Algorithm for Optimum Sizing of a Photovoltaic Water Pumping System

Imene Yahyaoui
Dept. Systems Engineering and Automatic
Industrial Eng. School
Valladolid, Spain

Mahmoud Ammous
Dept. Electric Engineering
National School of Engineeing
Sfax, Tunisia

Fernando Tadeo
Dept. Systems Engineering and Automatic
Industrial Eng. School
Valladolid, Spain

ABSTRACT
A sizing algorithm for a photovoltaic water pumping installation composed of photovoltaic panels, battery' bank, DC/AC converters and a water pump is presented. Considering criteria related to the battery' bank safe operation, fulfilling the water volume needed by the crops and ensuring a continuous operation of the pump, the algorithm decides the size of the installation' components. The installation' cost using the presented and the basic algorithms are compared. Obtained results confirm that the water demand is covered during the crops' vegetative cycle with a minimum use of the battery' bank and minimum cost.

General Terms
Sizing, Photovoltaic Energy.

Keywords
Photovoltaic energy, sizing algorithm, water, pumping.

1. INTRODUCTION
The need to save water and energy is a serious issue that has increased in importance over the last years and will become more important in the near future [1]. The low price of fuel is the reason why renewable energy sources are not used in several applications, including water pumping. So, pumping systems based on renewable energies are still scarce, even though it has clear advantages, namely, low generating costs, suitability for remote areas, and being environmentally friendly. Nowadays, the price of electric energy is rising constantly, and water and energy companies are investing in more efficient solutions [2].

Renewable Energies have been used in water pump applications, especially in remote agricultural areas, thanks to the potential of renewable energies. The renewable energies' use depends on the user's propensity to invest in renewable based pumping systems, his/her awareness and knowledge of the technology for water pumping, and also on the availability, reliability, and economics of conventional options [3]. Moreover, the evaluation of the groundwater volume required for irrigation and its availability in the area is also relevant in determining the profitability of using renewable energies.

Some installations combine solar panels and wind turbines to compensate the solar radiation and the wind velocity fluctuations. These sources act in a complementary way, since, generally, when the solar radiation is high, the wind velocity is low. This combination may result in a more reliable but complex water pumping, since electric power generated by wind turbines is highly erratic and may affect both the power quality and the planning of power systems [4].

Hence, there is a multitude of systems based on renewable energies. However, the choice of the energy source for the pump' supply depends essentially on the site characteristics and the water needed by the crops. As Tunisia's climate is considered semi-arid and it is good insolated country [5], the use of a photovoltaic autonomous installation for water pumping in remote areas is required. Thus, since the sizes of the photovoltaic installation components affect its autonomy [6, 7], it is necessary to define some adequate values for the components' parameters, such as the photovoltaic panel surface and the number of batteries [8, 9].

In this sense, researchers have established various methods to optimize the components' sizes of these installations, essentially the photovoltaic panels' surface and the battery bank' capacity [10]. For instance, some works have focused on developing analytic methods based on a simple calculation of the panels' surface and battery bank capacity using the energetic balance [11-13]. Other works have concentrated on the cost versus reliability question [14]. Moreover, some researchers have proposed sizing algorithms based on the minimization of cost functions, using the Loss of Load Probability (LLP) concept [15]. This LLP approach has also been combined with artificial neuronal networks and genetic algorithms [14]. However, these methods may result in an oversized system for one location and an undersized one for another location [16]. The oversized case results in high installation costs. With an undersized case, the system is unable to supply the load with the energy needed. Moreover, the system's lifetime is shorter, due to the excessive use of batteries. Hence, the component sizes must be carefully selected for each specific application and location [16].

Some tools have been designed to optimize the size of the PV installation components, by taking into account the energetic, economic and environmental aspects [17]. However, some softwares (such as COMPASS) does not include batteries. Hence, water pumping installations are limited to pumping over the sun. HOMER is a good tool for sizing. Despite it guarantees the installation' autonomy, it may give an oversized sizing, since it concentrates in the system' autonomy and it uses data base of 20 years of Nasa. RAPSim focuses on modeling alternative power supply options, using costs calculation throughout the lifespan [18]. RETscreen assists the user to determine the energy production, life-cycle costs and greenhouse gas emission reductions for various types of renewable energies [18], using statistical sizing [17]. Hence, these tools may give a good sizing for the installation' autonomy. However, they may result in oversized components. In this context, this paper presents a development for a previous published work in which, an algorithm for the optimum sizing of the photovoltaic pumping installation destined to tomatoes' irrigation is developed [19]. In fact, during the months that correspond to the crops' vegetative cycle, the selected values must guarantee the water volume needed for the crops' irrigation, the system's autonomy and the battery bank's safe operation [8]. Knowing the water volume needed for tomatoes' irrigating, the site characteristics, the solar radiation and the photovoltaic panel type, the proposed algorithm provides the optimum values of the panel surface and the number of batteries. Indeed, the idea consists in calculating the values that guarantee, on the one hand, the balance between the charged and discharged energy in the battery' bank, and on the other hand, the pumping of the water volume needed. It is important to point out that the components size chosen must fulfill the irrigation requirements for all the months of the tomatoes' vegetative cycle (March to July). In this paper, the algorithm is developed and validated using measured meteorological data. Moreover, an economic comparison between the proposed and the basic sizing methods is presented. The models used for the panels and the batteries are summarized in section 2. The sizing algorithm is proposed in section 3. The algorithm' results are summarized in section 4. Finally, the conclusion is presented in section 5.

