Days of autonomy for optimal Battery Sizing in Stand-alone Photovoltaic Systems

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ABSTRACT

Nowadays, the use of clean renewable energies is becoming increasingly necessary in order to preserve our environment and ensure our energy needs. Nevertheless, the integration of this type of energy still faces many challenges that must be overcome, especially the fluctuation and the storage. Researches for the optimization of these systems, particularly photovoltaic technologies, are getting widespread and diversified. The main purpose of our article is to optimize the battery sizing in a Stand Alone Photovoltaic System by identifying the most appropriate number of autonomy days. A case study in theregion of Errachidia in Morocco has been established and simulated to define the optimal number. In the others current researches, only a small importance has been attributed to the battery autonomy. The objective is generally to ensure a continuous presence of energy especially for isolated systems while this is not always optimal nor economical and does not necessarily guarantee a safe supply. However, an over dimensioning of the battery will lead to a consequent cost and a loss of energy. The results show that the number of days of autonomy must correspond to the minimum ratio linking the lack of energy to the surplus during a specific period.

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1. INTRODUCTION

In order to overcome the continuous and progressive energy needs, the use and exploitation of renewable energies becomes an obligation especially for the protection of the environment. The renewable energy market is becoming more and more promising thanks to the various and multiple advances that are emerging. Nevertheless, the exploitation of this type of energy is affected by a set of constraints linked essentially to the intermittence and fluctuation that characterize it. We have chosen in our research to focus on solar energy, particularly photovoltaic solar energy, which is quite widespread, available, and easy to implement compared to other types of clean energy. The main constraint of Photovoltaic Systems (PV Systems) is related to the difficulty and complexity of the storage systems. Then, a focus will be assigned first to decentralised Stand Alone PV Systems to analyse and present approaches for the optimisation of the battery capacity.

1.1. Photovoltaic Systems

Currently, there are several renewable sources with varying degrees of availability around the world. The choice of the type of renewable energy to be installed is defined according to the objective of the desired application. Photovoltaic energy is currently the most exploited, mainly due to its less complex application and its nature, which depends mostly on exploiting the natural sunlight. Photovoltaic technology is the best technology for converting solar energy into electrical energy [1]. PV Systems can be implemented on different scales, from small to large, depending on the requirements and the desired energy production. Additionally, PV applications are no longer limited to a specific location or size but extend to diversified services such as solar lighting and Building Integrated Photovoltaics (BIPV). Considering the continuous development of advancements in the photovoltaic field, it will be an important part of our daily lives in the future.

Given the emerging photovoltaic energy market, several researchers have focused on optimising these systems depending on the field they master, some researchers have given priority to improving the various components starting from the source, to conversion and production. Others analyse relevant parameters and their impact on the efficiency of the system. Technical and economic optimisation is also of great importance. The article [2] shows how current research is mainly focused on improving the sizing of photovoltaic systems and optimising their operation and maintenance. The suitable design of the system has an impact on the efficiency of the panels. Moreover, the right choice of location impacts the quality of the irradiation and thus affects the energy production of the panels. The more the installation is exposed to pollution factors such as the urban environment, the more the irradiation received will be weakened. Considering the load profiles and the photovoltaic generation profiles as variable data, a method for optimizing the placement and size of the photovoltaic source in the distribution grid has been presented in [3]. An adapted design is also associated with more appropriate storage systems as it will be described in the present work. Some studies also analyse the impact of photovoltaic energy production on the grid, especially for connected systems, and how accurate operation and configuration with inverters can reduce this negative impact and increase the quality of the energy produced. Regular maintenance is also essential in this type of systems, especially for photovoltaic modules. Any failure in the photovoltaic modules will negatively affect their durability, efficiency, and reliability. These failures can be caused during manufacturing, transport, set-up or during operation. External parameters also must be considered during maintenance, e.g. Dust and temperature rises. Cooling and cleaning systems should then be planned. With the accumulation of dust for one day, a rate of degradation of the efficiency of the panels can reach 6.24% [4].

1.2. Battery Storage Systems

Types of PV systems depend on the nature and purpose of their implementation and can be divided into three types: grid-connected systems with or without storage systems, stand-alone systems with or without batteries and hybrid stand-alone systems with the presence of other electricity generators.

Despite their development, energy storage in these systems is still a major focus for researchers since batteries are among the most expensive components of the system. Thus, we have chosen in our research to concentrate on storage optimization. Depending on the nature of the application, a storage system may or may not be essential. With the presence of a basic energy source such as the grid, the battery would be an additional tool for optimising and strengthening self-consumption, however for totally stand-alone systems, a strong storage system must be implemented in order to guarantee a continuous energy supply. Electrical energy can be stored mechanically, thermally, or chemically [5]. Electrochemical storage is a commonly used form of storage for PV systems. The storage devices, particularly solar batteries, should be designed and selected according to several parameters such as the large number of life cycles, a low self-discharge rate and a satisfactory lifespan [6]. Other parameters are to be taken into consideration sometimes especially with specific location characteristics such as operating temperatures. Generally, the choice of battery is based on its lower cost and relevant capacity, which makes the system less efficient and beneficial over time.

The battery is a very sensitive component of the PV system, in addition to its design and optimal choice, a maintenance and ventilation system should be ensured to guarantee its protection as long as possible. In addition, regulation systems are crucial to protect the battery from overcharging and deep discharge, which destroy these quite sensitive components.

1.3. Problematic

Solar energy is among the most promising renewable energies and the corresponding prices are increasingly reduced over the years. This field is rich and knows an incredible progress at the levels of research, we cannot currently neglect it. It is therefore necessary to invest in by looking for the most adequate solutions for its optimization. Nevertheless, this type of energy has an intermittent character related to the solar radiation, which causes instability of the energy flow in the network, generates losses and influences the quality of the energy especially for on grid systems [7] For the stand-alone systems, it is not possible to guarantee the presence and the continuous supply for the consumers. Therefore, it is sometimes required to over-size the system in order to maximize its autonomy, which is not beneficial.

A set of studies have followed different ways to demonstrate this. In the article [8], a monitoring and control system has been developed in order to ensure a low cost control aiming also at autonomy especially in specific weather conditions. In this case the effects of the inverter on the generation of losses were considered (which is neglected in most studies). The objective was also to avoid oversizing the battery while ensuring the power supply of the PV system.

In another study and in order to identify whether or not oversizing contributes to the profitability of a PV-battery system, a Python model was developed to determine the cost-optimal operation case for this type of system. Among the results presented, the optimal sizing is not related at all to the oversizing of the battery, but it does generate an increase in investment [9].

Other studies, in order to ensure the independence of their systems, have adopted the combination of batteries and super capacitors to guarantee the stability of micro grids. The exchange between the two sources of storage, despite its advantages, generates an over sizing and energy losses. The objective of the paper [10] was then to design a suitable controller based on a low pass filter to reduce the capacity of the storage system and improve the energy efficiency of the whole system.

