International Journal of Energy Applications and Technologies
Available online at
http://dergipark.gov.tr/ijeat/issue/31601
Research Article
Vol. 4
Issue 4
pp. 164-173
Year
2017

APPLICATION OF RURAL PHOTOVOLTAIC WATER PUMPING SYSTEM USING IMMERSED PUMP AND DC MOTOR

Jamel Chakchak[1*], Numan S. Çetin[1]

[1] Ege University, Solar Energy Institute, Energy Technology Department, 35100 Bornova - Izmir / TURKEY

Abstract

Tunisia has many isolated areas characterized by low rates of population in cores dispersed; suffering from water supply problems for consumption and irrigation. The photovoltaic pumping systems present the ideal solution for these problems. There is somes information like water flow rate, voltage and current of PV field, in addition to other meteorological information such as global solar irradiation on an inclined and horizontal surface and ambient temperature are used in the design of a Photovoltaic Water Pumping project. The current study proposes the sizing, designing, simulation and installation (practice) of a solar water pumping station located in Ben Guerdane -Tunisia that uses immersed pump and an AC Motor. In order to build a new station, the well, the storage tank, panels support and position of the solar panels were redesigned using AutoCAD and SolidWorks. Finally, the overall activity of the station was simulated using Matlab Simulink.

Key words: *Photovoltaic; Water pumping; Design; Simulation; Installation.*

Paper submitted: April 26, 2017

Paper accepted: December 20, 2017

Corresponding author, chakchakj@gmail.com

1. Introduction

In our days, the demand for water is increasing especially in rural areas and remote locations where access to conventional energy is difficult or impossible. There has been a growing interest in using photovoltaic generators as a new energy source. The utilization of a standalone photovoltaic pumping system is a practical, reliable, efficient and economical solution for the problem the lack of water, especially in desert areas.

Photovoltaic pumping system without batteries is simpler than systems with batteries. It is composed only by a solar panel, a motor controller and pump [1]. Maximum use of photovoltaic water pumping systems requires an optimal sizing of different system components [2]. Moreover, increasing the overall effectiveness of the system will reduce the photovoltaic array size that will reduce the total cost of the system [3]. There are several studies on the design of photovoltaic water pumping system using dc motor to supply water for irrigation or drinking [4-5-6]. A simulation model for DC photovoltaic water pumping system has been developed and validated [5-7]. Others research papers have been investigated for installed a rural photovoltaic water pumping system at hot ambient temperature and great potential of solar radiation [8].

Regarding to that, the Regional Offices of Agriculture Development (CRDA) of Médenine, has implemented some strategy that aimed for exploitation of solar energy in various activities such as isolated environments by the establishing water pumping stations by using solar PV. In this in-depth study, we dimensioned, designed, simulated and installed a photovoltaic water pumping station, which is located in Ben Guerdane Tunisia (southeast). The study focuses on investigating the feasibility for establishment of a photovoltaic water pumping with a water tank which has a capacity of 100m3 and a distance from the well by 300m; estimating the number of panels you will need to meet the electricity demand of the pump to a flow rate that equals to Q=1.5 l/s minimum two hours in the worst month in the year and establish an optimum coupling the photovoltaic panels and ensure the smooth running of the station. Many visits to site were conducted to identify relevant data, and to supervise the steps for the implementation of the station.

This paper is organized up to six sections: 2. Site Specifications and database; 3. Designing of The Photovoltaic Water Pumping; 4. Simulation; 5. Installation; And 6. Conclusion.

2. Site Specifications and Database

Ben Guerdane found the region of Medenine (Latitude: 32.91, Longitude: 11.40). Extends on over vast sandy plains with altitudes ranging between 25 and 35 m. Temperatures remain high throughout most of the year with maximum temperatures recorded in June and July ranges between 35 and 43 °C. On the other hand, the lowest temperature recorded is 3.5°C, while the annual temperature average ranges between 21.5 and 24 °C [9]. The site has well of water with 15m depth, a static level of 10.75m, drawdown of 3.2m and a geometric level of 12m [9].

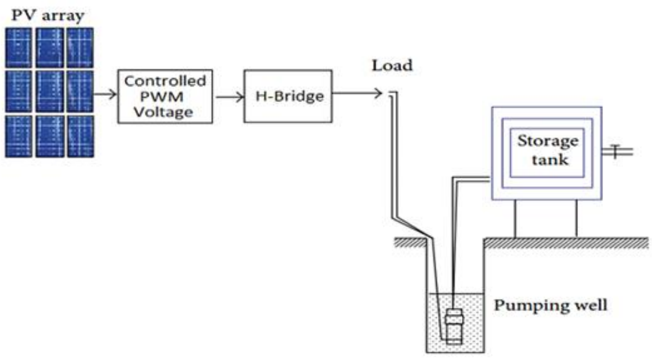

Fig.1. PV/water pumping system configuration.

