AN APPLICATION IN MATLAB GUI: ESTIMATION METHOD FOR ANNUAL 
ENERGY YIELD OF PHOTOVOLTAIC SYSTEMS

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Abstract

The need for long term forecasting energy production of PV systems have emerged for entrepreneurs in recent years. Referring this need, an estimation method for annual energy production is presented in MATLAB GUI for solar energy sources. Using the necessary data which consists of total module area, conversion efficiency and annual solar irradiance, the method achieves the annual energy production estimation. For more accuracy, the losses due to inverter, temperature increase, cables, weather conditions, and shading are added to the method and are editable by users. Also, single-axis and two-axis sun tracking systems together with fixed systems are regarded and compared to each other since they are among preferred ones for mass production PV systems.

Keywords: PV Systems, MATLAB GUI, Long Term Estimation, Annual Energy Production, Sun Tracking System

1. Introduction

Solar energy has rapidly spread around the world due to its environment-friendly characteristics. Many entrepreneurs and companies prefer to invest on solar energy modules. By the time photovoltaic (PV) system investment costs are reducing, and it attracts more investors. Predictable investments with respect to profit and production are always much preferable. Therefore, estimation tools for solar energy production becomes necessary.

As estimation tools, there are two types which have different aims regarding solar energy production. One type is short-term estimation which aims better adaptation of PV systems with grid network, and the other type is long term estimation which deals with long term production prediction of PV systems. There are many studies about short term forecasting studies. As some exemplary studies, predicting one-hour power output was tried by using NARX network-based forecasting model. Hottel’s radiation model was utilized for calculating clear-sky radiation incident. Also, as another important input, weather forecasting data from official websites was used. It was claimed that even for sudden weather condition changes, this proposed method can predict PV power output accurately since it has a strong adaptation to time-varying input. Rooftop PV system forecasting measurements verified the effectiveness of the method with high accuracy [1]. In another study, one-day ahead forecasting of PV power output for a grid connected system in Thailand was presented in 2011. For forecasting output power of the next day, the proposed method used calculation of solar radiation, weather forecasting data, and the
data from the installed PV system were used as input data. Through Elman neural network, forecasting of the next day was completed. The method seemed to be successful for one-day forecasting of output power [2]. Also, one-hour ahead forecasting of solar PV system power output was presented by Mandal et al [3]. Wavelet transform, and artificial intelligence methods were used in combination and the interactions of PV system with temperature and solar radiation were added to the hybrid forecasting method. A performance comparison was made with former existing methods in terms of various errors and this hybrid method was more accurate and efficient than the former methods for one-hour ahead forecasting. In the same year, PV system modeling was presented by using evolutionary programming algorithm [4]. It was seen that the most effective factors on a working PV system are solar irradiance, weather conditions and temperature. Evolutionary programming model supplied effective results for power prediction on sunny and cloudy days by comparing some other proposed methods. A one-day ahead forecasting model was developed for PV system output power, called the ARMAX model, which was a generalized version of the ARIMA model which did not require any meteorological forecast data [5]. Since the ARIMA model did not use any meteorological data that can be effective on the output power, the ARMAX model tried to develop it by adding the exogenous inputs which are temperature, precipitation amount, insolation duration, and humidity. The results on a grid connected 2.1 kW PV system showed that the ARMAX model improved forecast accuracy of the ARIMA model. In the same year, in 2014, a short-term hybrid forecasting method was developed by utilizing five different methods which are ARIMA, SVM, ANN, ANFIS, and some combination models using GA algorithm [6]. On this hybrid method, solar power output, solar irradiance, air, and module temperature data was used. This hybrid model gave a high precision and efficiency for one hour ahead forecasting and thereby claimed to be suitable for using in PV systems. As another example, in California, a day ahead forecasting study was presented based on least squares optimization of numerical weather prediction values [7]. On two fixed PV systems, three different variations of the proposed method were studied for three years between 2011 and 2014. The method was evaluated by observing standard error metrics. During these three years, 40% of exceeding from the prediction occurred only twice thereby the method showed a high reliability. These and other short-term forecasting studies aimed to estimate one-hour later or one-day later PV energy production. As long-term forecasting studies, firstly general influencing factors for annual energy production of PV systems were discussed by King et al [8]. Monthly power outputs of PV systems were investigated and seasonal energy production changes were also discussed. The discussion was made within two main parts which are AC power and DC power PV systems. In a case study in Toronto, the uncertainties for year-to-year climate changes, average horizontal insolation, estimation of radiation in the plane of the array, power rating of the system, dirt, soiling, snow, and aging were estimated for long term usage on a 10 MW AC PV system [9]. The total uncertainty was calculated through the mentioned factors. Although the uncertainties vary from one system to another, the proposed methodology was considered as widely applicable. In another study, by utilizing long term characteristics, a short-term prediction was studied. In the study, both output power and efficiency estimation methods of PV systems were developed by Su et al [10]. They validated their methods with real measurements on a grid connected PV system in Macau. Yearly and monthly average values of efficiency and power output were considered in their methodology. Although the method did not work for early morning and evening hours, it had a good estimation for the hours between 9 am and 4 pm. They found another result that efficiency of PV systems varies between 10.81% and 12.63% with slightly higher values in the months of winter. Also, optimum tilt angle
calculation was made to maximize the annual energy production for PV systems and solar panels in Ankara [11]. Different conditions were considered during the calculation of the tilt angle, i.e. fixed angle for a year, two angles for 6-months duration and 4 angles for each season in Ankara. Annual efficiencies were compared for these various cases.

