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Developed software to Design and Size Solar Pumping system

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***Abstract*— Software enabling design and sizing of solar pumping system has been developed and tested. This software is equipped with visually appealing GUI making interaction between user and the machine enthusiastic. Indeed this GUI is designed to be immediately intuitive and easily learned without assistance. Besides that, it allows to users to become easily acquainted with solar pumping system design steps. Results of a given sizing case study as applied to typical implementation was archived in a readily text file for printing on order from the user . The testing of this software to design and size a solar pumping system for Algeria typical semi-arid real case study revealed that to pump a 45 m^3 of water from a well having depth in range of 30-35 m a total of 1820 Watt Crete is required and a DC pump would accomplish this task.**

***Keywords*—** Watt Crete, Well, DC pump, Solar Pumping System

I. Introduction

Water is essential to all forms of life; it is the source of our existence. Although water exists in large quantity only a small portion of it is available for direct use. In arid and semi-arid areas water is usually found at several meters below ground. In remote locations, traditional power supply is unavailable or unreliable to power submersible pump motor. As a result an alternative source of energy is often sought to energize the pumping system. In South Algeria, solar rays shine over all year round and monthly average solar insolation of about 5 KWh is usually recorded. This free, non-pollutant and reliable source of energy is exploited in remote villages in Africa where hundreds of pumping systems based on solar energy are already operational. In south Algeria solar pumping system still out off reach and villagers, farmers and cultivators are often reluctant to introduce this technology in their daily life. This is mainly because of lack of skilled personal and the unaffordable initial cost of solar pumping system. Recently, the prices of photovoltaic modules and pumps and associated BOS dropped sharply as the Chinese products invaded the world market. Indeed these products have a satisfactory reliability and excellent performances. Besides that, wells with depth in the range of 25 to 50 m are widespread in Algeria semi-arid. These facts make photovoltaic system increasingly attractive as the initial cost is to reduce and performances are generally acceptable. Combined with recent Algeria government policy to subsidy the cost of PV modules in Local market semi-arid inhabitant especially agronomists are now tending to switch to solar energy based system specifically for irrigation purposes. In this current contribution a typical solar pumping system is described, its components are identified and their adequate sizing for specific application is explained. A comprehensive straightforward procedure for designing a solar pumping system is given and critical appraisal is carried out. Important recommendations are outlined. A dedicated software package is developed to help size a typical pumping system. Indeed this software is equipped with a user friendly graphical user interface making the interaction between user and computer enjoyable.

II. Solar Pumping system

Simply put, a solar pumping system is composed of few components namely solar photovoltaic generator, solar pump-motor set, water tank, accessories and some electronics devices such as power converter.

A. *Photovoltaic Generator*

It is used to energize the solar pump with clean electrical power. It is composed of one to several modules. PV modules convert solar energy that fall upon them in the form of light photon into electrical energy. This is achieved through the photovoltaic effect using a semiconductor wafer usually mono-crystalline silicon embedded in the PV module. The manner in which these PV modules are connected together is dictated by current and voltage of the corresponding load, in our case solar pump motor. .

B. *Solar controller*

Solar controller is used to enhance pump performances and energy input to load. It provides much better efficiency, a start

/stop control and it lengthens the life of solar system. Basically, pumps have a minimum required current which must be draw to function. If this is not met, the solar pumping action will not occur. A solar controller will convert any excess of voltage to more output current to satisfy the load need.

C. Solar Pump Motor set

This set is composed of pump connected to an electrical motor together hosted in a protective housing which permits the unit to operate under water. A plethora of solar pump types exists. Most often solar pumps are classified according to their functioning principle into centrifugal and positive displacement pump. In Centrifugal Pump, energy is imparted to water through centrifugal force which drives it outward. Water is admitted by impeller eye and flows along its axis. The rotation of impeller drives the water towards the outlet (volute) where its kinetic energy is increased. This creates a low pressure at the inlet and more water is admitted. Centrifugal pumps may have two or more impellers assembled together giving name to multistage pump. Multistage pump is used when high flow rate is required. Centrifugal pumps can further be subdivided into surface mounted or submersible according to their physical position. Surface pump is usually positioned at earth's surface above the well, it is used when low pumping head is in the range of 10 m. Whereas, the latter are best suitable for high pumping heads with moderate flow rates and are installed deep into the well or borehole. The starting torque is practically negligible. The pump carries on rotation even at low solar radiation level. The absorbed power is appropriately matched to PV modules yielding a reasonable efficiency.

