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Research Article

Solar Radiation Forecasts and a Tiny House PV Off-Grid System

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Abstract

In this article, which is discussed at a time when initiatives towards renewable energy sources are increasing and reducing fossil fuel consumption; the factors that need to be examined for the installation of an off-grid solar panel system were examined and in line with the data obtained, a system was designed for a tiny-house. Off-grid system with 10KWh power consumption with optimum irradiance data has been found how many square meters of PV system will be needed to operate it. How to meet the stable 10KWh need for the worst month, the amount of battery capacity required has been examined. A system inventory has been allocated.. A provenciet of Pamukkale in Turkey, with latitude of 37.89°, was chosen for the solar panel installation; It is aimed to meet all the electricity needs of the house, which was built in a forest area 8 km away from the mains, with the solar panel system to be installed. From theory to practice with an academic approach as well as solar energy sector jargon; in this article, includes a two-way study. A solar panel system was installed in line with the data obtained and the 7600Wh value that the house to be built would need, and 29 batteries integrated into the system was sized for cases where the system could not provide sufficient energy through the sun with a 1% probability. Thus, the design of the optimum "Solar Energy System" desired for a certain location and compatible estimation calculations will be able to provide examples of this study.

Keywords: Solar Insolation, Solar Radiation, Solar Angle Calculations, PV system, Solar Energy Off-Grid System.

Güneş Radyasyonu Tahminleri ve Şebekeden Bağımsız PV'li Kır Evi

Öz

Yenilenebilir enerji kaynaklarına yönelik girişimlerin arttığı ve fosil yakıt tüketimini azalttığı bir dönemde ele alınan bu yazıda; Şebekeden bağımsız güneş paneli sistemi kurulumu için incelenmesi gereken faktörler incelenmiş ve elde edilen veriler doğrultusunda güneş paneli sistemi ile küçük bir ev için sistem tasarlanmıştır. Optimum ışınım verileri ile 10KWh güç tüketimine sahip şebeke dışı sistem, onu çalıştırmak için kaç metrekarelik bir PV sistemine ihtiyaç duyulacağı bulunmuştur. En kötü ayda sabit 10KWh ihtiyacının nasıl karşılanacağı, gerekli akü kapasitesi miktarı incelenmiştir. Bir sistem envanter tahsisi yapılmıştır. Güneş paneli kurulumu için Türkiye'de Pamukkale'nin 37.89° enlemli bir ilçesi seçilmiştir; Şebekeye 8 km uzaklıkta ormanlık alana inşa edilen evin kurulacak güneş paneli sistemi ile tüm elektrik ihtiyacının karşılanması hedefleniyor. Güneş enerjisi sektörü jargonunun yanı sıra akademik bir yaklaşımla teoriden pratiğe; Bu yazıda iki yönlü bir çalışma yer almaktadır. Elde edilen veriler ve yapılacak evin ihtiyaç duyacağı 7600Wh değer için güneş paneli sistemi kurulmuş ve sistemin yeterli enerjiyi sağlayamadığı durumlar için sisteme entegre 29 adet batarya %1 olasılıkla boyutlandırılmıştır. Böylece bu çalışmanın, belirli bir lokasyon için istenilen optimum "Güneş Enerjisi Sistemi"nin tasarlanması ve uyumlu tahmin hesapları örnek sunabilecektir..

Anahtar Kelimeler: Güneş Işığı, Güneş Radyasyonu, Güneş Açısı Hesapları, PV sistemi, Güneş Enerjisi Şebekeden Bağımsız Sistem.

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1. Introduction

As it is known, in 2021, there is a need for decarbonization in energy-intensive sectors and an acceleration in energy transformation strategies regarding fossil fuel use, especially at the global level. It is also observed that the global energy transformation; This can be achieved through the creation of appropriate policies, financial models, and the development of cutting-edge technologies. Further investment in low-carbon energy technologies and the development of smart electricity grids will help equip what is being done with green systems. Thanks to the combination of storage and green hydrogen technologies by increasing the capacity of renewable energy sources, it seems possible to accelerate the aforementioned energy transformation and bring the costs of these technologies to public dimensions within 5-10 years. The renewable energy systems, which are specially designed according to the installation site and usage load, contribute to sustainable energy consumption with environmental friendly and low waste outputs [1-5, 14- 16].

