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To cite this article: G N Popa *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **477** 012030

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Study on a maximum power point tracking controller for photovoltaic panels

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Abstract. The maximum power point tracker is a DC-DC electronic converter that optimizes the match between the solar array (photovoltaic panels) and the battery bank (stand-alone type) or utility grid (grid-tie type). They convert a higher and variable voltage DC output from photovoltaic panels down to the lower voltage needed to charge batteries or for on-grid inverters. The MPPT controller depends on the operating conditions of the photovoltaic panels, but also on the electrical characteristics of the electrical loads. The aim of the MPPT controller is to keep the operating point as close to the maximum power point. The paper presents a MPPT controller with 8-bit microcontroller. The microcontroller monitors the voltage and current of the photovoltaic panel as well as charging the battery. The controller is a buck converter, having a P channel MOSFET transistor. A microcontroller that also manages the charging of the batteries with the three charging stages, bulk, absorption, float and, also, the manual equalization option. Also, the battery bank is monitoring by measuring the temperature with a NTC thermistor.

1. Introduction

The global energy context leads to an intense concern in the field of unconventional energies. Of these, solar power occupies an important place.

Solar technologies can generally be [1], [2]:

- passive (orientation of a building to the sun, optimal design of spaces, etc.);
- active (with photovoltaic panels and thermal collectors).

The maximum power point tracker (MPPT) is a DC-DC electronic converter that optimizes the match between the solar array (photovoltaic panels) and the battery bank (stand-alone type) or utility grid (grid-tie type). They convert a higher and variable voltage DC output from photovoltaic panels down to the lower voltage needed to charge batteries [3-7].

The MPPT controller depends on the operating conditions of the photovoltaic panels, but also on the electrical characteristics of the electrical loads [8].

The aim of the MPPT controller is to keep the operating point as close to the maximum power point.

2. Photovoltaic panels and systems

Photovoltaic (PV) or solar cells are semiconductor devices that convert solar energy into DC energy. Photovoltaic cells directly convert solar radiation into electricity.



A photovoltaic cell is similar to a diode (Figure 1). The upper layer is type N, and the lower layer is type P [9], [10].

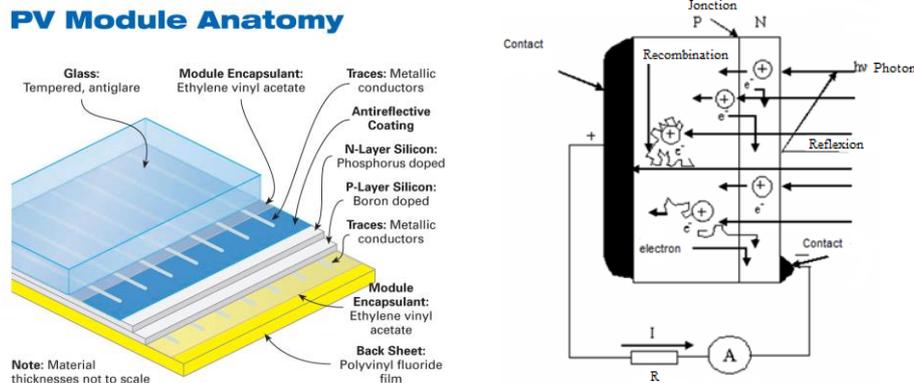


Figure 1. Structure of a photovoltaic junction P-N: design and operation [11]

When the photons hit the cell, the electrons are released. This causes a potential difference between the two material types (P and N). If a load is connected, an electric current will occur.

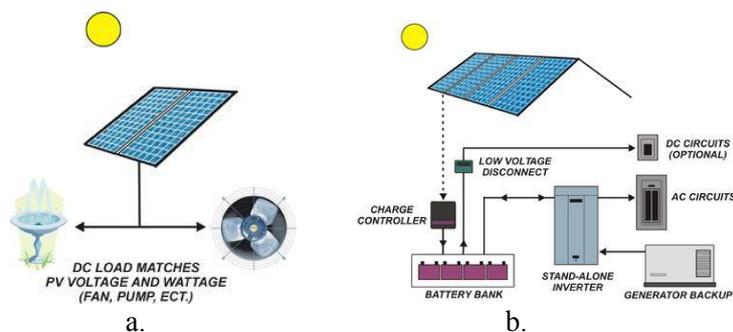
Basically, a PN junction is made up of a N-type silicon-tin pill, about 1 mm thick and 5 cm in length / width, placed on a metal base having a P-type thickness material just a few thousandths of a centimeter.