Ben Guerdane has significant solar resources conducive to the operation of this energy source. Indeed, benefit: An annual Irradiation on Horizontal Plane (Hh) exceeding 5.23 kWh/m²/day distributed on the months of year, it as follows: Jan=4; Feb=3.7; Mar=4.9; Apr=5.9; May=6.8; Jun=7.2; Jul=7.3; Aug=6.5; Sep=5.45; Oct=4.2; Nov=4 and Dec=2.9

(kWh/m²/day). An annual irradiation on a plan with the optimal inclination (Hopt) exceeding the 5.72 kWh/m^2/day distributed on the months of year, it as follows: Jan=4.9; Feb=5.2; Mar=5.4; Apr=5.7; May=6.1; Jun=6.6; Jul=6.8; Aug=6.6; Sep=6.1; Oct=5.5; Nov=5 and Dec=4.8 (kWh/m²/day) [9].

The adopted structure consists of a moto-pump powered by a photovoltaic generator. The proposed system consists of photovoltaic array, the Controlled PWM Voltage and HBridge blocks to control a DC motor and centrifugal pump.

3. Designing of the Photovoltaic Water Pumping

Generally, it is difficult to predict the specific performance of a solar pump under various operation conditions. To maintain data credibility, a simplified procedure that allows determining the size the pumping system with an acceptable degree of accuracy will be will be applied. The three most important factors that should be estimated carefully to obtain a reliable sizing are as follows: water needs, sunshine data and the performance of selected group (motor-pump) on the operating range of the system. The process occurs in three steps: Estimation of the hydraulic load, water pumping system selection, the photovoltaic field size determination.

3.1. Estimation of the Hydraulic Load

Daily Water Requirement: the daily water requirement is determined by the amount of water consumed during specific service duration. This need is equal to Qdy = 40 m^3 / day [9].

The Flow Rate: Calculated by dividing the daily requirement by the pumping time. The flow rate as specified by the CRDA will be equal to Q=1.5 l/s.

The Flow Velocity (v): The circulation speed of the existing circuit can be calculated by the following formula [10]: with, Q (l/s); the flow rate, S (m²); the conduit section and V (m/s) the flow velocity.

$$V = \frac{Q}{S} \tag{1}$$

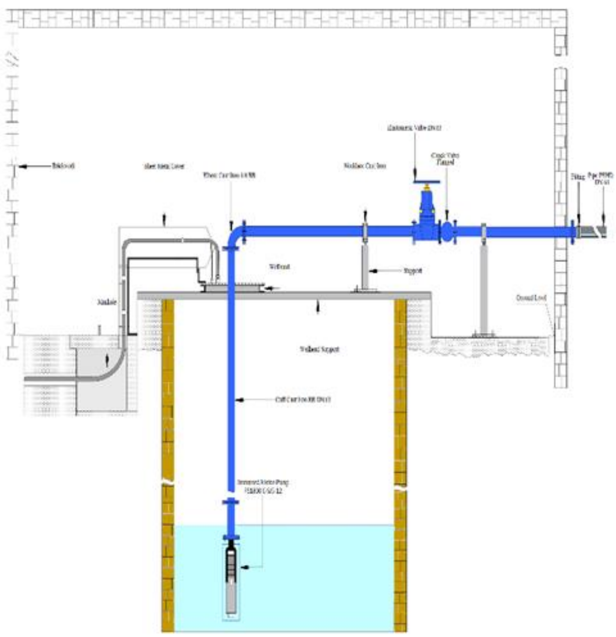

Fig.2. The New Proposal Design of the Well.

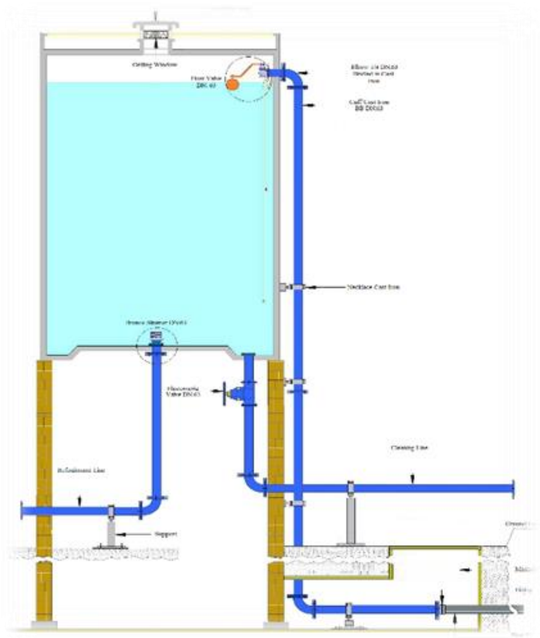

Fig.3. The Proposal Design of the Storage Tank (Stil).

