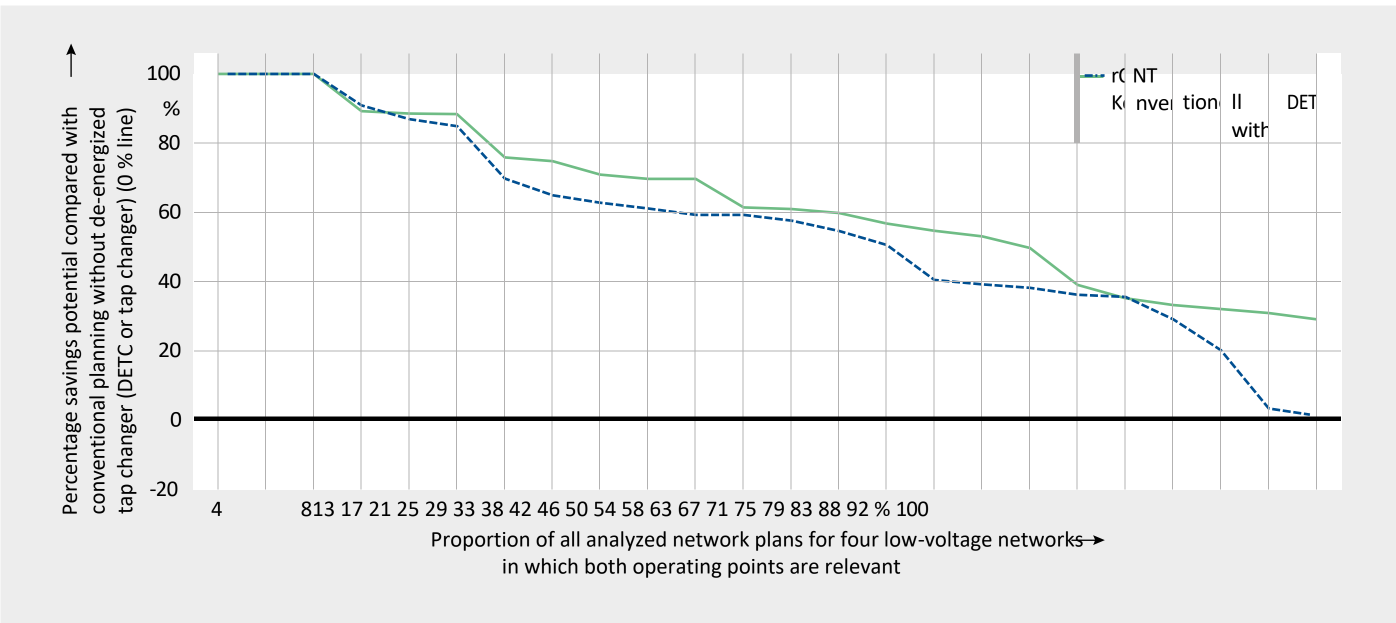

Fig. 2: Application potential as a function of the operating points "heavy load" and "heavy feed-in" for four low-voltage networks with
A total of 24 network designs [4]

