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Evaluation of Monocrystalline and Polycrystalline Photovoltaic Panels in Sinop Province Conditions

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Keywords
PV panel,
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Renewable energy

Abstract: Due to the increase in energy consumption and environmental pollution in recent years, countries have included renewable energy in their long-term energy policies by supporting researches to increase the usage diversity and performance of renewable energy sources. Solar energy, one of these renewable energy types, and its various applications are of great importance to increase the energy production diversity. In this context, evaluation of monocrystalline and polycrystalline photovoltaic panel performance was performed under Sinop's climate conditions. In the first stage, the most suitable panel tilt for Sinop province was found by recording the voltage and current values of the panels at different panel angles. According to the results obtained, the optimum angle value of the monocrystalline and polycrystalline panels was determined as 38 degrees. Then, in different days, the efficiencies of the panels were calculated using the determined optimum angle and compared with the literature. At the same angles, it was observed that the monocrystalline panel produced higher power than the polycrystalline panel and the monocrystalline panel was more efficient when examined from hourly measurements. Experimental panel yields were found to be 0.162 and 0.139 for monocrystalline and polycrystalline panels, respectively. Finally, the effect of temperature change on the panels was evaluated. With this study, the most suitable panel type is determined for Sinop province and its surrounding conditions, thus preventing unnecessary investments and efficiency losses.

Sinop İli Koşullarında Monokristal ve Polikristal Fotovoltaik Panellerin Değerlendirilmesi

Anahtar Kelimeler
PV panel,
Monokristal,
Polikristal,
Yenilenebilir enerji

Öz: Son yıllarda enerji tüketimi ve çevresel kirlilikteki artıştan dolayı ülkeler yenilenebilir enerji kaynaklarının kullanım çeşitliliğini arttırmak üzere olan araştırmaları destekleyerek yenilenebilir enerjiyi uzun vadeli enerji politikalarına dâhil etmektedirler. Bu yenilenebilir enerji türlerinden olan güneş enerjisi ve onun çeşitli uygulamaları enerji üretim çeşitliliğini arttırmak için büyük önem taşımaktadır. Bu kapsamda, Sinop ili iklim koşulları altında monokristal ve polikristal fotovoltaik güneş panelleri kullanılarak fotovoltaik panellerin performans değerlendirilmesi yapılmıştır. İlk aşamada Sinop ili için en uygun panel açısı farklı pozisyonlarda gerilim ve akım değerleri kaydedilerek bulunmuştur. Elde edilen sonuçlara göre monokristal ve polikristalin panellerin optimum açı değeri 38 derece olarak belirlenmiştir. Daha sonra belirlenen optimum açı kullanılarak farklı günlerde panellerin verimliliği hesaplanmış ve literatür ile karşılaştırılmıştır. Aynı açılarda, monokristal panelin polikristal panelden daha yüksek güç ürettiği ve saatlik ölçümlerden incelendiğinde monokristal panelin daha verimli olduğu görülmüştür. Deneysel panel verimi monokristal ve polikristalin paneller için sırasıyla 0.162 ve 0.139 olarak bulunmuştur. Son olarak sıcaklık değişiminin paneller üzerine etkisi değerlendirilmiştir. Bu çalışma ile Sinop ili ve çevresi koşullarında en uygun panel tipi belirlenerek gereksiz yatırımların ve verim kayıplarının önlenmesi sağlanmaktadır.

1. INTRODUCTION

Recently, energy is most important key parameter to become a developing or developed country and involves in each part of life; daily needs, hospitals, industry, transportation and etc. While satisfying this need of the countries, the energy production choice becomes crucial at this point since it might result in undesired conditions, such as dependency of other countries and environmental pollution, which threat the countries' future. In this regard, renewable energy sources are mostly studied and investigated by many researchers since the sources offer clean and domestic power. One of the best option among the renewable energy sources for Middle Eastern countries is the solar energy due to the reasons that the considerably high solar radiation in the region, its low cost and being environment friendly technology.

