REQUIREMENTS FOR ADVANCED DECISION SUPPORT TOOLS IN FUTURE DISTRIBUTION NETWORK PLANNING

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ABSTRACT

This paper describes the need and requirements for advanced decision support tools in future network planning from a distribution network operator perspective. The existing tools will no longer be satisfactory for future application due to present developments in the electricity sector that increase uncertainty. Advanced decision support tools can help network planners to select among the numerous alternatives for the optimal future distribution network layout and expansion schedule. This in contrast to the existing method, whereas the generation of planning alternatives is carried out heuristically by network planners based on design directives and experience. Advanced decision support tools require the most efficient optimization techniques, must be able to find the optimal investment path considering multiple scenarios, and should not only consider classic expansion strategies but also intelligent ones (e.g. energy storage and controlling active demand). Advanced decision support tools would greatly help network operators to make better decisions under uncertainty, which contributes to an affordable, sustainable, and reliable electric energy supply.

INTRODUCTION

Availability of electric power is an important topic for modern societies. Networks operators are aware of their social responsibility and want to ensure a sustainable, reliable and affordable energy supply, both in the present and in the future. The process of network planning is essential in achieving this goal in the long run. The resulting network expansion plan specifies ‘optimally’ where, how many, which, and when new assets must be installed in an electric system, such that it operates adequately within a specified planning horizon. However, long-term expansion planning of electricity networks is a very complex optimization problem due to its non-linear nature and the numerous connections/nodes. Furthermore, planning of electricity networks implies decision making under high uncertainty. The present developments in the electricity sector will especially challenge the planning of medium voltage (MV) distribution networks. The on-going energy transition results in an increasing share of distributed energy resources. Further on, in the (near) future, loads might become active, enabling demand side management, and more intelligent devices will be introduced in the distribution network for operation and control. With all these changes, the classic planning approach will no longer be applicable. Decision support tools can help network planners to select among the numerous alternatives for the optimal future distribution network layout and expansion schedule. Decision support tools, implemented as computer programs, perform planning functions automatically which reduces the effort required and improves consistency (i.e. contributes in standardizing the planning process). In addition, they can apply optimization to help identify which expansion solution, out of all possible alternatives, should be selected [1]. However, most existing tools and planning procedures have certain short-comings for future application. As a result, network operators require improved methods and tools for long term network planning. Appropriate methods that consider future aspects can reduce investment risks and this allows network operators to make informed decisions on network expansions.

This paper describes the need and requirements for advanced decision support tools in future network planning, from a distribution network operator (DNO) perspective. The paper is organized as follows. First, an overview of the existing distribution network planning process will be given; a generic planning method which is currently being used by several DNOs in The Netherlands. Furthermore, existing tools and the practical application will be evaluated. Then, requirements of advanced decision support tools will be treated and suggested, since the existing planning approach is insufficient for the dynamic behaviour of future distribution networks and the increasing uncertainties. Finally, some concluding remarks are given concerning distribution network planning tools and their development.

PRESENT NETWORK PLANNING PROCESS

Network investments have a high economic value together with long lead times and life cycles. DNOs have the responsibility to deal with the accompanying uncertainties and risks of network investments. Several DNOs in The Netherlands use a structured method to make well-founded and objective network planning decisions under uncertainty [2]. Figure 1 depicts a flowchart of the decision process [3].

<u>Decision process</u>

The network planning process starts when a *new development* arises (e.g. load growth issues, new network connections inside a horticulture / industrial area). If this development leads to a problem / bottleneck in the existing network, all relevant influencing factors should be assessed which will result in a *problem definition*. The next step is to classify the uncertainties and to define possible *scenarios* (e.g. development of load growth over time) including their probabilities. Multiple *alternatives / solutions* should be generated for these scenarios. The generation of solutions is manually executed by an engineer. The solutions are manually *checked*, with the help of power system simulation software, whether the (technical) requirements are satisfied.