An important factor in the design of PV systems is the angle of inclination created by the ground where the PV panel is located, the angle between the ground and the panel. The most suitable tilt angle, which is of great importance in terms of the amount of radiation absorbed, is determined according to the latitude angle of that region. Of course, it will be necessary to take into account seasonal factors in the angle of slope, and this allows to get rid of the burden of seasonal factors such as rain and snow, and thus to obtain efficiency [6-10].

In this study, collecting meteorological data in Pamukkale's coordinate according to the defined conditions and establishing a PV panel system that is suitable for the climatology of the region and that will meet the energy needs provides resource management and will environmentalist contribution.

For this, the situation of the region has been analyzed primarily by using data blocks that have been measured for many years. Then, the solar radiation received by the region in certain periods has been calculated. The best and worst months of the year determined. Besides, temperature, surface angle etc. factors have also been considered in the installation of this system.

1. Materials and Method

Before starting to design, it is necessary to determine in which situations a system will be designed to be used. Then it is necessary to compile and analyze the necessary information. In this study, due diligence will be made for a tiny house. Data will be calculated based on the fact that this house has been installed for a little longer than a few days. The designed system will be carried out in line with the possible and electricity use-based needs of the house where were natural wonder travertine region, located in Pamukkale provenciet of city of Denizli in Turkey [17].

In light of all the above mentioned considerations, after collecting and evaluating all the information, tiny-house has been designed the PV off-grid system.Furthermore, in this study,via PVGIS, a part of calculates the performance of PV systems that are not connected to the electricity grid but instead rely on battery storage to supply energy when the sun is not shining [13].

Energy Need: To estimate the electricity need of the tiny house, a list of items that need daily electricity consumption is created. The electricity consumption of these items is investigated and the total daily consumption is calculated.

Energy Sources and Devices: It should be ensured that sufficient energy source is used for the independent system. After the energy requirement has been calculated, a list is created to identify suitable devices for the energy required. At this stage, the performance, cost and ease of installation of the devices can be evaluated. Solar panels may be insufficient due to a temporary system and high energy usage requirement. In addition, the use of generators is also essential.

2.1. Location Information

Pamukkale in Denizli-Turkey, which was included in the World Heritage List by UNESCO in 1988, is a natural wonder location with its travertines.In this area, there is the ancient city of Hierapolis.It is a location that is visited by many tourists who love nature and landscapes and is tried to be protected.

Pamukkale, a visual feast created by thermal waters in Turkey's Aegean Region, Büyük Menderes basin, with a series of earthquakes 400 thousand years ago, is a rare place in the world where the picturesque travertine was formed over thousands of years [17].

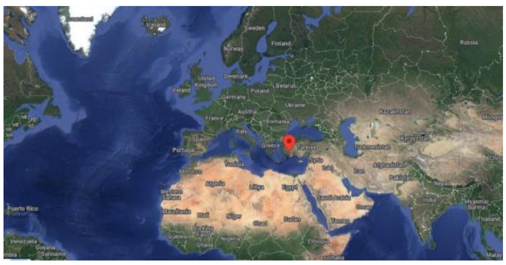

Figure1. Location of Pamukkale, Türkiye on the map [18]

Table 1. Data for Pamukkale Provencie in Turkey

Location Data	Consumption Data
City: Denizli	
Provencie: Pamukkale	
Location: Denizli, Turkey	
Coordinate: DMS 37° 55′ 26″ N, 29° 7′ 24″ E (Decimal: 37.923889, 29.123333)	
Elevation Above Sea Level: 251.712 m	Daily: 10 KWh
Installation Type: Off-Grid	Monthly: 300 KWh
Azimuth: -20	
TiltedAngle:20	
PV technology: CrystallineSilicon	
PV Panel: 330Wp/PERC-MONO Half-Cut (60 pcs)	

2.2. Meteorological Information

Pamukkale region has climate condidations that summers are hot-dry-clear, and winters are cold-rainy-partly cloudy. The temperature normally varies between 6°C and 27°C throughout the year, rarely below -3°C in winter session and above 39°C in summer session [19-21].

Much of the meteorological data is from NASA's Prediction of WorldwideEnergy Resource (POWER) Data obtained from the Data Access Viewer Enhanced (DAVe) project. In addition, data were obtained from the General Directorate of Meteorology, PhotovoltaicGeographical Information System (PVGIS) and WeatherSpark [19-22].