The configuration of the PV system, especially the autonomous ones, also contributes to the efficiency of the system. A mathematical model has been elaborated taking into account reference and minimal sunshine hours in order to determine the appropriate scenario with the adequate number of panels and also of batteries [11].

Moreover, and in some studies, a comparison between purely stand-alone systems and grid-connected systems has been established. Stand-alone systems are not always beneficial, especially since they generate investment costs as the batteries and PV systems are oversized to meet the consumer demand, the battery is only charged to its maximum during certain periods and a surplus is lost. This type of system can be suitable when the considered site has a high distance to 5 km from the grid [12].

From the different studies presented, we can notice that the topic of oversizing in sizing PV- Battery systems requires the interest of different researchers. So the target of our study is to find out how to optimize the battery sizing by making the right choice of the autonomy days for pure stand-alone systems, and to verify if the increase of the autonomy days is really effective in the dimensioning. The number of days of autonomy is recognized as the maximum number of days corresponding to the pure independence of the PV systems to meet the needs of the load especially with the presence of the battery [13]. However, it is also necessary to consider other parameters such as the correspondence between the surplus of energy and the lack while ensuring optimally and effectively the need of the consumers in a realistic way by avoiding the oversizing. This is what has been provided in our article. We are going first to give an overview about Stand-Alone PV systems sizing then the optimization of battery storage to finally focus on a case study to analyze the impact of autonomy days on battery sizing and efficiency of the system.

2. STAND-ALONE PV SYSTEMS

2.1. Characteristics

Before launching a photovoltaic system, it is essential to clarify its objective. This allows to specify the nature of the system to be implemented. Autonomous PV systems, for example, depend mainly on the existing solar resources, particularly irradiation. This type of system is noiseless, clean and contributes to the reduction of greenhouse emissions and therefore protects the environment. However, PV systems are first supposed to continuously satisfy the energy requirement. Therefore, Stand-Alone PV systems will still not be beneficial and effective for the whole application. The following parameters should be taken into account before identifying the nature of the PV system:

- **Grid Availability:** With the presence of the grid, a PV system connected to the grid would be more efficient in order to guarantee a continuous supply from the grid and at the same time a self-consumption. There are also different constraints while integrating Solar Energy into the grid such as challenges related to stability of the whole system. However, most of the studies have demonstrated the benefits of their implementation, especially in increasing the resilience of the grid, reducing line losses and lowering the cost of electricity generation [14].
- **Location:** In some cases, the work and the budget needed to ensure the transport and distribution of electricity is more important than the installation of Stand-Alone or hybrid PV systems, especially for decentralised areas. The selection of the site location should be done carefully in order to determine the appropriate configuration with presence of maximum solar resources. For a stand-alone system, a set of parameters must be taken into account when evaluating the location of the system: the choice of the installation (on the roof or on the ground while avoiding the presence of the shade which hinders the reception of the solar rays), the orientation of the panels and their direction and inclination, the layouts of the cables, the available surface and its correspondence with the energetic need [15].
- **PV application:** The nature of the PV application is also necessary to identify the correct configuration of the PV system. Solar pumping systems for example can be provided by Stand-Alone Systems. With the absence of the grid or the complexity of its implementation, a Stand-Alone

PV System becomes the right choice. For applications that require a mandatory and continuous supply of energy, a combination with the grid or other energy sources (hybrid) stays essential.

Several studies have shown that the integration of solar energy would be efficient and cost-effective in technical, economic and environmental terms. As an example, a photovoltaic installation was introduced in some academic buildings of the University of Johannesburg in South Africa. The results have allowed 25% reduction in the cost of energy use, 27% reduction in demand cost and a reduction in carbon emissions [16].

In addition to the application type, the efficiency of the battery depends also on the period of its operation and optimal design. Therefore, technical, and economic analysis should be carried out in advance in order to estimate the possible gain from the integration of a storage system.

2.2. Design of the main components of the Stand-Alone photovoltaic system

In this article, a focus will be given to a Stand-Alone photovoltaic system with the presence of a battery. This type of installation requires an optimal approach in its sizing aiming essentially to the continuous response to the energy need with an acceptable cost. The modeling, simulation and control of this type of system has become the subject of a set of research defining the most suitable model to ensure optimal performance of the systems [17]. A stand-alone PV system can be described as follows in Fig.1.

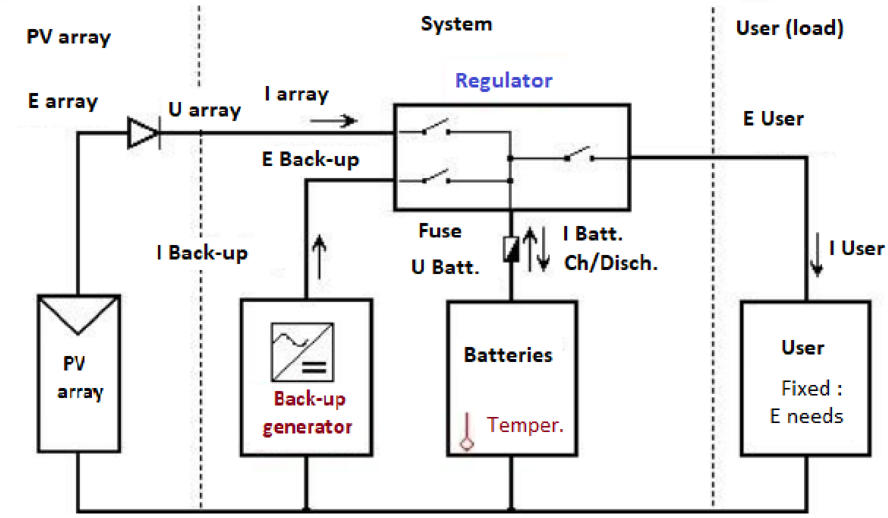

Figure 1. Basic diagram of a Stand-Alone PV System [18]

In most cases, researchers or project managers are moving towards hybrid or grid-connected systems in order to maximise gain with a continuous presence of electricity. However, there are still regions where the implementation of a Stand-Alone PV system is totally indispensable. Therefore, researchers have started to optimize all components separately. Others have chosen to optimise the connection between these different components through management systems. Whatever the purpose of the autonomous photovoltaic installation, intended for housing, for work or for tourism. The dimensioning from production to feeding should follow certain guidelines in order to be in conformity with the norms and to meet the needs of the load optimally. There are different methods and tools for optimization in this area [19]. The different components of the system will be presented in this following part.

a) Photovoltaic modules

The photovoltaic cell is the basis of every PV System. It is mostly composed of silicium and its operation is based on the conversion of solar energy from light rays into electrical energy that can be exploited through the optoelectronic physical phenomenon [20]. There are different types of silicium depending on the manufacturing and design, but polycrystalline technology offers a better compromise between efficiency and cost compared to amorph and monocrystalline.