Flow Regimes "Reynolds Number"(Re): The nature of the flow regime is determined by the "Reynolds number" that is expressed [10]: with, V (m/s) the flow velocity, D (m) diameter of the pipe and υ (m²/s) kinematic viscosity of the fluid.

$$Re = \frac{V \times D}{\upsilon} \quad (2)$$

Under most practical conditions, the flow in a circular pipe is laminar for Re ≤ 2300, turbulent for Re ≥ 4000, and transitional in between (2300≤ Re ≥ 4000) [10].

Loss Loads In The Circuit (ΔP): Is the sum of the linear load losses (the linear pressure loss) resulting from the straight lengths of pipes and singular pressure losses due to various attachments and changes in momentum (valves, Coude…).

$$\Delta P = \sum \Delta P \text{ linear} + \sum \Delta P \text{ singular} \quad (3)$$

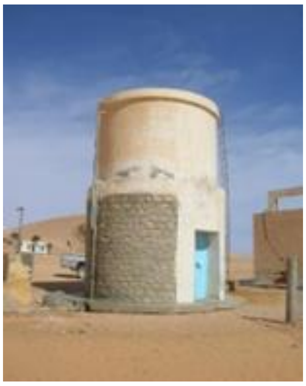

Fig.4. The Storage Tank (Stil).

Fig.5. The water Well.

The Linear Load Losses (J): We can calculate the linear pressure loss by the following formula of Darcy-Weisbach: with, D (m) The hydraulic diameter, ρ (kg/m3) The density, λ the Friction factor (laminar regime; ʎ = 0,316. Re-0,25), V (m/s) the flow velocity and L(m) the pipe Length [11-12].

$$J = ʎ. \left(\frac{\rho V^2}{2}\right) . \left(\frac{L}{D}\right) \quad (4)$$

According to the schematic diagram circuit figures 3 and 4. We notice the presence of two types of pipes with the following characteristics (Table.1):

Table 1. ζ of the Different Component Pipes.

Characteristics	Slot Conduit	PEHD Conduit
Inside Diameter	D_f = 80 mm	D_p = 55.74 mm
Thickness	e = 1.8-2.7 mm	e = 3.8 mm
Length	L_f ≈ 13,7 m	L_p ≈ 300
Flow Velocity	0.641 m/s	0.841 m/s

Singular Pressure Losses (Z): Can be calculated using the following formula [11-12]. With, ζ the loss coefficient for the pipe component, g the acceleration due to gravity, V (m/s) the flow velocity. Tab.2 shows the ζ [9] of the different component pipes.

$$Z = \zeta \frac{V^2}{2g} \quad (5)$$

Total Manometric Height (HMT): This is the difference of pressure in meters of water column between the suction and discharge ports. It is calculated by following formula [13]. With, ND (m) is the dynamic level of the aquifer in the well, HG (m) is the geometric difference in level between the well surface and the reservoir, NS (m) is the static level and R (m) is the drawdown.

$$HMT = ND + HG + \Delta P, \text{ and } \quad ND = NS + R \quad (6)$$

3.2. Choice and Characteristic of MOTO-POMPE

The Necessary Hydraulic Energy Eh: Once defined The Necessary needs by volume Qdy = 40 m^3/day of water for each month of the year and the characteristics of the well, we can calculate the average monthly hydro and need from the relationship: (Wh/day) [14-18].

$$E_h = \frac{\rho \times Q \times g \times HMT}{3600} \quad (7)$$

Electric Power Consumed Ec: For the calculation of the electric energy consumed by the pump, using the following formula: with, η is the MOTO-POMPE performance [14-18].

$$E_c = \frac{\rho \times \Delta Q(m^3/day) \times HMT(m)}{\eta} \quad (8)$$

The MOTO-POMPE Performance η: Hydraulic peak power (Eh) needed depending on the electrical peak power supplied by the photovoltaic generator (Ec) is given by [14]:

$$\eta = \frac{Eh}{Ec} \tag{9}$$

The chosen pump should to meet the varying site conditions. for a flow rate of Q=1.5 l/s (5.4m^3/h), a total manometric height (HMT) of 40m on a PS1800 C-SJ5-12 type motor-pump marketed by LORENTZ is chosen. Table 3 show the different motor-pumps characteristics.

