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Optimal Design and Parametric Assessment of Grid-Connected Solar Power Plants in Iran: a Review

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A B S T R A C T

Solar energy is used for domestic, industrial, and power plant consumption. From a nation-wide perspective, it has attracted increasing attention due to creating opportunities, reducing fossil fuels consumption, and also meeting the requirements for reduction of environmental pollutants. Given its geographical location which has endowed Iran with a desirable level of solar energy as a renewable source of energy, it is the first paper aimed to conduct a potentiometric study of constructing a 20 kW power plant in 31 capital cities in Iran, considering all the existing losses. PVsyst 6.7 and Meteonorm 7.1 software packages are used for analysis. Results showed that the required area for monocrystalline solar panels was less than that for polycrystalline ones and for polycrystalline less than thin-film panels. Furthermore, solar cells with higher manufacturing technology incurred lower costs, so that monocrystalline cells produced the cheapest solar-powered electricity, while the electricity generated by thin-film panels was the most expensive. In addition, it was found that ventilation had less impact on monocrystalline solar cells than polycrystalline, and less on polycrystalline panels than thin-film ones. The highest (39˚) and lowest (27˚) annual optimum tilt angle were related to Bojnoord and Bandar Abbas, respectively. Also, the results revealed that the highest (0.833) and lowest (0.771) annual performance ratios were obtained for Ardabil and Ahvaz, respectively. The highest (35276) and lowest (24031) amount of annual energy injected to the grid (kWh) were associated with Zahedan and Sari, respectively. Average annual energy injected to the grid (kWh) for the studied stations was 30942. For a more detailed evaluation of the effect that each type of losses had on the energy produced, annual loss diagrams, which are the most important outputs of PVsyst software, were evaluated for Zahedan and Sari stations.

1. Introduction

1.1. Current status of solar electricity in the world

In 2017, solar power capacity addition has been the highest in comparison with any other energy generation technology. Figure 1 indicates the global solar power capacity and its annual addition from 2007 to 2017. As it could be seen in Fig.1, the solar power capacity addition for 2017 is 29% higher than that for 2016 while solar photovoltaic capacity has seen growth by one-third, reaching around 402 GW in 2017.

Total solar PV capacity additions were higher than total net capacity additions in nuclear, coal-, gas-fired power-plants. Renewable power, in particular, solar cells, accounted for 55% of net additions to global power generating capacity. Renewable power has not seen much advancement in the Middle East, though some promising measures were taken in this region in 2017. In this region, renewable power represents a share of around 2.5% that, without accounting for hydropower, it declines to around 0.6%. In 2017, Saudi Arabia launched a series of solar and wind tenders and other countries, such as Israel, Jordan, Kuwait, and United Arab Emirates (UAE), have large-scale power plants under construction [1].

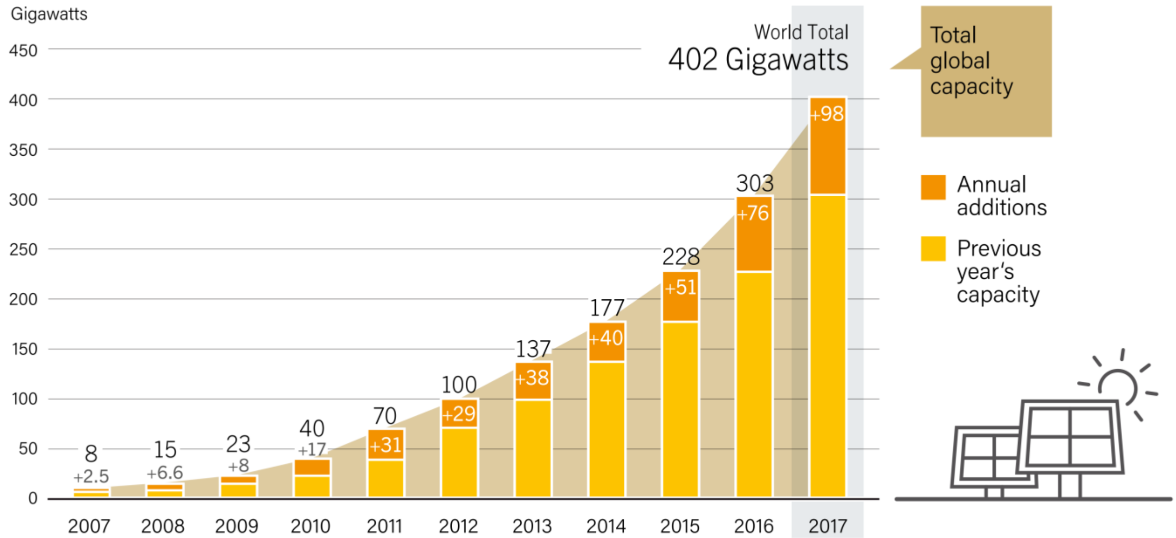

Figure 1. Global installed capacity for solar-powered electricity and annual additions [1]

1.2. Current status of renewable electricity in Iran

Around 99% of the Iranian population has access to electricity through a national grid power line and there are less than 1 million electricity-deprived citizens. At the end of November 2017, the highest consumption of electricity in Iran (34.9%) occurred in residential sector followed by industrial (30.4%) and agricultural (16.1%) sectors [2].

Due to the reports released by the Iran's Renewable Energy and Energy Efficiency Organization (SATBA) [3] and as depicted in Fig. 2, in the period from June 2009 to January 2019, 2.751 billion kWh of electricity was generated from renewable energies of which 64 million kWh was produced only in January in the present year. According to this report, this amount of electricity generation from renewable sources has saved around 1.898 million tons in GHG emissions, 44,000 tons of which is attributable to January of the present year. In addition, power generation from renewable sources of energy has resulted in 781 million m^3 reductions in fossil fuels consumption which are the main cause of air pollution. Also, 605 million Liters of water consumption reduction has been achieved under these renewable energy scenarios of which 14 million litters was achieved in January only. At present, renewable energy power plants with 445 MW of generation capacity are under construction while the installed capacity is 680 MW. Solar installations have the highest renewable installed capacity with 42% share in overall renewable power plants. Also, direct and indirect employment created by renewable energies is 43680 peoples. Analyses on the available figures and data revealed that renewable power plants consist of wind installation by 41%, solar cells by 42%, small hydropower by 13%, and heat recovery and biomass each by 2%. The significant point in this report is the 7% growth in the share of photovoltaic plants compared with the last 6 months.

1.3. The current status and future trends in solar-powered electricity in Iran

Power generation from solar energy in sunny areas of Iran has been added to an important priority to the government's agenda in the Sixth Development Plan and government authorities, including the CEO of environmental protection agency, have continually announced their full support of this program [4]. According to REN 21 report, Iran targets 5 GW of renewable wind and solar capacity by 2020 [1]. Based on the statistics released by Renewable Energy and Energy Efficiency Organization (SATBA) for December 2018, the electrical capacity generated by wind, solar, biomass, small-scale hydropower, and heat recovery plants has been 282, 286, 11, 88 and 14 MW, respectively, with solar-powered electricity ranking the second [5].

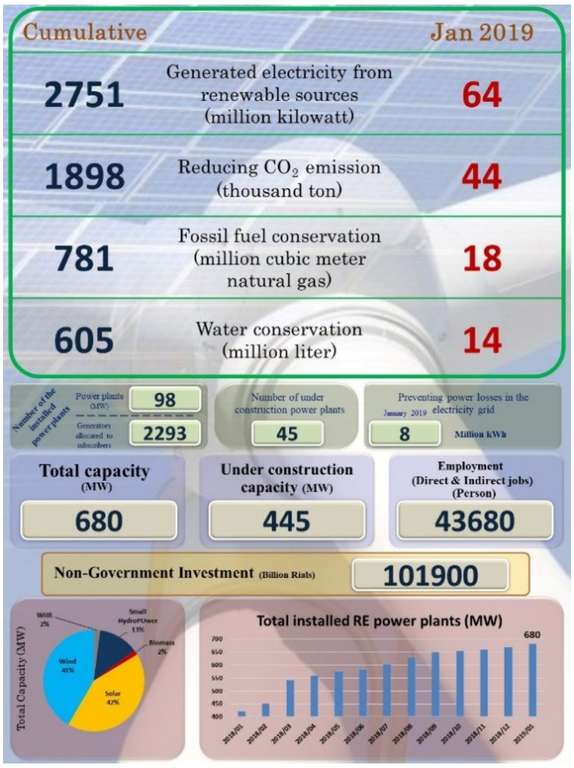

Figure 2. Savings in sources by using renewable energies [3]

The geographical location of Iran's renewable power plants is shown in Fig. 3 [6]. According to this figure, the major part of PV power plants is installed in the central area of Iran (Hamedan, Yazd, and Fars provinces) where there is high radiation. Detailed data about solar power plants are presented in Table 1 [7].

Higher energy prices after launching Targeted Subsidies plan in Iran encouraged major energy consumers to manage their energy consumption [8]. Through the implementation of a guaranteed electricity purchase tariff for renewable power plants, the Ministry of Power actually has taken a support initiative for the generation of renewable energies. In some cases, this support has been given as returning 50% of total investments. Figure 4 depicts the purchasing tariff for solar-powered electricity by capacity in Iran from 2012 to 2016 [9]. As shown in this figure, small-scale solar power plants have the highest price indicating the government's outlook for the promotion of solar energy production on a domestic scale. It is worth mentioning that, according to Fig. 4, the rate of purchasing tariff is decreased by increasing the capacity.

According to [10], the grid-connected system has superiority over the off-grid system in Iran. The reason for this is that the off-grid system, given its energy storage demands, is costlier. Based on [11], 90% of systems are connected to the grid.

In spite of the huge potential of solar power plants discussed in previous sections, this is an under-developed technology in Iran and accounts for only around 1% of total electricity generation [12, 13]. Due to Table 2, the upper bound for allowable solar capacity in Iran is 7417 GW [13], that is 15 times the allowable installed capacity of wind-powered electricity.

