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Multi-Criteria Analysis for decision making applied to active distribution network planning

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ABSTRACT

Along with increasing presence of renewable energy in the distribution network, active network planning approach is of utmost interest for distribution system operators to harness the maximum benefits from the resources. However, it has been a challenge for the decision maker to choose the optimal planning option considering the multiple conflicting criteria. In this paper, a systematic and automatized approach for project selection based on Multi-Criteria Analysis is proposed for assessing a large set of planning alternatives. A case study has been done for a typical rural distribution network, a Pareto front of planning alternatives obtained by means of a multi-objective optimisation is analysed. Each alternative involves the optimal siting and sizing of storage units along with traditional network upgrading solutions. An automatized pairwise comparison procedure within the Analytic Hierarchy Process is proposed for rejecting subjectivity. The promising analysis illustrates the 'best' project selection considering nine criteria for storage system deployment to provide flexibility to the distribution network. The proposed approach aims at identifying the planning alternative that best satisfies the stakeholders' expectation considering the multiplicity of decision makers' points of view.

1. Introduction

Currently, the electrical power system is facing a paradigm shift led by different political, economic, and technical drivers. The liberalization of the electricity market and the penetration of the renewable energy sources changed the behaviour of the distribution network. Since the related capacity installed became significant in the distribution network, innovative approaches for planning and operation have become necessary. As highlighted in Refs. [1,2], the traditional *fit and forget* approach is no longer effective due to the opportunities from the active management of distribution network. Unlike the *fit and forget* approach which is based on traditional network reinforcement (e.g., building new lines and substations, and/or upgrading the existing ones), the active management approach involves the *non-network* solutions as development (e.g., generator dispatch, demand-side management, reactive power management, system reconfiguration, etc.). In this context, the maximum exploitation of the existing infrastructure can produce more cost-effective solutions if uncertainties are properly managed with probabilistic optimization for risk containment [1,2].

Since the increased complexity, the modern distribution planning should be based on multi-objective approaches that are able to analyse, make compromises and select solutions among different alternatives [1,2]. In fact, distribution planning involves conflicting objectives such as maximize hosting capacity, reduce energy losses, improve service quality, reduce capital expenditure (CAPEX) and operational expenditure (OPEX). In literature, several optimization algorithms are used for solving the multi-objective problems; however, when multi-objective methods minimise an unique Objective Function (OF) obtained as the sum of multiple sub-objective functions they actually convert the multi-objective problem to a single objective [3]. This approach does not allow minimising/maximising the OFs independently; with the aim to find a number of optimal planning alternatives without introducing any a priori subjective preferences, a "true" multi-objective algorithm can be more effective [1]. The multi-objective a posteriori methods based on *evolutionary algorithms* have been widely studied for devising Active Distribution Network (ADN) planning alternatives [4–7]. The main advantage of multi-objective evolutionary algorithms used for network planning is the devising of a set of Pareto optimal alternatives of abstruse planning problems. However, when the Pareto front contains a large number of alternatives and/or the OFs are more

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than two, then it is difficult to accomplish a simple decision-making process [1–3]. In this context arises the main drawback of multi-objective planning, identify the best planning option became tremendously difficult for decision makers. In order to outclass this shortcoming, a systematic and automatized analysis of the Pareto front is necessary.

With the aim to identify the planning solution that best fits with the decision maker's point of view, the use of Multi-Attribute Decision Making (MADM) technique has been introduced in Literature [8–11]. In Ref. [8] a fuzzy Analytic Hierarchy Process (AHP) is used to rank a set of four smart grid planning alternatives. The case study concerns the siting and sizing of distributed generator in radial distribution feeders (IEEE 33-bus). A hierarchical structure of evaluation criteria is used, and criteria weights have been elicited according to the societal point of view by consulting a pool of experts. They proved that Multi-Criteria Analysis (MCA) is highly successful in the evaluation of alternatives in the presence of heterogeneous criteria. The selection of the best distribution planning alternative among a set of 3 options is made by means of the TOPSIS technique in Ref. [9]. The assessment is made through 8 output-based evaluation criteria. Three weight schemes are considered with the aim to assess three different point of views. In Ref. [10] the planning project selection problem of a rural feeder is faced by combining the AHP and the VIKOR techniques. The hierarchical structure of the evaluation criteria encompasses 4 main areas: technical, environmental, social, and economic. Four categories of experts have been involved in the weighting process, 13 planning alternatives have been analysed. Moreover, AHP is used [11] to identify the appropriate location of smart metering in distribution feeders considering conflicting criteria such as network losses, voltage levels and reliability. Six possible planning alternatives have been analysed. The criteria weights have been elicited by experts from the utilities with the goal of satisfying investment policies.