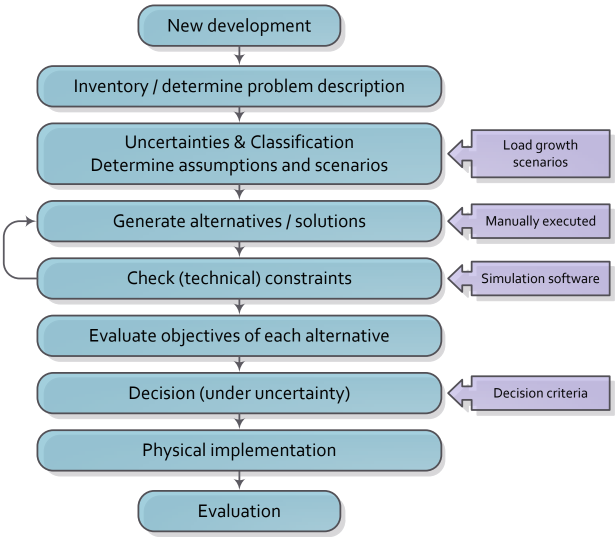

Fig. 1. Flowchart of network planning process

If no solution is feasible, either new (unconventional) solutions have to be generated or restrictions have to be reviewed or loosened. For the remaining alternatives the desired *objectives* need to be *evaluated* (e.g. economic feasibility, reliability). Subsequently, a solid and objective *decision* should be made between the various alternatives. Decision methods like 'least regret' and the 'Bayes criterion' can be used for this purpose [3]. The decision criterion per DNO depends on the utilities policy and asset management philosophy. Finally, the expansion plan will be *physically implemented* and an evaluation after each implementation phase is recommended, since uncertainties might change or decrease with time; resulting in another optimal solution.

Practical use

In theory this decision method would support DNOs to make sound and objective decisions for network planning. However, the practical situation is somewhat different. In practice it is still a quite complex and laborious process, especially when handling numerous new connection requests in short periods of time. This results in inconsequent use and subjective decisions which are based on intuition and gut feelings. Furthermore, if applied, the decision process is used in a reactive manner; for example, only when a customer requests a new connection or when a new neighbourhood is installed, the abovementioned decision process will be executed. At this moment, engineers do not look at how existing connections can change (generation / load growth) due to the present developments. They are captured by routine tasks and are mainly focused on new connection requests including the accompanying impact on the distribution network. DNOs worldwide face the same situation [4]. Moreover, at present, little or no consideration is given to distributed generation or demand side integration in the development of (load) forecasts and future network flows [5]. In addition, demand-side integration and active distribution network concepts are not taken seriously by utilities as viable alternatives in the planning process [5]. Besides, the tools that engineers use is limited (e.g. power system simulation software). The generation of solutions needs to be manually executed by an engineer, based on design directives and experience, which is a time consuming and inconsistent process. Automated (decision support) tools for network planning optimization purposes are rarely used in practice.

It is clear that the existing tools and planning procedures have serious short-comings for future application. As a result DNOs require improved methods and tools for long term network planning in order to guarantee an affordable, sustainable, and reliable electric energy supply.

REQUIREMENTS FOR FUTURE NETWORK PLANNING (TOOLS)

The classic planning process and tools are useful for conventional scenarios with regularly applied load growth factors. However, these techniques are insufficient for the dynamic behaviour of future distribution networks and the increasing uncertainties. This requires more sophisticated methods that consider the implication of time (i.e. investment steps), deal with investment paths which can switch between different alternative solutions over time, and include 'smart grid' planning solutions. These advanced methods are especially necessary in cases with high uncertainties and large investment consequences. For example, in cases like [6], where scenarios with large concentrations of distributed generation has let to huge network investments, but utilization of new assets failed to happen due to changing scenario conditions. Appropriate network planning tools are necessary to deal with these kinds of challenges in future distribution networks.

Optimization methods for network planning

Planning tools for future application needs automated generation of alternatives and optimization capabilities, since increasing uncertainties and new (smart grid) planning options substantially increase the number of possible network expansion alternatives.