Jacobson et al. [14] stated that, by 2050, Iran would be able to provide 100% of its energy needs through renewable energies and they observed that the share of photovoltaics, offshore wind, solar thermal energy, onshore wind and hydropower were 55, 21.8, 11.8, 9.5, and 1.9%, respectively. These suggestions are in agreements with the findings in [13]. As for reductions attained in GHGs emission in case of using PV cells for electricity generation, it was stated that each kWh of solar-powered electricity would prevent the emission of 715 g CO_2 [15].

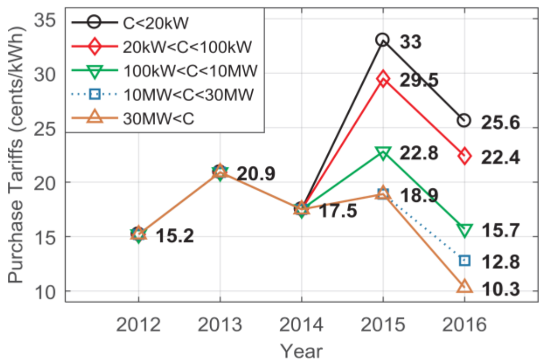

Figure 4. Solar-powered electricity tariffs for various capacities [13]

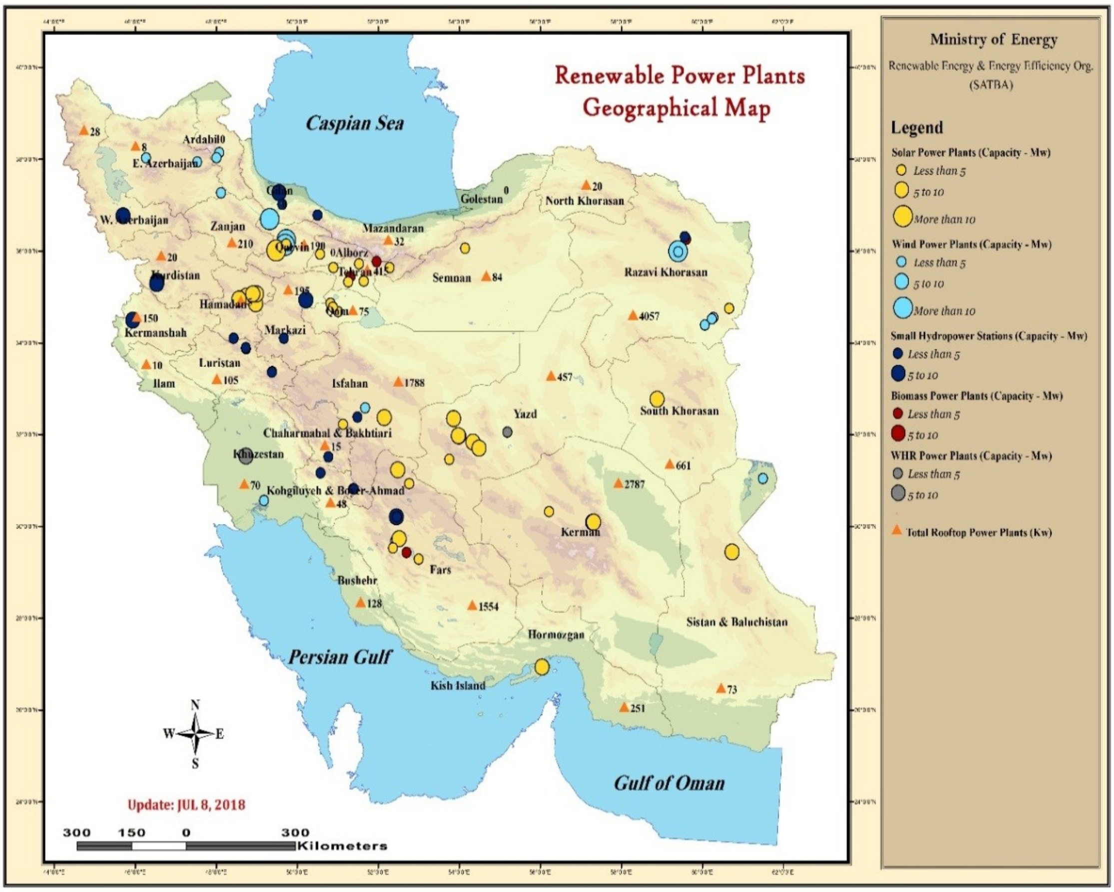

Figure 3. Geographical location of MW-scale solar power plant [6]

Table 1. The list of large power plants installed in Iran so far [7]

No	Project Name	Capacity (MW)	Construction Site	Date of Operation
1	Atrian Parsian	0.514	Malard, Tehran	2014
2	Pak Bana	1	Qom, Qom	2016
3	Tara Moshaver	0.23	Shams Abad, Alborz	2017
4	Ghadir Energy Investment Co.	10	Jarghouyeh, Isfahan	2017
5	Mehrad Energy Arvand	1.2	Rafsanjan, Kerman	2017
6	Tose-e Faragir Jask	10	Mahan, Kerman	2017
7	Solar Energy Arka	10	Mahan, Kerman	2017
8	Pejvak Omran Kish	10	Ardakan, Yazd	2017
9	Taban Energy Development	10	Eqlid, Fars	2018
10	Taban Energy Development	10	Abadeh, Fars	2018
11	Nika-Energy	10	Shiraz, Fars	2018
12	Tose-e Maksan Dehshir	3.5	Dehshir, Yazd	2018
13	Aftab Taban Kavir Part	10	Khusf, South Khorasan	2017
14	Sarzamin Abi Do Qeshm	10	Qeshm Island, Hormozgan	2017
15	Behnad Energy Pars Lian	4.6	Sarvestan, Fars	2017
16	Gostaresh Energy No Atiyeh	10	Zahedan, Sistan & Baluchestan	2017
17	Gostaresh Energy No Atiyeh	10	Ashkezar, Yazd	2017
18	Aftab Mad Rah Abrisham	7	Qahavand, Hamadan	2016
19	Aftab Mad Rah Abrisham	7	Aq Bolagh-e Latgah, Hamadan	2016

20	Aftab Mad Rah Abrisham	7	Kerdabad, Hamadan	2017
21	Aftab Mad Rah Abrisham	8.9	Qahavand, Hamadan	2017
22	Aftab Mad Rah Abrisham	8.6	Famenin, Hamadan	2017
23	Sanaye Siman Shahrekord	1.5	Shahr-e Kord, Chaharmahal and Bakhtiari	2017
24	ABO wind	1.313	Syed Abad-Damghan, Semnan	2017
25	Tose-e Khorshidi Mehriz Ghadir	10	Mehriz, Yazd	2018
26	Iran Tablo	0.628	Nazarabad, Alborz	2017
27	Pars Ray Energy Bahar	10	Shahr-e-Ray, Tehran	2017
28	Mahd Tejarat Gostaran Attar	10	Abadeh, Fars	2017
29	Mohandesi Moshaver Tajdidpazir Soheil	8.4	Damavand, Tehran	2017
30	Negin Setare Marzi Taybad Shayan	5	Taybad, Razavi Khorasan	2016
31	Ayandeh Sazan Sayareh Sabz	1	Kashan, Isfahan	2016
32	Taban Energy Mehr Afarin	0.02	Tehran, Tehran	2017
33	Tose-e Energy Sabz Shafagh	1	Boshruyeh, South Khorasan	2018
34	Energy Sabz Kavir Kish	10	Mahan, Kerman	2018
35	Khorshid Derakhshan Kavir	10	Chahak, Yazd	2018
36	Tose-e Energy Khorshidi Ghadir Qom	10	Qom, Qom	2018

Table 2. The upper bound for allowable installed [13] renewable capacity in Iran (GW)

Solar heating	Solar-powered electricity	Wind-powered electricity	Hydropower
14834	7417	554	21

1.4. Literature Review

Given the fact that Rwanda enjoys one of the best solar radiations in Eastern Africa and only 19.8% of its 11.92 million-people-population has access to the main power grid, Laetitia (2018) designed and evaluated a 1.3 MW solar power plant in this country [16]. The software used was PVsyst and they studied two scenarios including fixed-tilt and axis-tracker solar panels. Results showed that these two systems annually produced 1892338 and 2514113 kWh of electricity, respectively, and the performance index of 85% was calculated for both scenarios. Furthermore, from the results of various simulations of both states (fixed-tilt and axis-tracker), it was concluded that constructing a power plant was technically and economically viable.

Boyd (2018) examined three grid-connected monocrystalline silicon solar arrays in a university campus in Maryland for a one-year period [17]. Arrays were composed of similar modules but positioned in different angles and orientations. One array was installed on a parking lots roof with an eastern-western tilt, one in an open square, and one on a flat roof. Arrays were simulated in PVsyst and results were compared with the measurement data which showed a good agreement, especially for the roof-mounted arrays. Results indicated that all three arrays generally had a performance ratio of above 0.75 but their energy outputs were drastically different which was mostly because of their various operating temperature and less due to their varying angles.

Akram et al. (2018) designed and analyzed a 300 MW power plant in Pakistan using NASA meteorological data and PVsyst software package [18]. The studied sample was compared to Quaid-e-Azam solar park. Results revealed that the suggested configuration enhanced the performance ratio by 3-4% above that of Quaid-e Azam solar park, raised the energy injected to the grid by 4.5 MW annually, and reduced temperature losses by 4%. It is predicted that the physical realization of the suggested configuration will improve the energy performance of Quaid-e Azam solar park.

Nayak et al. (2018) used PVsyst commercial software to analyze and study the effect of various type of tracker systems on the energy output of a 400 kW solar power plant in Jaipur, India [19]. Their results indicated that, compared to the fixed-tilt solar panel, the energy production would increase by 4.91 and 22.91% in case of using single-axis and dual-axis tracking systems, respectively. In addition, their results were indicative of equal losses in the fixed-tilt and single-axis systems, yet they were higher for the dual-axis one.

Alshamani (2018) designed and modelled a large-scale solar water pumping system in Riyadh, Saudi Arabia [20]. They used HOMER and PVsyst software packages for their analyses and aimed to supply the energy demand for pumping 245 m^3 of water in a day from a 115m deep well. Withdrawal price per m^3 of water was estimated to be \$0.04. Moreover, studies suggested that both software packages predict rather similar results. Their research showed that the large-scale solar pumping system was a reasonable solution for such countries as Saudi Arabia.