As shown in Refs. [8–11], the MADM approach is suitable for supporting the project selection among a small set of feasible planning alternatives. In order to improve multi-objective planning process by outclassing its main drawback, an automatized MADM project selection method is proposed in this paper. The proposed project selection approach is then applied to a large set of optimal ADN planning options. The large set is the best-known Pareto front originated by a multi-objective optimization involving the optimal siting, sizing, and scheduling of Distributed Energy Storage (DES). The planning alternatives are compared by using an automatized pairwise comparison procedure that considers output-based performance indices. In order to obtain a robust result for all possible decision makers' point of view, the MADM evaluation is repeated and the outcomes combined. The proposed methodology for project selection can support the decision makers in analysing large sets of planning alternatives. Moreover, the presented formalisation aims at filling the gap in the multi-objective planning by means of an automatic analysis of the obtained outcome.

2. Multi-Criteria Analysis for decision-making in planning

Planning is a decision-making activity which requires the assessment of a set of feasible investment options for identifying the best one. Typically, the optimal solution has to achieve a comfortable level of performance on several conflicting criteria by minimizing the related cost. Since those goals can be mutually conflicting, the decision maker has to make trade-offs taking into account the stakeholder perspective. Traditionally, the planning options are assessed by means of economic-based tools (i.e., Cost-Benefit Analysis – CBA) which require the conversion of all project impacts in monetary terms. These methodologies are acknowledged tools for considering only costs and benefits that can be directly monetised. In contrast, the appraisal of projects which show wide range effects and/or non-negligible intangible impacts shows some underlying shortcomings related to techniques for quantifying, monetising, and discounting the impacts [12]. In this context, the project selection process is biased. In the planning processes, MCA has been introduced in several sectors (e.g., transportation and environment) to better consider sustainability aspects and improve the effectiveness of the process [13]. Similarly, smart grid planning is a complex task, it aims at achieving more goals than the cost minimisation and the enhanced reliability of supply. Even if services and impacts in power system have a related cost, the monetisation procedure may distort their actual relevance for the specific planning process. The need is for more transparent and objective output-based project selection approaches. Therefore, shifting from a traditional economic-based assessment to new assessment tools is recommended [1,14]. In Europe, several guidelines have been released with the aim to promote the use of a multi-criteria framework on smart grid project assessment [15–17]. Unlike CBA, MCA allows considering the impacts directly, the monetising procedure that introduces an undesired latent point of view is avoided. In addition, the uncertainties related to monetary conversion are prevented. Moreover, since MCA involves directly the stakeholder point of view, transparency on the project selection process is provided. In fact, the consequences of a change of the analysis perspective are clear, as the stakeholders' point of view influences only the evaluation criteria relevance and not also the impact metrics. Nevertheless, MCA and CBA are not conflicting tools, a joint use can combine their strengths by mutual compensating their respective weaknesses [13]. In fact, MCA lacks on imposing that overall benefits have to exceed costs therefore, unlike CBA, MCA may be unable to identify the most cost effective options [18].

MCA is a systematic approach helps the decision maker in finding the preferred solution. The scientific Literature proposed several methodologies that belong to MCA [18]. Among them, MADM methods are suitable for multi-criteria decision problems whose goal is to find the best alternative among an explicitly known set. Considering a planning process, multi-objective optimization and MADM are complementary: the former can be used for devising a set of Pareto optimal solution; while a MADM method can be used to identify the best alternative of the set according to the planner expectations. Key features of MADM methods are the Performance Matrix (PM), the hierarchy of evaluation criteria, and the preferences of the stakeholders [18]. The entries of the PM are the values of performance of the alternatives with respect to the evaluation criteria. In the scoring stage, the elements of the PM are normalized to a common numerical scale. The preferences of the stakeholders are used to define the relative importance of the evaluation criteria during the weighting stage, a numerical value is assigned to each criterion as a relative weight. Basically, an MADM method is an algorithm that assesses the given alternatives on the basis of the PM and weights of criteria. The output of the algorithm is a ranking of the alternatives, the alternative that dominates all the others is the best alternative according to the decision maker point of view.

3. Formalisation of the proposed automatized MADM approach

In this paper, the proposed MADM approach aims at finding the best alternative among a large set of options. The methodology presented is based on the AHP which is one of the most acknowledged MADM techniques [18]. Moreover, the proposed automatic pairwise procedure is inspired by the procedure in Ref. [19] which has been adapted and generalised for addressing any PM. The scientific novelty of the proposed methodology is the formalisation of an assessment procedure for completing a multi-objective ADN planning approach for a given MV network. Furthermore, in order to identify a robust result, the presented approach considers all possible stakeholder scenarios modelled by different criteria weight schemes. Even if a Pareto front is studied in this paper, the proposed assessment approach can be used for any appraisal of large initial set of planning alternatives.

The MCA methodology proposed in this paper can be resumed in 3 key steps.