Guided by computer science innovations, many network planning optimization approaches have been developed from the scientific point of view [7]. These studies show that (distribution) network planning is by its nature a complex optimization problem and it still remains extremely difficult 'to solve' large-scale real power systems in a dynamic way (i.e. considering optimal investment paths) with a long-term time horizon. It is, therefore, necessary to employ the most efficient optimization methods. So-called heuristic optimization methods are a promising option for these purposes [8]. These methods allow precise modelling of the optimization problem and seek good solutions to very complex problems, yet in a reasonable computational time. A DNO will have various objectives that need to be optimized at the same time in finding the optimal network expansion plan (e.g. investment costs, operational costs, reliability, losses). This will make the optimization problem multi-objective. Compared with single-objective optimization problems, which have a unique solution, the solution to multi-objective problems is a set of solutions that correspond to trade-offs between objectives. Exploring these trade-offs is particularly important because it provides DNOs the ability to understand and weigh the different choices available to them. Summarizing, future planning tools need automated multi-objective optimization capabilities. Evolutionary algorithms, a heuristic method, appears to be the most suitable candidates at this time for this purpose and future works should consider the state of the art in evolutionary computation [8].

Long term planning approaches

There are different network planning approaches regarding the implication of time. A common approach in network planning is to determine the optimal network situation for a certain scenario at the end of the planning horizon (see figure 2a). In literature this is also known as the *static planning problem*. The planner is not (yet) interested in determining when new power system parts should be installed, but in finding the final optimal network structure for a given (static) scenario of generation and load. The static planning specifies where and which type of new equipment should be installed in an optimal way that minimizes the installation and operational costs. Which new assets and in which topology these assets should be installed, depends on the network expansion strategy (see next section). A more desired planning approach for DNOs is solving the *dynamic planning problem*. This implies that the load and generation in the network is modelled dynamically. Furthermore, various stages are considered and an optimal expansion schedule or strategy is outlined over the whole planning period (see figure 2b). DNOs can thereby accommodate the changing demand/generation at minimum cost, using a long-term planning horizon. This dynamic planning problem is a larger and more complex optimization problem than the static planning problem because it has to consider not only the optimal quantity, placement, and type of expansion investments, but also the most suitable times to carry out the investments. Therefore, dynamic planning requires the consideration of many variables and constraints and it imposes enormous computational effort in order to achieve an optimal solution, especially for large-scale realistic distribution networks [7]. The previous two planning approaches only consider a single static input scenario. According to the decision-making-under-uncertainty philosophy, a decision should be made considering multiple uncertainties/scenarios [2]. A single scenario cannot cover all potential future developments. Therefore, DNOs require a dynamic network planning optimization environment for finding the most optimal investment path considering multiple scenarios (see figure 2c).

Classic and 'smart grid' planning solutions

An automated optimization environment for network planning needs to know the available planning solutions to solve a bottleneck in the distribution network. The so-called decision variables of the optimization algorithm should be specified in such a way that it resembles realistic expansion strategies/options. For this reason, classic expansion strategies (i.e. expanding the network with additional cables and transformers) need to be included. Figure 3 depicts an example of classic expansion options in a typical Dutch MV distribution ring (radially operated). In this example case, for some reason, the first segment of the lower feeder exceeds the allowable limits (e.g. overloading). A possible solution to solve bottlenecks in MV rings is network reconfiguration, i.e. moving normally open points (*option 1* in figure 3). Another option is to replace the specific cable one-by-one with a cable of higher capacity (*2*). Adding a total new feeder to the ring, half-way the existing feeder (*3*) or half-way the ring (*4*), result in a significant increase in capacity. Consequently, new NOPs should be placed in order to guarantee radial operation and an evenly distributed cable loading. Moreover, it is possible to connect the ring by a new cable with another existing or new MV distribution ring / substation (*5*). In conclusion, it is necessary to model these kind of classic expansion options accurately in order to find realistic and optimal planning solutions.