Chattopadhyay and Rajavel (2018) used PVsyst to conduct a comparative study on a 10 kW grid-connected photovoltaic system in 3 urban (Lucknow), rural (Bareilly), and coastal (Udupi) regions in India with relatively similar solar radiation [21]. For the studied areas, annual energy injected to the grid and performance ratios of 15.36 MW and 0.783, 16.74 MW and 0.819, and 16.35 MWh and 0.795 were calculated, respectively. As a general conclusion, they stated that solar panels outperformed in rural areas due to their lower temperature and humidity compared to urban and coastal areas.

Batista (2018) studied shadowing effects on photovoltaic systems and their reduction solutions using PVsyst [22]. Results of a study on a small system in Gavle city indicated that the chimney had a negligible shadowing effect around 1%. Results of other studies under real conditions showed the significant effect of optimizers on reducing shadow-induced electric losses. Additionally, modules interconnections can also affect the power output of the system and, at times, without installation of optimizers, they can help in cutting the costs. Based on the results, the best-case scenario was a combination of horizontal arrays and optimizer which yielded a performance ratio of 0.685.

1.5. Presentation and Novelties of the Current Work

The present work can contribute to the future perspectives of this industry by finding more accurate potentials, suitable locations, loss examinations, etc. in the renewable energy sector [23]. This comparative study is designed to be the first to consider electric energy production by solar cells at various regions in Iran. In other words, despite high solar energy potentials and Iran's geographical location on global sun-belt, these resources are not used into thoroughly and properly. So, this paper uses PVsyst 7.1 commercial program to evaluate the utilization of a 20 kW grid-connected solar power plant in 31 capital cities in Iran. The studied parameters will be panels spacing for minimum shading effects, estimation of initial investment, proper orientation and angle of solar panels at each station, appropriate arrangement of panels, the amount of power available at each station, and performance ratio. Other parameters include the highest energy injected to the grid from each station, identification of the station with highest energy injection to the grid in the country, and the effect of seasonal tilting on the energy injected to the grid at each station.

The most important output of PVsyst is the radiation to consumption energy flux diagram which was evaluated for the studied stations. In addition, the effect of the solar tracking system on its performance was studied. For each station, converter losses (converting DC electricity produced by solar cells to AC power consumed in the grid), heat losses, the appropriate tilt angle of solar panels, etc. were determined [24].

This paper is organized as follows. Section 2 presents the software used for studies. Theory and governing equations are formulated in section 3. In the next section, modelling process, analysis, and validation are discussed and in the fifth section, the simulation results will be presented. Section 6 provides the conclusion and future trends.

2. The used Software

PVsyst is an extensive application program used for solar systems which includes the required tools for investigating and research, sizing, simulation, and data analysis of PV systems that is designed in order to help architects, engineers, researchers, and ever students interested in research and work in this area. The software package contains a very precise user guide thoroughly explaining various models and methods so that one can be able to begin and finish their projects in a very user-friendly and intuitive environment. In PVsyst one can input meteorological data from various sources as well as other personal information (manually) and then analyze and have the result in the form of a full report. Key capabilities of software are analysis and simulation of PV systems, suitability for research and educational works about PV systems, ability to input meteorological data from different sources, provision of visual tools for solar systems sizing, having a internal database, preparing an accurate report of the simulated systems, analysis of PV systems behavior, etc. [24]. Meteonorm software was used to extract meteorological and solar radiation data, which is installed over PVsyst and both programs run simultaneously.

3. Theory and Governing Equations

The maximum power output of solar cells is obtained by calculating the optimal tilt angle of solar panels when the solar radiation arrives perpendicularly upon the surface [25]. The optimal tilt angle is obtained by the following equation:

$$\beta = L - \delta \quad that \quad \delta = 23.45\, sin\, [\frac{360(284+N)}{365}] \tag{1}$$

Where L is latitude and N is the day of the year number. The importance of proper angle and orientation for the PV system is that it can increase the efficiency by up to 30% [26].

The distance between axes in PV power plant arrays is obtained by equation (2) according to Fig. 5.

$$a = d\cos\beta + h\,\mathrm{cotg}\,\alpha_1 = d\,(\cos\beta + \sin\beta\,\mathrm{cotg}\,\alpha_1) \tag{2}$$

Parameters of the above equation are shown in Fig. 5.

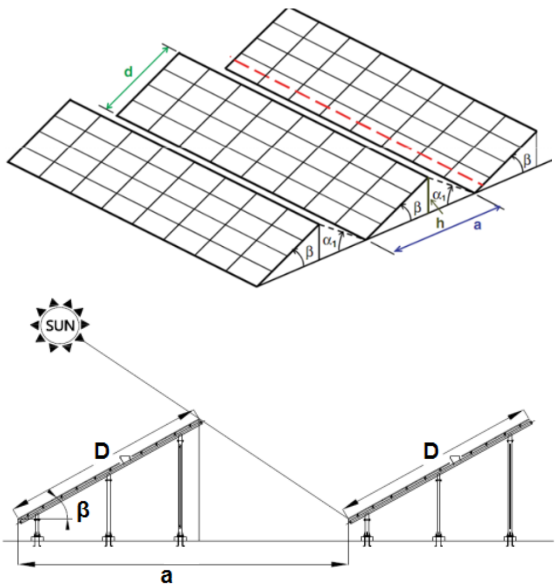

Figure 5. Axes Spacing

The optimal spacing is crucial because, in case of prolonged shading on a single cell of solar panel, it will turn into a hotspot and lowers the cell's efficiency which is observable in Fig. 6.

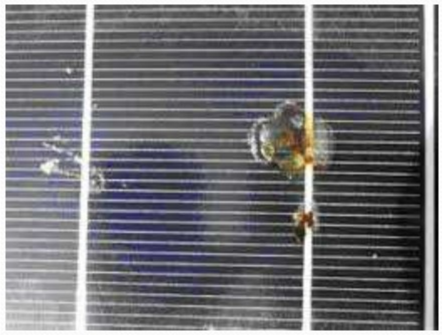

Figure 6. Failure of PV cells

Also, angular loss of panels is calculated by the following equation:

$$AL\,(\alpha) = \frac{1 - exp\,(-cos\frac{a}{\alpha_r})}{1 - exp\,(-cos\frac{-1}{\alpha_r})} \tag{3}$$

Where a is the irradiance angle of incidence, α_r is a constant value to fit in each case, and AL is angular losses.

The power output of a solar system which is considered as an essential parameter in the design calculations of a grid-connected PV power plant is calculated by the following equation [10]:

$$P_{PV} = \eta_{PV} \cdot \eta_{inv} \cdot A_{PV} \cdot G \tag{4}$$

As seen, the power output of the solar system is contingent upon many factors including solar irradiance intensity on the panel's surface (G; w/m^2), panel's area (A_{pv}; m^2), panel's efficiency (η_{PV}), and inverter's efficiency (η_{inv}). Panel's efficiency is obtained by:

$$\eta_{PV} = \eta_{rated}(1 - \Delta\eta) \tag{5}$$

$$\Delta\eta = \beta(T_{PV} - T_{ref}) - \gamma\, logG \tag{6}$$

Where η_{rated} is the rated efficiency, β is the temperature coefficient of efficiency, T_{PV} is the operating temperature of the solar cell, T_{ref} is the reference temperature of the solar cell (25 ˚C) and γ is the coefficient of solar irradiance. Since according to [27], the irradiance coefficient is taken to be zero, substituting equation (6) in (5) gives:

$$\eta_{PV} = \eta_{rated}(1 - \beta(T_{PV} - T_{ref})) \quad (7)$$

From [28], the temperature coefficient of efficiency is calculated by:

$$\beta = \frac{1}{T_0 - T_{ref}} \quad (8)$$

From [29], the value of T_0 is equal to the temperature at which electrical efficiency drops to zero. According to the discussions in [28], the cell's temperature depends on ambient temperature, solar radiation, wind speed, and solar cell temperature under normal conditions which is expressed as follows:

$$T_{PV} = T_{amb} + \left(\frac{9.5}{5.7 + 3.8V_m}\right)(T_{NOCT} - T_{aNOCT})\frac{G}{G_{NOCT}} \quad (9)$$

Where T_{amb} is the ambient temperature, V_m is the wind speed (m/s), T_{NOCT} is the nominal operating cell temperature, T_{aNOCT} is the ambient temperature at NOCT condition, and G_{NOCT} is the solar radiation at NOCT condition. Substitution of (9) in (7) gives:

$$\eta_{PV} = \eta_{rated}\left(1 - \beta\left(T_{amb} + \left(\frac{9.5}{5.7 + 3.8V_m}\right)(T_{NOCT} - T_{aNOCT})\frac{G}{G_{NOCT}} - T_{ref}\right)\right) \quad (10)$$

In [30] it is suggested that T_{NOCT} is calculated under specific conditions when the solar cell is operating in open-circuit, at 20 ˚C, radiation of 800 W/m^2, and wind speed of 1 m/s.

Performance ratio is an important parameter in studying the performance of a solar system. It is a dimensionless number representing the ratio of energy injected to the grid to the energy which would be produced if the system was continuously working at its nominal STC efficiency [31, 32]. It is obtained by the following equation:

$$PR = \frac{Y_f}{Y_r} = \frac{Energy\ effectively\ produced\ (used)}{Energy\ which\ would\ be\ produced} \quad (11)$$

The performance ratio effectively describes the efficiency of a solar power plant with higher percentages indicating higher efficiency. Because of thermal losses due to heating of PV modules and ohmic losses, maximum performance ratio is around 80% [33]. Other losses include cabling, mismatch, quality of solar module, shading effects, PV conversion, and incident angle modifier (IAM) [16]. Additionally, dust and inverter's efficiency also affect the performance ratio [17].

Ambient temperature is the most important parameter affecting the performance ratio [18]. It means that performance ratio is higher in cold months than in hot months unless the effect of lower radiation outweighs cooler temperature [34]. It is suggested that the main losses in a solar system are associated with heating of solar panels. Therefore, radiators and cooling systems need to be used for panels [35]. A system designed for this purpose is the hybrid thermoelectric solar collector in which a working fluid absorbs the heat from panels and cools them down.