2. SYSTEM COMPONENTS' MODELING

In order to size and control the system elements, an essential step consists in modeling the installation components. Hence, some models for the photovoltaic panels, the batteries and the pump are presented now.

2.1 Photovoltaic Panel Model

A yield based panel model is used to model the photovoltaic values (the temperature coefficient for the panel yield, the module [17, 20]. This yield is evaluated using the cell parameters panel yield at the reference temperature, etc.), and

the cell temperature module, which depends on the Nominal Operating Cell Temperature (*NOCT*) and the clearness index [20]. This model is given by:

$$\eta_{pv}(t) = \eta_r (1 - \beta_{pv}(T_c(t) - T_{ref})) \qquad \textbf{(1)}$$

where: η_r is the panel yield at the reference temperature, β_{pv} is the temperature coefficient for the panel yield ($°C^{-1}$), $T_c(t)$ is the cell temperature (ºC), T_{ref} is the reference temperature (°C).

The cell temperature $T_c(t)$ is calculated using [20]:

$$T_c(t) = T_a(t) + H_t(t,d)\frac{NOCT - T_{ref}}{800} \qquad \textbf{(2)}$$

where T_a is the ambient temperature (°C), $H_t(t,d)$ is the solar radiation on the tilted panel (W/ m^2), NOCT is the Normal Operating Cell Temperature (ºC).

The photovoltaic power is evaluated using [20]:

$$P_{pv}(t) = S\ H_t(t,d)\,\eta_{pv}(t) \qquad \textbf{(3)}$$

where S is the panel surface (m^2).

2.2 Battery Bank Model

A non-linear model for modeling the lead- acid battery is used [66]. In addition to its simplicity, this model has the advantage of using the battery current to describe precisely the battery behavior when charging or discharging. Its performance is then evaluated from its capacity C_p and its depth of discharge dod .

The stored charge in the battery C_R is described by [17]:

$$C_{R_{(k)}} = C_{R_{(k-1)}} + \frac{\partial k}{3600} I_{bat_{(k)}}{}^{k_p} \qquad \textbf{(4)}$$

where ∂k is the time between instant $k-1$ and k and k_p is the Peukert.

The depth of discharge dod is given by [17, 20]:

$$dod_{(k)} = 1 - \frac{C_{R_{(k)}}}{C_p} \qquad \textbf{(5)}$$

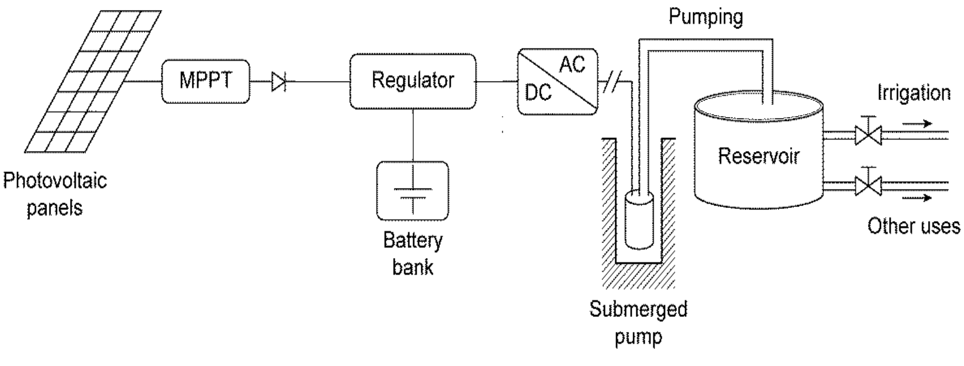

Fig. 1. Scheme of the off-grid photovoltaic irrigation system

where C_p is the Peukert capacity, considered constant (A.h).

2.3 Pump

As in most research related to water pumping, the motor pump adopted is an induction machine (IM), thanks to the simplicity of control and the encouraging price [17]. The total mechanical power on the shaft coupled to the pump P_L is [17]:

$$P_L = \frac{V\ g\ \rho\ H_h}{\eta_p\ \Delta t} \qquad \textbf{(6)}$$

where V is the pumped water volume (m^3), g is the gravity acceleration (m/ s^2), ρ is the water density (Kg/ m^3), H_h is the head height (m), η_p is the pump efficiency, Δt is the pumping duration (h).

