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Comparison of Charge Controllers on PV Panel Performance: An Experimental Study

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Abstract— **Nowadays, photovoltaic (PV) systems are widely used because of environmental concerns, electrical energy demand, cost of electricity generation, minimum service cost and support of governments on renewable energy conversion systems. The main drawback of PV systems is energy conversion efficiency. The two parameters that PV system output power depends on are solar radiation and temperature. Therefore, charge controllers are utilized to increase system efficiency. In this study, performance of 320 W solar panel groups which are controlled by two different charge controllers are investigated. The influence of charge controllers on system performance is presented with the analysis of obtained data. Experimental study is realized on a stand-alone energy system that is located in Davutpasa Campus of Yildiz Technical University.**

Keywords— Charge controller, photovoltaic panels, PV performance, stand-alone system

I. Introduction

Renewable energy sources have been much importance in last decade because of environmental concerns, and solar energy conversion systems particularly have been built continuously. These systems are realized as grid-connected and stand-alone. In both systems, maximum power point tracking (MPPT) control algorithm is used to capture the maximum power from photovoltaic (PV) panels because PV panels have non-linear electrical characteristic. Depending on the atmospheric conditions such as temperature and irradiation, output voltage and current of panels change. MPPT control algorithms observe the output voltage and current of PV panel and controls the converter [1],[2].

There are many MPPT algorithms in the literature. The most popular MPPT algorithms are Perturb and Observe (P&O), Incremental Conductance (IC), Constant Voltage (CV) [3], Only Current Photovoltaic (OCPV) and Short Circuit Current Photovoltaic (SCCPV) [20].

Addition to classical MPPT methods, novel algorithms such as neural network based [7],[8], fuzzy control based [9],[10] have been developed to overcome the disadvantages of traditional algorithms.

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MPPT algorithms are run in DC/DC converters such as boost, buck and sepic are utilized in stand-alone PV systems. PV panel current is controlled with DC/DC converter depending on the MPPT algorithm. The converter is connected to DC bus, and the bus voltage is regulated with another DC/DC converter that charges/discharges the battery bank. Battery bank is used to avoid atmospheric conditions. If the generated power by PV panels is not enough to supply load, energy stored in battery bank is transferred to load [11].

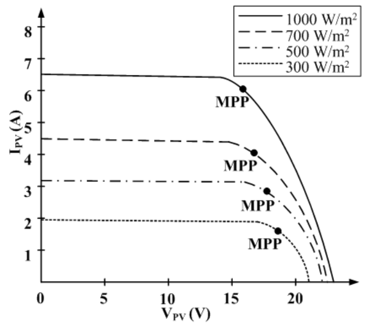
In stand-alone systems, boost converter is utilized for MPPT, and another bi-directional DC/DC converter is used to control the battery energy flow. Depending on the PV output power, battery supplies power to the load or it is charged. [12]. Another DC/DC converter, buck converter, can be connected to PV panel to realize MPPT. It is used in case DC bus voltage is lower than PV panel output voltage. Addition to PV panel converter, bi-directional DC/DC converter which has controls the power flow of battery allows power flow management in stand-alone system [13]. Stand-alone PV systems can be combined with super capacitors. Controlled bi-directional converter that is connected to super capacitor is used to reduce the small charging and discharging cycle of the battery [14]. Wind turbine and PV panel are combined in many stand-alone systems. Both sources are controlled with MPPT algorithm by DC/DC converters and supported with a battery bank [15].

In this study, performance of 320 W solar panel groups which are controlled by two different charge controllers are investigated. The models of panel groups are the same, and they are mounted in the same location to provide same weather condition effects on the panels.The influence of charge controllers on system performance is presented with the analysis of obtained data. Experimental study is realized on a stand-alone energy system that is located in Davutpasa Campus of Yildiz Technical University.