Table 3. The Different Characteristics of PS1800 C-SJ5-12.

Characteristics	PS1800 C-SJ5-12	Characteristics	PS1800 C-SJ5-12
Maximum Flow Rate	7 m³/h	Input Voltage (V)	max.200 V
Maximum HMT	70 m	Optimum Voltage (Vmp)	102V
Stages	58	Current; (Imax)	19 A
Efficiency	57 %	Motor Efficiency	98 %
Power (P)	1.8 KW	Power Factor; cos(ɵ)	0.85
Maximum Submersion	250 m	Motor speed	900-3300rpm

3.3. Sizing the Photovoltaic Field

Electrical Energy Produced by The Photovoltaic Generator (Ep): For the calculation of the electric energy produced by the photovoltaic generator using the following formula: with, (K) is a coefficient taking account of system components yields; (η_c) is the Wiring Yield, (η_t) Temperature yield and (FM) is the Matching Factor [10].

$$E_p = \frac{\mathrm{E_c}}{\mathrm{K}} \tag{10}$$

$$K = \eta_c \times \eta_t \times \mathrm{FM} \tag{11}$$

The Wiring Yield: is the yield due to imperfections in the wiring of the different elements of the system. The wiring yield is quite difficult to predict. However, in this study it is assumed that these losses do not exceed 3% [21].

Matching Factor: also called adaptation factor, is a return that reflects the fact that the solar cell almost never works at its maximum power point. However, the use of a MPPT controller can remedy this lack. The adjustment factor must remain close to 90%. It will also be assumed this condition is satisfied [21].

Temperature yield: this yield reflects the fact that the temperature of the cell has a small influence on the yield, the latter decreases with increasing temperature. It is calculated using the following formula: with, (C_{tp}) is Temperature Coefficient and (T_{cell}) is the cell operating temperature [16].

$$\eta_t = 1 - \mathrm{C}_{tp} \times (\mathrm{T}_{cell} - 25) \tag{12}$$

$$T_{cell} = \frac{(219+832\times\overline{K}_T)(\mathrm{NOCT}-20)}{800} + \mathrm{T_{amb}} \tag{13}$$

(T_{amb}) is the ambient temperature (°C), NOCT is the Nominal Operating Cell Temperature and ($\overline{K}_T$) is the Clarity Index calculated by: with, Hh is the annual Irradiation on Horizontal Plane and ($\overline{H}_0$) is the annual Irradiation extraterrestrial. For the calculation of $\overline{K}_T$ and $\overline{H}_0$ using the following formula: [15].

$$\overline{K}_T = \frac{Hh}{\overline{H}_0} \tag{14}$$

$$\overline{H}_0 = \begin{cases} \frac{24}{\pi} \times \mathrm{G_{sc}} \times \left[1 + 0{,}033\cos\left(2\pi\frac{n}{365}\right)\right] + \\ (cos\varphi.\, cos\delta.\, sin\omega s \; + \; \omega s.\, sin\varphi.\, sin\delta) \end{cases} \tag{15}$$

Table 4. Data of the Worst Month.

Data	December
Average Day N	344
Declination δ(°)	-23.04°
Hour Angle ws (°)	74.02°
Average Temperature	17°C
Average Irradiance (Time: 11:00-13:00)	813 [W/m^2]
Solar constant Gsc	1.367kW/m²

This method was used for Sizing the Photovoltaic Field during the worst months. Accordingly, the calculations related to the month of December, which as identified as the worst month, are presented in Table.4.

Remember that the main characteristics of solar panels are: “TENESOL TE 755”V_{oc}=25V, V_m=22V, I_{SC}=4.7A, I_m=4.4A, P=85Wc and NOCT=45°C.At Standard Test Condition (STC) i.e. at 25 [°C] temperature and 1000 [W/m^2] irradiance.

Peak Power İnstallation Pc (Wc): It can be determined by the following formula: with, Es is The available solar energy is expressed in Wh/m²/day or kWh/m²/day [17].

$$P_c = 1000 \times \frac{Ep}{Es} \tag{16}$$

The Estimated Number of Series Module Ns: The nominal voltage of the operation of motor-pump Vbus =100V.

