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A Survey on Performance of Photovoltaic Systems in Iran

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P A P E R I N F O

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A B S T R A C T

The Solar Thermal Electricity (STE) has significant capability to satisfy apart of energy demands. An integrated assessment shows that STE could play a promising role in Iran, helping to reach ambitious climate safety targets. This paper is response to the urgent need to accelerate the evolution of advanced energy technologies to refer the universal challenges of clean energy and sustainable development. The extensive aim of this paper is to exhibit the essential role of energy technologies. The two most prominent solar energy technologies are photovoltaic (PV) and concentrated solar power (CSP). PV systems are beneficial because of their flexible size; but they are costly and solely generate electricity. However, to investigate PV cell performance and power generation throughout Iran, 5 different regions across the country are considered. The obtained results showed that PV cells can generate electrical power from 155 to 385 Wh/module.day. This power generation is enough for the requirement of the isolated regions and can even utilize to support the grid. Economic analysis base on the payback period is included. The electricity generating costs estimation for five virtual cities in Iran shows a long-term reduction of power costs.

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NOMENCLATURE

A	area of the PV surface, m^2	R_b	ratio of beam radiation on tilted surface to that on horizontal surface, dimensionless
C_P	heat capacity of the cell, J/kg.K	T_{ref}	reference temperature of the PV cell, K
$a_0, a_1, k, a_0^*, a_1^*, k^*, r_0, r_1, r_k$	parameters for τ_b, dimensionless	α	absorptivity of the solar cell surface, dimensionless
G_0	extraterrestrial (AM0) solar radiation on horizontal plane, W/m^2	β_0	temperature of the PV cell, K
G_{bn}	beam radiation on horizontal plane, W/m^2	γ	angle between the cell and the ground, degree
G_{cn}	solar constant, 1353 W/m^2	$\eta_{\text{electricity}}$	electrical efficiency, dimensionless
I_{cdt}	diffuse radiation, J/m^2	η_{ref}	optimal electrical efficiency, dimensionless
I_{cd}	clear sky horizontal diffuse radiation, J/m^2	η_{total}	total efficiency, dimensionless
$I_{c\varsigma t}$	ground reflected radiation, J/m^2	ε	the emissivity, dimensionless
I_c	clear sky horizontal radiation, J/m^2	λ	slope of PV surface, dimensionless
I_{cb}	clear sky horizontal beam radiation, J/m^2	θ	solar incident angle with respect to PV normal vector, degree

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I_{0n}	extraterrestrial (AM0) solar radiation, J/m^2	θ_z	solar incident zenith angle, degree
I_T	solar radiation on tilted plane, J/m^2	ρ	Density, kg/m^3
P_{out}	heat lost in form of electricity generated, W	σ	Stefan-Boltzmann constant, W/m^2.K^4
M	altitude of observer, kilometers	ς	diffuse ground reflectance, dimensionless
q_{in}	incoming solar irradiance, W	τ_b	atmosphere transmittance for beam radiation, dimensionless
q_{out}	heat lost, W	τ_d	atmosphere transmittance for diffuse radiation, dimensionless
$q_{gen.}$	internal heat generation, W	Φ	overall incident irradiance on cell, W/m^2
q_{LR}	heat transfer refer to long-wave radiation, W	Φ_{ref}	reference solar irradiance of $1000\ W/m^2$, W/m^2
q_{SI}	heat transfer refer to shortwave convection, W		

INTRODUCTION

The quantity of energy sources such as hydropower, gas, coal and petrol are depleted due to extreme industrial usage. On the other side, the demand for electrical energy has risen along with technology development [1, 2]. The limited fossil fuel as energy resource is important and worldwide issues [3]. In order to supply the required electricity demand, thousands of new power plants had to be assembled [4]. Renewable energy can perform an essential position in meeting the main purpose of replacing large component of fossil fuels. One of the encouraging applications of renewable energy technology is the installation of solar systems to produce power without emitting pollutants and demanding no fuel[5].

