Advances in Reliability, Safety and Security

ESREL 2024
Collection of Extended Abstracts

Application Of Choquet Integral For The Multi Objective Optimization Of Energy Systems

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Keywords: energy systems, optimization, multi-objective, multi-criteria, Choquet integral

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The optimization of the design and operations of energy systems usually takes into account various criteria, such as economic performance, sustainability, and resilience. As these criteria can be conflicting, the corresponding optimization models are often challenging multi-objective problems. In the existing literature, various techniques have been proposed to address these problems. The most basic approach is, arguably, the weighted sum that allows to aggregate the different objectives, i.e. the different criteria, into one single objective function (Grabisch, 2009). However, this approach presents notable drawbacks:

- it can lead to compensation phenomena if the various objectives, i.e. the criteria to optimize, are not scaled properly;
- it does not identify non-convex regions of a Pareto front;
- it does not account for interactions and synergies between different objectives. Another popular technique is the ε-constraint approach (Wu et al., 2021).

It consists in running multiple optimization problems with one criterion as the objective and the other ones in the form of constraints in order to obtain a Pareto front (Wu et al., 2021). While this approach presents clear advantages in terms of quality of the Pareto front, it also suffers from some limitations:

- the quality of the Pareto front identified with this method strongly depends on the step size of the ε-constraint approach;
- in the presence of multiple criteria to optimize it might present issues of scalability.

Other techniques, such as compromise programming (Ren et al., 2010), have also been used.

In general, a wide range of approaches and techniques have been applied in the context of multi-objective optimization of energy systems (Eriksson et al., 2019; Fazlollahi et al., 2012; Lu et al., 2015; Ren et al., 2010; Wu et al., 2021). For more details, we refer the reader to the specialized literature (Khezri et al., 2020).

In this work, we argue that the integration of a multi-criteria decision-making framework directly within the optimization approach could lead to considerable advantages. In fact, multi-criteria decision-making tools are often applied after the Pareto front is identified, leading to considerable computational costs. Integrating a multi-criteria decision-making framework directly within the optimization model would allow the identification of an optimal solution that correctly represents the preferences of the decision-maker. In addition, as with this approach it is not necessary to identify the Pareto front, this solution does not require multiple runs of optimization such as for the ε-constraint approach, and it is more scalable with respect to the number of criteria to optimize. In particular, we propose an optimization framework with an objective function based on the Choquet integral, an aggregation function that allows to represent the preferences of the decision-maker, by taking into account single criteria, as well as interactions among any subset of criteria (Choquet, 1954; Grabisch, 2009; Grabisch et al., 2010). One of the possible formulations of the Choquet integral CI for a set of criteria N is shown in Equation (1):

$$CI(x) = \sum_{A \subseteq N} m(A) \min_{i \in A} x_i \quad (1)$$

where $m(A)$ corresponds to the Mobiüs transform on the subset of criteria A and x_i represents the value of the criterion i. For more details on the Choquet integral, the reader is referred to (Choquet, 1954; Grabisch, 2009; Grabisch et al., 2010).

In this work, we provide an illustrative example to demonstrate the advantages of a Choquet integral approach for the optimization of energy systems. Specifically, we rely on a generation expansion planning (GEP) problem in a power network with three contrasting criteria to optimize (cost, CO_2 emissions, resilience). Our preliminary results demonstrate the advantages of the proposed model if compared to traditional approaches. Future research directions and improvements are also discussed.

Acknowledgements

This work was supported by the European Defence Fund NOMAD project.

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