The photovoltaic module is therefore the result of a connection between several cells, which is then protected and encapsulated to ensure its protection. In order to achieve a specific production, small or large, the modules are placed in series and/or parallel depending on the desired need.

The basis of any PV panel modelling is the preliminary circuit of the cell and its parameters shown below in Fig.2:

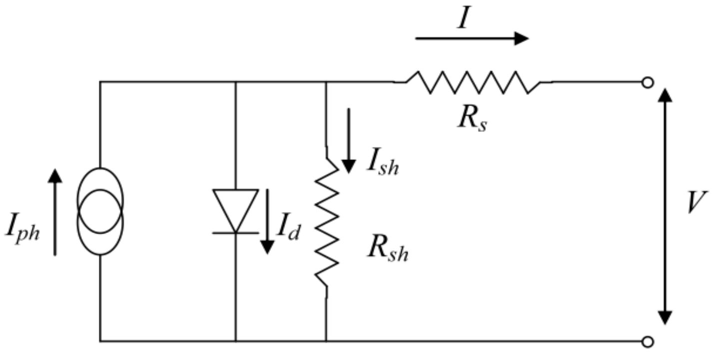

Figure 2. Equivalent circuit of a photovoltaic cell

The resistors R_s and R_{sh} represent respectively the joule and impurity losses. Based on the circuit below, the current at the diode and considering the shunt Resistance to be infinite, the characteristic current curve can be represented by the following equation [21]:

$$I = I_{ph} - I_s \left[exp(\frac{q(V + IR_s)}{NKT} - 1 \right] \quad (1)$$

I: Output current from the solar cell
I_{ph}: Current source
I_s: Saturation current of the diode
q: Electron charge
N: The diode ideality factor
K: The Boltzmann constant
T: The temperature of the p-n junction

b) Controller

The voltage controller or regulator is an essential element in a PV system to protect the battery from overcharging and deep discharge. The controller also helps to maximise the energy transferred from the PV generator to the load. The battery voltage should not exceed a certain limit while ensuring a satisfactory supply of energy to the load. The regulator can be described with the following circuit Fig. 3.

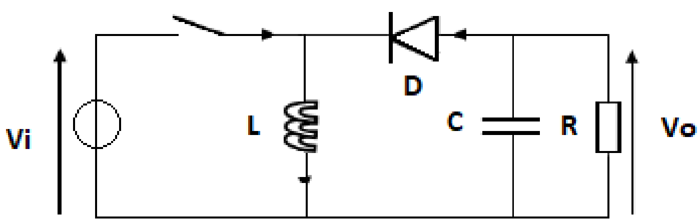

Figure 3. Equivalent circuit of a regulator

The switch is closed and opened to define if the load will be supplied by the PV generator or the battery [22]. The actual choice of the regulator depends on specific parameters and information about the PV generator, the load and the battery, such as voltage and current. For example, the nominal power of the regulator should be higher than the maximum power of the PV field. The output parameters of the regulator should also be adapted to the characteristics of the load and the battery.

c) Inverter

The production of the photovoltaic generator is a DC continuous production. Most components of the load require AC power. Thus DC/AC converters known as inverters guarantee this function. The rate of yield is one of the most important criteria when choosing the inverter. Only the minimum energy should be lost between the battery and the AC loads. Depending on the connection configuration between the inverter to the PV panels, the inverters can be configured as follows into three types Fig.4 [23]:

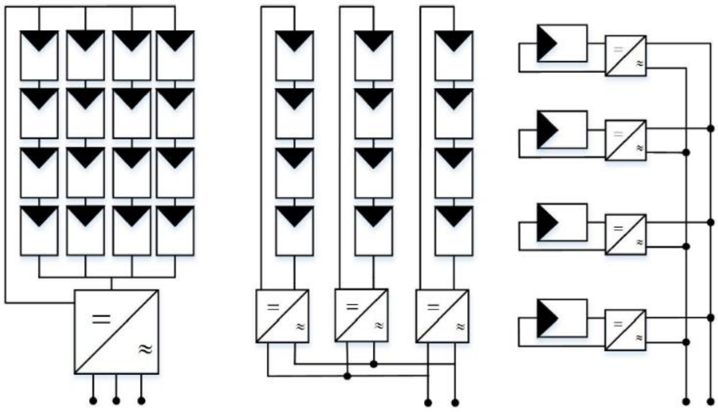

Figure 4. Types of inverter configurations

The first configuration is called the central inverter (a), which consists of connecting the entire PV field to a single central inverter. As shown in the diagram, it is also possible to assign an inverter to each PV string (b) which is called string inverter. The third configuration is called micro inverter (c) that is connected to each PV panel.

d) Battery

Storage can be direct in electrical form using capacitors or supercapacitors or indirect such as electro-chemical storage. Battery modelling like the others PV system components is based on the following circuit Fig.5 and its main identifier is the state of charge (SOC) [24]:

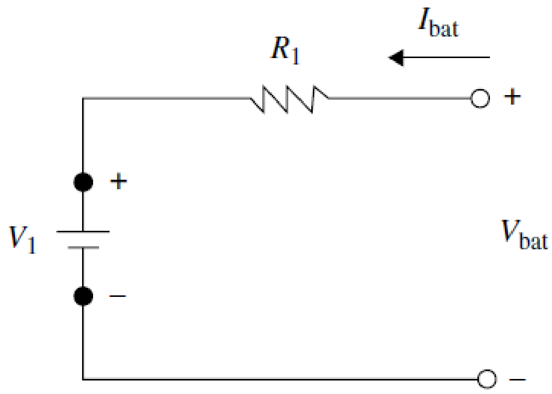

Figure 5. Battery circuit

$$SOC(t+dt) = SOC(t)\left[1 - \frac{D}{3600}dt\right] + \left[\frac{KV_{ch}I_{bat}}{3600}\right]dt \quad (2)$$

D: Self discharging rate
V_{ch}: Charging Voltage
K: Charging Efficiency
I_{bat}: Battery Current

During the charge and discharge of the battery, several parameters change and vary such as voltage, current which makes the state of charge difficult to predict [25].

3. OPTIMIZATION OF THE BATTERY STORAGE

3.1. Overview

Some scientists have chosen to focus on improving the battery itself by analysing the impact of external parameters such as the temperature impact on battery capacity. The battery should be protected in places with a temperature of 25 degrees [26]. The nature of the battery is one of the researchers' concerns to identify the most appropriate type of battery for PV systems.

