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Optimization of the Energy Production of an Autonomous PV System with a Charge Regulator Simple

Jacques Marie Ilboudo[1,] Sosthène Tassembedo[2,] Prof. Zacharie Koalaga[3] and Prof FrancoisZougmoré[4]
Laboratory of Materials and Environment, Physics Department, University of Ouagadougou, Burkina Faso

Abstract:*The photovoltaic solar energy is a theme at center of the topicality since the world conscience hold of the warming of planet by the greenhouse effect and of the rarefaction of the primary resources(Oil, gas…).For solve theseproblems environmental and of energy, the development of the photovoltaic solar energy becomes primordial.The PV system is the device which allows exploiting this inexhaustible energy source. Currently we distinguish several types of which the one met usually in the isolated sites is the autonomous PV system.*
*In this article, we studied the modelling and the optimization of the functioning of an autonomous photovoltaic system equipped with a charge regulator simple.The study is made in considering tensions of 12 V and of 24 V of the storage system.The voltage in open circuit represents the only parameter of the PV field taken into account in this study. After the investigations, the results obtained show on the one hand that a suitable operation of charge or discharge, from a storage system is obtained if the discharge or charge current is weak. On the other hand, the study on autonomous PV system showed that the tension in open circuit of the PV field adapted for the optimal functioning of an autonomous PV system of 12V is in the fork between 16 V to 23 V. In the case of an autonomous photovoltaic system of 24 V, this beach of tension is between 34 V to 43 V.The tension in open circuit of PV field is under the conditions of 1000 W/m^2 and a temperature of 25 °C.****Keywords:****PV modules, storage system, charge regulator simple, photovoltaic solar energy, optimization.*

I. Introduction

Energy is an essential element for the development of the human being.Currently in the whole world, energy production is dominated by the conversion of the origin sources fossil. But the decrease of the world content of this source of energy and its negative impact on the environment [1-5], require of orienting the research on other energy sources alternative.The renewable energies represent today an unquestionable solution and the future of the world. The photovoltaic solar seen the number of advantages which it offers, is in this moment, among the renewable energies, the most relevant solution.Indeed, the use of photovoltaics solar produces no greenhousegases.And also, the raw material of the photovoltaic (the sun) is available and inexhaustible in the whole world. On the PV system existing, the system autonomous PV is the most utilized in the regions not or weakly covered from electric network.It exist two principal types of autonomous PV system. The autonomous PV system with a regulator MPPT which has an optimized production and thosewith a simple regulator, present an inferior efficacy compared to the first. However because of the high price of regulator MPPT in relation to the simple regulator, optimize the production of autonomous PV system to simple regulator would reduce its cost in kilowatt-hour. To solve this problem, we carried out a study whose theme is: Optimization of the energy production of an autonomous PV system with a charge regulator simple.This study aims to determine for each tension of 12 V or 24 V of the storage system, the interval of open circuit tension of the PV field appropriate to optimize the production of autonomous PV system with a charge regulator simple.

II. Material and method

The autonomous photovoltaic systems exist for a long time for numerous applications called "in isolated sites", i.e. without connection with an electric network. On the autonomous PV system, the technological progress have been carried out essentially on the device of impedance adaptation of PV field to optimize the production of this last. Few investigations have been carried out on the configuration appropriate of the PV field to improve the efficacy of stand-alone PV systems without an impedance adaptation system.
Astand-alone PV system in its constitution is essentially composed of[6,7]:

- A PV field;
- A storage system;
- A regulator of load;
- A converter;
- Protection systems ;
- Theelectricequipment.

The general representation showing the structure of an autonomous PV system generally met is presented on the figure 1 below.

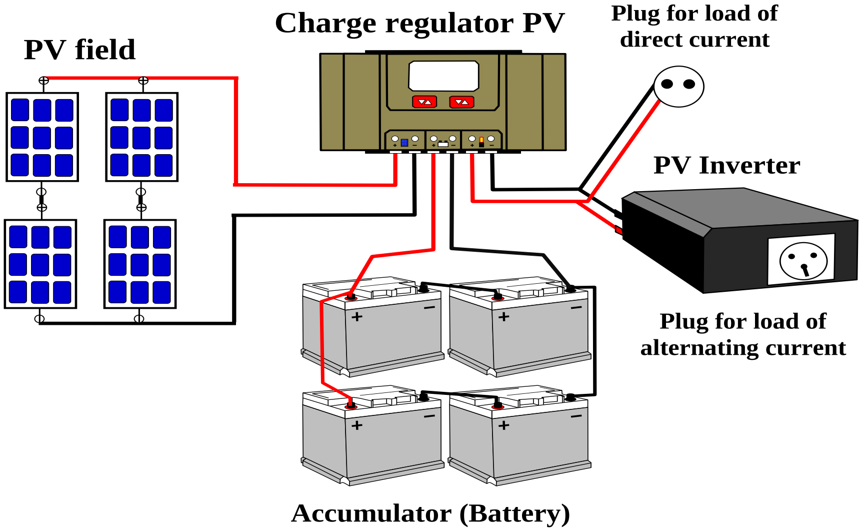

Fig.1: Representation of an autonomous PV system

The autonomous PV systems not equipped of a device of impedance adaptation are currently most widespread and least expensive.The major disadvantage in these PV systems is the direct dependence between the electric production of the PV field and the tension of the storage system.In fact, the power produced by the PV field depends of the point of intersection between the characteristic of current-voltage of the PV field and the one of storage system. To optimize then the production of the autonomous PV system, it is necessary that the point of intersection between the two characteristics (That of PV field and the storage system) is on or in the neighbourhood of the point of optimal functioning of the PV modules field. The methods that we will apply to determine the conditions necessary, for optimize the production of autonomous PV system, is founded on the tension in open circuit of PV field and the nominal voltage of the storage system. This method will consist totest by the simulation, several differ PV module on the autonomous PV system according to the nominal voltage from the storage system. The tension in open circuit of PV field adapted to the nominal voltage of thestorage system to the optimization of autonomous PV system will be thus deduced. The storage systems which will concern to the study are those whose nominal voltage is of 12 V and 24 V.The PV modules of the study will be those of the data base of the PVsyst software.

Thus for realize this study, of the investigations have been achieved on the modelling of the system autonomous PV. Of these investigations, mathematical models on the PV modules and the storage system were determined.

