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Reliable Standalone Solar Battery Charging System Using ARDUINO Based on MPPT Controller

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ABSTRACT

This paper aims to provide a study and a realization of a reliable standalone solar battery charging system, it is the main unit of the independent PV systems, used to manage the power sent from the photovoltaic panel to avoid damaging the battery, this one is a very sensitive device to charging / discharging. For this reason, a special control system (called charge regulator) is placed between the photovoltaic installation and batteries to maintain and optimize the functioning of the energy chain. The studied system consists of a photovoltaic module delivering 10w, and a static dc - dc converter of buck type, controlled by a rectangular signal PWM (pulse width modulation) by varying the duty cycle. the signal is generated by the ARDUINO-UNO board where the maximum power point tracking (MPPT) algorithm named perturb & observee (p & o) is implemented to charge a 12v battery, using the ISIS proteus software to make the virtual simulation of the different parts of the system before proceeding to the practical realization which results are satisfactory

1. Introduction

In recent years, the trend toward a renewable energy system has drawn much attention as a clean source, non-polluting and cheaper than non-renewable energy formatter will need to create these components, incorporating the applicable criteria that follow the maximum power point [1][2]. One of the most important sources of renewable energy is photovoltaic energy(PV), to feed a load through a pv installation. It is often necessary to equip the system with storage batteries. batteries can store energy for use when needed. however, the connection of batteries with photovoltaic installations can present a poor performance because the batteries are very sensitive to overloads and deep discharges , it is therefore necessary to add an adaptation system called a charge controller to optimize the operation of the energy chain charge controllers based on the mppt command (maximum power point tracker) [3][4]. are modern regulators. not only are they able to monitor the charging / discharging of batteries. but they can force the pv generator generates its maximum power regardless of the variation in climatic conditions (temperature and sunshine) [5] nowadays, various methods are proposed [6][7]The most common methods of MPPT is incremental conductance , perturb and observe , fractional open voltage and fractional short-circuit current methods[8] , after that, many methods have been developed in this field especially that rely on artificial intelligence. The goal of our work is the electronic realization of a solar battery charging, the main device in standalone

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photovoltaic systems that is used to manage the energy transmitted from the photovoltaic panel in order not to damage the battery, in this study we followed the technic p&o (perturb and observe). The PO technic operate by perturbing the reference value with specific sampling rates[9].a popular variation of the PO method [10]] is based on the relationship of the PV array output power and the switching duty cycle. This method is defined as the hill climbing search (hcs) technic in[8][11]. The system to be studied consists of a photovoltaic module delivers a power of 10w, and a dc-dc buck type static converter controlled by a rectangular PWM type signal by varying the duty cycle which represents a control correlation between the conduction time and the total switching period. During its operations, the mosfat turns on and off until the maximum power point delivered by the module is reached. The signal is generated by the Arduino Uno board where the MPPT algorithm named disturbance and observation (P&O) is implemented to charge a 12v battery, using ISIS proteus software to do the simulation before proceeding to practical realization.

1.2. Paper contribution :

This paper develop a new generater cherging system constitute of PV solar battery charger using UNO-ARDUIN controlled with classical MPPT technic and present the following points:

- Protect the battery from overcharging and under discharge limit.
- Force the PV generator generates its maximum power regardless of the variation in climatic conditions (temperature and sunshine).

2. Material And Method :

2.1. description of the photovoltaic conversion chain:

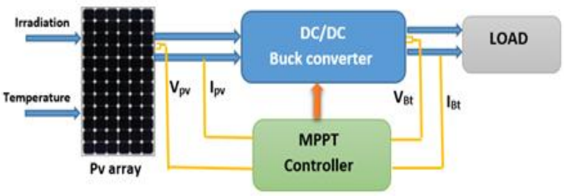

Figure 1 - PV system control structure.

The PV conversion chain is considered as a critical process in which reliable controls would improve the efficiency of the charging operation of connected storage batteries
figure 1 shows a simplified scheme of a standalone PV system with DC-DC buck converter.