The optimization of a storage system differs from one installation to another. When the system is connected to other energy sources, a management system is established to ensure optimisation especially in the case of connection to the grid by preserving the battery State of charge between two values E_{bmin} and E_{bmax}. The latter two values can respectively not exceed 20% and 90% of the SOC and depending on the state of PV Power and Load Power, grid connected PV System is managed as followed in Fig.6 [27]:

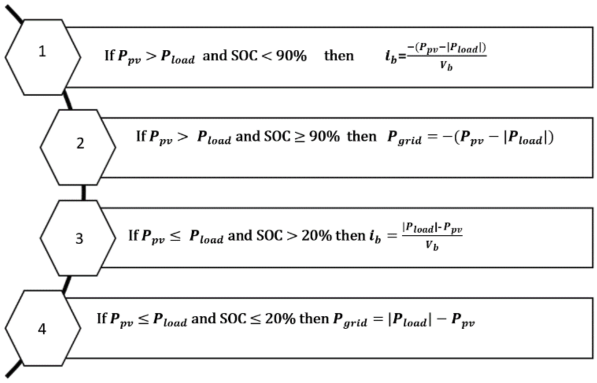

Figure 6. Overview of the energy management in Grid connected PV system

However, for Stand Alone Systems, two characteristics must be taken into consideration in addition to the SOC: The lack of energy generated (L) and the surplus of energy produced (S) [28]. And Overview of the Energy Management in Stand-Alone PV System is given in Fig.7.

$$L(t) = E_{load}(t) - \left(E_{pv}(t) + E_b(t-1) - E_{bmin}()_{inv}\right) \quad (3)$$

$$S(t) = E_{pv}(t) - \left(\frac{E_{load}(t)}{\eta_{inv}}\right) + \frac{(Eb_{bmax}())}{\eta_{bat}} \quad (4)$$

L: Lack of energy to generate
S: Surplus of the energy produced
E_{pv}: Electric energy produced by the photovoltaic source
E_b: Energy available in the unit of storage
E_{load}: Daily User needs
E_{bmin} : Minimum allowable storage energy
E_{bmax}: Maximum allowable storage energy

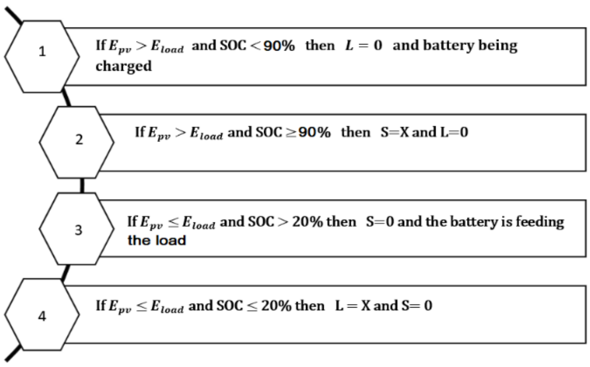

Figure 7. Overview of the Energy Management in Stand-Alone PV System

In some cases, and before implementing a storage system, the added value of the storage system to the PV system must be verified previously. In article [29], the researchers compared the "Demand Response" strategy and the addition of a storage system to promote self-consumption in a grid-connected household. The aim of these two configurations was to identify the most appropriate configuration for reducing the Energy bill. The consumption profile was analysed for four different weeks each in a season. Consequently, the analysis of the comparison demonstrated that a direct supply with shifting based on the grid connection would be more satisfying and effective in reducing the bill by up to 19% annually. This configuration remains valid even with significant reductions in battery costs.

Earlier, PV Systems had a different goal from producing clean electricity which is taking advantage from the feed-in tariff especially in some countries. Today, this approach is less prevalent, especially in countries where it is applied for residential and small or medium consumption. The researchers in paper [30] presented a set of configurations for the sizing of PV battery systems to demonstrate that the presence of a storage system, in contrast to the previous paper, is especially important for increasing self-consumption but stays more attractive for small scale systems.

Thus, the presence of the battery would always be beneficial if the average price of electricity corresponding to the chosen configuration is lower than the average purchase price of electricity from the network. Optimal Sizing is the common and only solution to overcome the disadvantages and high costs of PV Battery Systems.

3.2. Case Study

Thanks to its geographical position and diversified renewable resources. Morocco represents an appropriate location to implement renewable energy systems especially the solar ones. In this sense, an energy strategy has been adopted since 2009 with the objective of increasing the installed power of renewable energies to 52% by 2030 with an estimation of 4560 Mw for solar energy. The great potential in solar energy is of the order of 6.5 kwh/m2/d, which corresponds to an annual sunshine of 3000 hours [31]. This great potential in solar energy can only encourage more and more investments in PV systems.

In this part, we will analyse the impact of the days of Autonomy Days on the capacity of the battery particularly the Lack and Surplus. We will focus on a virtual system in Morocco, particularly in Errachidia, which is one of the sunniest regions in Morocco. The system is modelled and simulated on the software PVsyst. It is a software that allows to make simulations for all photovoltaic systems and to analyse their performance depending on the meteorological and technical data introduced based on real conditions [32].

a) Site characteristics

The main objective is to analyse the operation of the battery. The virtual installation is a stand-alone System dedicated to supplying power to a Household in a rural area. Below the distribution of the irradiation according to the months of the year (Fig.8).

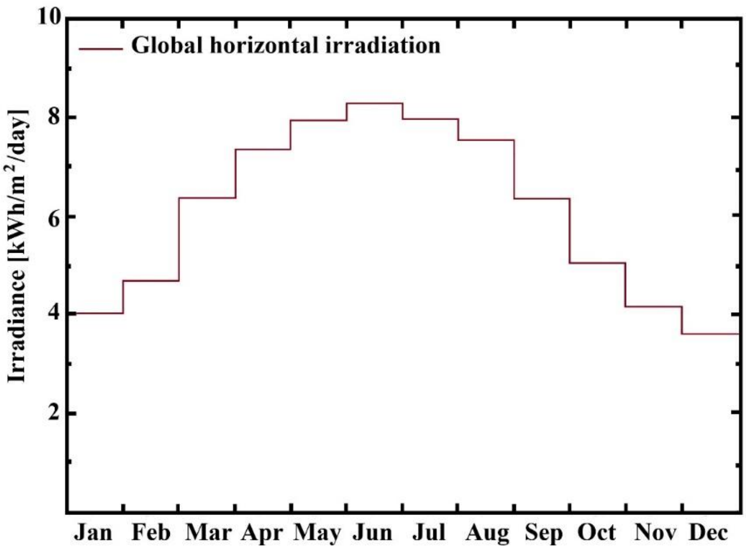

Figure 8. Global Horizontal Irradiation in Errachidia region

b) Energy Needs

We identified the appropriate needs for a household in a rural decentralized area in Errachidia. The daily requirement is around 4.3 kwh. The power of the photovoltaic generator is about 855 Wp. The energy needs are represented as follows during the day with a peak at the end of the day (Fig. 9). The effective energy coming out of the photovoltaic field, which depends mainly on the existing solar radiation, is shown in the following Fig.10

