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Dynamic Performance Comparison of the Different PV Modules with Real Data

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ABSTRACT

Nowadays, photovoltaic panels are an important source of electricity production and one of the preferable renewable resources. Many companies have started to produce because of increasing PV panel demand. It is a fact that the performance of PV panels under real environmental conditions in the application area will affect the benefit to be obtained from the application and the investment to be made. In this study, MATLAB/Simulink models of the PV panels are used for performance comparison with measured weather data in Istanbul, Turkey. The parameters of five different PV panels in the market are used for analysing the total energy generation performances under different weather conditions. Thus, the effects of using dynamic analysis to be obtained from more detailed simulation studies have been revealed instead of feasibility calculations to be made using only the data specified in the technical document.

1. INTRODUCTION

Today, where humanity's energy needs are increasing day by day, renewable energy sources have become an important alternative to meet this need and reduce the dependence on fossil fuels. Photovoltaic (PV) systems, which produce electricity, especially from solar energy, are the most preferred renewable energy sources. In addition, PV panels have an important effect on the spread of these systems with the incentives given to the electrical energy produced by them. The interest in PV systems helps decrease production costs, and also, this system becomes more advantageous as a cheaper energy source. PV systems have important advantages in grid-connected and off-grid systems in modular structures, accessible design, and hybrid operation with different sources. These systems allow electricity production in a wide range, from a small system that can meet the needs of a house to a large power plant that can meet the energy needs of a region. For this reason, it is an energy source that can be used by both end consumers and large energy investors.

Many studies focus on the ability of PV systems to produce more efficiently in this wide production range, their integration with the existing grid, proper positioning, and operation in hybrid systems [1-4]. In one of these studies, the advantages of positioning the PV panels at the appropriate angle were analyzed [4,5]. In addition, the effect of data resolution on the sizing of the hybrid energy system supplied with off-grid PV panels and wind turbines has been investigated [2]. Another study examined the economic analysis of solar tracking systems in a hybrid pumping system with PV panels [6]. The experimental setup has been done for analysis of the PV performance [7]. Also, performance comparisons of PV panel types with different production structures under real environmental conditions have also been carried out [8, 9].

These studies provide important information for more efficient operation of the systems in which PV panels will be used. Especially, general weather data of the region and efficiency parameters for the PV panels are used in the calculations made during the investment and projecting phase of large-scale solar farms [10]. In another study, the performances of monocrystalline and polycrystalline panels were compared under the same ambient conditions [11]. In one project in Morocco, different PV panel technologies were installed in 20 other cities, and the energy performance of the system was tested [12]. In addition, the long-term performance of PV panels in tropical climate conditions was also investigated [13]. The performance of PV panels is affected by environmental conditions directly. In one of the related studies, the performances of different PV modules have been compared under Australian climate conditions. [14]. Most studies aim to determine the factors affecting the performance of PV panels in real application conditions. Most of them use more general data (hourly and/or daily measurements) to do this. However, more dynamic data should be used for better results and accurate calculations.

PV panels are formed by combining PV cells with different sizes and power values. It is a fact that the efficiency and performance of the PV panels in the real system will directly affect the depreciation period and the profit to be obtained from installing the solar power plant. Generally, during the projecting phase of solar power plants, a general installation power analysis is made based on technical document data. For this reason, analyzes made only on the price or public values of the panels cannot obtain sufficient dynamic results. However, with the widespread use of dynamic pricing in energy markets, the importance of instantaneous power generation from power plants will emerge.

In this study, the situation of the PV panel manufacturers in the market to create 100kW solar power plants using five different PV modules in the same power band has been taken into account. The performances of five different PV systems with the same power have been analyzed in the simulation environment with the measured data at the exact location and weather conditions. PV models created in the MATLAB/Simulink program were used.

This study is organized as follows; in section 2, mathematical description of PV panel and electrical modeling are explained. In addition, the modeling of the PVs is given detailed. In section 3, the performances of different PV panels under the same conditions are analyzed with the case study. Finally, the outputs obtained in the results section were evaluated, and suggestions and conclusions were stated.

