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MODELING AND SIMULATION OF THE ENERGY STORED AND DELIVERED BY A BATTERY IN AN AUTONOMOUS PHOTOVOLTAIC SYSTEM

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ABSTRACT

This work presents the modeling and simulation of the energy stored and delivered by a battery in an autonomous photovoltaic system. In this system, the energy accumulator is the main element but also the most fragile element. This justifies the great attention paid to this device. During this work, we used the CIEMAT model which was developed to study the performance of a lead acid battery in the Sahelian zone. The simulation allowed us to describe the operation of the lead acid battery through the prediction of the state of charge (EDCc) and the charge voltage (VC) on the one hand, the depth of discharge (EDCd) and the discharge voltage of other parts, for several values of the temperature. Comparison of the results obtained with the work of other researchers reveals a good prediction of the energy stored and delivered by a lead acid battery used in the autonomous photovoltaic system.

KEYWORDS: Modeling, photovoltaic system, battery, voltage, intensity.

1. INTRODUCTION

Two billion people in the world do not have access to electrical energy [1]. However, this energy is not only a simple comfort service, it also provides access to drinking water, to more efficient healthcare services, and promotes the growth of socio-economic activities. It plays a key role in the development of developing countries. The production of electrical energy is dominated by the transformation of fossil-based resources, which has an impact on the environment. This situation requires the development of alternative energy sources with limited impact. The use of technologies using renewable energies is competitive with conventional solutions. Among the renewable energies, photovoltaic energy presents itself as a solution of the future because it offers a multitude of advantages. Its production does not emit greenhouse gases [1]. In addition, the sunlight being available everywhere and inexhaustible, photovoltaic energy can be exploited everywhere in the world [2]. However, due to day-night alternations, the energy produced by the photovoltaic panels is not available at all times [3]. To solve this intermittency problem, energy storage for later use is essential. We now have different types of accumulators for storing photovoltaic energy. But, they are one of the weak links in photovoltaic systems. To improve the functioning of the production system it is necessary to optimize the storage system ([4], [5], [6], [7]). It is in this problem that our study is situated. The aim here is to find the optimal conditions for the use of a storage battery through modeling that offers economic, environmental and energy benefits.

2. MATERIALS AND METHODS

Photovoltaic cells:

The photovoltaic cell or formerly called solar cell is the building block of photovoltaic modules. These are combined in series and in parallel to obtain the desired voltage and current. We will call "photovoltaic generator" the energy sub-system made up of the panel-battery assembly and producing electrical energy by photovoltaic conversion of solar radiation [8]. The energy produced is in continuous form as shown in figure 2 [9].

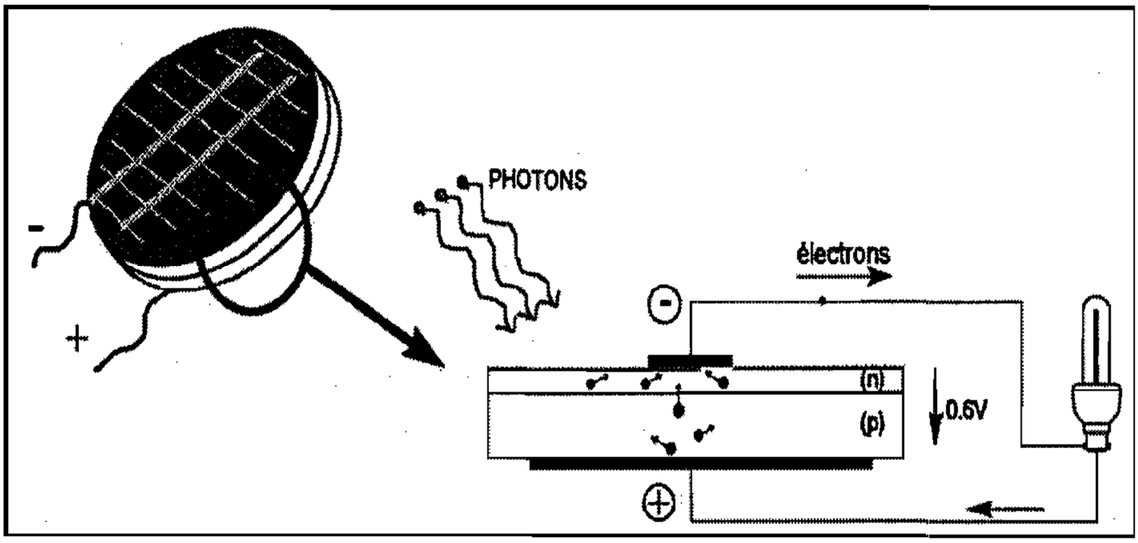

Figure 1: Principle of a photovoltaic cell [9]

Photovoltaic system
A stand-alone photovoltaic system generally consists of four elements:
A field of photovoltaic modules; An electricity storage device; A regulator and an inverter.
An example of an autonomous photovoltaic system is given in figure 1.