3. ALGORITHM PROPOSAL

A good sizing must fulfill that the installation provide the electrical demand of the load [17]. Hence, the proposed algorithm's main objective is to ensure the load supply throughout the day, while protecting the battery' bank against deep discharge or excessive charge and guaranteeing the water volume needed for the crops' irrigation. The scheme of the proposed approach is presented in Fig. 2 [19]. The algorithm depends on:

- the water volume needed,
- the site characteristics,
- the panel characteristics,

The algorithm aims to find the optimum panels' surface S_{opt} and the batteries' number $n_{bat_{opt}}$ that guarantee the installation' autonomy when supplying the pump. Hence, the idea consists in searching the optimal components sizes that ensure the balance between the charged and the extracted energies E_c and E_e, respectively. In fact, the battery bank supply the load when the panels do not generate the sufficient power, and is charged with the PV energy produced in excess (Fig. 3). The energy balance can be expressed by:

$$E_c \;;\; E_{AM} + E_{PM} \qquad (7)$$

The sizing algorithm is performed using two sub algorithms during the crops' vegetative cycle (March to July): the first Algorithm 2.1 allows the size of the panel surface S_M and the number of batteries n_{bat_M} to be determined for each month *M*. Then, Algorithm 2.2 is performed to deduce the final system components' sizes. Algorithm 2.1 is detailed now in steps following the approach presented in Fig. 4.

a) Algorithm 2.1: Determination of S_M *and* n_{bat_M}

Step 1 Estimation of the diffused and direct radiation [19].

Step 2 Deduction of the solar radiation $H_t(t,d)$ in a tilted panel [19].

Step 3 Estimation of the cell temperature $T_c(t)$ using (2).

Step 4 Deduction of the panel yield $\eta_{pv}(t)$ using (1) [17].

Step 5 Calculation of the crops' water needs *V*: The determination of the water volume needed for tomato growth is essential to define the amount of water to be pumped. The water volume depends essentially on the crop growth stage and the evapotranspiration [19]. In the literature, many models have been used to describe the evapotranspiration. For instance, [19] used the Penman Method, which depends essentially on the net radiation at the crop surface, the mean air temperature, and the wind speed. [19] presented some models to describe the evapotranspiration, such as the Thorenthwet method, which depends on the sunlight duration and the air temperature. The Blaney-Criddle method has also been used.

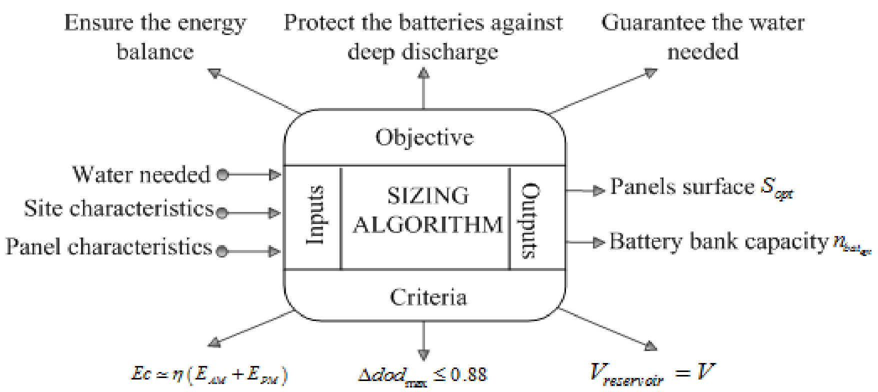

Fig. 2. Planning of the proposed sizing algorithm

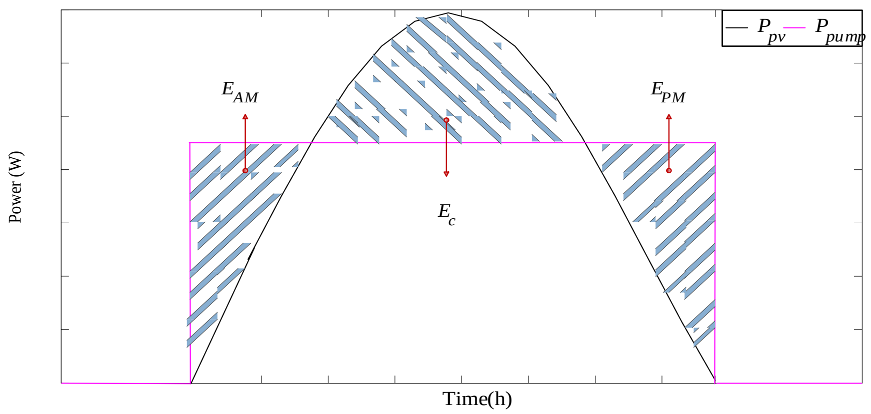

Fig. 3. Energy balance principle

This method includes the seasonal crop coefficient k_c, in addition to the sunlight duration and the air temperature, which provides better patterns of the needed water volume. For this reason, the Blaney-Criddle method is used.

