Effect of tilt angle selection on the performance of grid-connected photovoltaics: Turkey case study

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The purpose of this article is to constitute awareness about solar PV panels and investigate the effect of tilt angles on the performance at different latitudes of Turkey where the active solar systems are not widely used. The monthly average global and diffuse solar radiations of the locations were calculated numerically. A two-step screening was carried out for detecting the annual optimum tilt angles. Firstly a search between 0° and 75° with 5° steps, then a deeper analysis between 28° and 40° with 1° steps was employed. Then the monthly and seasonal optimum tilt angles were determined. Monthly and annual energy yield of the PV installations were obtained by using PVSyst 5.0 software. The monthly, seasonally and the yearly optimum tilt angles were detected for each locations. As a result it's found out that, the yearly optimum tilt angles for Antakya, Elazig and Sinop are 32.1°, 34.6° and 37.9° respectively. It is also found that mounting the panels at the monthly average tilt angles increase the energy output of PV systems with the ratios of % 5.2 for Antakya, % 6 for Elazig and % 6.3 for Sinop.

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Keywords: Grid-connected photovoltaics, Solar radiation, Optimum tilt angle, PVSyst, Electricity production

1. Introduction

Electricity is generated from a variety of sources in Turkey. In 2013 the installed power is stated as 64612 MW by Turkish Chamber of Electrical Engineers [1]. This power is generated by hydroelectric dams, natural gas and coal-fired power stations, wind turbines, geothermal power stations and others. Although solar radiation in Turkey is abundant because of its geographical position between 36°-42° N latitudes, the number of solar based electricity production stations are limited.

Solar energy is easily converted into electricity by photovoltaic (PV) systems. The generated electric power depends on the solar radiation intensity on the PV collector's surface. So, the position of the PV modules is an important parameter in electricity production. As the position of the sun changes not only during the day but also during the year continuously, determination of the optimum slope angle of the PV modules become important. Solar tracking systems can be more effective in maximum power generation, but the costs of these systems are higher than the classical fixed systems [2-3].

In literature, there are many studies carried out for determination of optimum tilt angle of solar collectors [4-17]. Jafarkazemi and Saadabadi [4], calculated the monthly average diffuse radiations in Abu Dhabi with a MATLAB code based a software by using 22 years average data obtained from NASA. The total solar radiations on the sloped surfaces for different orientations ($0° \leq \gamma \leq 90°$) and for different tilt angles ($0° \leq \beta \leq 90°$) were determined. So, they identified the optimum tilt angles for each orientation. Siraki and Pillay [5], proposed a simple method based on a modified sky model for calculating the optimum tilt angle for achieving the maximum annual and seasonal energy yield. Bakirci [6], carried out a study for determining the optimum tilt angles of solar panels in eight cities of Turkey for maximizing their energy collection. Benghanem [7], presented the results of the study which deals with the optimum slope angle for collecting the maximum solar radiation. Gunerhan and Hepbasli [10] aimed to determine the optimum tilt angle for solar collectors in Izmir province of Turkey by using the measured solar radiation in the solar-meteorological station of solar energy institute in Ege University. They suggested mounting the collectors at the monthly average tilt angle and adjusting once a month. Kacira et al. [14] calculated the amount of solar radiation on the inclined surfaces for identifying the optimum tilt angle for solar PV panels in Sanliurfa Turkey. They found out the minimum tilt angle is 13° (in June), and maximum tilt angle is 61°(in December).

This study is aimed to constitute awareness about solar based electricity production in Turkey. For this purpose three different cities (Antakya, Elazig and Sinop) were selected from different latitudes of Turkey from the south, middle and the north as shown in Fig. 1. The PV systems are assumed to be installed on the flat roofs of buildings. The available area for PV installations is considered to be 250 m^2 for each of the cities.