2.3. Calculations

In order to size the solar panel to be installed in the Pamukkale region and to get the desired efficiency throughout the year, the hourly and daily Watt (W) values per square meter from the sun to the desired location were first obtained theoretically. For this, first of all, the declination angle, which is the declination angle, was calculated by Equation 1.

$$\boldsymbol{\delta \approx \mathrm{sgn}(L)\, \delta 0 \sin\left([284 + n]\, 365 \times 360 \circ\right)} \quad (1)$$

Zenith angles of the days with known declination angles were also calculated in the 'solar noon' (w=0) by Equation (2) and illustrated to the table in the result section of this paper.

$$\boldsymbol{\cos(\theta Z) = \sin(\delta)\sin(|\,L\,|) + \cos(\delta)\cos(|\,L\,|)\cos(\omega)} \quad (2)$$

How many degrees our panel should have for the worst month was calculated with the python code written using the Equation3.

$$\tan(\boldsymbol{\beta opt}) = \frac{B_{ter}\tan(\theta_z)}{B_{ter}+\frac{1}{2}D(0)-\frac{1}{2}\rho[B(0)+D(0)]} \quad (3)$$

In the light of all these data, the hourly horizontal flux values reaching the earth on average are presented as a graphic that shows a character suitable for the effect of the Zenith angles calculated in the “solarnoon” due to the declination angles of the moons.

Once the appropriate tilt angle has been found for each day of the year, the most logical option to choose a fixed tilt angle is to choose the worst month of the year. Because, the system will be need to optimize the sunlight that comes in that month the most. Thus, 47°, which is the average value of the inclination angles inthe worst month, namely in December and January, was chosen as the inclination angle of our panel. The Optimal tilt angle calculation formula is given by the Equation 4 which includes latitude of Φ in northern hemisphere.

$$\beta = 1.3793 + \Phi(1.2011 + \Phi(-0.014404 + \Phi 0.000080509)) \quad (4)$$

With a separate discussion, it is also predicted that the optimum solar panel angle is 47.89°, with the Latitude+10 degree approach, for winter use only in Denizli/Pamukkale.

On the other hand, for the tiny house, an inventory of electrical appliances was created by taking into account the different working areas and durations of the existing electrical appliances, and the total daily needed Wh was calculated as shown in table 2 in the result section of this paper. The Total Required Power equals to Quantity multiple by Unit-hour Watt with product Hours.

While sizing the battery, the solar panel system to be installed is designed to meet the electricity needs of the house to be built for 3 days, assuming that the desired electrical energy cannot be obtained with a 1% probability throughout the year (cloudy days, etc.).In other words, the energy produced in 3 days of the year cannot meet the energy demanded to be used from daily solar energy at the rate of 3/365 ≅1% per year, according to the household inventory. Batery size has been calculated by Equation 5.

$$\boldsymbol{Q = \frac{Total\ Wh/d\ used\ by\ appliances * Days\ of\ usage}{0{,}85 * 0{,}6 * nomnal\ battery\ voltage}} \quad (5)$$

The main considered parameters for the battery capacity calculated in Ah are; daily energy need, the number of days the system will be fed only by the battery, the losses in the battery, the DoD value and the battery voltage (V). When these values are 9500Wh, 3, 0.85, 0.6 and 24, respectively, it is concluded with Equation 5 that the battery capacity should be 2328 Ah.

3. Results and Discussion

3.1. Calculation Results

Analysis of typical meteorological datasets for Pamukkale location as mentioned above was fair. Horizontal flux values were extracted for all months.The PV system has been sized to provide the necessary energy for every hour & day & month of the year.The optimum tilt angle of the panel was determined according to the worst month of the year.The daily values of the total horizontal flux were calculated and the standard deviation of the values of the months, namely 28, 30 and 31, was also found.An inventory of all electrical workers in the house was made.Load profile was determined for all days and months of the year.PV panel size and load loss probability were taken into account.The power of the PV panel was so adjusted according to the home inventory that there was a 1% chance of draining the battery. For 3 days of the year, the battery of the panel was not enough, so 3/365 had a probability of running out of battery at a rate of approximately 1/100.

The outputs obtained as a result of all these calculations will be presented in this section. In this context, first of all,Zenith angles for days with known computational declination angles are calculated as shown in the Table 2. The tiny house electric appliances evaluations are illustrated in the Table 3.