Photovoltaic (PV) panels are simply used to harvest the solar energy and then convert it into electricity by exciting electrons in silicon cells. There are different types of solar cells, classified based on the production technology. The well-known types of PV panels are amorphous, polycrystalline (pc-Si) and monocrystalline (c-Si), where the energy conversion efficiencies are in the range of 6-7, 11-15 and 15-20, respectively [1]. Since higher the efficiency is better, polycrystalline and monocrystalline panels are favorites in the application of solar systems. In addition, the tendency towards solar energy source motivated the researchers investigate the performance of solar panels and technologies, and it is mainly found that the performances of PV panels are affected by solar irradiance, ambient temperature, wind, humidity and the kind of technology used [2-4]. In this regard, investigation on different types of PV panels has been motivated and performed on different application of solar systems [5-8]. Their usage in various areas were reported: solar power generation [9], cooking [10], water heating [11], water pumping [5], heating of buildings [12], solar distillation [13], etc. As listed above, besides its application area, the location also differs due to fact that radiation irradiance and weather conditions are not the same everywhere. In this regard, many researches were reported for different locations such as the studies at Brazil [5], Jordan [14], France [15], Norway [16] and Italy [17]. In different regions of Turkey, similar studies have been performed and reported: Aegean region [18], Central Anatolian region [19], Mediterranean [20], Southeastern Anatolia [21] and Marmara [22]. There are not much detailed studies in Black Sea region, especially for the city of Sinop since low solar radiation is expected in its territory.

In addition, the performance of the solar energy depends on the incident insolation panel temperature and optimal tilt angle (inclination) of the solar panels. Therefore, they need careful attention and examination for the chosen application location before the establishment of the system. Since the position of the sun during the day affects the generated power, the optimum angle and orientation of the panels have to be determined. It is mainly depending on the season and which part of the world the system is.

When we are talking about the performance of solar energy system, not only are location and panel type considered but also photovoltaic panel temperature is taken into account. In order to determine impact of panel temperature on electricity efficiency, some studies have been already performed [1, 7, 23]. The temperature dependent electrical efficiency is defined as in Eq. 1.

$$\eta_{el,t} = \eta_r(1 - \beta(T_{pm} - T_r)) \quad (1)$$

Here, η_r, β, T_{pm} and T_r stand for reference efficiency of selected PV panel, temperature coefficient, temperature of the solar cells and reference temperature. These values could be found in Ref. [1].

In this paper, experimental evaluations of polycrystalline and monocrystalline PV panels were performed time dependently at out-of-door for City of Sinop in Turkey between March 20 and 23, 2019, where the geographical location is given as 42°.0280 N (latitude) and 35°.1517 E (longitude). On the first stage, the optimum angle for month of March was determined, and the considered measurements were carried out at the determined optimum angle. All measured results were compared and verified using theoretical expectations. On the final step, temperature dependency of PV panels was further examined.

2. MATERIALS AND METHODS

The experimental design includes solar panels, solar regulators, DC watt meters, temperature sensor and batteries, as illustrated in Fig. 1. Considered two different types of panels, with a power of 20 W and sizes of 0.43 m x 0.36 m (monocrystalline) and 0.419 m x 0.359 m (polycrystalline), were installed on the same stand-alone frame. Further details were given in Table 1. Besides, solar regulators are identical and work with a maximum current of 10 Ah and maximum voltage of 24 V. DC watt meters are identical and have working ranges of current and voltage as 0-100 A and 0-60 V, respectively. They were crosschecked with other panels to ensure that they are identical and do not have production deformations. Batteries, dry cell, are the same and characterized with 12 V and 7 A. All of the measurements presented here was conducted from March 20 to March 23, 2019, from 09:00 to 15:00 h. The setup was located far from the shades of any possible object.

In the first stage, the optimum angle for energy production of solar panels was determined by simultaneously increasing two degrees from 0 to 70 in Sinop Province in March. After the determination of the optimum inclination of the panels, the efficiency measurements were made at the obtained optimum angle.