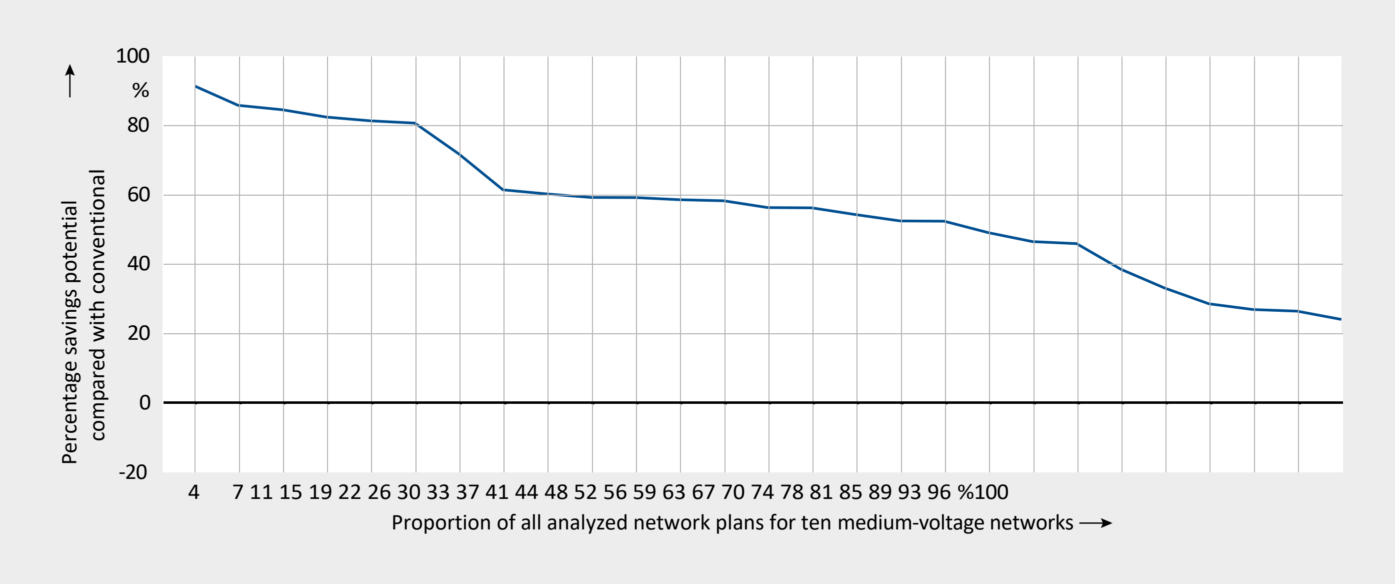

Fig. 3: Potential cost savings for ten medium-voltage networks with a total of 27 network plans.

In this case, the controllable local network transformer is only more favorable with a line extension of more than 75 meters. The following considerations are always based on complete rONT costs.

Figure 2 also shows the basic potential for four LV grids with a total of 24 grid plans, in which the operating points "heavy load" (maximum load with minimum feed-in) and "heavy feed-in" (maximum feed-in with minimum load) are equally relevant for the design [4]. The illustration shows the relative savings potential of controllable local network transformers (green line) compared to the reference variant without tap changer at the transformer. The use of a conventional tap changer (blue dashed line), which is always advantageous if only one extreme operating point has to be taken into account in strategic network planning, is also evaluated. The 0 %-Linie in **Fig. 2** represents the reference variant. Above this limit, the savings potential is positive and innovative network planning with a controllable local network transformer is more cost-effective. Below this limit, the use of rONT becomes more expensive. It can be seen that in all In these cases, network planning with controllable local network transformers is more cost-effective than the reference variant. In addition to the four LV networks analyzed without the use of the tap changer, in [5] also described that the controllable local grid transformer is more advantageous for grid plans where both extreme operating points have to be taken into account. Especially in LV grids with charging infrastructure and heat pumps as well as a very high proportion of photovoltaic systems, the use of the tap changer is generally not expedient because opposing operating points have to be taken into account.

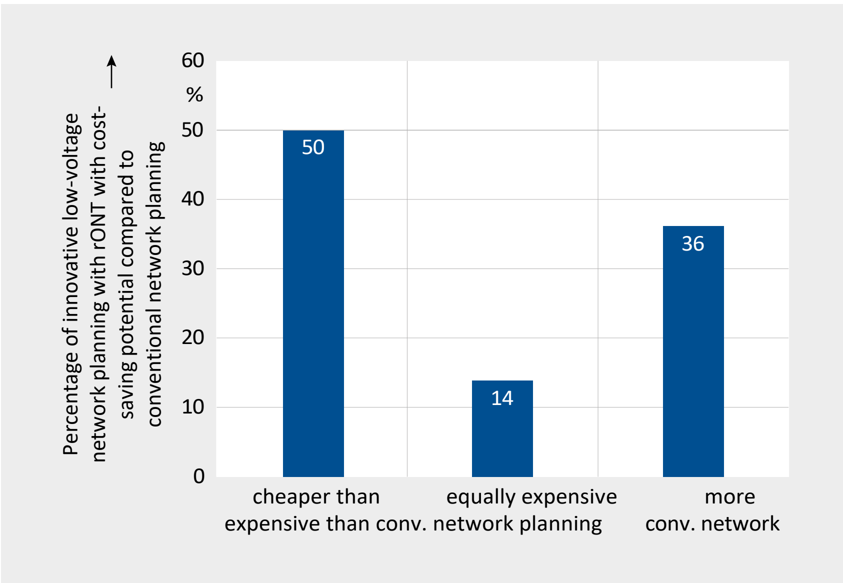

Fig. 4. Cost-side and relative savings potential for 46 low-voltage networks with a total of 166 network plans.