In the following section, the proposed method is explained in detail with the related theoretical information. In the third section, MATLAB GUI is explained with some obtained results. As the last section, conclusion part appears in the paper.

2. The Method Used in the Estimation

In this study, PV systems with three different types which are fixed, one-axis sun tracking and two-axis sun tracking systems were considered. In the calculation method for these three types, basically total installed panel area, solar panel’s yield performance value as percentage, and annual average solar irradiation are used commonly. Also, the system losses are common in the three types of PV system. In the following sub-sections, fixed system, one-axis, and two-axis sun tracking PV systems are investigated in detail. After these sub-sections, the losses of PV systems are explained within the context of used method.

2.1 Calculation Method for Fixed PV Systems

Since PV systems convert the solar energy into electricity, solar energy coming onto the solar system must be found. For this aim, annual average solar irradiation, since the estimation is annual, and total area of solar modules are needed. By multiplying these two terms, total solar energy can be calculated. However, the important thing is that solar irradiation should be with respect to the solar modules. In other words, if the PV modules have some tilt angle, the solar irradiation should be calculated considering the tilt angle.

After the solar energy is calculated, solar panel performance becomes critical and directly affect the electricity production. So, electricity production of a fixed PV system can be calculated by the formula below:

\[
\text{Electrical Energy} = A \times \text{AASI} \times \text{PCE}
\]

where, A is total PV module area, AASI is annual average solar irradiation, and PCE is the practical conversion efficiency of the solar PV system.

2.2 Calculation Method for a PV Systems with One-Axis Sun Tracker

In single-axis tracking systems, the modules follow the sun during day hours. This type of systems obtains about 35% of more energy in comparison with fixed systems. Therefore, basically the produced energy in fixed systems are multiplied with the factor of 1.35 to obtain one-axis tracking system output energy. This factor was obtained experimentally as an average value and may slightly change depending on latitude and tilt angle of the solar modules [12]. However, regarding possible unpredictable climate variations, this change remains small, and thereby, can be disregarded.

Since one-axis tracking systems follows the sun during day hours, inter-shading of the modules must be considered and some separation between the modules should be added to prevent inter-shading of the modules. As a result, more field is needed in PV systems with single-axis trackers comparing with the fixed systems.
2.3 Calculation Method for a PV Systems with Two-Axis Sun Tracker

Two-axis sun trackers follow the sun totally. In other words, PV modules plane vector is always towards the sun within the day hours of a whole year. The maximum energy output is achieved in this type of systems with the same solar panel area. On the other hand, two-axis tracking systems are generally not as much sustainable as the other two types. Therefore, the investors should think also about the sustainability of the PV systems.