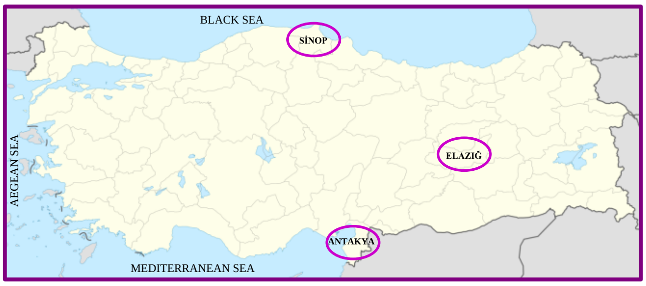

Fig. 1. The locations of the selected cities from different latitudes of Turkey

The certain data for the selected cities were given in Table 1. The annual electricity production potentials for each location were calculated with PVSyst 5.0 software [18] by employing the local climatic and geographical conditions. For choosing the best tilt angle for all locations, the PV panels are assumed to be mounted with the angles from 0° to 75°. The monthly, seasonally and yearly optimum tilt angles were determined for each location. The annual electricity yields of the cities calculated by using these values and finally the obtained results were discussed.

Table 1. Certain data for selected cities

City	Altitute (m)	Longitude (°)	Latitude (°)
Antakya	85	36°52′	36°12′
Elazig	1015	38°41′	39°14′
Sinop	32	42°01′	35°09′

2. Calculation of global and diffuse solar radiation on horizontal surfaces

Solar radiation is the most important parameter in determining the performance of PV systems, thus firstly the average monthly solar radiations on horizontal surfaces for the selected locations were calculated. The most widely used empirical correlation developed by Angstörm [19] was employed in this study. The ratio of global solar radiation on horizontal surface (Q) to the extraterrestrial solar radiation on horizontal surface (Q_0) is determined with the ratio of average daily sunshine duration to maximum possible sunshine duration.

$$\frac{Q}{Q_0} = a + b\frac{t}{t_d} \qquad (1)$$

a and b values in the equation can be calculated by using latitude (ϕ), declination (δ) and also by using the altitude of the location (Eq. 2-3). Where t is the daily sunshine duration and t_d is the day length which can be calculated which can be calculated by equation 4 given below.

$$a = 0.103 + 0.000017z + 0.198\cos(\phi - \delta) \qquad (2)$$

$$b = 0.533 - 0.165\cos(\phi - \delta) \qquad (3)$$

$$t_d = (2/15)\arccos(-\tan\delta\tan\phi) \qquad (4)$$

Declination angle is the angular position of solar rays from equator plane and varies between -23.45° and +23.45°. This angle can be approximately calculated by the correlation given by Cooper [20].

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

The monthly mean daily extraterrestrial solar radiation on the horizontal surface Q_0, is calculated with Equation 6. Where I_{sc} is the solar constant and equals to 1367 W/m^2, n is the number of the day from 1st January, ϕ and ω and are the latitude of the site and the hour angle in degrees respectively. Sunset hour ω_s is determined with Equation 7.

$$Q_0 = \frac{24}{\pi} I_{sc}(1 + 0.033\cos(\frac{360n}{365})) .(\cos\delta\cos\phi\sin\omega_s + \frac{\pi}{180}\omega_s\sin\delta\sin\phi) \qquad (6)$$

$$\cos\omega_s = \frac{-\sin\delta\sin\phi}{\cos\delta\cos\phi} = -\tan\delta\tan\phi \qquad (7)$$

Instantaneous global solar radiation (I_i) can be identified depending on daily total global radiation (t_d). The ratio of instantaneous global radiation to daily global radiation is expressed with the equation given below. ψ parameter in the equation is expressed in Eq.9.

$$\frac{I_i}{Q} = \frac{\pi}{4t_d} = \left(\cos(\frac{180\omega}{2\omega_s}) + \frac{2}{\sqrt{\pi}}(1-\psi)\right) \qquad (8)$$

$$\psi = \exp(-4(1 - \frac{|\omega|}{\omega_s})) \qquad (9)$$

Liu and Jordan [21] expressed the ratio of daily diffuse radiation to daily global solar radiation and clearness index (K_t) with the equations 10 and 11 given as below.

$$K_d = Q_d / Q \qquad (10)$$

$$K_t = Q / Q_0 \qquad (11)$$

Then Klein [22] suggested a third degree polynomial for the calculation of K_d depending on clearness index as,

$$K_d = 1.390 - 4.027K_t + 5.531K_t^2 - 3.108K_t^3 \quad (12)$$

The ratio of hourly diffuse radiation (I_d) to daily diffuse is expressed with the following equation [23].

