

Optimal sizing of a solar water pumping system for Koyli Alpha Village, Senegal

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Article Info

Article history:

Received Aug 21, 2021

Revised Feb 19, 2022

Accepted Mar 3, 2022

Keywords:

Cell temperature

Isoreliability curves

Loss of power supply probability

Water pumping

ABSTRACT

Our objective is to solve problems of water supply in the village of Koyli Alpha, in Senegal. Their boreholes are supplied by diesel fuels causing environmental drawbacks and the populations don't satisfy their water demand. In order to bring a positive response, we used solar energy to give back the borehole's autonomous and proposed intuitive and numerical methods applying on solar water pumping for finding the best method. A previous study used intuitive methods for determining the size of various components. In order to optimize the energy production, we propose two numerical sizing approaches in order to have an optimal operation. Then, we developed two solar cell temperature models in the numerical sizing method and did a simulation of system operating in MATLAB software. The first model of solar cell temperature depends only on the ambient temperature and the second one combines wind speed and ambient temperature. The results of simulation showed that among these numerical sizing methods, we choose the second solar cell temperature expression, which gives the best performance. The numerical sizing method which uses the second solar cell temperature model yields to the reduction of battery's size and the total life cycle cost found in the intuitive method, by 54% and 32%, respectively.

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1. INTRODUCTION

Nowadays, the increase of the world population leads to a high demand in energy, whose supply is largely covered by fossil fuels. However, the fossil fuels reserves are limited, decrease over time and their use has a number of some negative impacts [1]. Indeed, they are responsible of many environmental issues such as the global warming and climate change, and the poor air quality.

African developing nations, as the rest of the world, rely heavily on fossil fuels, despite the negative impacts mentioned above to cover their energy demand [2]. They have high solar irradiation, and are progressively adopting renewable energy sources in their politics, which have very low impacts [3]. For example, it is noted that Algeria receives more than 3000 hours of sunshine per year and the yearly average of daily solar irradiation in Adrar, ranges from 5 kWh/m²/day to 7 kWh/m²/day [4]. In Algeria, some areas suffer from serious problems of drinking water supply and water for irrigation. The optimal solution to overcome these problems is the solar photovoltaic water pumping system. Here, the authors seek to supply the pump with photovoltaic power ranging from 0 to 2.2 kW for pumping height and pumped water flow rate varying respectively from 0 to 120 m pet from 0 to 30 m³/h [5]. On the other hand, Y. Bakelli et al. tried to model the pump unit on an experimental bench carried out at the unit of applied research in renewable

energies, in the city of, Ghardaia, in Algeria. They simulate the operation of the pumping system for a maximum power of 2.75 kW, a pumping height of 120 m and a flow rate water 10 m³/h [6].

For the case of Senegal, we recorded an average of 5.8 kWh/m² per day. This solar potential encouraged the government to invest in large scale solar power plants in Bokhol, Malicounda, Mekhe, and Merina [7], and promote the use of solar energy in remote areas. For example, the village of Koyli Alpha is located in the department of Linguere, in the ferlo zone, Senegal. This zone is characterized by a lack of water justifying deep water tables. These characteristics have led to the transhumance of local residents to seek water and grass for the animals inside Senegal. In this context, the agency of great green wall had built boreholes in the ferlo, which supplied by diesel oil. Given that Senegal has a strong sunshine and wind potential, we are moving towards the applications of solar PV systems on boreholes hence the name of solar water pumping Solar energy is utilized in hydraulic sector for favoring the solar water pumping leading considerably to solve the lack of water and decrease the consumption of diesel fuel in remote areas.

In order to protect the Green Great Wall and solve definitively the water demand of Ferlo's inhabitants located in Green Great Wall, we decided to study the sizing water pumping solar systems. The challenge in this study is to design a solar photovoltaic water pumping system capable of ensuring the water supply to the village of Koyli Alpha. To do so, we will use the intuitive method to calculate the sizes of the photovoltaic generator and the batteries required to supply the water pumping system. In order to optimize the system, we will use numerical methods based on the impact on the impact of the cell temperature on the reliability of the system. Ammar *et al.* [8] used a type of water pumping over the sun to meet the demand for water from local residents but this system has limits because the demands are high and variable so it requires the use of storage batteries in our study.

In the literature, many methods of sizing are utilized. These are the numerical, the analytical and intuitive approaches. All these methods are applied on system for having an optimal sizing and used as inputs, the meteorological data. Some authors did their sizing by using the intuitive methods and brought into play monthly or annually average values of meteorological data. They mentioned many issues as the lack of data and the oversized the photovoltaic (PV) increased cost.