2.2. Modeling of the photovoltaic cell :

The equivalent circuit of a photovoltaic cell is represented in figure 2, it is formed by a current generator supplying a current Iph proportional to the light intensity, a diode modeling the PN junction and two resistors, the first is in series Rs representing the various contact resistances and the resistance of the semiconductor, the second resistor Rp parallel resistance characterizing the leakage current at the surface of the cell due to the non-ideality of the PN junction and impurities near the junction.

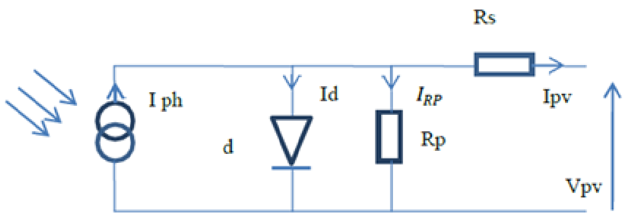

Figure 2-The equivalent circuit of photovoltaic cells

Ipv and Vpv are the output current and output voltage of the cell. applying kirchhoff's current law we can get the output current expression [12]

$$I_{pv} = I_{ph} - I_d - I_{Rp} \qquad (01)$$

The current flowing through the diode is given by :

$$I_d = I_s * \left[e^{\frac{q*(V_{pv}+R_i*I_{pv})}{nkT}} - 1 \right] \qquad (02)$$

Current flowing through resistor shunt

$$I_{Rp} = \frac{V_{pv} + R_s * I_{pv}}{R_p} \qquad (03)$$

The formula of the photo-current

$$I_{ph} = \left[I_{cc} + K_1 * \left(T - T_{ref} \right) \right] * \frac{G}{G_r} \qquad (04)$$

The output current of the PV cell is given from the law of the nodes

$$I_{pv} = I_{ph} - I_s * \left[e^{\frac{q*(V_{pv}+R_i*I_{pv})}{nkT}} - 1 \right] - \left(\frac{V_{pv} + R_s * I_{pv}}{R_p} \right) \qquad (05)$$

Where Iph is the photo-generated current (A),IS is the diode saturation current (A),Vpv is the Voltage at the terminals of the cell (V), Ipv is the output current of PV cell (A),Rs is the series resistance of the cell (Ω) and Rp is the shunt resistance of the cell (Ω).n is quality factor of the cell, K is the Boltzmann gas constant (1.38 × 10−23 J/K),q is the elementary charge (1.6 × 10−19 C),T is the absolute temperature of the cell (K), Icc short circuit current (A), Ki coefficient of temperature , Tref reference temperature of the cell (°k) Tref=298K (25c°),Gr reference solar irradiation Gr =1000w/ m², G solar irradiation of operation.

2.3. I-V and P-V characteristics:

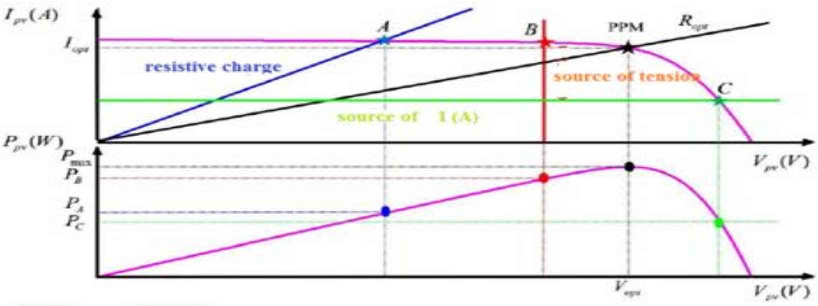

Figure 3-soler cell (current-voltage) and (power-voltage) characteristics

From Figure 3 we can see that the PV generator has a non-linear I-V correlation. And we can also notice that the generator can produce a maximum power at the point (Vopt, Iopt).

