Technical and Economic Efficiency in Photovoltaic Battery Systems

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Abstract

The production of electrical energy can have a series of consequences on the environment, which justifies the urgent and mandatory use of renewable energy. Morocco, thanks to its energy strategy, represents a great model for the integration of renewable energies to meet the growing energy needs. In our study, we will focus on photovoltaic (PV) systems with storage dedicated to the residential sector. This type of energy is characterized by its easy integration, especially for simple consumers. The abundance of solar energy in the country is also a very promising factor. In our research, two technical and economic parameters are identified to choose the most appropriate configuration for a grid-connected PV system in Marrakech.

Keywords
Photovoltaic energy, grid, optimization, technical efficiency, economical efficiency

1. Introduction
Several studies have been conducted by a group of researchers to optimize solar energy systems. A set of parameters should be considered from the smallest to the largest and the goal remains always the optimization of this type of system. Solar energy attracts the interest of many researchers and manufacturers. To meet the growing energy needs, the use of solar energy stays a priority option knowing its advantages in terms of availability, cost and efficiency. The article (Kabir et al.,2018) presented the different advantages, disadvantages, and challenges of solar energy technologies.

Among the factors that can be acted upon to optimize renewable energy systems are the appropriate composition and configurations. The configurations can consider as an example the location and the type of photovoltaic panels, the paper (Yoomak et al.,2019) discussed and presented the performance of a PV system installed in a set of regions in Thailand in order to identify the most suitable location, three types of photovoltaic panels were also compared including monocrystalline, polycrystalline, and thin-film. The results showed for example that the central region has higher solar power generation capacity than other regions and that thin-film solar panels are not suitable for solar roof systems. Other researchers have focused on the nature of the renewable energy system to identify the appropriate configuration. In the article (Okonkwo et al. ,2020), for example, two types of installations were analyzed: a hybrid PV/battery/wind system and a grid-connected system in terms of capital cost, replacement cost and operating cost. It was shown that the hybrid system is more beneficial in terms of cost and even energy production.

The optimization of these systems is also based on the technical and economic evaluation. This evaluation depends on each type of solar installation with its own constraints and its own parameters and functions, which leads to different results (Li et al.,2019) (Merei et al. , 2016)(Qiu et al. , 2019).

1.1 Objectives

In this paper, we have experimented different configurations of a PV system connected to the grid. In the addition to the grid, we will consider the presence of the storage part, the first one that contributes mainly in the technical optimization and the second on the economic optimization (Figure 1 to Figure 6).

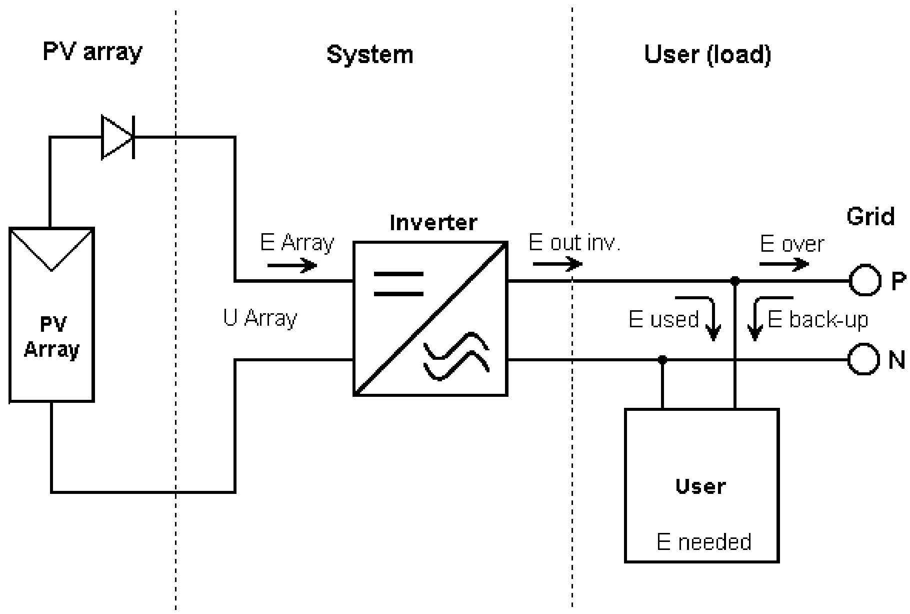

Figure 1: Simplified diagram of a Grid connected PV system

Therefore, a grid-connected photovoltaic system has been studied with a photovoltaic field and a storage system (reference configuration).