So as to optimize this solar PV system, the numerical sizing methods are often used. Some authors like Bouzidi and Diaf [9], search to optimize the photovoltaic system whose purpose is to reduce the cost of PV system and to present a good reliability. In their work, they used hourly irradiation of Adrar, in Algeria on the numerical sizing method and the results showed a very low LPSP which means less energy loss. Others have looked for parameters such as the wind speed and the solar cell temperature as inputs data. It is the case in Bilal *et al.* [10], where authors used the mean wind speed for two seasons: the dry season (from November to May) and the rainy season (from June to October) to evaluate the mean wind speed. In this study, the wind speed in Kayar, Potou, Gandon and in Sakhar is determined by using the data collected at two heights for each site. The results showed that the monthly average wind speed obtained in the Potou site were 5.6 m/s and 4.74 m/s for dry and rainy seasons, respectively. In conclusion, the dry season is characterized by strong wind regimes, while, the rainy one is characterized by lower mean wind speeds.

Ouammi *et al.* [11] evaluated also the wind energy potential by using the wind speed data recorded from four meteorological stations in Liguria region, in Northwest of Italy and during 7 years from 2002 to 2008. They showed that the wind speed regime is a fundamental factor to evaluate the wind potential in these four localities. The generated power depends on the wind speed data that allowed to evaluate monthly and seasonal variations of wind speed, as well as the height of wind speed and the wind potential. The probability distribution function of wind speed is fundamental to assess the wind potential in order to find the performance of a wind system for a given site. Authors, after noting the impact of wind speed in the expression's model of cell solar temperature during different seasons and localities, concluded that the wind speed decreases the production and reduces the cell solar temperature. Faye *et al.* [12] described in their studies the importance of the second expression's model of solar cell temperature using the wind speed and the ambient temperature compared to the first expression's model of solar cell temperature, which depends only on the ambient temperature and the solar radiation. Their study revealed that the wind speed is an important factor, which decreases the solar cell temperature. Their results have been confirmed by Kamgba *et al.* [13] who showed that, the power energy increases with the wind speed. In order to optimize the system, we are directly interested in model 1 which is a function of ambient temperature and irradiation and finished with model 2 which addresses the influence of wind speed in photovoltaic production in the sense of ensuring feeding the borehole.

This article is organized as follows: at first, we present materials and methods, then we talk about the intuitive sizing method that permit to calculate the size of components of solar photovoltaic system, and then focus on the method of numerical sizing with the use of two expression's model of solar cell temperature and of instantaneous weather data in the energy modeling. We finish with results and discussions.

2. METHOD

In the literature, we have found several methods for the sizing a water pumping photovoltaic solar system: the intuitive, the numerical, the analytical [14], and the artificial intelligence techniques [15]. In this part, we present at first two models of solar cell temperature using the hourly data such as the temperature and the solar radiation of the village of Koyli Alpha. We begin with the intuitive sizing methods that allow to delimit the workspace i.e. the size of the components, then after, we are looking to optimize the system. Thereby, we applied those meteorological data to the numerical sizing method. Therefore, two models of cell temperature have presented in this study and used the meteorological data in 2016 and in 2017. Secondly, we use an algorithm for the numerical sizing method and utilized as inputs the instantaneous meteorological data. The objective of this method is to choose the best numerical sizing method from these two models of solar cell temperature. For the choice of the best model, we first simulated the operating of the water pumping solar photovoltaic system in order to find the lowest power supply probability (LPSP). According to the chosen and fixed LPSP, we are looked for the optimal torque (panels-batteries) with a view to a future sizing.

2.1. Solar cell temperature modelling

Two models are used to calculate the cell temperature for the years 2016 and 2017. The first model of the cell temperature is given by (1) [16], [17]:

$$Tc_1(t) = Ta(t) + \left(\frac{G_{ref}}{800}\right)(T_{NOC} - 20) \quad (1)$$

Where:

$Tc_1(t)$: instantaneous cell temperature of the first model

t : is the time expressed in hours

T_{NOC} : nominal operating cell temperature

$Ta(t)$: instantaneous ambient temperature

G_{ref} : reference irradiance

The second model of the cell temperature is expressed in (2) [12], [18]:

$$Tc_2(t) = Ta(t) + G_{ref} \left(\frac{U_1}{U_2 + U_3 \cdot W(t)}\right) \quad (2)$$

where

$Tc_2(t)$: instantaneous cell temperature of the second model

U_1, U_2 and U_3 : empirical coefficients of the second model of cell temperature

$W(t)$ is the instantaneous wind speed.

After using the regression model, we found the empirical coefficients. Hence $U_1 = 0.32$, $U_2 = 8.91$ and $U_3 = 2$. This leads to a new expression of solar cell's temperature located in the ferlo zone. This expression is described by the first expression's model of the solar cell temperature, which becomes:

$$Tc_2(t) = Ta(t) + G_{ref} \left(\frac{0.32}{8.91 + 2 \cdot W(t)}\right) \quad (3)$$

2.2. Solar cell's temperature evolution

The first model of solar cell temperature depends only on the ambient temperature while the second model of solar cell temperature takes into account both the ambient temperature and the wind speed. We presented in Figures 1 and 2 the evolution of the solar cell temperatures obtained from these two models in 2016 and 2017, respectively.