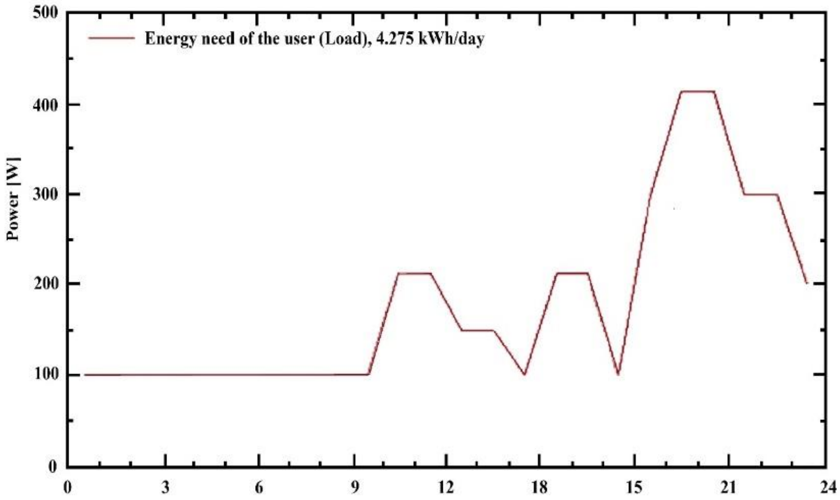

Figure 9. Energy needs for a sample day

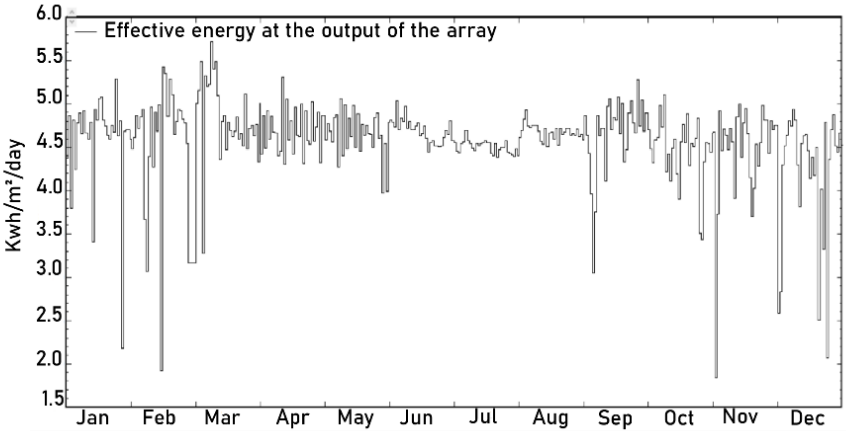

Figure 10. Effective Energy at the output of the PV Array

c) Battery Capacity

The capacity is expressed in Ampere Hours and corresponds to the electrical energy that the battery can deliver when it is fully charged. The capacity depends on four parameters: efficiency, depth of discharge, autonomy days , and nominal voltage .

$$C = \frac{N_d \times A}{U_{bat} \times \eta \times D} \tag{5}$$

C: Battery Capacity (Ah)
N_d: Daily Needs (Wh)
A: Autonomy days
U_{bat}: Battery Voltage (V)
η: Battery efficiency
D: Depth of discharge

The batteries can be connected either in series and/or parallel depending on the desired voltage or capacity. In our case, the capacity of the installation is identified on the basis of three different numbers of autonomy days.

d) Lack and Surplus

In the case of the Errachidia plant, the Lack and Surplus have been estimated considering the energy distribution of the PV generator (Fig. 10) and the state of charge of the battery. The following graph (Fig.11) represent the average state of charge of the battery.

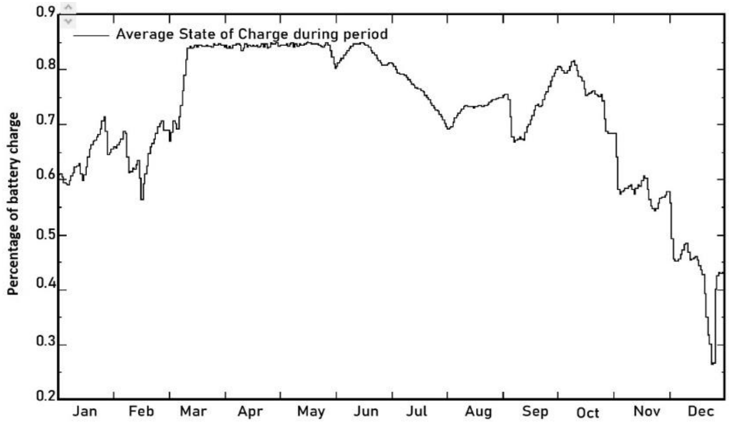

Figure 11. Battery State of Charge Overview

The state of charge differs from three cases. With battery capacity, it is recommended that SOC doesn't reach 90% and always exceeds 20%, which contributes to the protection of the battery throughout the year.

e) Autonomy

Most of the time, the days of autonomy are defined in order to ensure a safer supply of energy, especially on cloudy days.

The number of days of autonomy is generally chosen according to the climatic conditions of the site. The optimal choice is mainly related to the supply of the site facilities during the night and on cloudy days. The autonomy is chosen according to two identifiers: the solar irradiation and the consumption, autonomy days can go from 1 to 14 days [33]. Low irradiation cycles can influence the charging hours in critical applications, that is why some systems are designed with high autonomy values [34]. However, the number of days of autonomy must be chosen in an optimal way, having as an objective the reduction of the Lack but also the Surplus, avoiding the choice of smaller or larger batteries in terms of capacity. For this reason, we have chosen to simulate our installation on PVsyst for three possible types of autonomy (2, 3 and 4 days of autonomy).

- **Case 1**

The number of days of autonomy is 2 days, the Lack and the Surplus generated depending on months are presented in the following graph (Fig.12).