2. MODELING OF THE PV SYSTEMS

First of all, PV panels must be modeled in order to analyze the proposed system structure. A detailed description of the model used for this purpose is given below.

The five parameters used in the modeling of the PV cell are determined respectively as; a current source (I_L), a diode (I_0 and D_0), a series resistor (R_s), and a parallel resistor (R_{sh}). The current-voltage characteristics of the PV cell have been determined by using the relevant parameters. Accordingly, the mathematical definition of a single PV cell can be made with the equations given below;

$$I_d = I_0 + \left[\exp\left(\frac{V_d}{V_T}\right) - 1\right] \quad (1)$$

where I_d is the diode current (A), V_d is the diode voltage (V), and I_0 is the diode saturation current (A).

$$V_T = \frac{KT}{q} \times D_I \times N_{cell}. \quad (2)$$

where k is the Boltzmann constant (1.3806e-23), T is the temperature of the cell (K), q is the magnitude of the charge of an electron (1.6022e-19) and D_I is ideality factor of the diode. N_{cell} is the number of cells that are connected parallel and series in the PV module.

The electrical model of the PV cell, which has been modeled with related parameters, has been given in Figure 1. In the literature, the electrical model of the PV cell has been used as a single-diode model and a double-diode model. In this study, a single-diode electrical model of the PV has been chosen.

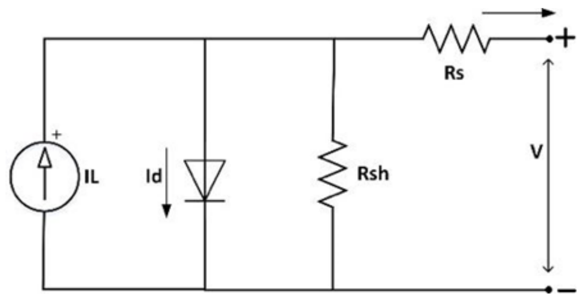

Figure 1. Electrical model of a PV cell

PV module is constructed by making a N_{cell} number of connections between PV cells. The serial and parallel connections of PV modules and the formation of PV panels' phases are given in Figure 2.

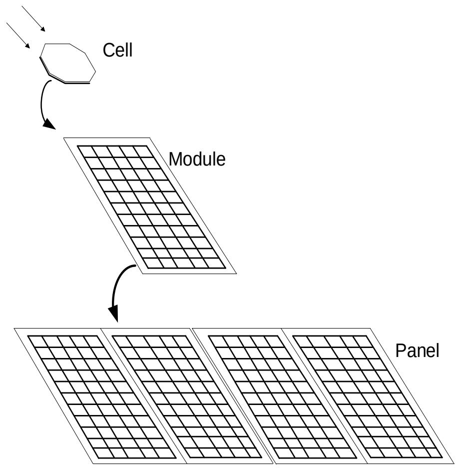

Figure 2. The transition from PV cells to panels

The PV model explained electrically and mathematically above is found as a ready model on MATLAB/Simulink setting [15]. Some panels' information is already included in this model, and new panel data can be defined manually. The information required to prepare the PV model on MATLAB/Simulink media is given in Table 1.

TABLE I
TECHNICAL DATA OF PV PANELS

Symbol	Parameter
Voc (V)	Open circuit voltage
Vmp (V)	Opt. operating voltage
TCOC (%/deg.C)	Temp. coefficient of P_{max}
Isc (A)	Short circuit current
Imp (A)	Opt. Operating current
TCSC (%/deg.C)	Temp. coefficient of short circuit current
Ncell	Number of cells

3. CASE STUDY

Five different PV models are obtained using the data given in Table 1, which are sold in Turkey. The measured radiation and temperature values of each model are defined, and the expected current and voltage values are determined. Each one of the PV modules has the same output power. In order to obtain the same output power with suitable voltage and current values, the PV modules are brought together with 100 parallel and 10 serial connections. In this way, five separate solar farms are formed with 300kW power values.