The variation of the solar cell temperature in these two models is taken over a range of 24 months between 2016 and 2017. In the literature, some authors utilized the model n°1 based on the ambient temperature and the solar radiation to estimate the values of the solar cell temperature [13], [14]. Our study showed that the model n°1 of solar cell temperature almost reaches its maximum value, 67.2 °C, in April and decreases randomly until reaching the minimum value, 31.6°C, in August for the year 2016. While, the model n°2 gives a maximum value, 62.5 °C, in October and a minimum value, 37.5 °C, in August. The temperature $Tc_1(t)$ is smaller than $Tc_2(t)$ in all months of the year 2016 except in August, where we recorded a higher ambient temperature, equal to 31.7 °C. This result can be justified by a heavy rainfall. For the year 2017.

$Tc_1(t)$ has a maximum value, equal to 65.5 °C in April and a minimum value estimated to 46.7 °C in November. $Tc_2(t)$ recorded a maximum value, equal to 62.6 °C in May and a minimum value equal to

46 °C in December. The analysis of these two models revealed that the model using the wind speed is more interesting because it provides the lowest values of solar cell temperatures during all months of the year 2017.

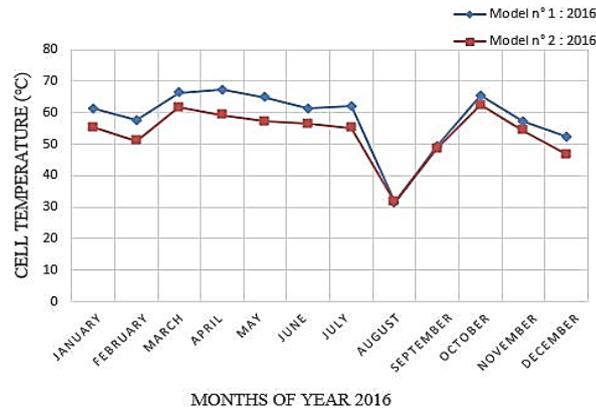


Figure 1. Mean monthly cell temperature from the two models in the year of 2016

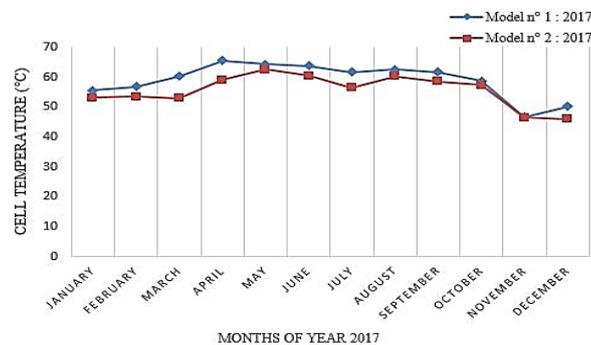


Figure 2. Mean monthly of solar cell temperature from the two models in the year of 2017

2.3. Intuitive sizing methods

Intuitive sizing methods give the size of solar photovoltaic system components. The application of the intuitive sizing method allows to find the total power capacity of the PV field required to satisfy the demand of Koyli Alpha site and the requisite battery capacity for two days without sunshine and during night. There are two different approaches of sizing on the intuitive methods. The first approach is based on the choice of the worst month corresponding to use the month having the lowest irradiances in the year. Leye et al. considered December as the worst month in their study done in Ndem, Senegal [19]. Sadio *et al.* [7] opted for the second approach, i.e., the use of mean values such as the annual average monthly data in the sizing process, to ultimately find out an optimal photovoltaic solar system.

According to the monthly mean data taken between august 2015 and august 2018, the month of December 2017 recorded the lowest value of solar radiation, therefore we adopt the approach of worst month. The intuitive methods use inherent formulas for each component. The sizes of photovoltaic field and batteries storage are given by (4) and (5), respectively [20].

$$P_{PV} = \frac{E_d \cdot G_{ref}}{k \cdot I_G} \tag{4}$$

E_d is the daily energy, estimated to 133640 Wh; P_{PV} is the peak power and is equal to 530044 W_P; G_{ref} is the reference irradiance that is evaluated to 1000W/m²; I_G is the monthly average of daily solar irradiation estimated to 3.877 kWh/m²/day, recorded in December 2017 from the meteorological station of Widou, k is the loss factor = 0.65. It takes into account all the losses of system, namely the different efficiencies of components, the resistive and the PV cell temperature losses.

