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Using Angstrom-Prescott (A-P) Method for Estimating Monthly Global Solar Radiation in Kashan

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Abstract

Today's world is witness to growing use of renewable energy as solutions for reduction of air pollution and provision of a healthier environment. Of all available types of renewable energy, solar energy is perhaps the one that can make the best contribution to this cause. In this article, first the data pertaining to solar radiation in all cities of Kashan region were gathered from Iran's national meteorological organization. Then, Angstrom-Prescott (A-P) method and MATLAB software were used to calculate the monthly radiation, maximum monthly radiation, constant coefficients, and solar radiation on a flat surface in each specific site. All cities in Kashan region showed a mean annual solar radiation of 8.32 hours a day, and constant coefficients were found to be 0.30 and 0.49. In conclusion, results show that Kashan region has a high solar radiation and thus solar energy generation potential.

Keywords: Solar energy; Estimate; Sun radiation; Mat lab

Nomenclature: H0: Monthly average daily extraterrestrial radiation on horizontal surface (MJ/m^2); H: Monthly average daily global radiation on horizontal surface (MJ/m^2); GSC: Solar constant; So: Monthly average of the maximum possible daily; s: Monthly average of the solar radiation; a: Regression coefficients; b: Regression coefficients; L: Longitude of the location

Greek letters: δ: Solar declination; φ: Latitude of the location; ωS: Sunset hour angle

Introduction

Adequate supply of energy always has been one of the important factors of economic growth and development [1]. On one hand, today's world is faced with rapidly increasing population and energy consumption, which gives rise to more extensive usage of fossil fuels. On the other hand, the global warming phenomenon triggered by the excessive use of these fuels has now become a pressing global issue. Hence, researchers have introduced and promoted the use of sustainable energy resources as a solution for tackling these major problems [2,3]. At present, most countries have developed or adopted national plans for decreasing the reliance on fossil energy and promoting the development of renewable energy and this is reflected in the multitude of renewable energy projects implemented in the last two decades in different points of the world [4]. Renewable energy resources are clean and widely available and provide a number of environmental and economic benefits which distinguishes them from conventional energy resources. Recent studies have shown a steady growth in use of renewable energy around the world [5,6].

There are different ways to estimate solar radiation and forecasting it, Angstrom- Prescott, klein, Doorenbos and Pruitt, Allen etc. presented a method to evaluate solar radiation, recently many of researchers demonstrated variety of methods for estimation solar radiation such as a novel and efficient 2-D model approach, using of intelligent ANN modeling for prediction of solar energy which is a precise method than before and using of MLP neural networks, Wavelet network, Adaptive Neuro-Fuzzy Inference System for prediction solar radiation, application of using hybrid renewable energy. To evaluate solar radiation in an area different parameters such as average global Solar radiation, global horizontal Irradiance, diffuse horizontal Irradiance ,daily average of global Solar radiation, daily average of GSR during month, maximum and minimum daily average GSR during month can be used [7-13]. Today, investigation of renewable energy potentials is part of planning policies of many countries [14-16]. Figure 1 shows Global Power Plant Market Shares in % and MW/a, 2004-2013 years. In this figure, the consumption of fuel gas that produce by power plants in 2004 year is 45% while with growth of the renewable energy this amount reduced and reached to 16% in 2013 year [17].

Today, the world is witness to a steady and continuous rise in the use of solar energy [18]. In the past decade the issues related to solar energy, including the estimation of solar and hybrid energy generation potentials have been the subjects of many researches [19-22]. Germany is one of the leading countries in regard with development and deployment of renewable energy technologies and the competition triggered by Germany as well as other developed countries has led to a significant drop in prices of solar energy generation equipment. In 1980 solar photovoltaic modules had an average price of 30 US $/Wpeak but by 2013 this price was reduced by 97% to 0.9 US $/Wpeak. In Germany, cost reductions were achieved primarily due to the Feed-in Law. Figure 2 shows the price trend of solar photovoltaic module [23].