$$\frac{I_d}{Q_d} = \frac{\pi}{24}\left\{\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\pi}{180}\omega_s\cos\omega_s}\right\} \quad (13)$$

3. PVsyst Software

PVsyst 5.0, is a software package which was developed for the needs of architects, engineers and researchers. It is effectively used in sizing, simulating and analysis of the PV system performances [24-26]. This tool allows sizing the required PV system power and equipments for grid-connected, stand-alone and pumping systems. Package program is generated by University of Geneva (Switzerland) and regarded as a reference in the sector.

Meteorological variants (global and diffuse solar radiations on horizontal surfaces, monthly average ambient temperature and wind velocity) and geographical parameters (latitude, altitude, etc.) are vital data for simulations. Users can generate the meteorological data by employing Meteonorm [27] and this file can be used in simulations. Users can also enter the monthly average meteorological data manually to the program. Simulations can be carried out for different tilt angles, shadow situations and different PV technologies (si-mono, si-poly, CdTe, CIS, a-si, etc.) on the market. This program is also capable of making economical evaluations for PV system installations.

4. Case study

PV installations on flat roofs can easily be adapted to different tilt angles by using supporting structures. For determining the electricity production potential of Turkey three different locations from different latitudes were selected. Firstly the monthly average global and diffuse solar radiations for Antakya, Elazig and Sinop were calculated numerically with a computer program written in MATLAB. The daily sunshine duration data of the cities for a period of 22 years (1990-2012) were employed in the solar radiation calculations. The monthly average global and diffuse solar radiations on horizontal surfaces of the selected cities are given in Fig. 2. The long-term monthly average ambient temperatures for the city samples are shown in Fig. 3.

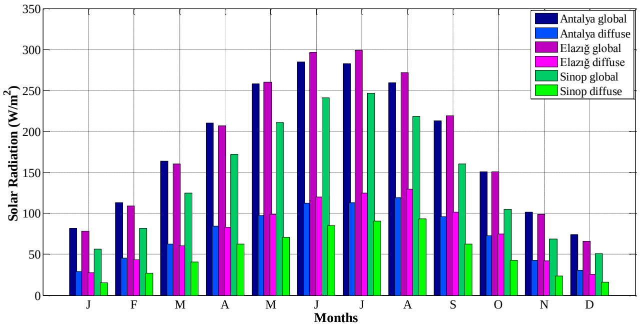

Fig. 2. Monthly average global and diffuse solar radiations on horizontal surfaces for the selected cities

There are many different types of PV technologies at the market. Monocrystalline silicon (si-mono), poly crystalline silicon (si-poly), copper indium diselenide (CIS), cadmium telluride (CdTe) and amorphous silicon (a-si) are some of the examples. In this study mono-crystalline silicon technology was preferred. As it is seen from the Table 2 shows that the efficiency of the PV technology increases when the unit cost decreases. In this study mono-crystalline silicon technology is preferred because of its high efficiency varying between 13%-17%

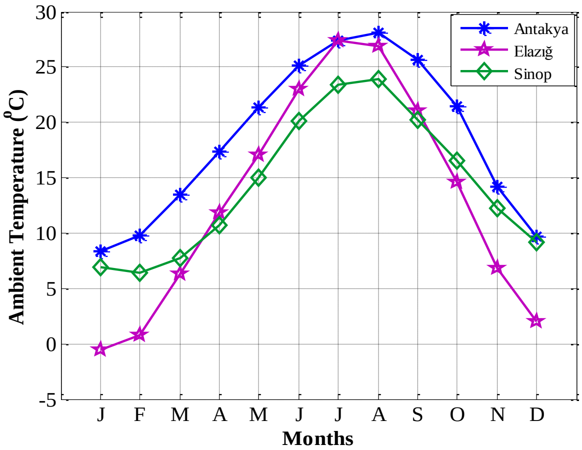

Fig. 3. Monthly average ambient temperatures for the selected cities

The technical properties of the preferred solar modules and the inverters are given in Table 3. The schematic view of the grid-connected PV systems is also shown in Fig. 4. The available area for system installation is considered to be 250 m^2 on rooftops of buildings. The PV array assumed to be constituted with 11 modules in series, 26 strings and 6 inverters.