PV cells can create part of the roof structure, walls or be floor mounted. Several types may lend themselves to different buildings. PV cells should be considered as an essential section of the total environmental strategy of energy-efficient building model. PVs can be an important part in furthering this approach to build and help us to move towards lower carbon, carbon neutral and carbon negative buildings. The utilization of new effective photovoltaic solar cells (PVSCs) has appeared as a significant solution in energy conservation and require-side management during the last decades [6]. In terms of cell generation, generation volume rose by 83% in 2008 (7.5GW) compared to amount of 4.1GW in 2007 [7]. In 2050, the projected share of solar power by International Energy Agency (IEA) is estimated to be 11% of world electricity generation[1]. Therefore, this is conditional on many countries putting in place stimulating schemes to help solar energy in the next decades so that investment costs to be reduced. The share would be roughly separated equally between photovoltaic and concentrating solar power.

Mpagalile et al. [8] constructed a new, batch activated oil press, powered by solar PV system designed to fit small-scale oil processors in developing countries with the press preparing an opportunity for the processor to apply various oilseeds and volumes of the materials being processed. Xi et al. [9] presented the progression and applications of two solar-driven thermoelectric technologies to improve and estimate the performance of the solar-driven thermoelectric devices [10]. Bechinger et al. [11] developed self-powered electrochromic windows where a semi-transparent PV cell prepares the power to start an electrochromic system deposited on top of the solar cell.

The economic analysis of solar energy system is performed in order to estimate the least cost of meeting the energy requirement [12]. The principal cause for the high cost of present PV modules is the high cost of the main material, ultra-pure silicon wafers, mainly applied in today's solar cell. Optional technologies that compete for more reduction in cost with decreased consumption material are termed thin film solar cell technologies. These contain technologies established on materials like amorphous Si, polycrystalline CIGS, thin-film polycrystalline Si, polycrystalline CdTe and organic solar cells. While decreasing material cost obtain a large cost reduction, further cost reduction leads to obtain a cost of photovoltaic electricity below to the bulk electricity cost; that only be possible if the conversion efficiency is raise to higher values than those of conventional Si solar cells.

This paper primarily focuses on the performance evaluation of photovoltaic systems in Iran. But it is recognized that there are other potentially important 'products' from solar plant such as water desalination [13], process steam for industry, alternative energy carriers such as syngas and hydrogen [14], and decontamination of water supplies. Although not discussed in detail, much of what is presented in this paper on the development of solar plant technologies

[1] Technology roadmap: solar photovoltaic energy. OECD/IEA, 2010. www.iea.org/.../TechnologyRoadmapSolarP...

such as PV cells [15-18] and economics will also be relevant to these alternative applications of solar plant. Furthermore, abundant factors that influence the instantaneous PV generation [19] are analyzed for special days in different conditions utilizing the case study of 5 cities in Iran (Tehran, Esfahan, Shiraz, Yazd and Tabriz). Also, the amount of extra output power generated by a fixed panel and Azimuth-Altitude Dual Axis Tracker (AADAT), installed with the yearly optimal tilt angle which is computed before, are estimated in this paper.

Distribution of the solar source in Iran

There is enormous solar power generation potential in Iran. Depending on special technology, a useful scale solar power plant may need between 5 to 10 acres per megawatt (MW) of producing capacity. Such as fossil fuel power plants, solar plant development needs some grading of land and clearing of vegetation. For example, many concentrating solar power plants require to be built on flat land with less than 1 percent slope. Modular technologies, like dish-engine systems, concentrating PV, and utility-scale PV cells can utilize land with steeper slopes and no water access.

The principal differences in the direct sun rays attainable from place to place arise from the composition of the atmosphere and the climate. Direct normal irradiation (DNI) is commonly obtained in hot regions with reliably clear skies, which typically lay at latitudes from 15° to 40° North or South. Adjacent to the equator the atmosphere is commonly very cloudy and moist in summer, and at area far from the equator the weather is excessively cloudy. DNI is meaningfully excellent at higher altitudes, where absorption and spreading of sun ray is very lower. Thus, Iran is positive regions for CSP source.

Figure 1 shows a solar map of Iran and gives the maximum annual amount of energy available on a horizontal surface. The same color legend depicts also potential solar electricity produced by a 1kWp system per year with photovoltaic modules established at a best inclination and assuming system performance ratio of 0.75. Figure 2 shows that overall irradiation and solar electricity potential for Iran.

Modeling the PV array and governing equation

Solar radiation

We are going to compute the solar radiation on horizontal and tilt surface applying Liu and Jordan's model [21]. Later, Dorota [22] exhibited that many models computing solar radiation on a surface of any particular orientation have been performed. Thus, diffuse part is

$$I_{cdt} = I_{cd}\left(\frac{1+\cos\lambda}{2}\right) \quad (1)$$

where, λ is the slope of the PV surface.