II.1 PV modules

II.1.1 Mathematical model for a photovoltaic module

A photovoltaic cell is the basic element of the conversion of the solar radiation into electricity.The association of several PV cells in series or in parallel constitutes a photovoltaic module.A PV cell is modelled by an electronic circuit which understands a source of current, a diode, a shunt resistance and a series resistance.The equivalent circuit of a PV module is almost identical to that of the PV cell represented by figure 2 below [8-14].

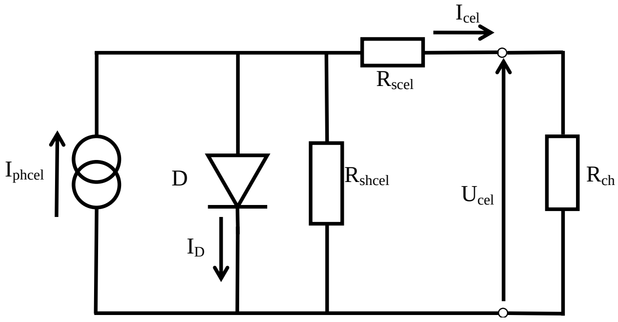

Fig. 2: Equivalent circuit of a photovoltaic cell

The characteristic equation of current - tension of the PV cell deduced from figure 2 above is[8-14]:

$$I_{cel} = I_{phcel} - I_{scel} \times (\exp(q \times \frac{U_{cel} + R_{scel} \times I_{cel}}{k \times T_{cel} \times n}) - 1) - \frac{U_{cel} + R_{scel} \times I_{cel}}{R_{shcel}} \quad (1)$$

In this equation 1, I_{phcel} is the photo-current of PV cell, V_t the thermal tension and I_{scel}, the saturation current of the diode of the PV cell. Thesedifferentmagnitudes are expressed with the relations 2; 3 and 5 below[8-18].

$$I_{phcel} = \frac{G}{G_{réf}}[I_{phcelréf} + \mu_{Isc} \times (T_{cel} - T_{celréf})] \quad (2)$$

$$I_{scel} = I_{scelréf} \times (\frac{T_{cel}}{T_{celréf}})^3 \times \exp[\frac{q \times E_g}{n \times k} \times (\frac{1}{T_{celréf}} - \frac{1}{T_{cel}})] \quad (3)$$

$$T_{cel} - T_a = \left(\frac{NOCT - 20}{800}\right) G \quad (4)$$

$$V_t = \frac{k \times T_{cel} \times n}{q} \quad (5)$$

The equations 6 to 11 give the relations between the parameters of PV cell and those of the PV module[8, 10, 11].

$$I_{cel} = \frac{I_{mod}}{N_{cp}} \quad (6)$$

$$U_{cel} = \frac{U_{mod}}{N_{cs}} \quad (7)$$

$$R_{scel} = \frac{R_{smod} \times N_{cp}}{N_{cs}} \quad (8)$$

$$R_{shcel} = \frac{R_{shmod} \times N_{cp}}{N_{cs}} \quad (9)$$

$$I_{scel} = \frac{I_{smod}}{N_{cp}} \quad (10)$$

$$I_{phcel} = \frac{I_{phmod}}{N_{cp}} \quad (11)$$

The characteristic current -tension of a PV module expressed by expression 12 below, is deduced from the relation 1 and of the equations 6 to 11 above.

$$I_{mod} = I_{phmod} - I_{smod} \times (\exp(q \times \frac{U_{mod} + R_{smod} \times I_{mod}}{k \times T_{cel} \times n \times N_{cs}}) - 1) - \frac{U_{mod} + R_{smod} \times I_{mod}}{R_{shmod}} \quad (12)$$

II.1.2 Reference model of the PV modules

For the study, we will consider the technical data of about twenty PV modules of different voltage in open circuit and we will present the results gotten of the PV modules displayed in the table below.

Table 1: Electrical characteristics data of PV modules

Letter assigned to PV module	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Mark	HeliosTechnology	Tenesol	PVT Austria	HeliosTechnology	Bosch Solar Energy AG	Sun Earth Solar Power Co Ltd	Suntech	SunPower
model	HT 70	TE70-36M-CR+	PVT-100AE-A	HT 230	BSM c-SI M 60 IN 301 25_V1_23	TPB156X156-72-P 230W	HiPerformaPLUTO200-Ade	SPR-230E-BLK-D
Uoc	20 V	22.1 V	26.4V	37V	37 V	43 V	45.4 V	48.2 V
Isc	5A	4.2A	4.8A	8.3A	8.4A	7.5 A	5.8 A	6.05 A
Uop	16	17.5V	22.2V	30.5V	29.7V	34 V	36.6 V	40.5 V
Iop	4.4 A	4A	4.42A	7.5A	7.9A	6.77 A	5.48 A	5.68 A
Pop	70W	70W	100 W	230W	230W	230W	200 W	230W

II.2 Model of the storage system

Solar energy is an energy intermittency source whose exploitation into photovoltaic requires a system of storage for supply of the electrical appliances during the unfavourable periods.The storage system usually utilized in the photovoltaic systems is generally constituted of batteries.From these batteries we distinguish several types of which those frequently met are presented on the table 2below [20].

Tab.2: Performance of differ type from batteries

Battery type	Yield	Cycle 100 %	Cycle 80 %	Cycle 33 %	Densities and mass (Wh/kg)
Li-ion	0.85 – 0.95	3000 - 5000	5000 - 7000	7000 - 10000	80 - 120
NiMH	0.65 – 0.85	600 - 1000	800 - 1200	2800 - 3000	35 - 55
NiCd	0.65 – 0.85	300 - 500	1000 - 1500	4800 - 6000	22 -30
PbA	0.7 – 0.84	320 - 800	400 - 1000	900 - 2000	20 - 32
VRB	0.6 – 0.8	2800 -3000	3000 - 4000	7000 - 8000	15 - 20

On the level of PV systems, the acid lead batteries are the most utilized. In the literature several mathematical models of which the one developed by CIEMAT allows to study the behavior of the acid lead batteries.This model is based on the electronic circuit of the figure 3.The battery is modelled in this case by atension source and a resistance [25,26].