The daily water volume, V_n, required by the crop is given by [19]:

$$V_n = k_c E_{To} \quad \textbf{(8)}$$

where k_c is the monthly crop growth coefficient, E_{To} is the monthly reference evapotranspiration average, which depends on the ratio of the mean daily daytime hours for a given month to the total daytime hours in the year p and the mean monthly air temperature T for the corresponding month, is evaluated [19]:

$$E_{To} = K\, p\left(0.46\,T + 8.13\right) \quad \textbf{(9)}$$

where K is the correction factor, expressed by [19]:

$$K = 0.03\,T + 0.24$$

To obtain the necessary gross water, it is essential to estimate the irrigation losses. For this, an additional water quantity must be provided for the irrigation to compensate for those losses. Thus, the final water volume is evaluated by [19]:

$$V = \left(k_c E_{To} - r_m\right)\left(1 + \frac{1 - f_i\left(1 - L_R\right)}{f_i\left(1 - L_R\right)}\right) \quad \textbf{(10)}$$

where: r_m is the the average monthly rain volume, f_i is the leaching efficiency coefficient as a function of the irrigation water applied [19], L_R is the leaching fraction given by the humidity that remains in the soil, expressed by [19]:

$$L_R = \frac{EC_w}{5\,EC_e - EC_w} \quad \textbf{(11)}$$

EC_w is the electrical conductivity of the irrigation water (dS. m^{-1}) and EC_e is the crop salt tolerance (dS. m^{-1}).

Step 6 Calculation of the pumping duration Δt. In the application, the pump's flux is constant. Thus, Δt can be evaluated by (12):

$$\Delta t = \frac{P_{pump}}{Q} \quad \textbf{(12)}$$

Step 7 Calculation of the minimum panel surface S_i, S_{max} and the initial battery capacity C_i using equations (13), (14) and (15) respectively, based on the irrigation frequency [20].

For March and April, $$S_i = \frac{P_{pump}\,\Delta t\,\frac{d_{aut}}{d_{rech}}}{W_{pv}\,\eta_{bat}^{2}\,\eta_l\,\eta_{pv}\,\eta_{reg}} \quad \textbf{(13)}$$

For May, June and July,

$$S_i = \frac{P_{pump}\,\Delta t}{W_{pv}\,\eta_{bat}^{2}\,\eta_l\,\eta_{pv}\,\eta_{reg}}\left(1 + \frac{d_{aut}}{d_{rech}}\right) \quad \textbf{(14)}$$

$$C_i = \frac{E_d\,d_{aut}}{V_{bat}\,\Delta dod_{max}} \quad \textbf{(15)}$$

with P_{pump} is the pump power (W), Δt is the water pumping duration (h), d_{aut} is the days of autonomy, d_{rech} is the days needed to recharge the battery, W_{pv} is the average daily radiation (Wh/ m^2/ day), η_{bat} is the electrical efficiency of the battery bank, η_l is the electrical efficiency of the installation, η_{pv} is the efficiency of each photovoltaic panel, η_{reg} is the regulator performance, E_d is the the daily consumption (W.h), V_{bat} is the battery voltage (V), Δdod_{max} is the the maximum dod variation (%).

Step 8 Calculation of P_{pvi} corresponding to the minimum panel surface S_i, using (16) [19]:

$$P_{pv\,i} = \eta_{pv}\,S_i\,H_t \quad \textbf{(16)}$$

where n_{pv} is the panels' yield (%), H_t is the solar radiation on a tilted panel (W/ m^2), S_i is the initial panel surface (m^2),

Step 9 Calculation of the energies expected to be stored and extracted from the battery each day by evaluating the area E_c and E_e, respectively, (Fig. 3).

If the discharged energy is higher than the charged energy, the algorithm increases the panel surface by the minimum increment of the PVP size commercially available: the algorithm looks for the best configuration to guarantee the balance between the demanded and the produced energies, by ensuring the equality between the charged E_c and discharged energies E_e in the battery bank (7).