The radiation and temperature values used in the analysis are acquired through the Vantage Pro2 weather station measurements in Istanbul, Turkey. This weather station is connected to an interface monitor in the main station where the data is collected with wireless communication. The data is saved to a computer system through the interface. The measured data is saved in minute intervals for better demonstrations of the dynamic performances of PV panels. So that the effects of dynamic radiation and temperature variables on PV performances can be observed clearly. In addition, the newest models of 5 different PV brands in Turkey market are chosen, which have 300 W power output and monocrystalline structure. The parameters of the determined PV panels modules (Under Standard Test Conditions; 1000 W/m2 radiation, spectrum value AM 1.5, and cell temperature 250C) are given in Table II [16-20].

TABLE II
PARAMETERS OF DIFFERENT BRAND PV PANELS

Parameter	PV1	PV2	PV3	PV4	PV5
P_{max} (W)	300	300	300	300	300
V_{oc} (V)	39.9	39.7	39.4	39.8	40.1
V_{mp} (V)	32.6	32.5	32.4	32.6	32.7
TC_{OC} (%/deg.C)	-0.34	-0.29	-0.29	-0.29	-0.30
I_{sc} (A)	9.65	9.83	9.76	9.77	9.66
I_{mp} (A)	9.21	9.24	9.26	9.19	9.16
TC_{SC} (%/deg.C)	0.06	0.05	0.05	0.05	0.04
N_{cell}	60	60	60	60	60

According to the parameters given in Table II, current-voltage and power-voltage graphs of selected PV panels are shown in Figure 3.

The view of the system created in MATLAB/Simulink environment for performance analysis of PV modules is given in Figure 5. The panels are connected in series and parallel so that the nominal output power of each PV system is 300 kW. The DC bus voltage (output voltage) of the system is selected as 400V. For this reason, each model module is connected as 10 serial and 100 parallel cells.

Since the study aims to obtain dynamically how the output power of the five different PV panel systems change when using dynamic radiation and temperature data, if only DC output power has been considered. Maximum power point trackers (MPPT) and converter and/or inverter structures used are in the practical applications of PV systems. However, these parts have not been taken into consideration for this study. One of the reasons the related power electronics systems are not included in the simulation study is that the modeling of the related systems is carried out at high-frequency values, so long-term (weekly) simulation analysis is not possible with existing computer hardware.