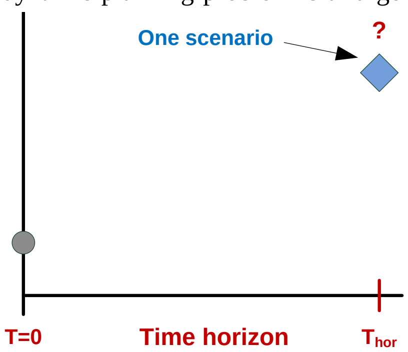

Fig. 2a. Graphical impression of *static planning problems*

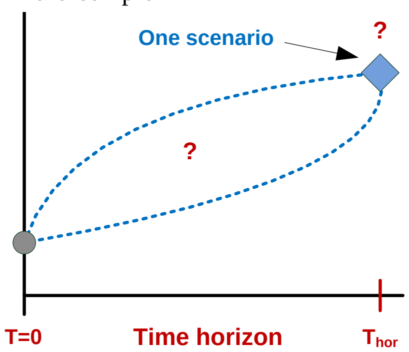

Fig. 2b. Graphical impression of *dynamic planning problems*

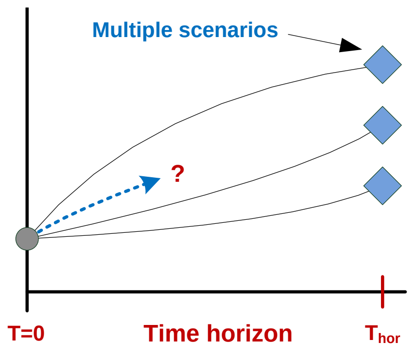

Fig. 2c. Graphical impression of *dynamic planning problems under uncertainty*

Future network planning tools should not only consider classic expansion strategies but also intelligent ones (e.g. energy storage and controlling active demand). From a planning point of view, it is interesting to see the effect of storage and demand side management on the asset (peak) loadings. Since the peak load is an important design parameter, reducing the peak load, or damp the effect of new load growth, will postpone network investments. This should be quantified and the 'smart grid' solutions should be included in the optimization environment as viable alternatives for network planning.

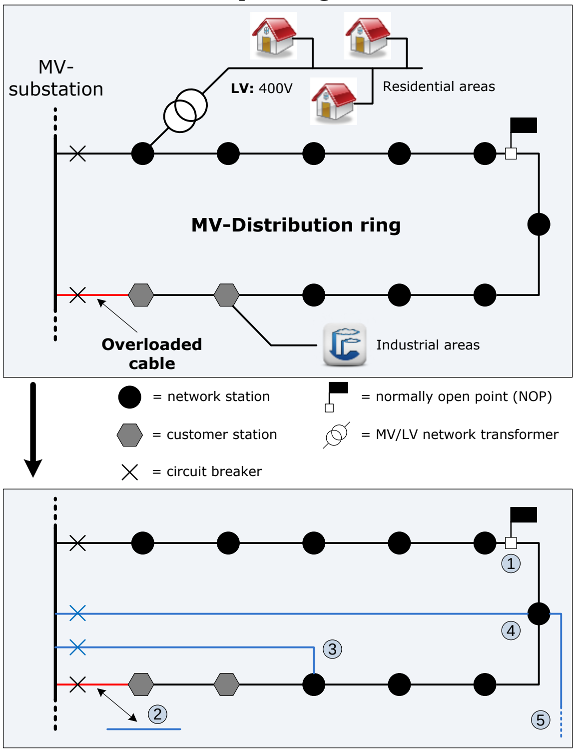

Fig. 3. Classic expansion options in MV distribution networks

Other requirements

Apart from capacity, reliability is also an important aspect in routine network planning. It should therefore be investigated how reliability aspects can be incorporated in a network planning tool. However, this is not at all straightforward, as the reliability observed in reality is influenced by many different factors which are often difficult to model in an absolute sense [9]. Furthermore, probabilistic forecasting methodologies, combined with advanced risk management tools, might be required for risk reduction, better estimation of risks, and eventually more founded decisions [2].

CONCLUSIONS AND FUTURE WORK

Until now, decision making in network planning is mainly done using traditional approaches, practically without the support of automated optimization tools and methods. The existing tools will no longer be satisfactory for future application due to present developments in the electricity sector that increase uncertainty. Advanced decision support tools are necessary to deal with the challenges in future distribution networks. These tools need automated generation of alternatives as well as optimization capabilities, since inclusion of time aspects and new (smart grid) planning options substantially increase the number of possible network expansion alternatives. Moreover, automation can reduce the effort required and improve consistency (i.e. contributes in standardizing the planning process). Applying multi-objective optimization methods will present decision makers a collection of different "trade-off" solutions. Overall, these properties require very efficient optimization techniques. Advanced decision support tools would thus greatly help DNOs to make better decisions under uncertainty, which contributes to an affordable, sustainable, and reliable electric energy supply. Our future work will deliver such tools, taking into account the abovementioned considerations regarding future network planning.

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