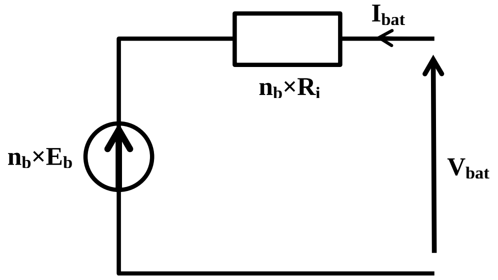

Fig.3 Equivalent electric circuit of nb elements accumulator in series

In considering nbaccumulator cells in series, the terminal voltage of a battery is given by expression 13 below [25, 26].

$$V_{bat} = n_b \times E_b + n_b \times R_i \times I_{bat} \tag{13}$$

During the functioning of the battery, the evolution of the capacity Q (t) is described by the equation 14 below.

$$Q(t) = \int I(t)dt \tag{14}$$

In charge, the evolution of the terminal voltage of a battery is deduced from expression 15

$$U_C = n_b \times (2 + 0.16 \times EDC_c) + n_b \times \frac{I_{bat}}{C_{10}} \times \left(\frac{6}{1 + I_{bat}^{0.86}} + \frac{0.48}{(1.04 - EDC_c)^{1.2}} + 0.036 \right) \times (1 - 0.025 \times (Tam - Tref)) \tag{15}$$

With $EDC_c = EDC_{c0} + \dfrac{Q(t)}{C_{bat}(t)}$ (16)

The behavior of the terminal voltage of a battery during the operation of discharge is given using relation 17 below.

$$U_d = n_b \times (2.085 - 0.12 \times (1 - EDC_d)) - n_b \times \frac{|I_{bat}|}{C_{10}} \times \left(\frac{4}{1 + |I_{bat}|^{1.3}} + \frac{0.27}{(0{,}04 + EDC_d)^{1.5}} + 0.02 \right) \times (1 - 0.007 \times (Tam - Tref)) \quad (17)$$

Where $EDC_d = EDC_{d0} - \frac{Q(t)}{C_{bat}(t)}$ (18)

A battery is degraded according to its mode of use. To slow down this degradation, the photovoltaic regulators are installed in PV system.

II.3 Regulator of charge

The regulator of charge / discharge is a device placed between the PV module and the battery on the one hand and on the other hand between the battery and the electric equipment.The photovoltaic regulator protects the battery against the discharges deep and the overloads. This protective characteristic of the regulator, limits the evolution of the terminal voltage of the battery or the storage system to a beach of tension. According to the nominal voltage of the storage system, the table 3 belowpresents the tensioninterval of the battery limited by the photovoltaic regulator.

Tab.3: Voltage beach of the battery according to its nominal voltage

Nominal voltage of the storage system	Minimal discharge voltage authorized by the regulator	Maximum charge voltage authorized by the regulator
12 V	11.2 V	14.7 V
24 V	22.4 V	29.4 V

Currently we distinguish two types of photovoltaic charge regulator simple. The charge regulator series of which its protection mode of the battery is of open the connection circuit of the PV field at storage system.The charge regulator shunt, short-circuit the PV field to reduce the charging current of the storage system. The choice of a charge regulator must make itself according to the tension in open circuit and of the intensity of the current of short-circuit of PV field.The intensity of short-circuit current of PV field must satisfy the relation 19 below for the correct functioning of PV system.

$$I_{scPVfield} = \frac{I_{Cadr}}{1.2} \quad (19)$$

II.4 Measurement device of the solar irradiation and the temperature of PV module

It is necessary to constituteof the data on the solar irradiation and the temperature of PV modules for realized of simulations of the behavior of PV system.The device presented on the figure 4 below is realized to obtain these climatic data.This device is composed of a PV module, a measurement device of the solar radiation, a thermocouple K and a data acquisition system (KEITHLEY 2701).The measurements realized on these climatic data are made in considering of measurementssteps of two second.

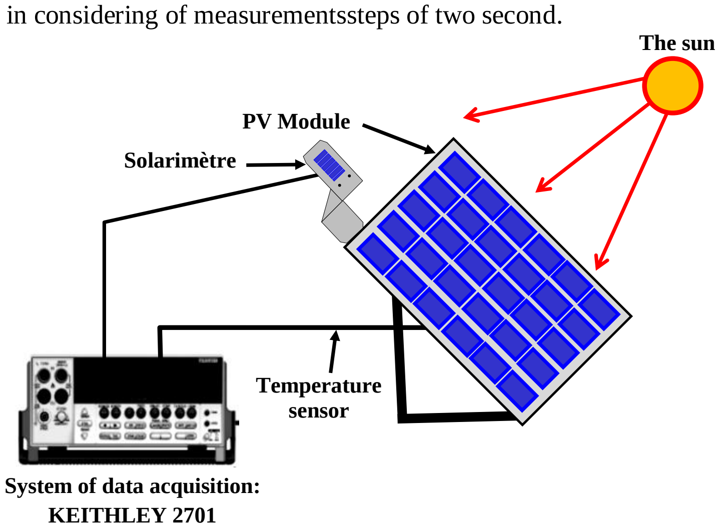

Fig.4: Data acquisitionexperimental device

III. Result and discussion

III.1 Results of the experimental study of the solar irradiation and the temperature of PV module:

The measurements of the solar irradiation and the temperature of the PV modules realized with the device of the figure 4 above,will allow integratingthe climatic data in the mathematical model for thesimulation realization of thePV system behavior.Themeasurementsresults of these climatic data obtained are presented on the figure 5 below to help of the Easy Plot software.