All models assume that the ground reflected component is isotropic as follows [23, 24]:

$$I_{c\varsigma t} = I_c \varsigma \left(\frac{1-\cos\lambda}{2}\right) \quad (2)$$

For snow free ground, the ground reflectance ς, is given as 0.212 and for snow ground 0.702.

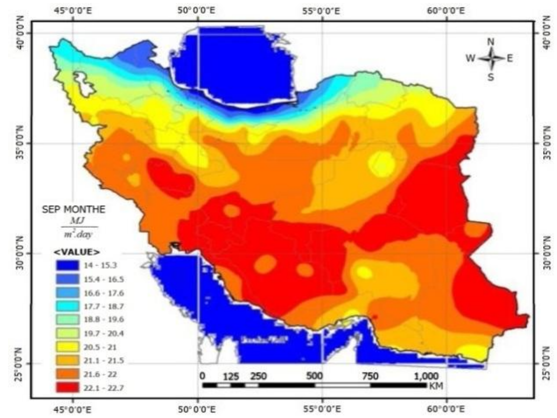


Figure 1.Total irradiation and solar electricity potential in Iran [20]

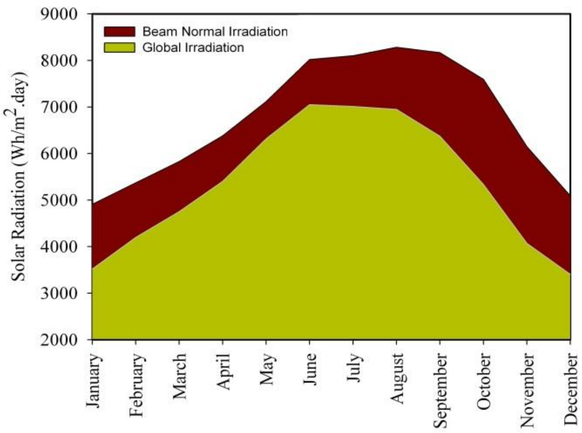


Figure 2. Total radiation descending to the ground in Iran

The beam radiation on tilted surface can be computed by multiplying on a horizontal surface by a geometric factor R_b . Thus, solar radiation is given by,

$$I_T = I_{cb}R_b + I_{cd}\left(\frac{1+\cos\lambda}{2}\right) + I_c\varsigma\left(\frac{1-\cos\lambda}{2}\right), \quad (3)$$

R_b is depends on the zenith and incidence angles. Therefore,

$$R_b = \frac{\cos\theta}{\cos\theta_z} \quad (4)$$

Where θ is solar incident angle with respect to PV normal vector (referring to Figure 3) and I_{cb} is the clear sky horizontal beam radiation, which can be computed by Hottel's model [25]:

$$I_{cb} = I_{0n}\tau_b \cos\theta_z \quad (5)$$

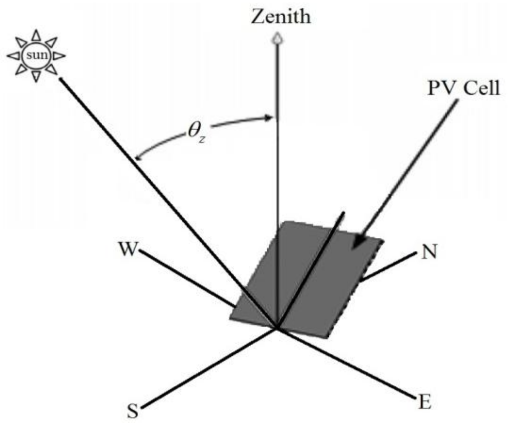


Figure 3. Geometry definition of PV cell

The location of the sun during time of day is computed by understanding the azimuth and the elevation angles. Also, the atmosphere transference for beam radiation τ_b is the ratio of the beam radiation G_{bn} to the air mass zero extraterrestrial radiation G_0 ,

$$\tau_b = G_{bn}/G_0 \quad (6)$$

That can be exhibited as,

$$\tau_b = a_0 + a_1 e^{-k/\cos\theta_z} \quad (7)$$

For the standard atmosphere, the constants $k = r_k k^*$; $a_0 = r_0 a_0^*$; $a_1 = r_1 a_1^*$ with 25 km visibility are know from k^*, a_0^* *and* a_1^*, which are given for altitudes less than 2.6 km by,

$$\begin{aligned} k^* &= 0.2711 + 0.01858(2.5 - M)^2 \\ a_0^* &= 0.4237 - 0.00821(6 - M^2) \\ a_1^* &= 0.5055 + 0.00595(6.5 - M)^2 \end{aligned} \quad (8)$$

a is the altitude of the observer in kilometers. The parameters r_0, r_1 and r_k rely on the climate and are given in previous work [26].

