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Assessing the technical performance of renewable power plants and energy storage systems from a power system perspective

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ABSTRACT

In the electric power system, the share of renewable energy sources (RES) and energy storage systems (ESS) is increasing continuously. These changes have a considerable impact on the operation and performance of the power system. Therefore, in order to maintain a high performance, it is essential to assess and in a next step to improve the impact of RES and ESS on the power system. Methods of assessing the impact and of assessing RES and ESS in general are not developed sufficiently yet.

Therefore, the objective of this paper was to introduce a novel assessment method for the technical performance of RES and ESS installations from a power system perspective.

The assessment approach involves two assessment parameters which describe the temporal and geographic performance of a power plant in general and in particular of RES. The parameters were derived by comparing the temporal power profile and the geographical or electrical distance of the power generation and the electric loads. The assessment parameters allow the technical analysis and the comparison of different RES and EES installations from a power system perspective. Based on that, decisions regarding the realization or improvement of RES plants can be made. A graphical illustration shows the technical performance at a glance and enables the assessment of different improvement methods as well.

The paper deals with three improvement methods to enhance the technical performance of RES plants: the combined installation of RES plants and ESS, the selection of appropriate grid coupling points and the clustering of RES plants were discussed in case studies. The results show how the different improvement methods can enhance the temporal performance and/or the geographic performance of RES plants.

The assessment approach is useable for several purposes, e.g. for system operators, ESS manufacturers or policymakers in order to promote RES and ESS installations with a high technical performance and a beneficial impact on the power system.

1. Introduction

With the aim to reduce greenhouse gas emissions and to establish sustainable and clean energy systems, the share of renewable energy sources (RES) is increasing steadily in electric power systems. Since RES plants are different to conventional power plants in many respects, RES integration has a high impact on operation and performance of the power system. The transition from large, central and dispatchable production units to small, distributed and fluctuating power sources is one of the main aspects and bears the risk to deteriorate power system performance [1]. Moreover, emerging technologies like energy storage systems (ESS), which provide new operational options like a bidirectional power flow, affect the power system operation.

Therefore, in order to maintain a high performance of the power system, it is essential to assess and in a next step to improve the impact of RES and ESS on the power system. Methods of assessing the impact and of assessing RES and ESS in general are not developed sufficiently yet. In this paper, we present an approach to assess and to improve the impact by assessing and improving the temporal and geographic performance of RES and ESS installations.

The state of the art gives several perspectives of RES and ESS assessment. Among them are investor or end-user perspective [2–4], the power system perspective [4–13] or a multidisciplinary perspective [4]. The assessment of investors or end-users usually involves economic cost-benefit analyses such as electricity bill improvement from the load-shifting capability of ESS [2] or production cost and revenue calculations for PV power plants [3,4].

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Nomenclature

RES	Renewable energy sources
PV	Photovoltaic
WT	Wind turbine
ESS	Energy storage system
$J_{RES,t}$	Temporal performance index of RES plant
$J_{RES,\rho}/J_{RES,l}$	Geographic performance index of RES plant (geographical/electrical distance approach)
$\underline{J}_{RES,t,\rho}/\underline{J}_{RES,t,l}$	Comprehensive performance index of RES plant (geographical/electrical distance approach)
E_{RES}	Annual electric energy production of RES plant
$\Delta E_{RES,load}$	Energy deviation between RES generation and load profile
$\Delta P_{RES,RMS}$	Power fluctuations of RES generation
$\Delta P_{load,RMS}$	Power fluctuations of load profile
$r_{RES,load}$	Correlation coefficient between RES generation and load profile
ρ_{RES}/l_{RES}	Supply radius/supply length of RES plant (geographical/electrical distance approach)
$\rho_{c,load,RES}/l_{c,load,RES}$	Distance between RES plant and load centroid (geographical/electrical distance approach)
η_{RES}	Capacity factor of RES plant

The impacts of RES and ESS from a power system perspective are more complex to quantify and usually require a comprehensive power system model. Based on these models, the impacts can be assessed technically or economically, for example in terms of system production costs [5] or outage costs [6]. The technical impacts analyzed in literature include the amount of overall CO_2 emissions [4,5,7,8], the amount of RES curtailment [4] or the impact on conventional plants (number of shut-down and start-up cycles) [5]. Other approaches consider the capacity of replaced conventional generation (referred to as capacity credit) [9–11], line losses and voltage improvement by optimal RES allocation [12] or the maximum feasible RES penetration, which can be increased by ESS plants [7], optimal RES placement [12] or reactive power control [12].

