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A General Framework for Active Distribution Network Planning

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SUMMARY

The "Copernican revolution" from the current passive distribution system to the future Smart Grid paradigm aims at applying at distribution level techniques and solutions that have been used for decades in the transmission system. The future availability at this level of an integrated system for its operation is changing the planning objectives that will be mostly oriented to the maximum exploitation of existing assets and infrastructures, by working them much closer to their physical limits than in the past. The future distribution network planning will be defined with less network investments since operation's issues can be fixed with the so called "no-network" solutions, like generator dispatch, demand side integration, control of transformer taps, reactive power management, and system reconfiguration.

For these reasons, it is crucial that modern planning tools for the Active Distribution Networks integrate network operation practices in the set of feasible planning alternatives, in order to identify the best technical and economic balance between the innovative active management (that tends to maximize the utilization of existing assets in distribution network) and the traditional network expansion. The representation of load and generators cannot be based yet on unique yearly values as assumed until now by the traditional distribution planning tools, but there is the need of adopting time-series (or time dependent) models, in order to capture the operational aspects that can affect the planning stage. Obviously, for an accurate comparison of the planning options, the costs of the active management implementation should be defined, taking into account the dependency on the ICT and on the Regulatory environment (policy for refunding investments, obligation to serve or remuneration of the ancillary services). However, this evolution of the distribution network planning tools is not an easy task and many challenges arise that have to be faced.

The paper presents the results of the activity conducted by the "Method for Active Network Planning" Task Force, part of the C6.19 working group, on this topic and proposes a general framework to be used as reference scheme for Active Distribution Network planning. Specifically, it is emphasised the need to apply probabilistic network calculations and risk assessments, to consider no-network solutions among the planning alternatives and to adopt Multi-Objective approaches.

KEYWORDS

Active Distribution Network, Distribution Planning, Probabilistic Network Calculation, Multi-Objective Programming.

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INTRODUCTION

In order to facilitate the integration of the imminent potential changes in generation (unpredictable renewable energy sources), load (plug-in electric vehicles) and the electricity infrastructure itself (electricity storage), the use of a more active approach of managing distribution networks (including both network elements and participants) has been proposed in the last decade by academia and industry. The CIGRE Working Group C6.11 highlighted the fact that Active Distribution Networks (ADNs) affect all planning activities and, consequently, Distribution Networks Operators (DNOs) need to move from the passive planning paradigm towards one where integration -not simply connection- of Distributed Energy Resources (DERs) is taken account of at a reasonable cost [1]. The availability of communication, monitoring and control systems at a distribution level will increase the observability of these systems and it makes possible to operate them much closer to their physical limits than in the past. Future distribution network planning will in many cases result in less traditional network investments since operation issues can be fixed with the ADN solutions such as generator dispatch, demand side integration, reactive power management, and system reconfiguration. Therefore, ADN solutions will have a significant role in the optimal development of the distribution network and they have to be implemented in modern planning tools [2]. For these reasons, the CIGRE WG C6.19 was activated in August 2010 with the aim to address the following issues:

1. Survey on the state of the art on planning for active distribution systems;
2. Requirements of planning methodologies (a questionnaire has been sent to distribution companies and a summary of the results of this questionnaire will be presented);
3. Identification of short, medium and long term models for active distribution system planning;
4. Reliability models of active distribution systems;
5. Algorithms for active distribution system expansion and upgrade planning, including demand-side integration and storage.

The survey carried out to determine the state-of-the-art and identify which developments are needed for the planning of ADNs showed that 90% of the respondent utilities follow traditional steps of the typical planning process [3]. Clearly, while ADNs concepts interest many utilities, they are not yet considered as viable alternatives in the planning process, due to the lack of suitable planning tools and of ad hoc business cases that prove the corresponding benefits.

This paper provides the results of the Working Group activities on the methodologies and models for active distribution network planning, by proposing a general framework to be used as reference scheme for modern planning tools.