Step 10 The balance between the accumulated and the extracted energies does not guarantee the system's autonomy, due to the fluctuation in the solar radiation and the energy losses in the installation' components. Thus, to ensure the system's autonomy and protect the battery against deep discharges, the algorithm is performed by adopting an efficiency coefficient η that allows the dod to be less than dod_{max} (η is equal to 1.14* η_{error}). Thus, equation (7) becomes:

$$E_c \;;\; \eta\left(E_{AM} + E_{PM}\right) \quad \textbf{(17)}$$

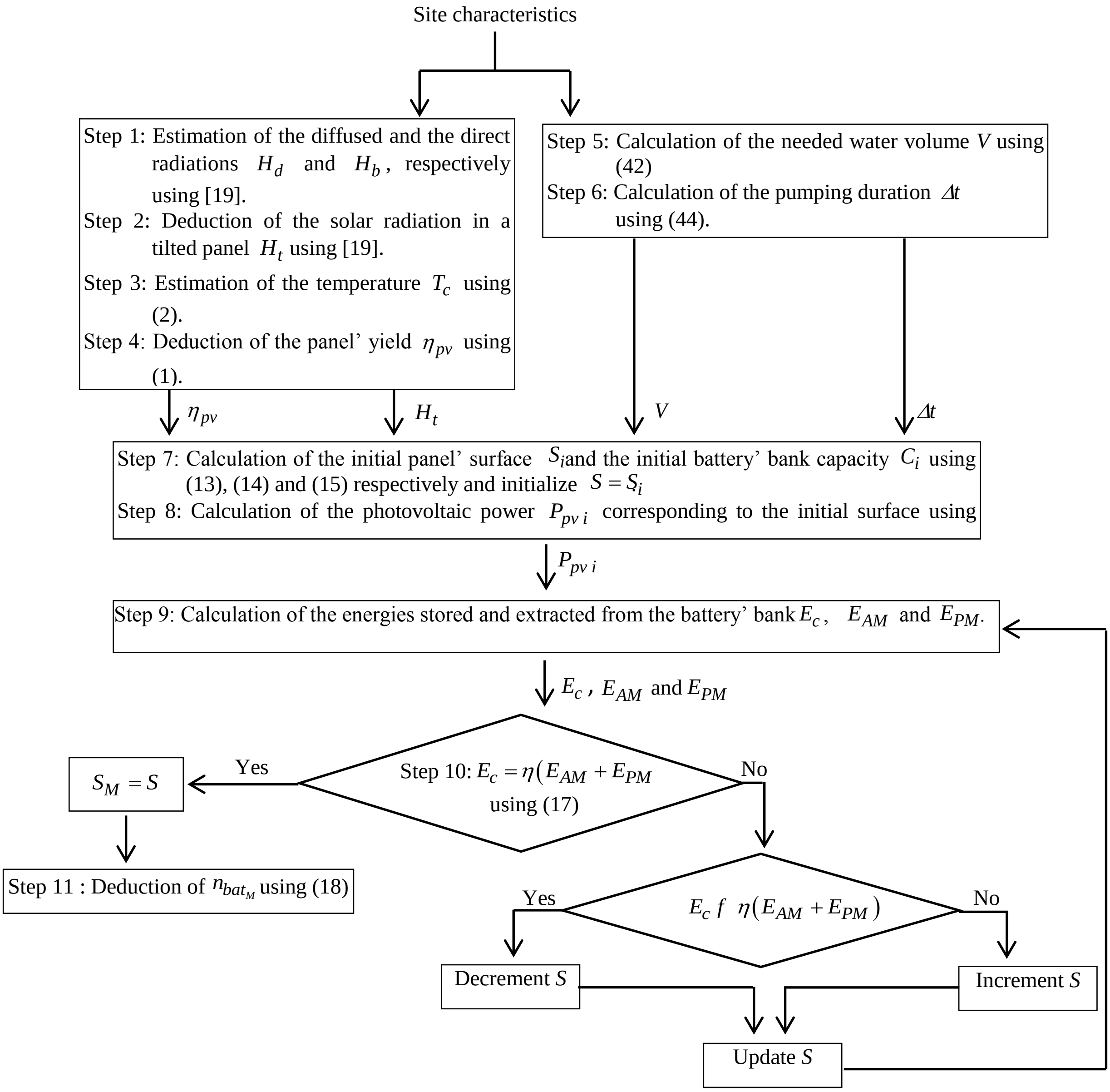

Fig. 4. Sizing Algorithm 2.1 for each month *M*

Step 11 Deduction of n_{bat_M} [19]:

$$n_{bat_M} = \frac{E_c}{C_{bat}} \qquad \textbf{(18)}$$

where E_c is the energy charged in the battery bank (Wh) and C_{bat} is the nominal capacity for one battery (Ah),

b) Algorithm 2.2: Deduction of S_{opt} and $n_{bat_{opt}}$

Using Algorithm 2.2, presented in Fig. 5, the final values of the panel surface S_{opt} and the capacities number $n_{bat_{opt}}$, are then deduced. S_{opt} corresponds to the maximum value of the panel surface obtained during the months. The optimum batteries number is the corresponding value for S_{opt}, since it is the most critical month.