The yearly, seasonally and monthly energy outputs of the PV installations were calculated and optimum values of the tilt angles were determined. The results were compared with each other and four different solar tracking samples.

Table 2. Variation of efficiency, energy density and costs according to PV technology

PVCell Material	PV Module Efficiency (%)	Energy Density (kWp/m^2)	Cost
Hybrid PV	18+		
Monocrstalline silicon PV	13-17		
Polycrystalline silicon PV	11-15		
Amorphous silicon PV	6-8		

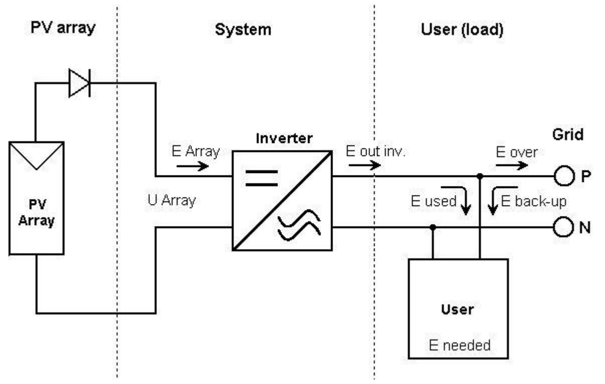

Fig. 4. The simplified schema of the grid-connected PV systems

Table 3. Technical properties of PV modules and inverters employed in simulations

Solar Pannel		Inverter	
Technology	Si-mono	**Manufacturer**	Mitsubishi
Manufacturer	Siemens Solar	**Model**	PV-PN06B3
Model	SM110	**Min MPP Voltage**	115
Power (Wp)	110	**Max MPP Voltage (V)**	350
Efficiency (%)	14.70	**Absolute Max PV Voltage (V)**	350
Voc (V)	21.70	**Power Threshold (W)**	25
Isc (A)	6.90	**Weight (kg)**	21.4
Vmpp (V)	17.50	**Grid Voltage (V)**	230
Impp (A)	6.30	**Max Efficiency (%)**	94.5

5. Results and discussions

The effect of tilt angles on the energy output of PV installations assumed to be located at three different latitudes of Turkey was investigated for a-year period. The optimum tilt angles of the PV panels were determined by employing a two-step simulation process. First search was carried out for 16 tilt angles from 0° to 75° with 5° steps regularly. The annual maximum energy outputs are achieved when the tilt angle adjusted as 30° annually for Antakya and Elazig whereas 35° for Sinop. The system productions related to the tilt angles for all locations are shown in Fig. 5.

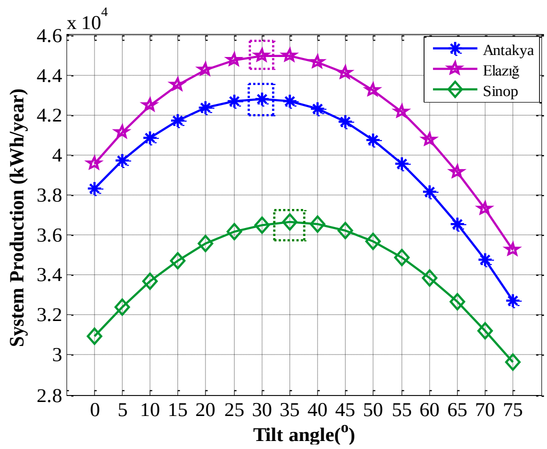

Fig. 5. Annual system production variation of PV installations for different tilt angles

It is expected to achieve the maximum energy output in Antakya region because of its big solar energy potential related to its geographical position at low latitude. But the maximum annual energy productions are obtained in Elazig. As the small portion of the solar radiation on PV modules converted to electricity, some of the radiation is reflected and the rest is converted to heat and increases the panel temperature [28]. It is known that the increase in the panel temperature causes reductions in the efficiency and electricity production of the photovoltaics [29, 30]. The results claimed that the high monthly average temperatures increase the impact of the solar radiation and decrease the system efficiency in Antakya region. This coarse search was continued with a finer search between 28° and 40° tilt angles with 1° steps regularly. The results are given in Figs. 6-8. The annual maximum yield is achieved with 29° annual adjusted tilt angle for Antakya and 31 and 36 for Elazig and Sinop respectively.