Today, the use of solar energy has become a global trend and as a result an increasing number of companies are becoming engaged in production of solar panels [23]. Solar energy is perhaps the best-known types of renewable sources and one of the most important resources

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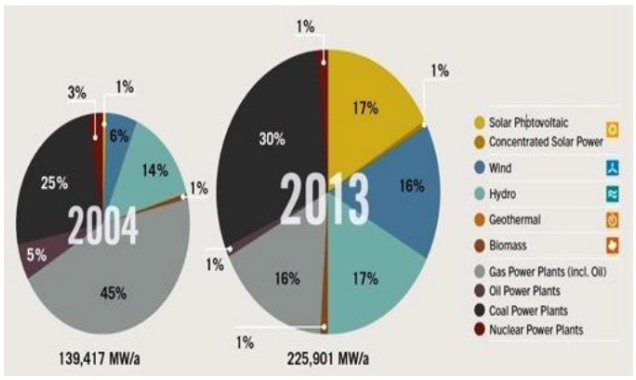

Figure 1: Global Power Plant Market Shares in % and MW/a, 2004-2013 [17].

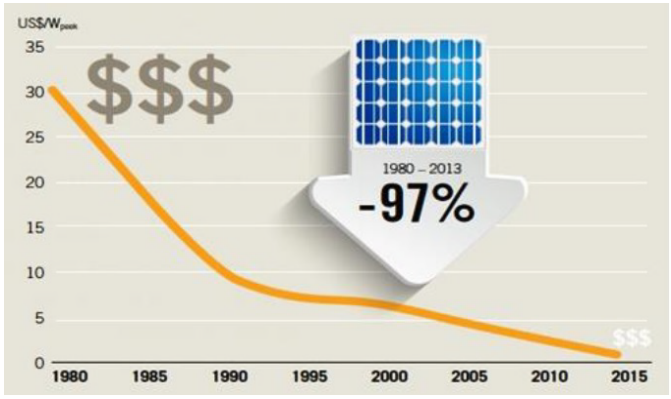

Figure 2: Development of Solar Photovoltaic Module Prices [17].

for production of economic, clean and sustainable energy [24]. In Iran, photovoltaic cells (PV) have proved to be a high performance technology with great potential as an element of large-scale energy generation schemes [25]. Sabziparvar et al. have studied and estimated the global solar radiation in central arid deserts of Iran [26].

Area Studied

Kashan is a city in the Isfahan province (Iran), with population 335875 and 9647 km^2 area respectively. The mean of kashan back to a tribe with name kasho that after years it changed and converted to kashan. This city is located at 51.27° N and 33.59° E and at an altitude of 982.3 meters above sea level. Kashan has a temperature 28° and approximately cities such as Yazd with 26°, Isfahan 27° and arak 25° has similar climate as kashan. The region where Kashan is located has a warm and relatively dry climate, but due to a lot of variety ancient places and historical attractions has high visitor during year, actually Kashan is widely known as a touristic city and is famous for its ancient and beautiful houses [27,28]. Figure 3 shows the location of the studied area on the map of Iran. As can be seen, Kashan is located in the central parts of Iran and it's obvious with red color [29].

Solar Analysis

Solar radiation estimate is an important factor for analysis and assessment of solar radiation potential of a given region. There is an equation called Angstrom- Prescott (1940) which can be used for this purpose [30,31]:

Figure 3: Map of Iran showing the geographical location of Kashan [29].

$$\frac{H}{H0} = a + b\left(\frac{S}{S0}\right) \quad (1)$$

Where H0 Monthly average daily extraterrestrial radiation on horizontal surface (MJ/m^2 day), H Monthly average daily global radiation on horizontal surface (MJ/m^2), n is the mean daily number of hours of bright sunshine per month and N is the mean value of day length per month in a specific region, we also use the following equation to calculate the coefficients 'a' and 'b' [32,33]:

Parameters a and b are the regression coefficients.