3.1. Influence of temperature and irradiance on the current / voltage characteristic :

The operation of the photovoltaic cell depends on the level of solar irradiance and the temperature of the cell. In this part, we will demonstrate the influence of changing weather conditions on the current and voltage generated by the solar panel.

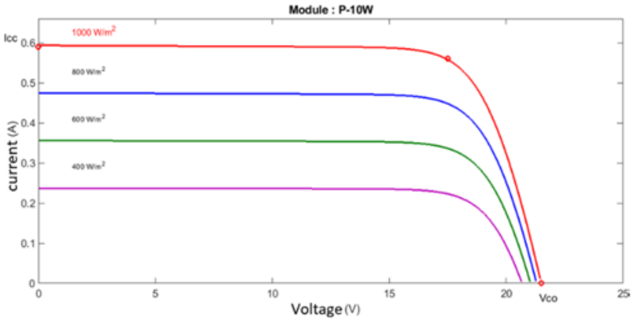

Figure 4- Influence of irradiance on current-voltage characteristic

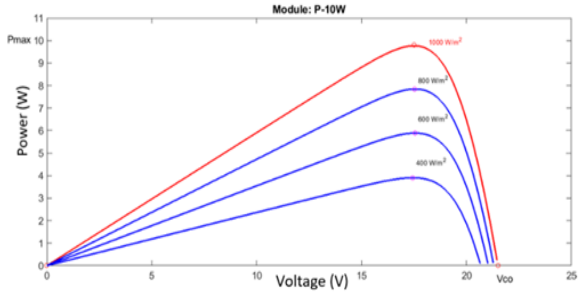

Figure 5- Influence of irradiance on the power-voltage characteristic

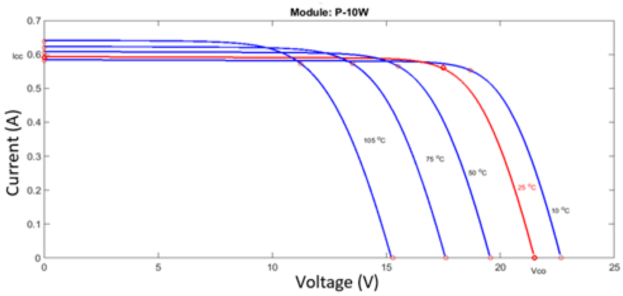

Figure 7- Influence of temperature on current-voltage characteristic

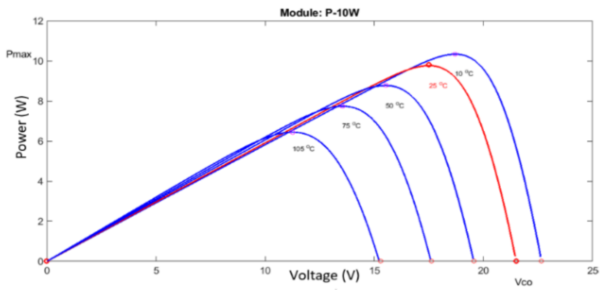

Figure 6- influence of temperature on power-voltage characteristic

From the figure 4 we can observe that the increase in solar irradiance causes the value of the short-circuit current to increase while the value of the open circuit voltage, varies very little. And figure 5 shows that the increase in solar irradiance causes the increase of the power of PV panel. On the other hand from the figure 6 we can observe that as the temperature increases and goes away from 25 °C the open circuit voltage Vco decreases, so the temperature has a negligible influence on the value of the short-circuit current. And figure 7 shows that when the temperature of the solar panels goes away from 25 °C the power diminishes.

2.4. Photovoltaic energy storage batteries:

A solar battery is intended to store the electrical energy in chemical form, used in photovoltaic systems because the demand for electricity does not coincide with the production because of the poor performance of the generator. The storage of energy is done to ensure the proper functioning of the system when solar energy is not sufficient or available.

There are several types of electrochemical accumulators (Pb, Ni¬Cd, Li¬ion, ...). However, the oldest and most commonly used are those made of lead and nickel cadmium. In the solar field, lead-acid batteries are the most used because they can withstand many cycles of charging and discharging without being damaged [13].