After the determination of yearly optimum tilt angles of the selected cities, the monthly optimum values were investigated. The monthly energy production of the PV installations related to the tilt angles were calculated, the monthly energy outputs of PV systems are shown in Tables 4-5 and 6.

The optimum angles providing maximum energy productions are marked in the tables. Optimum tilt angles for Antakya region varies between 25° and 0° in summer period (April-September), while the tilt angles changes between 35° and 60° because of the shallow incidence angle of the solar radiation in winter. The energy yield in summer period is obtained as 26867 Wh and 18311 Wh in winter.

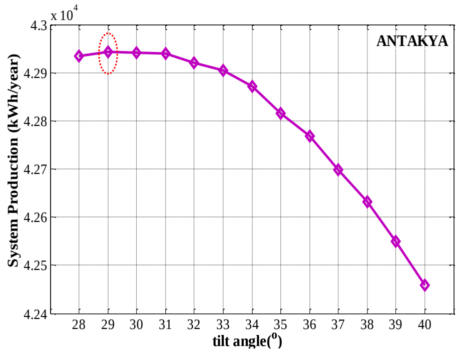

Fig. 6. Finer search for the optimum tilt angle determination of Antakya

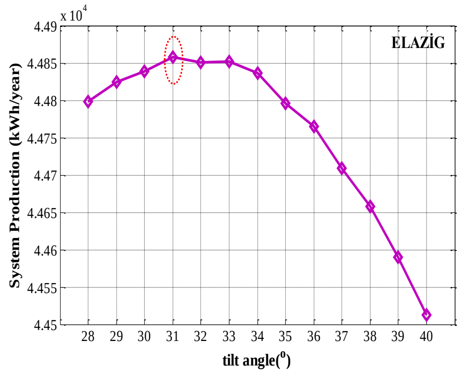

Fig. 7. Finer search for the optimum tilt angle determination of Elazig

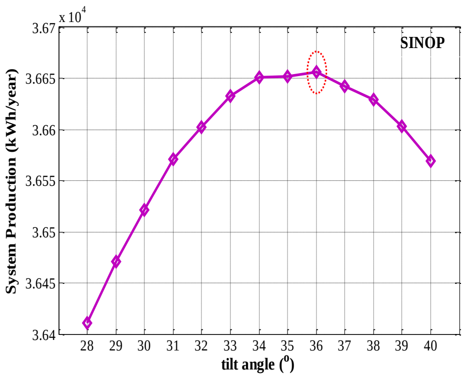

Fig. 8. Finer search for the optimum tilt angle determination of Sinop

For Elazig city, optimum tilt angle of January is determined as 60° and decreases to 5° in June and July. The output energy is 2650 Wh in December while the tilt angle is 65°. Electricity production in summer period is 28314 Wh and 19233 Wh in winter. The highest tilt angles were determined for Sinop region. The tilt angle in summer varies between 5° and 35° while 45° and 70° in winter period. The energy productions in Sinop are 23455 Wh and 15509 Wh for summer and winter periods respectively. In summer period, the electricity production in Sinop is 12.69% less than Antakya and 17.16% than Elazig. In winter conditions the energy production is 15.27% and 19.33% less than Antakya and Elazig respectively.

The annual energy productions of the PV installations by the usage of monthly, seasonally and yearly optimum tilt angles were calculated and the results were shown in Figs. 9-11 for the city samples. It is evident that the maximum electricity generation due to maximum solar radiation is achieved with monthly optimum tilt angles. But it is stated in many study that this situation is not practical in daily life [5,31,32], the seasonal adaption of the panels seems more acceptable. Hence two different tilt angles for summer and winter periods were determined by using the average values of monthly tilt angles. The seasonal tilt angles of summer and winter for Antakya are 13.33° and 50.83°, 15° and 54.16° for Elazig and 18.33° and 58.32° for Sinop. Consequently it is seemed that employing the monthly tilt angles is advantageous than the seasonal and yearly tilt angles with the average ratios of 5.8 % and 1.1 % respectively.