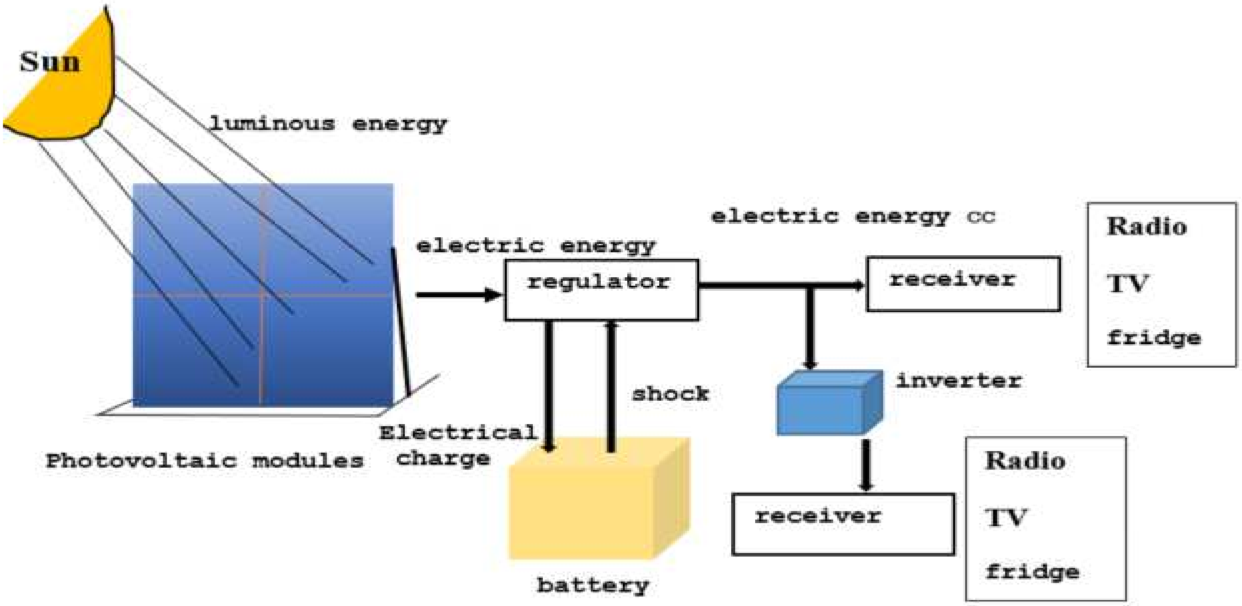

Figure 2: Autonomous photovoltaic system for solar energy production [2].

Materials
Our work will consist of modeling the energy stored and delivered by a lead acid battery chosen for economic, environmental, technical and availability reasons. We will describe in detail how it works.

Battery Operation Lead Acid:

The battery consists of two electrodes (positive and negative) and an electrolyte.

The positive electrode is lead dioxide (PbO2) and the negative one is lead. The electrolyte is a solution of sulfuric acid (H2SO4) which allows the flow of ions between the two electrodes and creates a current [10].

The flat wall separating the two electrodes is made of a porous material which, while allowing the passage of ions, prevents the two electrodes from touching each other. The electrode-electrolyte assembly is the site of an oxidation-reduction reaction, the equations of which are as follows:

- At the positive electrode we have:

$$PbO_2 + HSO_4^- + 3H_3O^+ + 2e^- \rightarrow PbSO_4 + 5H_2O \quad (i)$$

At the negative electrode we obtain:

$$Pb + HSO_4^- + H_2O \rightarrow PbSO_4 + H_3O^+ + 2e^- \quad (ii)$$

Which gives us overall:

$$PbO_2 + Pb + 2HSO_4^- + 2H_3O^+ \rightarrow 2PbSO_4 + 4H_2O \quad (iii)$$

Equation (3) can be written:

$$PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O \quad (iv)$$

Too deep discharges can lead to an irreversible loss of capacity.

There are two types of efficiency which are: energy efficiency and faradic efficiency for the lead acid battery.

- Energy efficiency: This is the ratio of the energy available in discharge by the energy injected into the battery during charging.

$$\eta_{energ} = \frac{\text{energy actually available in discharg}}{\text{energy injected into the battery during charging}} \quad (v)$$

- Faradic efficiency: It is defined by the ratio of the discharge capacity by the load capacity.

$$\eta_{farad} = \frac{\text{discharge capacity}}{\text{charge capacity}} \quad (vi)$$

The cost of lead-acid batteries varies between 50 and 150 Euros / kWh; lead-acid batteries are more widely used because their cost remains the most affordable. This is one of the main reasons lead acid batteries are used a lot [10], [11], [12], [13].

Methods

The behavior model used for our study is the CIEMAT model.

Modeling of the load:
A battery is said to be charging as soon as a current is supplied to it, and not only when a voltage greater than its fem., is applied to it.