In positive displacement pump a volume of water is trapped in an expanding cavity at the suction side then forced out into discharge pipe by stretching the cavity. Typical example of positive displacement pump is helical rotor pump. Starting torque of this kind of pump is three to four times the nominal one making a direct coupling to PV generator not economically viable. Solar pump is driven by electrical motor which can be either DC or AC.

As accessories we may count assortment of balance of system (BOS) hardware including wiring, overvoltage, overcurrent and surge protection devices. Valves and fitting are also common in typical solar pumping system. In some applications of PV pumping system battery may be used instead for several reasons including energy storage for later use when solar irradiance will be low. To operate the PV array at its maximum power point to drive the pump at stable voltage and supplies the starting current to motor and inverter.

In most cases a battery charge controller is used in these systems to protect the battery from over charge and deep discharge.

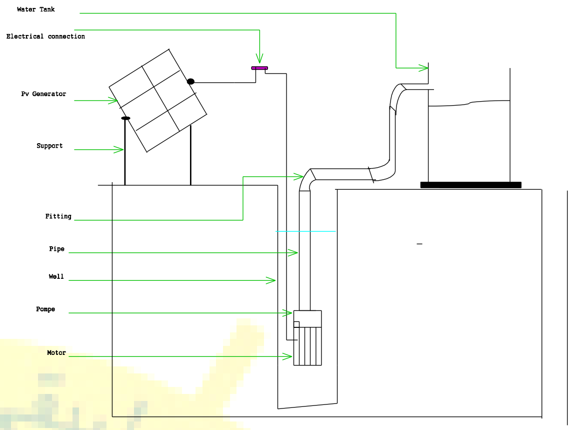

Fig. 1 Schematic of Typical Directly Coupled Solar PV System

Fig. 1 depicts a synoptic of typical solar pumping system where its essential elements are shown.

Solar pumping systems are put together based on well depth and the amount of water needed per day from the water source. Selecting the right pump for specific application reduces significantly the size of PV generator. Thus an adequate sizing of pumping system would significantly reduce the cost. ,

D. Water Requirement

Basically, sizing a PV pumping system consists in optimizing the size of the photovoltaic generator and the pump taking into account the load (daily required amount of water), total dynamic head which water must overcome to reach the storage tank yet satisfying PV-pump voltage, current and power compatibility.

Thus solar pumping system designer is often challenged by two constraints, the availability of solar energy over the year and the fulfilment of user's water need.

Solar pumping system may be used for domestic purposes, irrigation and livestock watering. The determination of required amount of water is too complex and depends on several factors. For example crops water needs depends on climate conditions such as temperature, wind speed, humidity and solar radiation. Furthermore, crop water need depends on crop type and growing season. Livestock required amount of water varies from a species to another and vary also with animal age. Several norms exist for estimating daily required amount of water for domestic uses. The determination of the exact amount of water is beyond the scope of the current work and is the subject of an incoming article. The table I below summarizes the water need of typical Algerian semi-arid community.

TABLE I. DAILY REQUIRED AMOUNT OF WATER OF TYPICAL ALGERIAN SEMI- ARID VILLAGE

Domestic water Use			
Number of Families	**Member per Family**	**Litter per Capita**	**Total in m^3**
70	7	30	14700
Livestock			
Type	**Number of heads**	**Litter per Head**	**Total in m^3**
Camel	20	40	
Sheep and Goat	100	10	
poultry	200	0,1	
Orchard			
Type of trees	**Number of Trees**	**Litter per Tree**	**Total in m^3**
Palm	60	30	1,8 m^3
Orange	50	80	4 m^3
Apple	60	70	4,2 m^3
Pears	50	70	3,48 m^3
Market Gardening			
	Eggplant, Green Pepper ,Potatoes		15 m^3
Daily Total Required Amount of water			45,00 m3

Fig. 2 displays the water need of typical Algeria semi-arid community.

