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Assessment of the capacity credit of wind power in Mexico

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A B S T R A C T

A comprehensive assessment of the capacity credit of potential wind power developments in Mexico has been conducted for the first time. The analysis is based on an 80 m wind speed map generated from the North American Regional Reanalysis (NARR) data base and a set of restrictions, including proximity to transmission lines and major roads. Potential wind farm sites complying with all restrictions were populated with wind farms according to different scenarios; consecutive deployment of wind power from 1% to 15% system penetration was considered in all cases. In a set of one-region scenarios the evolution of the capacity credit was studied for different levels of intra-regional diversification. Near-generic decay according to a power law was observed at high penetration levels, whereas a notorious benefit was obtained from diversification at low and intermediate wind power penetration. In order to assess the potential benefits of inter-regional diversification, an optimization procedure was conducted. A significant improvement of the capacity credit decay curve was obtained for all levels of penetration. Optimal sets are characterized by a balanced utilization among regions with a relative insensitivity with respect to the exact composition of the wind farm set. The results are believed to be useful for the expansion planning of the Mexican electric grid.

1. Introduction

As the participation of fluctuating renewable energy sources in the power sector grows, the assessment of the impact of renewable power plants on the reliability of the electric grid becomes more important [1–3]. While traditionally it has been assumed that fluctuating generating facilities do not contribute to the reliability of the grid in terms of an effective firm capacity, this perception has been changing over the last decade, leading to the general recognition of a capacity credit of renewable energy sources [4,6,8]. Different indices such as the Loss of Load Expectation (LOLE) [5–7] and the Loss of Load Probability (LOLP) [6,7] have been traditionally used to discuss system reliability on transmission networks and can be conveniently generalized to include the effect of fluctuating power sources. The different approaches to calculating capacity credit of renewable energy sources have been reviewed by different authors, including Milligan and Porter [6] and Dent and al [8]. Rather than *qualitatively* different from conventional generating plants such as coal- or gas-fired plants based on thermal cycles renewable energy power plants differ only *quantitatively* from the former in the sense that the variable characterizing availability of conventional plants has to be replaced by the actual power output of the renewable power plant. Evidently, the availability of a conventional plant is generally much higher (of the order of 80%–90%) than the average power output of a –say – wind farm (with a typical capacity factor of the order of 30%–40%) and the fluctuations of the output of the conventional plant are much lower than those of the renewable plant, but the conceptual framework to be used is the same.

The general approach with regards to the contributions of a renewable energy source to system reliability is to determine the effective firm capacity that can be ascribed to the fluctuating source. A typical procedure [9], the one used in the present work, is to first determine the Loss of Load Expectation (LOLE) of the system without the addition of the renewable energy capacity, i.e. the number of yearly hours during which the available generating capacity is unable to meet the load. The effective firm capacity of the projected renewable nameplate generation capacity P_0 is then calculated by either (i) assuming that a certain amount of firm capacity (i.e. capacity assumed to have an availability of 100%) is replaced by P_0, while maintaining the system LOLE at its original

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level or (ii) calculating the additional firm load that can be served by the projected nameplate capacity P_0 if the latter is added to the generating pool. The corresponding results are known as equivalent firm capacity (EFC) and equivalent load carrying capacity (ELCC), respectively. For low levels of penetration of renewable energy sources both approaches have been shown to lead to similar results [9]. Conceptually, the ELCC approach is more likely to represent the situation in emerging economies like Mexico where the electricity consumption is steadily rising, so that renewable energy addition are likely to fuel the growth, rather than replace conventional generating capacity.

The objective of the present work is to conduct a comprehensive assessment of the capacity credit in Mexico for the specific case of wind energy, currently the strongest growing renewable energy source in Mexico, based on an evaluation of the technical potential for wind power development, different plausible scenarios, and the ELCC method combined with a stochastic time series approach. To our best knowledge, this is the first attempt to systematically assess the capacity credit of wind power in Mexico based on technical potentials. The benefits of a diversified national development strategy vs. the current business-as-usual strategy based on a massive expansion of the wind power capacity in the La Ventosa region will be apparent from the results.