2.4.1. The battery charging cycle:

2.4.1.1. Normal cycle or Bulk charge:

Bulk charge is a constant current charging mode, it represents the first step of the charging cycle to follow where the photovoltaic panel charges a battery discharged by the maximum current allowed. During this charging mode the voltage across the battery gradually increases and ensures a quick recovery of the battery capacity

2.4.1.2. Equalization cycle or load absorption:

The Battery Voltage Must Be Maintained At The Vr Regulation Value In Order To Complete The Battery Charge And Avoid The Overload.[13]

2.4.1.3. End of charge or float charge:

This step is a step maintenance where the battery voltage is reduced to a fair enough level vf to compensate self-discharge of the cells. And the charging current become very weak and almost constant, this is the state full charge.[13]

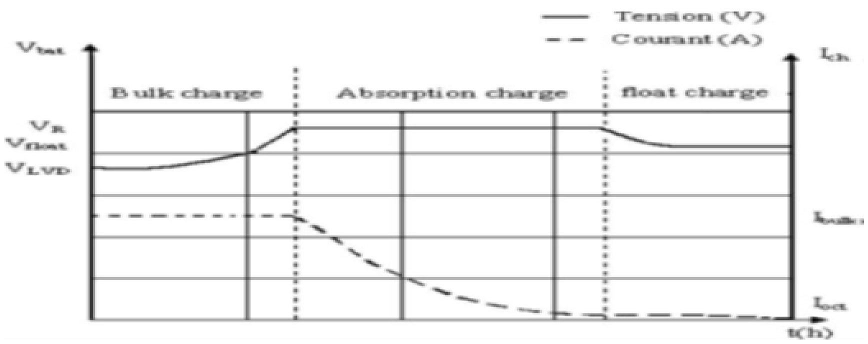

Figure 8 - Three-step charging algorithm

2.5. the purpose of inserting a charge controller :

The direct connection between the photovoltaic generator and the battery is simple to perform but does not offer good performance and has a poor performance because the batteries are very sensitive to charging / discharging, therefore the latter must not be too charged or too discharged as this influences their lifetime. It is necessary to ensure a better adaptation of an autonomous photovoltaic system with a battery, this is done through the insertion of a component named "MPPT battery charger" whose role and to maintain the life of the battery and force the generator to operate at its maximum power and transfer it to the battery which often suffers from a maladaptation because frequently, the operating point of the GPV is far from the maximum operating point because of the change of weather conditions and the variation of the state of charge of the battery.

2.6. Buck converter:

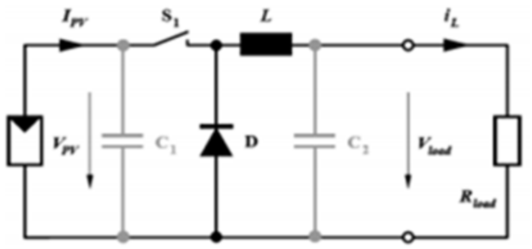

Figure 9 - Buck converter structure

Figure (9) shows the appearance of the pulse width modulated (PWM) signal of fixed frequency and variable pulse width which controls the switch S1. It is adjusted by the parameter α named the duty cycle in the time when the switch is closed (Ton) divided over the period of its switching T.