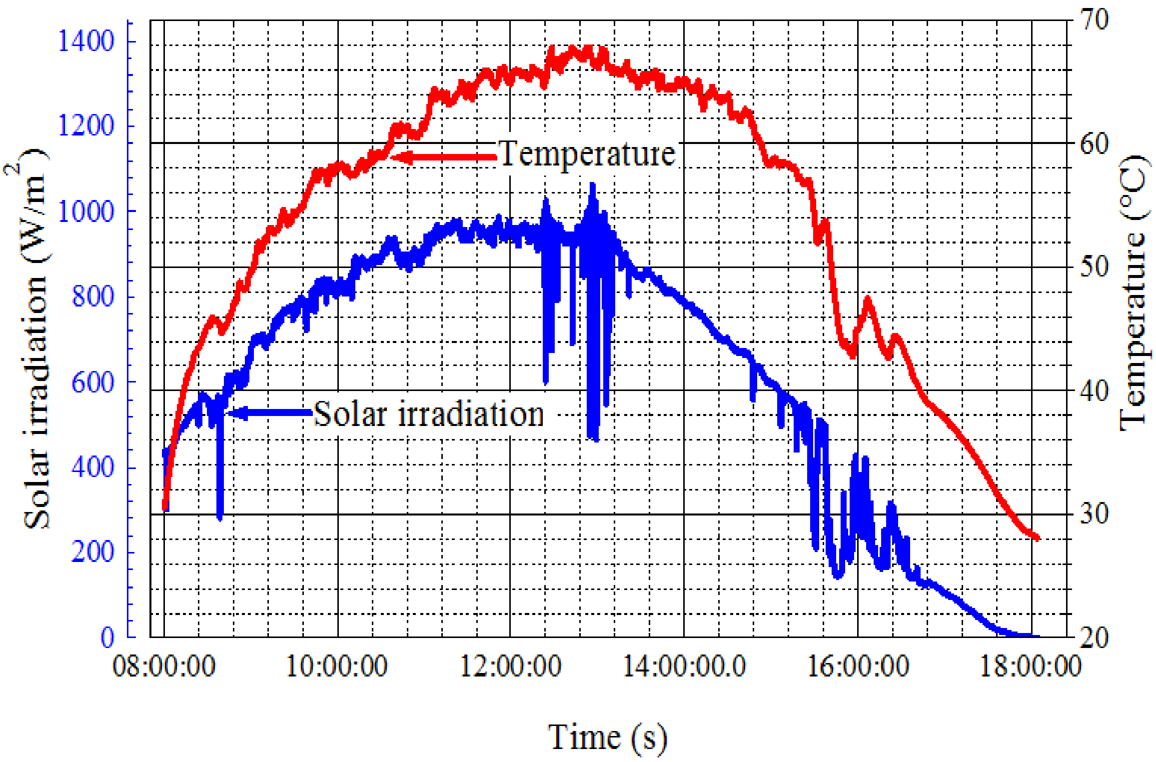

Fig.5 Evolution of the solar irradiation and of the temperature of a PV module during one day

In observing this figure 5, we notice that the curve of the solar irradiation and the one of the temperature presents a similar evolution.The maximum solar irradiation measured towards 13 hour is of 1062.64 W/m^2 and the temperature recorded is of 66.52°C.By example, we present on the table 4 below, some values of the solar irradiation and of the temperature of PV module measured at certain hours of the day.We will refer to these values in the study of the simulation of PV system.

Tab.4 :Climatic data

Hour of the day	Measuredsolarirradiation	Temperature measured on PV module
13 h	1062.64 W/m^2	66.52 °C
12 h	958.35 W/m^2	64.85 °C
11 h	910.19 W/m^2	61.2 °C
10 h	818.2 W/m^2	48.2 °C
9 h	668.2 W/m^2	49.5 °C
8 h	430.4 W/m^2	30.6 °C

III.2 Simulation result on the behavior of a battery

A battery is anenergy storage device of which thefunctioning depends of several electric parameters such as the tension, the current and the charge state.In this part we did a simulation of the behavior of a battery, in putting the effect of the charge current and the current of discharge on the behavior of the terminal voltage of the battery in evidence.The results obtained with the formulas 13 to 18 above are presented on the figures 6 and 7 below.

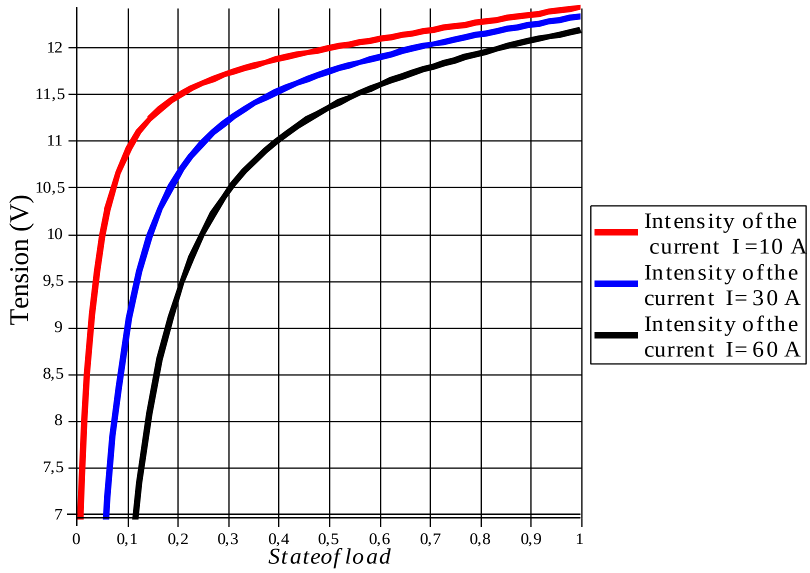

Fig.6: Curves ofdischarge of the lead-acid battery to different regimes

The graph above shows that the terminal voltage of a battery decreases with the fall of the charge state of the battery.This decrease of the terminal voltage of the battery is accentuated when the battery undergoes the discharge with an elevated current.With the negative effect of the deep discharge on the lifespan of the battery, the terminal voltage of the battery during the operation of discharge is limited by the charge regulator generally to 11.2V.In considering this limiting value of the terminal voltage of the battery and the figure 6 above, we determined the charge state of the battery according to the current of discharge.The results are displayed on the table 5below.

Table.5: Charge state of the battery according to the discharge currentfor a tension of 11.2 V

Currentintensity of discharge	Charge state of the battery
10 A	14.2 %
30 A	29.8 %
60 A	45.26 %

The data of the table 5 above show that the capacity available of a battery depends of the discharge mode. More a battery is unloaded quickly (with a discharge current important), more the available capacity is weak.That is probably due to the phenomenon of diffusion of the ions.Indeed with a current of discharge of 60 A, we can discharge to the maximum on a battery of 300 Ah, 54.74 % of stored energy in battery. On the other hand with a current of discharge of 10 A, 85.8 % of the energy stored in the battery isrecoverable.

