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Performances evaluation of a photovoltaic energy system for lighting storage

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ABSTRACT

The increasing energy demand in the world and the pollution of nature directed the researchers to develop the axis of the renewable energies. The electricity production via these sources of energy offers a bigger safety of supply to the consumers while respecting the environment. For that reason, the principal objective of this paper is to study and to size a system of storage by photovoltaic intended for the lighting. We considered the variety of solar equipment occurring in these installations, such as solar panels, solar batteries, and conditions of the sites of installation (period of sunshine and temperature). Our approach of sizing is based on the modeling of various components describing the functioning of every part of the installation, among others. We can mention the production, consumption, and the storage of energy through a solar battery.

1. Introduction

Nowadays, much of the world's energy is provided by fossil sources. The consumption of these sources gives rise to emissions of greenhouse gases and thus to an increase in pollution (Cheon, 2019). Thus, renewable energy from the sun, wind, heat, earth, water, or biomass represents the future of the planet and represents an unlimited energy resource. However, electricity from renewable sources is intermittent and dependent on weather conditions. To do this, these renewable generators are usually coupled to a storage system providing continuous availability of energy. The renewable generator selected for this study is a photovoltaic array (PV) with a storage system that is ensured by the battery. This system is called PV-battery systems. The storage type generally used in this system is the lead-acid battery. However, the use of such a battery on a seasonal scale is unfeasible. To protect against excessive charging, we must disconnect them from the system, so it is impossible to use all of the renewable resources. To this end, our paper is structured in three parts: A general description and also the principle of operation for each element constituting the photovoltaic system presented. After that, we present and model each part of the system. Finally, the design and simulation of our solar storage.

2. Generalities

2.1. Structure of the photovoltaic system

Photovoltaic system storage can be composed by Petibon (2009):

- Photovoltaic generator
- Buck converter
- A system of regulation and control
- Storage battery
- DC load (solar lamp)
- Solar Electric cables

Various models have been suggested in the literature of a photovoltaic cell, like our model we proposed. A block diagram of a system of self-photovoltaic storage is shown in Fig. 1.

2.2. The photovoltaic cell

This is the basic element of solar panels which can:

- Absorption of the photons in the semiconductor
- The transfer of the photon energy to electrical charges

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There are different types of solar cells (η is the energetic efficiency of the cell):

- Monocrystalline cells $12\% \leq \eta \leq 16\%$
- Polycrystalline cells $11\% \leq \eta \leq 12\%$
- Cells Amorphous $16\% \leq \eta \leq 10\%$

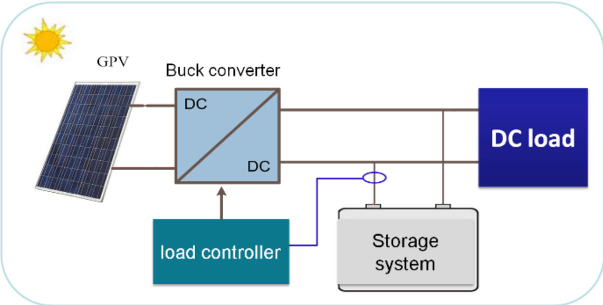

Fig. 1: Block diagram of a system of self-photovoltaic storage

2.3. Photovoltaic generator

The PV generator is a series/parallel combination of photovoltaic cells.

- Association series➔ increases the voltage
- Parallel association➔ increases the current

The interconnection of the PV cells or panels may be in series or in parallel, which leads to increase power.

2.4. The storage battery

We can use the solar system in two ways:

- With storage PV
- No storage PV

The two principal types of batteries currently used in the PV system are:

- The lead-acid battery
- Battery Nickel Cadmium

3. Modeling system storage PV

In this paper, we present the model of photovoltaic array and its characteristics and the model on the storage system (battery).

3.1. Modeling a PV cell

A photovoltaic cell can be modeled as a current source in parallel with a diode. However, when the intensity of light incident increases, the current is generated by the photovoltaic cell (Petibon, 2009). The equivalent circuit diagram of a photovoltaic cell, respectively, for ideal and real cases, were shown in Fig. 2.