$$a = -0.110 + 0.235\cos\varphi + 0.323\left(\frac{S}{S0}\right) \quad (2)$$

$$b = 1.449 - 0.553\cos\varphi - 0.694\left(\frac{S}{S0}\right) \quad (3)$$

H0 is expressed as: [34]

$$H0 = \frac{24*3600*GSC}{\pi}\left[1+0.033\cos\frac{360n}{365}\right]\left(\cos(\varphi)\cos(\delta)\sin(\omega S)+\frac{2\pi\omega S}{360}\sin(\varphi)\sin(\delta)\right) \quad (4)$$

where, H0 is the Monthly average daily extraterrestrial radiation on horizontal surface (MJ/m^2day), GSC is the solar constant and is equal to 1367 Wm^2, δ is the solar declination, ωS is the mean hour angle at sunrise in a given month, solar declination (δ) and mean hour angle at sunrise, and ωS can be calculated by equations (22) and (24) [35]. The following formula is used to obtain δ .The solar declination (δ) and the mean sunrise hour angle (ωS) can be calculated by the following equations (5) and (6). In order to obtain the amount of solar declination (δ), there is an expression: [36]

$$\delta = 23.45\sin\left(360\frac{284+n}{365}\right) \quad (5)$$

Also mean sunrise hour angle can be obtained by:

$$\omega S = \cos^{-1}(-\tan\varphi\tan\delta) \quad (6)$$

The monthly average of the maximum possible daily can be

obtained [37]:

$$No = \frac{2}{15} cos^{-1} (-tan\ \varphi \tan \delta) \quad (7)$$

Table 1 presents the constant coefficients, solar radiation on a flat surface in a specific region, mean daily solar radiation and maximum daily radiation.

Table 2 presents the regression coefficients, solar radiation on a flat surface, Monthly average daily extraterrestrial radiation on horizontal surface (MJ/m²day), Monthly average daily global radiation on horizontal surface (MJ/m² in Kashan city.

Figure 4 illustrates the mean solar radiation per month. As this figure shows, maximum and minimum radiation in February with 6.06 and January with 10.97 was obtained respectively.

Figure 5 depicts the monthly average daily global radiation on horizontal surface and the monthly average daily extraterrestrial radiation on horizontal surface. According to this figure, maximum (44.28) and minimum (16.69) monthly average daily global radiation on horizontal surface have been observed in January and May. Maximum and minimum monthly average daily extraterrestrial radiations on horizontal surface are 24.12 and 9.67 and have been observed respectively in August and December.

Figure 6 shows the monthly solar radiation in Kashan. In this figure, minimum (178.71) and maximum (340.23) radiations can be observed in February and August.

Conclusion

Global warming and environment problems are crucial factors that need to be considered in clean energy utilization decisions. The present paper was a statistical analysis of solar radiation for the city of Kashan by the use of Angstrom-Prescott (A-P) method. First, the data pertaining to solar radiation in all cities within Kashan region were gathered from Iran's national meteorological organization. Next, the Angstrom-Prescott (A-P) method, which is a known method of solar radiation analysis, was used along with MATLAB software to calculate the amount of radiation per month, the maximum amount of possible radiation per month, constant coefficients of equation, Monthly average daily extraterrestrial radiation on horizontal surface (MJ/ m^2day), Monthly average daily global radiation on horizontal surface (MJ/m^2), for the specified areas. After analysis, the average amount of annual solar radiation for the cities of Kashan was calculated to 8.32 hours a day. Moreover, the constant coefficients obtained for

Month	ωS	δ	Mean solar radiation per month
Jan	106.74	23.44	187.53
Feb	77.15	-18.50	182.01
Mar	102.93	18.62	224.16
Apr	96.08	9.06	242.76
May	73.44	-23.21	276.75
Jun	91.04	1.58	328.16
Jul	76.05	-19.94	324.06
Aug	101.7	16.98	340.23
Sep	97.65	11.33	307.11
Oct	73.84	-22.72	257.63
Nov	90.11	0.17	209.96
Dec	82.36	-11.31	178.71

Table 1: Mean monthly global solar radiation and its input parameters in Kashan.