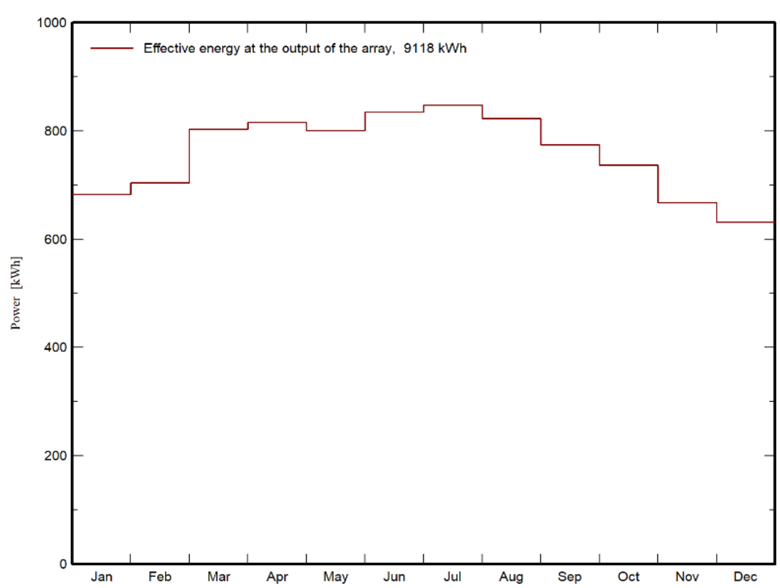

Figure 2: Effective energy at the output of the array

The objective of this paper is to compare three configurations for a grid-connected installation with the presence of the battery. The aim is to analyze the impact on the whole system, especially the technical and economic impact. We will consider the first reference configuration with a normal sizing, the other two configurations are based on the increase of the battery capacity (Configuration 2) and the increase of the photovoltaic field (Configuration 3).

2. Technical and economic parameters in PV Battery Systems:

In this section, it has been demonstrated how changing configurations can impact the photovoltaic system and its efficiency. We will present three possible configurations with their technical characteristics. We will focus on the presentation of three types of energy:

- **Energy from the sun:** it represents the energy supplied by the photovoltaic field and the battery during one year;
- **Energy from the grid:** it is the energy supplied by the grid when the photovoltaic source is not able to provide it (Photovoltaic field + Battery);
- **Energy injected to the grid:** it is the excess energy that is produced when the consumer's need is ensured;

2.1. Configuration 1:

In this part, a photovoltaic system has been sized in a standard way to meet the needs of the consumer which is estimated at 21kwh. The energy provided by the photovoltaic field is about 5.3 kwp with a storage capacity for the battery of about 1480 Ah. The present configuration requires 11 photovoltaic modules and 10 batteries.

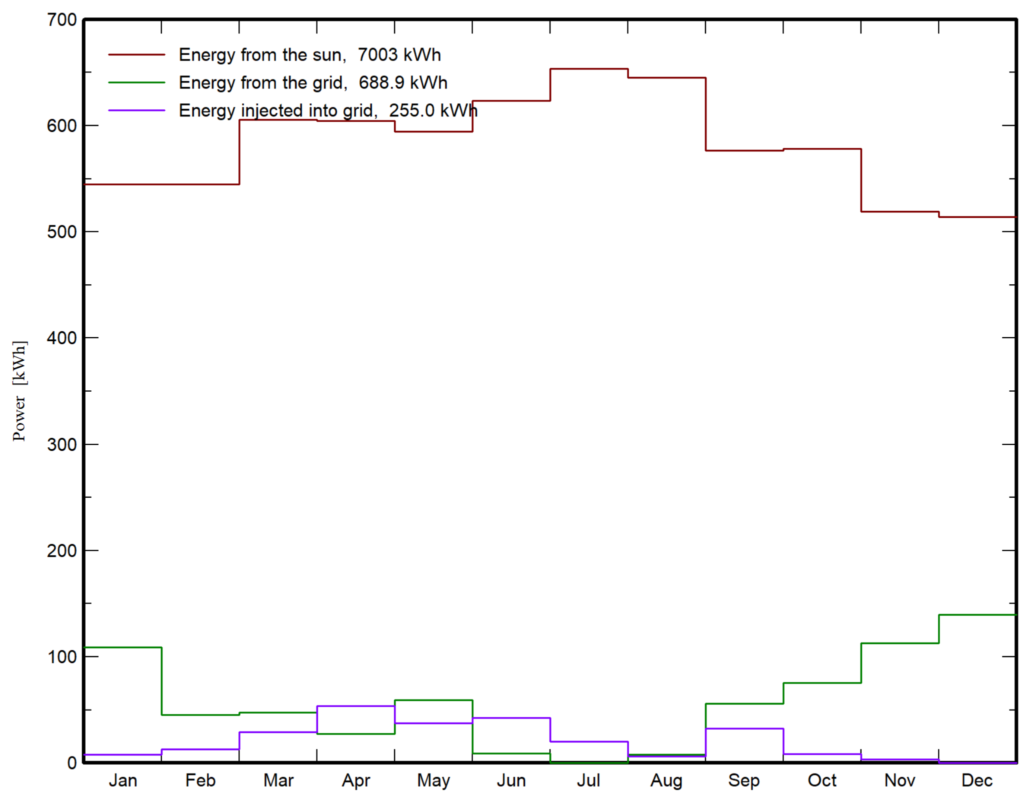

Figure 3. Energy supplied from the sun, from the grid and injected to the grid in configuration 1