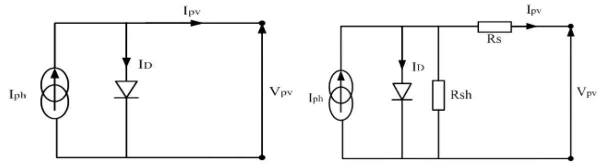

Fig. 2: Equivalent circuit diagram of a photovoltaic cell respectively for ideal and real cases

- Ideal case

$$Ipv = Icc\frac{E}{Er} + Kisc(T - Tr)\frac{E}{Er} - Is\left[\exp\left(\frac{Vpv}{Vt}\right) - 1\right] \quad (1)$$

- Real case

$$Ipv = Icc\frac{E}{Er} + Kisc(T - Tr)\frac{E}{Er} - Is\left[\exp\left(\frac{Vpv+RsIpv}{Vt}\right) - 1\right] - \left(\frac{Vpv+RsIpv}{Rsh}\right) \quad (2)$$

3.2. Modeling of a PV generator

The PV generator is a series/parallel combination of photovoltaic cells. The modeling of a PV generator is shown in Fig. 3. Fig. 4 shows the characteristics of the photovoltaic panel and Fig. 5 shows different values of the insolation when P=f(v) and I=f(v).

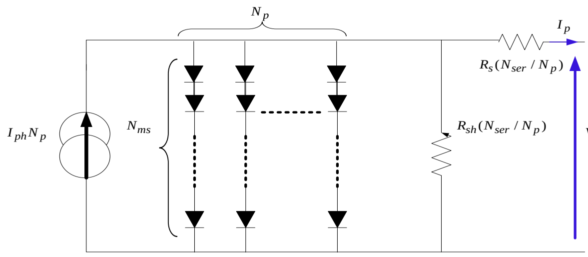

Fig. 3: Modeling of a PV generator

$$I_G = N_P I_{ph} - N_P I_0 \left(\exp\left(\frac{Vpv+RsIpv}{Vt}\right) - 1\right) \quad (3)$$

where, $N_p = 1$ and $N_s = 1$

We can see that the voltage is not affected when the irradiation decrease. I=f(v) and P=f(v) for different values of the temperature were shown in Fig. 6.

3.3. Modeling of the buck converter

Equation of the output voltage: is as follows:

$$(Ve - Vs)Ton = Vs(T - Ton) \quad (4)$$

3.4. Control for optimal operation of a Gpv

The tracking algorithm of maximum power point (MPP) the most frequently used and as the name suggests it is based on the perturbation of the system by increasing or decreasing the reference voltage (Vref), or directly on the duty cycle of the converter (DC-DC), and observing the effect on the output power for possible correction of the duty ratio (Kumar et al., 2013).