TRADITIONAL DISTRIBUTION NETWORK PLANNING

Distribution networks are, in general, sized to cope with the worst-case scenario (mainly in terms of loads and voltage drops, and certain security constraints) of a given load forecast and in a way that minimum or no operation is required. This approach, known as 'fit and forget', is carried out in a deterministic way, i.e., without considering uncertainties. Fig. 1 presents a generic flow chart that resembles this common practice. Once a planning study is defined, different alternatives might be considered. These are then technically assessed taking account of the (load) conditions for the corresponding planning horizon. If a planning alternative is not technically feasible, network reinforcements are applied. Otherwise, the next step is to evaluate the corresponding cost. The most cost-effective solution is finally the planning alternative likely to be adopted.

When it comes to connecting distributed generation, the ‘fit and forget’ approach is also applied. Although other relevant technical aspects such as congestion, voltage rise, reverse power flows, etc. are considered [4], it is mainly based on maximum generation-minimum demand scenarios that, for renewable sources, do not occur frequently. While this passive way of planning and operating distribution networks has proven cost-effective in the last decades, it might in the future become a barrier for increasing penetrations of DG and non-conventional loads. In addition, the uncertainties in planning consents and financial support surrounding medium-scale DG investments pose DNOs with major challenges as to what, where and when to reinforce the system, in order to facilitate the transition to a low-carbon economy without the risk of stranded assets. This lack of certainty and planning coordination translates into DNOs often connecting DG plants in the aforementioned ‘fit and

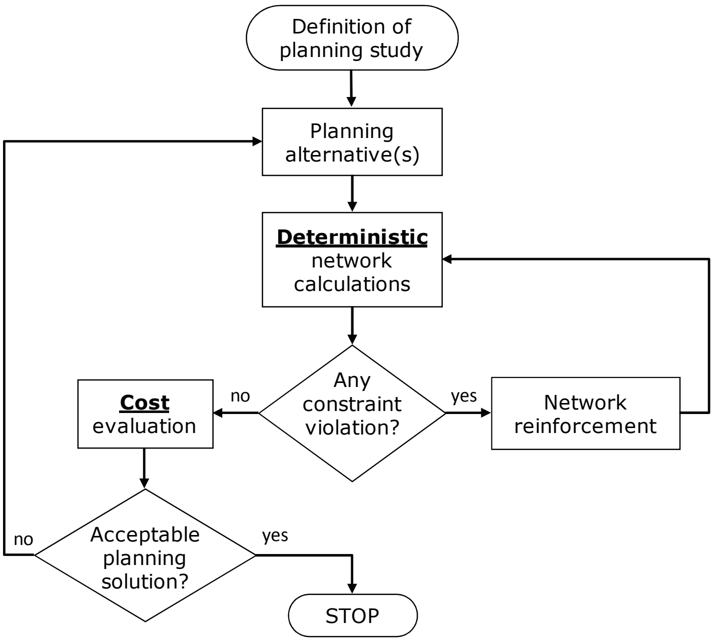

Figure 1: General Planning Framework for Passive Networks.

forget', case-by-case manner. Thus, any sophisticated solution –albeit potentially more cost-effective for society in the long term– is left behind.

To overcome most of these inadequacies ADN solutions can be incorporated in the planning procedure in a way that uncertainties are also accounted for.

CHALLENGES TOWARD MODERN DISTRIBUTION NETWORK PLANNING

The key feature of a modern planning tool for ADNs is the integration of future network operation practices in the set of feasible planning alternatives in order to identify the best technical and economic balance between an innovative solution (that tends to maximize asset utilization) and traditional network expansion. To this end, the representation of loads and generators cannot be based on a snapshot of the operating conditions (e.g., max generation/min demand, min generation/max demand) as commonly assumed by current planning methods and tools. There is the need of adopting time-series (or time dependent) models in order to capture the operational aspects that can affect the planning stage. Obviously, for an accurate comparison of the planning options, the costs of the active management implementation should be defined, taking into account the dependencies on the ICT infrastructure and on the corresponding regulatory environment.

