Applied Energy 222 (2018) 25–41

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Performance assessment of grid-interactive solar photovoltaic projects under India's national solar mission

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HIGHLIGHTS

- Performance evaluation of solar photovoltaic projects under India's Solar Mission.
- Inter-comparability of solar radiation databases for solar photovoltaic projects.
- Mean percentage error analysis for capacity factor and levelized cost of electricity.
- Energy yield assessment of photovoltaic projects using solar radiation databases.
- Long-term measured or high-resolution time series databases should be preferred.

ARTICLE INFO

Keywords:
Solar photovoltaic
National solar mission
Global horizontal irradiance
Solar radiation databases
Capacity utilization factor
Levelized cost of electricity

ABSTRACT

Lack of long-term global solar radiation data has often been a significant challenge to the solar power sector development primarily in developing countries. The choice of a solar radiation database is projected to have a considerable impact on the predicted performance of a solar power project and consequently on its techno-commercial viability. Therefore, use of reliable and well- characterized solar radiation data source is important for bankability of solar power projects. This study presents the technical and economic performance evaluation of grid-interactive solar photovoltaic (PV) projects implemented under the first phase of India's national solar mission. For performance assessment, we compare annual energy yield predictions using several solar radiation databases and monitored data of 39 solar PV power plants located across the country. Technical simulations have been carried out for each project location using static and dynamic solar irradiance data obtained from various databases available in the Indian context. PV_{SYST} software has been used for energy yield assessment of solar PV projects after taking into account the key design and technical parameters and associated energy losses during solar energy conversion. The inter-comparability of capacity utilization factor and levelized cost of electricity of operational solar PV projects have also been analyzed with the estimates obtained through different solar radiation databases. Mutual deviation for the techno-economic performance of solar PV projects varied from −12% to 31% for the projects under the first phase of India's solar mission. Our study indicates that the long-term measured or high-resolution time series databases should be preferred for the bankability of solar power projects. Further, solar power policies of the country must provide clear guidelines for selection of solar radiation databases to enhance their bankability.

1. Introduction

Solar energy is one of the most promising renewable energy resources because of its widespread availability. Technology advances have drastically reduced the costs of solar PV panels by almost 80% from 2008 to 2015 [1]. In 2016, the annual installed capacity of solar PV increased approximately 50% to at least 75 GW – raising the global total installed capacity to 303 GW [2]. This rapid development of solar power projects over the world requires substantial investments, financial/economic risk assessment and stable policy framework about which solar technology should be installed in priority in a given location [3–5]. A major concern of the SPP stakeholders (including project developers, EPC and O&M contractors, financier, etc.) is that how much solar electricity can be generated by any SPP in a given location. This is especially true for 126 countries worldwide with feed-in tariff policies [2]: due to fixed tariffs and guaranteed rights to feed in all electricity

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https://doi.org/10.1016/j.apenergy.2018.03.135
Received 20 December 2017; Received in revised form 27 February 2018; Accepted 28 March 2018
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Nomenclature

AC	alternating current
CdTe	cadmium telluride
CERC	central electricity regulatory commission
COD	commercial operation date
CSP	concentrating solar power
CUF	capacity utilization factor
DC	direct current
EPC	engineering, procurement and commissioning
FiT	feed-in tariff
EYA	energy yield assessment
GBI	generation based incentive
GHI	global horizontal irradiance
GSS	grid sub station
IEA	international energy agency
IMD	indian meteorological department
IREDA	indian renewable energy development agency
JNNSM	jawaharlal nehru national solar mission
kW	kilowatts
kWp	kilowatt peak
LCOE	levelized cost of electricity
MC	multi-crystalline
MNRE	ministry of new and renewable energy
MPE	mean percentage error
MW	megawatts
MWp	megawatt peak
NASA	national aeronautics and space administration
NEG	net energy generation
NIWE	national institute of wind energy
NREL	national renewable energy laboratory
NSM	national solar mission
NTPC	national thermal power corporation
NVVN	ntpc vidyut vitran nigam
O&M	operational and maintenance
OPEX	operation and maintenance cost
PPA	power purchase agreement
PR	performance ratio
PV	photovoltaic
PVPS	photovoltaic power systems programme
RE	renewable energy
REMS	renewable energy management stations
RPSSGP	rooftop solar pv and small solar power generation programme
SECI	solar energy corporation of india
SEG	specific energy generation
SLDC	state load dispatch center
SPP	solar power project
SRDB	solar radiation database
SWERA	solar and wind energy resource assessment
TF	thin films
TMY	typical meteorological year
UNEP	united nation environment programme
VGF	viability gap funding

generated [6], one of the major uncertainties for an investment in an SPP is the evaluation of the expected electricity generation within its lifetime or its investment time horizon [7,8].