4. APPLICATION TO A CASE STUDY

The proposed algorithm is tested during the months that correspond to the vegetative cycle of tomatoes (March to July), using data of the target area. Algorithm 2.1 is first evaluated. In fact, the solar radiation accumulated on a tilted panel is evaluated [19]. Then, the panel yield is calculated for each month using (1) (Table 1). In parallel, the water needed V is calculated, depending on the crops vegetative cycle and the site characteristics using (10). The initial values S_i, and C_i are summarized in Table 2, and used to test the condition presented in (17). Indeed, if the charged energy is higher than the discharged energy, the panel surface is increased by the minimum panel available surface in the market (the increment is 0.5 m^2), and vice versa.

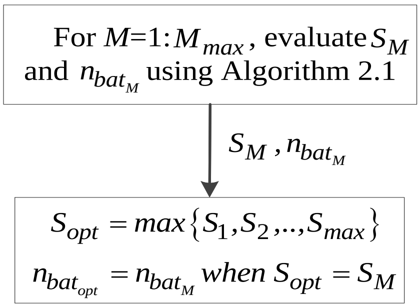

Fig. 5. Sizing Algorithm 2.2

Algorithm 2.1 results are summarized in Table 3 and Fig. 6-7. They show that the proposed algorithm always ensures the needed water volume, respects the battery bank' depth of discharge limits and the energy balance. In fact, in Fig. 6 the proposed algorithm guarantees the needed water volume for the crops irrigation, since the pump is supplied by the panels and the battery bank. This has been proved for March to July (Fig. 7). Moreover, this algorithm ensures the energy balance for each month *M*. For example, in Table 3, the efficiency coefficient is around the fixed value (η_1=1.26) throughout all the considered months. For this value, Δdod is guaranteed to be equal to 0.88. Thus, the extracted energy (E_e) is almost equal to the accumulated energy (E_c). For instance, in March, the generated photovoltaic power during the morning is used to supply the pump together with the battery bank during the pumping duration. Then, the photovoltaic power generated is used to charge the batteries for the rest of the day hours. The quotient between the cumulated and extracted energies is equal to 1.29, which is near to the value initially fixed in Algorithm 2.1 $(\eta = 1.26)$. For July, the error coefficient is fixed to be 66.67 %

Hence, the obtained panels' surface S_{opt} and the batteries number $n_{bat_{opt}}$ satisfy the energy balance. In other terms, all the stored energy is consumed, thanks to the batteries number calculation, which is done by considering the same maximum $\Delta\, dod_{max}$ value for all the months ($\Delta\, dod_{max}$ = 0.88). Hence, the panels' surface allows the load to be supplied during the pumping duration and provides the energy needed to charge the batteries (Fig. 8).

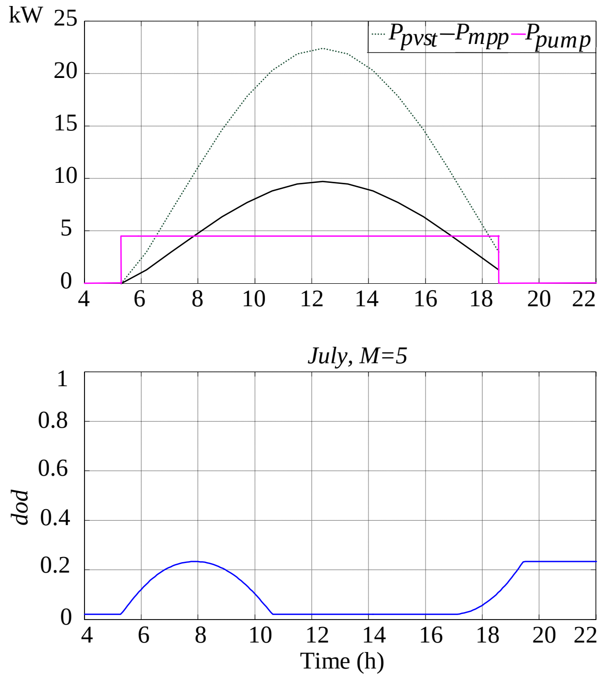

Fig.6. Evaluation of Algorithm 2.1 for each month using mean climatic data values

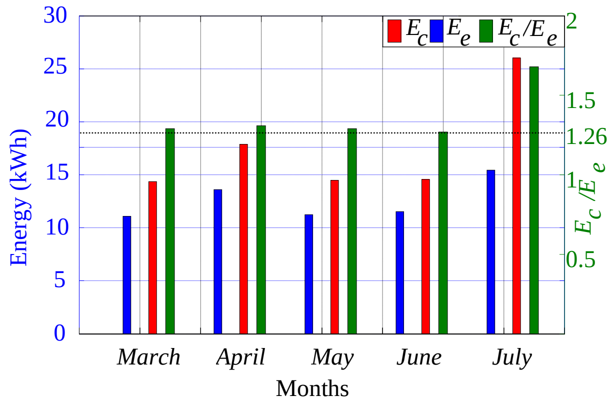

Fig.7. Daily energies using mean climatic data values for each month *M* using algorithm 2.1