Generally, the performance ratio is between 0.6 and 0.8 which depends on the site, solar radiation, and climate conditions [36]. The value of performance ratio is not indicative of the energy produced, because a system with a small performance ratio, yet in a location receiving high radiation, may produce more energy compared to a system with larger performance ratio locating in an environment with lower solar radiation [37].

Calculations in PVsyst are performed as follows. First, data from Meteonorm software, which are radiation values for various points, are used as input. Then, the aforementioned relations are used to find the optimal tilt angle of panels, optimal inter-panel spacing, energy output, etc.

4. Modelling, Analysis, and Validation

The details and geographical location of each 31 studied stations were the capital cities of the country's provinces, are presented in Table 3 [38]. The reason for using Table 3 was that only 8 stations of Hamedan, Zanjan, Birjand, Tehran, Urmia, Tabriz, Bojnord, and Mashhad exist as default in the (meteorological) database of PVsyst software and data required for simulations in PVsyst needed to be obtained for other stations using Metonorm 7.1 software.

PVsyst has attracted increasing attention from scholars and engineers around the world. Many researchers have compared their results with experimental and theoretical data and they all admitted that the good agreement between the software results and experimental data. Table 4 gives a summary of works on software validation.

Table 3. Required data for defining new stations in Meteonorm 7.1.

City	Longitude	Latitude	Height (m)
Shahrekord	50.9	32.3	2060
Yasuj	51.6	30.7	1816
Kerman	57.1	30.3	1756
Hamedan	48.5	34.8	1741
Arak	49.7	34.1	1708
Zanjan	48.5	36.7	1638
Esfahan	51.7	32.6	1571
Shiraz	52.5	29.6	1519
Sanandaj	47.0	35.3	1463
Birjand	59.2	32.9	1444
Ilam	46.3	33.4	1387
Karaj	51.0	35.8	1380
Kermanshah	47.1	34.3	1374
Tehran	51.4	35.7	1368
Urmia	45.0	37.3	1363
Khorramabad	48.4	33.5	1347
Tabriz	46.3	38.1	1345
Zahedan	60.5	29.3	1344
Ardabil	48.3	38.3	1338
Qazvin	50.0	36.2	1279
Yazd	54.4	31.9	1230
Semnan	53.2	35.3	1130
Bojnord	57.3	37.5	1086
Mashhad	59.4	36.2	1065
Qom	50.9	34.7	932
Gorgan	54.5	36.8	174
Sari	53.0	36.3	54
Ahvaz	48.7	31.3	10
Bandar Abbas	56.2	27.1	9
Bushehr	50.5	28.6	4
Rasht	49.3	37.2	0

Table 4. Validation of PVsyst software

Reference	year	The sample used for comparison	Different (%)
[39]	2013	Experimental data of 200 kW power plant in India	1.4%
[40]	2014	Comparison with experimental data of Yazd city and Sunny design software	1.47% by experimental data and 6.5% by Sunny design software
[41]	2016	Experimental data	1.5
[42]	2016	Theoretical calculations	5.6%
[43]	2017	Comparison with Openei-SWERA database	1-26% for various cities and parameters
[44]	2017	Experimental data of Yazd	1.8%
[45]	2017	Experimental data of solar pumping system in India	60.2%
[17]	2018	Experimental data of solar power plant in NIST university, USA	3.5-13.8% for various arrays
[18]	2018	Experimental data of Quaid-e Azam solar part in Pakistan	3-4%
[46]	2018	Comparison with data derived from Skelion software	0.5%
[20]	2018	Solar pumping data by HOMER	12.5%
[47]	2018	Experimental data of a 6 kW power plant in Kazablanka	1.2-2.9% for various materials of solar panel

5. Simulation results

Figure 7 is a schematic representation of the solar power plant simulated by PVsyst 6.7. Modules and inverter are the most important components of the grid-connected PV system [48]. In PVsyst, technical analysis can be conducted by inputting the capacity of the solar power plant and selecting the type of solar cell, electric converters, and their number. This paper is a potentiometric study about the construction of 20 kW solar power plant in capital cities of Iran's provinces. Also, Climate data required for Meteonorm 7.1 are obtained.

The solar cell technology used in the present paper is of polycrystalline type, solar cells are mounted on the ground, they are well-ventilated on the back side with air flowing around them, in other words, they are naturally ventilated. For economic calculations, loan interest rate of 18% and solar module and converter prices of $1.2 and $0.31 per kWh of energy generated were considered, respectively [49]. YL250P-29b solar modules are manufactured by Yingli Co. each with a capacity of 250 W. The SE4000H converters used are the product of SolarEdge Technologies Inc. each with a capacity of 4 kW. Furthermore, P500 optimizers from SolarEdge with a capacity of 500 W are used. Yearly, summer and winter optimum tilt angle ranges are presented in Table 5.

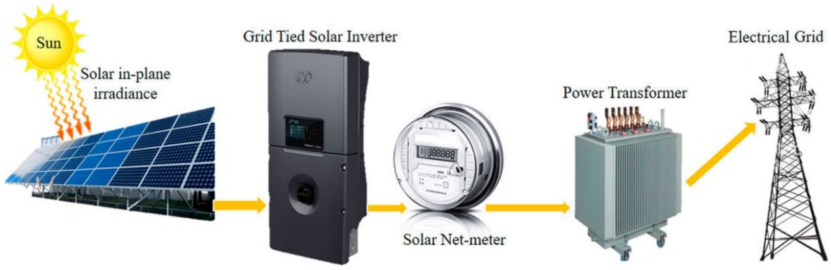

Figure 7. Schematic of the simulated solar power plant

Table 5. Results of annual, summer and winter optimum tilt angles for 31 studied stations

Station	Annual optimum tilt angle range	Summer optimum tilt angle range	Winter optimum tilt angle range
Shahrekord	28-31	8-18	49-52
Yasuj	27-29	5-17	48-51
Kerman	29-32	5-17	49-52
Hamedan	31-35	10-21	52-55
Arak	32-35	12-18	52-55
Zanjan	34-37	11-23	54-57
Esfahan	31-34	8-18	51-55
Shiraz	27-30	4-16	48-51
Sanandaj	30-34	10-21	52-55
Birjand	31-35	8-19	52-55
Ilam	30-33	8-19	51-54
Karaj	33-36	11-22	53-56
Kermanshah	31-35	12-17	52-55
Tehran	32-36	11-22	53-56
Urmia	32-36	11-23	55-58
Khorramabad	30-34	9-19	51-55
Tabriz	33-37	12-25	54-58
Zahedan	28-32	4-16	49-52
Ardabil	34-38	12-25	55-58
Qazvin	33-37	11-23	53-57
Yazd	30-33	7-18	50-54
Semnan	34-38	10-22	54-57
Bojnord	35-39	12-24	55-58
Mashhad	32-36	11-23	53-56
Qom	33-36	13-18	53-56
Gorgan	33-37	11-23	53-56

Sari	34-38	13-18	52-55
Ahvaz	27-30	6-18	48-51
Bandar Abbas	24-27	0-15	44-47
Bushehr	25-28	3-15	46-49
Rasht	33-37	10-22	53-56

In calculations used for obtaining Table 5, zero losses in performance compared to the optimum state was considered. As such, an angle range was produced by software, with the maximum value in this range taken as the installation angle for each station (Table 5). Moreover, it should be mentioned that in the present paper, calculations were performed based on the annual optimum tilt angle.

Based on the simulation results in Table 5, the highest (39˚) and lowest (27˚) annual optimum tilt angles were obtained for Bojnord and Bandar Abbas. The results obtained by using these values are shown in Figs. 8 and 9 for Bojnord and Bandar Abbas, respectively. It is noteworthy that results in Table 5 are unchanged for all designs by PVsyst (initial design, project design, grid-connected, off-grid, and solar pumping).

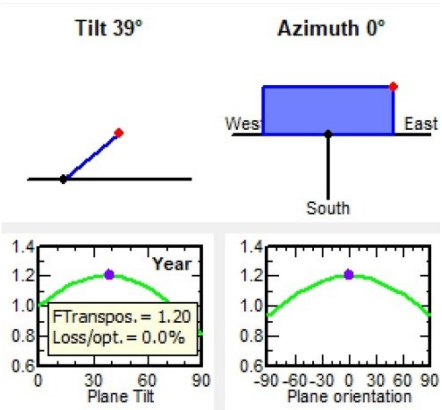

Figure 8. Annual optimum tilt angle for Bojnord

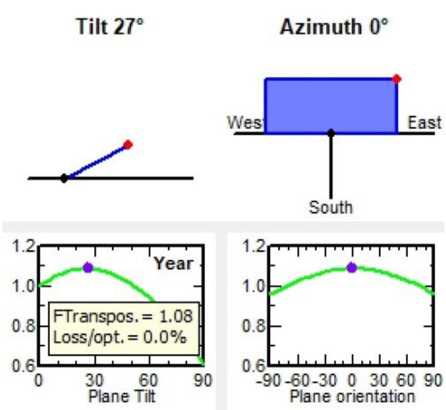

Figure 9. Annual optimum tilt angle for Bandar Abbas

Table 6 presents the price per kWh of solar-powered electricity generated based on summer and winter optimum tilt angle. Results indicate that in case of not using annual optimum tilt angle, average radiation on a tilted angle and subsequently the total annual energy generated will decrease which in turn leads to higher approximate prices per kWh of solar-powered electricity generated. It is obvious that optimum tilt for summer is more suited for energy production than optimum tilt for winter and this is reasonable because of higher solar radiation in summer compared to winter.

Table 6 indicates the parameter of approximate price per kWh of solar-powered electricity generated for 31 studied stations and three scenarios of annual, summer, and winter optimum tilt. From this table, it is clear that the highest ($0.57) and lowest ($0.38) costs per kWh of solar power for annual optimum tilt are associated with Sari and Zahedan cities.