$$C_b = \frac{E_d \cdot N}{DOD \cdot V_b \cdot \eta_b} \tag{5}$$

N is the number of the autonomous days, V^b corresponds to the voltage of the system and is equal to 48 V, deep of discharge (DOD) is estimated to 0.80 for acid batteries, η^b is the efficiency of the storage battery, evaluated to 80%. It is important to estimate the cost of solar PV system installation. Hence, the technical parameter for evaluating the price of the components and the maintenance is named total life cycle cost (TLCC). It is the best indicator to evaluate the total cost of the solar PV system in order to predict an optimal system. Thus, the TLCC used five components: the PV panels, the pump, the motor AC, the storage battery, and the inverter. Moreover, the TLCC is defined as the sum of initial investment cost, the replacement cost and the maintenance cost. It is given by (6) [21]:

$$TLCC = C_I + C_R + C_{O\&M} \quad (6)$$

The initial total cost is the sum of all components of our PV system and takes into account to the price of the installation, and the civil works. The initial total cost is given by (7) [21].

$$C_I = C_{PV} \cdot C_{Unit,PV} + C_b \cdot C_{Unit,b} + C_{inv} \cdot C_{Unit,inv} + C_{pump} \cdot C_{Unit,pump} + C_{mot} \cdot C_{Unit,mot} + C_0 \quad (7)$$

C_{PV} and $C_{Unit,PV}$ are the total capacity and the unit cost of the PV array, respectively;

$C_{Unit,b}$ is the unit cost of the battery;

C_{inv} and $C_{Unit,inv}$ are the total capacity and the unit cost of the inverter, respectively;

C_{pump} and $C_{Unit,pump}$ are the total capacity and the unit cost of the pump, respectively;

C_{mot} and $C_{Unit,mot}$ are the total capacity and the unit cost of the motor, respectively.

C_0 represents the total constant cost which includes both the civil work and the installation cost. All these components required to be replaced during the system lifetime which depends on the storage battery, the pump, the motor AC and inverter. Thus, the replacement cost C_R is given by (8) [21].

$$C_R = C_{Unit} \times C_{nom} \left(\sum_{i=1}^{N_R} \left[\frac{1+FR}{1+IR} \right]^{LP \cdot i} \right)^{\frac{LP \cdot i}{N_R - 1}} \quad (8)$$

The values of the inflation rate (FR) and interest rate (IR) of the components of the system are considered in this work. C_{unit} represents the unit component cost of the storage battery, the pump, the motor AC, and the inverter; C_{nom} means the nominal capacity of the replacement system components; and N_R refers to the number of replacement of each component over the system life period (LP). The operation and maintenance cost are defined by (9) and (10) [21]:

$$C_{O\&M} = \left\{ C_{O\&M0} \left(\frac{1+FR}{IR-FR} \right) \left(1 - \left[\frac{1+FR}{1+IR} \right]^{LP} \right) \right\} \text{ for } IR \neq FR \quad (9)$$

$$C_{O\&M} = \{ C_{O\&M0} \times LP \} \text{ for } IR = FR \quad (10)$$

$C_{O\&M0}$ is the operation and maintenance cost in the first year.

2.4. Numerical sizing method using instantaneous meteorological data

Before elaborating the sizing algorithm to find the best combination of components, we deal with the parameters. The adopted model to describe the PV generation gives the instantaneous photovoltaic energy after taking into account the solar cell temperature expressed here in two different models as presented above. Hourly data of the ambient temperature, the solar radiation, and the wind speed are obtained from weather station of Koyli Alpha. Our objective is to determine which of these two models of solar cell temperature is the most appropriate for the numerical sizing method. Hence, the instantaneous energy production of the PV array for the two models is given in (11) and (12), respectively:

$$E_{PV,1}(t) = A_{PV} \cdot I_G(t) \cdot \eta_{inv} \cdot \eta_{ref} \cdot \eta_W [1 - \beta(Tc, 1(t) - T_{ref})] \quad (11)$$

and

$$E_{PV,2}(t) = A_{PV} \cdot I_G(t) \cdot \eta_{inv} \cdot \eta_{ref} \cdot \eta_W [1 - \beta(Tc, 2(t) - T_{ref})] \quad (12)$$

$E_{PV,1}(t)$: the instantaneous photovoltaic energy field for first model;
 $E_{PV,2}(t)$: the instantaneous photovoltaic energy field for the second model;
 A_{PV} : the area photovoltaic field;
 η_{inv} and η_w are the inverter and wire yields, respectively;
 η_{ref} : the reference yield;
 β : the temperature coefficient.