July, M=5

Table 1 Panel efficiency calculation and irrigation parameters estimation

Months	*March*	*April*	*May*	*June*	*July*
W_{pv} (W.h)	8094.0	10254.0	11197.0	12974	12077
η_{pv} (%)	12.37	12.21	11.90	11.50	11.17
Water volume $m^3 / 10\, ha$	60.70	100.37	179.82	241.10	321.03
Pumping duration Δt (h)	2.51	4.14	7.42	9.95	13.25

Results

Table 2 Initial values of the panels' surface and number of batteries

Months	*March*	*April*	*May*	*June*	*July*
Initial panel surface (m^2)	11	27.5	92	108.5	156.5
Initial batteries numbers C_i	11	5	9	12	16

Results

Table 3 Calculation of the minimum panel surface and the batteries' number needed to fulfill the energy requests each month *M*

	March	*April*	*May*	*June*	*July*
η_{error} (%)	90	90	90	90	66.67
$E_{AM} + E_{PM}$ (W.h)	11100.0	13606.0	11232.0	11511.0	15450.0
E_c (W.h)	14347	17882.0	14499.0	14572.0	26018.0
E_{pump} (W.h)	11278	18648.0	33409.0	44796.0	59040.0
E_{PV} (W.h)	16034	25122	40488	52741	81822
$S_M \left(m^2\right)$	17.5	23	31.5	40	68
n_{bat_M}	6	7	6	6	13
$\eta_1 = \dfrac{E_c}{E_{AM} + E_{PM}}$	1.29	1.31	1.29	1.27	1.68

Results *Months*

To demonstrate the efficiency of the proposed algorithm from an economic point of view, a brief economic comparison is now presented. Hence, the installation' cost (19) is evaluated, using the components sizes obtained by the proposed and the standard sizing methods [21] (table. 4):

$$Cost = n_{pv}\left(C_{pv} + n_y\, M_{pv}\right) + n_{bat}\left(C_b + y_b\, C_b + \left(n_y - y_b - 1\right) M_b\right)$$
$$+ n_{chop}\, C_{chop}\left(y_{chop} + 1\right) + n_{chop}\, M_{chop}\left(n_y - y_{chop} - 1\right) + C_{inv}\left(y_{inv} + 1\right) \quad \textbf{(19)}$$
$$+ M_{inv}\left(n_y - y_{inv} - 1\right)$$

Table 4 Cost evaluation of the PV installation

Sizing	**Standard method**	**Proposed algorithm**
Cost (€)	74068	41916

where n_{pv} is the number of photovoltaic modules and n_{bat} is the batteries number

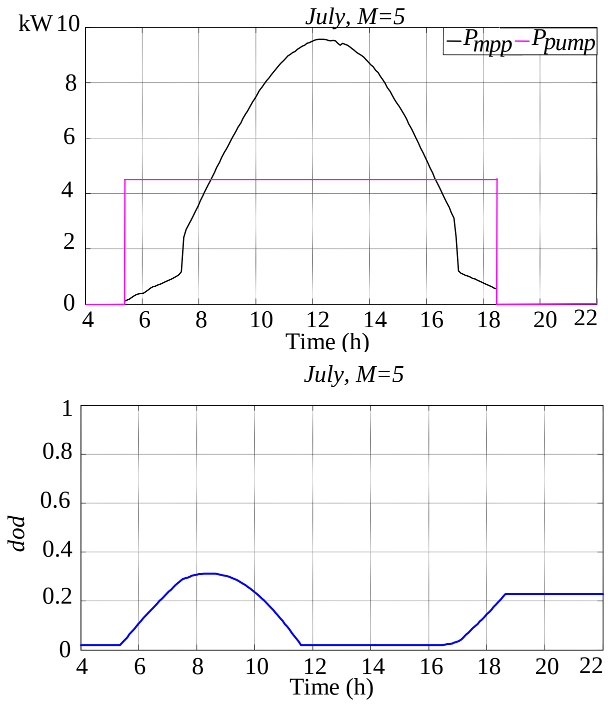

Fig.8. Evaluation of the algorithm 2.2 using measured data for July

5. CONCLUSIONS

An algorithm to decide on the components sizing of a pumping installation is proposed and tested for a 10 ha land surface in the Northern of Tunisia. The algorithm ensures the system's autonomy, the batteries safe operation and the needed water volume for irrigation. A cost comparison between the basic and the proposed sizing methods proves that the proposed algorithm allows the installation' cost to be decreased.