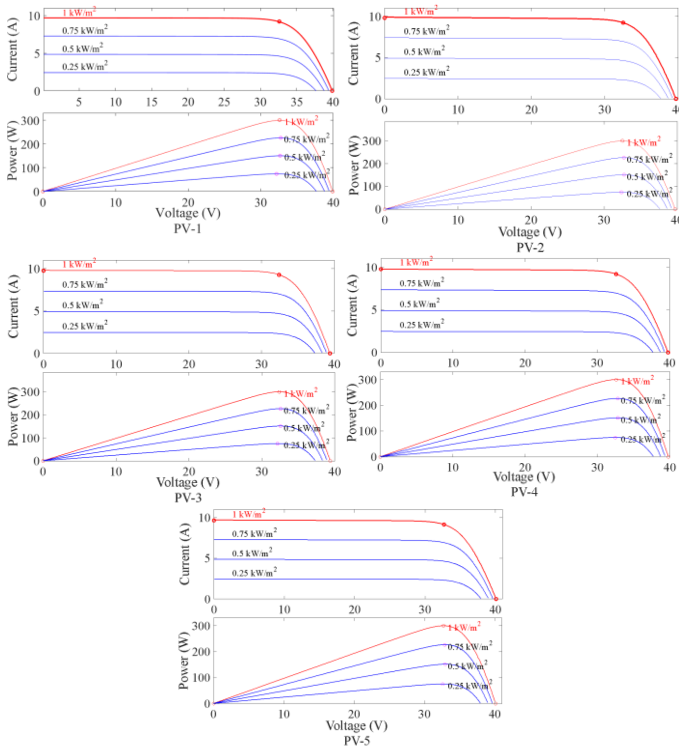

Figure 3. Current-voltage and power-voltage graphs of selected PV modules

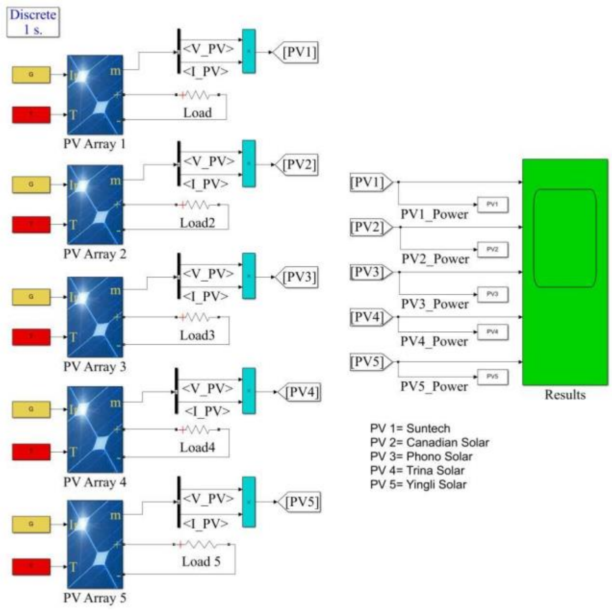

Figure 4. MATLAB/Simulink comparative model of PV panels

For the analysis study, seven days (a week) real radiation and temperature data are used as given and explained in Figure 5.

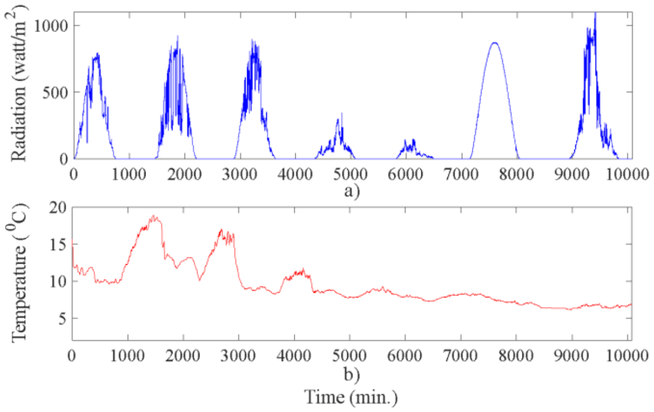

Figure 5. Measured weather data for one week
a) Radiation b) Temperature

The related real-life data is gained through a weather station located in Istanbul, the European side, in which various weather conditions are chosen for each day. So, it is aimed to examine different real-life conditions of PV panel performances that can come upon a sunny day, partly cloudy day, and cloudy day. Depending on the compare/ contrast study of the data, the power value differences of the PVs are given in Figure 6.