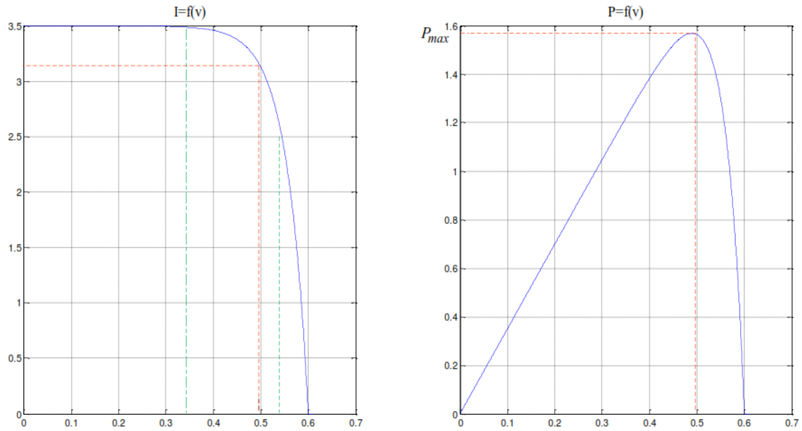

Fig. 4: I= f(v) and P= f(v) Characteristics of the photovoltaic panel

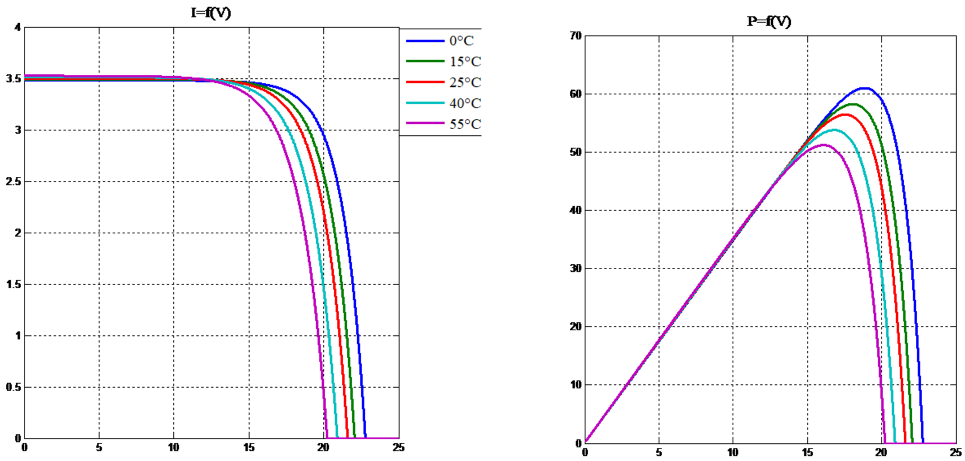

Fig. 5: P=f(v) and I=f(v) for different values of the insolation

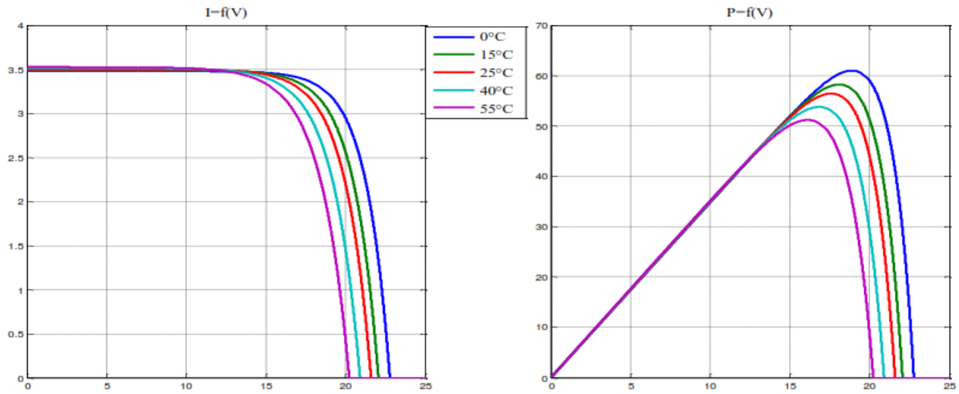

Fig. 6: I= f(v) and P= f(v) for different values of the temperature

If the value of the current power P (k) of the generator is higher than the previous value P (k-1) when the same direction is kept previous perturbation if we reverse the perturbation of the previous cycle (Kumar et al., 2013). The graphs of the algorithm perturbation and observation (P & O) is given by Fig. 7 and Fig. 8.

These drawings represent the trajectory of the points of maximum power for various values of insolation and temperatures.