The optimal angles alter with situations like for example the geographic latitude, climate, utilization period and so forth. The variable I_{cd} in Eq. (1) is the diffuse radiation, which can be computed applying Liu's model [27]:

$$I_{cd} = I_{0n}\tau_d \cos\theta_z , \quad (9)$$

$$\tau_d = 0.2710 - 0.2939\tau_b \quad (10)$$

Heat transfer in PV cells

Because of solar PV cells interact with their environment; they passively absorb about 83% of the arriving solar beam as heat [28]. The PV cell temperature has a significant effect on the PV output power. Therefore, it is essential to compute the PV cell temperature in order to estimate for this important effect.

The main energy input is solar beam in the form of shortwave radiation. The solar cell endures heat removal by conduction, convection, and radiation. We have to commence by determining the energy balance between, the solar energy absorbed by the PV cells and the electrical output plus the heat transfer to the surroundings.

A schematic of heat transfer mechanism is shown in Figure 4. It is value noting that some solar cells have an anti-reflection coating to reduce reflection losses and raise real solar irradiance incident on the cell [29].

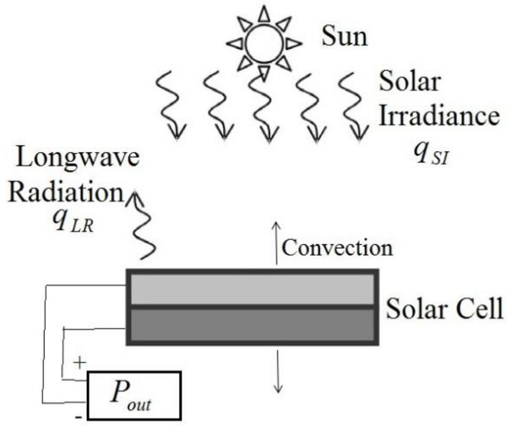


Figure 4. Heat transfer in a solar PV cell

Developing a thermal model

In a single Si cell, about 32 % of the incident energy is used to raise the kinetic energy of the electrons in the conduction band. Heat transfer is of specific significance because of the opposite relationship with its efficiency. A simple heat balance model of the heat accumulation in a system is equal to the heat in q_{in}, minus heat out q_{out} , plus internal heat generation $q_{gen.}$,

$$(q_{in} - q_{out}) + q_{gen.} = \rho C_P \frac{DT}{Dt} \quad (11)$$

ρ is the density, and C_P is the heat capacity, T is the temperature. For the PV system, q_{in} is the incoming solar irradiance, q_{out} is divided into heat lost to radiation, convection, and as electricity, and $q_{gen.}$ is zero because there is no heat production. Then, the unstable temperature of the solar cell can be modeled for PV cells, as follows,

$$(q_{lw} + q_{sw} + q_{conv.}) - P_{out} = \rho C_P \frac{DT}{Dt} \quad (12)$$

where C_P is the heat capacity of the cell, q_{LR} is the heat transfer refer to long-wave radiation, q_{SI} is the heat transfer refer to shortwave convection, and P_{out} represents the heat lost in form of electricity generated. The long-wave radiation can be computed by altering the Stefan-Boltzmann law to contain a part radiated to the sky, the ground and the cell,

$$q_{LR} = A\sigma\left[\frac{1+\cos\gamma}{2}\varepsilon_{sky}T_{sky}^4 + \frac{1-\cos\gamma}{2}\varepsilon_{ground}T_{ground}^4 - \varepsilon_{PV\ cell}T_{PV\ cell}^4\right] \quad (13)$$

σ is the Stefan-Boltzmann, ε is the emissivity, and γ is the angle between the cell and the ground. The used the shortwave radiation described as,

$$q_{SI} = \alpha\Phi A \quad (14)$$

where α is the absorptivity of the solar cell surface, Φ is the overall incident irradiance on cell, and A is the area of the PV surface[29].