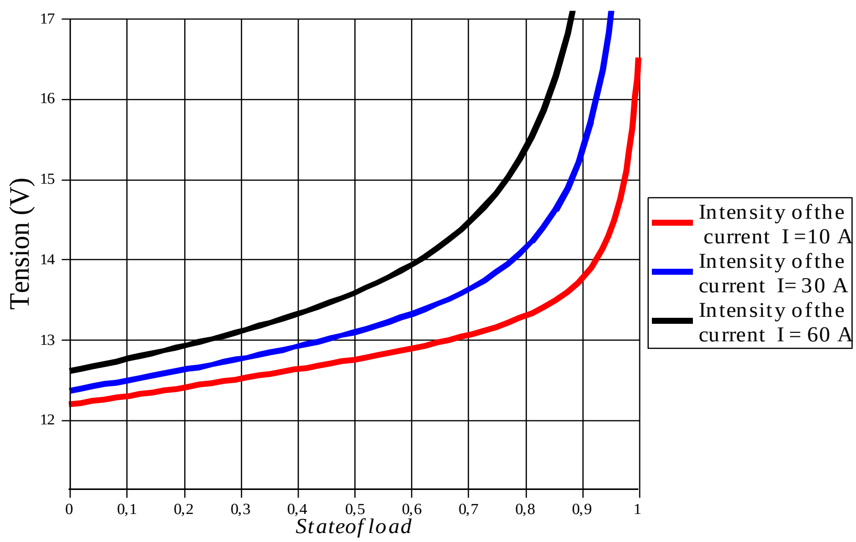

Fig.7: Curves of charge of the lead-acid battery to different regimes

The figure 7 above shows that the terminal voltage of a battery increases with the rise of the charge state of the battery and the charge current.In an autonomous PV system, to protect the battery from the overload, the terminal voltage of the battery is limited by the charge regulator generally to 14.7 V.In considering figure 7 above, we determined the charge state according to the charging current of a battery of 300 Ah with a tension of 14.7 V.The results are displayedon the table 6below.

Table.6: Charge state of the batteryaccording to the chargingcurrent for a tension of 14.7 V

Intensity of chargingcurrent	State of charge
10 A	96.7 %
30 A	86.3 %
60 A	73.7 %

The data of the table 6 above show that the maximum storage capacity of energy of a battery decreases if during thecharge operation, the current intensity applied to the battery is important.Indeed, in carrying out an operation of chargeof a battery of 300 Ah with a current of 60 A, we can store to the maximum that 73.7 % of the total capacity of the battery.On the other hand with a charge current of 10 A, the battery is loaded up to 96.7 % of the total capacity.From these results,we deducethat an operation of optimal charge or ofoptimal discharge of a battery is gotten if the charge current or the discharge current applied to the battery is weak.

III.3Optimalfunctioning of a PV module according to the beach of tension of the battery

In this part, we did a simulation on the optimization of an autonomous PV system with a charge regulator simple in considering two types of storage system of a capacity of 300 AH. The storage system of 12 V and of 24 V.The yield of the charge regulatorwillbe 0.94. This simulation will be carried out according to each PV module of table 1 above, the climatic data on of figure 5 and also in considering the nominal voltage of the storage system.

The simulation of the autonomous PV system with each PV module A, B, C and D is made with the storage system of 12 V. By against the study of the behavior of the autonomous PV system with each PV module E, F, G, H will be made with the storage system of 24 V. These simulations will be realized in basing itself on the current-voltage characteristic of the PV module and also on the energy production by Watt- peak of each PV module of the table 1 in the autonomous PV system.

III.3.1 Functioning optimal of a PV module according to the beach of tension of a battery of 12 V

The simulation results obtained from formulas 12 to 18 aboveand the data of table 1 are presented on the 5 figures below.

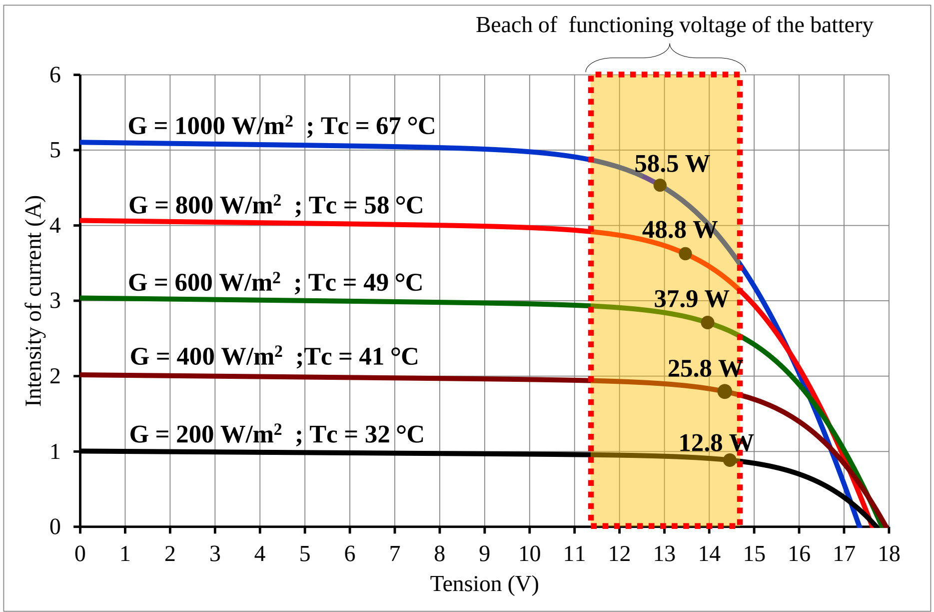

Fig.8: Position of theoptimal functioning points of PV module (A) in relation to the beach offunctioning tension of a battery of 12 V

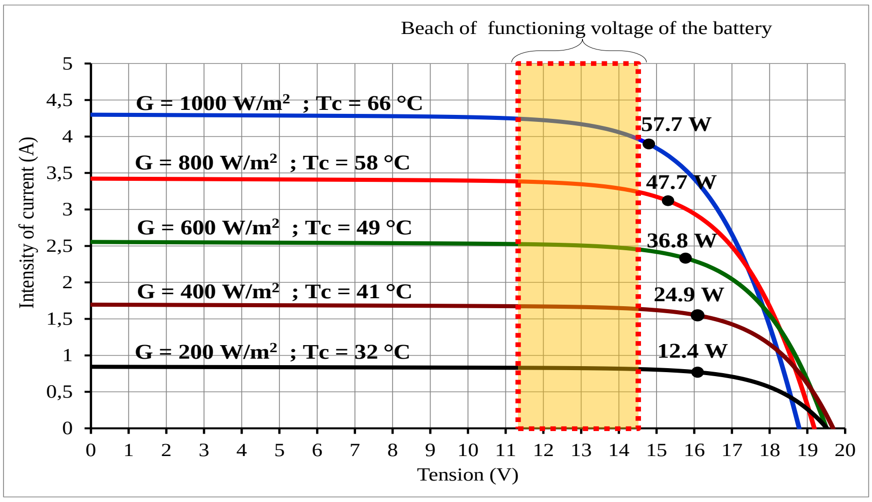

Fig.9: Position of theoptimal functioning points of PV module (B) in relation to the beach of functioning tension of a battery of 12 V

