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Demand response modeling: A comparison between tools

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HIGHLIGHTS

- A comparison of the demand response strategies of existing modeling tools is made.
- The aggregation of DHW backup loads as manageable flexible loads is studied.
- Improvements for the modeling of flexible demand in existing tools are suggested.

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ABSTRACT

The potential to reschedule part of the electricity demand in energy systems is seen as a significant opportunity to improve the efficiency of the systems, especially on remote and isolated systems. From the supply point of view, that flexibility might bring significant improvements to the generation dispatch, especially when in the presence of renewable resources; from the demand point of view, that flexibility could allow customers to benefit from reducing their energy bills. To study these types of implications, modeling tools have been introducing the possibility to include flexible loads on the optimization process, although some use very simplified methodologies to do it. This study compares how different modeling tools consider fixed and flexible loads in the dispatch optimization, analyzing their different strategies. Three different scenarios were simulated in HOMER, EnergyPLAN and an economic dispatch self-built model in Matlab, using as case study the Corvo Island, Portugal. The comparison results indicate that HOMER and EnergyPLAN still assume that flexible loads are a second priority load that are met in off-peak hours or in the presence of excess electricity from renewable sources, not taking directly into account the economic impact of such decision. On the other hand, the self-built model that is more flexible on the optimization approach is the more close to the actual operation and presents the best savings when using demand response strategies, albeit representing only a 0.3% decrease in the operation costs. We conclude that the modeling tools should evolve and refine their optimization strategies to capture the total benefits of using demand response to improve energy systems performance.

1. Introduction

The ability to reschedule part of the daily electricity load is expected to lead to a decrease of the dispatch costs of the electricity generation systems. The accurate understanding of available resources and, in case of renewables, their dynamics, matching the installed capacities with investment and operating costs, creates new opportunities to improve economic dispatch through the implementation of demand response programs. Demand response (DR) can be defined by a voluntary and temporary adjustment of power demand taken by the end-user as a response to a price signal, or taken by a counter-party, like the utility, based on an agreement with the end-user [1]. Therefore, demand response might have a pivotal role on the future planning of smart grids, making them more cost effective and supporting the balance between supply and demand [2,3]. However, modeling the impact of demand response strategies, especially on remote and/or isolated systems, is a challenge to current energy modeling software. One of the main obstacles is the time resolution: long term is useful for projecting and optimizing investments on energy systems, but there is actually the need for a more refined time resolution in order to have a realistic, efficient and reliable system operation [4].

With that in mind, many authors [4–7] have focused on assessing strategies that use and combine different time resolutions,

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from long term investment strategy to short-term optimization of generation dispatch. If on one hand, when considering a long term horizon there is the need to decide on which capacity and type of energy supply the investments should be made to respond to a certain electricity demand and growth; on the other hand, there is also the need to be able to model different energy suppliers and loads, preferably using higher time resolutions. The combination of the two time resolutions will help the achievement of an optimal economic dispatch with less operation costs, losses or, in case of renewable integration, no excess of generation capacity.

Managing correctly all the grid variables between demand and supply, becomes more crucial when dealing with isolated micro-grids, such as islands, where we need to assure reliable and self-sustainable energy systems, preferably reducing fossil fuel imports to the island, and consequently the associated CO_2 emissions, and having an efficient energy use on the demand side [8].

There are several modeling tools available as reviewed by [9], with HOMER [10] being the most used for modeling micro-grids, and EnergyPLAN [11] normally used for larger systems, particularly at the regional level. Although they are popular and include flexible load options that can be used to model demand response actions, there is a gap on studying what is their approach to model it, the impacts it has on the modeling of the system and its main limitations. Demand response modeling has driven a lot of studies lately, but the main denominator is that each one develops its one algorithm, instead of using the available modeling tools. For instance in [12,13] demand response models that aggregate residential appliances are developed; in [14,15] different DR frameworks to accommodate electric vehicles are proposed; in [4,16,17] the potential of DR models to integrate renewable resources is studied and developed; and from the grid operation point of view, [18–20] reveal the technical and economic impact of DR programs at regional grid-level, trough self-built models. In [21] a self-built model is also presented to model virtual power plants as DR agents in grids with decentralized energy resources. Therefore, most studies on flexible loads are based on self-built models instead of using some of the most used modeling tools.