- The capacity:

The capacity model is established from the expression of the current I_10 corresponding to the operating regime C_10 in which ΔT is the temperature rise of the accumulator (assumed to be identical for all the elements) compared to the ambient temperature which is equal to 25 ° C. The capacity C is used as a reference to determine the state of charge of the battery or EDC in French or SOC in English (State of Charge). The latter will be formulated according to the quantity of charge missing from battery Q ([14], [15]).

$$C = C_{10} \frac{1.67}{1+0.67[\frac{\bar{I}}{I_{10}}]^{0.9}}(1 + 0{,}005.\Delta T) \quad (vii)$$

With : $\Delta T = (T_C - T_{ref})$, With T ref = 25°C

$$EDC = 1 - \frac{Q}{C} \quad (viii)$$

The temporal evolution of Q depends on the operating mode of the battery [15].

- The voltage:

The expression of the voltage at the terminals of the battery under charge is described by two equations:

$$V_C = n_b.[2 + 0{,}16EDC] + n_b.\frac{I}{C_{10}}[\frac{6}{1+|I|^{0{,}86}} + \frac{0{,}48}{(1-EDC)^{1.2}} + 0{,}036](1 - 0{,}025.\Delta T) \quad (ix)$$

When the voltage at the terminals of the battery reaches $\boldsymbol{V_g}$ (gasification voltage), then the evolution of the voltage shows a sudden increase; characteristic of the gaseous evolution of hydrogen and oxygen: this is the phenomenon of gasification [15].

The temporal evolution of this phenomenon is approximated by an exponential law. The expression of the tension is established starting from the moment $\boldsymbol{T_g}$ where $\boldsymbol{V_C} = \boldsymbol{V_g}$ which is the tension of saturation $\boldsymbol{V_{SC}}$.

$$V_{SC} = n_b V_g + n_b (V_{ec} - V_g)\left[1 - \exp\left(\frac{T - T_g}{\tau_g}\right)\right] \quad \text{(x)}$$

The values of the gasification voltages $\boldsymbol{V_g}$, and end of charge $\boldsymbol{V_{ec}}$ as well as that of the time constant τ_g, are obtained from equations (xi), (xii) and (xiii).

$$V_g = \left[2{,}24 + 1{,}97.\ln\left(1 + \frac{I}{C_{10}}\right)\right].(1 - 0{,}002.\Delta T) \quad \text{(xi)}$$

$$V_{ec} = \left[2{,}45 + 2{,}011\ln\left(1 + \frac{I}{C_{10}}\right)\right].(1 - 0{,}002.\Delta T) \quad \text{(xii)}$$

$$\tau_g = \frac{\mathbf{1{,}73}}{\mathbf{1+858}\left(\frac{I}{C_{10}}\right)^{\mathbf{1{,}76}}} \quad \text{(xiii)}$$

In our study, we will always work below the gasification voltage [15].

- Charging efficiency:

The value of the charging efficiency is determined by:

$$\eta_c = \mathbf{1} - \boldsymbol{EDC}\left[\frac{\mathbf{20{,}73}}{\frac{I}{I_{10}} + \mathbf{0{,}55}}.(\boldsymbol{EDC} - \mathbf{1})\right] \quad \text{(xiv)}$$

Modeling of the discharge

During the discharge, there is oxidation at the negative plate which results in loss of electrons and reduction at the positive plate or gain of electrons. The displacement of electrochemical charges is favored by the electrolyte used in the battery [16].

The expression of the battery discharge voltage is given by equation (xiv) [16]:

$$V_d = n_b[2{,}085 - 0{,}12(1 - EDC)] - n_b \frac{|I|}{C_{10}}\left[\frac{4}{1 + |I|^{1.3}} + \frac{0{,}27}{(EDC)^{1.5}} + 0{,}02\right] \times (1 - 0{,}007.\Delta T) \quad \text{(xv)}$$

The resolution algorithm:

Like all physical systems, the modeling of an autonomous photovoltaic system is essential for all operations to optimize the performance of this system.

The choice of a mathematical model that simulates the behavior of the battery is determined according to the climatic characteristics of the environment considered. In our study, for reasons of similarity, we will perform our analyzes with the CIEMAT model ([17], [18]). This model was developed to study the impact of temperature on battery operation in the Sahelian zone. As part of the simulation of the operation of the battery, we used the MAPLE 12 programming software, in order to observe the impact of certain parameters of the battery on its operation, which are: the temperature of the medium, its capacity, its state of charge, its depth of discharge, its voltage in charge and its voltage in discharge finally its intensity [19].

The diagram in Figure 9 shows the algorithm that was used to perform this simulation. It is described as follows: We record the values of the constants C10 and I10; following this we declare our variables which are: the intensity (I) of the current and the temperature (T)

We calculate the capacity (Cbat) of the battery for different temperature values depending on the intensity [20].