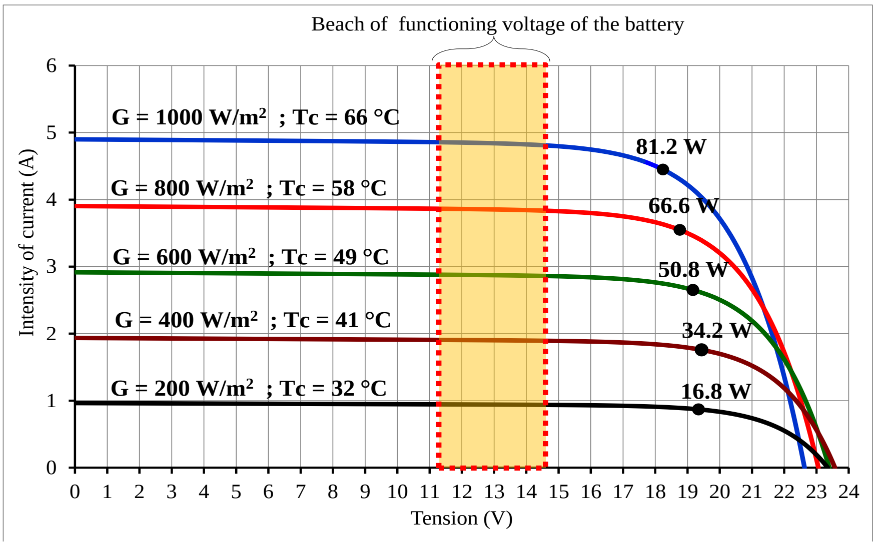

Fig.10: Position of theoptimal functioning points of PV module (C) in relation to the beach of functioning tension of a battery of 12 V

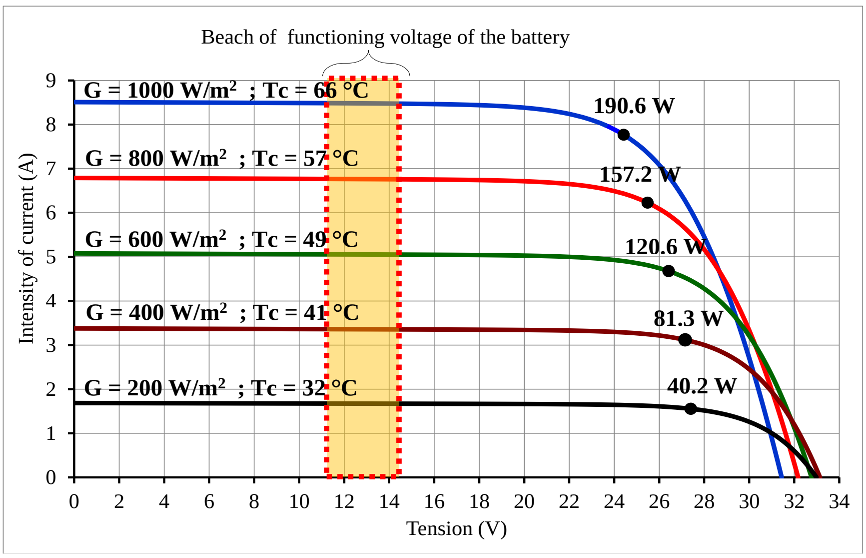

Fig.11: Position of theoptimal functioning points of PV module (D) in relation to the beach offunctioning tension of a battery of 12 V

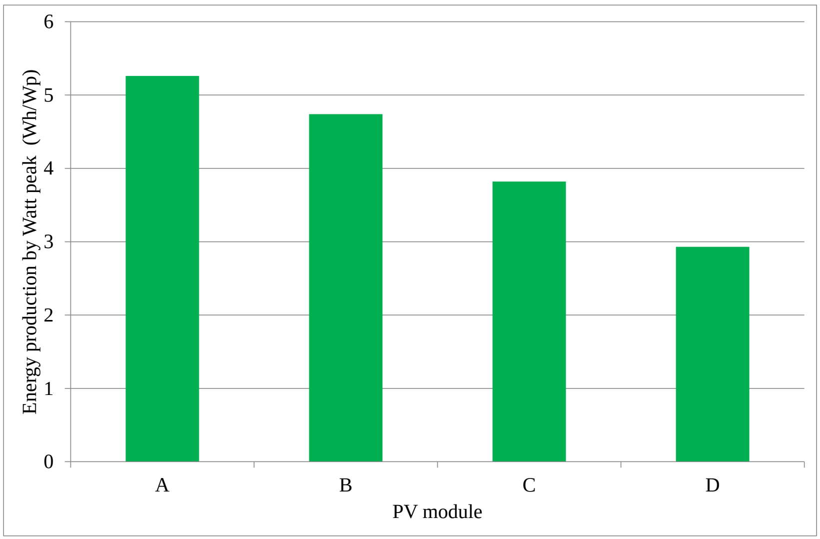

Fig.12: Energy production by watt- peak of the autonomous PV system of 12 V according toPV modules A, B, C and D

In an autonomous PV system with a charge regulator simple, thefunctioning point of the PV field is fixed by the terminal voltage of the battery [27]. The optimal production of this type of PV system depends then of the evolution of the terminal voltage of the battery in relation to the tension at point of optimal functioning of the PV field. Indeed on the figures 8 and 9 we note that the points of maximum power of the PV modules A and B are all practically at the inside or at proximity of the beach of functioning voltage of the battery.By against, those of PV modules C and D on the figures 10 and 11 are very distant from this beach of functioning tension of the battery. Also the energy productions by watt - peak of the PV modules A and B, shown by the figure 12above, are superior at that of the PV modules C and D. Therefore, only the PV modules A and B can provide an optimal energy production in an autonomous PV system of 12 V withoutimpedance adaptation device. The PV modules A and B provide an open circuit voltage less than 23 V.Thoseprovide bythe PV modules C and D are superior to 23 V. Thus the optimal functioning of an autonomous PV system of 12 V with a charge regulator simple depends of the choice of the PV module or the conception of the PV field according to the tension into open circuit. From these investigations and those done on other PV modules or PV field, we conclude that an autonomous PV system of 12V with a single charge controller can function of optimal way if the open circuit voltage of the PV field underthe conditions of 1000W/m^2 and 25 °C is in interval of 16 V to 23 V.