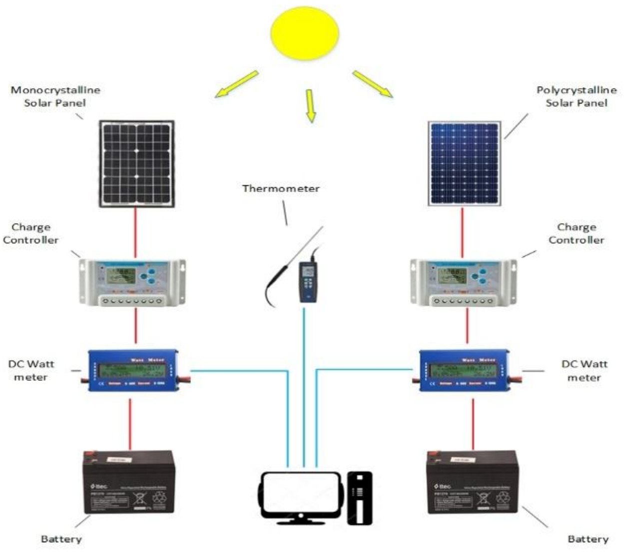

Figure 1. Experimental design

Table 1. The used PV panel specifications

Solar Module Type	Monocrystalline Solar Panel	Polycrystalline Solar Panel
Material	Crystalline silicon	Crystalline silicon
Maximum power P_{mp}	20 W	20 W
Max. power voltage V_{mp}	17.38 V	17.38 V
Max. power current I_{mp}	1.15 A	1.15 A
Open circuit voltage V_{oc}	21.60 V	21.46 V
Short circuit current I_{sc}	1.21 A	1.21 A
Size(mm)	430 x 360 x 22	419 x 359 x 22

Using the proposed experimental design, the power outputs of polycrystalline and monocrystalline photovoltaic panels were measured simultaneously in the city of Sinop in Turkey between March 21 and 23, 2016. Fig. 2 shows the 3D diagrams of the experimental setup and a picture of measurement system. Measurements were performed at out-of-door conditions to ensure providing a recommendation to determine a suitable panel for the environmental characteristics in the region of Sinop. With the help of obtained power outputs of each solar cell, the efficiencies were obtained using Eq. 2:

$$\eta_{sc} = \frac{FF\, I_{sc}\, V_{oc}}{AE} \qquad (2)$$

where FF, A and E define fill factor, area of the collector and global solar irradiation. Here, daily global solar irradiation for the Sinop city were obtained using pyranometer. Afterwards, a reference efficiency was compared to the results of Eq. 1.

3. RESULTS AND DISCUSSION

On the first step of the measurements, optimum photovoltaic panel angle of Sinop city was determined by scanning a wide range of PV panel angle starting from 0 to 70°. The angle of the panels was changed simultaneously to ensure the same solar irradiation and environmental conditions. The measurement was carried out with the proposed experiment design at the determined optimum angle between 11:30 – 12:05 am on March 20, 2019. The results of the measurements were analyzed and graphed as a function of PV panel angle and given in Fig. 3. Maximum powers of monocrystalline and polycrystalline photovoltaic panels were measured at the same angle and they were found to be as 13.3 W and 12.89 W, respectively. The figure shows that monocrystalline solar panel produced more power than polycrystalline panel for each chosen angle under the same environmental conditions.

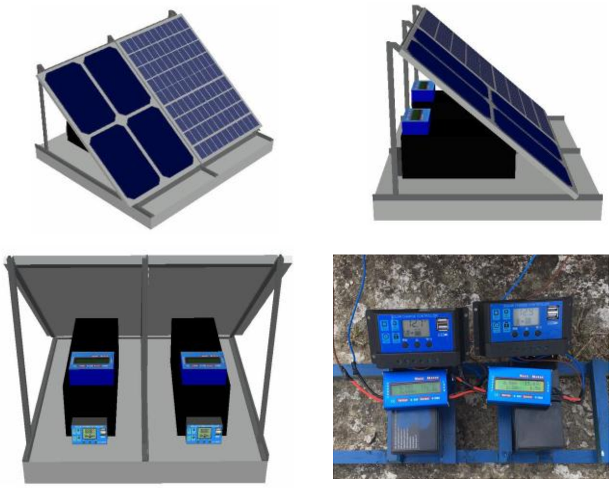

Figure 2. 3D diagrams of the experimental setup and a picture of measurement system

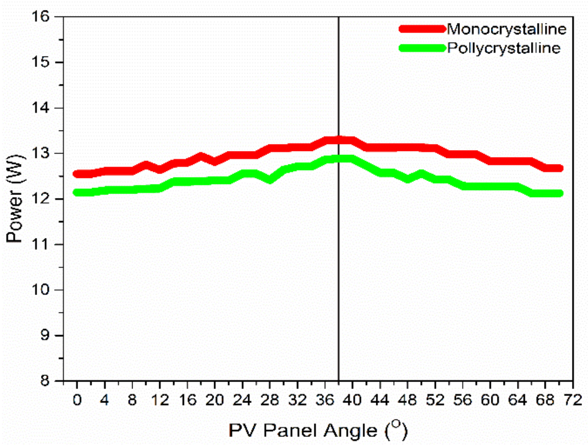

Figure 3. PV panel angle–dependent power outage of different PV panels

As mentioned in the section of materials and methods, the efficiency measurements of solar panels were performed on March 21, 2019 at the determined optimum angle, and the obtained efficiencies are given in Table 2. The given efficiencies were calculated using Eq. 2. The temperature of the solar panels during the measurements were varied from 9.73 to 12.13 °C so that it was not expected significant temperature dependence hourly. Monocrystalline solar panel efficiency was found to be significantly higher than the one obtained for polycrystalline. This remarkable efficiency difference leads greater production differences at larger scales. For example, if we compare the power production per 100 m^2 by taking 12:00 am as the reference, monocrystalline choice produces 8509 W while 8166 W would be obtained from the choice of polycrystalline. This reveals the advantage of monocrystalline for bigger solar panel application area.