6. ACKNOWLEDGMENTS

Miss Yahyaoui is supported by a grant from MICInn BES-2011-047807.

7. REFERENCES

[1] Gaikwad, D. D., Chavan, M. S. 2015. A Novel Algorithm for MPPT for PV Application System by use of Direct Control Method. International Journal of Computer Applications. (2015), 10-15.

[2] Ramos, J. S., Ramos, H. M. 2009. Sustainable application of renewable sources in water pumping systems: Optimized energy system configuration. Energy Policy. (2009), 633-643.

[3] Sree Manju, B., Ramaprabha, R., Mathur, B.L. 2011. Design and Modeling of Standalone Solar Photovoltaic. International Journal of Computer Applications. (2011), 41-45.

[4] Díaz-González, F., Sumper, A., Gomis-Bellmunt, O., Villafáfila-Robles, R. 2012. A review of energy storage technologies for wind power applications. Renewable and Sustainable Energy Reviews. (2012), 2154-2171.

[5] Rana, G., Katerji, N., Lazzara, P., Ferrara, R. M. 2012. Operational determination of daily actual evapotranspiration of irrigated tomato crops under Mediterranean conditions by one-step and two-step models: Multiannual and local evaluations. Agricultural Water Management. (2012), 285-296.

[6] Kaldellis, J. K., Zafirakis, D., Kondili, E. 2010. Optimum sizing of photovoltaic-energy storage systems for autonomous small islands. International Journal of Electrical Power & Energy Systems. (2010), 24-36.

[7] Sidrach-de-Cardona, M., Mora López, L. 1998. A simple model for sizing stand-alone photovoltaic systems. Solar Energy Materials and Solar Cells. (2010), 199-214.

[8] Eteiba, M. B. A., El Shenawy, E. T., Shazly, J. H., Hafez, A. Z. 2013. Photovoltaic (Cell, Module, Array) Simulation and Monitoring Model using MATLAB®/GUI Interface. International Journal of Computer Applications. (2013), 69, 14-28.

[9] Jakhrani, A. Q., Othman, A.K., Rigit, A., Ragai. H., Samo, S. R., Kamboh, S. A. 2012. A novel analytical model for optimal sizing of standalone photovoltaic systems. Energy. (2012), 675-682.

[10] Acakpovi, A., Xavier, F. F., Awuah-Baffour, R. 2012. Analytical method of sizing photovoltaic water pumping system. In the proceedings of the 4th IEEE International Conference on Adaptive Science & Technology, 65-69.

[11] Shrestha, G. B., Goel, L. 1998. A study on optimal sizing of stand-alone photovoltaic stations. IEEE Transactions on Energy Conversion. (1998), 373-378.

[12] Barra, L., Catalanotti, S., Fontana, F., Lavorante, F. 1984. An analytical method to determine the optimal size of a photovoltaic plant. Solar Energy. (1984), 509-514.

[13] Groumpos, P. P., Papageorgiou, G. 1987. An optimal sizing method for stand-alone photovoltaic power systems. Solar Energy.(1987), 341-351.

[14] Mellit, A., Benghanem, M., Hadj Arab, A., Guessoum, A. 2003. Modelling of sizing the photovoltaic system parameters using artificial neural network. In the proceedings of the IEEE Conference on Control Applications, 353-357.

[15] Yang, H., Zhou, W., Lu, L., Fang, Z. 2008. Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. Solar Energy. (2008), 354-367.

[16] Mellit, A., Benghanem, M., Kalogirou, S. A. 2007. Modeling and simulation of a stand-alone photovoltaic system using an adaptive artificial neural network: Proposition for a new sizing procedure. Renewable Energy. (2077), 285-313.

[17] Ben Ammar, M. 2011. Contribution à l'optimisation de la gestion des systèmes multi-sources d'énergies renouvelables. Thesis presented at the National School of Engineering of Sfax, Tunisia.

[18] Bernal-Agustín, J. L., Dufo-López, R. 2009. Simulation and optimization of stand-alone hybrid renewable energy systems. Renewable and Sustainable Energy Reviews. (2009), 2111-2118.

[19] Yahyaoui, I., Chaabene, M., Tadeo, F. 2013. An algorithm for sizing photovoltaic pumping systems for tomato irrigation. In the proceedings of the IEEE Conference on Renewable Energy Research and Applications (ICRERA). (2013), 1089-1095.

[20] Chaabene, M. 2009. Gestion énergétique des systèmes photovoltaïques. A master course at the National School of Engineering of Sfax, Tunisia, (2009).

[21] Eftichios, K., Dionissia. K., Antonis, P., Kostas, K. 2006. Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms. Solar energy. (2006), 1072-1088.