This paper uses the case study of the island of Corvo, a small and isolated island in the mid-Atlantic Ocean, where recently the Municipality has installed electric domestic hot water systems (DHW), consisting of heat pumps (HP) and solar thermal (ST) collectors to offset the gas consumption. This has introduced an additional electric load that needs to be managed in order to avoid negative impacts, like peak increases [22]. For that purpose, the possibility of installing load controllers in each system in order optimize the electricity supply, by rescheduling the DHW systems, is currently under consideration [23], however no DR system has been deployed in the island yet.

This paper compares the HOMER and EnergyPLAN modeling tools, with a newly self-built economic dispatch model [23], exploring the advantages and limitations of each tool using demand response strategies in Corvo Island. The self-built economic dispatch model used in this paper introduces technical constraints from the generation and distribution network [24] and optimizes the reschedule of demand response through genetic algorithms, as described in [23].

Overall, there is a lack of knowledge on why the most used modeling tools are not typically considered for modeling flexible loads. As such, the scientific contributions of this paper are:

- Assessment of the impact of aggregating individual DHW back-up loads as manageable flexible loads, using genetic algorithms to optimize its placement in an innovative self-built model;
- Comparison of the results obtained with the self-built and some of the most used modeling tools (HOMER and EnergyPLAN), by assessing how they optimize flexible loads and its impacts;
- Presentation of recommendations for improving the modeling of flexible demand in existing tools, to enable them to perform a wider variety of studies.

The paper is organized as follows. Section 2, describes the importance of modeling micro-grids and the problem of demand response, and introduces the modeling tools that are used in this paper. In Section 3, the Corvo Island case study is presented. Section 4 describes the different scenarios that are modeled and in Section 5, the results are presented and discussed. Section 6 makes the final statements of the work.

2. Modeling micro-grids and demand response

With the increase of distributed generation, micro-grids are becoming more viable. The vision of having power grids that can be composed of many micro-grids that can also operate on an *islanded mode*, brings new challenges and opportunities [25]. However, in isolated systems (physically or not) small changes on the electricity grid (either on the demand or supply side) may lead to large impacts that have to be prevented.

The interest on studying the impacts of demand response is growing, especially on domestic demands, where detailed studies are arising. The potential of domestic sector is huge: for example in [26], the authors present a high resolution model for identifying potential flexible loads; in [27,28] the potential from mixed thermal needs is analyzed, like heating/cooling [29], DHW needs [23], and large electric consuming appliances [13,30]. In [12] a similar approach to our study is developed, with the aggregation of air conditioning systems as demand response loads of 900 houses. The industrial sector is also a promising target [31], which is normally considered within regional-scale approaches, like in [32], where an extensive assessment of the potential of flexible loads in a future energy scenario in Denmark is presented, or in [33] where a more theoretical approach to flexible loads from the electricity pricing markets point of view is performed.

2.1. Software modeling tools

There are several modeling tools able to optimize energy systems that integrate renewable energy (listed and compared in [9]) and eventually to optimize some kind of demand response approach.

In [8], a list of studies of hybrid renewable energy system analysis on isolated micro-grids is presented, where some case studies use modeling tools as system optimization method. HOMER is the most referenced tool, and there are several studies that use it for that purpose: in [34] a case study demonstrates the use of HOMER to design a renewable polygeneration energy container in order to provide energy in remote regions, and in [35] HOMER is used for deciding which renewable energy system scenario is more suitable for making Karpathos Island, in Greece, a self-sustainable island. There are already some examples of using HOMER's demand response (DR) options: in [36] HOMER is used coupled with another framework, in order to incorporate more technical constraints on the modeling of an isolated micro-grid; in [37] a water treatment plant is used as DR tested on isolated and connected micro-grid; and in [17] a biomass gasification plant is modeled as DR to improve renewable energy penetration.

EnergyPLAN is also a very popular tool to design large energy systems for countries or regional grids, like in [38], where the tool was used to analyze the integration of multiple renewable capacities in Denmark. However, it has also been used in smaller systems like in [39], where the tool was applied to evaluate the energy system of the small island of Mjlet, in Croatia, presenting successful