The availability of solar radiation data for a given location under consideration is essential for performance assessment of PV projects. The performance of PV systems in terms of predicted annual yield[1] would depend upon the availability of global horizontal irradiance as provided in the solar radiation database used besides several other designs and operational variables [9,10]. Solar-resource uncertainty and inherent seasonal variability represent a performance and revenue risk for an SPP that is tied primarily to the quality of the data (i.e. GHI) available and the commercial risks dictated by the contractual arrangements governing the sale of solar electricity [11]. Therefore, the choice of an SRDB is expected to have a considerable impact on the predicted performance of an SPP and consequently on its techno-commercial feasibility [12]. For example, use of an SRDB that provides higher GHI values (as compared to those actually available through the ground measurements) would overestimate the annual energy yield. Consequently, the actual field performance of a PV system would not match the performance predicted by the SRDB. In such a situation, the stakeholders may incur a substantial financial loss as the viability of the PV system was appraised based on higher GHI values. Therefore, for the economic viability of a PV project, the choice of the SRDB is critically important.

India, being a tropical country, is endowed with vast solar energy potential where most parts of the country receive 4–7 kWh/m^2/day of solar radiation [13] with 250–300 sunny days in a year [14]. In 2010, the Indian government launched the National Solar Mission (also known as the JNNSM) under its National Action Plan on Climate Change with a target of (i) deployment of 20 GW of grid-connected solar power by 2022, (ii) 2 GW of off-grid solar applications including 20 million solar lights by 2022, and (iii) 20 million m^2 solar thermal collector area [15]. In its Intended Nationally Determined Contributions under the Paris Agreement, India committed to increasing the amount of electric power from non-fossil resources to 40% by 2030 [16]. A total of 175 GW of RE installed capacity was promised to be achieved by 2022, of which 100 GW is the target set for solar power alone, 60 GW of wind power, 10 GW of biomass and 5 GW of hydro projects by 2022 [15]. The upgraded target of 100 GW from solar is planned to be achieved in seven years period and approximately consist of 40 GW grid-interactive rooftop projects and 60 GW large and medium size ground-mounted SPPs [15–17]. Appropriately designed transmission infrastructure and updated grid integration and operation mechanisms are key to scaling-up RE to 175 GW by 2022 [18]. Internationally, where penetration of RE has been increasing in the power generation mix, various changes to grid design, technology, and its operation have been implemented to allow cost-effective grid integration of RE [19–22]. In order to manage such a high share of intermittent power on the grid, the Indian government is working on strengthening of T&D infrastructure through developing green corridors, establishing renewable energy management stations and enhancing the capabilities of regional load dispatch centers [23–26].

In 2008, the cumulative installed capacity of grid-connected solar power was 2.1 MW that has grown up to 17,052 MW by December 2017 [27]. Fig. 1 presents the cumulative installed capacity of SPPs in India. In 2016, the newly installed capacity of PV power projects reached 3.0 GW [28]. In spite of this impressive progress, the cumulative installed capacity of SPPs is still far away from their respective potential [28–30] as in 2016 PV accounted for only 1% of electricity generation in the country [31]. Several studies have pointed out many barriers acting as a hindrance to achieving the target set by NSM [6,32–35]. Over the years the Central/State governments and regulatory bodies have taken many path breaking initiatives to address the impediments to the NSM. Still, there are several barriers to be overcome to achieve the revised NSM target of 100 GW by 2022.

As mentioned above, the financial returns of an SPP are highly sensitive to the solar radiation levels [36] therefore, errors in the solar radiation measurements can significantly impact upon the return on investment. For the financial/economic feasibility of SPPs, a bankable

[1] Annual yield prediction is an estimate of the annual electricity generation by a PV system at a specific location.

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