Table 2. Data for Pamukkale Provencie in Turkey

Month	**δ (°)**	**θz (°)**	**Midday**
Jan	-21,28	59,17	15
Feb	-13,6	51,49	45
Mar	-2,46	40,35	75
Apr	8,48	29,41	105
May	18,76	19,13	135
Jun	23,26	14,63	165
Jul	21,69	16,2	195
Aug	14,47	23,42	225
Sep	3,48	34,41	255
Oct	-8,41	46,3	285
Nov	-18,1	56	315
Dec	-23,1	61	345

Table 3. Tiny House Eelectrical Inventory in Pamukkale Provencie in Turkey

Apliances	**Wh**	**Usage hours**	**Total Wh**
Refrigerator	1000W	24	2400
TV	75W	2	150
Airconditioner	950W	5	4750
Laptop	50W	5	250
WifiRouter	10W	5	50
			7600Wh

When the average hourly horizontal flux data in the Figure 2 is multiplied by the average day length of each month, the daily average irradiance value per square meter is obtained.

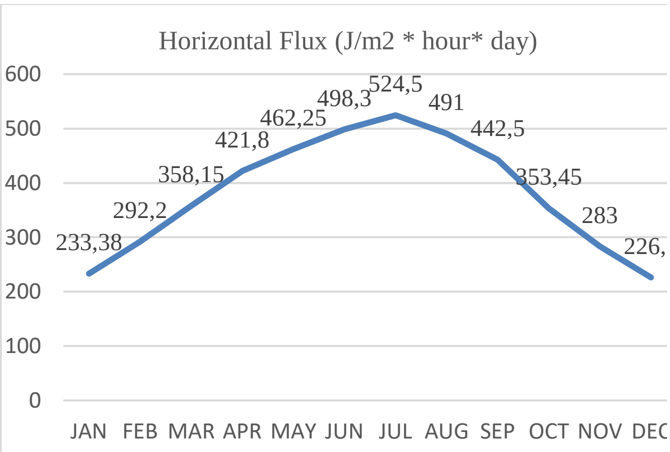

Figure 2.The hourly horizontal flux values reaching the earth on average

3.2 Other Online Sources Results

As mentioned above parts, the data sets are from NASA's Prediction of WorldwideEnergy Resource (POWER), the General Directorate of Meteorology, and PhotovoltaicGeographical Information System (PVGIS) and also WeatherSpark.The coldest month in Pamukkale is January; the average low temperature in this month is 2°C while the high temperature is around 12°C [20-24].

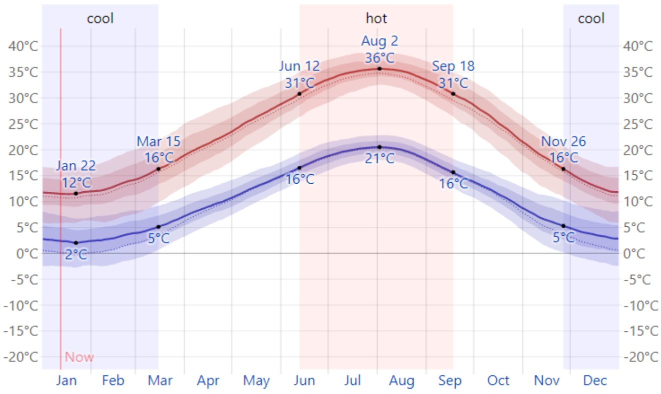

Figure3.Average High (red line)and Low (blue line)Temperature in Pamukkale. The thin dotted lines are the corresponding average perceived temperatures [24]

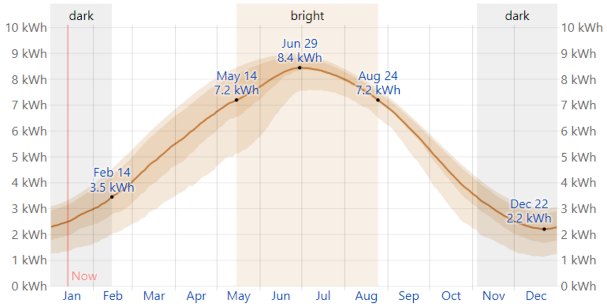

Figure 4. Average Daily Incident Shortwave Solar Energy in Pamukkale from Online Evauation [24]

Figure 3 and Figure 4 show that the hot season in Pamukkale is about 3 months with a daily average high temperature above 31°C; On the other hand, it is seen that the cold season lasts for 4 months and the daily average temperature is the lowest 2°C and the highest 12°C.