Table 2. The efficiencies of solar cells (21.03.2019)

Hour	E (W/m^2) [14]	Polycrystalline I (A)	V (V)	η_{sc}	Monocrystalline I (A)	V (V)	η_{sc}
09:00	469.41	0.72	13.1	0.120	0.74	14.1	0.144
10:00	550.26	0.88	13.9	0.133	0.9	14.7	0.155
11:00	555.31	0.90	14.1	0.137	0.91	15.2	0.161
12:00	525.08	0.89	13.8	0.140	0.89	14.8	0.162
13:00	429.43	0.78	12.5	0.136	0.81	13.7	0.167
14:00	306.21	0.47	11.6	0.107	0.5	12.3	0.130
15:00	172.4	0.22	10.5	0.081	0.22	11.6	0.095

Besides, it is worth to compare the obtained electrical efficiencies with the theoretical expectations that could be calculated using Eq. 1 and the values from Ref. [1]. Fig. 3 presents the outcomes of Eq. 1 for polycrystalline and monocrystalline panels, separately. The electrical efficiency expectation bands were drawn based on these values. On the day of March 21, 2019 at 12:00 am, the solar panel temperature was measured as 11.58 °C, and the obtained efficiencies of polycrystalline and monocrystalline panels were 0.162 and 0.139, respectively. It is clearly seen that the measured results agree well with the efficiency bands drawn on Fig. 4. The obtained efficiency of monocrystalline panel is close to lower band of expectation from the literature. The electrical efficiencies of both the panels are expected to decrease by the increase of the solar panel's temperature. Based on the comparison graph, it is seen that there is small intersection of mono and polycrystalline panels starting from about 25 °C. In other words, the slope of monocrystalline band is slightly deeper than the one expected for polycrystalline. Additionally, based on the judgment of Fig. 4, the possibility of finding polycrystalline efficiency is higher than monocrystalline efficiency was found to be very small.

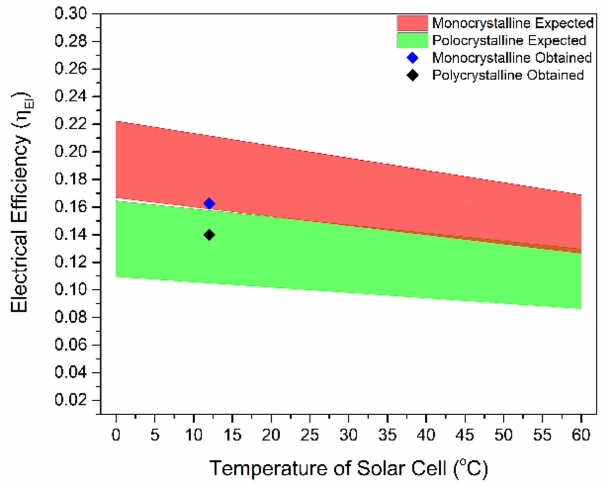

Figure 4. The temperature–dependent electrical efficiency of different PV panels.