However, the development of new planning tools is not straightforward and many challenges arise that have to be faced. Some of them have been discussed in the following questions and answers in order to set the general framework required by modern planning tools for Active Distribution Networks and, in general, for Smart Grids.

To what extent do operational aspects need to be modelled in planning?

A modern planning tool for the ADN has to incorporate into its optimization procedure the features and the capabilities of the future active operation system. This requires the definition of models able to adequately represent the behaviour of operating solutions in the planning calculations. For instance, while fine granularities (e.g., minute by minute) are capable of capturing detailed operational aspects, when it comes to planning calculations they often prove to be unnecessary and can also lead to time-consuming processes, especially in medium- to long-term horizons. On the other hand, simplistic representations (e.g., daily or every few hours) will not bring the benefits from operational strategies to the planning studies, affecting the quality of the results. Consequently, specific studies should be carried out to identify the benefits that a more granular model brings as wells as its effects on the planning methodology, both in terms of computational time and quality of the planning solution.

To what extent are sophisticated tools needed?

The Smart Grid paradigm considers not only the integration, at a distribution level, of several distributed energy sources. It will also cater for the participation of customers in system operations by offering their loads and storage capability as resources. This vision implies a simultaneous active management of a huge number of energy resources (or actors) and network elements, making current techniques (such as energy management systems used by system operators) unfeasible. Future planning methods should be able to deal with real, large-scale cases but is crucial to investigate the role of simplified approaches in providing acceptable solutions.

How can uncertainties be dealt with?

Traditional distribution planning relies on deterministic models. The majority of DNOs still adopts this approach even with relative high penetrations of renewable energy sources in place [3]. However, more and more uncertainties will be faced in the future due to changes in demand, generation, prices, policy, etc. Therefore, modern planning should consider probabilistic methods in order to adequately consider DER and other sources of uncertainty [1]. This implies the creation of stochastic models and the introduction of risk concepts for the assessment of constraint violations. It should be noted that the application of a probabilistic approach to network studies is more complex and specific assumptions have to be done to make them feasible within a planning tool. Moreover, the uncertainties are not only related to the main data of the distribution planning problem but also the planning scenarios are uncertain due to potential changes in policy and the interdependencies with other infrastructure (such as gas and heat networks). Decision making under uncertain scenarios causes risks that should be explicitly dealt with by planning tools in order to allow objectivity and transparency [5].

How can ICT infrastructure be cost-effectively planned for the long term?

The integration of Smart Grid solutions requires a versatile two-way communication infrastructure that is more flexible and much more demanding than the existing one (low latency, redundancy, etc.) [6]. However, the lack of experience, the increase in complexity, and the use of novel communication systems are perceived by DNOs as weaknesses of ADNs. Reliability analyses and large-scale demonstration projects are necessary to reduce uncertainties and increase understanding of the corresponding implementation challenges. Current planning algorithms and software tools have significant shortcomings in dealing with these emerging issues. Considering that the communication infrastructure will not be an add-on to the distribution network but an essential part of it, increasingly responsible for the overall reliability, simultaneous analysis of both power and communication systems will be useful [7].

How should the huge amount of data in ADNs/Smart Grids be handled?