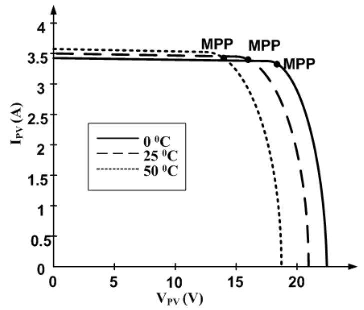
II. Background and Notations

PV system operating point depends on the environmental conditions (solar radiation, outside temperature, etc.) [16],[17]. Dependence on the environmental conditions (Figure 1) complicates the extraction of maximum power from PV. A control system is used between PV and load to extract maximum power continuously. This control interface is named as Maximum Power Point Tracker (MPPT).

A number of MPPT algorithms are proposed in the literature. In practice, it cannot be directly known which algorithm is used at charge controller. Experimental study is the only way to compare MPPT algorithms for end users.



(a) Radiation



(b) Temperature

Figure 1. PV I-V curves [16],[17]

The commonly used MPPT algorithms are Perturbation and Observe, Incremental Conductance, Constant Voltage, Only Current Photovoltaic and Short Circuit Current Photovoltaic algorithm. The basic idea behind these algorithms is to ensure that the PV operates on the maximum power point [18].

P&O algorithm is one of the hill-climbing methods. It's fundamental idea is using an iterative method to track maximum power point. P&O algorithm measures the power values of PV panel and then compares the operation point with prior one. It controls dP/dV value. Operating point is moved to right side on power curve if dP/dV<0, and to left side if dP/dV>0. Algorithm is implemented based on these facts until the maximum power operating point. Because of the algorithm, operating point oscillates around the maximum point [4].

Fundamental idea behind the Incremental Conductance algorithm depends on (1) and (2) [19];

$$\frac{dP_{PV}}{dV_{PV}}=I_{PV}\frac{dV_{PV}}{dV_{PV}}+V_{PV}\frac{dI_{PV}}{dV_{PV}}=I_{PV}+V_{PV}\frac{dI_{PV}}{dV_{PV}}=0 \qquad (1)$$

$$-\frac{I_{PV}}{V_{PV}}=\frac{dI_{PV}}{dV_{PV}} \qquad (2)$$

where, P_{PV} is PV panel output power, V_{PV} and I_{PV} are PV panel voltage and PV panel current respectively.

IC algorithm controls the sum of I/V and dI/dV instead of dP/dV. This algorithm was developed to improve the P&O performance [5].

Another MPPT algorithm is constant voltage. This algorithm is based on V_{mpp}/V_{oc} ratio. The algorithm decreases the PV current to zero, and measure the open-circuit voltage. The measurement value is used to calculate the operating voltage. Although this ratio changed for different panels, commonly used value is 76% [6].

Only Current Photovoltaic algorithm use PV current to track the maximum power point. The main idea of this algorithm is power variation respect to the duty-cycle (D) of the converter. Mathematical expression of this algorithm is given for boost converter in (3) [18].

$$P_{PV}=V_{PV}I_{PV}=V_0\left(I_{PV}\left(1\text{-}D\right)\right)=P^{*}_{boost}V_0 \qquad (3)$$

Where, V_0 defines converter output voltage and P_{boost} is boost converter power.

Short Circuit algorithm depends on the linear relation (k) between maximum power point current (I_{MPP}) and PV short circuit current (I_{SC}) [20]. k can be taken as a constant value (4).

$$k=\frac{I_{MPP}}{I_{SC}}\cong \text{Constant}<1 \qquad (4)$$

III. System Description

The location of the analyzed system is YTU Davutpasa Campus that is shown in Figure 2.

Figure 2. Location of YTU Davutpasa Campus

The hybrid system includes a wind turbine (600 W), eight PV panels (8 x 80 W), a hybrid charge controller (1000 W), a PV MPPT charge controller (500 W), four batteries (4 x 210 Ah) and an inverter (1000 W).

PV panels are divided into two groups; each group has four panels with 320 W total power capacities. While one of the groups (PV_1) is controlled with a hybrid charge controller (Controller 1), other PV group (PV_2) is controlled by MPPT charge controller (Controller 2). Technical specifications of charge controllers show that Controller 1 has no end of charge voltage and Controller 2's end of charge voltage is 27.8 V. Battery group has two series and two parallel elements. Inverter is operated between 21-30 V_{dc} to protect batteries from over and deep charge.