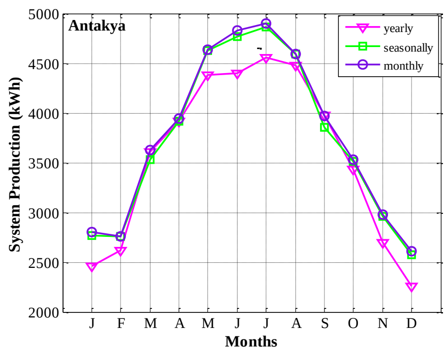

Fig. 9. Energy yield variation of PV systems in Antakya for differently adjusted tilt angles

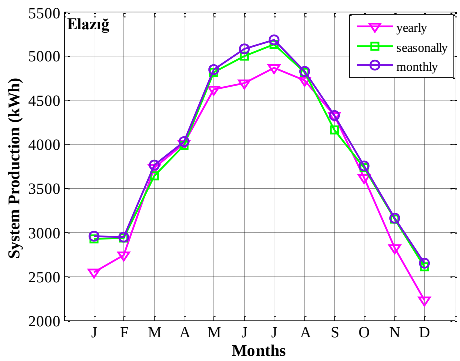

Fig. 10. Energy yield variation of PV systems in Elazig for differently adjusted tilt angles

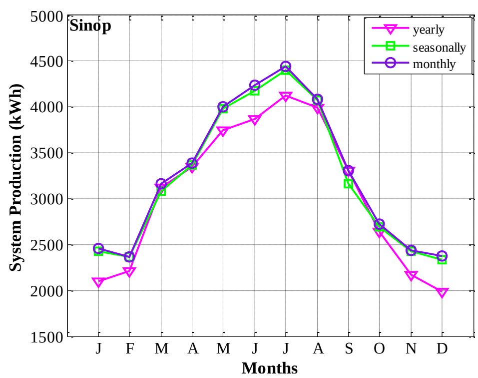

Fig. 11. Energy yield variation of PV systems in Sinop for differently adjusted tilt angle

Table 4. Monthly electricity production (Wh) of PV systems in Antakya for different tilt angles

ANTAKYA	Months	Tilt angles															
		0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°
	January	1505	1701	1885	2054	2207	2344	2464	2566	2651	2717	2764	2792	2800	2790	2762	2713
	February	1900	2058	2202	2331	2444	2540	2619	2681	2726	2752	2762	2753	2726	2682	2621	2542
	March	3041	3190	3319	3426	3512	3574	3613	3630	3626	3598	3548	3475	3379	3264	3127	2969
	April	3729	3818	3885	3926	3846	3944	3918	3869	3800	3706	3590	3452	3293	3114	2915	2698
	May	4603	4633	4638	4614	4562	4480	4385	4264	4122	3954	3762	3547	3305	3049	2786	2513
	June	4825	4822	4794	4737	4653	4540	4402	4251	4077	3879	3658	3409	3143	2877	2602	2312
	July	4888	4900	4887	4844	4773	4680	4559	4410	4246	4055	3842	3598	3345	3071	2792	2500
	August	4473	4536	4576	4590	4580	4542	4479	4393	4285	4152	3995	3814	3609	3386	3144	2884
	September	3573	3697	3800	3879	3937	3970	3979	3695	3929	3868	3785	3679	3550	3400	3229	3037
	October	2673	2848	3006	3143	3260	3357	3432	3486	3520	3531	3521	3490	3436	3363	3270	3155
	November	1767	1963	2143	2307	2455	2585	2697	2791	2866	2922	2959	2976	2974	2953	3912	2852
	December	1346	1531	1705	1866	2014	2147	2263	2364	2449	2516	2566	2598	2612	2610	2590	2552

Table 5. Monthly electricity production (Wh) of PV systems in Elazig for different tilt angles