The finite differences model contains conduction inside the cell between the PV cells and the glass [30]. This model also contains the electrical efficiency $\eta_{electricity}$, directly in the computations with the equation (15),

$$\eta_{electricity} = \eta_{ref.}\left[1 - \beta_0(T_{PV\ cell} - T_{ref.}) + \Phi Log\,\Phi_{ref.}\right] \quad (15)$$

η_{ref} is the optimal electrical efficiency of PV cells, T_{ref} is the reference temperature of the PV cells, β_0 is the temperature of the PV cells and Φ_{ref} is reference solar irradiance of 1000 W/m^2 [29]. The total efficiency η_{total}, of the integrated system is defined as,

$$\eta_{total} = \eta_{electricity} + \eta_{thermal} \quad (16)$$

Case study

Presentation of the selected regions in Iran

In the recent research, 5 regions have been chosen for feasibility research of building a CSP. Data of these regions is exhibited in Table 1. Esfahan, Tabriz, Tehran, Shiraz, and Yazd have higher annual solar radiation comparing to the other regions. The chosen regions are presented in Figure 5. It could be watched, the chosen regions have been selected from various places of country.

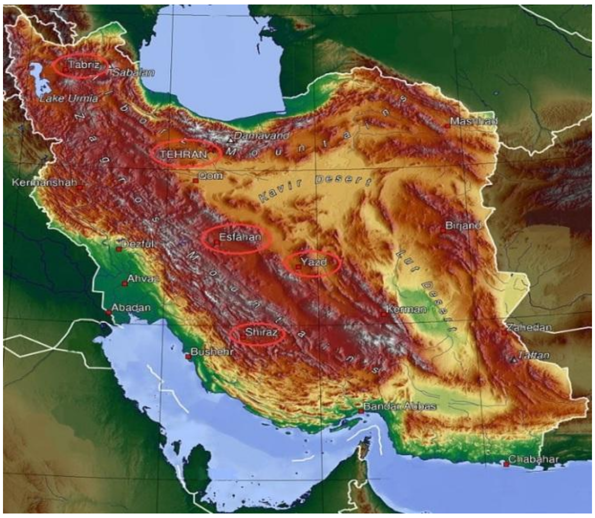


Figure 5. Iran map with exhibition five cities for case study

TABLE 1. Annual total solar radiation situation of 5 chosen regions in Iran [31]

Region	Average annual temperature (K)	Annual sunlight duration (h)	Annual solar radiation (MJ/m^2)
Esfahan	289.45	3273.5	6852.296
Tabriz	282.7	2451.6	4687.537
Tehran	290.66	2993.4	6323.384
Shiraz	291.92	3313.5	7177.641
Yazd	292.74	3263.1	6891.051

The averages of total solar radiations at the chosen area versus month are shown in Figure 6. Between these five regions, Shiraz has higher solar radiation while four other present similar variations during the year. Atmospheric temperature variations of these five regions present similar behaviors (Figure 7). Maximum temperature is shown in June.

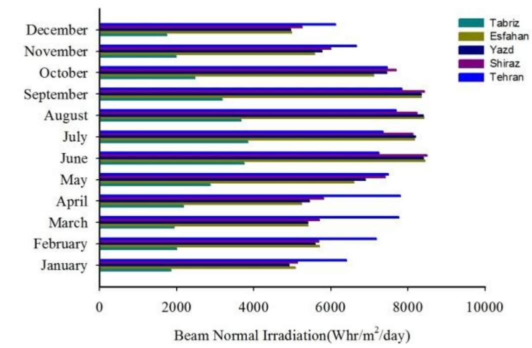


Figure 6. Average of total solar irradiance at the chosen regions in Iran

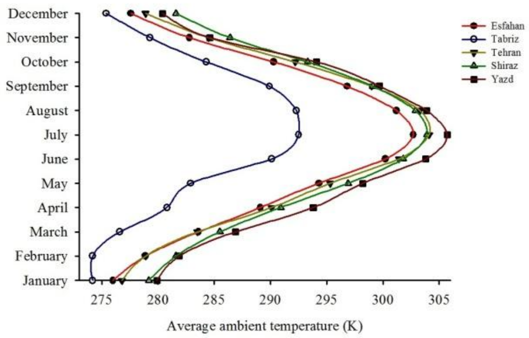


Figure 7. Average variations of ambient temperature at the chosen regions in Iran

Performance of PV cell in the selected regions

Figure 8 shows the electrical power generation of three types for PV cells in five chosen regions of Iran which regions are presented in Table 1. As expected, the electrical power generation is uniform and proportional with solar radiation profile. Among the considered regions, Yazd, Shiraz, Tehran, and Esfahan have higher power generation per year. The obtained results from the selected regions showed that PV cells can generate from 155 to 385 Wh/module.day. The output energy of PV cells has nearly similar values while in June, July, and August Yazd PV cells showed much higher values.