These results are in perfect agreement with Fig. 10 [50] because Zahedan is among the cities with the highest radiation potential and Sari with lowest. According to Fig. 3 and Table 1 that show the geographical location of renewable power plants in Iran, more investments in the area of solar energy are needed in Zahedan. Employment and skills training are not easily achievable in the deprived region of Zahedan where people suffer from a shortage of water, agriculture is dying, and there are no other industries to be invested in. Therefore, renewables are among the very few alternatives left for job creation and development in this region. Also, according to the results in Table 6, the average price per kWh of solar power generated for annual optimum tilt angle is $0.44 in Iran.

To further study the effect of various ventilation types used on the back of solar arrays (the effect of panel’s heating) and the solar cell technology used, Table 7 presents the results for Zahedan that enjoys the highest solar energy potential. This table reveals that, accoeding to higher power generation efficiency, the area required for monocrystalline solar panels is less than that for polycrystalline ones and still lesser than thin-film panels. For example, to produce the same amount of energy, thin-film solar panels require an area which is 75 m^2 more than that needed for monocrystalline technology. This added area is also accompanied by other costs such as cabling and repair and maintenance which

Table 6. Results for price per kWh of solar-powered electricity generated ($)

Station	Annual	Summer	Winter
Shahrekord	0.44	0.44	0.47
Yasuj	0.43	0.44	0.46
Kerman	0.40	0.41	0.43
Hamedan	0.45	0.46	0.48
Arak	0.43	0.45	0.46
Zanjan	0.43	0.44	0.46
Esfahan	0.40	0.41	0.42
Shiraz	0.41	0.42	0.44
Sanandaj	0.44	0.45	0.47
Birjand	0.40	0.41	0.43
Ilam	0.43	0.43	0.46
Karaj	0.45	0.46	0.48
Kermanshah	0.43	0.44	0.45
Tehran	0.45	0.46	0.48
Urmia	0.41	0.42	0.44
Khorramabad	0.43	0.44	0.46
Tabriz	0.43	0.44	0.46
Zahedan	0.38	0.39	0.40
Ardabil	0.48	0.48	0.51
Qazvin	0.45	0.46	0.48
Yazd	0.41	0.42	0.43
Semnan	0.40	0.41	0.42
Bojnord	0.45	0.46	0.48
Mashhad	0.49	0.49	0.52
Qom	0.42	0.43	0.44
Gorgan	0.51	0.52	0.54
Sari	0.57	0.59	0.60
Ahvaz	0.43	0.44	0.47
Bandar	0.45	0.46	0.48
Bushehr	0.44	0.45	0.47
Rasht	0.55	0.56	0.58

give rise to the total costs. Another point that can be drawn from table 7 is that the ventilation type on the back of solar cells does not affect the required area of solar cells and for all three types of ventilation, equal areas are estimated for solar cells. Furthermore, given the price per kWh of electricity generated, it can be inferred that solar cells with higher technologies incur lower costs so that monocrystalline solar panels produce the cheapest solar power while thin-film ones produce the most expensive electricity. Other important points concluded from table 7 are similar results for free standing and ventilated and also very close results for monocrystalline and polycrystalline solar panels. This can justify applying polycrystalline panels instead of monocrystalline ones. Also, by studying the effect of ventilation at the back of solar cells on their performance, it was found that it has affected less on monocrystalline than polycrystalline and less on polycrystalline than thin-film panels.

Regarding price per kWh of solar-powered electricity generated, the prices will escalate by 2.1 and 6.4% in case of using summer optimum tilt and winter optimum tilt, respectively. The highest rises in price by applying summer and winter optimum tilt angles are associated with Arak and Ahvaz stations by 4.7 and 9.3%, respectively.

Table 8 presents the solar cell losses (%) due to shading effect of one string of panels on another compared to single string mounts. According to power industry experts, a shading effect of lower than 3% is a desirable design value. This represents the optimum spacing between solar cells. The appropriate values for each station are shown by bold numbers in each row.

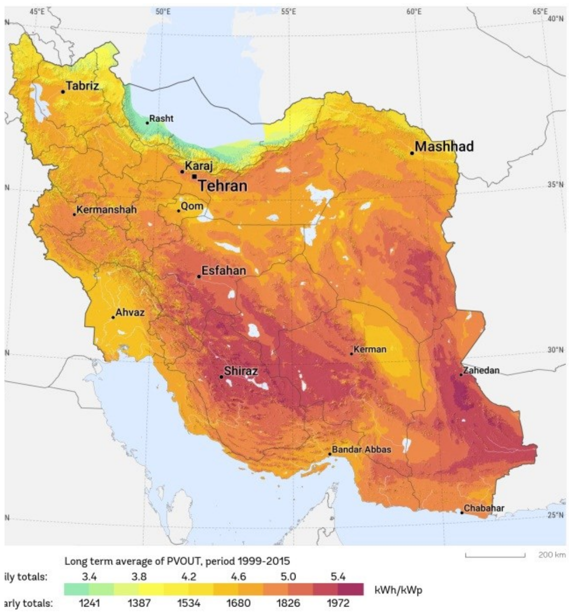

Figure 10. Solar power generation potential in Iran [50]

The results of table 8 indicate that for none of the stations, the optimum inter-panel spacing is 4 m. For Yasuj, Shiraz, Zahedan, Bandar Abbas, and Bushehr, the optimum spacing is 5 m, for Shahrekord, Kerman, Esfahan, Ilam, Khorramabad, Yazd, and Ahvaz, it is 6 m, for Hamedan, Arak, Sanandaj, Birjand, Karaj, Kermanshah, Tehran, Urmia, Tabriz, Semnan, and Qom, it is 7 m, for Zanjan, Qazvin, and Mashhad, it is 8 m, for Ardabil, Bojnord, Gorgan, and Rasht, the optimum spacing is 9 m, and for Sari, it is 10 m. Generally, from the results in Table 8, it can be concluded that at higher latitudes, because of the higher tilt angle of solar panels, they have higher shading effect on each other so their spacing has to be increased to reduce the shading losses. Due to the results of Table 8, average losses (%) for 4, 5, 6, 7, 8, 9, 10, and 20 m spacings are 8.1, 4.5, 3.2, 2.6, 2.3, 2.1, 1.9, and 1.2%, respectively. In addition, according to the results, the highest and lowest losses due to the shading effect of strings on each other are related to Sari and Yasuj stations, respectively.

Table 7. The effect of ventilation and technology of solar panels on the performance of a 20 kW solar power plant in Zahedan

Technology type	Ventilation type	The area of solar cells (m^2)	Price of solar electricity **($/kWh)**
Monocrystalline	Free standing	125	0.37
	Ventilated	125	0.38
	No ventilation	125	0.43
Polycrystalline	Free standing	133	0.38
	Ventilated	133	0.38
	No ventilation	133	0.44
Thin film	Free standing	200	0.42
	Ventilated	200	0.42
	No ventilation	200	0.51

The effects of angles of incidence on the panel's surface, i.e. the IAM profile used in this paper, for various angles from 0˚ to 90˚ are presented in Table 9.

Radiation on a horizontal surface (kWh/m^2), radiation incident on collector's surface (kWh/m^2), energy efficiency considering IAM and shadings losses (kWh/m^2), energy output of arrays (MWh), energy injected to the grid (MWh), and performance ratio for 31 stations are presented in Table 10. From the results in Table 10, it can be seen that the highest (0.833) and lowest (0.771) annual performance ratios are related to Ardabil and Ahvaz, respectively. This result is in good agreement with experts claim in power industry of ChaharMahal and Bakhtiari province that regions with both high temperature and radiation are not appropriate for constructing solar power plants. For 31 studied stations, the average annual performance ratio is 0.804.

The highest (35276) and lowest (24031) energy annually injected to the grid (kWh) are obtained for Zahedan and Sari, respectively. The fact that Ardabil does not have the highest energy injection to the grid corresponds well with suggestions in [37] where it is stated that the value of performance ratio is not indicative of the energy produced. The average annual energy injected to the grid (kWh) for the studied stations is 30942.

The highest (35863) and lowest (24445) energy output of solar arrays (kWh) are obtained for Zahedan and Sari, respectively. The annual average energy output of solar arrays for the studied stations is 31460 kWh. The difference between the energy output of solar arrays and the annual energy injected into the grid lies in the converter and ohmic losses.

Also, the highest and lowest values for effective energy, considering shading and IAM losses, radiation on collector's surface, and radiation on the horizontal surface, are 2325.1 and 1503.5, 2500.8 and 1623.9, 2244.4 and 1427.4 (kWh/m^2), respectively, for Zahedan and Sari stations. Furthermore, for the studied stations, average values for shading and IAM losses, radiation on collector's surface, and radiation on a horizontal surface are 1985.4, 2140.2, and 1896.8 (kWh), respectively.

Table 8. Solar cell losses (%) due to shading caused by front rows of PV arrays compared to single string installations

