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Accentuating the renewable energy exploitation: Evaluation of flexibility options

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ABSTRACT

A global energy transition is currently happening mainly through the shift from conventional to renewable electricity resources in power energy systems. On this transition, the flexibility of the power grid complies a fundamental role to permit the full integration of renewables. Therefore, the purpose of this work is to develop a methodology that permits evaluating the current technological flexibility options available in power grids to exploit the integration of renewables fully. A Mixed Integer Linear Programming model is developed. The model incorporates pumped energy and battery storage systems, demand response, virtual power plant, and transmission-distribution energy transactions. The work is focused on the operation planning considering daily, weekly and seasonal factors regarding renewables and load patterns. The general results show, that all the flexibility options have the capacity to integrate, in a mayor extent, the renewable energy into the power grid. For example, from a base integration of 40.6% of renewable energy, all the flexi-options added an extra 27.1% of energy from RES. Suggesting, that the best option to integrate renewables is the incorporation of a diverse set of flexibility options. Interestingly, options like demand response and virtual power plant, presented the best renewables integration figures (17.9% and 6.9%) compared to options like energy storages (6.05% average). Therefore, it is strongly recommendable to analyze particularly options which, with plausible modifications and minor investment requirements, can offer a suitable flexibility capacity to the existent power grid. Finally, distribution-distribution or transmission-distribution energy transactions also have a great potential to diminish the renewable curtailment. For example, they permitted integrating an extra 13.9% and 93.53% respectively, for the full flexi-option.

1. Introduction

The large scale integration of Renewable Energy Sources (RES), like wind and photovoltaic generation, presents a significant challenge to any power system due to the uncertainty of these resources. Normally, this is the first mentioned drawback about the exploitation of RES. However, it is rarely mentioned that RES, especially wind generation, possess a high and fast change rate of active power injection to the grid [1], added up to a frequency response that depends on power electronics rather than inertial physics. These two factors are critical in stability matter because the network has been designed to work with relatively small or slow, power change rates and to count on large amounts of energy stored in the inertia of large generators. Consequently, large and sudden power flow variations in the network produce a numerous quantity of undesirable effects. Therefore, it is important to evaluate different strategies-that subsequently evolve in new methodologies-that allow a secure and efficient operation of the power system under high penetration of RES. In this sense, the flexibility of the power grid complies a fundamental role to permit the full integration of RES.

1.1. Motivation

This work is mainly motivated by the current German energy scenario; nevertheless, this study represents no impediment to be considered as a comparative model for other power systems confronting currently, or in the future, the same energy transition challenge.

Germany has designed an energy transition to trigger a change in the energy system and technologies. Mainly through the shift from conventional to renewable energy. This transition pursue for smart

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energy use and better consumer participation coupled with the implementation of energy efficiency measures. The German transition is a long-term and evolving process. This concept adopted in 2010, have resulted in a considerable RES deployment in Germany, particularly in the power sector. For example, more than 19% of the countrys electricity generation was from RES in the year 2010. Currently, nearly 34% (>185 TWh) of the total generation is from RES [2]. Now is entering the next phase of this transition, focused on how higher shares of RES can be accommodated and how the grid infrastructure can be expanded to ensure that the power system and its actors are more flexible to allow for the integration of electricity from RES.

In 2016, the share of RES wind and solar in power generation exceeded 21.2% [3]. This share was achieved without any major problems. Factors contributing to this achievement include the strength of the German grid, flexibility of conventional generation, balancing markets, forecasting, trades with neighboring countries and improvements in distribution systems. The successes achieved thus far, are not sufficient to take Germanys RES share to 35% of the total energy mix by the countrys 2020 target [4]. Higher shares of RES will require more flexibility and balancing. To trace the way for higher shares of RES, an active discussion around two competitive market designs a capacity market and an energy-only market is on the run. Also, flexibility for renewable grid integration is under discussion; ranging from cross-border and neighboring grids exchange and expansion to demand-side management and storage [5] with various technologies for each voltage level.

Given this energy transition scenario, this work is focused on the evaluation of the most prominent flexibility options available nowadays in the German power grids.

1.2. Approach

This work is focused on the operation planning without disregarding daily, weekly and seasonal factors which strongly affect RES and load patterns. In this sense, we define monthly scheduling horizons for the summer, winter and autumn seasons. These seasons are commonly considered the most representatives to enrich a realistic study with the incorporation of weather effects.