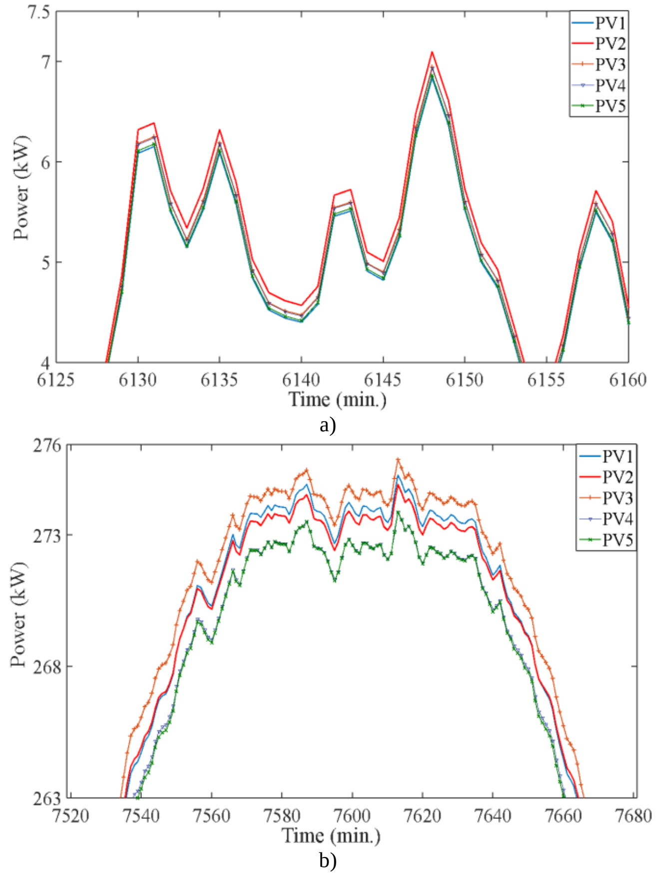

Figure 6. Generated powers of the different PVs
a) Cloudy day
b) Sunny day

In Figure 6, the dynamic performances of five different PV panels are given for the sunny day and cloudy day conditions. In order to observe the dynamic variations better, the time interval is limited for power value differences in Figure 7. In addition, the total energy production of PV panels is a critical criterion for massive PV farm performances, which directly affects the investment feedback and system profits.

Depending on the performance examination, the total energy production of the PV systems with the same power values and different weather conditions are calculated for one week time interval. Based on the survey above, weekly and yearly calculated energy values are given in Table III.

TABLE III
ENERGY PRODUCTION OF DIFFERENT PV PANELS

Parameter	PV1	PV2	PV3	PV4	PV5
Generated energy (week)	56620 MWh	57168 MWh	57113 MWh	56600 MWh	56386 MWh
Generated energy (annual)	2944 GWh	2972 GWh	2970 GWh	2943 GWh	2932 GWh

When the data in Table III is analyzed, the PV2 system provides; 28496 MWh higher than PV1, 2869 MWh higher than PV3, 29536 MWh higher than PV4, and 40664 MWh higher than PV5 in terms of the energy production performances. That is because PV2 has better performance than others on cloudy days. Based on that, PV2 has generated more energy than others. Hence, the PV panel's dynamic performance is critical, which should be analyzed before choosing a PV panel product for investment.

4. CONCLUSION

PV panels are making rapid progress in terms of being an important energy source of the future. In this study, the performances of panels produced by different brands with the same power output in real weather conditions were compared over the simulation model. In the relevant model, the technical parameters of each PV panel are taken into account. The performance study was examined with the measured dynamic radiation and temperature data in this comparison. The calculation error because of using only the label power values is analyzed. It turns out that a general calculation based on the label value and the sunshine duration causes more errors than the calculation with dynamic data. In addition, it is seen that considering only the panel price is not sufficient for the total benefit to be obtained from the panels. Each of the PV panels has different energy generation under the same conditions. PV2 has the best energy generation performance. Annually the best-performance PV panels generate 40 GWh more than the lowest-performance PV panels.

The improvements to be made in the unit efficiency of PV panels will contribute to the generation of more electrical energy in smaller areas. Thus, it is certain that PV panels will consolidate their place in human life as an indispensable energy source in the future. In this way, PV panels, one of the most environmentally friendly and renewable energy sources, will also provide solutions for global warming and other environmental problems.

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BIOGRAPHY

Onur ELMA obtained his BSc degree in electrical engineering from Yildiz Technical University (YTU) Istanbul, Turkiye, in 2009. Onur Elma received his M.S. and Ph.D. degrees in Electrical engineering from YTU, in 2011 and 2016 respectively. He worked as a project engineer in the industry between 2009 and 2011. He has been employed as a research assistant in the Electrical Engineering Department at YTU from 2011 to 2017. He has been in the Smart Energy Research Center (SMERC) at the University of California, Los Angeles (UCLA) as a visiting researcher from 2014 to 2015. Also, he has worked as a post-doc researcher at the Ontario Tech University (ONTechU) from 2017 to 2020. He has worked as an Assistant Professor in the Department of Electrical Engineering at YTU between January and September 2021. He is currently working as an Assistant Professor in the Department of Electrical and Electronics Engineering at Canakkale 18 Mart University (COMU). He participates in many national and international projects also has more than 40 papers. He has national and international patents. His research interests include smart grid, electric vehicles, home energy management systems, energy storage, and renewable energy systems.