There have been different PVs called first generation, second generation and third generation (Table 1). PV efficiency has reached tens of percent efficiency (third generation).

In practice, different PV architectures are used (Figure 2): there are PV systems without battery bank and without connection to the grid - PV direct (Figure 2.a.), PV systems with battery bank and without grid connection - PV stand-alone (Figure 2.b), PV systems without battery bank and with grid connection with an on-grid inverter - Grid TIE without battery (Figure 2.c), and PV systems with battery bank and grid connection - Grid TIE with battery backup (Figure 2.d). The systems of Figure 2.a are the cheapest and easiest to use, and the systems in Figure 2.d are the most complex.

Table 1. Commercial PV Module Types [12]

Technology	First generation	Second generation	Third generation
Cell efficiency (%)	14-22	5.4-12.7	30-38
Module efficiency (%)	11-19.7	20-22	24-25
Area/kW	7-8	10-15	12



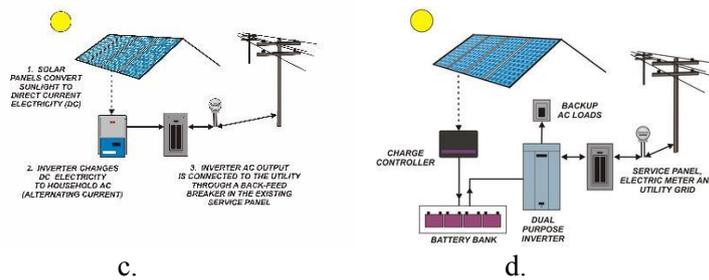


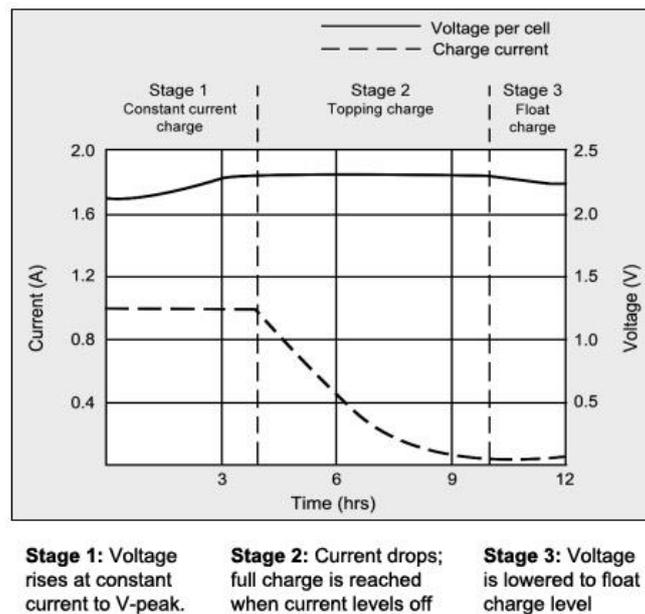
Figure 2. Types of photovoltaic systems [1], [13], [14]
 a. PV direct; b. PV stand-alone; c. Grid TIE without battery;
 d. Grid TIE with battery backup

3. Charge controllers for photovoltaic systems

Charging regulator is used to charge the batteries in photovoltaic systems. The correct dimensioning of the capacity for an accumulator battery is made according to the rated power of the consumers and the consumption diagram on hourly intervals.

The battery life of a battery depends on how much it is discharged and the working temperature [15]. If it is not discharge more than 30%, the batteries resist several thousand charge/discharge cycles. If the batteries discharged regularly up to 80%, it takes about a thousand cycles. It is very important how the voltage of a battery varies during charging and discharging, because the charger, which regulates the current flow from the panel to the batteries, uses voltage as a "control signal" to protect batteries and extend their life [3-5].

The electrical power delivered by a photovoltaic cell is not sufficient for most domestic or industrial applications. For this reason, the photovoltaic cells are connected in series to increase the voltage value at the terminals and thus a panel (module) is made. Then the modules connect either in series to increase the voltage even more, or in parallel to increase the current through the circuit (series-parallel connections form the photovoltaic systems).