Replacing the expressions of $T_{C;1}(t)$ (1) and $T_{C;2}(t)$ (3), in (11) and (12), we end up with (13) and (14), respectively:

$$E_{PV,1}(t) = A_{PV} \cdot I_G(t) \cdot \eta_{inv} \cdot \eta_{ref} \cdot \eta_w \left[1 - \beta(Ta(t) + \left(\frac{G_{ref}}{800}\right) \left((NOCT - 20) - T_{ref} \right)) \right] \quad (13)$$

and

$$E_{PV,2}(t) = A_{PV} \cdot I_G(t) \cdot \eta_{inv} \cdot \eta_{ref} \cdot \eta_w \left[1 - \beta(Ta(t) + G_{ref} \left(\frac{0.32}{8.91+2 \cdot W(t)}\right) - T_{ref}) \right] \quad (14)$$

The instantaneous energy difference between energy produced by the modules and the daily energy load expressed from (15) and (16), respectively, for the two models allows to know the batteries behavior. The instantaneous energy difference is calculated using (15) and (16), respectively [20]:

$$\Delta E_1(t) = E_{PV,1}(t) - \frac{E_d}{\eta_{inv}} \quad (15)$$

and

$$\Delta E_2(t) = E_{PV,2}(t) - \frac{E_d}{\eta_{inv}} \quad (16)$$

$\Delta E_1(t)$ and $\Delta E_2(t)$ correspond to the instantaneous energies difference given by the expression of the models n°1 and n°2 of the solar cell temperature, respectively, E_d is the daily load energy. If the values $\Delta E_1(t)$ and $\Delta E_2(t)$ are less than zero, and the batteries are discharged, then, the instantaneous energy stored is calculated for the first and second models from (17) and (18), respectively [18]-[20]:

$$E_{b1}(t) = E \left(\frac{E_d}{\eta_{inv}} - E_{PV,1}(t) \right)_{bmin} \quad (17)$$

and

$$E_{b2}(t) = E \left(\frac{E_d}{\eta_{inv}} - E_{PV,2}(t) \right)_{bmin} \quad (18)$$

If the values of $\Delta E_1(t)$ and $\Delta E_2(t)$ are greater than zero, respectively, then, the batteries are charged, and the instantaneous energies stored, in the batteries, are calculated using (19) and (20) [20], for model 1 and model 2, respectively:

$$E_{b,1}(t) = E \left(E_{PV,1}(t) - \frac{E_d}{\eta_{inv}} \right)_{bmin} \quad (19)$$

and

$$E_{b,2}(t) = E \left(E_{PV,2}(t) - \frac{E_d}{\eta_{inv}} \right)_{bmin} \quad (20)$$

In order to protect the batteries against overcharge, discharge, and drastic reduction of its life cycle, instantaneous energy stored in the battery is subject to the given restriction [22]:

$$E_{bmin} \leq E_{b,1}(t) \leq E_{bmax} \quad (21)$$

$$E_{bmin} \leq E_{b,2}(t) \leq E_{bmax} \quad (22)$$

E_{bmax} and E_{bmin} are the maximum and minimum energies of the batteries.

The instantaneous loss of power supply which represents the missing energy quantity to satisfy the load demand during 24 hours is computed for the two models by (23) and (24):

$$LPS_1(t) = E_d - (E_{PV,1}(t) + E_{b,1}(t) + E_{b\ min})\eta_{inv} \tag{23}$$

and

$$LPS_2(t) = E_d - (E_{PV,2}(t) + E_{b,2}(t) + E_{b\ min})\eta_{inv} \tag{24}$$

The instantaneous loss of power supply probability (LPS) represents the percentage of power supply that is not able to satisfy load demand and is obtained by the summation of all instantaneous loss power supply at specific time over the load energy, in accordance with (25) and (26) for the two models, respectively:

$$LPSP1(t) = \frac{\sum LPS1(t)}{E_d} \tag{25}$$

and

$$LPSP2(t) = \frac{\sum LPS2(t)}{E_d} \tag{26}$$

Loss of power supply probability (LPSP) indicates the reliability of power supply to load. If LPSP (t) is equal to 0, it means that the system satisfies totally the load demand while on the other hand, if LPSP is equal to 1, it means that the load demand is not satisfied by the PV system. An LPSP (t), which is between 0 and 1 means that the supplied power cannot fully cover the load demand because there are an insufficient energy production from the PV array and not enough energy stored in the batteries [22]. The objective is to calculate the storage capacity corresponding to each PV capacity value, considering all these operating conditions of the PV system. The PV capacity varies from a minimal value equal to the unitary PV module capacity, up to a maximal value corresponding to the PV power found by applying the intuitive method. The Figure 3 shows the sizing algorithm of numerical method.