This work evaluates different flexibility options, existent or to be incorporated. This aim is achieved analyzing the behavior of variables such as generation costs, RES generation and spillage, reserve contributions, and energy transactions with the Transmission System Operator (TSO) and with neighboring Distribution System Operator (DSO).

A Mixed Integer Linear Programming (MILP) model is developed. Different flexibility options are considered, for example, Pumped Energy Storage System (PESS), Battery Energy Storage Systems (BESS), Industrial Demand Responses (DR), and Vertical-Horizontal Energy Interchanges. The emphasis is placed in the maximum exploitation of renewable energy with the minimum impact on higher voltage levels of the grid.

We use a Germany's regional grid with yearly demand, wind and solar patterns. Representative scenarios, monthly-seasonal patterns, are simulated. Simulation steps of 15 min are used to capture the sudden changes of RES. A linear AC network formulation is derived under properly given assumptions. This approach has proven to be accurate enough for the purpose of this work.

1.3. Literature review

To the best of our knowledge, we were unable to find a similar work to ours. That is to say, reference works (to compare) proposing a model to numerically evaluate the integration of RES into grids incorporating different flexibility options. In this sense, we collected works focused in: the integration of RES to the grid; with any flexibility option among the ones we incorporate in our model; and the evaluation of RES potential into real power systems. Most of the works found are real case evaluations and very recent, thus, they form a starting point to consider the current importance of the topic by the research community. In this regard, articles [6–9] deserve to be highlighted as very detailed and exhaustive reviews.

Studies which incorporate a storage flexibility option are: work [14] which analyzes the Portugals energy system planning for achieving 100% RES electricity production; work [22] which considers the impact of integrating RES with EVs; work [24] which assesses the wind market value in Sweden where hydroelectric stations with large reservoirs prevail; work [25] which analyzes how RES and storage systems can contribute to improve the energy independence and reliability of isolated power systems located in remote areas of Russia; work [26] which uses a multi-period equilibrium model to simulate power markets incorporating different types of generators and energy storage systems; and work [13] which explores a storage market for RES grid integration with a production cost model.

Regarding the BESS option, work [12] focuses on the operation, size and cycling of a Li-ion-based BESS to limit the variability of photovoltaic power plants. Additionally, work [27] shows a BESS new business model by offering flexibility to system operators. Regarding the PESS option, work [15] analyzes different scenarios of increased penetration of RES in Cape Verde's power system, using pumped hydro as a storage technique.

Demand response applications are vastly, to our work's aim can be mentioned: work [17] which analyzes the DR potential across all the European demand sectors like industrial and residential ones; work [18] which compares different strategies for fixed and flexible loads in the dispatch optimization of an isolated system; work [19] which focuses on a more accurate representation of the Irish power sector, integrating operational constraints associated to the short-term horizon while maintaining the temporal resolution of long-term model; and work [20] which presents a method for generation system planning, specifically accounting for flexibility at high penetration levels of RES.

Regarding grid interconnections, work [21] focuses on the potential of coordination among TSOs with respect to operation of controllable devices like phase-shifting transformers and high-voltage direct current.

Several works gather mixed flexibility options, among them we can cite: work [16] which examines the replacement of conventional energy sources by RES under storage and interconnection; work [23] which explores flexibility options for high levels of RES integration and reliability in France; work [11] which evaluates the integration of high shares of RES with PESS, BESS, EV and European grid interconnections in the long-term evolution of the power system; and work [10] which proposes a cost optimization planning model of the USA electricity system, evaluating flexibility mechanisms like storage and DR from EVs.

1.4. Contributions

Considering the above literature review, the contributions of this study are:

1. To develop a methodology that permits evaluating the current technological flexibility options available in power grids to exploit the integration of RES fully. The model incorporates pumped energy and battery storage systems, demand response, virtual power plant, and TSO-DSO/DSO-DSO energy transactions.
2. To develop a methodology to evaluate the potential of horizontal energy transactions between DSO.
3. To carry out a number of insightful, realistic studies to comprehend the effects of using these options and to measuring up to which extent RES can be exploited.
4. To derive some recommendations to facilitate the process of the energy transition from a thermal-dominated to a renewable-dominated electric power system.