Stage 1: Voltage rises at constant current to V-peak.
Stage 2: Current drops; full charge is reached when current levels off
Stage 3: Voltage is lowered to float charge level

Figure 3. Typical charging of lead acid battery [16]

The voltage-current characteristic (U-I) of a photovoltaic panel depends mainly on the intensity of solar radiation and cell temperature [8].

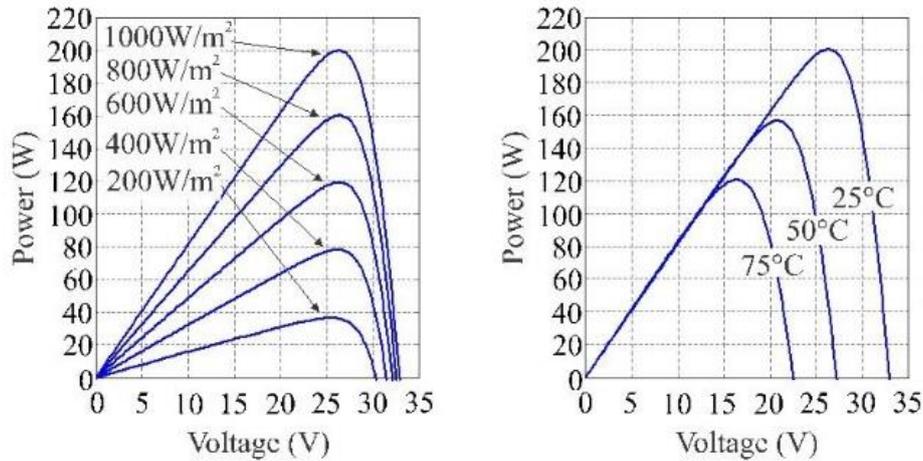


Figure 4. PV panels depends on solar incident radiation and temperature [17]

At the intersection of the PV U-I characteristic with the consumers characteristic of the photovoltaic panel terminals, there is the operating point (PF). This point generally differs from the maximum power point (MPP) at which the system can work when the optimum power transfer is achieved between the photovoltaic panel and the load.

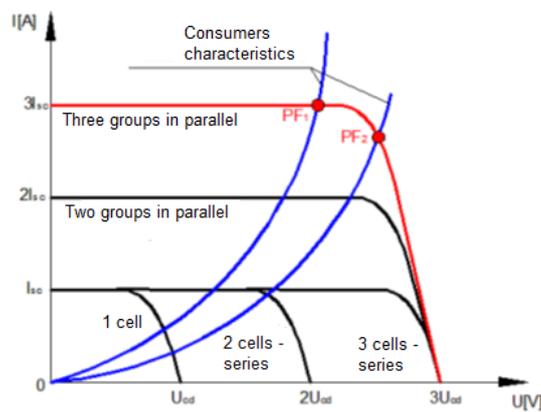


Figure 5. PV cells connected in series and parallel

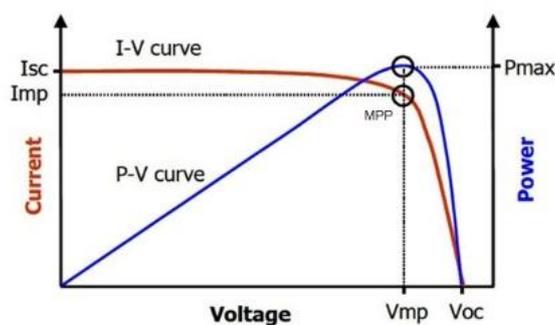


Figure 6. PV characteristics and MPP

As a result, MPP depends on the operating conditions of the photovoltaic panel, but also on the electrical characteristics of the terminal loads. The purpose of MPPT is to keep the operating point as close MPP.

4. MPPT for photovoltaic systems

Figure 7 shows the basic scheme of a MPPT solar charger. The key element is a DC-DC converter that allows the panel to operate at a voltage different from that of the battery. The MPPT controller quickly determines, in real-time, the maximum power point (MPP) of the solar panel system, depending on the power of the consumers and the battery charge status, at different times of the day, and in various stages of the weather [5-7], [18], [19].