Results on the savings potential

Figures 3 and **4** show the consolidated results of the meta-study for a total of 56 distribution networks and the underlying network plans. In 51 of 244 network plans, no measures were necessary, so that the corresponding evaluations for the MV level contain 27 network plans and for the LV level 166 network plans.

Using the same presentation system as in **Fig. 2**, **Fig. 3** shows that the controllable local grid transformer is more cost-effective than the purely conventional grid expansion in all MV plans, with savings potential of significantly more than 50 % in 50 % of all grid plans. **Figure 4**, on the other hand, shows an evaluation for the network plans of the LV networks. This shows that the controllable local network transformer in

50 % of network planning is more cost-effective than the reference variant. In 14 %, however, it is just as expensive. The use of controllable local network transformers is therefore not always effective, for example, if there are only equipment overloads and other measures have to be implemented instead. In 36 % of the network plans, the controllable local network transformer is the more expensive measure if, for example, in addition to the integration of the local network transformer, other measures have to be implemented.

In addition to the installation of an rONT, additional leasing measures are necessary to eliminate line congestion, which is particularly the case in urban areas with a high proportion of load infrastructure for electromobility and heat pumps [5].

The results from **Fig. 4** are presented in a more differentiated way in **Fig. 5.** It becomes clear that in rural LV grids, the potential for controllable local

The use of controllable local transformers is much greater than in urban areas. Furthermore, it is clear that the use of controllable local network transformers offers little savings potential, especially in urban and inner-city LV networks, since line overloads are the dimensioning factor for expansion measures. Across all suburban LV networks, the controllable local network transformer is more cost-effective in around 42 % of all network plans.

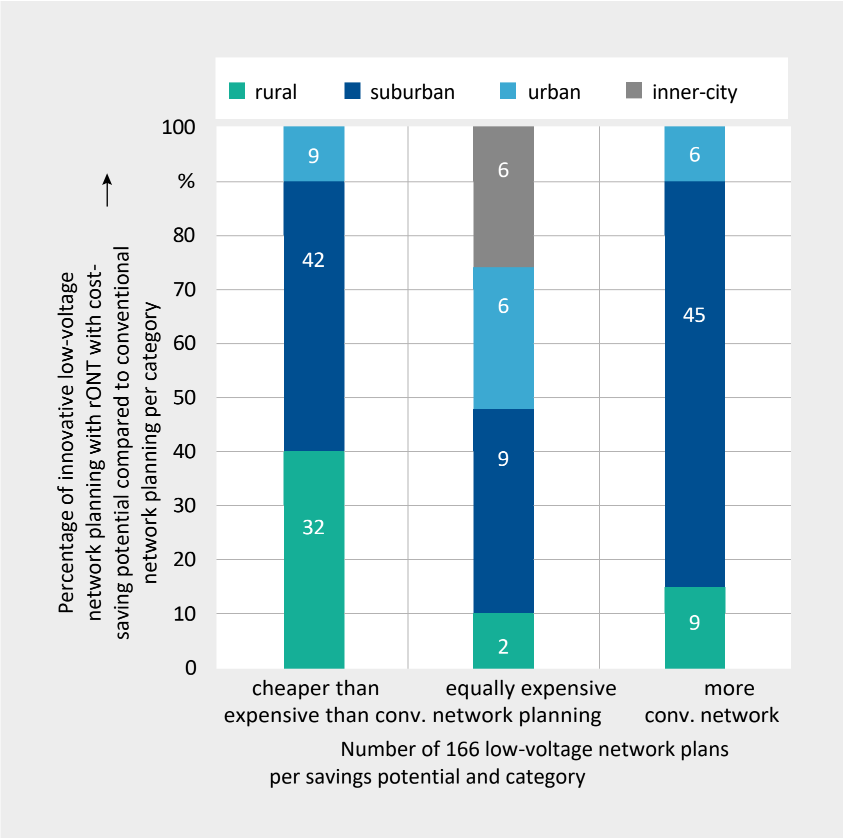

Fig. 5: Application potential of controllable local network transformers depending on the network structure.

Results for the alternative valuation model

In the future, additional criteria will become more and more important for strategic network planning beyond a pure cost consideration. Therefore, an alternative evaluation model is used in [5-6], the results of which are detached from the meta-study and are additionally presented in a reduced form in **Fig. 6** for 17 LV networks of the urban area type. This alternati- ve evaluation contains a point model that relates the criteria "investment and operating costs", "network losses", "disturbance frequency", "voltage stability" and "resource expenditure" for six different weightings. According to the traffic light colors, the best evaluation, i.e. the highest rank with a correspondingly high number of points, is shown in green, whereas unfavorable network plans are shown in red with the evaluation model. At first glance, it is thus immediately apparent that strategic network planning with controllable local network transformers offers a clear advantage over the reference variant in all weightings beyond the cost-based weighting. Especially in the criterion

"Voltage stability", the controllable local network transformer can make a significant difference.