In order to make the Smart Grid envisioned controllability, making the system significantly observable is of paramount importance. Measurement devices act as the eyes of the grid, allowing constant monitoring of every aspect of the distribution network. They can operate as interfaces between DNOs and the end consumers (e.g., smart meters) or they can be devoted to the management of the network by sending information to the Intelligent Electronic Devices (IEDs). A significant challenge for the Smart Grid management is to tackle the huge amount of data that can arise when the number of monitored points and parameters increases. In fact, a typical fully centralized control scheme may not be able to process promptly all these data and the communication infrastructure may be patchy and without sufficient bandwidth. Therefore, the potential volume of data leads to the need of flexible and efficient control architectures that allows hierarchically limiting the information's flow to the Distribution Management System (DMS). Data aggregator modules should exist to collect data from the monitors, sorting them with specific priority criteria, combining less significant data and sending them via suitable wireless backhaul links to the nearby regional data centre. The data aggregator can also receive specific control signals from the DMS to operate available DER or network elements. This prospective vision is important for the correct representation of the ADN in reliability analyses, but it also affects the distribution planning. Indeed, with a hierarchical scheme the active management can be modelled only from the DMS to the data aggregators and MV level resources (network elements and medium-scale DER), or from the data aggregators to the consumers and LV level resources (network elements and small-scale DER).

How can the business case for ADNs be correctly assessed?

One of the main goals of a planning tool is to find the most cost-effective solution. In contrast to the current distribution network architecture, the future ADN has several unknowns when it comes to cost. Two factors are responsible for this: the relative young age of many technologies that will be applied, and the lack of a clear regulatory environment. While the unknowns on these new equipments affect the definition of their CAPEX and OPEX, the absence of well-defined rules to govern the future active management makes doubtful the return on investment. However, if well structured, modern planning tools will help DNOs to perform comparative analyses among different planning solutions by comparing benefits, costs and risks in a Multi-Objective approach, but they can be useful also for regulators when verifying the impact of different regulatory scenarios. For the latter, it will come in handy the availability of reference models and reference distribution networks for benchmark studies.

GENERAL FRAMEWORK FOR ACTIVE DISTRIBUTION NETWORK PLANNING

Despite the different approaches followed by researchers and distribution engineers, a general framework can be proposed and used as the reference scheme for ADN planning. In contrast with the traditional distribution planning philosophy, calculations should be based on probabilistic approaches to capture the uncertain behaviour of the demand and the generation. In addition, the assessment/comparison of alternatives can also be based on one or more objectives.

The most significant changes that should characterize the new planning tools for ADN have been included in a general framework for ADN planning (fig. 2) proposed by many authors [2] and accepted by international organizations [1] even though not yet exploited by DNOs [3].

Data modelling

Traditionally, techniques of load analysis and synthesis were applied to generate characteristic load