For the calculation of the number of series module, the following formula is used: with, Vm is the maximum solar panel voltage.

$$N_s = \frac{\mathrm{V_{Bus}}}{\mathrm{V_m}} \tag{17}$$

The Estimated Number of Parallel Module (Np): (I_m) is the maximum current of a module, (V_m) is the maximum solar panel voltage and (W_c) is the power of module. The number of parallel module (N_p) can be calculated using the following formula:

$$N_p = \frac{W_c}{\mathrm{N}_s \times V_M \times I_m} \tag{18}$$

The Power of the Inverter (Pin): the apparent power of the motor Pam can be calculated using the following formula:

$$P_{am} = \frac{Pm}{\cos(\varphi)} \tag{19}$$

Taking into account the factors above and overloads, it can take a 20% flexibility on the apparent power.

Therefore, the power of the inverter *Pin* is:

$$Pin = 1,2 \times Pam \tag{20}$$

4. Simulation

4.1. Description and Modelling of the System

Figure 6, showing Proposed MATLAB/SIMULINK model of the photovoltaic powered centrifugal pump. The proposed system consists of photovoltaic array (15 panels; Ns=5, Np=3), the Controlled PWM Voltage and H-Bridge blocks to control a DC motor and centrifugal pump.

The DC Motor block uses manufacturer datasheet parameters (Table 3).

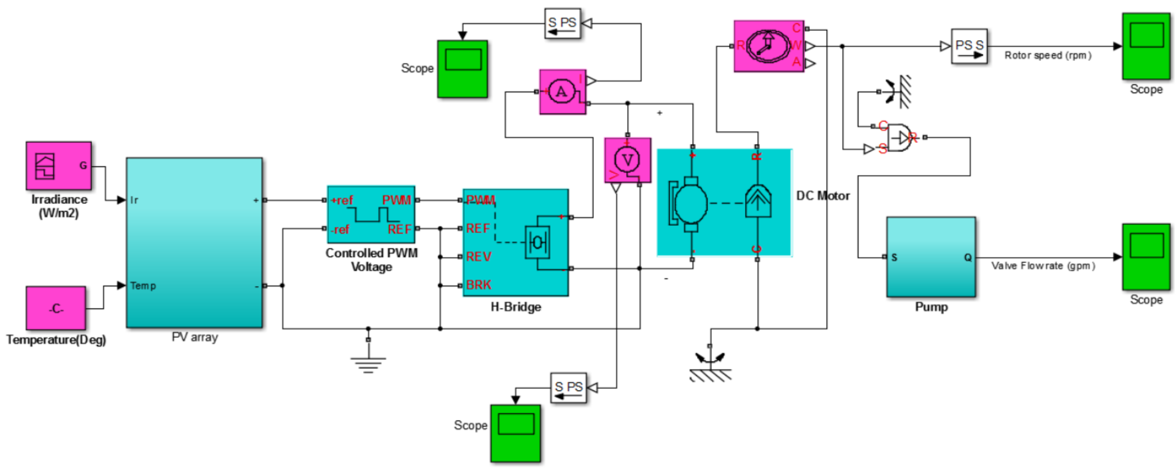

Fig. 6. Proposed MATLAB/SIMULINK

4.2. PV Cell Model

Equations, which define the model of a PV cell are given below [19], [20]:

The reference temperature is given by $T_{ref} = 273 + 25$; the thermo voltage of cell V_t, is given by:

$$Vt = \frac{KT}{q} \tag{21}$$

The open-circuit voltage V_{OC}, is given by:

$$VOC = Vt \ln\left(\frac{Iph}{Is}\right) \tag{22}$$

The diode current Id, is given by:

$$Id = Is.Np\left[e^{\frac{(V+I.Rs)}{(n.Vt.Ns)}} - 1\right] \tag{23}$$

The diode reverse saturation current I_s, is given by:

$$Is = IRs\left(\frac{T_{OP}}{T_{ref}}\right)^3 e^{\left[\frac{qEg}{nK}\left(\frac{1}{T_{OP}} - \frac{1}{T_{ref}}\right)\right]} \tag{24}$$

The diode reversed saturation current at T_{op}, is given by:

$$IRs = \left[\frac{Isc}{e^{\left(\frac{V_{OC}.q}{KCT_{OP}n}\right)} - 1}\right] \tag{25}$$

The Shunt current I_{sh}, is given by:

$$Ish = \frac{V + IR_S}{R_P} \tag{26}$$

The light-generated current I_{ph}, is given by:

$$Iph = Gk\left[I_{SC} + K_I(T_{OP} - T_{ref}\right]. \tag{27}$$

The output current from the PV panel I, is given by:

$$I = I\,ph\,NP - Id - Ish \tag{28}$$

Considering the environmental and cell parameters, a PV cell simulation set up model based on equations (21) - (28) is developed in MATLAB/SIMLINK [21].