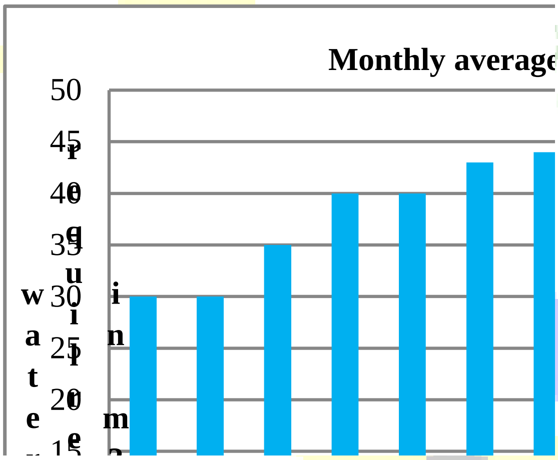

Figure 2 Chart Showing Typical Semi-Arid Water Requirement Monthly Variation

The first design step is the determination of hydraulic energy. This quantity depends on daily required amount of water, total dynamic head and hydraulic constant. Hydraulic energy is given by:

$$E_h = C_h * Q_d * TDH \qquad (1)$$

Where C_h it is called hydraulic constant in case of water its value is equal to 2.752 kg.m^2, Q_d is the total amount of water and TDH is the total dynamic head.

In Algeria wells with depths ranging from 20 to 60 m are frequent in semi-arid regions.

E. Total Dynamic Head

It is the total equivalent head that water must overcome to reach the discharge point i.e. water tank taking into account head loss. Head loss is the additional head created in the discharge path due to resistance to flow by friction within pipe and fittings.

The head loss is of two types namely major losses and minor losses. Major losses are complex function of pipe geometry fluid properties, nature of flow in the pipe. For turbulent flow Darcy-Weisbach suggested the following expression to compute these losses [1]

$$H_l = f\, L/D\, \frac{v^2}{2g} \qquad (2)$$

Where D is the pipe diameter, v is the flow speed and L is the pipe length, f is Darcy friction factor. Table II outlines different heads that may exist in solar pumping system.

TABLE II FEATURES OF TYPICAL WELL HYDRAULIC CHARACTERISTICS

Static Height (SH) in m	**Drawdown (D) in m**	**Dynamic Height (DH) in m**	**Tank Height**	**Friction Loss (FL) in m**	**Total Dynamic Head in (m)**
	5	25	3	2,5	30,5

Several formulas were proposed to determine Darcy friction coefficient, Colebrook found an explicit correlation for friction factor in round pipe as in [2].

$$\frac{1}{\sqrt{f}} = 2log\left[\frac{\varepsilon}{3.7} + \frac{2.51}{R\sqrt{f}}\right] \qquad (3)$$

Where R is the pipe radius.

This formula was used by Moody to obtain the so called Moody diagram to determine friction loss in terms of relative roughness and Reynolds number. On the other hand, minor losses are due to sudden or gradual contraction, and or restriction and fittings for example valves, elbow and joints.

Minor losses are proportional to the square of fluid average velocity and friction factor K and is given as in [3]

$$h_m = K\frac{v^2}{2g} \qquad (4)$$

The friction factor K is typically provided and tabulated for various devices and every , K is supplied by standard handbook.

Total dynamic head is generally measured in m and it is the sum of three factors, total vertical lift, friction loss in pipe and loss due to fitting and sudden change in streamline both expressed in meter head. Total vertical lift is the sum of the elevation and pumping level. Pumping level is in turn the sum of static level and drawdown. Figure iii clearly describes these quantities.