Ground coverage ratio	Distance (m)	Shahrekord	Yasuj	Kerman	Hamedan	Arak	Zanjan	Esfahan	Shiraz	Sanandaj	Birjand	Ilam	Karaj	Kermanshah	Tehran	Urmia	Khorramabad
75%	4	5.9	5.1	6.3	8.3	8.3	9.6	7.3	5.4	7.5	8	7	9.2	8.3	9	8.6	7.5
60%	5	3.2	**2.7**	3.2	4.6	4.5	5.5	3.7	**2.8**	4.2	4.1	3.7	5.2	4.5	5.1	4.8	4.1
50%	6	**2.4**	2.1	**2.4**	3.3	3.2	3.7	**2.7**	2.2	3	3	**2.7**	3.6	3.1	3.5	3.1	**2.9**
43%	7	2	1.7	2	**2.7**	**2.6**	3	2.3	1.8	**2.5**	**2.5**	2.2	**2.9**	**2.6**	**2.9**	**2.6**	2.4
38%	8	1.8	1.5	1.8	2.4	2.3	**2.6**	2	1.6	2.2	2.2	2	2.6	2.3	2.6	2.2	2.1
33%	9	1.6	1.4	1.6	2.1	2.1	2.4	1.8	1.4	2	2	1.8	2.3	2.1	2.3	2	1.9
30%	10	1.5	1.3	1.5	2	1.9	2.2	1.7	1.3	1.8	1.8	1.6	2.1	1.9	2.1	1.9	1.8
15%	20	1	0.8	1	1.3	1.2	1.4	1.1	0.9	1.2	1.2	1.1	1.4	1.2	1.4	1.3	1.1
Ground coverage ratio	Distance (m)	Tabriz	Zahedan	Ardabil	Qazvin	Yazd	Semnan	Bojnord	Mashhad	Qom	Gorgan	Sari	Ahvaz	Bandar Abbas	Bushehr	Rasht	
75%	4	9	5.8	10.4	9.6	6.8	9.9	11.3	9.4	9	10.7	11.7	6.1	5.1	5.1	11.2	
60%	5	5.2	**2.9**	6.3	5.5	3.5	5.4	6.6	5.4	4.9	6.3	7	3.3	**2.9**	**2.9**	6.8	
50%	6	3.5	2.2	4.2	3.8	**2.6**	3.5	4.4	3.8	3.4	4.3	4.8	**2.5**	2.2	2.2	4.6	
43%	7	**2.8**	1.9	3.4	3.1	2.2	**2.9**	3.6	3.1	**2.8**	3.6	4	2.1	1.8	1.8	3.8	
38%	8	2.5	1.6	3	**2.7**	1.9	2.5	3.1	**2.7**	2.4	3.1	3.4	1.8	1.6	1.6	3.3	
33%	9	2.2	1.5	**2.7**	2.4	1.7	2.3	**2.8**	2.4	2.2	**2.8**	3.1	1.7	1.4	1.4	**2.9**	
30%	10	2.1	1.4	2.4	2.2	1.6	2.1	2.5	2.2	2	2.5	**2.8**	1.5	1.3	1.3	2.7	
15%	20	1.4	0.9	1.6	1.4	1.1	1.4	1.6	1.4	1.3	1.6	1.7	0.9	0.8	0.8	1.6	

Table 9. The effect of angle of incidence on the panel's surface

Tilt angle	0	20	40	60	70	75	80	85	90
Incidence angle modifier	1	1	1	0.96	0.88	0.80	0.67	0.43	0

Table 10. Results of project design for 31 stations during the year

Station	Radiation on	Radiation on	Effective	Energy	Energy	Performance
Shahrekord	1953.3	2144.1	1986.4	31842	31307	0.811
Yasuj	1998.1	2179.8	2019.8	31941	31406	0.800
Kerman	2106.7	2336.0	2167.7	33859	33302	0.792
Hamedan	1854.1	2085.5	1933.4	31240	30723	0.818
Arak	1907.9	2159.5	2003.4	32083	31549	0.812
Zanjan	1862.7	2148.6	1993.9	32351	31814	0.823
Esfahan	2093.8	2370.5	2201.5	34582	34009	0.797
Shiraz	2078.1	2282.0	2116.0	32953	32411	0.789
Sanandaj	1894.4	2122.1	1967.8	31354	30838	0.807
Birjand	2063.4	2352.4	2185.9	34375	33810	0.798
Ilam	1967.5	2195.5	2037.7	32126	31596	0.800
Karaj	1805.4	2054.2	1905.0	30229	29727	0.804
Kermanshah	1943.1	2200.1	2041.9	32358	31828	0.804
Tehran	1826.7	2075.5	1924.5	30469	29967	0.802
Urmia	1977.0	2286.7	2124.7	34291	33721	0.819
Khorramabad	1942.0	2177.7	2020.3	31992	31466	0.803
Tabriz	1885.1	2178.0	2022.1	32494	31955	0.815
Zahedan	2244.4	2500.8	2325.1	35863	35276	0.784
Ardabil	1697.6	1948.8	1806.4	29731	29231	0.833
Qazvin	1812.6	2068.1	1917.6	30741	30231	0.812
Yazd	2064.0	2319.5	2153.2	33326	32776	0.785
Semnan	2010.2	2350.6	2183.5	34359	33790	0.799
Bojnord	1754.1	2057.5	1909.5	30482	29982	0.810
Mashhad	1695.6	1918.8	1779.1	28478	28007	0.811
Qom	1960.3	2261.4	2100.3	32974	32438	0.797
Gorgan	1596.7	1824.3	1690.1	27183	26736	0.814
Sari	1427.4	1623.9	1503.5	24445	24031	0.822
Ahvaz	1964.9	2176.8	2019.1	30701	30215	0.771
Bandar Abbas	1951.9	2110.2	1954.3	30021	29549	0.778
Bushehr	1975.1	2147.8	1990.3	30798	30304	0.784
Rasht	1487.8	16898.8	1564.4	25623	25199	0.828

For more accurate investigation of the effect of each type of loss on the amount of electrical energy produced, Figs. 11 and 12 indicate the annual loss diagrams for Zahedan and Sari stations, respectively, which are the most significant output of PVsyst software. Moreover, monthly diagrams of loss-production and performance ratio for these two stations are presented in Figs. 13 to 16.

From the annual losses diagrams in Figs. 11 and 12 it can be concluded that tilted solar cells compared to horizontal ones are more effective in Sari than in Zahedan (+13.8% in Sari compared to +11.4% in Zahedan). Also, it is observed that losses due to radiation angle are lower in Zahedan than in Sari, yet temperature-induced losses are higher in Zahedan (-12.4%) compared to Sari (-7.2%) which is obvious and justifiable given the higher temperature of Zahedan than Sari.

Considering the normalized monthly energy diagrams in Figs. 13 and 14 for Zahedan and Sari, it can be seen that losses due to arrays and converters are lower in Sari than Zahedan. This difference occurs mainly in hot months of the year and can be attributed to the effect of temperature on the performance of solar cells. The temperature effect also appears in Figs. 15 and 16 which show the monthly performance ratio, so that in hot months, performance ratio drops to a minimum which is also in agreement with results in [18] where it is suggested that ambient temperature is the most crucial parameter affecting the performance of solar cells.

