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Research Article

# PREDICTING THE ENERGY PRODUCTION OF A ROOFTOP PV PLANT BY USING DIFFERENTIAL EVOLUTION ALGORITHM

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**ABSTRACT**

In this study, a simple and plain closed-form mathematical expression has been obtained to precisely estimate the monthly production of a rooftop photovoltaic (PV) plant installed in Adana, Turkey. The proposed model is developed by utilizing the Differential Evolution (DE) optimization algorithm based on the PV plant's 5-year (August 2013 – July 2018) real measurement data. The PV plant is a grid-connected rooftop solar PV system located at Kıvanç Textile in Adana, Turkey. The PV system is equipped with an online monitoring system that provides real time data. The study shows the actual energy production is 730 MWh/year on average for 5 years. In order to test the robustness and precision of the present model, it has been compared with the long-term real measurement data of the PV system. The key benefit of the model is giving a convincing prediction of the future production of the PV panel in a simple way. It also does not require any further information other than time. Average percentage error was reached as small as 7.4% for 5-year data.

***Keywords:*** *Energy Production Estimation, Rooftop PV Plant, Optimization, Long Term Performance, Adana*

## 1. INTRODUCTION

During last decades, diminishing of fossil fuel sources and rising of energy demand have motivated the scientist and engineers to center their studies on renewable energy sources (Bayhan *et al*., 2018; Arslan *et al*., 2016; Bulut *et al*., 2007).

The main renewable energy resources are currently wind, wave, geothermal and solar. Solar energy has the highest potential among those resources. Current technology allows humankind to use solar energy potential by converting it to process heat or converting directly to electric energy by using photovoltaic panels. Another advantage of solar energy is that it is available all over the world.

For the future energy sources, solar energy can be accepted as a key alternative. Therefore, the solar energy is being severely considered for meeting major part of the energy demand in Turkey, and the world. Based on these facts, engineers should properly estimate future solar production of existing PV panels to project their future energy demands. Many studies have been presented in recent years on this issue for Turkey's different cities (Bulut *et al*., 2007; Ecevit *et al*., 2002; Hepbaslı *et al*., 2002; Kaygusuz *et al*., 1999; Kaygusuz *et al*., 1999; Ogulata *et al*., 2002; Togrul *et al*., 1999; Togrul *et al*., 2002; Ulgen *et al*., 2002).

The energy production of PV systems depends upon so many parameters. (Almorox, 2011) sorted those parameters as astronomical factors (distance between Earth and Sun, solar declination, solar constant, and hour angle); geometrical factors (azimuth of the location, surface tilt angle, solar altitude, and solar azimuth); geographical factors (latitude, longitude, and altitude); meteorological factors (atmospheric pressure, cloudiness, temperature and total sunshine duration, air and soil temperature, relative humidity, evaporation, and precipitation number of rainy days, etc.) and physical factors (albedo, water vapor content, scattering of air molecules, scattering of dust and other atmospheric constituents); These parameters are neither deterministic nor completely random; so it is very hard to express all variances mathematically to estimate energy production of PV systems.

Moreover, it is essential to have the data of weather changes throughout the year as well as possible. For this reason, many studies have been carried out to improve models for prediction of typical weather factors such as solar radiation, temperature, and relative humidity both hourly and daily (Knight *et al*., 1991).

In the present study, a simple model to accurately calculate the monthly production of a rooftop PV plant installed in Adana-Turkey was developed by using the DE optimization algorithm. However, in this study only time series was used as an input to predict the energy production of the plant for the sake of simplicity of the model. Since the model is predicting the 30-day production, it is not easy task to have future information about environmental factors such as astronomical, meteorological, and physical factors.

## 2. MODELLING THE PREDICTION OF FUTURE ENERGY PRODUCTION

The PV plant is a 499,20 kWp grid-connected rooftop solar PV system located at Kıvanç Textile in Adana, Turkey. It was installed on 12.000 $m^2$-roof of fabrication building. It was the biggest rooftop PV plant of Turkey at the installation time. The plant consists of 3840 Mitshubishi 130 Wp thin film tandem modules with two orientations 10° east and 10° west while north south orientation is 20°. Orientation of the PV panels can be seen in Fig. 1. The PV array is configured in a way that the system contains 40 Fronius inverters which has 12 kWp AC output capacity.

The PV system is equipped with an online monitoring system that provides real time data. The study shows the actual energy production is 730 MWh/year on average for 5 years.

Fig. 1. Orientation of PV plant, panels faces to south.

From studies in the literature (Bulut *et al.*, 2007; Ecevit *et al*., 2002; Hepbaslı *et al*., 2002; Kaygusuz *et al*., 1999; Kaygusuz *et al*., 1999; Ogulata *et al*., 2002; Togrul *et al*., 1999; Togrul *et al*., 2002; Ulgen *et al*., 2002), it can be concluded that the energy production of PV systems is a function of time since solar radiation changes distinctively from season to season. Therefore, in this study a new model is created only depending on time parameter based on 5-year measurement of the PV plant.

Daily measurement data can be seen in Fig. 2 from July 2013 to July 2018. It can be easily seen that the data has DC and AC components.

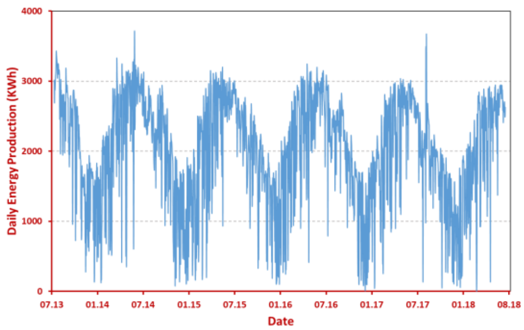


Fig. 2. Daily production of the PV plant.