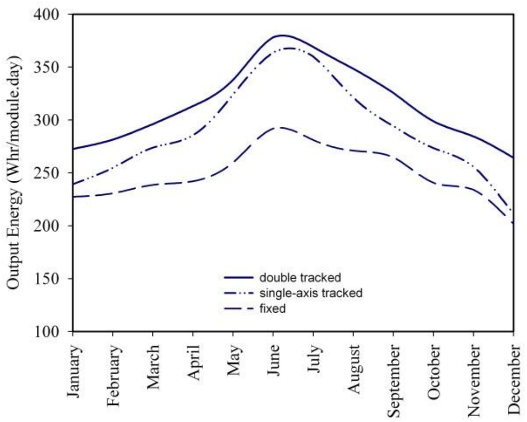
The absorption of light by a PV cell is dependent on its angular location to the sun. A PV cell must be perpendicular to the sun for maximum solar absorption, which is completed by applying a tracking system. Multiple tracking systems exist, which vary in accuracy, reliability, cost and other factors. A tracking system must be selected smartly to guarantee that the tracking method raise the power gained instead of losing it.

If a tracking system is not employed, the PV cell must still be oriented in the best condition. The cell requires to be placed where no shadow fall on it at any time of the day. In addition, the optimum tilt angle must be estimated establish on the geographical position of the cell. Since a total guideline for the northern hemisphere, the PV panel must be placed at a tilt angle equal to the latitude of the site and facing south [32].

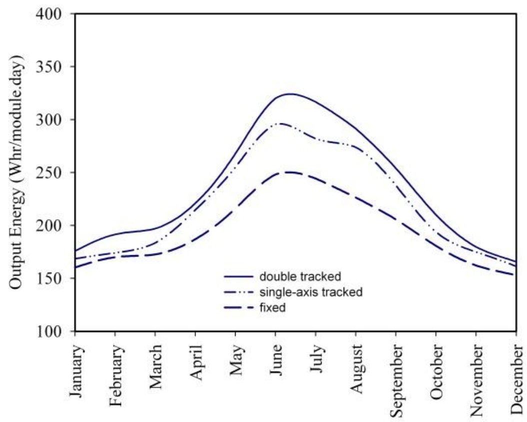
First of all, the above figures obviously showed that the dual-axis tracking system, despite its error, is absorbing almost all the available light. Finally, the immobile tracker clearly has the least amount of absorption as it does not compensate for its error in either direction. These illustrations clearly showed that the Single-Axis tracker has a greater amount of energy generated over the fixed PV cells. Furthermore, the dual-axis tracker outlined in this research generated more energy than Single-Axis trackers, and fixed PV cells across the entire surface of the planet. The average PV power generation for 5 cities in Iran is depicted in Figure 8.

Cost analysis

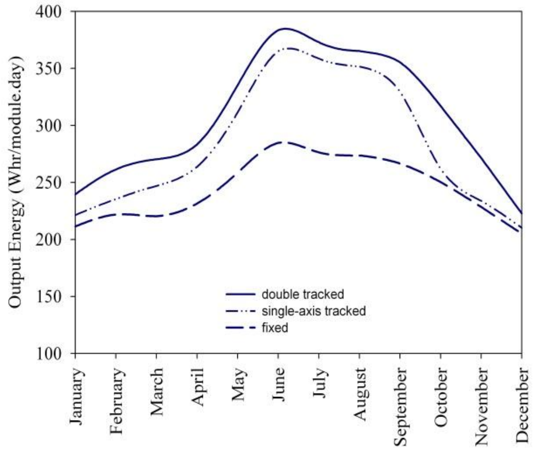
However a tracker may be highly efficient and give an excellent mean energy gain compared to an immobile system or a single axis system, this is not sufficient still to claim the system is beneficial over its alternatives. The added tracking part to the system must prepare sufficient power gain that there is either an immediate payback or the payback period is less than the lifetime of the system. Therefore the primary cost of the system, the lifetime, and the payback period demand to be found to estimate the cost impressiveness of the tracker system.