$$\alpha = \frac{T_{on}}{T} \quad (06)$$

Conduction time

$$T_{on} = \alpha T \quad (07)$$

Blocking time

$$T_{off} = (1 - \alpha) * T \quad (08)$$

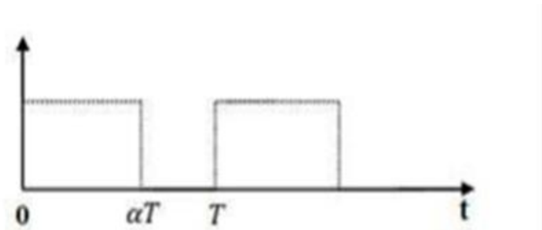

Figure 10 - Switch control signal

2.7. P&O MPPT algorithm :

The perturb and observe (P&O) algorithm is generally the most commonly applied in the control of MPPT algorithm for the PV generator. It has simple structure, low cost, easy to implement, reduced number of parameters, the possibility to introduce improvements and may result in top-level efficiency[14][15] This algorithm is depending on investigating the relation between PV module output power and its voltage. The behavior of solar panel indicating MPP and operating principle is shown in Fig. 11 which indicates that the resulting change of PV power is observed as follows: When the PV module operating point is on the left side of the curve (ΔP/ΔV is positive), which means the PV module output power increases, the perturbation of the PV module voltage should be increased[16]

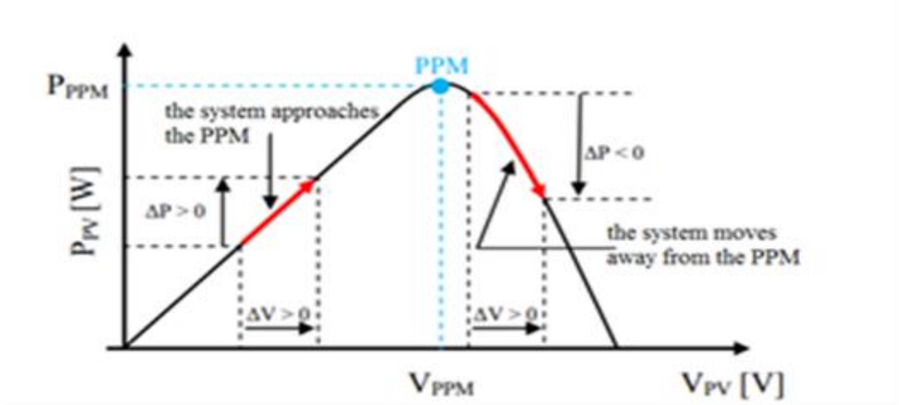

Figure 11 - Characteristic power - voltage of the photovoltaic generator

Figure (12) shows the classical algorithm associated with a P & O type MPPT control, where the evolution of the power is analyzed after each voltage disturbance. For this type of control, two sensors (current and voltage of the GPV) are necessary to determine the power of the PV at every moment.

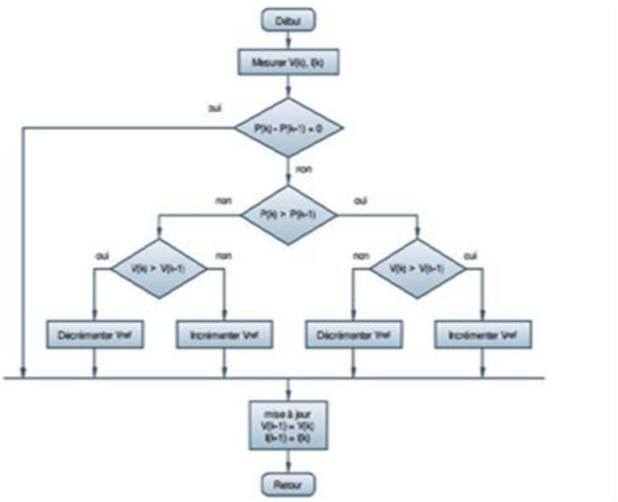

Figure 12 - Organizational chart of the disrupt & observe algorithm

3. Simulation :

Virtual simulation was done using ISIS Proteus to test the proper functioning of the system.