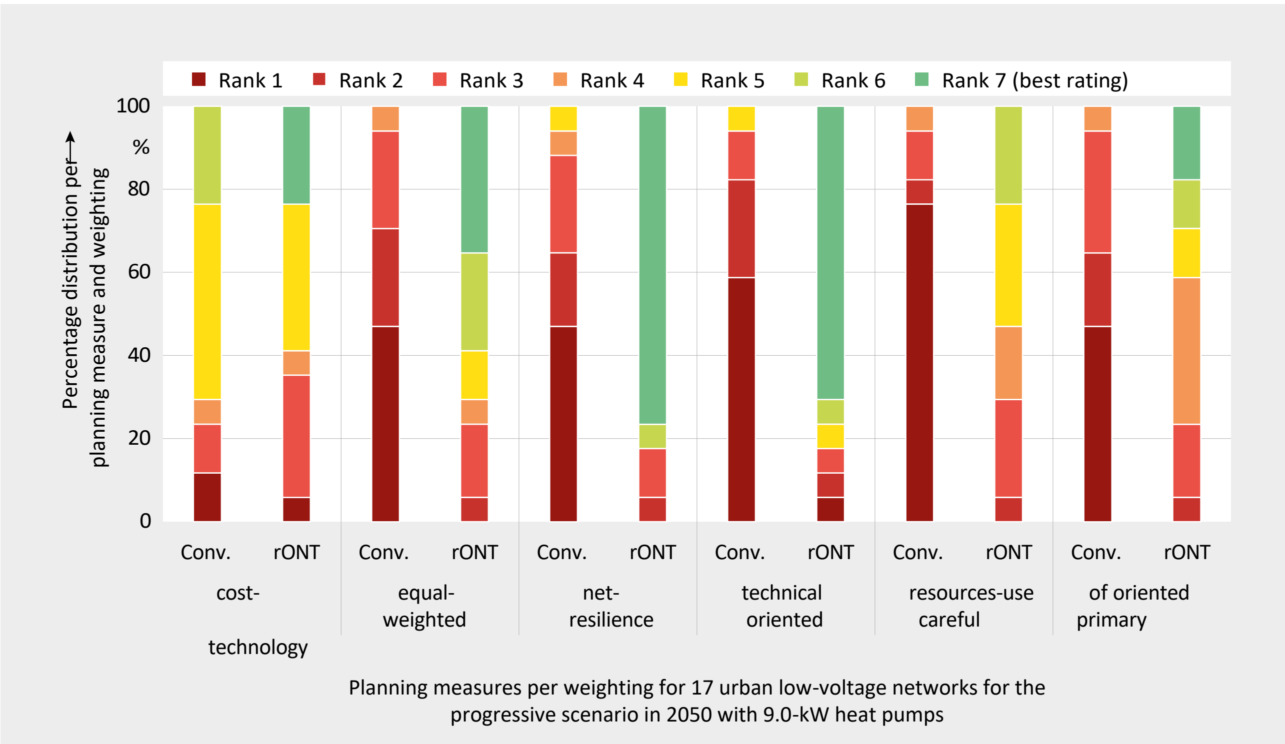

Figure 6. Results on the alternative evaluation model for five different weightings taking into account the criteria of investment and operating costs, network losses, fault frequency, voltage stability and resource consumption for 17 urban low-voltage networks [6].

The method is based on the principle of maintaining a voltage reserve in contrast to conventional measures. A detailed description of the method and a comparison with other innovative planning measures, e.g. load management and energy storage, can be found in [5-6].