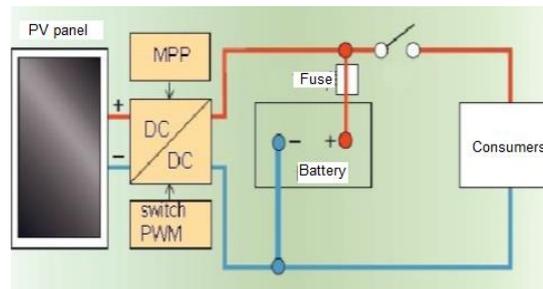


Figure 7. The schematic diagram of an MPPT controller

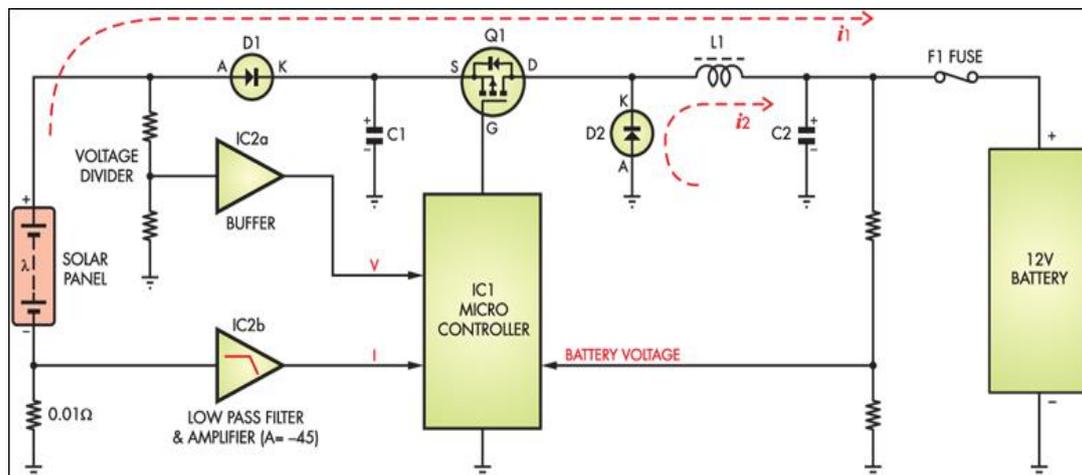


Figure 8. Block diagram of a MPPT controller with microcontroller

The microcontroller monitors the voltage and current of the photovoltaic panel as well as charging the battery.

When the MOSFET Q1 is on-state the current i_1 passes through the coil L1 to the capacitor C2 and the battery. When Q1 is off-state, the energy stored in the L1 coil is transmitted via the D2 diode to the battery (current i_2).

The rate of change of I_L can be calculated from:

$$V_L = L \cdot \frac{dI_L}{dt} \tag{1}$$

with equal to during the on-state to during the off-state.

Therefore, the increase in current during the on-state is given by:

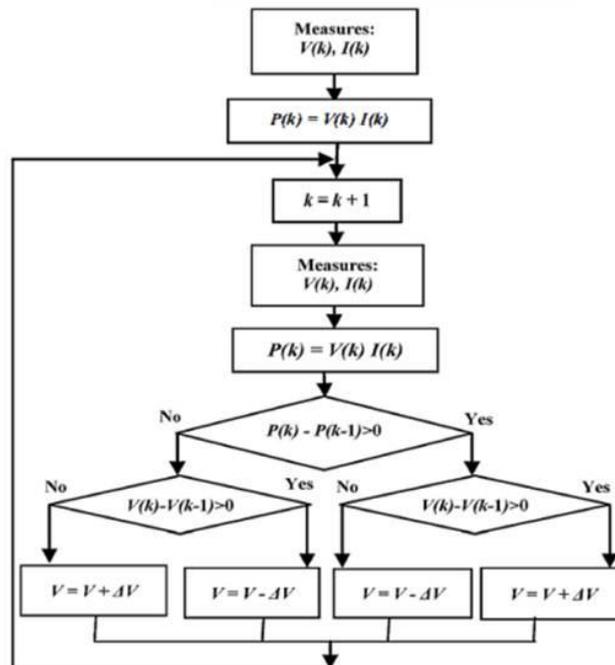


Figure 10. The main flowchart for program

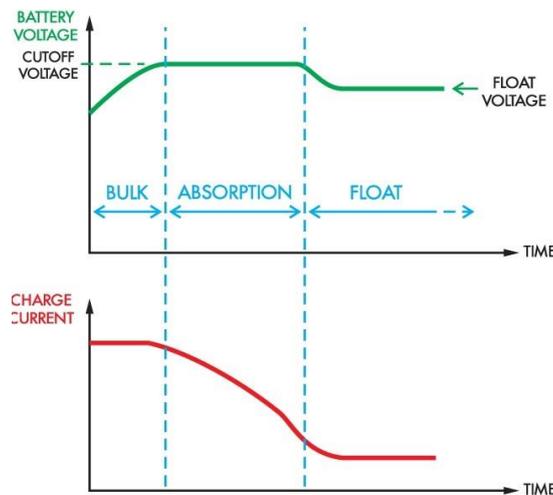


Figure 11. Standard charging

Table 2. Experiments with battery 7 Ah, U=13.14 V

Elevation angle (°)	N-E Orientation				E orientation			
	U _{PV} (V)	I _{PV} (mA)	U _{bat} (V)	I _{bat} (mA)	U _{PV} (V)	I _{PV} (mA)	U _{bat} (V)	I _{bat} (mA)
15	14.03	120	13.67	60	14.33	240	13.87	180
30	14.05	130	13.69	80	14.36	280	13.88	220
45	14.46	170	13.72	120	14.20	290	13.72	220
60	14.07	100	13.65	50	14.36	310	13.87	240
90	13.94	40	13.61	20	14.19	250	13.74	190

Elevation angle (°)	S-E Orientation				S Orientation			
	U _{PV} (V)	I _{PV} (mA)	U _{bat} (V)	I _{bat} (mA)	U _{PV} (V)	I _{PV} (mA)	U _{bat} (V)	I _{bat} (mA)
15	14.43	290	13.98	210	14.32	270	13.86	210
30	14.24	160	13.82	100	14.23	260	13.77	200
45	14.35	220	13.89	150	14.36	190	13.65	140
60	14.54	260	14.09	200	14.14	110	13.57	70
90	14.29	180	13.88	120	13.96	50	13.52	10

Table 3. Experiments with battery 9 Ah, U=11.12 V

Elevation angle (°)	N-E Orientation				E orientation			
	U _{PV} (V)	I _{PV} (mA)	U _{bat} (V)	I _{bat} (mA)	U _{PV} (V)	I _{PV} (mA)	U _{bat} (V)	I _{bat} (mA)
15	12.60	230	11	210	12.33	330	11.83	250
30	12.12	270	11.65	210	12.38	330	11.86	270
45	12.53	240	11.57	180	13.02	330	11.88	270
60	12.20	230	11.57	160	12.30	300	11.80	240
90	12.06	150	11.55	100	12.06	220	11.52	150

Elevation angle (°)	S-E Orientation				S Orientation			
	U _{PV} (V)	I _{PV} (mA)	U _{bat} (V)	I _{bat} (mA)	U _{PV} (V)	I _{PV} (mA)	U _{bat} (V)	I _{bat} (mA)
15	12.33	300	11.83	240	12.23	280	11.74	220
30	12.37	330	11.86	260	12.61	270	11.72	230
45	12.34	320	11.83	260	12.12	250	11.65	200
60	12.26	300	11.77	240	12.57	220	11.57	180
90	12.07	250	11.61	190	12.04	210	11.6	160

The measurements were made only with PV, MPPT and an lead acid battery (without any electrical load). The two batteries used in experiments were not preloaded. When the measurements were made, it was a sunny summer day, between 9⁰⁰ h to 12⁰⁰ h. The place where the measurements were made was Romania, at the latitude of 45⁰, for which an ideal elevation angle is 30⁰ for summer and 60⁰ for winter for fixed PVs (without automatic solar tracking systems).

The current absorbed by the PV depends on the panel orientation, the elevation angle, and the lead acid battery charge state. It was found that the maximum charge (by maximum current) of lead acid batteries was obtained for orientation S-E, S and E (depending on the time interval when the measurements were made) at elevation angles between 15⁰-45⁰. The charging current is higher for the larger capacity battery.

5. Conclusion

Despite the price and dependence on external factors, solar panels for power generation are a solution for the future. The most significant advantage is that, at least theoretically, they have a long service life and a very low maintenance cost. Initial investment is the major drawback of all alternative energy systems and photovoltaic panels.

There are, of course, other drawbacks, among which we can list the low photovoltaic cell yield and the acute dependence on solar radiation (radius angle, temperature, intensity, etc.). The MPPT Charge Controller is essential under the following conditions:

- in winter and/or sky with rain, when it is always necessary to have extra power;
- cold weather - solar panels work better at low temperatures;

- when the battery is very low, the lower the voltage on the batteries, the MPPT controller introduces a higher current.

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