Assessment of Solar PV Power Generation Potential in Pakistan

Khanji Harijan, Mohammad A. Uqaili, and Umar K. Mirza

Abstract—**Pakistan is an energy starved country. About 38% of the country's population still does not have grid access. About 65% of the total conventional electricity is produced from the gas and oil. The country is facing severe blackout problems due to shortage of about 5-8 GW electricity supply. Fortunately, the country lies in an excellent solar belt range. The vast solar energy resource of the country can be harnessed for the production of electricity through solar photovoltaic (PV) systems. This paper presents an assessment of the PV electricity generation potential in Pakistan. Considering social and technical constraints, the technical potential of PV electricity generation has been estimated. The study concludes that 3.525 × 10^6 and 455.3 GWh of electricity can be generated annually in Pakistan from grid-connected and off-grid PV systems respectively. The estimated results clearly demonstrate that the solar PV electricity generation systems have the potential to meet country's present as well as future electricity needs.**

Index Terms—**Pakistan, energy, electricity, solar PV.**

I. Introduction

Only 62% of the Pakistan's total population has grid access and per capita electricity supply is only 520 kWh. About 65% of the country's population resides in remote rural villages. Most of the remote rural villages are not connected to the grid. Due to electricity deficit of about 5-8 GW, the industries of the country have been adversely affected. The people are also facing severe blackout/load shedding problems due to unavailability of grid power. The blackout problem is costing $ 2.5 billion per year to the country's economy. Also because of the electricity shortage, around 0.4 million people are losing their jobs annually [1]-[4].

The main sources of electricity generation in Pakistan are oil, gas, hydel energy and nuclear energy. Oil, gas, hydel energy and nuclear energy have 35.3%, 29.1%, 30% and 5.5% shares respectively in the total electricity production. The share of coal in total electricity generation in the country is only 0.1% [5]. Recently, two wind farms of about 106 MW total capacity have been integrated with the grid. There is huge coal resource potential (about 185 billion tonnes) in the country. The indigenous coal has not been exploited due to number of reasons and the country meets about 55% of its coal demand from imports. Pakistan's reserves of liquid and gaseous fuels are limited and the country heavily depends on the import of oil and coal. About 60% of the country's total foreign exchange is spent on the import of oil and coal [1]-[3], [6]. Fortunately, the country lies in an area of one of the highest solar insolation in the world. The solar radiation incident is in the range of 5-7 kWh/m^2/day over 95% of the country's total ara (see Fig. 1). This vast solar energy resource potential can be harnessed for the production of electricity through solar photovoltaic (PV) systems [6]-[8]. This paper presents an assessment of the PV electricity generation potential in Pakistan.

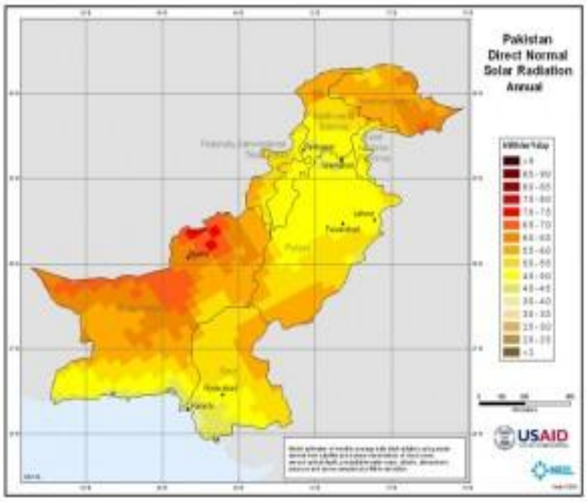

Fig. 1. Solar map of Pakistan [6]

II. PV Electricity Generation Potential in Pakistan

A. Status of PV Electricity Generation Systems

Submit your There has been a significant growth of the PV technology during the past two decades. Currently, PV is considered as an important technology for the future. Almost 30 GW of new PV capacity has been added worldwide in 2011, increasing the global to 70 GW. The vast majority of installed PV capacity today is grid-connected (GC), the off-grid PV capacity is only 2% of global total PV capacity. Yet there is growing interest in off-grid PV systems, particularly in developing economies. Interest in building-integrated PV (BIPV) has also been on the rise [9], [10]. In Pakistan, 3000 Solar Home Systems (SHS) have been installed in 49 villages of district Tharparkar, Sindh. There is only one GC PV systems installed in Pakistan which is of 360 kW. Solar PV systems of almost 54.77 MW have been imported during the last seven years by private sector companies. These solar panels / solar modules are deployed all over the country. Sixteen LOIs for cumulative capacity of

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Khanji Harijan and Mohammad A. Uqaili are with Mehran University of Engineering & Technology, Jamshoro, Pakistan (e-mail: khanji.harijan@faculty.muet.edu.pk, aslam.uqaili@faculty.muet.edu.pk).