Conclusion

The use of controllable local network transformers is specified in more detail within the scope of the meta-study carried out on the basis of an extensive data base and thus serves network operators as a further decision-making basis for strategic network planning in order, among other things, to meet the requirements of DIN EN 50160 [7] for permissible voltage values. In summary, the following general statements and findings can be derived:

1. For (very) short line sections (bottleneck), the use of a controllable local network transformer is uneconomical compared to conventional line measures.
2. The use of controllable local network transformers is suitable wherever either both operating points, heavy load and heavy injection, are relevant for the design (e.g. suburban areas with a lot of photovoltaic systems) or for one of the operating points the benefit for the MV and LV level is given.
3. If no tap changer can be used on the MV/LV transformer or if the taps are not sufficient, a variable local network transformer is in almost every case more cost-effective than purely conventional network expansion.
4. In all MV planning, regardless of the scenario selected, the adjustable local grid transformer is more cost-effective than the purely conventional planning.
5. In rural LV grids, the potential for a controllable local grid transformer to be more cost-effective than conventional planning is much greater than in urban grid areas.
6. If, in addition to the economic criterion of investment and operating costs, other technical criteria become relevant, the use of controllable local network transfor- mators has a considerable advantage over purely conventional planning.

Outlook

The results presented are based on target grid plans taking into account the integration of charging infrastructure for electromobility, heat pumps and photovoltaic systems without knowledge of the age structure and residual values of the existing equipment within the grids. This means that the costs of a complete controllable local grid transformer are used when comparing the necessary measures. **Figure 1** shows, however, that the use of a controllable local network transformer within the scope of an age replacement can be far more economical, since in this case only the surcharge between rONT and an uncontrolled local network transformer has to be applied. A proactive use of rONT for the applications mentioned in the conclusion could further increase the share of network planning, especially with voltage band violations, in which controllable local network transformers are cheaper than conventional network expansion. On the other hand, however, it could entail an investment risk (in the aforementioned example in the amount of €5,500 per network) in the event of widespread use, since this measure could also result in controllable local network transformers being used in networks in which none would have been necessary retrospectively. This applies above all to networks with line overloads. To what extent such a proactive rONT strategy affects the discussed cost saving potential and how the investment risk of a preferred rONT deployment relates to that of a preferred conventional network expansion is to be considered in further work and research projects.

Literature

[1] Frings, R.; Zimmer, P.; Rahmen, T.; Herbert, A.: Netzplanung von intelligenten Verteilnetzen - Szenarien und Netzpla nungskriterien. Final report on the Smart Area Aachen in the collaborative project. Aachen, December 16, 2016.

[2] Braun, M.; Krybus, I.; Becker, H.; Bol garyn, R.; Dasenbrock, J.; Gauglitz, P.; Horst, D.; Pape, C.; Scheidler, A.; Ulf fers, J.: Distribution Grid Study Hesse 2024- 2034. BearingPoint GmbH, Frankfurt/ Main, April 16, 2018.

[3] Harnisch, S.; Steffens, P.; Thies, H. H.; Monscheidt, J.; Münch, L.; Böse, C.; Gems jäger, B.; Zdrallek, M.: Planungs- und Be triebsgrundsätze für ländliche Verteilungsnetze - Leitfaden zur Ausrichtung der Net ze an ihren zukünftigen Anforderungen.

In: Zdrallek, M. (Ed.), New Energy from Wuppertal, vol. 8, Wuppertal, 2016.

[4] Göbelsmann, F.; Wintzek, P.; Ali, S. A.; Zdrallek, M.; Monscheidt, J.; Gems jäger, B.; Slupinski, A.: Potentials of a CostOptimized Application of Regulated Distribution Transformers in Urban Low Voltage Grid Planning with a High Share of Charging Infrastructure, Heat Pumps and Photovoltaic Systems. IEEE Power and Energy Student Summit (PESS), Kas sel, 25-26 November 2021.

[5] Wintzek, P.; Ali, S. A.; Monscheidt, J.; Gemsjäger, B.; Slupinski, A.; Zdrallek, M.: Planungs und Betriebsgrundsätze für städtische Verteilnetze - Leitfaden zur Ausrichtung der Netze an ihren künf tigen Anforderungen. In: Zdrallek, M. (Ed.), New Energy from Wuppertal, Vol. 35, Wuppertal, 2021.

[6] Wintzek, P.; Ali, S. A.; Zdrallek, M.; Mon scheidt, J.; Gemsjäger, B.; Slupinski, A.: Development of Planning and Operation Guidelines for Strategic Grid Planning.
of Urban LowVoltage Grids with a New Supply Task. Electricity 2021, Volume 2, Issue 4, pp. 614-652.

[7] DIN Deutsches Institut für Normung e. V.: DIN EN 50160:2020-11 Characteristics of voltage in public electricity supply networks; German version EN 50160:2010 + Cor.:2010 + A1:2015 + A2:2019 + A3:2019. Beuth Verlag GmbH, Berlin, November 2020.

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