(a)



(b)



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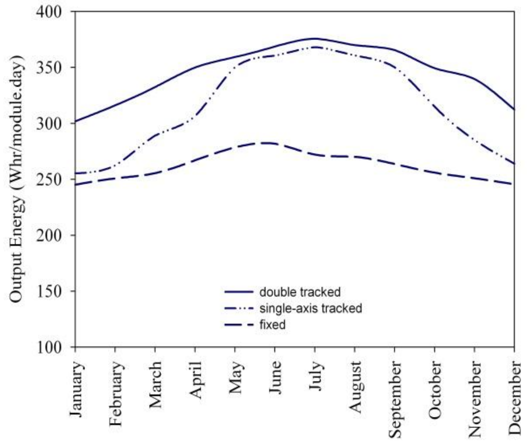
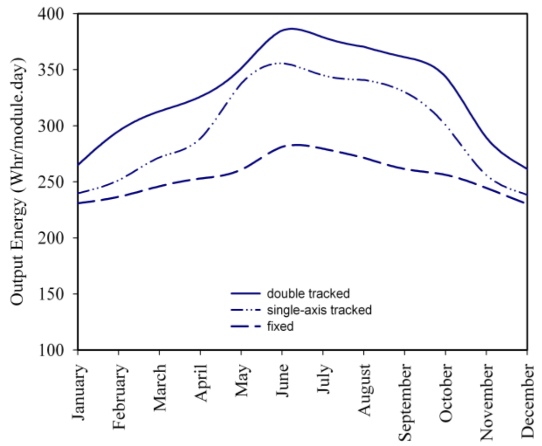


(d)



(e)

Figure 8. Average PV power generation for a) Esfahan b) Tabriz c) Tehran d) Shiraz e) Yazd

Cost summary was providing for a determined 1,000 units. The costs values were taken from various part distributers. The total cost for a single tracker, cost $316.25. Shipping and handling were once again not included. Cost analysis for the immobile system versus the AADAT system were compared for solar cells from one to twenty 20 Watt cells. This information can be seen in Figure 9. Also, the payback period for a 20 Watt solar cell is estimated. We are considered; the solar cell is immobile, an X-axis tracker is used, a Y-axis tracker is used and the AADAT designed is used. In Massachusetts the US Energy Information Administration estimated the electricity rate was 15.29 cents per kWh. It is assumed this value is also the payback cost. The payback period for the immobile system versus the AADAT system were compared for solar cells from one to twenty 20 Watt cells. This information is illustrated in Figure 10. For four 20 Watt solar cells the payback period of the AADAT system is 29.63 years while it is 29.17 years for the immobile system. At twenty cells the payback period is 21.12 years for the AADAT system, while it is constant at 29.09 years for the immobile system. Also, energy generating for the immobile system versus the AADAT system were compared for solar cells from one to twenty 20 Watt cells (Figure 11).