III.3.2 Functioning optimal of a PV module according to the beach of tension of a battery of 24 V

In this part, the study is done on an autonomous PV system of 24 V with a charge regulator simple. The results obtained of this research are represented on the figures below.

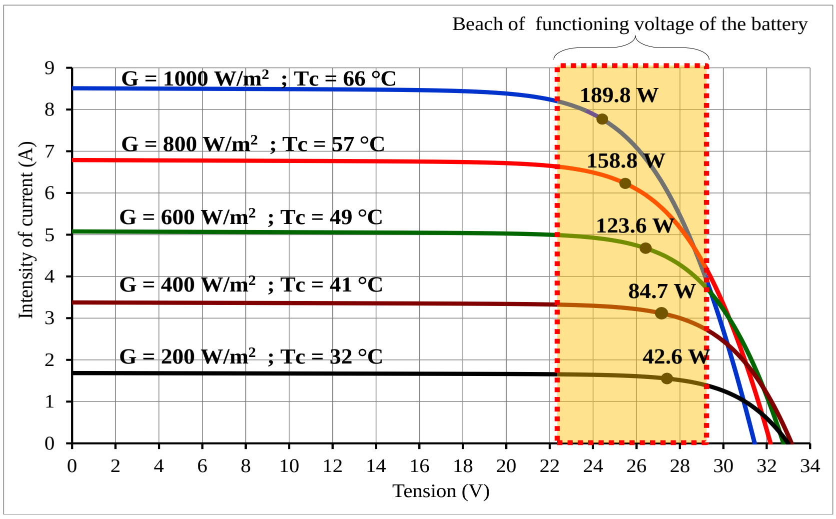

Fig.13: Position of theoptimal functioning points of PV module (E) in relation to the beach of functioning tension of a battery of 24 V

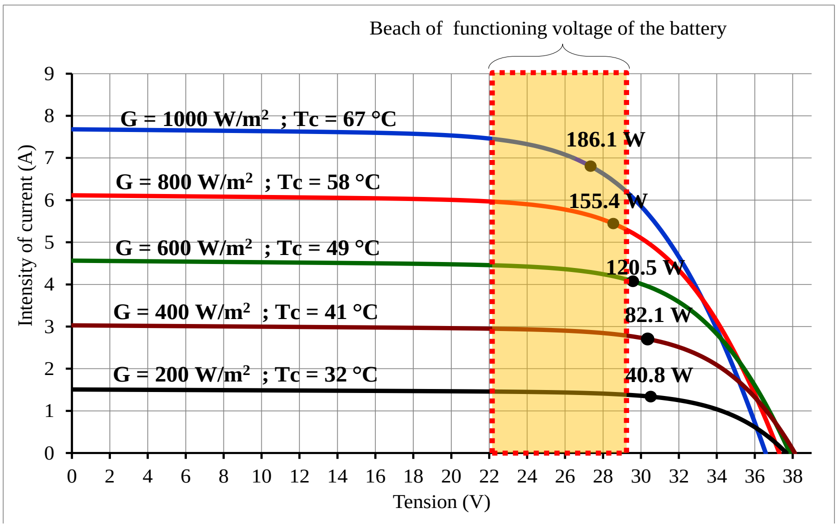

Fig.14: Position of theoptimal functioning points of PV module (F) in relation to the beach offunctioning tension of a battery of 24 V

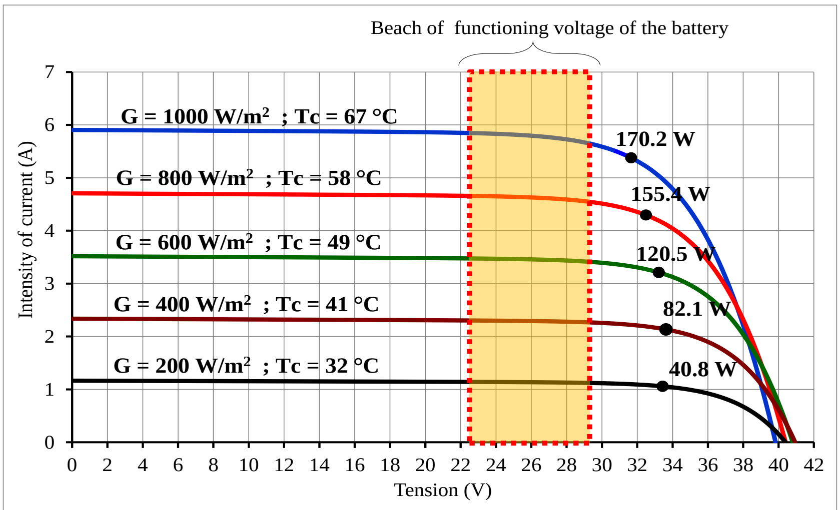

Fig.15: Position of theoptimal functioning points of PV module (G) in relation to the beach offunctioning tension of a battery of 24 V

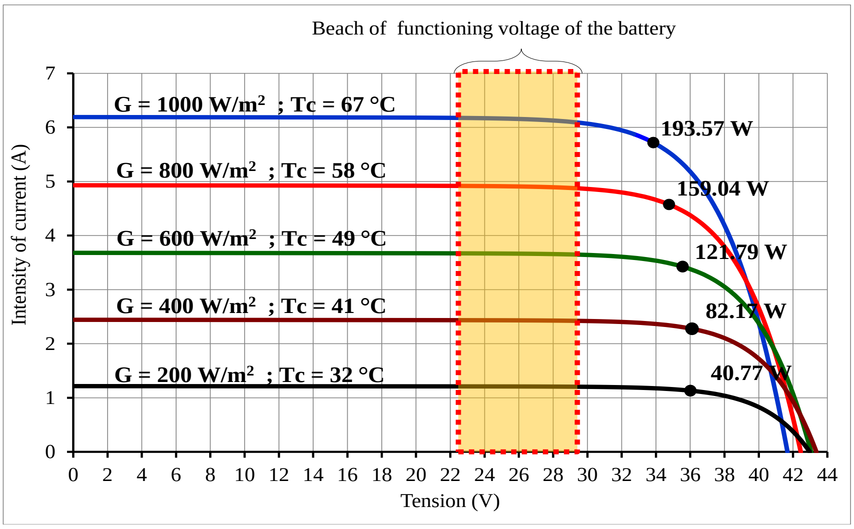

Fig.16: Position of theoptimal functioning points of PV module (H) in relation to the beach offunctioning tension of a battery of 24 V