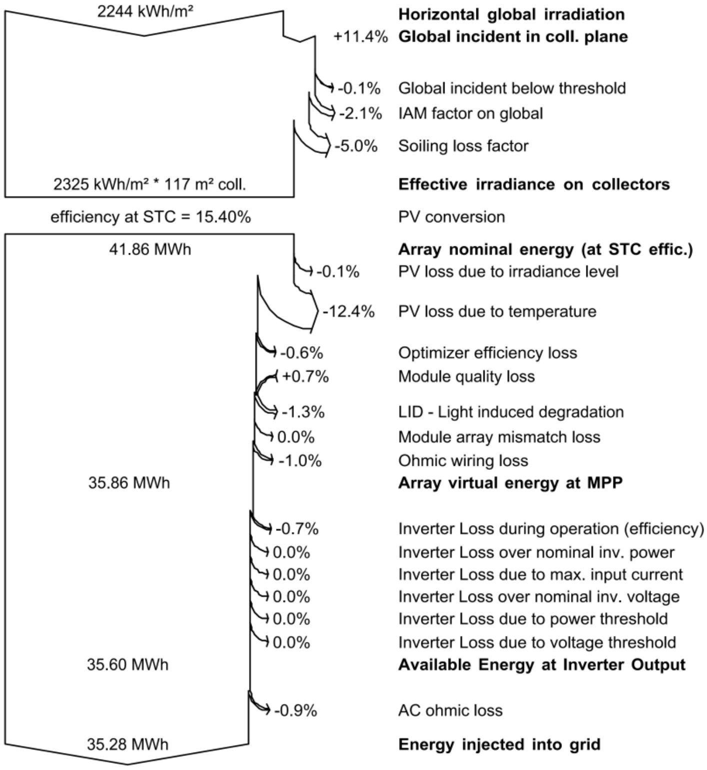

Figure 11. Annual loss diagram for Zahedan

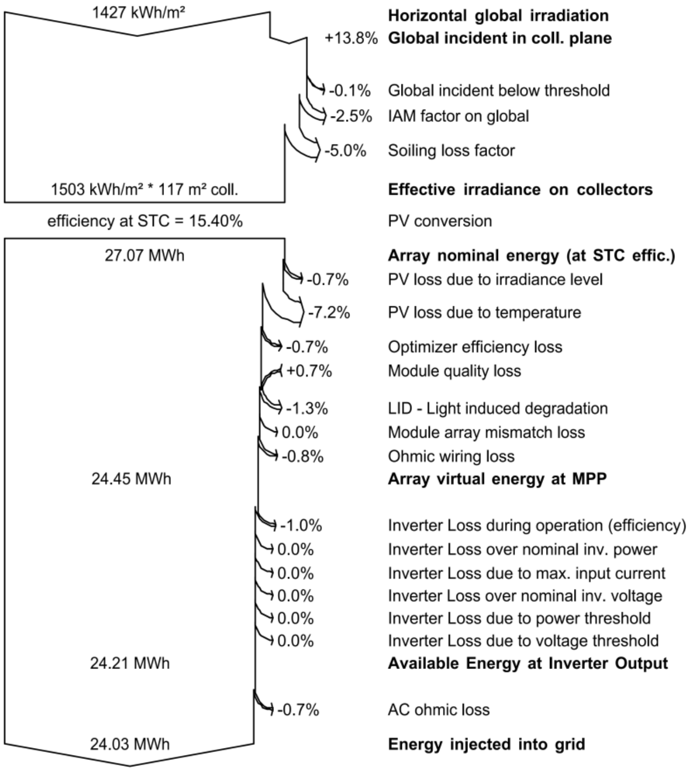

Figure 12. Annual loss diagram for Sari

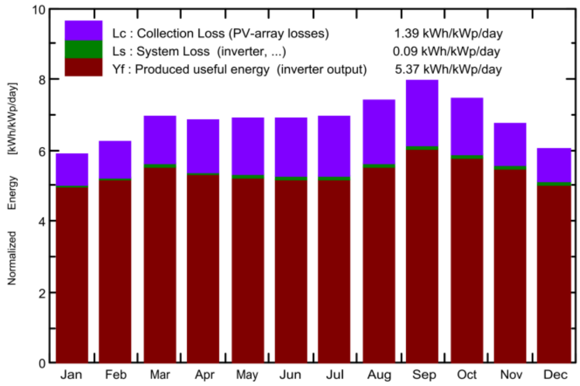

Figure 13. Normalized productions per installed kWp for Zahedan

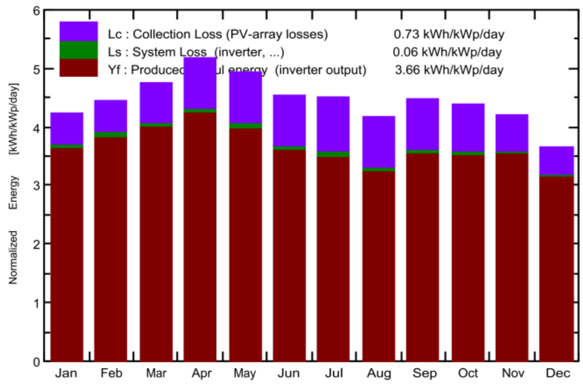

Figure 14. Normalized productions per installed kWp for Sari

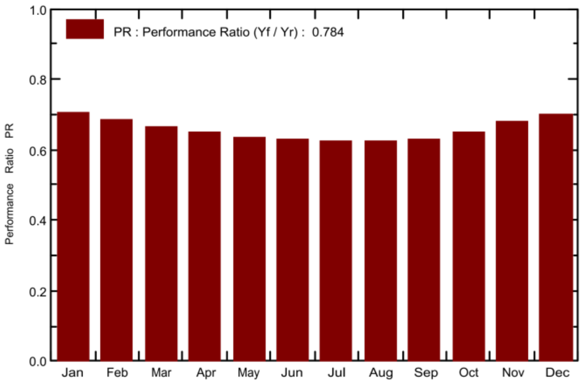

Figure 15. Performance ratio diagram for Zahedan

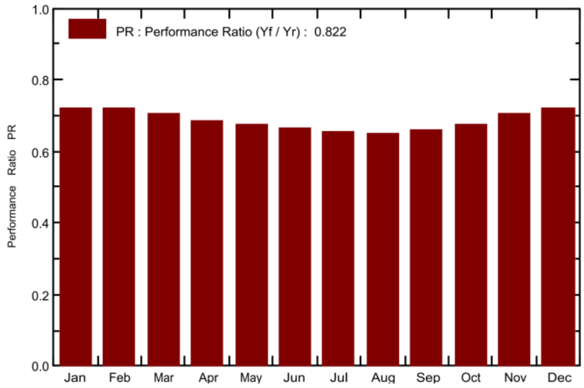

Figure 16. Performance ratio diagram for Sari

The effect of unfixed solar panels during the year for three seasonal tilting (summer and winter), single-axis, and dual-axis tracking systems is presented in Table 11. Results revealed higher energy production for three states of unfixed solar panels compared to annually fixed tilt for solar panels. From the results, it is clear that, similar to the results obtained for fixed annual tilt of panels, in case of using seasonal tilting, single-axis, and dual-axis tracking systems, the most suitable and unsuitable stations for using solar energy are Zahedan and Sari, respectively. Using seasonal tilting, single-axis, and dual-axis tracking, solar panels in Sari produce 25003, 29665, and 30596 kW/Y of electricity injected to the grid while these figures for Zahedan are higher by 47.4, 58.8, and 58.5%, respectively. Regarding seasonal tilting for solar panels, it should be mentioned that, on average, seasonal tilt increases the energy injected to the grid for the studied stations by 3.8%. In this respect, Esfahan and Zahedan by 4.5% and Semnan by 0.5% increase had the highest and lowest rise in the energy injected to the grid, respectively.

According to results in Table 11, regarding the use of single-axis tracking system which is of the fixed-tilt (equal to the optimum annual angle for that station) and eastern-western tracking type, there is an annual average increase of injected electricity to the grid by 30.5% with Urmia and Sari cities attaining the highest and lowest percent by 33.9 and 23.4%, respectively. In case of using dual-axis tracking for solar panels, it is noted that the results are so close to the single-axis scenario with a maximum difference of 14.3% between these two scenarios (i.e., dual-axis for Urmia and single-axis for Sari). In case of using double-axis tracking system, energy injected to the grid would increase on average by 34.2% for all stations compared to annual fixed tilt state. In this regard, the highest (37.7%) and lowest (27.3%) increase in the annual energy injection to the grid were obtained for Urmia and Sari, respectively.

6. Conclusion and recommendations

PVsyst is widely used in Iran due to its ease of implementation, simplicity, and the ability to be adapted to various power plant sites. The

Renewable Energy and Energy Efficiency Organization (SATBA), which is the authority responsible for the construction of power plants and solar systems in Iran, acknowledges this software as a reasonable reference for designing and accepts its outputs for feasibility plans. It should be mentioned that, compared to other software packages commercially available, PVsyst contains more professional and advanced capabilities, though slightly more complicated [24]. According to these facts, present paper uses PVsyst 6.7 for designing a 20 kW solar power plant at 31 capital cities of Iran and utilizes meteorological data of Meteonorm 7.1 for its simulations. Polycrystalline solar cells by Yingli Co. and converters and optimizers manufactured by SolarEdge Inc. are used in this paper.

The most important analysis and design results obtained by software are as follows:

Table 11. Energy injected to the grid for seasonal

Station	Seasonal tilting	Single-axis	Dual-axis
Shahrekord	32439	41445	42454
Yasuj	32581	41479	42556
Kerman	34732	44136	45384
Hamedan	31948	40400	41540
Arak	32874	41353	42505
Zanjan	33075	41854	43017
Esfahan	35529	45078	46382
Shiraz	33783	42633	43825
Sanandaj	31978	40977	42059
Birjand	35288	44670	45964
Ilam	32870	41823	42979
Karaj	30867	38905	40010
Kermanshah	33227	42031	43236
Tehran	31109	39226	40333
Urmia	35108	45164	46422
Khorramabad	32759	41539	42723
Tabriz	33115	42673	43816
Zahedan	36865	47109	48499
Ardabil	30308	38353	39413
Qazvin	31356	39844	40946
Yazd	34134	43336	44529
Semnan	33949	43264	44529
Bojnord	31228	38867	40029
Mashhad	28987	36066	37073
Qom	33814	42324	43554
Gorgan	27723	33801	34812
Sari	25003	29665	30596
Ahvaz	31296	38317	39415
Bandar Abbas	30591	36914	38034
Bushehr	31415	38573	39690
Rasht	26169	31207	32193

-The highest and lowest costs for producing solar-powered electricity were obtained for Sari ($0.57/kWh) and Zahedan ($0.38/kWh).

- Analysis and design results were consistent with Iran's solar radiation potential map. Given the fact that solar power plants have been less investigated for Zahedan, it is suggested that more measures be taken to attract higher investments in this city.

- Studies on the effect of ventilation at the back of solar cells on their performance revealed that it had less effect on monocrystalline than polycrystalline solar panels and less on polycrystalline than thin-film ones.

- Average losses (%) for 4, 5, 6, 7, 8, 9, 10, and 20 m spacings are 8.1, 4.5, 3.2, 2.6, 2.3, 2.1, 1.9, and 1.2%, respectively.

- According to the results, the highest and lowest losses due to the shading effect of strings on each other are associated with Sari and Yasuj stations, respectively.

- The highest (35276) and lowest (24031) annual energy injected to the grid (kWh) were related to Zahedan and Sari which was in agreement with initial and preliminary design results.

- Studies about the performance ratio, revealed that the highest (0.833) and lowest (0.771) performance ratios were related to Ardabil and Ahvaz, respectively, which, according to the reasons mentioned in section 3, it could be attributed to temperature (heating of panels) which was the most important factor affecting the efficiency of a solar power plant.

- Regarding seasonal tilting for solar panels, it should be mentioned that, on average, seasonal tilt increases the energy injected to the grid for the studied stations by 3.8%.

- Given the results for using single-axis tracking system, annual average energy injected to the grid would increase by 30.5%.

- In case of using double-axis tracking system, energy injected to the grid would increase on average by 34.2% for all stations compared to annual fixed tilt state.

In the future works, it is recommended to numerical [51] or experimental works [52-54] be done for exact validation of results. Exergy analysis [55] or comprehensive analysis of solar water heaters [56] for Iran based on available data are other ideas for continuing work.

References

[1]. Renewable energy policy network for the 21st century, Renewables 2018 global status report-REN21, www.ren21.net/gsr-2018, Accessed: 28.07.2018.

[2]. Iranian Ministry of Energy, Statistical summary of Iran electricity industry, http://amar.tavanir.org.ir/pages/project/generation/week/2018/2.pdf, Accessed: 12.01.2018.

[3]. Renewable Energy and Energy Efficiency Organization, Conserving sources by developing renewable and clean energies, http://www.satba.gov.ir/suna_content/media/image/2018/06/6061_orig.png?t=636656966754027500, Accessed: 28.07.2018.

[4]. The future of solar energy in Iran, Mehrsun energy group, http://mehrsunenergy.ir/intersolar, Accessed: 28.07.2018 (In Persian).

[5]. Iran Ministry of Energy, Renewable Energy and Energy Efficiency Organization, Statistics of RE power plants, http://www.satba.gov.ir/en/investmentpowerplants/statisticsofrepowerplants, Accessed: 31.10.2017.

[6]. Renewable Energy and Energy Efficiency Organization, Renewable Power Plants Geographical Map, http://www.satba.gov.ir/suna_content/media/image/2018/07/6071_orig.jpg?t=636666551115625937, Accessed: 28.07.2018.

[7] .Investment (Power Plant), Statistics of RE Power Plants, Installed Renewable Power Plant in Iran (1st October 2018), http://www.satba.gov.ir/en/investmentpowerplants/statisticsofrepowerplants, Accessed: 02.17.2019.

[8]. Mirzahosseini, A.H. and Taheri, T., 2012. Environmental, technical and financial feasibility study of solar power plants by RETScreen, according to the targeting of energy subsidies in Iran. Renewable and Sustainable Energy Reviews, 16(5), pp.2806-2811.

[9]. Iranian cabinet Website Accessed from http,//www.dolat.ir/.

[10]. Firouzjah, K.G., 2018. Assessment of small-scale solar PV systems in Iran: Regions priority, potentials and financial feasibility. Renewable and Sustainable Energy Reviews, 94, pp.267-274.