Depending on the condition checked by the current (I) of the battery, the program proceeds as such: (I> 0), the battery is charging then we calculate the charge voltage (Vc), the state of charge (EDCc), (I <0), the battery is discharging so we calculate the discharge voltage and the depth of discharge (EDCd). We end with a recording of the values and a display of the curves.

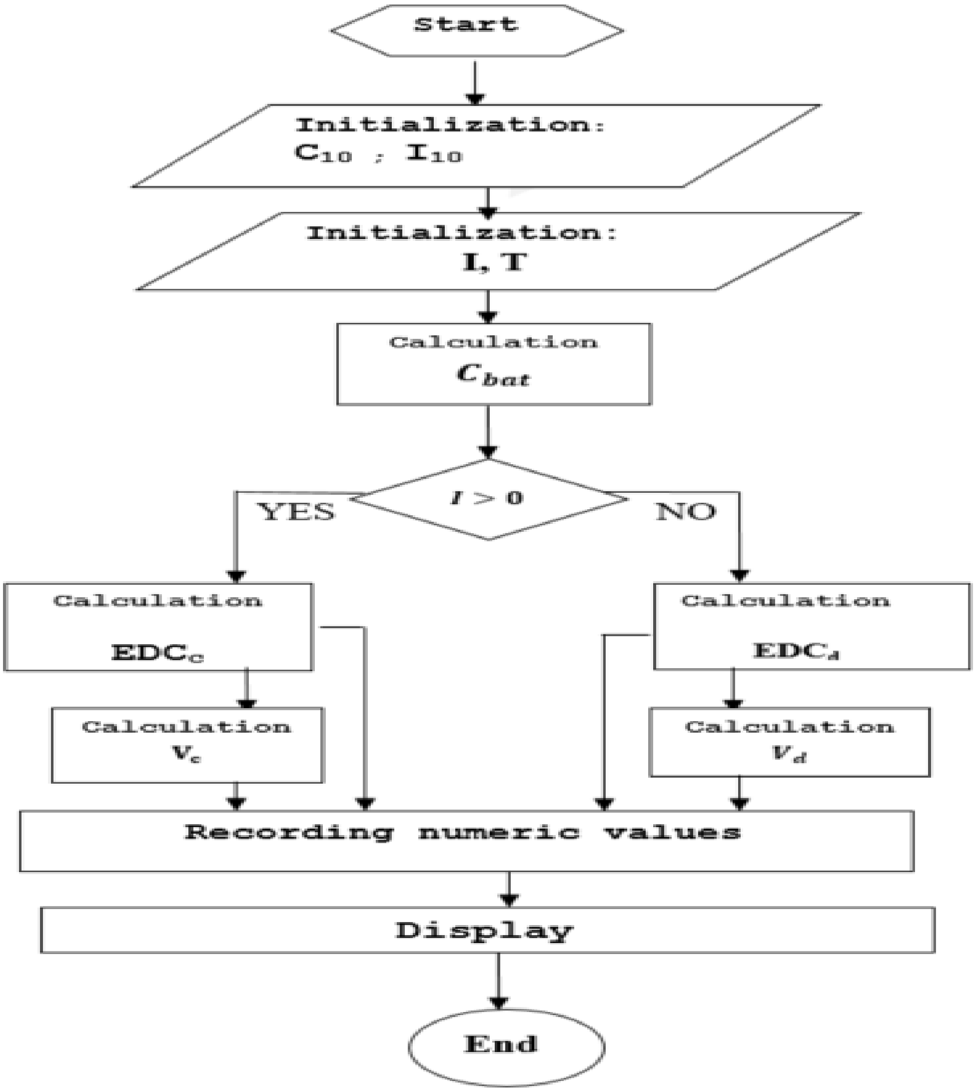

Figure 3: Diagram of the simulation algorithm

3. RESULTS AND DISCUSSION

- Evolution of the capacity as a function of the current for different temperatures:

Temperature influences the behavior of the basic operating characteristics of the storage system and in particular its storage capacity.

