A BASIS FOR SMART PLANNING: REQUIREMENTS FOR EXPANSION PLANNING OF FUTURE DISTRIBUTION NETWORKS

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ABSTRACT

This paper investigates recent developments in distribution network expansion planning and aims to provide a starting point for those interested in integrating new concepts and technologies in the planning process to develop a new future proof 'Smart Planning' approach. The use of more detailed load models is necessary to properly taking into account the impact of new (stochastic) generation and loads and accurately assess the benefits brought by smart grid technologies. A modern planning approach should also be able to account for the impact of the smart market and, to achieve a true optimum, include the costs and benefits for all involved stakeholders.

INTRODUCTION

To cope with the effects of the ongoing energy transition towards a sustainable society, new innovative techniques and technologies are being developed, enabling new possibilities to create a so-called smart grid. In such a smart grid advanced monitoring and control operations are enabled by means of additional ICT infrastructure, and involvement of consumers in the electricity market may be facilitated [1].

To sensibly and optimally integrate these new innovations in the electricity networks it is not sufficient to merely look at what is technically optimal, but societal needs and wishes must also be taken into consideration. Different smart grid strategies are possible, with different main goals which impact the involved stakeholders in different ways [2]. These numerous different stakeholders all have their own, more often than not conflicting, goals and incorporating new technologies subject to these different views asks for a new look at the network planning process. On top of that it is increasingly clear that maintaining the classic 'fit and forget' planning approach with worst-case scenarios considering new technologies will lead to massive network investments [3], which may be reduced by applying smart grid techniques.

This paper investigates recent developments in distribution network expansion planning and aims to provide a starting point for the integration of new concepts and technologies in the planning process by developing a new future proof 'Smart Planning' approach.

The next section starts with an overview of several relevant actual research topics related to network planning and identifies various promising techniques. Then the expected upcoming challenges are discussed and it is considered how the new techniques can be used to successfully integrate the smart grid concept in the planning process and help to cope with these challenges.

DEVELOPMENTS

As depicted in figure 1, the network planning process is conceptually straightforward. Gathering the necessary data, forecasting the expected load and generation, developing possible alternatives, evaluating the alternatives' feasibility and effectiveness and finally selecting the 'best' alternative based on a set of criteria.

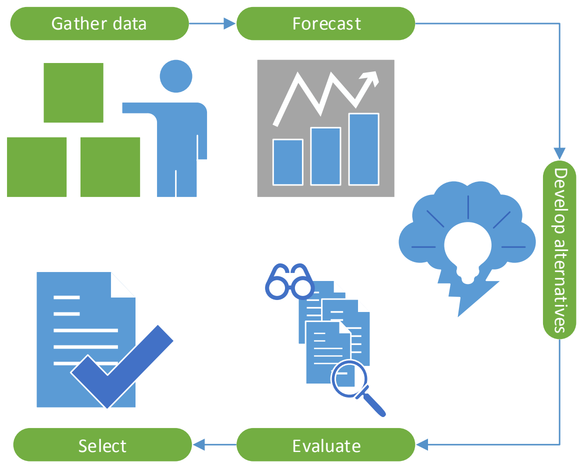

Fig. 1. The essence of the network planning process

With the advent of the smart meter and an increase in measurement points in the grid itself more, and more detailed, data is becoming available. In order to use this to its full extent a prerequisite is knowledge about what data is necessary and to what level of detail.

Load profiles and forecasting

Most utilities apply a peak-planning approach to estimate and forecast network loading. These are usually based on periodical peak measurements and/or yearly energy usage, i.e. Rusck/Velander [4], while using coincidence factors to account for simultaneity of loads. Load growth is extrapolated from historical peak load trends complemented with information from city and country planning. While these techniques have proven effective over multiple decades the increase in renewable and distributed generation (DG), as well as the addition of ‘new’ loads (i.e. electric vehicles, heat pumps) and the trend towards more efficient grids has spurred the demand for more detailed load models. Moreover to properly consider smart grid concepts (e.g. energy storage, dynamic reconfiguration) as viable alternatives in planning a profile modelling approach becomes necessary [5].

Different load profile modelling methods exist, for instance methods that use aggregated empirical data and assign specific profiles to defined user groups [6][7]. Recent research has also been done to expand these methods with measurements from automatic meter reading (AMR) or smart meters to improve precision [8]. However, these do not take into account the changing profiles due to addition of new and upcoming technologies.

Another approach described in literature is the bottom-up approach [9]. These methods starts at the level of individual users or appliances, which are subsequently aggregated in different ways [10][11]. Advantages are that potentially very accurate load estimation might be achieved and no empirical data is required, ensuring broad applicability. However, obtaining the necessary information on local users and appliances may pose too large a challenge in practice. Moreover even if these data might all be available, the level of detail obtained with such approaches (while surely useful for short-term forecasts) may be rendered obsolete by the uncertainties in the >10 year time horizons which are common in network planning.