In this study, wind turbine is switched off and performances of PV panels are investigated depending on charge controllers. The block diagram of the investigated system is shown in Figure 3. Technical specifications of the PV panels are given in Table I.

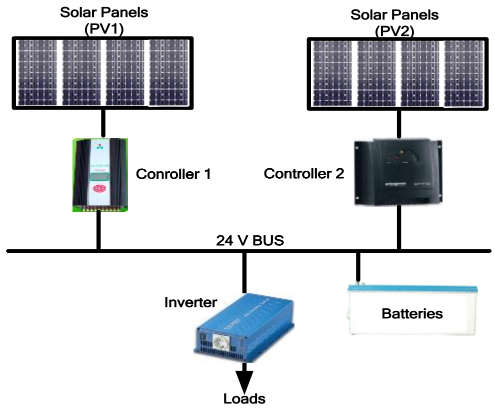


Figure 3. Block diagram of investigated system

TABLE I. CHARACTERISTIC VALUES OF PV PANELS

Quantity	Value
Peak Power	80 W
Max. Power Current	4.54 A
Max. Power Voltage	17.64 V
Short Circuit Current	4.85
Open Circuit Voltage	21.92 V

IV. Case Study

In this study, the effects of two different charge controllers on PV panel performances are investigated. The weather conditions and electrical values of the system are recorded simultaneously with a weather station and a data logger. The analyzed data are recorded between 10 Oct. 2013 and 30 Oct. 2013 for 20 days. The variation of solar radiation on the location is shown in Figure 4.

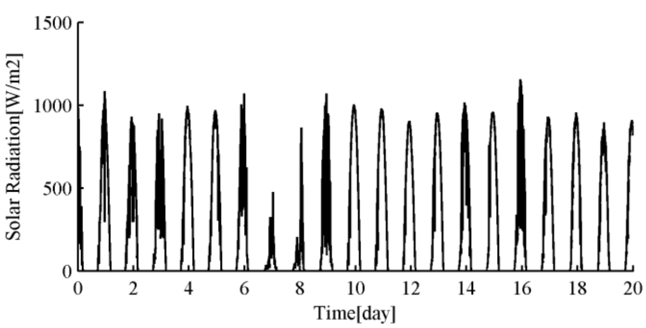
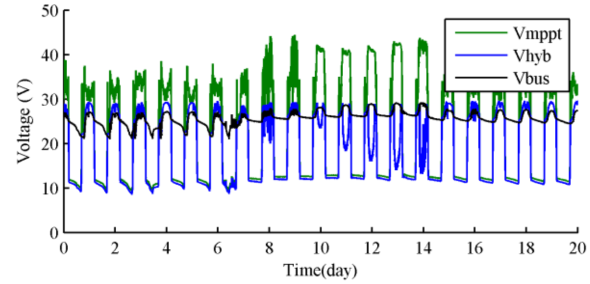


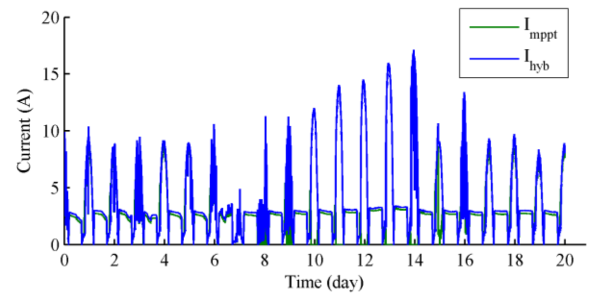
Figure 4. Variation of radiation

Current and voltage values of PV panels are recorded for duration of a minute. Output voltage and current values of two panels are shown in Figure 5. V_{mppt} and I_{mppt} define output voltage and current of PV_2, V_{hyb} and I_{hyb} identify output voltage and current of PV_1, and V_{bus} describes DC bus voltage.

DC bus voltage variation is kept in desired limit between 21 V and 30 V as clearly seen in Figure 5. The output voltages of both panels drop to 10 V when the solar radiation is minimum. Output voltage of PV_2 increases up to 45 V when the radiation is maximum whereas maximum output voltage of PV_1 stays under 30 V.