3.1. Simulation of the solar panel :

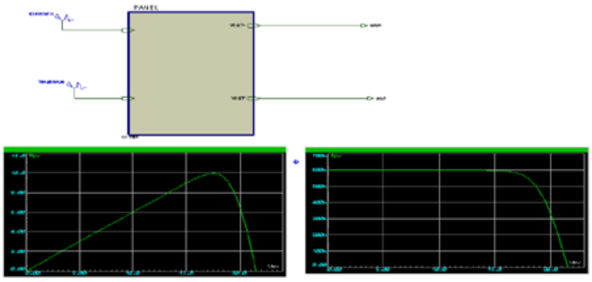

Figure 13 - Simulation of the solar panel used

3.2. Simulation of the control part:

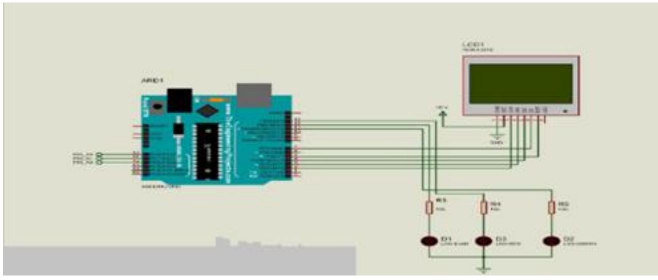

Figure 14 - Arduino Uno under ISIS PROTEUS

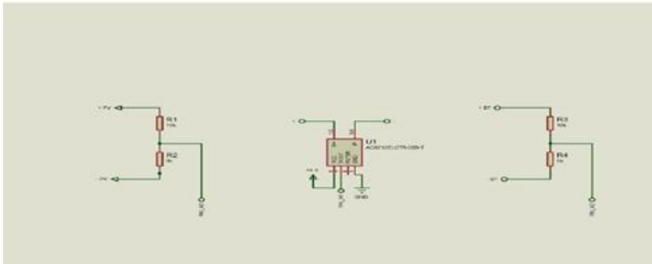

Figure 15 - Simulation of different sensors

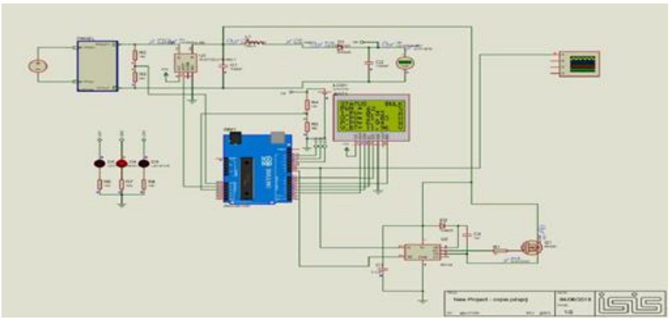

Figure 16 - Overall scheme of the device realized unde ISIS Proteus

4. Results And Discussion:

4.1. Experimental trials :

After the simulation stage we are interested in the practical side in this case the control part by ignoring the presence of the power section. For this, we performed several tests with the four states of charge of the battery (On, Bulk, Float, Off). Knowing that the outputs of the solar panel are variable depending on the illumination and the ambient temperature, also the voltage at the terminals of the battery depends on the state of charge, we used potentiometers to get closer to the reality and the experimentation of three scenarios relating to the operation of the solar panel. as illustrated by the picture below, we have connected Arduino pin A0 to first potentiometer, representing the voltage across the solar panel, Pin A1 of the Arduino to the second potentiometer, representing the current generated by the panel solar and pin A2 of the Arduino to the third potentiometer, representing the voltage across the battery.

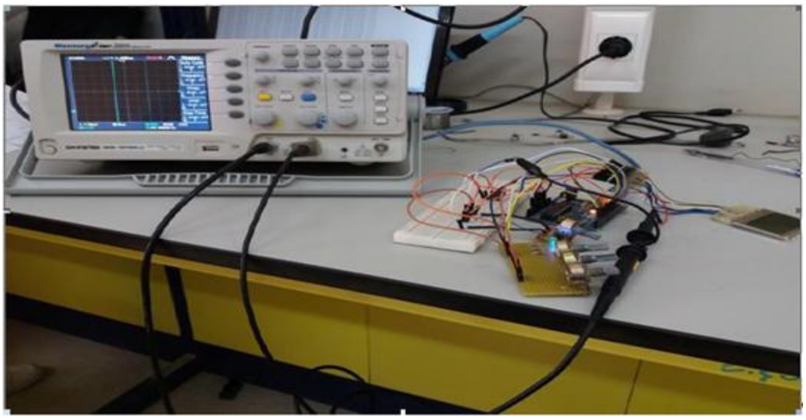

Figure 17 - Realization of the command part

4.2. First scenario "Constant temperature":

The temperature considered is 25 ° C, hence the outgoing voltage of the solar panel is optimal, 17.5 volts, while the illumination is variable, therefore the current obtained away from the optimal current given by the manufacturer of the panel, that is 0.56A.