4.3. Simulation Results

Figure 7 and Figure 8 shows The power-voltage (PV) and current-voltage (IV) curves of the photovoltaic array at:

- Standard Test Condition (STC) i.e. at 25 [°C] temperature and 1000 [W/m2] irradiance.
- The worst month (December); 17 [°C] temperature, and 813 [W/m2] Irradiance. [9]

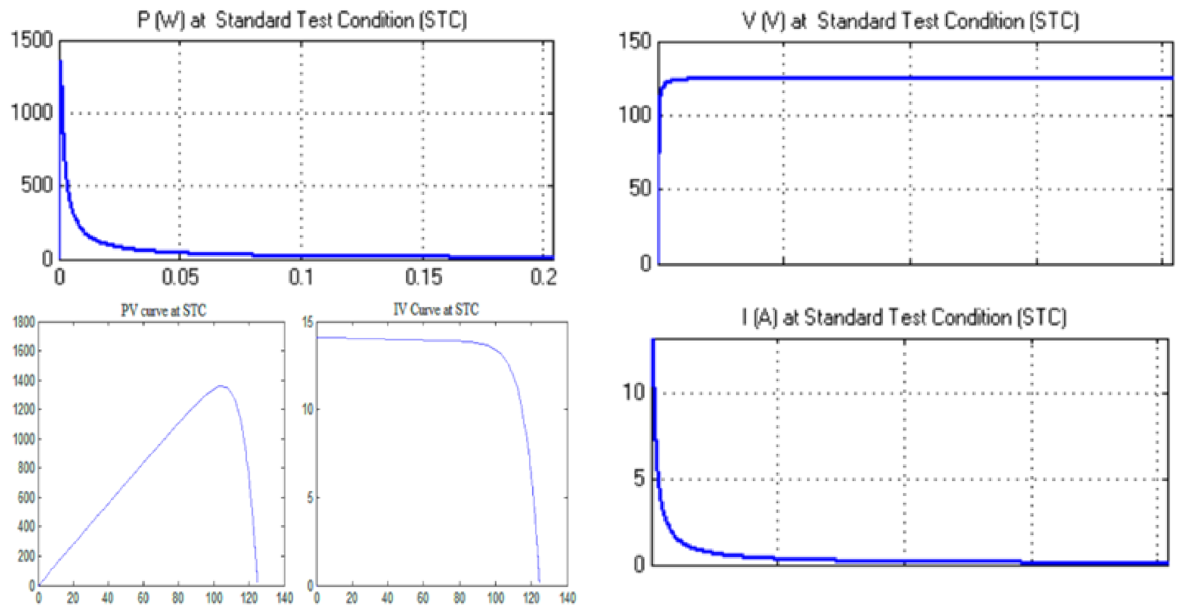

Fig. 7. Array I, V, and P curves with constant radiation and Temperature musered at Standard Test Condition.

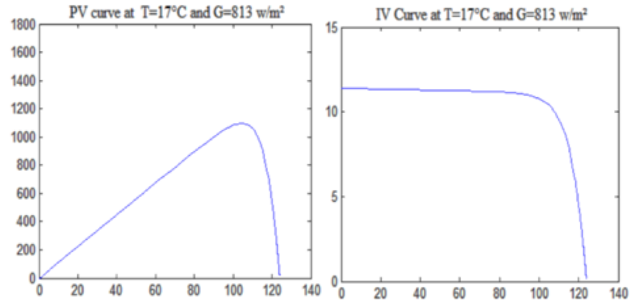

Fig. 8. Array I, V, and P curves with constant radiation andTemperature musered at the worst month (December).