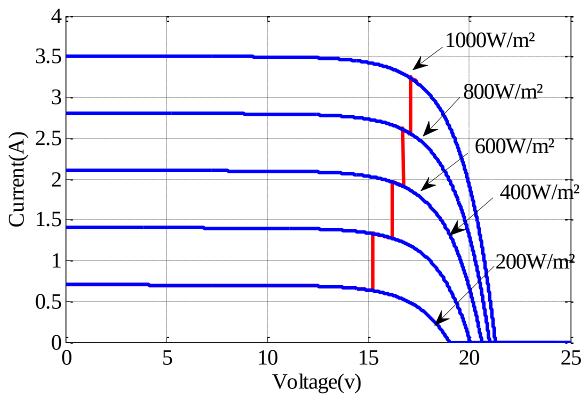

Fig. 7: Influence of insolation

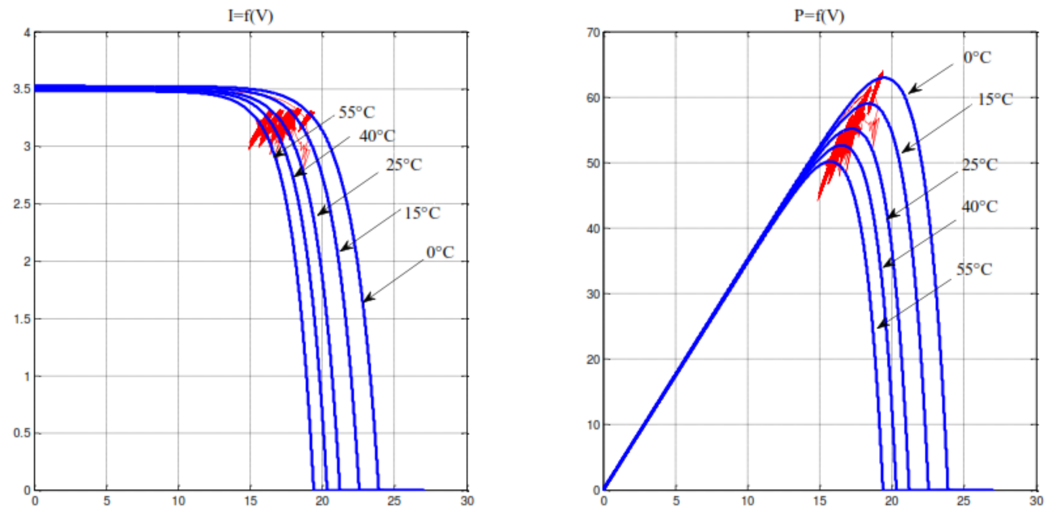

Fig. 8: Influence of temperature

3.5. Modeling the battery

Fig. 9 shows the electrical schematic of the battery.

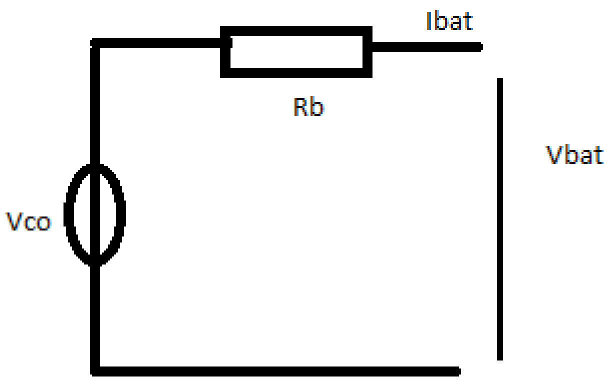

Fig. 9: Electrical schematic of the battery

- Model of battery charge (Maxwell, 1892),

$$C_{bat}(t) = C_{bat}(t-1)(1-\sigma) + (P_{pv}(t) - P_L(t))\mu \qquad (5)$$

- Model of the battery discharge (Maxwell, 1892),

$$C_{bat}(t) = C_{bat}(t-1)(1-\sigma) + (Pl(t) - PV(t)) \qquad (6)$$

where

$C_{bat}(t)$= amount of charge and discharge at time t
$C_{bat}(t-1)$= amount of load you discharge at time t-1
P_{pv}= Power PV panel
P_L = required load at time t
σ = the hourly load

- Battery voltage:

$$V_{bat}(t) = \eta_b\, V_{co}(t) + \eta_b I_{bat}(t)\ R_{bat}(t) \qquad (7)$$

- Battery-Current: $I_{bat}(t) = \frac{P_{pv}(t)-P_L(t)}{V_{bat}(t)}$ (8)
- Battery-efficiency: $\eta_{bat}(t) = \frac{P_{discharge}}{P_{charge}}$ (9)

4. Dimensioning and simulation system

4.1. Adjusting the plane PV

Photovoltaic Adjusting a level is to identify its direction and its inclination relative to the horizontal by the angle given.

The photovoltaic panel needs to be in an optimum position, so as to capture the maximum of solar energy.

In our case, the full south orientation of the panels can capture maximum light during the day.

The insolation is important for the period spanning from April to September, while for the other months, it is less important but remains significant since it exceeds 2000Wh/m^2/d.