By applying different voltages to the battery, we found that the state of charge of the battery behaves according to the instructions of the program given to the lights, some pictures taken during the realization and an illustrative table of recorded data.

Table 1 results of the first scenario

$V_{PV} = 17{,}5$ V					
Voltage of battery (V)	current (A)	Power (W)	duty cycle %	State of charge	Colors of the LEDs
≈ 9	0.1	2.79	100	ON	Green light
	0.2	3.49	100	ON	Green light
	0.3	5.24	63	BULK	Light blue
	0.4	6.99	61	BULK	Light blue
	0.5	8.74	60	BULK	Light blue
≈ 12	0.1	1.74	100	ON	Green light
	0.2	3.49	100	ON	Green light
	0.3	5.23	60	BULK	Light blue
	0.4	6.98	60	BULK	Light blue
	0.5	8.72	60	BULK	Light blue
≈ 14	0.1	1.75	100	FLOAT	All LEDs on
	0.2	3.84	100	FLOAT	All LEDs on
	0.3	5.24	63	FLOAT	All LEDs on
	0.4	6.99	61	FLOAT	All LEDs on
	0.5	8.74	60	FLOAT	All LEDs on
≈ 16	0.1	1.74	60	OFF	Red light
	0.2	3.49	60	OFF	Red light
	0.3	5.23	60	OFF	Red light
	0.4	6.98	60	OFF	Red light
	0.5	8.72	60	OFF	Red light

4.3. Second scenario "Constant illumination"

The illumination considered is 1000W / m², hence the current coming out of the panel Solar is optimal, that is to say 0.56A, whereas the temperature is variable part consequently the obtained voltage moves away from the optimal voltage given by the panel manufacturer, or 17.5Volts.Applying different voltages to the battery, we found that the state of battery charge behaves according to the instructions of the program data the indicator lights below, the figure below shows some pictures taken during the realization and all the data recorded in the table (2).

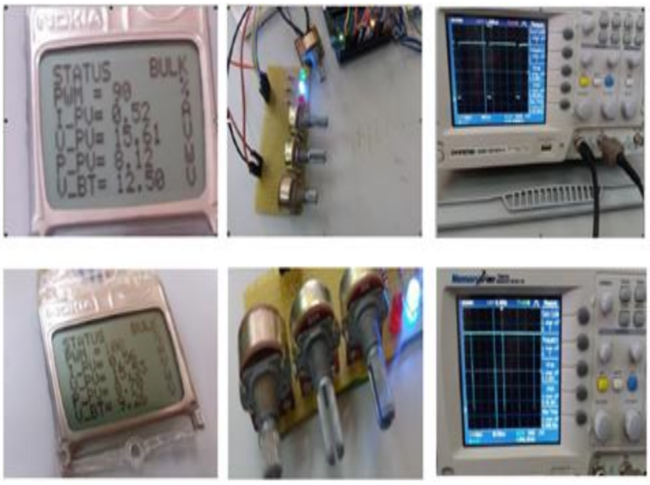

Figure 18 - Pictures taken from the second scenario

Table 2 results of the second scenario

I_{PV} = 0.55 A					
Voltage of battery (V)	Voltage panel (V)	Power (W)	duty cycle %	State of charge	Colors of the LEDs
≈ 9	15.01	7.81	77	BULK	Light blue
	15.61	8.12	80	BULK	Light blue
	16.04	8.34	75	BULK	Light blue
	16.63	8.65	81	BULK	Light blue
≈ 12	15.01	7.81	85	BULK	Light blue
	15.61	8.12	90	BULK	Light blue
	16.04	8.36	89	BULK	Light blue
	16.63	8.85	93	BULK	Light blue
≈ 14	15.01	7.82	60	FLOAT	All LEDs on
	15.61	8.12	60	FLOAT	All LEDs on
	16.04	8.36	60	FLOAT	All LEDs on
	16.63	8.66	60	FLOAT	All LEDs on