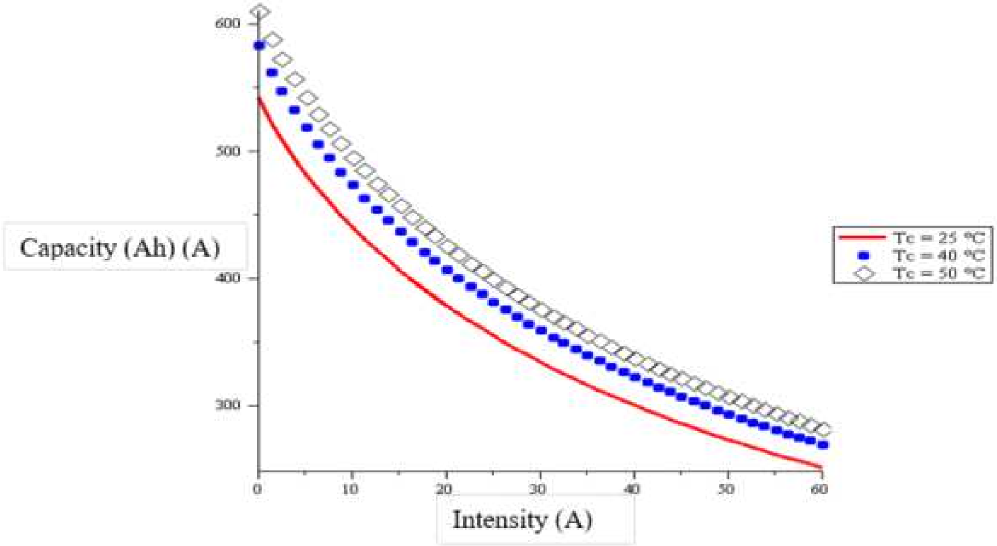

Figure 4: Curve of the evolution of the capacity as a function of the current for different temperatures and temperatures

Figure 4 shows that the increase in temperature is accompanied by a moderate increase in the storage capacity of the battery for temperatures up to 50 ° C. This is in accordance with the results of research carried out on the same type of battery by A.O. M YAHYA, A.O MAHMOUD and I. YOUM [21]. At low temperatures the battery capacity reaches minimum values more quickly compared to high temperature values.

- Evolution of the battery charge and discharge as a function of the current intensity:

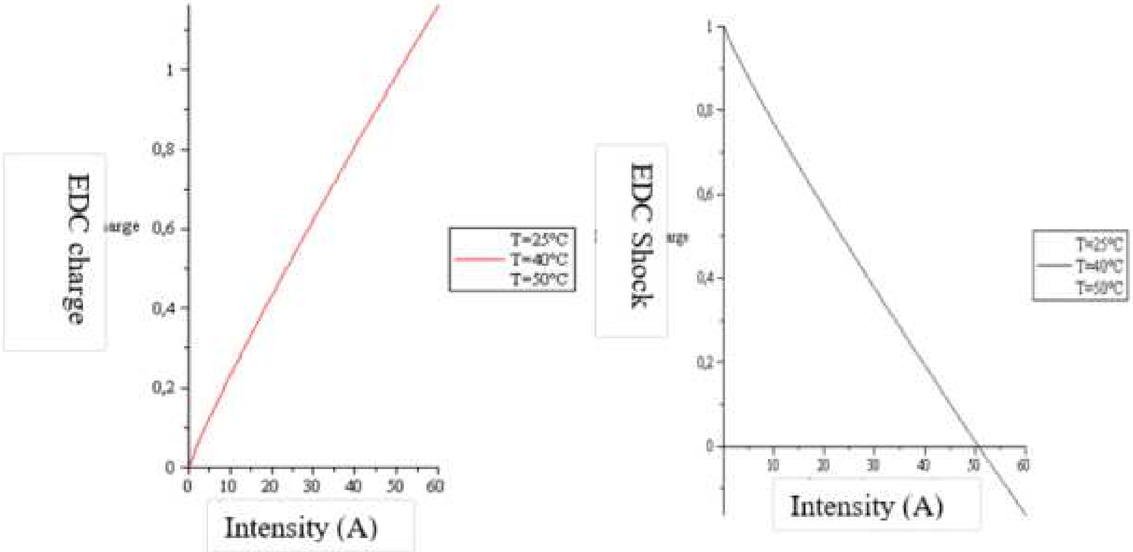

Figure 5: Evolution of the state of charge and discharge as a function of the intensity of the current for different temperatures

These curves above make it possible to say that the evolution of the state of charge and of the depth of discharge depends on the value of the intensity of the current flowing through the battery. We will focus on the impact of temperature and current on the voltages at the battery terminals.

- Evolution of the battery charging voltage as a function of time for different values of the current:

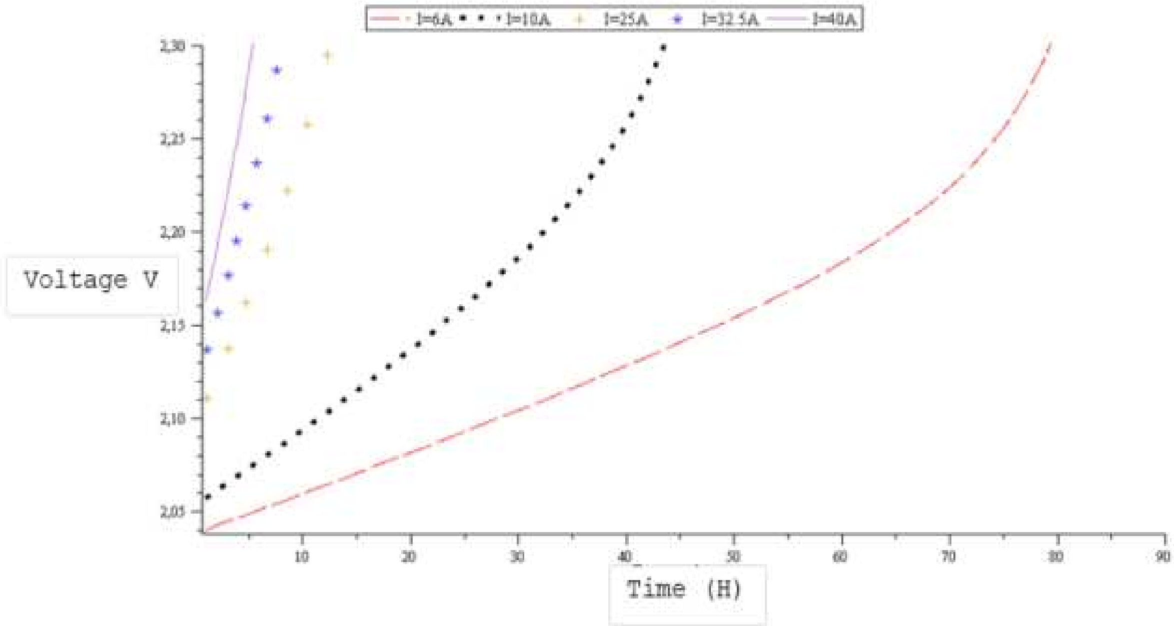

Figure 6: Evolution of the battery charging voltage

Figure 6 shows that for low currents of 6 A and 10 The time taken by the battery to reach a charge value of 2.3 V is longer than for large current values. If the battery is charged with large intensities of the current, the charge of this one evolves very quickly. This is reflected in FIG. 6 by curves with an almost linear appearance. It should be noted that the value of the degassing voltage of the battery is reached more quickly if the latter is charged with very large currents. For better battery life, charging with medium current is preferable.

- Influence of temperature on the charging voltage as a function of time:

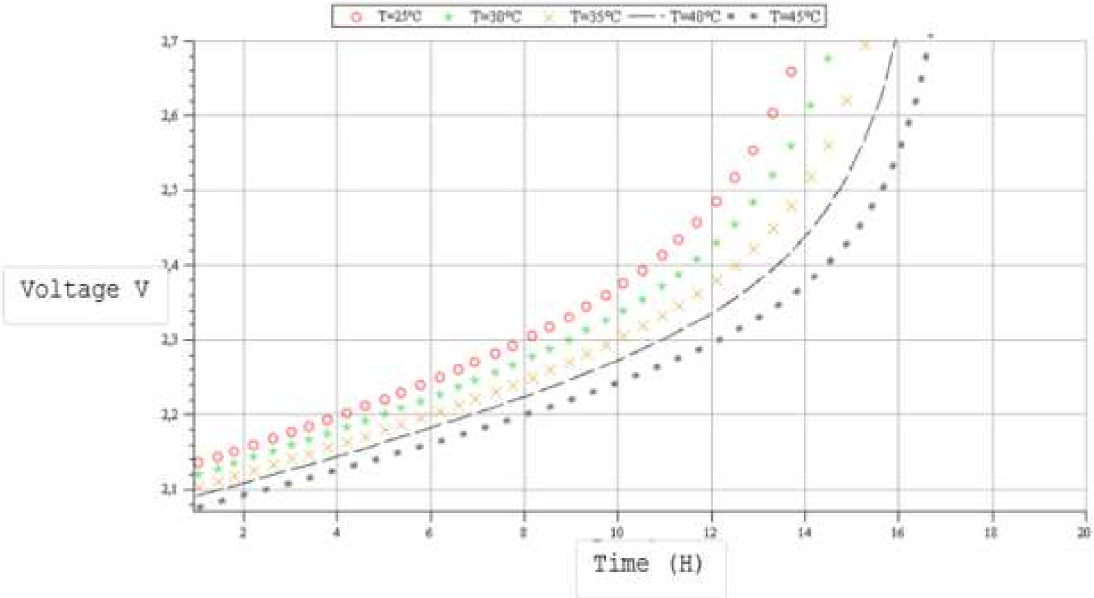

Figure 7: Evolution of the battery charging voltage as a function of time for different temperature values

In this simulation we set the current to a precise value of 32.5 A. According to figure 7 the battery voltage during charging varies with the temperature reached by the battery. Indeed, for low temperatures we notice that the battery charge is faster and the time taken is shorter than for high temperatures. We note from Figure 7 that for a value of 2.3 V reached by the battery charge, the latter is reached more quickly for a temperature of 25 ° C and the time is about 8 hours. However, for a temperature of 45 ° C, this load value is reached in 12 hours. The impact of temperature on the battery charge is felt on the battery capacity.