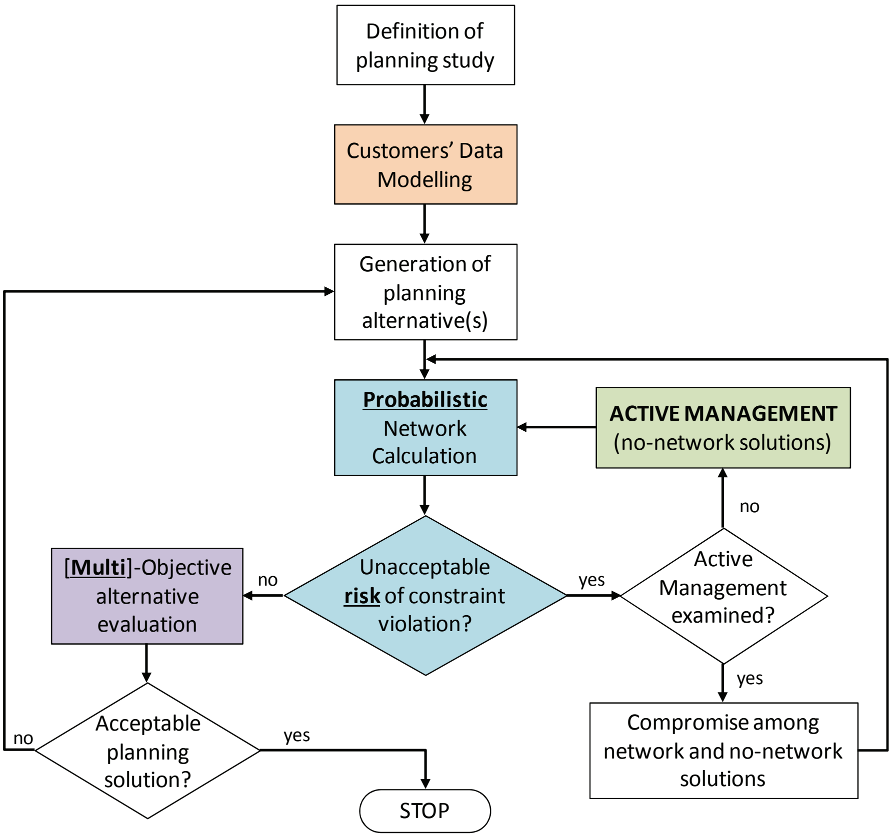

Figure 2: General procedure for Active Distribution Network planning.

profiles used to categorize customers into different classes - an approach still used by most distribution utilities. The results of the load analysis were used to produce suitable approximations of the peak demand based on annual energy consumption. This traditional representation was used in distribution planning studies by assuming unique annual values of demand and generation. Peak values were calculated to identify worst-case operation conditions. They were also used, with a constant annual growth rate, in the 'fit and forget' approach to plan network expansions for a given horizon. Average values (if necessary) were considered to estimate Joule losses and for reliability analyses. The main drawback of this deterministic approach is that the distribution network is designed assuming the worst-case conditions as certain, even if actually they have a very low probability of occurrence.

These simplified representations are unsuitable for the planning studies of future ADNs. In order to capture the operational aspects that can affect the planning stage, the variability of demand and generation has to be explicitly represented. As aforementioned, the challenge is to find to what extent operational aspects need to be modelled in planning, in order to bring the benefits from operational strategies to the planning studies without resorting to excessive granularities (time-consuming) or simplistic representations (low quality of the results).

Two possible directions can be followed to represent the hourly variability of demand and generation: classify all the states in a year and group them in some typical conditions [8] or identify distinctive daily profiles adopted for the whole year or differentiated for seasons [2]. In each operating condition (clustered period or elementary interval of typical days) the active management can be taken into account as a valid planning alternative (no-network solution) to the traditional ones in order to solve possible constraints violations (e.g. curtail DG production instead of upgrade network equipment) or to improve network performances (e.g. reduce energy losses).

Probabilistic Calculations

The uncertainties that are inherent to current and future distribution networks suggest both the use of probabilistic models to better represent planning data and the introduction of the risk concept in the selection of planning alternatives. Depending on the adopted stochastic distributions (i.e., Gaussian, Beta, Rayleigh, etc.), network calculations can be performed by tailored probabilistic load flow (PLF) algorithms or the more general Monte Carlo simulation approach. The results of these calculations are the stochastic representations of the nodal voltage and branch current variables. Technical constraints can then be verified with a relative confidence (acceptable risk of violation).

It should be recognised that probabilistic calculation are sometimes complex and cumbersome and it is often not easy the proper modelling of distribution systems particularly when strong correlations do exist among the stochastic variables and external correlations are imposed by market or by operation control centres. Also with parallel computing, the application of a precise approach causes a dramatic increasing in the computation time, especially for planning purposes where calculations has to be repeated several time within an optimization procedure (for network design or DER allocation). Consequently, some simplifications should be adopted to make this problem more manageable, as for instance the linearization of the load flow equations and the assumption of normally distributed random variables [2]. In any case, investigations should be done to check the validity of the assumed simplifications in terms of planning results.

