ASSESSMENT OF FLEXIBILITIES AND SMART GRID TECHNOLOGIES IN THE PLANNING AND OPERATION OF CONGESTED EUROPEAN DISTRIBUTION NETWORKS

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ABSTRACT

In this contribution the approaches that were developed in the European project SmartGuide are presented. Within its scope it is analysed how to address the challenges in planning and operating distribution systems resulting from the general transformation of the energy system, in particular concerning the development of generation and load. The paper presents four different methodologies and tools that facilitate the assessment of flexibilities and smart grid technologies for the reinforcement of European smart grids. Subsequently, the derivation of European planning guidelines by utilising the results of the tools is described.

INTRODUCTION

The requirement to decrease fossil fuels dependency and the policies imposing the reduction of Greenhouse Gases (GHG) emissions induce several changes in the planning and operation of distribution networks. Future distribution systems will come across many modifications mostly due to large-scale integration of Distributed Energy Resources (DER), such as photovoltaic (PV) generators, and new loads, such as Electric Vehicles (EV) and heat pumps, as well as storage devices. The uncertainty related to the future integration of these resources and loads will make distribution systems planning and operation a more complex and much harder task. In addition [1] proposed the need of additional tools and methods to optimise the planning process of distribution networks.

Given this context, the SmartGuide project is developing improved and generalised planning and operating guidelines for European smart distribution systems, considering demand-side services (flexibilities) that arise from smart market applications (e.g. demand response (DR), ancillary services provision, etc.) as well as innovative network technologies and measures, such as regulated transformers or generation curtailment. The tools that were developed to assess and compare the different technical measures and the methodology to derive planning and operation principles are presented in the following chapters.

METHODOLOGIES

<u>The automated network planning tool</u>

With the use of innovative technologies and measures the future challenges for distribution grids can be addressed efficiently [2, 3]. Although many innovative technologies and measures have already been developed, they have so far only rarely been used in practice, since distribution system operators (DSOs) have not anchored them in their planning principles as standard technology throughout Europe.

In order to determine the most cost-effective reinforcement measures for DSOs, a tool for automated, optimised network planning was developed at the University of Wuppertal.

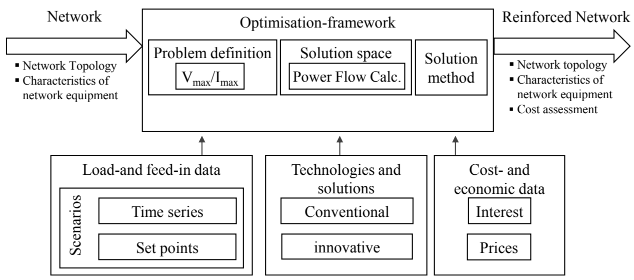

Figure 1: Scheme of the automated network planning tool

Figure 1 shows the flowchart of the tool which can compare different network reinforcement strategies considering innovative and conventional measures. After evaluating the different optimisation algorithms and methodologies (cf. [4]) a genetic algorithm was chosen. It offers sufficiently accurate results in an adequate runtime. The individual describes a node and edge model of the investigated network. The genes indicate the use of different technologies and measures to solve the constraints in the network, such as overvoltages or excessive loading of equipment. To evaluate the fitness of the individual a power flow calculation is carried out and the costs resulting from the technologies and measures are totalled. In order to evaluate the technical feasibility and operational capability for the elimination of constraints, various technical measures are considered and their installation and operating expenditures are taken into account. The evaluated measures are:

- Conventional equipment (lines, transformers)
- Regulated Distribution Transformer (RDT) with On-Load Tap Changers (OLTC)
- Line Voltage Regulator (LVR)
- Dynamic curtailment of DER, using an Active Network Management system
- Static curtailment of DER, limiting the maximum feed-in power of the plants to 70 % of their installed power

On the one hand, the planning tool offers the possibility to calculate a large number of networks. In the future, this will be of particular interest for planning of low voltage networks since manual planning would not be a feasible effort. On the other hand, the influence on external factors, such as the development of load and generation, can be analysed with sensitivity analyses. Thus, the usability of different network technologies and measures can be evaluated in general.