Time	a	b	Ho (KJ/m²-day)	H (KJ/m²-day)	H/Ho	s	S0	s/S0
Jan	0.22	0.68	44.28	17.13	0.38	6.25	14.23	0.43
Feb	0.27	0.58	20.54	10.12	0.49	6.06	10.28	0.58
Mar	0.26	0.61	41.23	19.36	0.46	7.47	13.72	0.54
Apr	0.28	0.56	35.96	18.42	0.51	7.83	12.81	0.61
May	0.37	0.35	16.69	10.93	0.65	8.92	9.79	0.91
June	0.36	0.38	31.21	20.09	0.64	10.58	12.14	0.87
July	0.41	0.27	18.54	12.98	0.70	10.45	10.14	1.03
Aug	0.34	0.43	39.17	24.12	0.61	10.97	13.56	0.80
Sep	0.33	0.46	37.07	22.25	0.6	9.90	13.02	0.76
Oct	0.36	0.38	17.52	11.27	0.64	8.58	9.84	0.87
Nov	0.27	0.58	32.13	15.84	0.49	6.99	12.01	0.58
Dec	0.22	0.69	25.32	9.67	0.38	5.95	10.98	0.42
Year	0.30	0.49	29.97	16.01	0.54	8.32	11.87	0.70

Table 2: Monthly solar radiation, regression coefficients, mean monthly solar radiation, Monthly average daily extraterrestrial radiation on horizontal surface (MJ/m²day), Monthly average daily global radiation on horizontal surface (MJ/m²).

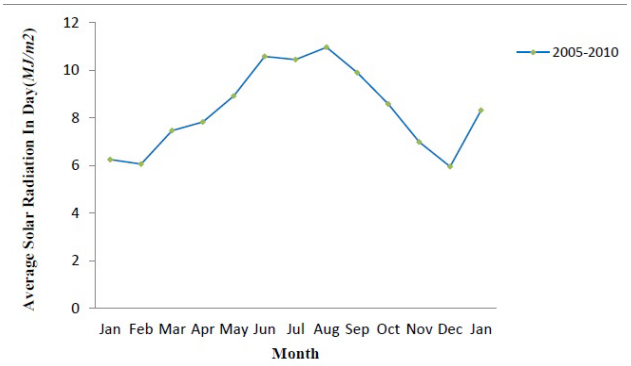

Figure 4: Mean Solar Radiation in Kashan.

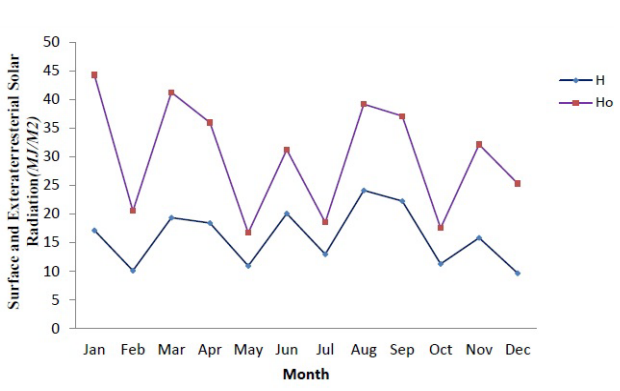

Figure 5: Graph showing global radiation on horizontal surface and extraterrestrial radiation on horizontal surface.

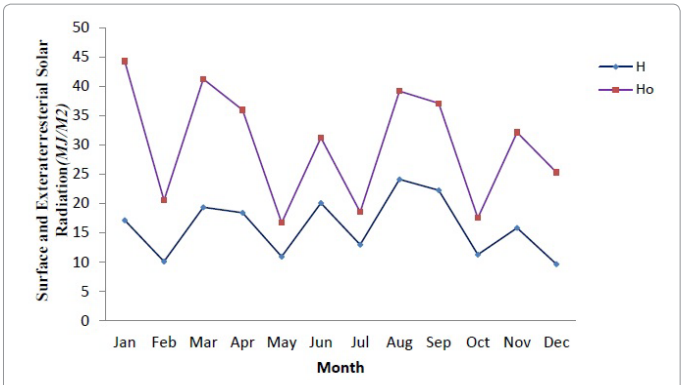

Figure 6: Monthly Solar Radiation in Kashan.

Kashan were 0.30 and 0.49. Also, Monthly average of the maximum possible daily calculated to be 14.23 and 9.79 (KJ/m^2-day). Finally, the technical and economic analysis demonstrated that investment on solar energy of this area is justified. The results indicate that Kashan region has a high solar radiation and thus solar energy generation potential.

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