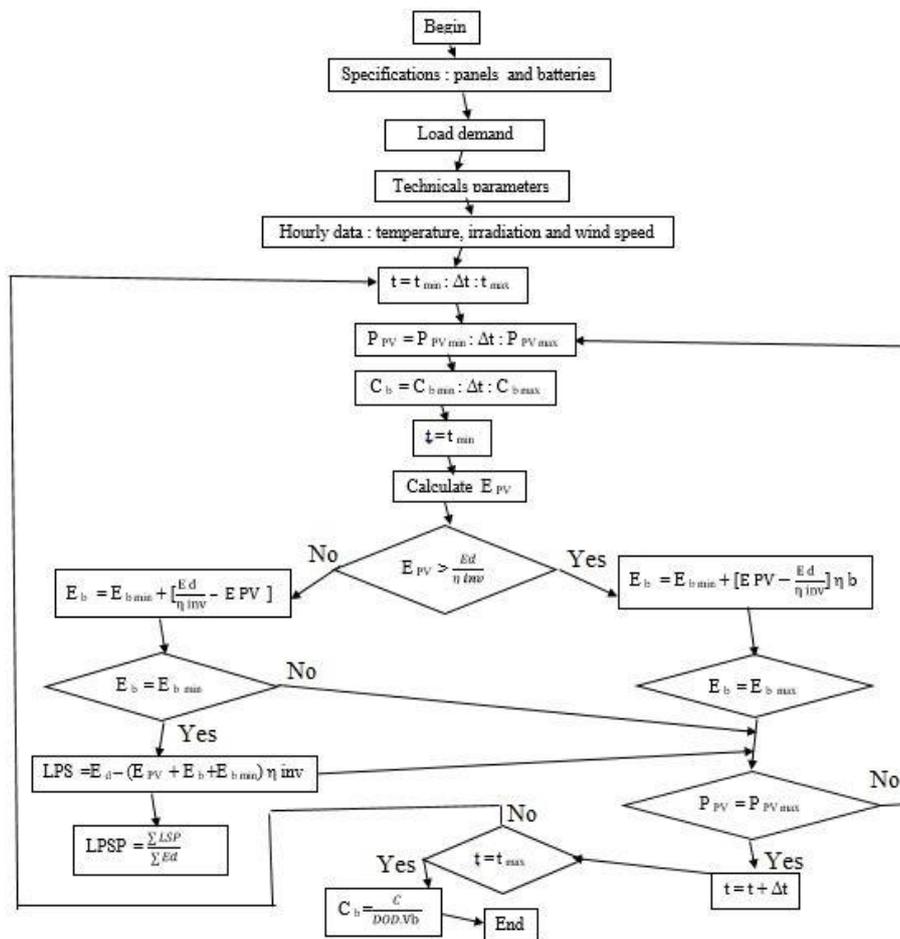


Figure 3. Sizing algorithm of numerical method for the two expression’s models of solar cell temperature

3. RESULTS AND DISCUSSION

3.1. Results

In the intuitive sizing method, we found a total PV array capacity and a storage system capacity, equal to 53,044 W_p and 6,960 Ah, respectively. If we increase this storage capacity about 20% to take into account the depth of allowed discharge, it grows to 8,352 Ah. The TLCC of the pumping photovoltaic solar system then turns around 920,304.8998EUR. After modeling the system operating, the sizing algorithm using two models of solar cell temperature is running on Python software. The results are shown in Figures 4-7. Figure 4 shows the different combinations of PV array capacity and the storage system capacity at different reliability levels, called isoreliability curves, when the first expression's model of the solar cell temperature is utilized.

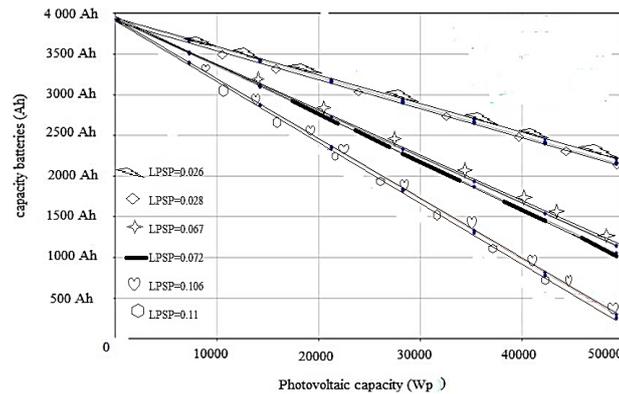


Figure 4. Different PV/battery combinations with numerical sizing method using the first expression's model of solar cell temperature.

The goal of this work is to look for a good combination panel/battery in order to have a good reliability and a reduction cost. In this optimization, we worked with the probabilistic approach using hourly data in the energetic photovoltaic model. We remarked that the batteries capacity increases inversely proportional with photovoltaic capacity. It means that, during the sunnys days, the photovoltaic field ensures the energetic production, therefore, the batteries supply the load during the night and the days without sunrise. This study is done between 10 am and 3 pm and we observed that the best reliability corresponding to the best production in capacity (photovoltaic/batteries). Among the is reliability curves, we chose the one which corresponds to the lowest loss of power supply probability to find the best PV/battery combination. It depends on high power produced by panels and batteries in the PV system. The values of LPSP vary between 0.026 and 0.11. The best PV/battery combination which satisfies a reliability level of 97.4% is given in Figure 5.