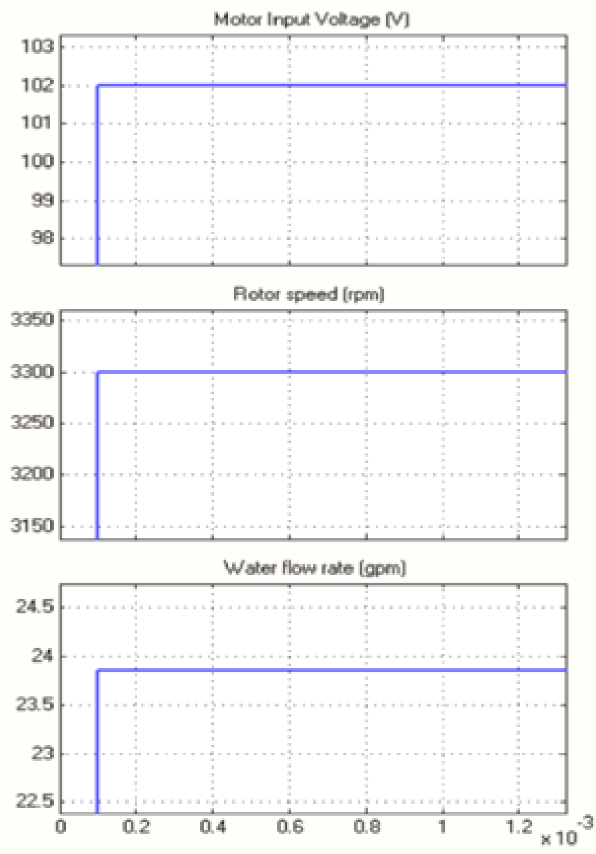

Fig. 9. Characteristics of the rotor speed (MRS) of themotor, the motor input voltage (Vinp) and the pump waterflow rate (Qp).

Figure.9 shows the rotor speed (MRS) of the motor, the motor input voltage (Vinp) and the pump water flow rate (Qp). The simulation shows that;

- The motor stator rotates with a speed of MRS=3300 rmp, over the motor rated speed is between 900 and 3300rmp.
- The motor input voltage equals to the motor optimum voltage (Vmp) that equals to Vmp=Vinp=102V.
- The pump water flow rate equals to Qp=23.7 g/m =1.5 l/s.

We can say that; The station that consists of photovoltaic array (15 panels "TENESOL TE 755, P=85Wc"; Ns=5, Np=3) and MOTO-PUMP (PS1800 C-SJ5-12) at total manometric height (HMT) of 40m. Is able to provide a water flow rate equal to Qp=1.5 l/s minimum two hours in the worst month in the year.

5. Conclusion

Mechanical Assembly: The solar generator does not work correctly if certain conditions location and positioning are not met. In this context we offer a support (Figure 10) which has confirmed the ideal position of the panels with an optimal inclination angle specific for the site of Ben Guerdane.

Positioning of The Generator On Site: avoid that the modules receive the shadow of any obstacle (buildings, trees, etc.) throughout the year. The occlusion of a small part of the generator will greatly reduce its performance. To facilitate the positioning of the generator on site, Figure11, shows the minimum distances for a set of barriers to the north, south, east and west of the generator.

PV modules are mounted according to the manufacturer's instructions. They should be located away from children's games, falling objects, cattle, etc., and easily accessible to facilitate cleaning. It is important to provide a protective fence.

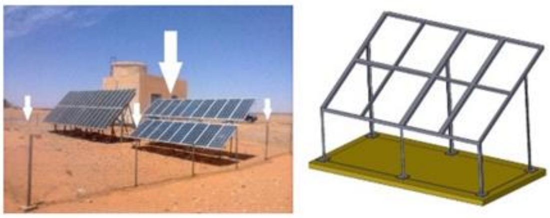

Figure 10. Solar Generator and 3D Modeling of the Support.

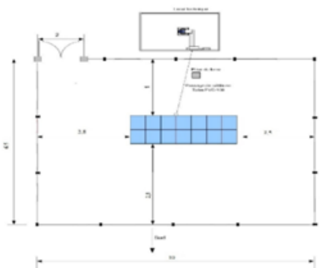

Fig. 11. Proposal of Planting the Module Fields and Wire Fence.

Electrical Assembly: When mounting the modules to be respected designation of terminals and their polarities. It will connect the panels of the field starting from the lowest voltage. The connections must be carried out in small groups, so as to push the achievement of higher voltage circuits as close to the final connections. It is important to make a good tightening of cables and cable glands, and ensure a good seal to the various cable entry points.

6. Conclusion

In this study, we analyzed the components of photovoltaic water pumping station to achieve the desire of the Regional Offices of Agriculture Development of Médenine which is estimating the number of panels you will need to meet the electricity demand of the pump to a flow rate that equals to Q=1.5 l/s minimum two hours in the worst month in the year and establish an optimum coupling the photovoltaic panels and ensure the smooth running of the station.
This study showed that the elements governing the choice of a pump depends on several important factors: the type of the required pump, the total head of the installation, the type and voltage-current (V / I) engine, the power required for pumping, etc. This choice requires knowledge of the depth of the water source. Optimizing the choice and dimensioning presupposes an extensive inventory of all the characteristics of motor-pumps sold on the market.
Analysis is almost identical to the selection and sizing of solar panels: their builders' characteristics of voltage and power are variable from one model to another, an inventory of panels marketed is necessary. In this way, the characteristic U / I of the panels and those of the pumps can be compared readily to optimize the choice and the arrangement of the panels. The orientation of solar panels and their location can be calculated. These require some knowledge of the site's geographical parameters and its sunshine.