Since the data has also very significant noises all over the production time, 30-day total production values have been used instead of daily production as can be seen in Fig. 3.

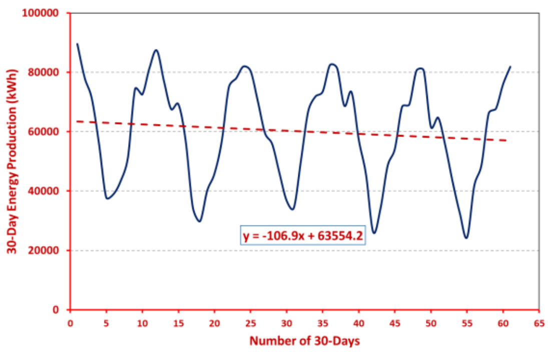


Fig. 3. 30-Day total production of the PV plant.

Fig. 3 shows that the noise is minimized and both DC and AC components are very explicit. DC components have been reached by using regression of the whole data. DC component also gives the degradation of the PV plant. When subtract the DC component from the data we can have AC component which gives the seasonal dependency of the production of the PV system. Because the seasonal dependency is periodic, we choose a basic model with sinusoidal functions for AC component.

### 2.1. Problem Formulation

The DE algorithm, which was developed to optimize a problem by repeatedly trying to make better a potential solution with regard to a required measure of quality, was used as the optimization tool. The DE algorithm has been preferred to have a solution for many numerical problems with a good performance (Ak *et al.*, 2018; Storn *et al.*, 1997). It reaches to correct global minimum point of the cost function very fast when compared to other optimization tools. For the optimization, many expressions ranging from simple to complicated ones were tested while modeling the energy production of the system. However, it was figured out that the predictions of simpler models, which have less number of coefficients, are not well agreed with measurements and the more complicated models, which have more coefficients, make just a little progress in the predictions at the expense of the increased complexity. Therefore, the ideal model, which establishes a simple expression and delivers satisfying estimations, was chosen as:

$$P(t) = P_0 - St + \left[c_1\,Cos\big(D(c_2Mt + c_3)\big) + c_4\,Sin\big(D(c_5Mt + c_6)\big)\right] \quad (1)$$

$P_0$: 63554.2 (starting point of DC linear regression)
S: -106.9 (performance drop of the PV system by the time, degradation of the PV plant)
t: Time (30 days)
D: $\pi/180$ (radian degree conversion constant)
M: 360/(73/6) ( periodicity conversion constant)

Where $c_1, c_2, \ldots c_6$ are the coefficients to be optimally found by the DE algorithm to minimize the following average percentage error (APE).

$$APE = \frac{100\sum\left|\frac{P_m - P_c}{P_m}\right|}{Total\ Number\ of\ Data} \quad (2)$$

Here, $P_m$ and $P_c$ are measured and calculated power values that is obtained by Eq. (2) respectively. Each coefficient of the model is determined by DE algorithm to optimize its influence based on the measurement data. The all coefficients found by DE optimization algorithm were given in Table 1.

Table 1. Coefficients determined by DE algorithm

| $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ | $c_6$ |
|---|---|---|---|---|---|
| 25200 | 1 | 4 | -4300 | 3 | -66.667 |

By substituting determined coefficients into Eq. (2), developed formula can be simply described as:

$$P(t) = 63554.2 - 106.9t + [25200Cos\big(D(Mt + 4)\big) - 4300Sin(D(3Mt - 66.667))] \quad (3)$$

### 2.2. Comparison of the Results

Fig. 4 presents the estimations of the derived expression and 5-year real production data. As it can be seen from the graph, the estimations are very close to the measurements within 7.4 % APE. This good self-consistent agreement between predictions of the developed formula and real measurements shows the success of the new model.

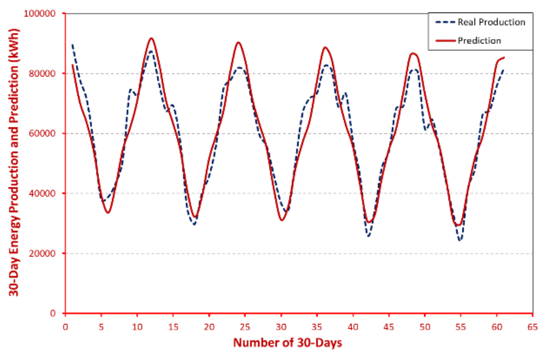


Fig. 4. Real production and prediction of the model.

## 3. CONCLUSION

In this contribution, a computationally efficient and plain closed-form formula has been attained to estimate the production of energy in a 30-day period for a rooftop PV plant located at Adana, Turkey. The model has been selected so that it has 2 parts; the first part represents the DC component of the energy production while the second part represents the AC part of it. DC part is easy to obtain with the help of linear regression method of the whole production data. However, AC part strongly depends on seasons since the solar radiation changes drastically from winter to summer. Differential Evolution algorithm is used for determining the constants of the model. Because the seasonal solar radiation is not constant from year to year, the model overestimates the production of the energy for some years especially for summer and winter seasons. Nevertheless, the model is very successful during the seasonal transitions for the spring and fall seasons as can be seen in Fig. 4. When we compare the model with whole data set, it achieves a significant consistency and the APE is reached as 7.4 % which is very satisfactory error level for long term estimation process.

The fundamental contribution of the model is yielding a satisfying estimation of the energy production for a 30-day period with a plain and simple expression. Since the proposed expression accurately estimates energy production for a real PV plant, it can be reliably used to predict the long term future productions for the plants that have similar local specifications. Since the model only takes time series as an input, there is no need to have the further environmental information. One can simply calculate the energy production even with a hand calculator or with a excel sheet in a couple of easy steps.

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