An approach able to include upcoming and future technologies is described in [1]. In this scenario-based methodology aggregated profiles per individual new technology are developed and then summed up with the regular residential demand for several different future scenarios. Because the new technologies are modelled separately, different growth and penetration scenarios can be investigated.

In [12] demand/supply profiles are generated stochastically, integrating all the impacts of the uncertainties to grid capacities. This also allows for probabilistic analysis which enables for instance estimation of probabilities of overloads. Such an approach was applied in [13] to investigate the influence of distributed generation on planning methods.
Taking into account the probabilities of occurrence of certain peak loadings supports the possibility of integration of new (smart) planning alternatives to deal with these peaks. Combining this with modelling the new developments separately as in [1] allows for analysis of different future scenarios. While the increased observability in the grid caused by smart meters can assist in verifying and continuously improving the accuracy of these new load and generation models and profiles.

Smart grid expansion options

The changes on the load and generation sides have also raised interest in new innovative ‘smart’ ways to facilitate this transition on the grid side and progress towards a more efficient and sustainable electricity network. A few examples of such smart expansion alternatives are given in figure 2. Technical possibilities and grid impact of individual smart technologies are widely discussed in literature but a view at actual grid integration from a planning perspective is a relatively new field.

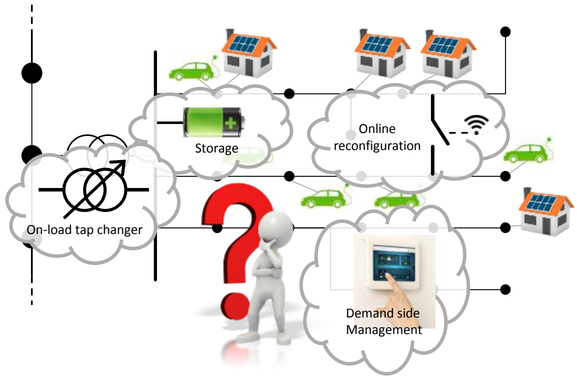

Fig. 2. Example of several 'smart grid expansion options'

Energy storage is one of the prime examples of a smart grid option, possibly offering services such as load levelling, energy loss reduction, balancing and voltage support [14]. Although the investment costs are still high, the possible flexibility provided by storage might make it an attractive option in the future, especially for high penetration rates of DG and new loads [3]. Depending on regulation, an energy storage may be owned by the DSO or by an independent operator. This has severe consequences for the goals, costs and benefits linked to such a system and poses one of the barriers as to how it should be integrated in grid planning. Integration and comparison to traditional planning for DSO-owned storage systems is shown in [3] and [14]. Reference [15] investigates an independently owned storage system, and also includes multiple-stage investments. In either research the overall objective was the minimization of total costs for the DSO. The use of more detailed load models, such as discussed in the previous paragraph, are a necessity to be able to accurately quantify the benefits brought by energy storage systems. Moreover, the way in which storage is integrated into the market will have a large impact on the quantity and allocation of these benefits and should therefore also be regarded.

Another possible smart grid option is the use of on-line reconfiguration of grids, which can increase reliability of supply as well as lifetime of components while reducing operational losses [16]. By being able to remotely or automatically open or close connections, outages can be cleared faster and cable or transformer loadings can be partially controlled. Next to the possibility of reducing operational losses, partially controlling component loadings can also lead to investment deferral by being able to relieve overloaded network components by temporarily transferring load to different feeders. This does however require knowledge about the time and probabilities of occurrence of local peak loads.

Local voltage control using for instance on-load tap changers (OLTC's) is a solution which may be of use in areas with a significant voltage swing due to large presence of DG [17]. This can defer traditional network upgrades when the voltage level is the first limiting factor and capacity congestion is not yet reached. Voltage support can also be realized with VAr control which allows for power factor correction by for instance switched capacitor banks [18] or influencing DG inverter set points [19]. Again accurate load models will be required to accurately predict the benefits of Volt/VAr control and integrate them in network planning [18].

Demand side management (DSM) might also be regarded as a smart grid solution because it can also significantly impact the grid, due to shifting of loads to off-peak times or more closely matching local demand and supply, without using traditional network investments. Especially with growing penetration of heat pumps and electric vehicles there is huge potential to use DSM to defer network investments, because of the large potential peak loads and large flexibility potential of these technologies. However, enabling DSM means adding more active users to the mix, that might also have negative impact on grid investments depending on how the market is organized. Therefore a planning approach incorporating DSM should not only take capacity limits into account, but also look at the operation of the (local) energy market [20].