2.2. Configuration 2:

The second proposed configuration aims at introducing more battery storage capacity to guarantee more autonomy and independence of the system. The photovoltaic energy is the same as configuration 1 with a battery capacity of about 2072 Ah. The battery capacity has been increased by increasing the number of days of autonomy. The adequate choice for this type of parameter can also contribute in the optimization of photovoltaic systems especially stand- alone (Andam et al., 2023). In the present configuration, 11 modules are used and 14 batteries.

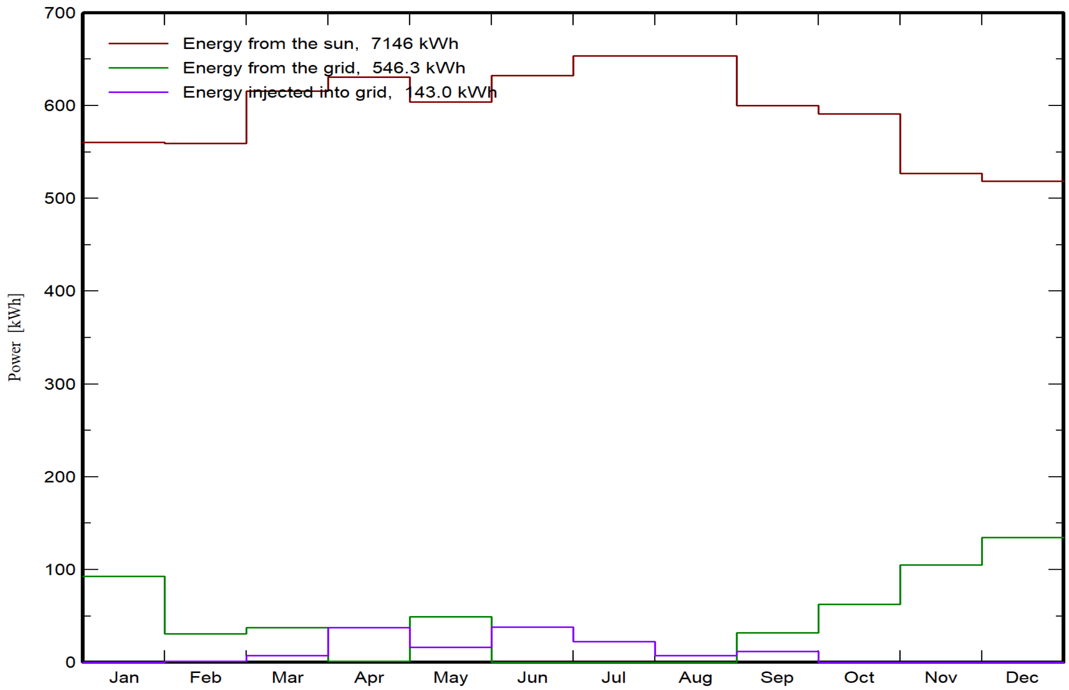

Figure 4. Energy supplied from the sun , from the grid and injected to the grid in configuration 2

2.3. Configuration 3:

The third configuration proposes an increase of the photovoltaic field while keeping the same storage capacity. 15 modules were mobilized, which corresponds to 7,1kwp and a storage capacity of the battery of about 1480 Ah.