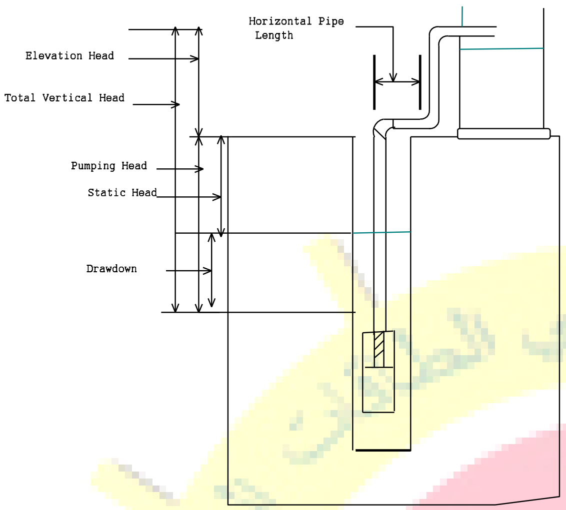

Figure 3 Designations of Different Heads

In Fig 3 different heads that water must overcome to reach the tank.

All in all to reduce the loss head one must construct the water tank near to the well and avoid maximizing the use of fittings. Generally, for convenience the pipe diameter is often sized in such way that head loss doesn't exceed 10% of the total geometric head.

F. *Solar Resources*

As mentioned in the introduction Algeria arid and semi-arid is rich in solar resource, the table III puts in evidence the wealth in solar resource.

To demonstrate clearly the wealth in solar resources that south Algeria has, the values given in table III are plotted as a chart.

TABLE III: MONTHLY DAILY MEAN SOLAR RADIATION ON LATITUDE ANGLE TILTED COLLECTOR

Month	Monthly average Solar Radiation in PSH
January	4.429
February	4.81
Marsh	6.582
April	7.615
May	7.617
June	7.173
July	7.309
August	7.309
September	4.179
October	5.334
November	5.508
December	5.308

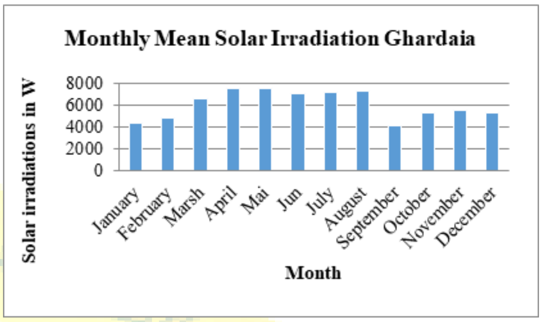

Fig 4 Chart Outlining Monthly Mean Solar Radiation in Latitude Angle Tilted Collector

It can be seen from the chart that solar radiations are more tens in summer and spring time. But also they may have a high value even over cold season(winter and autumn). By inspection of the two charts it can be inferred that water is needed most when the sun shines the brightest. Maximum of enery is extracted from PV module under full sun conditions when typically water need is the highest. Because of synchronism between water need and solar energy availability, solar pumping system option is the convenient choice over others. Based on the above it is safe and adequate to choose a month in which solar radiation and water need are both the highest as the design month. In this current design prices July is taken as the design month, PSH is in the range of 7.173, Q_d is about 45 m^3. And TDH is in the range of 30.5 m, the hydraulic energy is found to be equal to 3746.93 kwh.

G. *Selection of the Pump*

The most important criteria in determining the optimum solar pump is by finding the pump that satisfies both daily water need and pumping head requirements. Normally, a solar pump operates in wide range of water flow rate in response to variation of solar irradiance.

The hourly flow rate is given as in [4]:

$$V = Q_d/D \tag{5}$$

Thus V is equal to 6.27m^3/h and the TDH is equal to 30.5 m. following , these two determining factors, from GrundFos Company web site www.GrundFos.com one can choose 25SQFlex-7 solar Pump.

TABLE IV: ELECTRICAL CHARACTERISTICS OF MSF-3 MOTOR

Maximum Current	DC Power Supply	AC Power Supply	Maximum speed	Maximum Power
8,4 A	30-300 VDC	1X90-240 V, 10%/,50-60Hz	36000m-1	1400 W

. From irs performance curve we can infer that this pump would deliver water at a rate of about 6.36 m^3/h from a well depth of 35 m.