ADN Implementation

The first step to integrate ADN solutions into planning is the identification of impacts from control strategies. For instance, operation of automatic voltage controls have small time delays, requiring the use of high granularity time-series representation of loads and generators. However, during normal operation, no significant changes are expected on voltages and currents after control actions take place. Therefore, this kind of controls has in general very low impact on planning studies. Continuous power flow management, instead, can change Joule losses which constitutes a fundamental performance parameter in distribution networks, affecting Operational Expenditure (OPEX). The potential provision of reactive power support to the transmission system, could also influence the location and sizing of DER, its corresponding revenue (depending on the regulatory environment), and even the network expansion plan. Moreover, most ADN solutions used to tackle capacity related issues have a direct impact on the Capital Expenditure (CAPEX) as they defer investments that otherwise would be needed. When security of supply requirements, such as N-1 contingencies, are considered, the deferred infrastructure (and hence CAPEX) could be even more significant.

Considering the above and modelling demand and generation data through daily profiles, it is then possible to technically assess each potential planning solution (Fig. 3). At first, the network is pre-sized using existing or minimum allowable cross-sections. Then, for each time interval and network configuration (normal and under contingencies), all nodal currents injected or absorbed are identified from the input data. If operational actions from a particular ADN solution are considered, they have to be integrated at this point to modify the known variables of the PLF (for instance, the optimal scheduling of a distributed energy storage device). The stochastic network calculations should identify the expected values as well as the standard deviations of nodal voltages and branch currents (used to check the risk of constraint violations). If some contingencies appear, the procedure tries to solve them initially through the use of ADN solutions or alternatively with network upgrades. Because the former might require the control of energy resources (generators, storage, loads), its implementation is formalized as a classic Optimal Power Flow (OPF) problem. To reduce the computational burden, this sub-problem can also be simplified (e.g., linearized and solved with Linear Programming techniques). The outputs of this global procedure that will be used to assess the fitness of the planning solution are the expected values of the branch currents (used to evaluate the energy losses), the network upgrades, and the statistics of the ADN interventions, needed to estimate the operational costs of the corresponding solution (e.g., due to the provision of ancillary services).