[11]. EPIA European Photovoltaic Industry Association, 2014. Global market outlook for photovoltaics 2014–2018. Brussels, Belgium.

[12]. EIA-Energy Information Administration (2015) Country data: Iran, Washington, DC. https://www.eia.gov/beta/international/analysis.cfm?iso=IRN. Accessed 22.03.2016

[13]. Aghahosseini, A., Bogdanov, D., Ghorbani, N. and Breyer, C., 2018. Analysis of 100% renewable energy for Iran in 2030: integrating solar PV, wind energy and storage. International Journal of Environmental Science and Technology, 15(1), pp.17-36.

[14]. Jacobson, M.Z., Delucchi, M.A., Bauer, Z.A., Goodman, S.C., Chapman, W.E., Cameron, M.A., Bozonnat, C., Chobadi, L., Clonts, H.A., Enevoldsen, P. and Erwin, J.R., 2017. 100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world. Joule, 1(1), pp.108-121.

[15]. Shahsavari, A., Yazdi, F.T. and Yazdi, H.T., 2018. Potential of solar energy in Iran for carbon dioxide mitigation. International Journal of Environmental Science and Technology, pp.1-18.

[16]. Laetitia, U., 2018. Design simulation and evaluation of photovoltaic plant, Master of Science thesis, Near East University.

[17]. Boyd, M.T., 2018. Comparative Performance and Model Agreement of Three Common Photovoltaic Array Configurations. Journal of solar energy engineering, 140(1), p.014503.

[18]. Akram, I., Awais, M., Bashir, A., Khan, R.A.J. and Iqbal, J., 2018, February. Design and analysis of 300MW solar configuration and its comparison with Quaid-e-Azam solar park. In Engineering and Emerging Technologies (ICEET), 2018 International Conference on IEEE, pp. 1-7.

[19]. Nayak, A.K., Vijayvargiya, A., Goyal, K., Sharma, G., Bhardwaj, K., Trivedi, K., 2018, Solar Tracking Methodologies for PV Panels. International Journal of Scientific Research in Science, Engineering and Technology, 4(4), pp. 226-230.

[20]. Alshamani, A., 2018. Design and modelling of a large-scale solar water pumping system for irrigation in Saudi Arabia, Master thesis, Memorial University of Newfoundland, Canada.

[21]. Chattopadhyay, M. and Rajavel, R., 2018. A comparative study on performance of a grid connected solar PV system installed in the urban, rural and coastal region of India. In 2nd International Conference on Inventive Systems and Control (ICISC), IEEE, pp. 131-135.

[22]. Batista, R., 2018. The impact of shadowing in photovoltaic systems and how to minimize it: An analysis with the PVsyst Software, Master Thesis, University of Gävle.

[23]. Mollahosseini, A., Hosseini, S.A., Jabbari, M., Figoli, A. and Rahimpour, A., 2017. Renewable energy management and market in Iran: A holistic review on current state and future demands. Renewable and Sustainable Energy Reviews, 80, pp.774-788.

[24]. PVsyst 6.78 - Photovoltaic system study, General organization of the help, http://files.pvsyst.com/help/index.html, Accessed 02.18.2019.

[25]. Absorption of maximum power in solar cells by calculating the optimal angle of the solar panel in Saveh using fuzzy neural network algorithm, 2014, https://www.civilica.com/Paper-NCAEE01-NCAEE01_039.html (In Persian).

[26]. Comparison of annual energy production of photovoltaic power plant in the case of fixed base and optimizer systems for panel installation, Case study of 50 kW power plant design of East Azerbaijan Telecommunication Company, 2015, https://www.civilica.com/Paper-IEAC02-IEAC02_260.html (In Persian).

[27]. Evans, D.L., 1981. Simplified method for predicting photovoltaic array output. Solar energy, 27(6), pp.555-560.

[28]. Skoplaki, E. and Palyvos, J.A., 2009. On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. Solar energy, 83(5), pp.614-624.

[29]. Garg, H.P. and Agarwal, R.K., 1995. Some aspects of a PV/T collector/forced circulation flat plate solar water heater with solar cells. Energy Conversion and Management, 36(2), pp.87-99.

[30]. Tiwari, G.N. and Dubey, S., 2009. Fundamentals of photovoltaic modules and their applications. Royal Society of Chemistry.

[31]. Häberlin, H., 2012. Photovoltaics: system design and practice. John Wiley & Sons.

[32]. Masters, G.M., 2013. Renewable and efficient electric power systems. John Wiley & Sons.

[33]. Javed, K., Ashfaq, H. and Singh, R., 2018. Optimized Load Profile & Cost Analysis of Stand-alone Photovoltaic System for Rural Power Applications in Indian Scenario. Smart Science, pp.1-11.

[34]. Hathout, A., 2018. A Comprehensive PV Systems Installation Guide and Designing a Roof-Based PV System as a Demonstration System for Troubleshooting Errors in PV systems Installations, Master Thesis, Dalarna University.

[35]. Hafeznia, H., Yousefi, H. and Astaraei, F.R., 2017. A novel framework for the potential assessment of utility-scale photovoltaic solar energy, application to eastern Iran. Energy Conversion and Management, 151, pp.240-258.

[36]. Kumar, B.S. and Sudhakar, K., 2015. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. Energy Reports, 1, pp.184-192.

[37]. Marion, B., Adelstein, J., Boyle, K.E., Hayden, H., Hammond, B., Fletcher, T., Narang, D., Kimber, A., Mitchell, L., Rich, G. and Townsend, T., 2005, January. Performance parameters for grid-connected PV systems. In Photovoltaic Specialists Conference, 2005. Conference Record of the Thirty-first IEEE, pp. 1601-1606.

[38]. https://fa.wikipedia.org/wiki/ List of centers of Iranian provinces based on altitude (In Persian).

[39]. Sharma, V. and Chandel, S.S., 2013. Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India. Energy, 55, pp.476-485.

[40]. Mahdian MA, Saemi A, Kalantar V, 2014. Yazd university photovoltaic power plant simulation and comparing results' validity with empirical data and presenting efficiency-increasing strategies, Iranian journal of energy, 17 (3), pp.39-52 (In Persian).

[41]. Investigating the construction of a grid-connected photovoltaic power plant in Gonabad and comparing the operating conditions of system in cities of Berlin, Beijing, Tokyo and Gonabad using PVsyst software, 2016, https://www.civilica.com/Paper-ICELE01-ICELE01_008.html (In Persian).

[42]. Muñoz, Y., Vargas, O., Pinilla, G. and Vasquez, J., 2017. Sizing and Study of the Energy Production of a Grid-Tied Photovoltaic System Using PVsyst Software. *Tecciencia*, 12(22), pp.27-32.

[43]. Lacchini, C., Antoniolli, A.F. and Rüther, R., 2017. The influence of different irradiation databases on the assessment of the return of capital invested in residential PV systems installed in different locations of the Brazilian territory. *Solar Energy*, *155*, pp.893-901.

[44]. Fereidooni, M., Mostafaeipour, A., Kalantar, V. and Goudarzi, H., 2018. A comprehensive evaluation of hydrogen production from photovoltaic power station. *Renewable and Sustainable Energy Reviews*, *82*, pp.415-423.

[45]. Singh, H., Saxena, B.K. and Rao, K.V.S., 2017, December. Performance study of a solar photovoltaic water pump used for irrigation at Jaipur in Rajasthan, India. In 2017 International Conference on Technological Advancements in Power and Energy (TAP Energy), IEEE, pp. 1-6.

[46]. de Oliveira, H.M. and de Aguiar Sodré, E., 2018, May. Study of a grid-tied photovoltaic system in Caruaru using PVsyst and Skelion. In 2018 Simposio Brasileiro de Sistemas Eletricos (SBSE), IEEE, pp. 1-6.

[47]. Karami, E., Rafi, M., Ridah, A., Hartiti, B. and Thevenin, P., 2018. Analysis of Measured and Simulated Performance Data of Different PV Modules of Silicon in Casablanca, The second international conference on Smart Application and Data Analysis for Smart Cities, Morocco, pp. 1-7.

[48]. Hafeznia, H., Yousefi, H. and Astaraei, F.R., 2017. A novel framework for the potential assessment of utility-scale photovoltaic solar energy, application to eastern Iran. Energy Conversion and Management, 151, pp.240-258.

[49]. Okoye, O.C., Taylan, O., Baker, D.K., 2016. Solar energy potentials in strategically located cities in Nigeria, review, resource assessment and PV system design. Renewable and Sustainable Energy Reviewes, 55, pp. 550-566.

[50]. Solargis, Solar resource maps of Iran, https://solargis.com/maps-and-gis-data/download/iran, Available: 11.08.2018.

[51]. Joshi, U., Geete, A., 2016. Numerical simulation on effect of climate and design parameters on the single slope solar still. International Journal of Engineering Associates, 5(5), pp. 06-10.

[52]. Geete, A., Kothari, S., Sahu, R., Likhar, P., Saini, A., Singh, A., 2016. Experimental analysis on fabricated parabolic solar collector with various flowing fluids and pipe materials. International Journal of Renewable Energy Research, 6(4), pp. 1454-1463.

[53]. Sharma, R., Geete, A., 2017. Experimental analyses on parabolic solar collector at various operating conditions. Universal Journal of Mechanical Engineering, 5(2), pp. 25-34.

[54]. Geete, A., Sharma, R., 2018. Experimental exergy analyses on fabricated parabolic solar collector with/without preheater and different collector materials. International Journal of Ambient Energy, 40 , pp. 1-13.

[55]. Geete, A., Dubey, A., Sharma, A., Dubey, A., 2018. Exergy analyses of fabricated compound parabolic solar collector with evacuated tubes at different operating conditions: Indore (India)", Journal of Institute of Engineers India: Series C, Volume 100, Issue 3, pp 455-460.

[56]. Geete, A., 2019. Exergy analyses for parabolic solar collector at different conditions: PAPSC software. Journal of Solar Energy Research, 4(1), pp. 41-52.

[57]. Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A., Khechekhouche, A., 2018. Feasibility Study of Solar Water Heaters in Algeria, a Review. Journal of Solar Energy Research, 3(2), pp. 135-146.