From Figure 5, it is noted that a value of total PV array capacity of 49,250 W_p necessitates a storage system capacity of 2,700 Ah. If we increase this storage capacity about 20 % to take into account of the depth of allowed discharge, it grows up to 3,240 Ah. The TLCC of this combination is 143,477.268 EUR. The proposed sizing method enabled to reduce the number of batteries needed by the PV system to 68 % and the TLCC to 40 %, with only 0.026 of LPSP, when compared to intuitive method. Figure 6 presents different combinations of PV/battery at different reliability levels using the second expression's model of the solar cell temperature.

The values of LPSP, from Figure 6, vary between 0.62 and 0.0197. When the value of LPSP is 0.62, we record many losses energy, which lead to a poor reliability. For a constant value of LPSP, the batteries capacity vary conversely proportional and increase corresponding to the decreasing of the panel's capacity. For example, for a LPSP equal to 0.0197, the best combination is found with the lowest TLCC. The results of our study are compared to a work done in Sohar region, in Oman. In this study, H. A. Kazem et al utilized geographic, climatic and sunshine coordinates as inputs of photovoltaic/battery system [23]. Theirs results generated a good reliability of 98.7%, i.e a LPSP equal to 0.013 while our study applied in Koyli Alpha site has given a reliability of 98.03% corresponding to a LPSP equal to 0.0197 when, the second expression's model of the solar cell temperature is used. The best PV/battery combinations that satisfies a reliability level of 0.0197 are shown in Figure 7.

From Figure 7, it is noted that the best PV/battery combination corresponds to a value of total PV array capacity equal of 51,080 W_p and at a storage system capacity estimated to 3,847 Ah. If we increase this storage capacity about 20% to take into account of the depth of allowed discharge, it grows to 4,680 Ah. The results of our study are summarized in Table 1. Here, a comparative study of the intuitive method is made

compared to numerical methods using respectively models 1 and 2 of cell temperature. The use of numerical methods allows an optimization of the photovoltaic solar water pumping system applied to the boreholes of the village of Koyli Alpha. These methods reduce the cost of batteries and TLCC. The goal is to choose the best cell temperature model applied to the numerical sizing method. The choice is based on the lowest LPSP justifying good energy production at an acceptable cost.

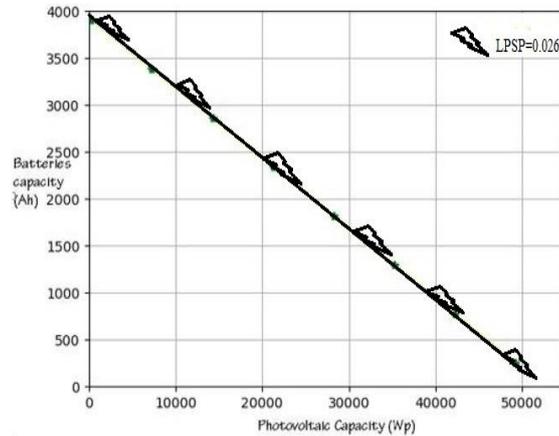


Figure 5. Different PV/battery combinations with numerical sizing method using the first expression's model of the solar cell temperature at LPSP equal to 0.026

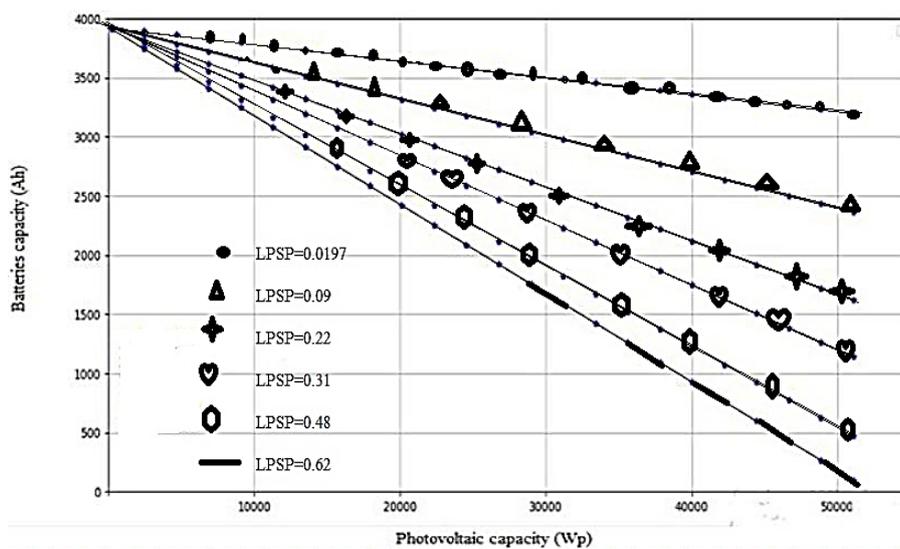


Figure 6. Different PV/battery combinations with the numerical sizing method using the second expression's model of the solar cell temperature