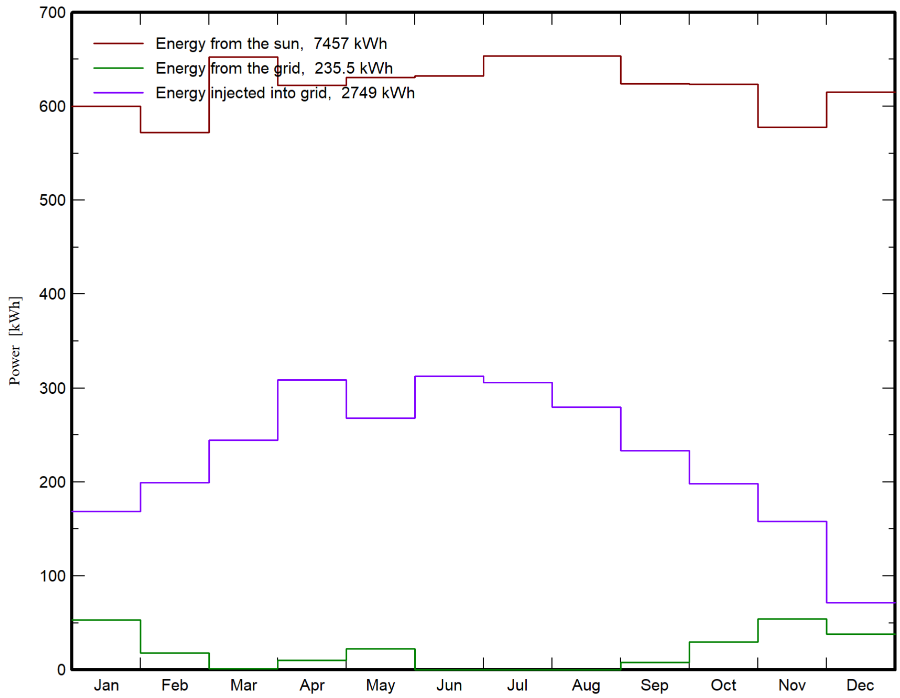

Figure 5. Energy supplied from the sun, from the grid and injected to the grid in configuration 3

3. Results and Discussion

By analyzing the previous results and also taking into consideration the energy supplied by the grid and injected to the grid , we can define a new technical ($\boldsymbol{E_t}$) and economic ($\boldsymbol{E_c}$) efficiency parameter which is identified as follows:

$$\boldsymbol{E_t} = \frac{\textbf{Energy from the grid}}{\textbf{Energy from the sun}} \quad \textbf{(1)}$$

$$\boldsymbol{E_c} = \frac{\textbf{Energy from the grid+Energy injected to the grid}}{\textbf{Energy from the sun}} \quad \textbf{(2)}$$

Our system would be profitable and economically beneficial when the dependence on the grid is minimal, which can be reflected by the first technical parameter $\boldsymbol{E_t}$. However, regarding the economic benefit, we have a loss of energy that is provided to grid. The parameter $\boldsymbol{E_c}$ is taken into account in this case as described in formula (2) because we considered the current case in Morocco where the excess energy is injected into the grid without economic gain for the present consumers.

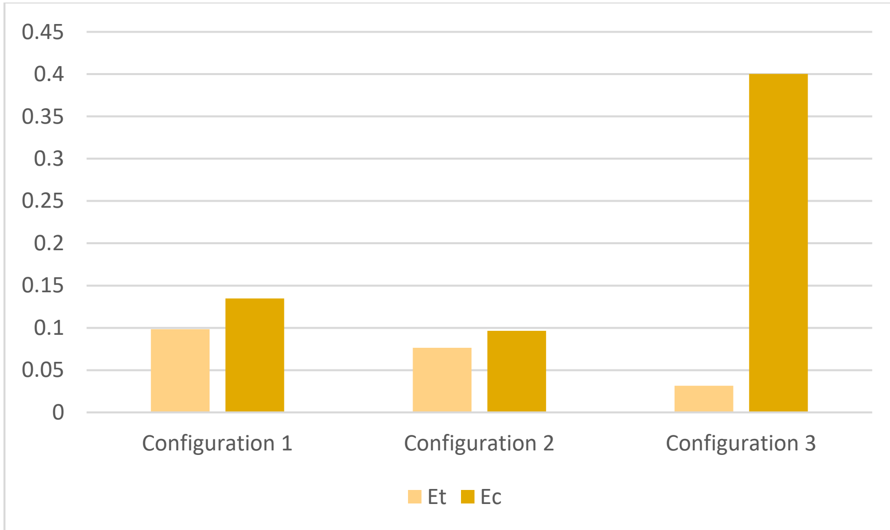

Figure 6. Comparison between the technical and economic efficiency of the three configurations

According to the different results presented, the most efficient configuration is the one that corresponds to the minimum of the two mentioned parameters $\boldsymbol{E_t}$ et $\boldsymbol{E_c}$. The most technically efficient configuration is configuration 3 and the most economically efficient is configuration 2. If we consider the technical and economic gain in parallel, the configuration 2 would be the most appropriate.

4. Conclusion

In this paper, we have analyzed the response of three possible configurations for a grid-connected photovoltaic installation, considering a normal sizing, a sizing with increased storage capacity and a sizing with increased photovoltaic field. Technically, the increase in photovoltaic production had a beneficial impact on the system. Economically, more storage is needed because the price of the excess in our case is not taken into account. It should also be noticed that the economic parameter E_c can change, especially the formula in other countries, especially with the existence of feed-in tariffs. The feed-in tariffs and net metering processes are still being developed and improved (Wonsuk et al. ,2019, Zander et al.,2021) (Rehman et al., 2020, Le et al. 2022).

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Biographies

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