ELAZIG	Months	Tilt angles															
		0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°
	January	1488	1703	1905	2091	2262	2415	2549	2665	2763	2840	2898	2936	2953	2951	2928	2885
	February	1914	2093	2258	2406	2538	2651	2747	2823	2882	2921	2941	2942	2922	2885	2829	2753
	March	3081	3245	3389	3509	3607	3682	3733	3760	3765	3746	3703	3637	3547	3436	3303	3148
	April	3781	3878	3951	4002	4030	4033	4011	3967	3901	3810	3696	3560	3401	3221	3022	2803
	May	4785	4829	4846	4832	4790	4723	4628	4503	4362	4192	3999	3779	3532	3272	2994	2704
	June	5077	5082	5063	5015	4938	4826	4696	4542	4369	4170	3945	3696	3420	3135	2847	2544
	July	5168	5191	5186	5151	5088	4989	4870	4732	4572	4385	4173	3935	3670	3386	3104	2804
	August	4700	4771	4817	4834	4825	4785	4727	4642	4533	4398	4238	4053	3842	3610	3353	3085
	September	3799	3948	4076	4177	4253	4303	4328	4327	4302	4250	4174	4071	3944	3794	3620	3423
	October	2768	2962	3138	3292	3426	3537	3626	3692	3737	3758	3757	3732	3684	3615	3525	3411
	November	1786	2000	2199	2382	2548	2695	2822	2930	3019	3087	3134	3161	3165	3150	3115	3057
	December	1239	1437	1624	1799	1959	2104	2233	2345	2441	2519	2579	2621	2645	2650	2638	2607

Table 6. Monthly electricity production (Wh) of PV systems in Sinop for different tilt angles

	Months	**Tilt angles**															
		0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°
SINOP	January	985	1182	1368	1542	1704	1852	1985	2102	2203	2288	2355	2405	2437	2452	2450	2429
	February	1349	1512	1663	1800	1925	2035	2130	2209	2273	2321	2353	2369	2367	2351	2318	2268
	March	2359	2526	2676	2806	2917	3007	3076	3124	3154	3161	3147	3113	3057	2982	2887	2772
	April	3154	3242	3311	3357	3385	3392	3375	3343	3292	3220	3128	3016	2885	2737	2571	2386
	May	3928	3973	3998	3997	3971	3919	3847	3749	3641	3509	3355	3180	2984	2767	2538	2305
	June	4215	4236	4236	4211	4162	4083	3988	3868	3728	3572	3394	3194	2970	2741	2493	2244
	July	4395	4429	4441	4428	4388	4325	4240	4129	3992	3839	3663	3464	3239	3009	2759	2496
	August	3872	3959	4026	4066	4086	4080	4049	3993	3916	3819	3700	3557	3393	3209	3007	2786
	September	2775	2910	3026	3121	3198	3253	3287	3302	3297	3270	3224	3156	3069	2963	2838	2694
	October	1874	2031	2174	2301	2413	2507	2585	2645	2688	2714	2722	3712	2684	2640	2579	2500
	November	1173	1354	1524	1682	1827	1958	2074	2174	2259	2327	2379	2414	2431	2432	2416	2382
	December	866	1061	1246	1420	1583	1733	1868	1988	2094	2183	2256	2312	2351	2373	2378	2366

The annual system productions that can be achieved with a solar tracking system for different cities are given in Table 7. The usage of a solar tracking system will be more beneficial with the ratios of 30.5%, 25% and 24% than the adaptation of the modules to the annual, seasonal and monthly optimum tilt angles respectively for Antakya and Elazig. This tracking system will increase the electricity production in Sinop with the ratios 34%, 28% and 26% than the optimum yearly, seasonal and monthly optimum angles.

Table 7. System productions of the locations for different types of tilt angles

	Antakya	Elazig	Sinop
System Production annual	42943 kWh/year	44858 kWh/year	36656 kWh/year
System Production seasonal	44846 kWh/year	46917 kWh/year	38516 kWh/year
System Production monthly	45178 kWh/year	47547 kWh/year	38969 kWh/year
Solar tracking	56041 kWh/year	58580 kWh/year	49295 kWh/year

6. Conclusion

The objective of this paper is to estimate annual seasonal and monthly optimum tilt angles for PV systems for three different locations of Turkey. For achieving the maximum electric energy output annual, seasonal and monthly optimum tilt angles were determined separately and the obtained results were compared.