Smart market

Several smart grid solutions such as energy storage and DSM include more actors than just the DSO. Most notably for DSM the end-users of electricity are becoming directly involved and can have a direct active influence on its impact, whichever overarching goal is aimed for. Their behavior is therefore important to take into account in power system planning [21].

To enable DSM (local) smart markets will be organized, providing consumers and/or prosumers with (price) incentives to shift their load or generation. Ideally these smart markets would not be limited by the grid, such that the social surplus of the market can be maximized. This could however potentially lead to large required grid investments and consequentially high overall costs for society. On the other hand by including grid constraints in the incentive signals grid costs can be limited and an optimum can be achieved for society as a whole.

Several pilot projects exist where the operation and grid impact of such a smart market is investigated, such as for instance discussed in [22-24]. Adopting different market optimization and distinct ways of involving the end-users in the market. Because different pilots implement the simultaneous optimization of the goals of various stakeholders in different ways the impact of DSM in different settings can be analyzed. However the challenge to integrate the implications of such a smart market into distribution network planning remains.

The impact of DSM and different smart market strategies may be pre-modeled in the load profiles as was done in [1]. However, this treats the implementation of the smart market as a given fixed impact. In order to find a real optimum between integrating smart grid solutions and limitation of the smart market, it should be modeled as a decision variable in the optimization model [5].

Planning tools

At present, smart grid expansion options are not factored in as serious options in practical distribution network planning [25]. From the previous paragraphs it becomes clear that properly assessing the costs and benefits brought by new smart solutions require more detailed modelling and calculations than most grid operators apply so far. Also the (often conflicting) objectives of different stakeholders have to be taken into account to find 'compromise' solutions that benefit all stakeholders [26]. Therefore there is a tendency to develop advanced planning tools to support grid operators in their alternative evaluation and decision making. In such planning tools several aspects such as multi-objective optimization, reliability constraints, modeling under uncertainty and multi-stage planning, which are usually treated separately can be dealt with in an integrated way [27].

Increasing complexity due to the dynamic behavior and increasing uncertainties in future distribution networks, require these tools to adopt advanced optimization algorithms [28]. Many different classes and types of optimization algorithms have been developed over the years [29]. Present research focuses mostly on heuristic methods, such as Genetic Algorithms [30] or Particle-Swarm-Optimization [31]. These are able to deal with multi-objective optimization and can handle large search spaces.

Two major barriers for implementation lie in the fact that DSOs are not used to using custom (if any) optimization codes and that some of the proposed techniques cannot consider a sufficient range of scenarios to tackle real world problems [32]. On top of that there are no tools as of yet that take into account an integral optimization that includes advanced smart grid solutions and the implications of smart market strategies.

FUTURE CHALLENGES

Looking ahead we can distinguish several challenges for network planning to be able to properly deal with the upcoming developments.

The first challenge lies in developing suitable (stochastic) load/generation models. These must be detailed enough to take into account operational aspects relevant for planning, properly represent the uncertainty and also be able to factor in future technologies.

Secondly, determining the costs and benefits of implementing smart grid solutions. These have to reflect both DSO and other involved stakeholders.

Thirdly, taking into account the ways in which the future smart market may be organized and combining this impact with the smart grid solutions to find a true optimum for integration of these new technologies.

Finally, integration of the previous three in an integral planning approach, assisted with suitable planning tools, able to execute the necessary calculations and provide network planners with clear information.

CONCLUSIONS AND FUTURE WORK

Improving distribution network planning is a topic of continuing high interest, and therefore is and has been the focus of many researches. Due to the recent increase of distributed and renewable energy resources and upcoming smart grid technologies we see a shift from the deterministic peak planning methods to more detailed and probabilistic modelling. This increasing complexity goes hand in hand with a renewed focus on planning tools and optimization methods. At this point an important issue is integration of new developments in the planning of the future (smart) grid. So far, only few and relatively small use cases are available where smart grid solutions are integrated as viable expansion alternatives, and costs and benefits of these new options are subject to many uncertainties. Moreover an integrated approach considering both smart expansion options as well as the smart market concept is important to maximize the benefits. And while it is clear that in integration of smart grid concepts many parties are involved, the number of studies that take into account overall costs and benefits for all these involved actors is still limited.

Future work should not only focus on refining models, but even more so on improving practicality of developed methods. Also if many new technologies are to be applied, a deeper insight must be obtained in their overall costs and benefits for society as a whole. Ultimately, a practical, integral planning approach should be developed, considering both classical and smart grid solutions as well as integrating user flexibility, optimizing for overall cost and benefits for all actors involved.

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