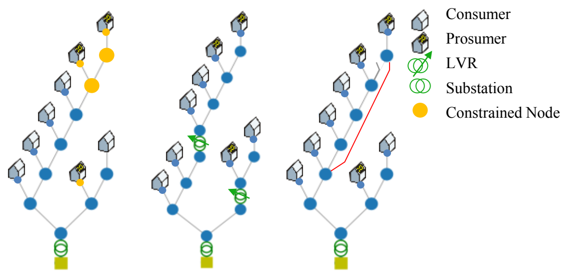

Figure 2: Exemplary Planning Results from the automated network planning tool

Figure 2 shows examples of the results of planning variants in which different technical measures are chosen to solve the constraints. The integration of domestic PV systems leads to the violation of voltage constraints at three nodes in the exemplary network (marked yellow). While the usage of two LVRs was necessary to deal with the voltage constraints, building a new line was necessary when considering only conventional network equipment.

With the use of the tool a large amount of real low voltage networks will be reinforced, and the results will be synthesised into planning recommendations. After the first calculations the application of innovative technologies and methods seems to be in favour, compared to conventional network reinforcement, considering costs. In the future more analyses will be undertaken regarding the stability of the solutions when changing assumptions or the distribution of DER in the network.

Multi-objective optimisation of network reinforcement planning

Nowadays, network planning is inefficient: network infrastructure is oversized to meet the worst-case scenario, which usually occurs during a few days in a year. In addition, flexibility provided by controllable loads is not taken into account at all. This section presents an approach that integrates the potential flexibility of DERs in the planning exercise.

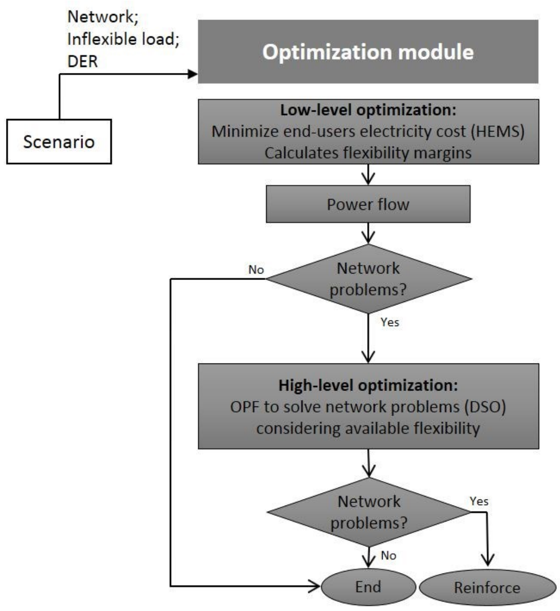

Figure 3: Flexibility utilisation

Use of flexibility

The methodology developed by INESC TEC, **Figure *3***, is composed of two optimization processes. The *low level* module calculates the consumption profile in each secondary substation considering all downstream resources and loads, as well as their optimal operation by the end user perspective. After defining the consumption profiles and the detailed flexibility margins, technical network violations are verified. In case of technical problems, such as branches' overload or voltage limits violation, the *high-level* optimization reschedules the flexible DER, using two interactive processes:

- An Optimal Power Flow (OPF) is run using the available margins of flexibility to solve the network problems.

- A process similar to the *low-level* optimization is run. It receives the limits imposed by the previous process and reallocates the consumption profiles. This process verifies whether the use of requested flexibility is consistent with the resources' intertemporal constraints in each secondary substation, sending a signal to the previous process with the adjusted level of flexibility.

If the strategic schedule of flexible loads is not enough to solve all the problems, the physical reinforcement is triggered. Further information about this methodology can be found in [5].

Reinforcement plan

The network reinforcement procedure is divided into two sub-problems: branches overloading and voltage limits violation. For the former, lines with larger sections replace the overloaded branches, or parallel lines are installed, if the first solution does not solve the problem. For the latter problem, an Evolutionary Particle Swarm Optimization (EPSO) algorithm is used to identify the most advantageous branches to replace, defining the best reinforcement strategy that solves all the voltage problems detected. When the reinforcement process is computed, flexible resources are already rescheduled in a way to minimize network violations and the need for network reinforcement.

Selecting the best plan

This methodology uses a set of scenarios to provide an equal number of possible reinforcement plans. Each plan will be evaluated according to each scenario. The plan that presents the best performance is selected, that is, the plan in which the maximum energy not supplied is the lowest comparing to other plans.