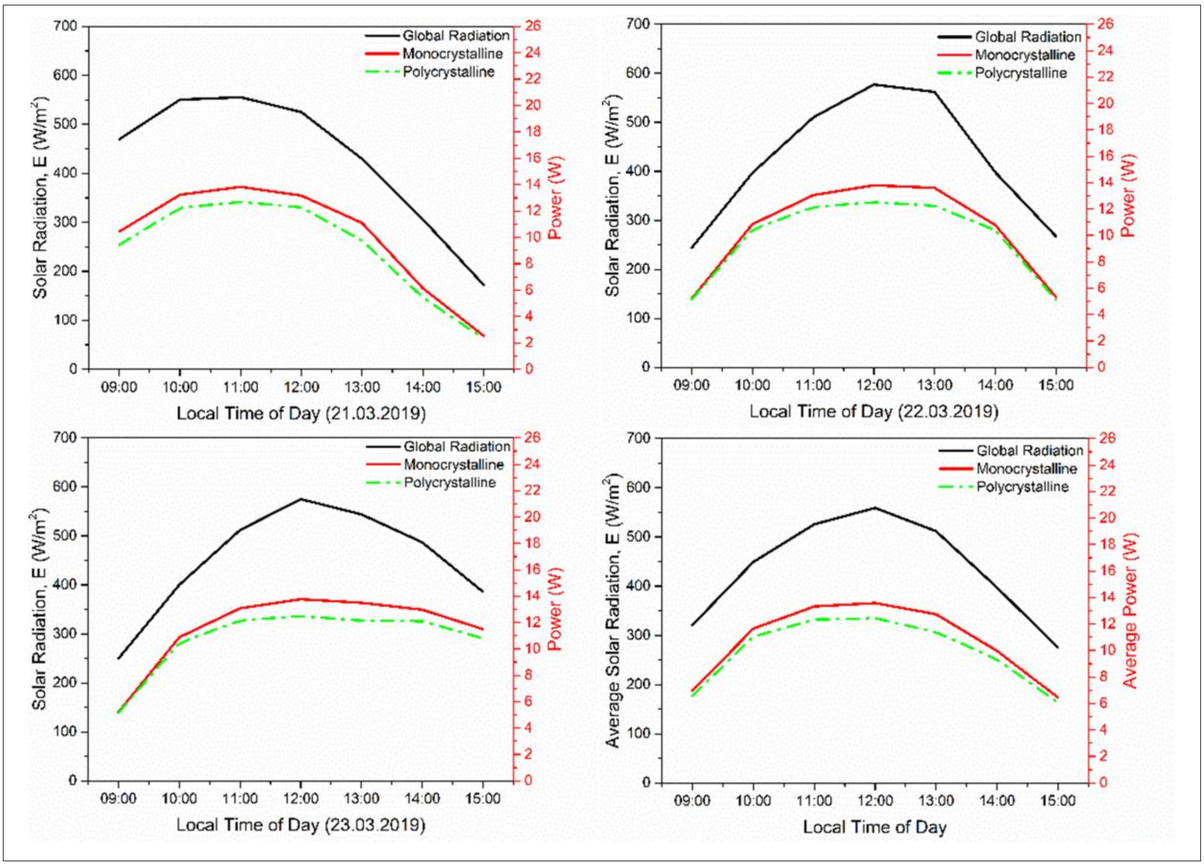

Figure 5. Daily and average results

Within the scope of this study, time dependent solar cell performances and power values of the chosen solar panels were also evaluated. The measurement performed on March 21, 2019 was hourly repeated on March 22 and 23, 2019. Fig. 5 presents daily and hourly panel power productions and the measured global solar radiations. All results indicate that monocrystalline panel had always higher efficiency than polycrystalline panel. Especially, significant differences were observed between 10:00 am and 14:00 pm. Average global solar radiation and the generated powers of the chosen three days were also shown in Fig. 5.

Here, it should be also given that Sinop’s (Turkey's) average daily sun exposure time and solar radiation intensity are about 5.21 (7.2) hours and 5 (3.6) kWh /m2, respectively [24-26]. The results should be evaluated and compared with other regions of the country in the light of this information. In studies conducted for Balıkesir [27], Tekirdağ [28], Manisa [29], Şanlıurfa [30], and Batman [31] provinces, the approximate electrical efficiency of PV panels was 12%, 15%, 13.5%, 6.5-7% and 13.65%, respectively while the yields of monocrystalline and polycrystalline panels, in this study conducted in Sinop, were found to be as 16.2% and 13.9%, respectively.

4. CONCLUSION

This study aims to optimize the use of photovoltaic panels in Sinop province in terms of panel angle and panel type. In the evaluation made according to the power obtained, the optimum angle value of the monocrystalline and polycrystalline panels was determined as 38 degrees. At the same angles, the monocrystalline panel has been found to produce higher power than the polycrystalline panel. In order to see the power distribution obtained during the day and to examine panel efficiencies according to the hours, current and voltage values per hour were taken from two panels placed at an angle of 38 degrees. When the data obtained from hourly measurements are examined, the monocrystalline panel is found to be more efficient. Experimental panel efficiency was determined as 0.162 and 0.139 for the monocrystalline and polycrystalline panels, respectively. This study will contribute the real users to using panels at most effective way in Sinop and provide resources for researchers.

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