(a) Voltage variations



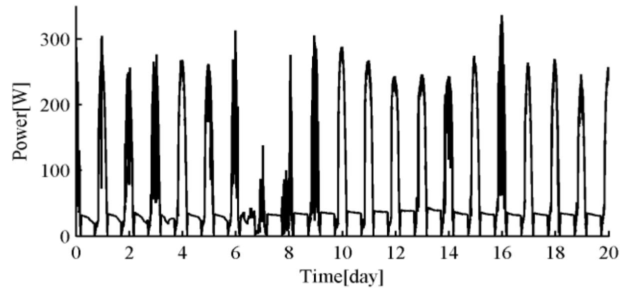
(b) Current variations

Fig 5. Output voltage and current of PV panel

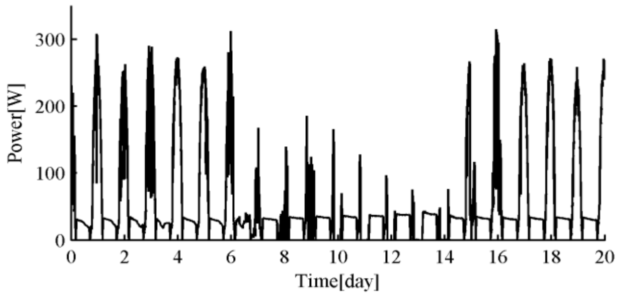
If the current variations are examined, although PV_1 gives higher current than PV_2, similar characteristics can be seen in both systems. In the days between 9th and 15th that solar radiation is maximum in, output current of PV_2 is minimum since Controller 2 monitors and controls the DC bus voltage to prevent the voltage exceed 27.8 V.

Output power variations of panels are shown in Figure 6. The output power characteristic varies in proportion to solar radiation as seen in Figure 6. Operation characteristic of PV_2 panel group controlled by Controller 2 depending on DC bus voltage can be seen clearly in the figure.

Since DC bus voltage reaches to maximum value between 9th and 15th days, Controller 2 restricts the related panel output power. This feature contributes to system stability. In the same time interval, there is no limitation in other panel output power. Although Figure 6 creates perception that the generated power by PV_1 is higher than PV_2, the total energy obtained from PV_1 is 39.826 kWh whereas PV_2 is 45.366 kWh in the measurement interval. The energy generated from PV_2 is higher by 16.81% from PV_1.



(a) Output power of PV1



(b) Output power of PV_2

Figure 6. Output powers

The power difference between two panel groups is caused by Controller 2 that always provides maximum power point operating. While output power of PV_1 oscillates in high range, there is stable output power in PV_2. It clearly seen from Figure 5a that DC bus voltage is higher than 27.8 V between the day 9^{th} and 14^{th}. The generated energy values in these days and remain days are given in Table II.

TABLE II. ENERGY VALUES DEPENDING ON THE DC BUS VOLTAGE

	V_{bus} < 27.8 V	$V_{bus} \geq 27.8$V
W_{mppt}	40.366 kWh	5 kWh
W_{hyb}	34.566 kWh	5.26 kWh

It is seen from Table II that obtained energy from both PV panels are very close over 27.8 V DC bus voltage, however the captured energy with Controller 2 is higher by 16.8% than Controller 1 under 27.8 V DC bus voltage.

V. Conclusion

In this study, the influences of charge controllers on PV panel performance are investigated. The analysis are realized with data recorded from the system located in YTU Davutpasa Campus. In order to clearly get the influence of controllers, the same panels are used in experimental studies. The obtained results show that,

- Output voltage of PV_2 reaches up to 45 V, whereas output voltage of PV_1 stays around 30 V.
- Controller 2 monitors the DC bus voltage, thus stop operating while DC bus voltage exceed 27.8 V. Therefore, power is restricted in measurement interval that solar radiation is high in,
- PV_2 generates more power than PV_1 by 16.81%.
- PV_2 power generation is significantly higher than PV_1 while DC bus voltage is lower than 27.8 V,
- Both panel output power values are very close while DC bus voltage is higher than 27.8 V.

The experimental studies show that controllers have different algorithms and operating principles change the performance of PV panel performance. Controller selection has much importance as panel type, application area and battery size in photovoltaic system design.

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