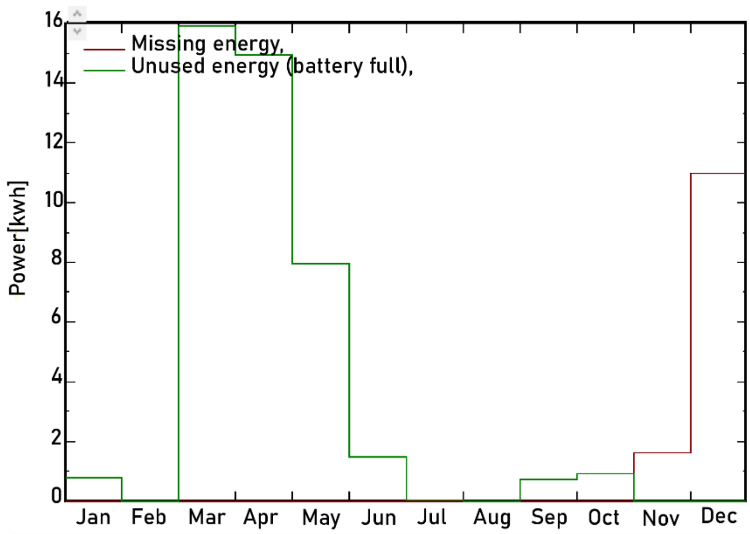

Figure 12. Estimation of the Missing and Unused Energy during the year (case 1)

- **Case 2**

The number of days of autonomy is 3 days, the Lack and Surplus during a year are represented as follows in Fig.13:

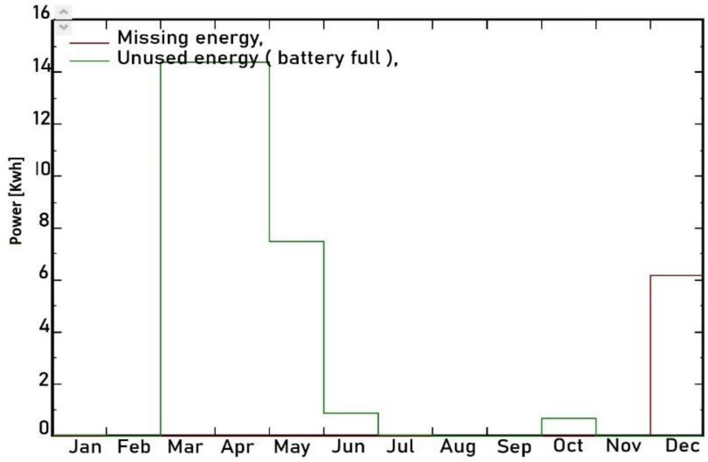

Figure 13. Estimation of the Missing and Unused Energy during the year (Case 2)

- **Case 3**

The number of days of autonomies is 4 days, the Lack and Surplus during a year is represented as follows in Fig. 14:

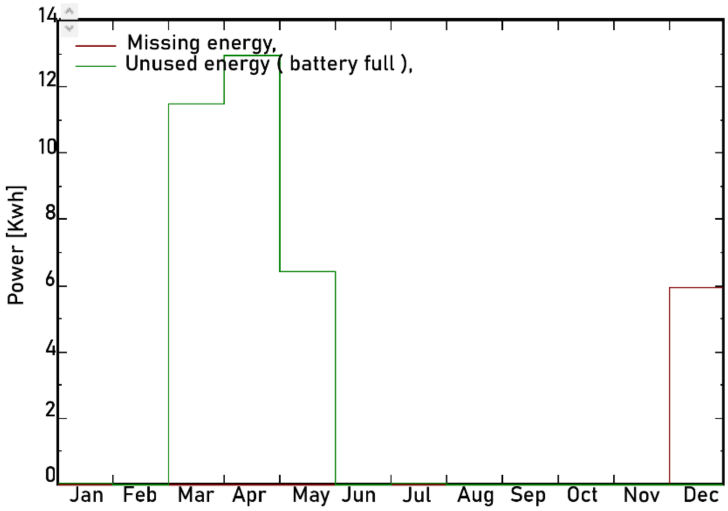

Figure 14. Estimation of the Missing and Unused Energy during the year (Case 3)

- **Comparison**

Based on the three previous graphs and focusing on missing energy and unused energy, we have calculated the sum of lack and the sum of surplus. In order to determine the most appropriate number of autonomy it is necessary to choose the most optimal ratio (R_o) during a year which is defined as follows:

$$R_o = \frac{\sum Surplus}{\sum Lack} \tag{6}$$

The optimal days of autonomy and consequently the efficient size of the battery correspond first to the minimum R_o. Another important parameter that should be defined and analyzed to confirm this choice is the value of the missing energy or the Lack. This parameter should be affordable for the user. For our system, we can notice that the lack of energy is more present at the end of the year in November and December. The four graphs below represent respectively the Lack in the three cases. For case 1 we have the lack for two months November and December as represented in the Fig.15 and Fig.16. For case 2 and case 3, we have only Lacks in December as showed respectively in Fig. 17 and Fig.18.

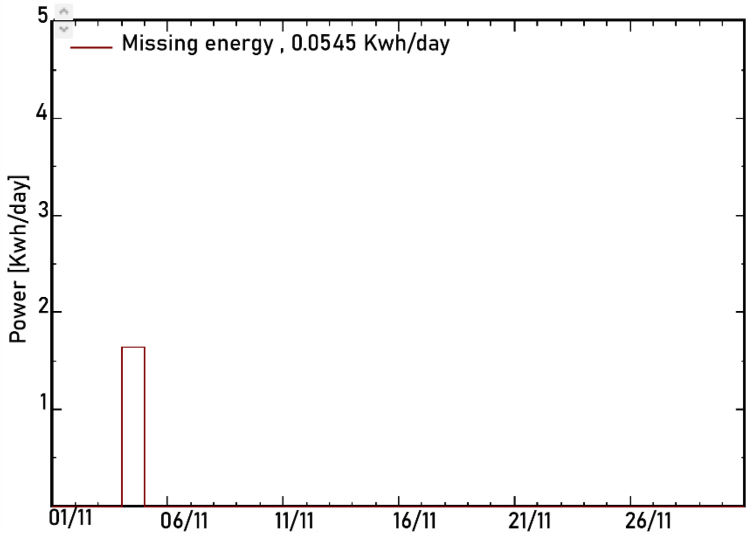

Figure 15. The Lack of Energy in November (Case 1)

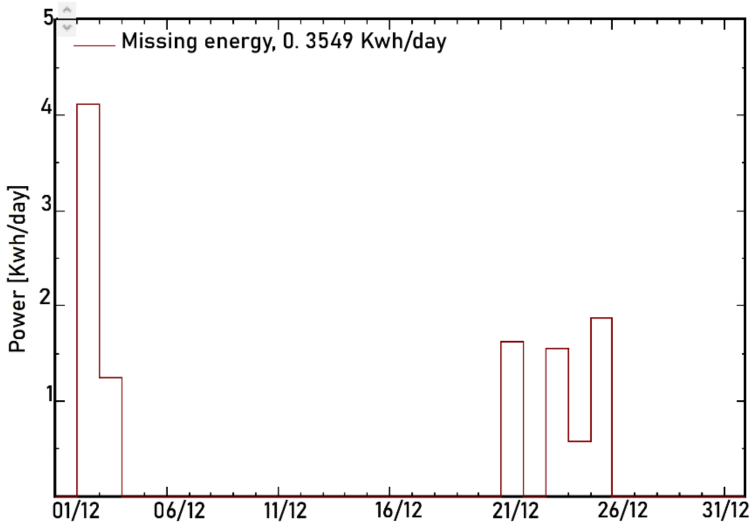

Figure 16. The lack of energy in December (Case 1)