2. Methodology

2.1. Identification of suitable regions for wind power development

Since wind power development in Mexico so far has occurred almost exclusively in the La Ventosa region in the state of Oaxaca (with the exception of a 10 MW wind farm in Baja California and a recently inaugurated 28.8 MW wind farm in Southern Chiapas) a practical approach had to be defined in order to explore the expected installed wind power capacity in the near and medium term future. One possible approach, relied upon by Pöller [10] was to build projections from the official permits granted by the Energy Regulatory Commission (CRE, *Comisión Reguladora de Energía*) for the construction of future wind parks. These permits almost exclusively referred to new projects in the La Ventosa region, leaving projects in other regions with significant potential for wind power developments outside the scope of that study. These regions include the states of Tamaulipas where a new development focus exists, and Nuevo León, as well as Baja California. However, most information about these projects is anecdotal or subject to confidentiality agreements.

From a planning perspective, on the other hand, it is important to anticipate wind power developments and their possible impact on grid reliability well before they occur. In the current practice, the initiative lies almost exclusively with the developers who request interconnection with the state utility (CFE, *Comisión Federal de Electricidad*) based on development considerations such as wind resource, availability of suitable land, and access to transmission lines, among others. By mimicking this development process a reasonable estimate of the expected wind power development potential can be conducted, which is part of the approach used in the present work; in an additional effort an attempt has been made to optimize the system expansion based on wind energy capacity from a utility planning perspective where the focus is on maintaining the capacity credit at high values. The reference year for all capacity credit calculations presented in this work is the year 2017; the installed capacity for that year has been anticipated from the official growth projections of the state utility [11].

As an initial consideration any potential development in the states of Baja California and Baja California Sur is discarded due to two reasons: (1) These states are not currently electrically interconnected with the Interconnected National Electric System (SIN, *Sistema Interconectado Nacional*), though plans exist to establish such a connection in the medium term. (2) The state of Baja California is interconnected with the US grid and therefore exchanges energy with that system, which would have introduced significant additional complexity into the study. The remaining territory is then classified according the following criteria:

(1) *Available wind resource.* A minimum average annual wind speed v_{av} of 6.5 m/s at a height of 80 m above ground level was required for a location to qualify as a possible wind farm location site. Given the availability of an increasing number of wind turbines capable of harvesting wind power at low-wind sites with net capacity factors exceeding 30% it is reasonable to assume that sites with $v_{av} \geq 6.5$ m/s will be exploited economically at some point in time if other development criteria look favorable.
(2) *Terrain slope.* Since a large fraction of the overall land in Mexico has a significant inclination, development at these locations may be more costly and lead to increased environmental impacts, such as those caused by road grading. While no generally accepted criterion exists, a slope of 20° was chosen as the maximum value allowed for the purposes of this study.
(3) *Access to transmission lines.* Since interconnection through cutting into existing transmission lines by the use of suitable switchyards is a common practice [12], the closest distance from the nearest high-voltage transmission line (rather than the distance to the nearest substation) was taken as the relevant criterion. While the economically viable length of a feeding line will depend on the size of the wind project and can therefore not be anticipated with certainty, it was assumed that most projects to be developed in the medium term will be able to support the cost of a 50 km feeding line, the cost of which was estimated to be around 8 million US$ for a 230 kV single-line circuit and 13 million US$ for a 400 kV single-line two-conductor circuit, based on current cost estimates in Mexico [13]. For a typical 100 MW wind project with an estimated total development and construction cost of about 240 million US$ the cost of the feeder line would amount to 3.4% and 5.6% of the total project cost for 230 kV and 400 kV lines, respectively, which is believed to be a tolerable cost item in case other critical issues (such as rights-of-way) can be solved in a timely and cost-effective manner.
(4) *Road access.* Evidently, construction of a wind farm requires transportation of heavy parts and machinery which in turns requires paved roads with at least two lanes in order to get near the construction site. New access roads on the site will have to be built, but their tolerable length was estimated to be 10 km in order for the project to be economically viable.
(5) *Construction restrictions.* Three criteria were used to exclude non-suitable lands: (a) Urban areas, (b) water bodies, (c) natural protected areas.

The elevation information (step (2)) consists of a digital elevation model (DEM) of terrain data obtained from the Global Digital Elevation Model (GDEM) operated jointly by the Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) [19]. The data are generated by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with a resolution of 30 m × 30 m, covering land surfaces between 83° N and 83° S. This represents a significant improvement in elevation data used by the