Umar K. Mirza is with Pakistan Institute of Engineering & Applied Sciences, Nilore, Islamabad, Pakistan (e-mail: mirzauk@yahoo.com).

343 MW GC PV power plants have been issued by the Alternative Energy Development Board (AEDB). Four companies have submitted the feasibility studies of their projects and one feasibility study is approved by AEDB [2], [6].

B. Estimation of PV Electricity Generation Potential

First of all, theoretical solar energy potential is estimated using the solar irradiation and land area data. Then geographical and technical potentials are estimated by considering the social and technical constraints. The theoretical potential of solar energy can be estimated using the expression [11]:

$$AEA_{th} = \sum I.A.365 \tag{1}$$

where AEA_{th} is the theoretical potential of solar energy i.e. annual energy available in (MJ/m^2/yr); I is the global average solar irradiation (MJ/m^2/day), A is the total land area (m^2) and 365 are the number of days in a year.

Using the Eq. (1) and information about land area and average global solar insolation, AEA_{th} has been estimated as 15.5×10^{14} kWh per year [8]. However, during exploitation, some social constraints such as land use, geographical area and climate and technical constraints are encountered. Therefore we have estimated the potential of electricity generation through solar PV systems from the viewpoint of a specific application.

1) Grid connected solar PV systems

There are two types of *GC* solar PV applications (1) Centralized GC (CGC) applications and (2) Decentralized GC (DCGC) applications. The geographical potential of electricity generation through solar PV systems GP_i (kWh/yr) can be estimated using the equation [11]:

$$GP_i = I_i.A_{s,i}.365 \tag{2}$$

where I_i (kWh/m^2) is the average global solar insolation in area type *i*; $A_{s,i}$ is the area (m^2) suitable for installation of PV systems in area type i and 365 are the number of days in year. To estimate the area available/suitable for installation of PV systems, we have introduced a suitability factor (f_i). This factor is the fraction of the area (A_i) suitable for installing the PV electricity generation systems. The available area in area type *i* can be estimated using the expression:

$$A_{s,i} = f_i.A \tag{3}$$

We have assumed that the CGC PV systems are to be installed on land surface and DCGC systems are to be installed at roof-tops. The area suitable for installation of CGC PV systems depends on competing land use options. The suitability factors for different land use types taken from [12], as shown in Table I, are introduced in this study. The suitable area for CGC PV systems is calculated as 16865 km^2 which is about 2.12% of the total area of Pakistan. The total annual irradiance on this surface is estimated at about 33.3×10^6 GWh.

The available area for DCGC PV applications can be estimated by multiplying the available per capita roof-top area with the total urban population. The population density and the GDP data used in this study are taken from Economic Survey of Pakistan [14]. For estimating the average roof-top area, equation developed by Hoogwijk [11] is used in this study. The roof-top area per capita (R) (m^2/cap) as a function of the per capita GDP ($/capita) for Pakistan is expressed as follows:

$$R = 0.06.(G_c)^{0.6} \tag{4}$$

The suitable area for DCGC PV electricity generation systems is estimated as 120 km^2 as shown in Table II. The total annual irradiance on this surface is estimated as 236.5×10^3 GWh.

TABLE I: ASSUMED SUITABILITY FACTORS AND TOTAL SUITABLE AREA FOR CGC PV

Land use type	Land-use suitability factor (f_i) [12]	Area per land-use type (Million m^2) [13]	Land-use area as percentage of total terrestrial area	Suitable area for centralized PV (Million m^2)
Urban areas	0.00	1592.2	0.2	0
Snow, Ice and Water bodies	0.00	83590.0	10.5	0
Forests and bioreserves	0.00	49358.0	6.2	0
Agriculture	0.01	244401.5	30.7	2440
Rangelands	0.01	160811.4	20.2	1608
Wasteland	0.05	256342.9	32.2	12817
Total		796096	100.0	16865

TABLE II: SUITABLE AREA FOR DCGC SOLAR PV

Per capita GDP ($)	Per capita roof-top area (m^2)	Suitable area for DCGC PV (Million m^2)
465	2.5	120