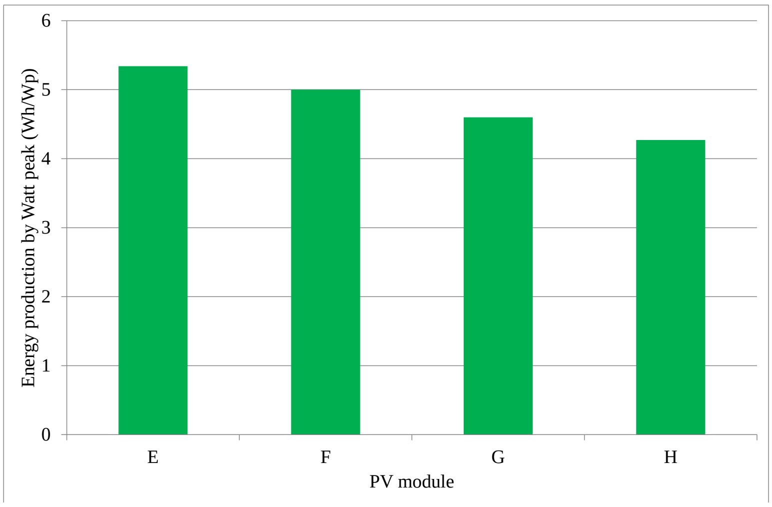

Fig.17: Energy production by watt-peak of the autonomous PV system of 24 V according toPV modules E, F, G and H

Like that of autonomous PV system of 12 V, we also notice, that the functioning of an autonomous PV system of 24 V with a charge regulator simple depends of the choice of PV modules according to the tension in open circuit. Indeed observing the figure 13 to 16 and also the energy production by watt-peak of the PV modules in autonomous PV system presented on the figure 17, we note that the PV modules E and F are appropriate in an autonomous PV system of 24 V. From these results and those obtained with other PV modules, we deduce that an autonomous PV system of 24 V with a simple charge controller can function of optimal way if the open circuit voltage of the PV field under the conditions of 1000 W/m^2 and 25 °C is between 34V to 43 V.

IV. Conclusion

In this article, we did a work which led us to model a PV module and a storage system. These models then enabled us to make simulations on these elements. The results of these simulations obtained show that an adequate operation of discharge or of charge of a storage system is obtained with a weak current of charge or of discharge. Concerning the study on the optimization of the autonomous PV system with simple regulator of the appreciable results are obtained. These results show that the appropriate choice of a PV module according to the tension into open circuit to realize an autonomous PV system with charge regulator simple is very important to optimize the production of PV system. Indeed with a tension of 12 V of a storage system, the range of the open circuit voltage of PV field to optimize the production is understood between 16 V to 23 V. With a system of storage of tension of 24 V, this beach of the tension in open circuit of the PV field appropriate to optimize the production is between 34 V to 43 V. The open-circuit voltage of the PV field isconsidered underthe conditions of 1000 W/m^2 and a temperature of 25 °C.

Abbreviations	
I_{cel}	Current of the PV cell
U_{cel}	Voltage acrossthe PV cell
I_{phcel}	Photo-currentof thePVcell
$I_{phrefcel}$	Photo-current of the PV cell in the reference conditions
I_{scel}	Reverse saturation currentof the diode of thePVcell
$I_{srefcel}$	Reverse saturation currentofthediodeofthePVcellinreference conditions
R_{scel}	Seriesresistanceof thePVcell
R_{shcel}	Shuntresistance of thePVcell
G	Solar radiation(W/m^2)
G_{ref}	Solar radiation (W/m^2) inthereference conditions
I_{mod}	Current of the PV module
U_{mod}	Voltage acrossof the PV module
I_{phmod}	Photo-current of the PV module
$I_{phrefmod}$	Photo-current of the PV module in the reference conditions
I_{smod}	Reverse saturation currentof the diode of the PV module
$I_{srefmod}$	Reverse saturation currentof the diode of the PV module inthereference conditions
R_{smod}	Seriesresistanceof thePV module
R_{shmod}	Shuntresistance of thePVmodule
I_{sc}	Short circuit current
μ_{Isc}	Temperature coefficient oftheshort circuit current
U_{oc}	Open circuit voltageof the PV module

k	Boltzmann constant
q	Electron charge
T_{cel}	Temperature of thePVcell
T_a	Ambient temperature
T_{celref}	TemperatureofthePVcellinthe reference conditions
NOCT	Nominal functioning temperature of the PV cell
n	Quality factor
E_g	Energygap
N_{cs}	Number of PV cellsconnected in series
N_{cp}	Number of branches of PV cells
C_b	Batterycapacity
V_{bat}	Voltage acrossthe battery
Vc	Terminal voltage of the battery during the operation of the charge
Vd	Terminal voltage of the battery during the operation of the discharge
$I_{scPVfield}$	Intensity of the short-circuit of PV field
I_{cadr}	admissible current intensity of the regulator
Ri	Resistanceinternsbattery
EDC_c	State of charge of the battery during the charge operation
EDC_d	State of charge of the battery during the operation of the discharge
EDC_{c0}	Initialcharge state of the battery during thecharge operation
EDC_{d0}	Initialcharge stateof the battery during the operation of the discharge
I_{bat}	Current Intensity of the battery
Tam	Temperature of the batteries
Tref	Functioning temperature of the battery under the reference conditions
PbA	Lead–acid
NiCd	Nickel–cadmium
VRB	Vanadium
NiMH	Nickel–metal hydride
U_{op}	Optimalvoltage PV module
I_{op}	Optimalintensity ofcurrentof the PV module
P_{op}	Optimal power of the PV module

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