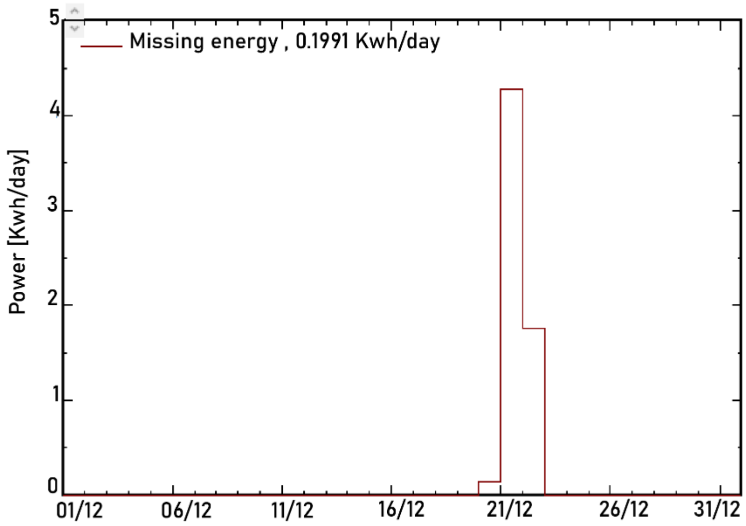

Figure 17. The lack of energy in December (Case 2)

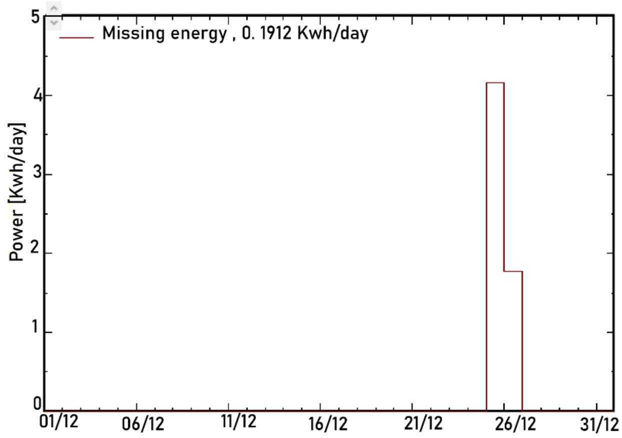

Figure 18. The Lack of energy in December (Case 3)

4. RESULTS

4.1. Analysis and discussion

Respectively with three different numbers of days of autonomy (2,3,4). The average Lack of energy in December is estimated respectively to 0,3549 Kwh/d, 0,1991 Kwh/d and 0,1912 Kwh/d. Normally the addition and doubling even of the number of days of autonomy is supposed to ensure less Lack, this is clear and remarkable but only in December where the Lack is present 6 days for the case 1, 3 days for the case 2 and 2 days for the case 3.

The increase in the number of autonomy days will automatically increase the capacity of the battery and therefore the price of its purchase and implementation. It is true that the energy needs must be covered all year round, but with an optimal gain. With four days of autonomy which is very satisfying, we will still have a Lack in December even if it is moderated. With 2 Autonomy days less, the result is also satisfying for the whole year except for November with a very low need and for December with a difference of about 0,16 kwh/d available 20 % of the month. This analysis leads to considering whether the increase of the number of days of autonomy really guarantees a secure energy supply or whether it only generates additional costs. The results of the simulation on PVsyst show that on average the energy Lack is present in December in the three cases and the gain in energy is not significant enough especially when increasing the capacity.

In order to choose the most theoretically optimal number of days of autonomy, it is therefore essential to calculate the smallest R_o that allows a certain balance between the Lack and Surplus present throughout the year. R_o must be as low as possible, i.e. the correspondence between the lost energy and the missed energy must be as similar as possible. For the three cases we obtain the following results:

Table 1. Optimal ratio between Surplus and Lack of Energy

	R_o
Case 1	3,41
Case 2	6,24
Case 3	5,28

According to the results achieved, a high number of days of autonomy does not always mean a continuous availability of energy. Further experimental analysis studies in German regions [35] have shown that despite the increase in the degree of autonomy there are still periods of power shortage in all regions. The authors of this study have shown that the appropriate choice of the degree of autonomy is essential for the optimization of a decentralized energy system, e.g. costs and technical parameters (surplus of electricity) are affected if the degree of autonomy increases.

In many cases of modeling PV systems, the notion of autonomy is not properly taken into consideration. The research results in the article [36] showed that the performance of stand-alone systems with the number of days of autonomy exceeding 1 depends mainly on irradiation and location and a good consideration of autonomy could meet the need to a certain percentage up to 15%.

4.2. Integration of Back –Up Generator

a) Overview

We have noticed that despite the increase of autonomy days' number, we will always have a need in terms of energy that it is better to meet. Thus the use of back-up generators would be an adequate solution especially when consumers have specific needs or are under critical conditions. It is important specially to provide a continuous power supply for the refrigerator, for some lights during the evening or to ensure a protection and conservation of some medicines. Certainly, the objective is also to ensure a certain comfort for the consumer, but it remains only an emergency power supply, especially with the presence of adequate solar storage.

In the framework of a stand-alone system in Japan with the presence of a photovoltaic system, a wind power supply, a storage system, a diesel generator was also added. The authors of the article [37] have suggested an operating mode that manages the presence of the battery and the diesel generator. We recall the following two usual operating modes:

- **Normal operating mode:**

In this case, the electricity production is provided by renewable sources. When the production exceeds the need, it is the battery that is charged and if it reaches 100% of its charge, the surplus production is removed. In the opposite case, it is the battery that ensures the need of the load when the renewable production is not sufficient.

- **Back-up mode:**

The diesel generator also provides power in addition to the renewable source in preference to the load. The power of the generator can be modeled from the following formula [38]:

$$C_g = \alpha P_{gr} + \beta P_g \quad (7)$$

C_g: Generator consumption
α : Fuel transfer coefficient
P_{gr}: Nominal capacity of the generator
β: Fuel slope for generator
P_g: Power of the generator

b) Application to case study

In our case study, the lack of energy is present mostly in November and December, but this definitely generates some discomfort for the consumer. Therefore, we have in this part introduced a generator with a nominal power of 1.5 kw. The space constraints are not taken into account because the area considered is an isolated area. The generator meets the needs of the consumer in case of Lack. Thus and for the three previous cases we notice the following results:

- **Case 1:** The battery capacity required for the first case is 419 Ah. As presented previously, the energy shortage is present in November and December and therefore the solution would be to mobilize the emergency generator during this period.
- **Case 2:** The capacity required for the second case corresponds to 629 Ah. The generator would be used in December.
- **Case 3:** The battery capacity required for the first case corresponds to 838 Ah. The generator will be mobilized in December.

The following Fig. 19 describes respectively the duration of operation of the generator which is logically mobilized only in November and December during case 1 and in December for the two other cases.