- Evolution of the discharge voltage as a function of time for different values of the current:

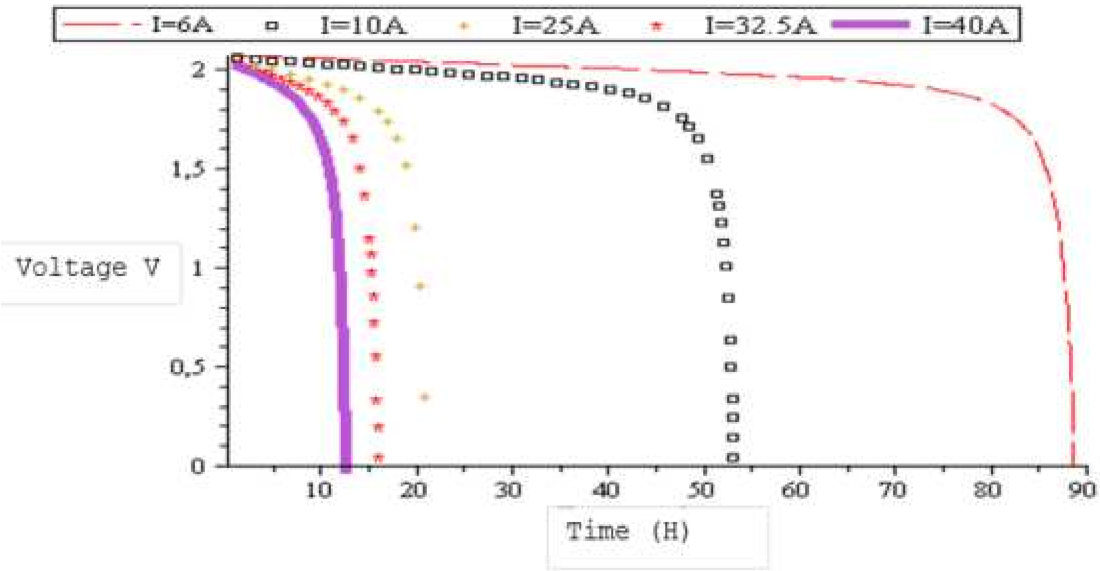

Figure 8: Evolution of discharge voltage as a function of time

The battery discharge time varies according to the values taken by the current. As shown in FIG. 8, it can be seen that the greater the discharge current, the faster the voltage discharge. This allows us to say that the battery has a very large capacity if the discharge current is low and conversely its capacity decreases if the discharge current is very high.

- Evolution of battery discharge as a function of temperature:

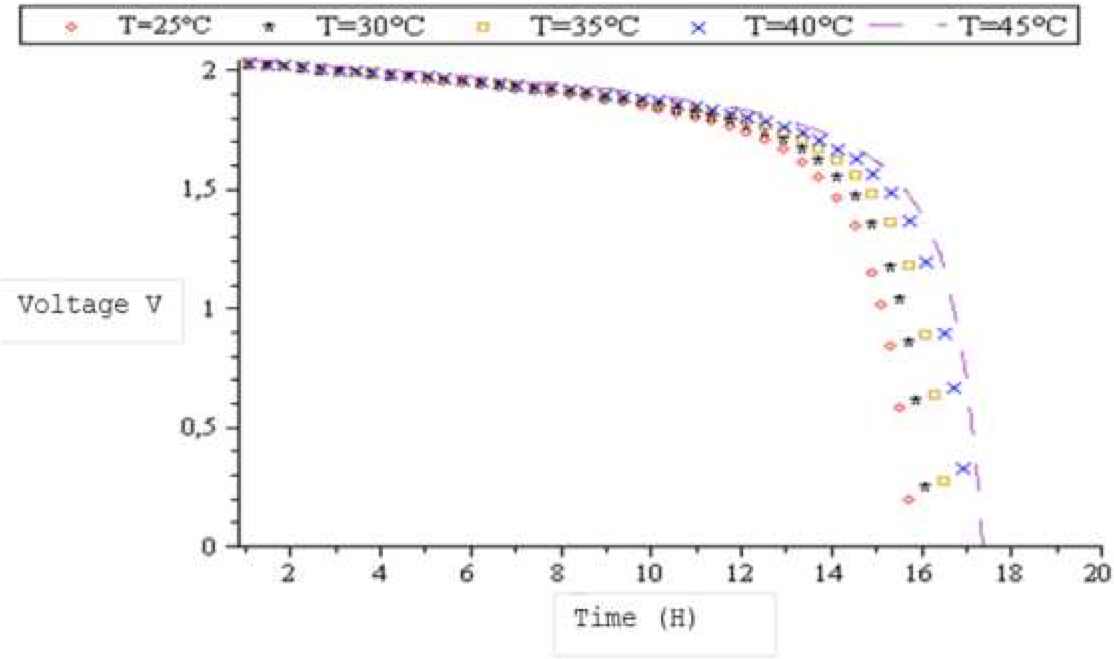

Figure 9: Evolution of the discharge voltage as a function of temperature

Beyond 10 hours of operation, we notice its impact. For a value of 40 ° C the battery voltage takes nearly 8 hours to discharge, yet for a temperature of 25 ° C it takes less than 6 hours to discharge. We can interpret this by saying that when discharging if the temperature increases, in other words the capacity of our battery increases and if the temperature decreases its capacity also decreases; nevertheless, the temperature values must remain within a range close to that given by the manufacturer.