In general, the assessment methods [4–12] can be denoted as top-down approaches. They require a comprehensive power system model (e.g. as hourly unit commitment formulation [4,5]) in order to assess the impacts of RES and ESS installations. Therefore, modelling accuracy is a crucial issue and effects that are not considered in the model (e.g. electric grid constraints not considered in [4]) may influence the results considerably. Moreover, performance requirements of RES and ESS installations and methods to improve their impact on the power system cannot be derived directly.

In contrast to that, the assessment method presented in this paper pursues a bottom-up approach. It aims at assessing single RES and ESS installations rather than entire power systems. Therefore, only small system models are required but the assessment results are applicable to the power system in general. The proposed assessment parameters are abstract numbers rather than specific quantities like the feasible RES penetration level in [7] and [12] or the amount of RES curtailment in [4]. However, from the abstract numbers the impact on any specific performance quantity, e.g. those applied in [4–12], can be deduced.

The assessment method is derived from the basic task of an electric power system to provide energy at the right place and at the right moment as required from the electric loads [14]. Therefore, RES plants which are neither adaptive to the temporal power profiles nor to the geographical locations of electric loads usually have a low technical performance and an adverse impact on the power system.

In order to assess the performance, two performance indices for the temporal power profiles and the geographical location of RES plants will be introduced. Up to now, such a classification into temporal and geographic issues has not been found in literature. For example, in [15] only the temporal power profile of a RES installation is evaluated but without respect to the electric loads, whereas [13] assesses only the geographical location. [4] emphasizes the need for a temporal and geographic assessment of PV and wind complementarity, but leaves it as an open research topic.

Therefore, this paper deals with a comprehensive temporal and geographic analysis of RES and ESS installations and presents a technical assessment method from a power system perspective. It combines the assessment methods described in [16] and [17] and introduces geographical and electrical load distances for a more generalized assessment approach.

The assessment results show the benefits and drawbacks of RES and EES installations. Based on that, decisions can be made in terms of new grid installations of RES and EES or technical improvement measures of existing installations. The paper proposes and evaluates three improvement methods for RES plants: the combined installation of RES plants and ESS, the selection of appropriate grid coupling points and the clustering of RES plants. Based on graphical illustrations, the method provides a powerful tool to analyze, quantify and compare the technical performance of different RES and ESS installations. Therefore, the approach is usable for several purposes, e.g. for system operators, ESS manufacturers or policymakers in order to promote RES and ESS installations with a high technical performance and a beneficial impact on the power system.

The paper is organized as follows: Section 2 presents the general idea of the assessment method. In section 3, the mathematical formulation of the assessment parameters is derived analytically. This includes the geographical and the electrical distances between power generation and load as well as the correlation of their temporal profiles. The result is a two-dimensional parameter set which can be illustrated graphically. Section 3 is concluded by comparing our approach with other commonly applied RES assessment methods. The case studies in Section 4 comprise several RES and ESS configurations. They show the considerable potential of our assessment method to quantify and to compare the technical performance of different RES installations and improvement methods. In particular, the improvements obtained by new technologies like ESS or new grid integration methods can be derived and evaluated directly.

2. Idea and assessment method

The basic idea of the proposed assessment method is to quantify the technical performance of RES and ESS installations from a power system perspective by introducing a comparable two-dimensional performance index.

Generally speaking, RES have a high technical performance and a beneficial impact on the power system, if they are installed close to electric loads and if their temporal power profiles match the local load's time curves. On the other hand, RES plants which are installed far away from loads and have a power profile inverse to the load's profile have a low technical performance and an adverse impact on the power system due to the need of energy transport equipment and additional backup power plants.