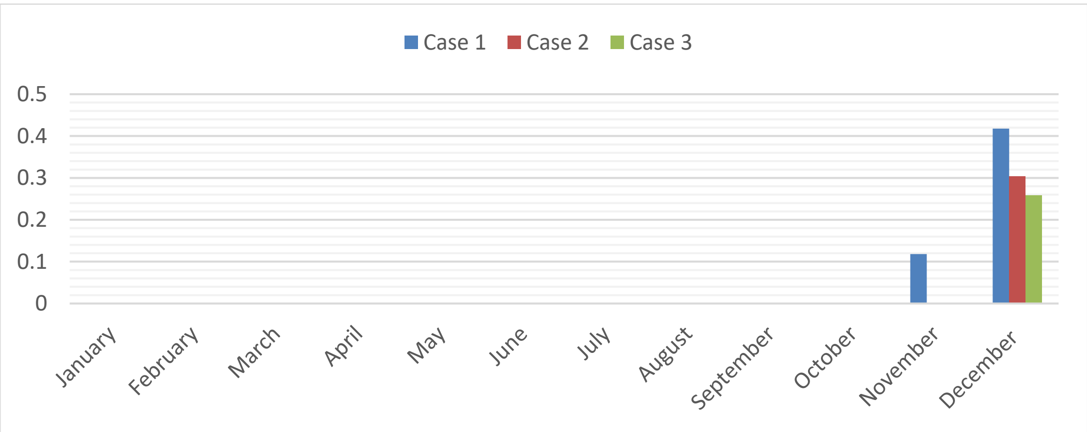

Figure 19. Back-up Generator running duration (hour)

Comparing the three cases, we can notice that even with the presence of the generator, the duration of its operation on average differs with a low rate in the three cases while the capacity can be doubled especially from the first case to the third. It should also be remembered that the energy provided by the generator correspond exactly to the Lack present during the year.

c) Economic evaluation

In order to better value the impact of the days of autonomy on the optimization of the storage system at the level of the Stand-alone photovoltaic systems, an economic evaluation has been drawn up with and without the presence of the Back-up generator as follows:

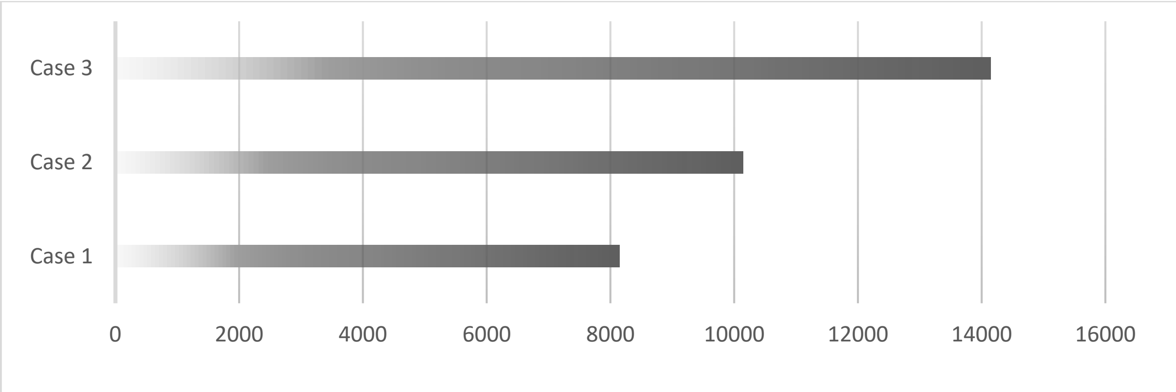

Figure 20. Comparison between the costs of a PV system installation in the three cases without the presence of the Back-up Generator (Euro)

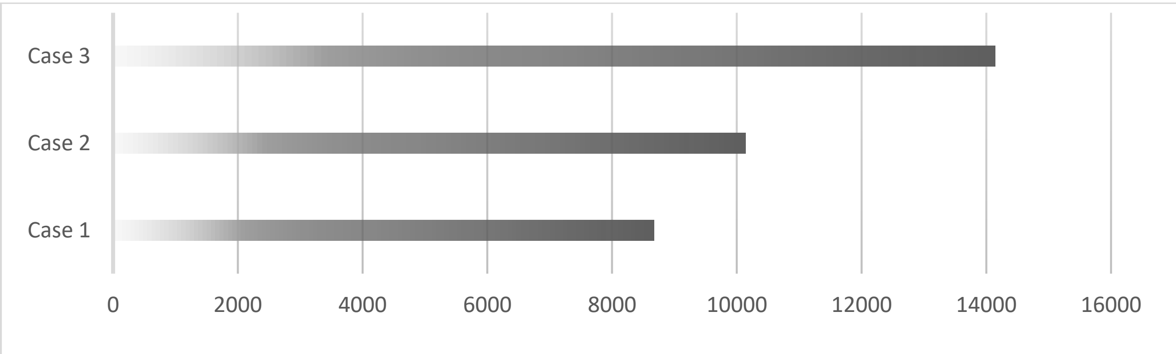

Figure 21. Camparison between the PV installation costs in the three cases with the addition of the Back-up genrator only for Case 1(Euro)

Analyzing Figs. 20 and 21, it can be noticed that Case 1 is still advantageous even with the addition of the generator in terms of economic evaluation. Therefore, with a reduced number of days of autonomy, we have the optimal ratio R_o, a cheaper PV installation and an absence of energy Lack that can guarantee a security for the consumer during critical periods.

5. CONCLUSION

PV Systems are increasingly becoming a promising market for the supply of clean energy and the reduction of CO_2 emissions. The future of this technology is becoming more attractive and even the prices of individual components are falling continuously. Despite the diversified advantages of this technology, it is essential to optimally estimate the energy capacity and the required investment by identifying the appropriate design before any PV project. The results must be a compromise between the cost generated and the optimal satisfaction of the energy needs. For areas such as Errachidia with a lot of sunshine, the presence of the battery ensures more the night needs and energy Lacks are only visible at the end of the year with reduced rate. Therefore, the increase in capacity would be less efficient if the target is only to satisfy the need for a few hours of one month. However, it cannot be denied that the presence of the Lack remains a big disadvantage of the autonomous systems and must be overcome using other alternative energy sources and generators at the same time.

Furthermore, other parameters indirectly affect the efficiency of a photovoltaic installation particularly the battery such as the consumer behavior. This is especially important for residential use with higher consumption in the presence of other appliances. A rational behavior of the electricity use (for stand-alone as well as on grid) would be a gain for the PV Systems by adapting the operation of certain appliances to the Surplus periods and avoiding their use at night at low energy levels. The adoption of some technologies such as renewable energies in daily life depends on the behavior of the consumer which impacts the success or not of the exploitation of this kind of system [39].

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