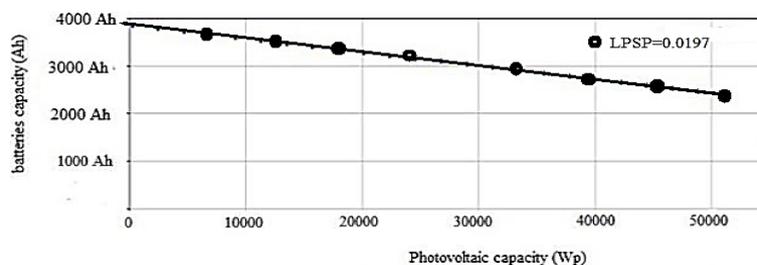


Figure 7. Different PV/battery combinations with numerical sizing method using the second expression's model of the solar cell temperature at LPSP equal to 0.0197

Table 1. Results obtained the intuitive methods and numerical methods using two models of cell temperature

Designations	Intuitive methods	Numerical methods using cell temperature: Tc,1)	Numerical methods using cell temperature: Tc,2)
PV capacity (Wp)	53,044	49,250	51,080
Battery capacity (Ah)	8,352	3,240	4,680
TLCC (EUR)	920,304.9	143,447.3	163,917
Capacity reduction	//	7.15%	3.7%
Battery reduction	//	68%	54%
TLCC reduction	//	40%	32%
LPSP	0	0.026	0.019

3.2. Discussions

The TLCC of this combination is 163,917 EUR. The proposed sizing method based on the second expression's model of cell temperature and when the LPSP equal to 0.019 enables to reduce the number of battery needed by the PV system by 54 % and the TLCC by 32%. Sadio *et al.* [24], in their researches, compared the intuitive and numerical methods and the results showed that the storage capacity decreases by 25% and permitted to reduce the TLCC by 49% with numerical method. Bilal *et al.* [25] adopted a sizing methodology of a hybrid solar/wind/battery systems using a multi-objective genetic algorithm to minimize cost and increase reliability. They worked with hourly solar irradiation, temperature and wind speed annual data from Potou located in the northwest coast of Senegal. Compared to the case study applied in one region of Malaysia using data of the year 1999, Shen [26] kept the load demand constant and fixed the LPSP at 1%. Therefore, W.X. Shen simulated a solar photovoltaic system on MATLAB, and the results generated a ratio battery/panel equal to 0.18 Ah/Wp while in our study, the first expression's model generated a ratio battery/panel equal to 0.095 Ah/WP. The obtained results showed that the cost of the optimal configuration decreases by 25% when the probability of loss of power supply (LPSP) goes from 0% to 1%. The reliability of our solar photovoltaic water pumping systems system can be justified by the use of hourly weather data of Koyli Alpha site. To show the importance of taking into account the parameters, which can influence the PV system performance, two expression's models cell solar temperature are considered. In terms of reliability, the second model of cell solar temperature, which integrates wind speed, is better than the first model of cell solar temperature, which doesn't consider the wind speed influence. Indeed they provided LPSP values, equal to 0.0197 and 0.026, respectively. The convection of wind speed is a cooling factor for the solar cell, confirming the effectiveness of numerical method using expression's second model of solar cell temperature.

4. CONCLUSION

In this study, we presented a technique for optimizing the size of panels and batteries in a solar PV water pumping system for hourly weather data from Koyli Alpha village. The objective is to find an optimal response to energy demand for good reliability at minimum cost. This numerical sizing method using hourly data revealed two solar cell temperature models applied to the energy model. The first model depends only on ambient temperature, and the second is expressed as a function of ambient temperature and wind speed. The comparative study showed that the numerical sizing method which uses the second model is more accurate because it recorded at the lowest LPSP which is equal to 0.0197 versus 0.026 for the numerical sizing method based on the first model of of the solar cell temperature. This study concluded the positive yield of wind speed in energy production. Finally, the lowest LPSP which equals 0.0197 and gives the best reliability is chosen and several PV capacity/battery capacity combinations are found. The best panel/battery combination is the one with the lowest cost. The comparison between the numerical sizing method using the second expression model of solar cell temperature and the intuitive method revealed a reduction of 54% for storage batteries and of 32% on the TLCC.

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