When a voltage of 15 volts is applied, the power obtained is sufficient for the battery to be in the "Bulk" position, which is quickly charged with the maximum power using the disturbance and observation method.

The algorithm continues its calculations until reaching the maximum voltage across the battery. All the indicator lights come on, this is the position "Float" or end of charging the battery, then a loop of the program ensures the protection of the battery by disconnecting the GPV to avoid its overload and the warning light is red.

4.4. Third scenario "Variation of irradiance and temperature"

The purpose of this scenario is to verify the behavior of the program with respect to variations in climatic conditions, including illumination and temperature at the same time, as well as their impact on the current and voltage generated by the solar panel. By applying different voltages to the battery, we found that the state of the battery behaves according to the instructions of the program. As shown in the figure below and Table III gives the different responses of the system due to the random variations of two parameters influencing at the same time the characteristic of the panel .

Table 3 results of the third scenario

Voltage of battery (V)	Voltage and current panel (V and A)	Power (W)	duty cycle %	State of charge	Colors of the LEDs
≈ 9	(17.50V – 0.56A)	9.86	83	BULK	Light blue
	(12.23V – 0.30A)	3.67	100	ON	Green light
	(17.23V – 0.20A)	3.45	100	ON	Green light
	(13.00V – 0.56A)	7.67	75	BULK	Light blue
≈ 12	(17.50V – 0.56A)	9.86	99	BULK	Light blue
	(12.23V – 0.30A)	3.77	100	ON	Green light
	(17.23V – 0.20A)	3.45	100	ON	Green light
	(13.00V – 0.56A)	9.66	80	BULK	Light blue
≈ 14	(17.50V – 0.56A)	9.86	60	FLOAT	All LEDs on
	(12.23V – 0.30A)	3.67	60	FLOAT	All LEDs on
	(17.23V – 0.20A)	3.44	60	FLOAT	All LEDs on
	(13.00V – 0.56A)	7.38	60	FLOAT	All LEDs on

From Table 3 we find that When we apply an optimal voltage and current(17.50V – 0.56A), the power obtained is sufficient for the battery to be in the "Bulk" position and the battery is charged quickly with the maximum power, and When we apply a weak voltage and current the power obtained is not sufficient for the battery to be in the "Bulk" position and this one will be in the "ON" position with the stepwise running of the program until the maximum voltage is reached, While when we apply a low voltage and an optimal current, the power obtained is sufficient for the battery to be in the "Bulk" position and the battery is charged quickly with maximum power, and When we apply a an optimum voltage and a low current, the power obtained is not sufficient for the battery to be in the "Bulk" position and the latter will be in the "ON" position with the step-by-step program until the maximum voltage is reached. The algorithm continues its calculations until reaching the maximum voltage across the battery, all the lights come on, this is the position "Float" or end of charging the battery, by the another protection loop ensures the automatic disconnection of the battery and the indicator light is red

5. Conclusion :

This paper presented a simulated and experimental study of the realization of a reliable standalone solar battery charging system capable of tracking the maximum power point using a perturb & observe technic in very low cost .

The experimental results in tables 1, 2 and 3 shows the system response at different stages of battery charging and ensure that storage batteries are protected from overcharging and under discharge limit as well as improving the efficiency of the photovoltaic generator.

The use of an ARDUINO UNO has reduced the expense of additional circuits needed to protect the storage element. Instead of using expensive sensors for current and voltage sensing, simple and cheap circuits using resistors are used.

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