Global insolation on an inclined plane is calculable with the following equation.

$$E' = \frac{E\,K'\cos(\theta-\beta-\delta)}{\cos(\theta-\delta)} \qquad (10)$$

where

θ: Latitude location
K': Correction factor sunshine
δ: Declination of the sun
β: Inclination of the plane PV

Fig. 10 shows insolation using a standard day of each month:

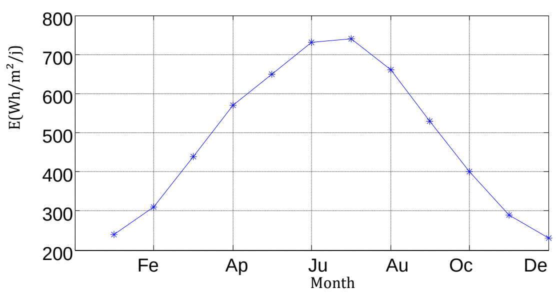

Fig. 10: Insolation using a standard day of each month

Dimension of the PV generator power of the module is:

$$P_{mp} = V_{mp}\, I_{mp} = 17.05 * 7.92 = 135W \quad (11)$$

The photovoltaic module monocrystalline chosen is because it benefits from several advantages (Maxwell, 1892):

- High Returns
- Power at high enough m^2
- High availability on the market
- Less sensitive to shading and temperature

Dimensioning of the battery is:

- *Voltage: 12V*
- *Autonomy: 2 days*
- *Rated capacity of the battery:*

$$C(Ah) = \frac{Consumption}{Voltage} Autonomy = \frac{500}{12} 2 = 83.33\ A \quad (12)$$

Using a battery of 100 AH for the kit can operate correctly.

4.2. Dimension of the buck converter

Interval limits the duty cycle α ε [αmin, αmax] such that:

$$\alpha_{max} = \frac{V_{bat\,max}}{V_{min}} = 0.7 \quad (13)$$

$$\alpha_{min} = \frac{V_{bat\,min}}{V_{max}} = 0.55 \quad (14)$$

4.3. Dimension of the control system and regulating

Dimensioning criteria of the control system are as follows:

- The value of sunset
- The luminosity
- Maintaining the operation.
- Maintaining the battery voltage above 10.6 VDC.
- Optimizing Battery Life

Table 1 shows the different sequences of operation control system and command (Chaurey and Deambi, 1992).

Table 1: The different sequences of the operation control system and command (Chaurey and Deambi, 1992)

	1	2	3	4	5	6
Types of power						
12 V	ON					
24 V	OFF					
Hours of operation:						
Sunrise and sunset	OFF	ON	OFF			
6 Hours	ON	ON	ON			
8 Hours	ON	ON	OFF			
10 Hours	ON	OFF	ON			
12 Hours	ON	OFF	OFF			
24 Hours	OFF	ON	ON			
8 seasonal Hours	OFF	OFF	ON			
10 seasonal Hours	OFF	OFF	OFF			
Test:						
Put on					ON	
Put out					OFF	

4.4. Simulation of the system storage

We note that the current of the PV module depends only on the level of sunlight. However, the current from the battery and the load depends on the level of insolation, the state of charge (SOC), and the energy requirement of the system. Fig. 11 shows Current waveforms of battery, Pv panel, and the load (1000 W/m²).

These drawings represent the shape of the power on the storage system in the highest and least sunny day. We note that the power generated from the PV module (Ppv) is proportional to the sunshine. But the powers of the battery (Pb) and the load (Pch) depend on the level of sunshine, state of battery charge, and system power consumption. Fig. 12 shows State of charge SOC.

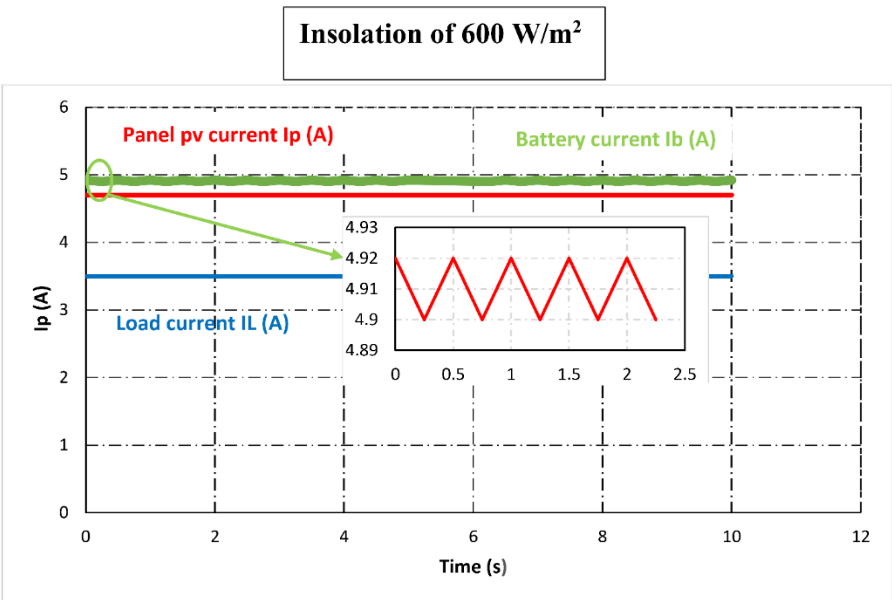

Fig. 11: Current waveforms of battery, PV panel and the load (1000 W/m²)