The technical potential of annual PV electricity generation can be estimated using the expression:

$$AEP = \sum GP.\eta_m.pr \tag{5}$$

where η_m is the PV module's conversion efficiency and *pr* is the PV system's performance ratio. The efficiency of PV module depends on the type of solar cells and module temperature. We have considered 14% average module (crystalline silicon) efficiency for CGC as well as DCGC PV electricity generation systems. The output of a PV electricity generation system also suffers from losses occurring in the other components of the system. At present, the performance ratios (*pr)* of best PV electricity generation system are in the range of 0.66 to 0.85 [11], [15]. We have considered the value of *pr* for both CGC and DCGC PV systems as 0.75. The estimated results of technical potential of CGC and DCGC solar PV electricity are presented in Table III. The technical potential for CGC and DCGC PV applications is estimated at 3.5×10^6 and 25×10^3 GWh per year respectively.

TABLE III: TECHNICAL POTENTIAL OF CGC AND DCGC SOLAR PV

	Geographical potential (PWh/yr)	Module efficiency (η_m)	Performance ratio of PV (pr)	Technical potential (PWh/yr)
CGC PV	33.3	14%	0.75	3.5
DCGC PV	0.2365	14%	0.75	0.025
Total	33.5365			3.525

2) *Off-grid solar PV systems*

Off-grid solar PV systems have many applications such as water pumping, telecommunication, power generation, etc. These systems are competitive only in areas/villages far away from the grid transmission line due to their high capital cost. The estimation of the potential of SHS is, therefore, practically the search for households in solar rich remote rural villages not connected to the national grid. Considering 157 million as total population and 7 persons as average household size [14], the total number of rural households (RHH) in Pakistan is estimated to be about 15 millions. Since, about 63% of the rural population has no access to electricity; the number of RHH without access to electricity would be about 9.45 millions. For these households, the supply of electricity using SHS would be highly valuable. It is assumed that about 50% of the RHH without access to electricity today would be electrified through central grid connections and other decentralised options, and the remaining 50% RHH could afford and would be willing to pay for a SHS. The potential of SHS would be about 2.3625 million units. Assuming a RHH would be equipped with a 88 Wp SHS which is sufficient for meeting the electricity needs, the respective capacity would amount to 208 MW [16]. The technical potential of SHS can be estimated using the expression

$$AEP = RHH_{ue}.C_{spv}.CUF_{spv}.8760 \qquad (6)$$

where AEP (kWh) is the annual electricity production potential of SHS, RHH_{we} is the number of non-electrified RHH which would afford to pay for SHS (thousand), C_{spv} is the capacity of a SHS (Watt), CUF_{spv} is the capacity utilization factor and 8760 is the total number of hours in a year.

For PV systems, the CUF is decided by the insolation characteristics at the site with a maximum CUF of 25%. Since Pakistan lies in excellent solar belt range, therefore, we have considered the CUF for solar PV applications as 25%. Using the Eq. (6), the annual technical potential of SHS for rural electrification applications has been estimated to be 455.3 GWh [16]. This value is a factor of only 0.014 of the current electricity consumption in the domestic sector of Pakistan.

III. CONCLUSION

Considering the social and technical constraints, the technical potential of PV electricity generation was estimated and presented in this paper. The study concludes that $3.525\text{x}10^6$ and 455.3 GWh of electricity can be generated annually in Pakistan from GC and off-grid PV systems or SHS respectively. The potential (installed capacity) of GC PV electricity generation was estimated at 1600 GW. The total installed capacity of off-grid PV systems or SHS for rural electrification was estimated at 2.3625 million units or 208 MW. The estimated results clearly demonstrate that solar PV systems have the potential to meet country's present as well as future electricity needs.

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Khanji Harijan was born in Sindh, Pakistan on August 13, 1970. He received the B.E. and Ph.D. degrees in mechanical engineering from Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan, in 1994 and 2008, respectively.

He has joined the Department of Mechanical Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan as a lecturer in August 1996. Since 2010, he has been working as a full professor in the Department of Mechanical Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan. His teaching activities cover a range of energy engineering topics including renewable energy systems, power plants, pollution control systems, hydrogen technologies and fuel cells, energy economics and management. He is the author of over 100 articles and book chapters. Currently, his research focuses on design, modeling and simulation of renewable energy systems.

Prof. Harijan is a member of World Society of Sustainable Energy Technologies, International Association of Computer Science and Information Technology, Pakistan Renewable Energy Society, etc.