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Assessment of small-scale solar PV systems in Iran: Regions priority, potentials and financial feasibility

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ABSTRACT

As Iran is rich in oil and gas resources, renewable energy was known as a luxurious source of electric power generation for a long time. New policies and targeted subsidy reform plan for fossil fuel products have changed the view of decision-makers and energy sector investors toward renewable energy resources. According to the climatological studies, two-thirds of Iran's land has three hundred sunny days which indicates great potentials for providing solar energy. This paper deals with small-scale solar energy potentials in different cities of Iran. The considered solar systems are based on the combination of photovoltaic panels in order to obtain the nominal values of 1, 5 and 10 kW for 15 selected cities of Iran. Design of the photovoltaic (PV) systems is carried out based on optimum fixed tilt angles of the panels and efficiency variation due to the temperature changes of different locations. The final decision on financial assessment of the mentioned solar PV projects is based on different concepts of engineering economy such as rate of return (ROR), present worth of benefit and cost (PWB, PWC), extra investment analysis, levelized cost of energy (LCOE). The amount of calculated income and the expected benefit are also investigated under certainty and uncertainty of guaranteed solar electricity purchase tariff in a 30-year project lifetime.

1. Introduction

The change in the perspective of replacing new energy sources is unavoidable due to an increase in energy demand and a reduction in the amount of fossil fuels. Environmental issues and greenhouse gas emissions enforce the need for this change and replacement. Therefore, application of renewable energy resources such as solar and wind are the main concerns for power and energy sectors.

In terms of solar energy, Iran is among the most desirable countries for the duration of radiation. According to estimates, Iran has an average of more than 2900 h of sunshine per year which reaches to 3200 h in some other regions in the country. Therefore, there are more than 300 days of sunshine in most parts of the country. The solar radiation in Iran is about 1800–2200 kWh/$\frac{m^2}{year}$, which is higher than the global average [1]. Two main approaches in solar energy applications are the solar thermal energy conversion systems and the solar radiation using photovoltaic devices.

Providing the energy for rural areas and some other small-scale energy generations were among the first applications of the solar energy in Iran. But recently, Iran has invested on the large-scale photovoltaic power plants via international funding and guaranteeing long-term purchase of the solar electricity [2]. In addition to the above-mentioned projects, several studies have also been carried out in the field of solar radiation modeling and annual radiation in Tehran, Shiraz and other cities. An approximate algebraic formula is proposed in [3] to estimate the radiation in Iran. Recently, more accurate calculations have been made with a higher resolution of the solar radiation intensity in different parts of the world, including Iran [4,5]. Rooftop solar cells are investigated in [4] which lead to a reduction in electricity bills. A guaranteed purchase tariff from government is investigated in [5] which facilitates further investments in this technology. Ranking of different regions for the implementation of solar power projects has been made in [6]. Other studies are carried out in [7,8] on the development of renewable energy in Iran with detailed technical and economic aspects.

Earlier investigations have indicated that the solar electricity generation is not economically feasible due to the availability of the fossil fuels in Iran. According to [9], the cost per watt for solar power was reported up to a maximum of 10 USD. Considering the very long investment periods for solar panels, there has not been much interest for the private sector investors to enter this market. However, it is recommended that short-term profitability should not be prioritized in developing renewable energy policies [10].

Nowadays, policymakers' awareness of the potential impacts of renewable energies on national development is increasing. In early 2013, at least 138 countries set targets for the development of renewable

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Nomenclature

Abbreviations

PV	Photovoltaic
FIT	Feed-in Tariffs
REFIT	Renewable Energy Feed-in Tariff
EIA	U.S. Energy Information Administration
ROR	Rate of Return
NPW	Net Present Worth
EUAC	Equivalent Uniform Annual Cost
EUAB	Equivalent Uniform Annual Benefit
ROC	Return of Capital
PWB	Present worth of benefit
PWC	Present worth of cost
MI	Monthly income
MC	Maintenance cost
LCOE	Levelized Cost of Electricity
USD	United State Dollar