Curtailment Assessment of Distributed Generators in Active Network Management Systems

Active Network Management (ANM) allows DERs to connect to constrained distribution networks without the expense and delays associated with traditional reinforcements [6]. DER developers may consider a lower-cost network connection at the risk of occasional energy export curtailment.

Curtailment Assessment

To quantify this risk and assess a project's commercial viability, curtailment assessment studies are performed to estimate the frequency and severity of control actions. The development of this Curtailment Assessment methodology is well-documented [7], [8]. Smarter Grid Solutions has been exploring this methodology to identify best-practice for curtailment estimation, reflecting emerging developments such as increasing flexibility (energy storage, demand-side response); EV integration; and improving data availability and quality.

Smarter Grid Solutions has developed a high-resolution curtailment assessment methodology, utilising improving quality of historic network data: 1-minute resolution profiles of network behaviour, as opposed to the half-hourly (or hourly) time-series profiles typically used.

The high-resolution study allows the modelling of ANM control system dynamic behaviour, reflecting the behaviour during a curtailment event, which cannot be modelled for half-hourly resolution studies. The following characteristics are modelled:

- Escalating control actions and DER response time;
- Granular release of ANM device set-points; and
- Stability timers.

Example Study Case

The high-resolution and low-resolution curtailment assessment methodologies were applied to a 33 kV case study network, consisting of seven different constrained circuits and 20 associated wind DER sites with aggregate capacity of 25 MW. The assessment approximated curtailment across a single month, where the lower-resolution profiles were derived from original 1-minute resolution data, creating profiles with resolution of 0.5, 1, 2 and 4 hours. These data profiles were derived based upon the following conditions observed in the high-res:

a) Minimum load and maximum generation;
b) Average load and average generation;
c) Maximum load and minimum generation.

Study Outputs

The simulation outputs are presented as the total energy curtailment of all ANM-controlled DER sites, for each study scenario, shown in **Figure 4**. The results show accuracy increases with the higher resolution of input data, presenting outputs closer to the 1-minute resolution case (879 MWh curtailment). The use of average data gives the most accurate estimate (b), with (a) over-estimating and (c) underestimating curtailment volumes.

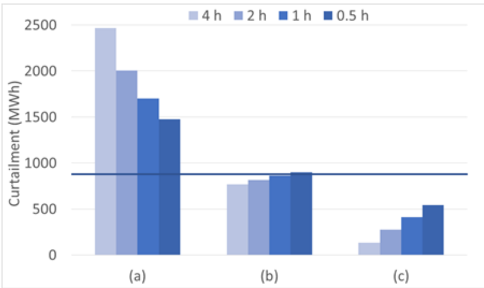

Figure 4: Total estimated curtailment under different resolutions and derivation methods

From observations, it is recommended that DSOs log time-series load and generation levels that reflect observed *average* behaviour, as this has a benefit in future planning studies. It is noted that in cases this diverges from current DSO standards, where the logging of *maximum* loading

measurements is common at substations, reflecting historical planning to reflect peak-loading conditions.
Where high-resolution data is unavailable, the logging of measurement data at a half-hourly resolution provides the most representative and granular modelling. An evident observation, but one that brings significant improvements when estimating ANM operation based on historical data. The clear benefit shown in the studies highlights to DSOs that there is value of increasing the volume of logged operational network data.

Development of estimated load and generation profiles

Planning of distribution grids in Norway has traditionally been performed with use of historic load profiles for different customer types, representing the "typical" customer. Each profile consists of 24-hours for different day types (weekday/weekend) and seasons (winter/ summer), making it possible to build a yearly, hourly profile according to temperature. This yearly profile is levelled according to the total yearly consumption for the customer, making it possible to estimate the peak load for the customer.

These historic profiles are representing the typical customer, and do not include new smart grid technologies such as EV charging, PV production or demand response. In Norway, 1/1/2019 was the deadline for deployment of smart meters to all customers, and the requirement is that the electricity consumption should be metered at least on an hourly basis. This will give valuable information about the electricity consumption for the customers.

In SmartGuide, SINTEF Energy Research has developed a tool which can use smart meter data from an actual customer to create a load profile and model the change in the profile if different smart grid technologies are added. This makes it possible both to analyse the typical profile for the customer today, but also to perform what-if-analysis related to introduction of new smart grid technologies.