References

[1] M. Abu-Aligah "Design of Photovoltaic Water Pumping System and Compare it with Diesel Powered Pump". Jordan Journal of Mechanical and Industrial Engineering. Volume 5, Number ISSN 1995 3, June - 6665 2011, Pages 273 – 280.

[2] Argaw A. "Optimal load matching in photovoltaic water pumps coupled with DC/AC inverter". Int J Solar Energy 1995; 18:41–52.

[3] Langridge W, Lawrance W, Wichert B. "Development of a photovoltaic pumping system using a brushless DC motor and helical rotor pump". Solar Energy 1996; 56:151–60.

[4] Aicha ZNIDI, Said CHNIBA, Emna BOUAZIZI "Etude d'une Installation de Pompage Solaire à Moteur à Courant Continu". IJSET. Vol.3-pp.116-122, Copyright - IPCO 2015.

[5] Sarah, R. El Bachtiri, A. Med Amine "Modeling of a photovoltaic pumping system using centrifugal pump and DC motor". MGEF-13. Vol.2: pp.1-6: mgf13s-002.

[6] M. DURSUN, S. OZDEN "Application of Solar Powered Automatic Water Pumping in Turkey". International Journal of Computer and Electrical Engineering, Vol.4, No.2, April 2012.

[7] R. Kumar, G.K. Dalal "Design and Simulation of Photovoltaic Water Pumping System". IJSR. Volume 3 Issue 9, September 2014.

[8] Benghanem M. "Measurement of meteorological data based on wireless data acquisition system monitoring". Appl Energy 2009;86(2651):60.

[9] J. CHAKCHAK, A. SEIFENNASR « Contribution A L'étude D'une Station De Pompage D'eau Moyennant L'énergie Solaire Photovoltaïque » Rapport De Projet De Fin D'études, Master En Electromécanique. Soutenu le 29 Juin 2013. Avec Mention Très Bien.

[10] B. Achour, A. Bedjaoui, M. Khattaoui, M. Debabeche « Contribution au Calcul des Ecoulements Uniformes a Surface Libre et En Charge » LARHYSS Journal, N°.01, Mai 2002. P10.

[11] O. Reynolds, 1883 'An experimental investigation of the circumstances which determine whether the motion of water shall be direct or sinous, and of the law of resistances in parallel channels' Phil Trans Roy Soc London, 174, 935-982.

[12] White, F.M., Fluid Mechanics, 2nd Ed., McGraw-Hill Book Co., New York, 1986.

[13] Kenji Suzuki "Artificial Neural Networks – Architectures and Applications" chapter:11. pp.231-233. ISBN-13: 9789535109358. Publisher: InTech 2013.

[14] Hadj Arab, M. Benghanem et A. Gharbi, « Dimensionnement de Systèmes de Pompage Photovoltaïque » Rev. Energ. Ren. Vol. 8 (2005) 19 – 26, pp.20.21

[15] H. Gunerhan, and A. Hepbasli, Determination of The Optimum Tilt Angle of Solar Collectors for Building Applications, Building and Environment, vol. 42, pp. 779-783, 2007.

[16] H. A. Rahman, K. M. Nor, and M. Y. Hassan "The Impact of Meteorological Factors on the Energy Yields for the Building Integrated Photovoltaic Systems in Malaysia". Centre of Electrical Energy System (CEES), Faculty of Electrical Engineering. 81310 UTM, Skudai, Johor, MALAYSIA.

[17] Labouret (a.), cumunel (P.), Braun (j.-P.), Faraggi (B.), « Cellules solaires – Les bases de l'énergie photovoltaïque » Dunod, coll. EtSF, 2010.

[18] J.Royer, T.Djiako, E.Schiller, Bocar Sada Sy, Eric Schiller « Le Pompage Photovoltaïque : Manuel De Cours A L'intention Des Ingénieurs Et Des Techniciens ». IEPF, EIER, CREPA, ISBN 2-89481- 006-7.

[19] Francisco M. González-Longat - 2do congreso iberoamericano de estudiantes de ingeniería eléctrica, electrónica y computación, "Model of Photovoltaic Module in Matlab" (II CIBELEC 2005).

[20] J.A. Ramos-Hernanz,J.J. Campayo ,J. Larranaga , E. Zulueta ,O. Barambones ,J. Motrico ,U. Fernandez Gamiz, I. Zamora, "Two photovoltaic cell simulation models in Matlab/Simulink "- (IJTPE), Iss. 10, Vol. 4, No. 1, Mar. 2012.

[21] http://fr.mathworks.com/matlabcentral/fileexchange/41537-aphotovoltaic-panel-model-in-matlab-simulink.