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# Impact of renewable energies on the indian power system: Energy meteorological influences and case study of eefects on existing power fleet for rajasthan state

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ABSTRACT

India is aiming at a large scale integration of renewable energy with an ambitious target of 100 GW solar and 60 GW wind, by 2022. For economical and optimal integration of such a high renewable energy (RE) capacity, detailed planning based on meteorological data is necessary. This study uses time series of wind and solar resource data in order to quantify the correlation, smoothing effect, simultaneity and seasonality at various spatial scales over the whole country. Additionally, a simplified power plant dispatch optimization for the state of Rajasthan has been done, for specific future scenarios. This attempt at assessing the grid impacts of variable Renewable Energy (vRE) for India could be a foundation block for vRE Integration efforts.

## 1. Introduction

The Government of India has put forward an ambitious plan to set-up 175 GW of renewable capacity by 2022 (Niti Ayog, 2015). Out of this, 100 GW is expected to be achieved by solar power, 60 GW through wind power, 10 GW though small hydro power and 5 GW through biomass power projects. However, renewable energy generators, like wind and solar, are significantly different from the conventional generation technologies, due to their inherent uncertainty and variability. In order to plan and manage the integration of such a high capacity of RE, a detailed analysis of the supply characteristics of wind-solar power outputs and their impact on the grid has become the need of the day. As of 31st December 2016, the total installed capacity of wind power and solar power in India were 28,700.44 MW and 9012.66 MW respectively, according to the Ministry of New and Renewable Energy (MNRE) data (MNRE, 2016b). Already, wind and solar energy projects have started facing major hurdles in many states across India because of transmission bottlenecks and frequent power curtailment (Chandrasekaran, 2016; Ubhaykar, 2016). Anees (2012), mentioned some challenges of integrating large amount of RE into the Indian Electricity grid along with their probable solutions, including countering the intermittence of RE generation by distributing the RE units over a large geographical area, rather than concentrating them in a single area. However, no quantification of this intermittency smoothing effect has been performed yet in India. Mukhopadhyay et al. (2012), recommended, among others, the use of storage systems to manage the uncertainty in RE feed-in. George and Banerjee (2009) proposed an approach based on annual load duration curve for generation expansion planning with higher penetration of wind power, in order to quantify the potential savings in base and peak capacity required, and applied it to the state of Tamil Nadu in India. Barpanda et al. (2015) presented some challenges and way forward for RE integration in India, including generation reserves and intra-state deviation settlement mechanisms for dealing with the uncertainty of RE supply. Chattopadhyay and Chattopadhyay (2012) recommended a “climate-informed” policy, which will take into account the spatial and seasonal distribution of wind and solar resource, while determining the renewable purchase obligation (RPO) of a State. However, no analysis of the seasonality in wind and solar power generation output or the quantification of the spatial distribution of wind and solar power output has been attempted at, till now in India. Lolla et al. (2012) analysed seasonal scale variability in wind and solar energy availability, for each of the 5 regional transmission grids, to see if they can reduce intermittency by offsetting each other. However, smoothing effect within individual states and their quantification was not performed. In CEA (2016), generation data of the existing solar and wind generation units were collected and scaled-up to reflect the behaviour of 160 GW of wind and solar, using statistical tools, in order to analyse the correlation of wind and solar power with load, and smoothing effect of diversity. However, it did not use time series data of RE and the up-scaling was done on the basis of longitude, latitude & random statistical tools, without considering any weather model data.

At the moment, several efforts are underway in India for removing

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the barriers of grid integration of large scale renewable energy. In addition to the Green Energy Corridors project for inter and intra state transmission capacity enhancements, several regulations by the central and state regulatory commissions, related to the grid integration of RE, are already in the pipeline or have been published. This includes, among others, the Staff Paper on Electricity Storage System in India (CERC, 2017), Draft Indian Electricity Grid Code Fifth Amendment (CERC, 2016a), Draft Regulations on Forecasting, Scheduling, Deviation Settlement and Related matters of Wind and Solar Generation Sources (TNERC, 2016b), Renewable Purchase Obligation, its Compliance and Implementation of Renewable Energy Certificate Framework (MERC, 2016), Ancillary Services Operation Regulations (CERC, 2015), Framework on Forecasting, Scheduling and Imbalance Handling for Variable Renewable Energy Sources (Wind and Solar) (CERC, 2016b). Recently, MNRE has brought out the Draft National Wind-Solar Hybrid Policy to promote wind-solar hybrid projects (MNRE, 2016a). The Solar Energy Corporation of India (SECI) has recently issued a Notice Inviting Tender for a 2.5 MW solar and wind hybrid plant with 1 MWh energy storage system at Rangreek, Himachal Pradesh (SECI, 2016). Evidently, a detailed study of the correlation between wind and solar power is imperative for such a type of system. It is also quite apparent that smoothing effect is a vital input to any policy decision related to renewable capacity addition, storage system addition and inter-state power flow capacity expansion.