4. CONCLUSION

By taking into account the complexity of modeling the behavior of the storage system, we used the CIEMAT model. This model allowed us to characterize the operation of the battery according to well-defined parameters. Through this model we reflected on solutions to the problem of storing and managing solar energy in our environmental context.

REFERENCES

[1] C. Miller and P.N. Edwards, 'Changing the Atmosphere Expert Knowledge and Environmental Governance', Cloth / June 2001.
[2] C. Iskander Yousif, 'Recent Developments of Applying Solar Photovoltaic Technologies in Malta', Proceedings of the 'Enemalta' 25th Anniversary Conference on Energy Efficiency, Mediterranean Conference Centre, 18th-19th October, Valetta, Malta, 2002
[3] R. Mingant, « Optimisation de la gestion de charge d'une nouvelle technologie d'accumulateur Li-ion pour applications renouvelables », Thèse Institut Polytechnique de Grenoble, Grenoble 2008.
[4] Datasheet VL10E lithium-ion battery, SAFT documents, 2008, http://www.saftbatteries.com.
[5] D. Guyomard, « Stockage de l'énergie », cours de DEA de Chimie Avancée de l'Etat Solide, 1998.

[6] M. Dubarry, B.Y. Liaw, "Development of a universal modelling tool for rechargeable lithium batteries", Journal of Power Sources, Volume 174 (2007), Issue 2, 856-860
[7] G. DILLENSEGER, "Characterization of new charge maintenance modes for stationary emergency batteries.", Doctoral thesis of Montpelier II University, December 2004.
[8] S. BUSQUET, "Study of an autonomous energy production system coupling a photovoltaic field, an electrolyzer, and a fuel cell: Realization of a test bench and modeling. ", Doctoral thesis, at the Ecole des Mines de Paris, December 2003.
[9] M.C. LISHOU, "Study, Modeling and Real-Time Simulation of Photovoltaic Energy Storage Systems. Application to the operational safety of hybrid solar power plants. », Doctoral thesis, Cheick Anta Diop University of Dakar, January 1998.
[10] A. T. SINGO, "Photovoltaic Power System with Hybrid Storage for Autonomous Energy Housing", doctoral thesis, at Henri Poincare University, February 2010.
[11] A. NANA, "Study of Energy Accumulation Systems in Rural Areas in Photovoltaic Installations", doctoral thesis at the University of Ouagadougou, 2014.
[12] Kiehne, H. A., Berndt, D., Fischer, W., Franke, H., König, W., Köthe, K. H., Preuss, P., Sassmannshausen, G., Stahl, U.-C., Wehrle, E., Will, G., and Willmes, H. (2000). Batterien : Grundlagen und Theorie aktueller technischer Stand und Entwicklungstendenzen, Expert Verlag, Renningen.
[13] A.-Ch. Rufer, "La conversion d'énergie électrique pour le stockage", Laboratoire d'électronique industrielle LEI EPFL CH 1015 Lausanne, 2000.
[14] J. McDowall, "Battery solutions – Energy vs. Power", SAFT documents, 2001.
[15] A. Teyssot, « Etude de l'interface lithium métal, électrolyte polymère fondu et gélifié », Thèse Ecole Polytechnique de Grenoble, janvier 2005.
[16] M. Barack (Ed.), T. Dickinson, U. Falk, J.L. Sudworth, H.R. Thirsk, F.L. Tye, "Electrochemical Power Sources: Primary and Secondary Batteries", IEE Energy Series 1, A. Wheaton & Co, Exeter, 1980.
[17] D. Linden, "Handbook of Batteries", Second Edition, McGraw-Hill, New-York, 1995.
[18] H.J. Bergveld, W.S. Kruijt, P.H.L. Notten, "Battery Management Systems, Design by Modeling", Kluwer Academic Publishers, 2002.
[19] F. BAGHDADI, "Modeling and Simulation of the Performances of a hybrid installation for the conversion of renewable energies", Thesis by Magister, University of MOULOUD MAMMERI DE TIZI-OUZOU, September 2011.
[20] O. GERGAUD, "Energy modeling and economic optimization of a wind and photovoltaic production system coupled to the grid and associated with an accumulator", Doctoral thesis, Brittany branch of the École Normale Supérieure de CACHAN University Ker Lann - 35170 BRUZ, December 2002
[21] AO M YAHYA, AO MAHMOUD and I. YOUM, "Modeling of a storage system integrated in a hybrid system (PV / Wind / Diesel)", Université de Nouakchott, Mauritania, Vol 10, N ° 2,205 - 214, 2007.
[22] N. ACHEIBOU, A. MALEK, and N. BACHA, "Aging model of lead-acid batteries in PV systems", Revue Energy, chemss. 61-66, 2000.