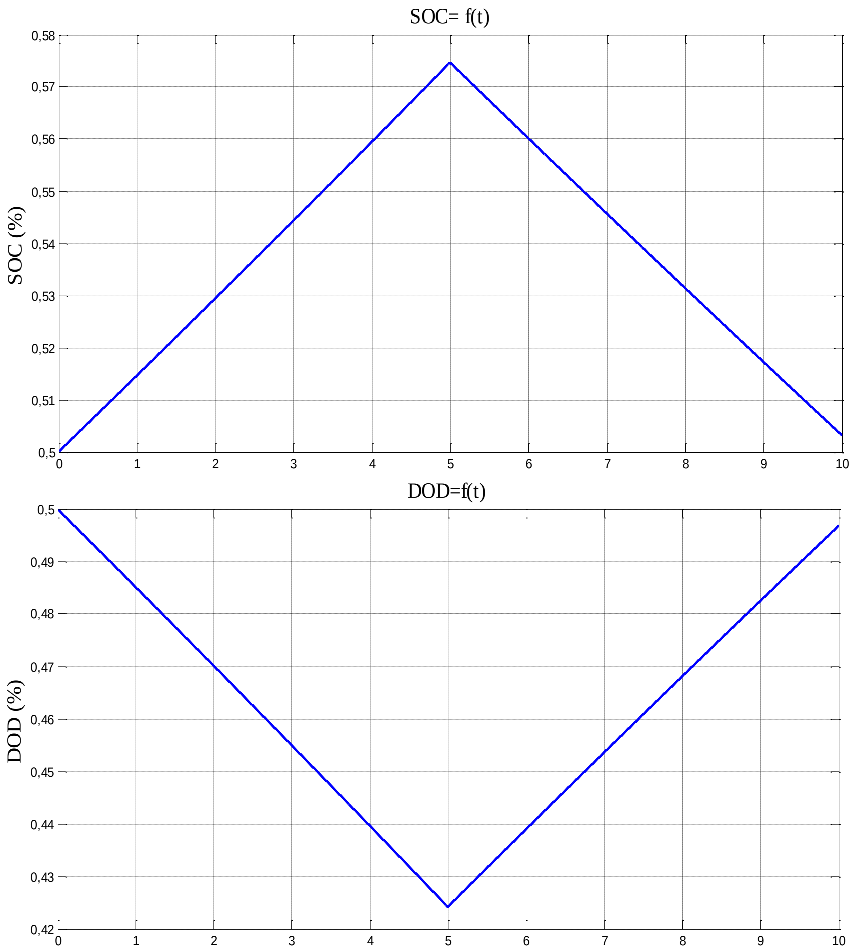

Fig. 12: State of charge (SOC)

These drawings represent the shape of the voltage on the storage system in the highest and least sunny day. Note that the voltage Vpv module exists only during the day and does not depend on changes in the sunshine. The battery voltage and the load exist for 24 hours and constant values.

These drawings indicate that the state of charge of the battery system remains constant during sunny and cloudy days, respectively (Divya and Østergaard, 2009).

Thus, it is clear that SOC does not depend on the level of sunshine during the day.

The maximum depth of discharge DOD battery has reached the fraction of discharge from the battery. We note that this profile is the complement to the unity of the state of charge SOC that does not exceed the maximum value is 40% designed (Divya and Østergaard, 2009).

5. Conclusion

The work presented in this paper focuses on the study and analysis of storage systems for low solar power for lighting off-grid. In general, this work has made the necessary solutions to problems related to the storage battery. In this regard, we have presented a description of the storage elements of the electrical energy. Generally, the energy storage is provided by lead-acid battery because of the large mass energies of their low cost.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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