The tool has been developed in Microsoft Excel (VBA). As illustrated in **Figure 5**, it consists of two alternatives to calculate a load profile depending on which input data the user has.

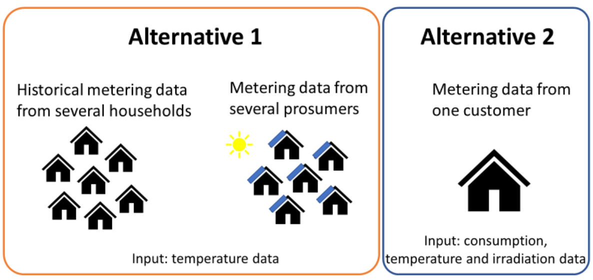

Figure 5: The basis of different load profiles possible to visualise in the tool.

In alternative 1 it is possible to view already made historical profiles and prosumer profiles (profiles of household customers with PV). The user of the tool needs to give temperature data (hourly values for one year) as input. In alternative 2 it is possible to view the profile of a specific customer. The user of the tool needs to give temperature, consumption and irradiation data as input (hourly values for one year).

All profiles are made from linear regression on consumption data versus temperature data for each hour. The analysis gives a temperature dependent and a constant value. Before performing the regression, the data is classified after hour, day type (weekday or weekend) and season type (low load/summer or high load/winter).

Figure 6 shows a comparison of consumption profiles made by the tool for households in Norway, UK and Germany, by using alternative 2. The profiles are made for low load (summer) and shows how the profiles change if the production from a PV panel of 3 kW_p is added. More information on how these profiles were obtained can be found in Ref. [9].

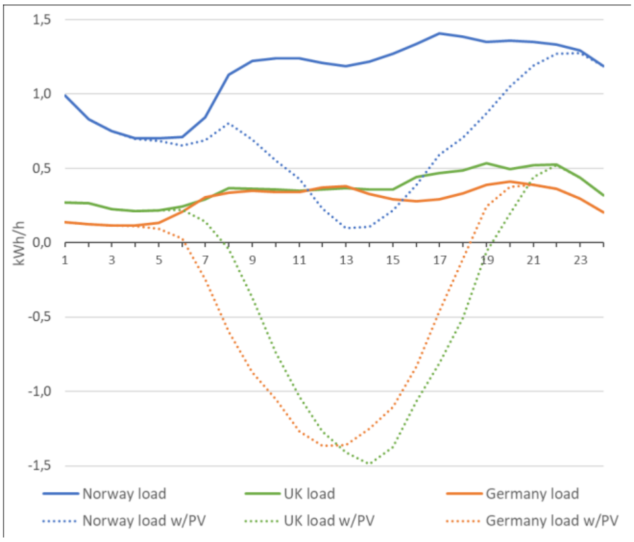

Figure 6: Average household consumption profiles for Norway, UK and Germany for low load, with and without the average summer production of a 3 kW_p PV panel

DERIVING GUIDELINES

The SmartGuide project will present network planning guidelines, deriving these from the tools and methods developed by project partners and their studied benefits, as highlighted in this paper. The process for deriving guidelines reflects the diversity in planning methods and tools developed by the project partners, combining project outputs in a coherent fashion. **Table *1*** presents the steps to derive planning guidelines that enable the smart grid transition.

Table 1: Guideline Derivation Methodology Steps

Study Observations	A detailed review of outputs from development of planning tools and their application to relevant case studies. Evaluate the study observations to directly derive guidelines based upon the tools and methods that should value to power system planning activities.
Enabling Recommendati ons	Assessment of the observed benefits of the planning tools, considering barriers to realising benefit. Inform the identification of recommendations that will enable or accelerate benefits, or conversely mitigate risks observed in the studies.
Assimilation of Common Themes	Grouping common observations and guidelines from across the project studies, mapping resultant guidelines across common themes and presenting these in context for targeted relevant stakeholders.

SUMMARY AND OUTLOOK

The scope of the large network studies based on the four tools facilitate the derivation of European guidelines on how to plan, reinforce and operate smart distribution grids in Europe. Preliminary results show that the use of innovative approaches, such as innovative network equipment, flexibilities and ANM systems prove to be a feasible alternative to conventional reinforcement in the future network development process and need to be taken into account by DSOs, regulatory authorities and policy makers. Further information to the separate approaches and preliminary results are also available in CIRED 2019 contributions n° 961 and n° 1092.

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