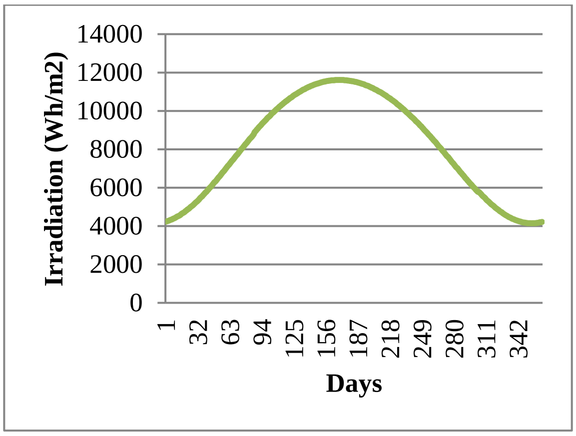

Figure 5.The variation of average solar radiation by days (for clear skies)[22].

The radiation distribution graph for Pamukkale, which was created using the datasets obtained from NASA, is given in figure 5. Efficiency estimation of solar power generation with data from PVGIS-5 is shown the figure 6.

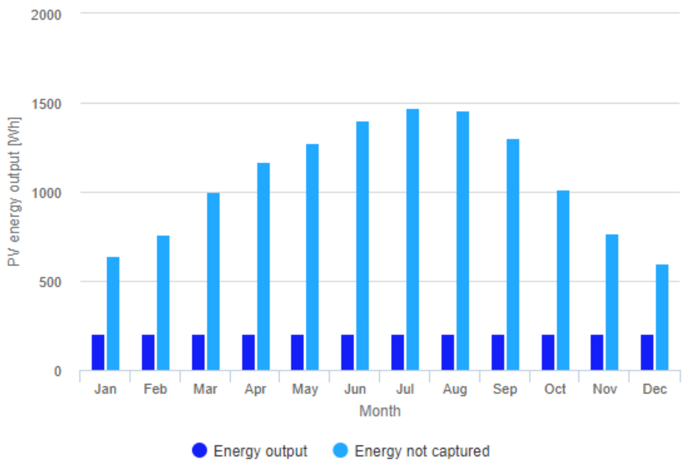

Figure 6.Power production estimate for off-grid PV system via PV-GIS[23]

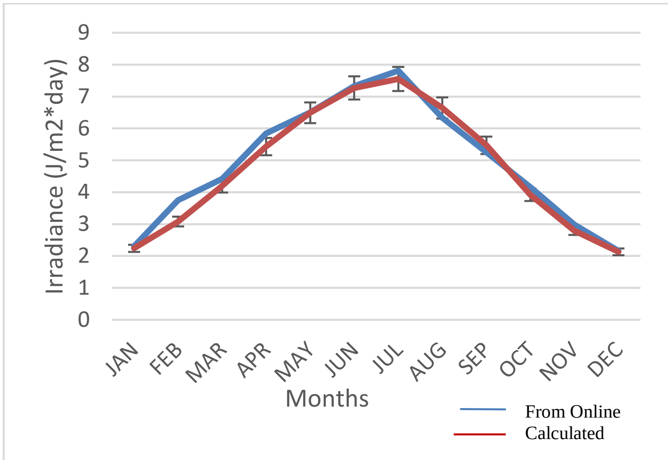

Figure 7.Comparision of the variation of average solar radiation by month (for the whole sky)

The compliance behavior between the obtained data sets and the calculated data was examined and presented in Figure 7. While the deviation of the data is consistent, slight deviations of the calculation results from the online values have been observed, but these deviations are negligible.

4. Conclusions and Recommendations

It seems that Pamukkale, which is in the northern hemisphere, has the maximum clearness index in June and the least in December and January.This correlates with the reaching radiation and effective irradiance.

In this study, Python programming language was used for calculations.

When making calculations:

- Transferring libraries to be used in calculations,

- Functions that calculate monthly-daily averages using the GHI and Clearsky GHI data in the data sets,

- Graphs to show the amount of radiation reaching from the suncreated.

As a result, based on the meteorological data, it is determined that the month with low solar radiation is December and January for the PV panel of the tiny house in Pamukkale.It has been determined, and from the horizontal flux data, the optimum panel angle is about 47 degrees. The clearnes index has been determined that it decreases to around 5% in winter months.Also, taking into account the 1% risk of battery loss, in December and JanuaryIt has been calculated and determined that the required panel tilt angle for the tiny house will be approximately 47 degrees.

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