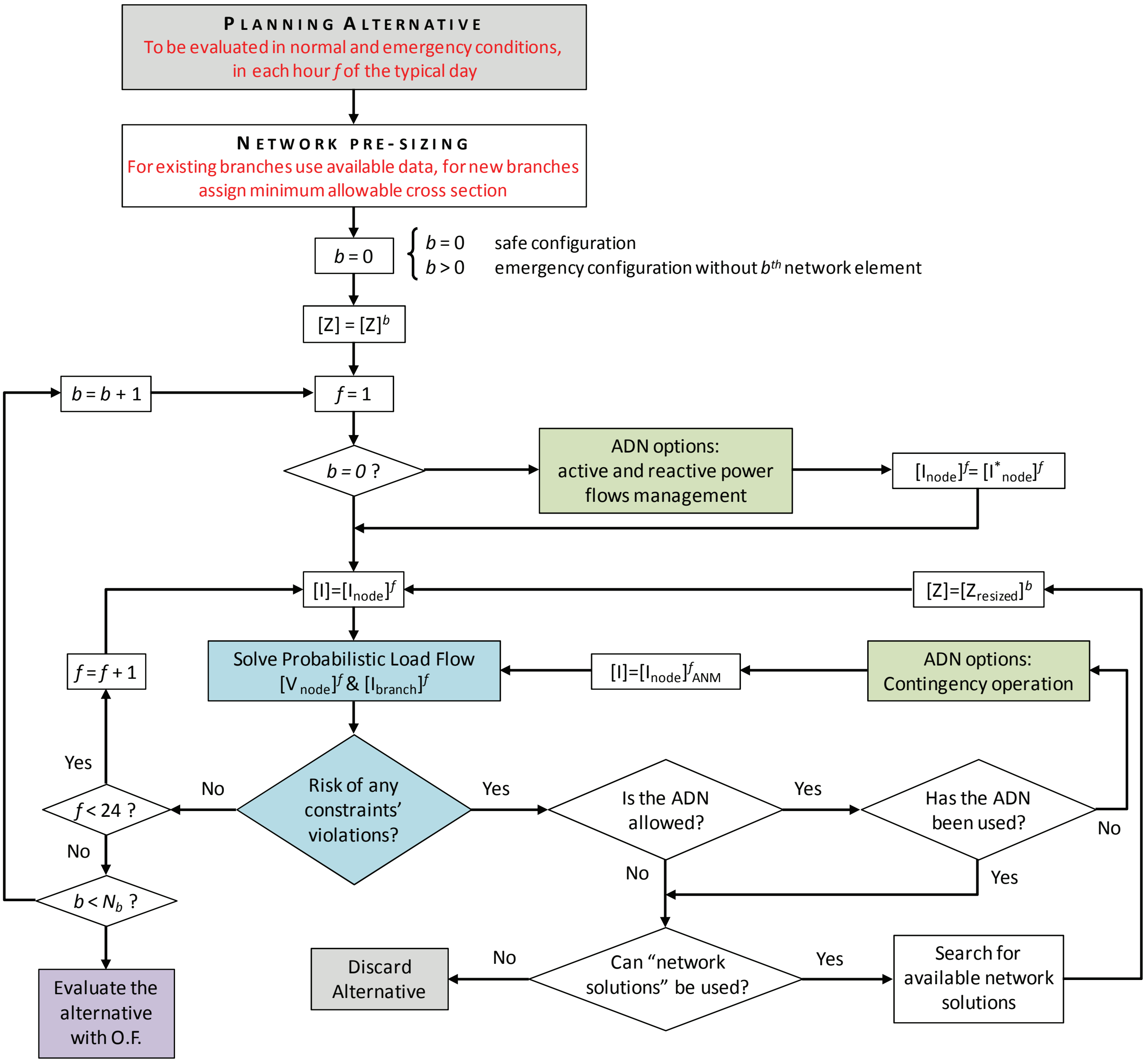

Figure 3: Flow chart of the technical assessment of planning solutions.

Multi-Objective Approach

In the uncertain scenario that characterizes the future ADN, Multi-Objective (MO) approaches could prove to be useful for utilities compared to the traditional single objective function of minimizing the overall network cost. In fact, the impact of several new technologies and control architectures required by ADNs is hard to characterize exclusively in terms of costs. The lack of clear rules that should govern ADN solutions (e.g., incentives for ancillary services) also adds complexity. Therefore, it is easier and more effective to keep separated the various and non-homogeneous objective functions by comparing known costs with benefits brought about by ADN solutions measured in terms of specific performance indexes. Moreover, the liberalization of the electricity market has broken the vertical monopoly into different players where competition exist at the generation and commercialization ends and regulated monopolies exist at transmission and distribution levels. The need to find good compromises for the conflicting goals of the stakeholders and the difficulty in defining a single objective function is another significant reason that leads to the use of MO approaches.

MO programming is a powerful tool but one of its strengths could also be interpreted as a weakness: the provision of more than one solution requires expert interpretation and this might be left open to the subjectivity of the planner. For this reason, this modern approach has to be always combined with the application of Decision Making tools that assign a fitness value to a planning solution representing the overall goodness or risk of its implementation.

CONCLUSIONS

A possible course has been charted for the evolution of the planning tools of the future Active Distribution systems, highlighting the main points of improvement against the traditional planning procedures. However, DNOs are traditionally risk-averse given that their paramount objective is to (safely) keep the lights on. Due to the many uncertainties related to the adoption of future technologies by end customers, planning permissions for medium to large-scale generation, life-span of electronic-based components, regulatory frameworks, etc., it is even more difficult for DNOs to make investment decisions that will not end up as stranded assets. Consequently, the adoption of ADN will only happen if clear business cases or incentives are in place. The next activities of the CIGRE C6.19 WG are focussed on preparing such business cases that will be included in its final report in 2013.

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