This study presents an important work, on the use of wind and solar resource time-series data to quantify the combined smoothing effect of wind and solar photovoltaic (PV) energy supply for India, as well as for the different states and intra-state regions. By doing so, we seek to obtain answers to, among others, the following key questions: (1) Are there seasonal patterns of RE production within India and how are they geographically distributed? (2) How strong is the spatial correlation for hourly feed-in of wind and solar PV power all over India? (3) Is there a significant simultaneity of feed-in between wind and PV within different states of India? (4) Does a higher spatial distribution of variable RE across India lead to lower fluctuations in RE feed-in. Additionally, a residual load analysis and power plant dispatch of Rajasthan for the future scenarios in the year 2018 and 2022 has been done, using certain assumptions. The motive behind this endeavour is to illustrate, as an example, how much of RE power can be integrated from a state perspective and how much must be exported to another state or stored. This analysis is performed for different flexibility parameters of conventional generation units.

Results of the smoothing effect analysis show that both wind and solar PV output exhibit seasonality and vary with region. Wind outputs exhibits loose correlation as distance between the sites increase, while solar PV output exhibits strong correlation all over the country. So, it makes more sense to distribute the vRE capacity all over the country. Simultaneity factor, a measure of geographical smoothing, is higher and more uniform for solar PV output compared to wind. Combined simultaneity values are even lower than the simultaneity values for wind output and show a large bandwidth for 18 of the Indian states, implying that some states have greater benefits of combining the two sources than others. Results of the power plant dispatch optimization for the state of Rajasthan show high seasonal variability in wind output and considerably less in solar PV output. Daily profile of the solar PV output requires a higher integration effort in terms of backing-down conventional generation on a daily basis, when employed on a large scale. With increased vRE capacity, negative residual load occurs frequently, necessitating power export to other states. Plant Load Factor (PLF) of the conventional generating units decreases due to the nature of vRE supply. However, peak power needed from firm capacity stays in the same order magnitude as without vRE. Conventional generating units will require faster ramping in order to tackle the quick changes in residual load. The average number of start-up and shut-downs, i.e. flexibility requirements, of conventional generating units increases significantly.

The rest of the paper is organized as follows – Section 2 describes the methodology of vRE feed-in time series generation, smoothing effect quantification and dispatch simulation. Section 3 presents the results obtained from smoothing effect quantification and dispatch simulation studies, with its associated discussions. Finally, Section 4 discusses the implications of the results obtained and how they can be used as inputs for further future studies.

## 2. Methodology

This section describes the method employed and tools used for – (1) Preparation of spatially-temporally resolved wind speed and solar irradiation data for the whole country, (2) Determination of the spatially-temporally resolved feed-in time series of wind and solar output, (3) Dispatch simulation for the state of Rajasthan with Unit Commitment Model (SCOPE) and scenario generation. Historical meteorological data is used for the preparation of wind speed and solar irradiation data for India. The RE feed-in time series is determined using physical models developed by Fraunhofer IWES. Furthermore, this RE feed-in time series is used as input in order to perform dispatch simulation for the state of Rajasthan.

### *2.1. Resource data preparation*

In order to process and display data in reference to a specific geographical position, a basic weather information grid has been defined with a spatial resolution of 0.2° × 0.2° (approximately 20 km × 20 km). All further meteorologicallogical data are transformed to match this basic grid.

Wind speed data has been obtained from a macro-scale meteorologicallogical model, known as Modern-Era Retrospective Analysis for Research and Applications (MERRA) (Lolla et al. 2012; NASA al., 2015). The wind speed data is extrapolated to a height of 100 m above ground level (a.g.l) from the available MERRA data at heights of 10 m and 50 m, in order to match the turbine height approximately. To do this, a logarithmic wind profile is assumed and roughness lengths, obtained from self-calculated roughness maps based on the local land use and orography, are used. The original temporal resolution for wind speed within the MERRA model has hourly resolution and so no further data manipulation is necessary.

Simulating PV feed-in requires hourly resolution time series data on Global Horizontal Irradiation (GHI) and ground temperature data, which has been derived from NREL Indian Solar Resource Data, 2011. (Sengupta, 2012) The Data has a native spatial resolution of 0.1° x 0.1° and a temporal resolution of one hour. To match the above mentioned reference grid, nearest neighbour interpolation has been performed. Additionally for Rajasthan, measurement data of GHI from 12 ground stations, provided by the Ministry of New and Renewable Energy (MNRE), is used. (Schwandt et al., 2014; Kumar et al., 2014)

### *2.2. Feed-in time series simulation*

In-house models developed of the Fraunhofer IWES, are used for calculating feed-in time series for wind turbines and PV devices. Realistic time series feed-in data of wind power and PV are generated by coupling these wind power and solar PV models with the resource data prepared above.

The time series model for a single weather information grid is developed by taking into account feed-in from different wind turbine and PV types, as well as shading and smoothing effect due to spatial distribution of the units. This process is repeated further for all weather information grid cells in India.

In order to simulate feed in time series of wind turbines, two different turbine types with specific power densities of 345 W/m2 and 290 W/m2 are chosen. Fig. 1 shows the simulated spatial smoothing for those two types. The power curves are simulated by interpolation