Variables

η_{PV}	Efficiencies of the panel
η_{inv}	Efficiencies of grid-connection system
P_{PV}	Module power (W)
G	Solar radiation intensity on the panel surface (W/m^2)
A_{PV}	Panel area (m^2)
T_{ref}	Normal temperature of the solar cell
T_{PV}	Cell performance temperature
β	Temperature coefficient of the efficiency
γ	Solar radiation coefficient
η_{rated}	Nominal efficiency
η_{PV}	Panel efficiency at the desired temperature
$\Delta\eta$	Variation of efficiency associated with temperature variations
T_{ambient}	Ambient temperature
T_{NOCT}	Nominal operating cell temperature
T_{aNOCT}	Ambient temperature at NOCT condition
G_{NOCT}	Solar radiation at NOCT condition
V_m	Wind speed at the monitored surface (m/s)
n	Index of year
t	Index of month
P_0	Present worth of Capital Cost
MC_n	Maintenance cost at the end of the n^{th} year
MI_t	Income at the end of t^{th} month
d	Discount rate
k	The rate of increase in income at the beginning of each year
m	Maintenance cost of the system at the end of n^{th} year
MC_n^{Present}	Present worth of maintenance costs
ROR_{Δ}	ROR of the difference of two projects
$ROR_{(k=15\%)}$	ROR in k = 15%
$ROR^{Uncertain}$	ROR under uncertainty
ΔROR	Maximum changes in the rate of return
MARR	Minimum Attractive Rate of Return

technologies. Governments can promote renewable energy markets in different ways [11]. These strategies are divided into long-term and short-term categories [12]. The most common short-term strategies include investment subsidies, tax cuts for renewable energy, carbon tax on fossil fuels, international and governmental loans.

The major contributions in long-term strategies are Renewable Energy Feed-in Tariffs (REFITs) strategies and quota obligation. Feed-in Tariff (FIT) is an important policy tool for attracting private investors in the field of renewable energy to increase the production. The Iranian Ministry of Energy in partnership with the Renewable Energy and Energy Efficiency Organization defined FIT in 2009 [13]. Furthermore, the rise in energy prices with the start of the targeted subsidy plan in Iran led to the management of energy consumption by major energy consumers [14].

The Ministry of Energy has applied a protection scheme for renewable energy through the implementation of a guaranteed electricity purchase tariff from renewable and clean power plants. In some cases, this support was carried out at a cost of 50% of the total investment. Fig. 1 shows the purchase tariff of solar generated electricity from 2012 to 2016. As shown in this figure, small solar power plants have the highest price which reflects the government's view of promoting domestic solar energy generation.

It should be noted that the purchase tariff rate is reduced as the capacity increases. Another incentive criterion is the discounted start-up fee which includes the costs of equipment and installation. The impact of tax credit on reducing start-up costs and increasing investment returns, considering reliability of the used equipment is investigated in [15].

According to the latest data from the U.S. Energy Information Administration (EIA), the average retail electricity cost in 2016 was 13 cents/kWh, while the cost of residential solar PV is currently around 3 USD/W. Fig. 1 shows the difference in the average retail electricity cost between Iran and US. Solar power generation has different costs in two stand-alone and grid connected forms. Due to the energy storage demand for stand-alone applications, the cost of this project is very high. According to [16], 90% of the systems are grid-connected. Investment costs, maintenance, lifetime and geographical conditions are among the economical justification parameters of solar electricity. Therefore, the economic evaluation of a plan in a financially competitive environment requires a comprehensive view on different parameters.

The justification for the expansion of solar power projects in the northern regions is a controversial issue in Iran. The dominant view in the production of solar electricity is to emphasize the superiority of the central and southern regions (due to their hot and dry climate) compared with Caspian Sea coastal areas with a moderate climate.

The focus of this paper is to investigate the potentials of solar energy production in different regions of Iran as well as financial study of the projects with the same conditions in intended areas. What distinguishes the contribution of this article is the comparison of solar energy in the investment scopes considering the uncertainty of the guaranteed energy purchase tariff or a 30-year project lifetime. General data regarding solar radiation, percentage of sunny days, temperature variation and optimum panel tilt angle for fixed PV systems are discussed in Section 2. Solar system design including cost and capacity for different regions is

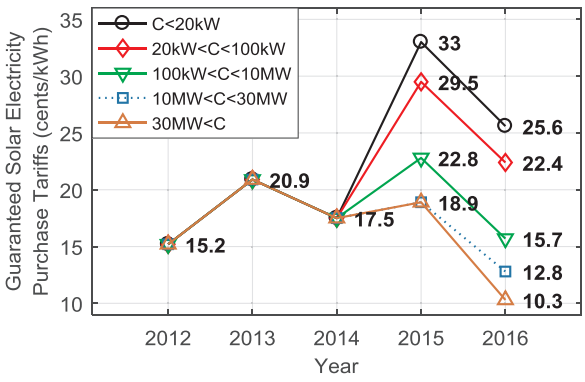

Fig. 1. Solar Power purchase tariffs in different capacities [17].