In two-axis sun tracking systems, since the modules follow the sun totally, the produced electrical energy is estimated through the following formula:

\[
Energy = Fixed\_Energy \times (1.4 + \sin \left( L \left( \frac{\pi}{180} \right) \right) \times 0.1) \tag{2}
\]

where, Fixed\_Energy is the produced electrical energy calculated through the method in section 2.1, and L is the latitude of the place PV system installed. The formula above was used to estimate two-axis sun tracking system output.

2.4 Loss Factors

As the most common losses in PV systems, the losses due to inverter, temperature, shading, weather conditions and cables are considered. Inverters are used to obtain AC electricity from DC electricity. Typical values are generally between 6-15\%. As temperature increases, since the conversion efficiency of semiconductor structure of solar cells reduces, temperature loss is a considerable loss which is generally between 5-15\%. Shading losses varies according to cloud conditions between 0-40\%. Losses due to different weather conditions like dust, snow etc. are generally about 2\%. Also, cable losses typical values are 1-5\%. In addition, there may be other unpredictable losses which were considered in the estimation method. The formula below was used to estimate total performance of solar systems:

\[
P = (1 - Inv/100)(1 - T/100)(1 - Cbl/100)(1 - Sh/100)(1 - Wth/100)(1 - Oth/100) \tag{3}
\]

where, P is performance ratio and the other terms are the loss effects of inverter, temperature, cable, shading, weather and other factors, respectively. When the performance ratio is obtained, since it influences directly the output energy, the formula of produced annual energy becomes as the following:

\[
Electrical\ Energy = A \times AASI \times PCE \times P \tag{4}
\]

One reminder is that, the total area of solar panels is used in the method for simplicity. Area of the ground used for PV system installation may change depending on the system types, which are fixed, one-axis and two axis tracking systems in this study.

3. MATLAB GUI Specifications and Results

The generated MATLAB GUI for the estimation takes total solar panel area, solar panel conversion efficiency in percentage, and annual average irradiation of the place as input data together with the type of PV system in “Solar Panel Properties” section. One of the three types of systems, which are fixed, one-axis and two-axis tracking systems can be chosen from the pop-up menu in the same section. If two-axis tracking system is chosen, latitude of the place is
also wanted from the user as shown in Figure 1. Since north or south does not make any difference, not they but only the value of latitude is asked in the GUI.

![Figure 1](image1.png)

**Figure 1** “Latitude of Panel” appearing in “Two-Axes Tracking” choice

In “Losses” section, the most common losses are determined and if there are any, other loss factors can be added to the system in “Other Losses” part.

![Figure 2](image2.png)

**Figure 2** MATLAB GUI for PV System Annual Energy Output Estimation

After all the input data is taken, the needed calculations are done and “Annual Estimated Production” of PV system is given in kW-h/m² unit, as shown in Figure 2.

As an extra feature, comparison mode is added to the GUI to see all the types together. As seen in Figure 3, annual energy yield of three types of the systems are calculated together using the same input data.
In comparison mode, all the three types can be seen together. In Figure 3, the produced annual energy 28401 kWh in fixed system, whereas it increases to 38342 kWh in one-axis tracking system for the same input data. There is 35% of difference as it is expected. In two-axis tracking system, the output energy increases to 41060 kWh which is almost 45% higher than the fixed system. This result is also suitable with the real experimental measurements [13-15]. As a result, the MATLAB GUI for estimating power output of PV systems works in a realistic manner.

4. Conclusion

In MATLAB graphical user interface, an estimation tool for annual energy production of silicon-based PV systems were implemented. Taking solar panel area and energy conversion percentage, annual solar irradiation, latitude and loss data as input, the GUI calculates total annual energy production as kilowatt-hour. Also, one-axis and two-axes solar tracking systems are added together with fixed systems as preferences to the GUI. It was seen that the estimation results are compatible with real application values. Therefore, this GUI may be utilized for estimating annual electricity production of PV systems. In later studies, losses due to weather conditions may be automatized by using latitude and longitude information and monthly energy production estimation may be possible.

References