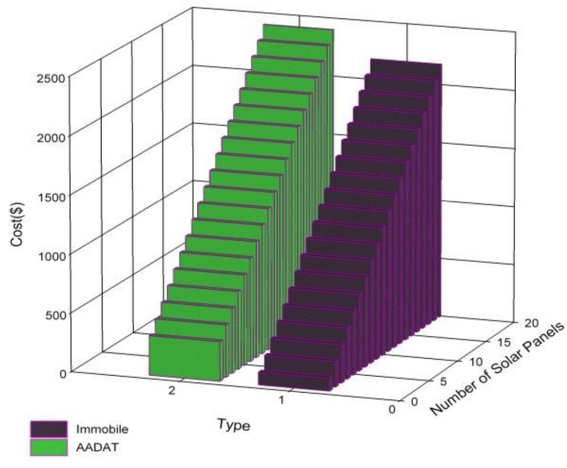


Figure 9. Cost analysis for Immobile and AADAT

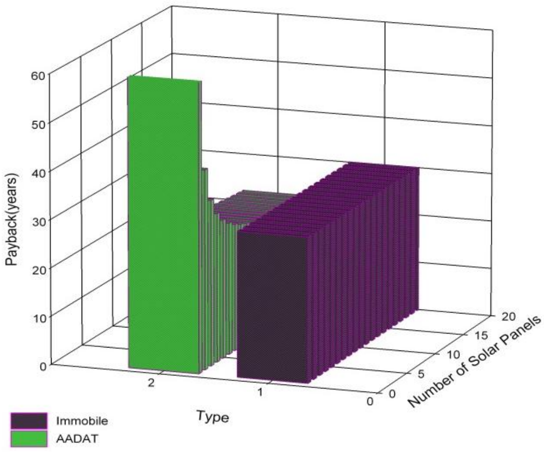


Figure 10. Payback Periods for Immobile and AADAT

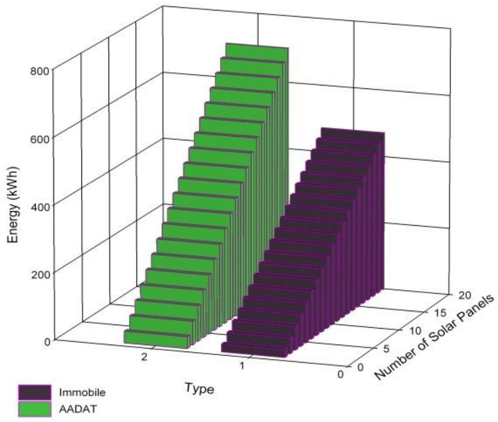


Figure 11. Energy generating for Immobile and AADAT

CONCLUSIONS

An overview on research works on solar radiation basics, estimation of technology progression, cost investigation and photovoltaic generation are summarized. In fact, model of PV cells have been discussed to assess the total solar radiation on horizontal and tilt surface. A method for evaluating the output power of a PV module is developed. The simulation, and cost analysis this paper met its original targets. Using the case study of Iran, the obtained results show that:

1) Applying one axis of tracking could prepare a meaningful power gain to the system. For an extra power gain a dual-axis tracking system could be applied. The percent gain from going from an immobile to a dual-axis system is small, but as long as the system doesn't use more power than gained, it still helps.
2) The power production of a PV cell in central and southern regions is higher than other regions in Iran caused by the higher annual solar irradiation.
3) In order to more optimize the solar systems utilization, a dual-axis tracking installation can be applied. The gains build by a dual-axis tracking panel relative to a customary fixed panel are evaluated. This gain in winter and summer solstice days at the chosen regions increased about 29.5 and 38.3%, respectively. In addition, the power output by single-axis panel in the winter and summer solstice days at the chosen regions increased about 16.4 and 22.7%, respectively.
4) The cost analysis shows that for a PV cell, the cost reduction did not alter very much if the size of the flat plate PV module was larger than 140 Wp. For smaller flat plate PV cell sizes (<100 Wp), the cost reduction for a PV cell with single-axis tracking and fixed panel became insignificant.

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Persian Abstract

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چکیده

برق حرارتی خورشیدی دارای قابلیت قابل توجهی برای برآورده کردن مطالبات انرژی می باشد. یک بررسی جامع نشان می دهد که برق حرارتی خورشیدی می تواند نقش مهمی بواسطه کمک به دستیابی به آب و هوای ایمن تر در ایران داشته باشد. این مقاله پاسخ به نیاز فوری برای سرعت بخشیدن به تکامل فن آوری های پیشرفته انرژی بمنظور اشاره به چالش های جهانی انرژی پاک و توسعه پایدار است. هدف اصلی این مقاله نشان دادن نقش اساسی فناوری های انرژی است. دو تکنولوژی برجسته انرژی خورشیدی سیستم های فتوولتاییک و متمرکزکننده خورشیدی هستند. سیستم های فتوولتاییک به دلیل استفاده در هر اندازه ای مفید هستند. اما آنها پر هزینه و منحصر به تولید برق هستند. با این حال، به منظور بررسی عملکرد سیستم های فتوولتاییک و تولید برق در سراسر ایران، ۵ منطقه مختلف در سراسر کشور در نظر گرفته شده است. نتایج به دست آمده نشان داد که سلول های فتوولتاییک توان تولید برق از ۱۵۵تا ۳۸۵ Wh/module.dayرا دارند. این تولید برق برای نیاز مناطق انتخاب شده کافی است و حتی می تواند برای حمایت از شبکه مورد استفاده قرار گیرد. تحلیل اقتصادی برپایه دوره بازپرداخت قرار داده شده است. برآورد هزینه های تولید برق برای پنج شهر در ایران یک کاهش طولانی مدت در هزینه های تولید برق را نشان می دهد.