It is found that the optimum tilt angle varies for different months related to the variation of sun's position during the year. The annual optimum tilt angles for Antakya and Elazig are obtained as 29° and 31° respectively. The annual optimum value of the tilt angle for Sinop is obtained as 36°. Adjusting the tilt angle with monthly-determined angles provides average 5.83% more energy production than yearly values. If this situation is onerous for PV installations, seasonal (summer: April-September, winter: October-March) adjustment of the panels will be 1.06% profitable than annual mounting.

References

[1] http://www.emo.org.tr. Available at: November 25st 2014.
[2] F. A. Uba, E. A. Sarsah, Advances in Applied Science Research, **4,** 108 (2013).
[3] M. Lave, J. Kleissl, Renewable Energy **36,** 1145 (2010).
[4] F. Jafarkazemi, S. A. Saadabadi, Renewable Energy, **56**, 44 (2013).
[5] A. G. Siraki, P. Pillay, Solar Energy, **86**, 1920 (2012).
[6] K. Bakırcı, Renewable and Sustainable Energy Reviews, **16**, 6149 (2012).
[7] M. Benghanem, Applied Energy, **88**, 1427 (2011).
[8] H. R. Ghosh, N. C. Bhowmik, M. Hussain, Renewable Energy, **35**, 1292 (2010).
[9] S. Bari, Energy Conversion and Management, **41**, 855 (2000).
[10] H. Gunerhan, A. Hepbasli, Building and Environment, **42**, 779 (2007).
[11] V. H. Morcos, Renewable Energy, **4**, 291 (1994).
[12] E. D. Behleri, P. L. Zervas, H. Sarimveis, J. A. Palyvos, N. C. Markatos, Renewable Energy, **35**, 2468 (2010).
[13] G. R Saraf, F. A. W. Hamad, Energy Conversion and Management, **28**, 185 (1998).
[14] M. Kacira, M. Simsek, Y. Babur, S. Demirkol, Renewable Energy, **29**, 1265 (2004).
[15] E. D. Mehleri, P. L. Zervs, H. Sarimveis, J. A. Palyvos, N. C. Markatos, Renewable Energy, **35**, 2468 (2010).
[16] H. M. S. Hussein, G. E. Ahmad, H. H. El-Ghetany, Energy Conversion and Management, **45**, 2441 (2004).
[17] I. H. Rowlands, B. P. Kemery, I. Beausoleil-Morrison, Energy Policy, **39**, 1397 (2011).
[18] www.pvsyst.com, Available at: November 25st 2014.
[19] A. Angstorm, Quarterly Journal of the Royal Meteorological Society, **50**, 121 (1924).
[20] P. I. Cooper, Solar Energy, **12**, 333 (1969).
[21] B. Liu, R. C. Jordan, ASHRAE Journal, **3**, 53 (1961).
[22] S. A. Klein, Solar Energy, **21**, 393 (1977).
[23] U. T. Aksoy, O. Kelesoglu, Journal of the Faculty of Engineering and Architecture of Gazi University, **22**, 103 (2007).
[24] X. Wu, Y. Liu, J. Xu, W. Lei, X. Si, W. Du, C. Zhao, Y. Zhong, L. Peng, J. Lin, Energy and Buildings, **88**, 174 (2015).
[25] E. A. Essah, A. R. Arguelles, N. Glover, Renewable Energy, **73**, 36 (2015).
[26] C. L. Azimoh, F. Wallin, P. Klintenberg, B. Karlsson, Applied Energy, **136**, 336 (2014).
[27] www.meteonorm.com Available at: November 25st 2014.
[28] M. U. Siddiqui, A. F. M. Arif, Applied Energy, **112**, 300 (2013).
[29] S. Dubey, J. N. Sarvaiya, B. Seshadri, Energy Procedia, **33**, 311 (2013).
[30] M. Chandrasekar, S. Rajkumar, D. Nalavan, Energy and Buildings, **86**, 692 (2015).
[31] M. A. M. Yakup, A. Q. Malik, Renewable Energy, **24**, 223 (2001).
[32] S. F. Khahra, K. Tabbassum, S. Talpur, M. B. Alvi, X. Liao, L. Dong, International Journal of Electrical Power & Energy Systems, **64**, 1073 (2015).

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