From manufacturer web site it can be concluded that the 25SQFlex is a a centrifugal pump with maximum flow rate in the order of 150 L/m and maximum head in the range of 58 m. this pump is equipped with pre-installed dry run protection sensor enabling the pump to be shut down if water shortage is detected. The motor features are:

- Design for maximum efficiency and satisfactory reliability.
- Integrated electronics system eliminating the need for complicated external unit is fitted in.
- Built in protection against high temperature, over and under voltage voltage operations are among features.

Moreover, the motor is designed in a wide range of voltage extending between 30-300 VDC. Besides that, motor can be run directly without extra electronic system from AC generator.

The following figures outlines the results obtained through the developed software.

On executing the program the user is asked to introduce the required password which is in this case the acronym for our research unit i.e. IRAER. After, after entering the password and pressing the Enter key the next form appears. This form allows to users to choose between stand-alone solar pumping system or pumping system with battery. In our case user is the first option is selected through a check box. The third form permits to user to enter the essential parameters to compute the required hydraulic energy. By clicking the button with caption “Compute hydraulic energy”, the result is displayed on the next form. This form includes a button to access to the next calculating form.

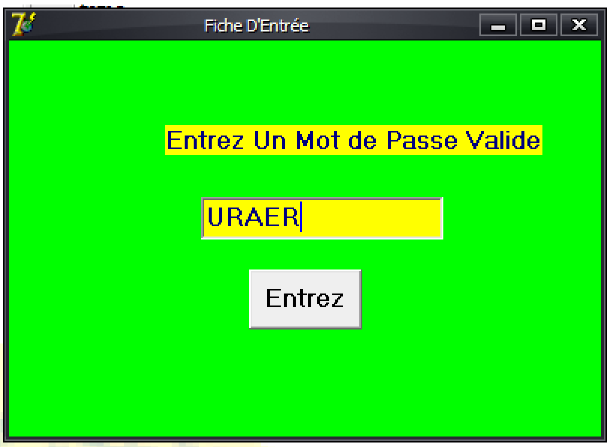

Figure 5: Form1Prompting User to Enter a Valid Password

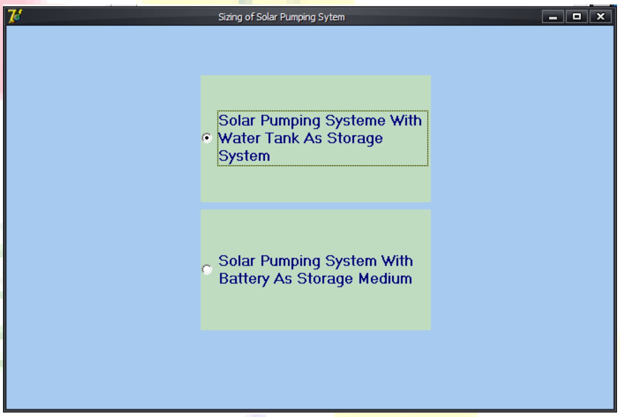

Figure 6: Form2 Allowing Selection Between Pumping Systems

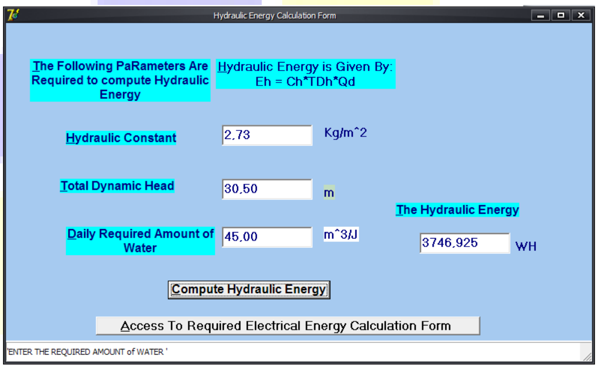

Figure 7: Form3 for hydraulic energy computing

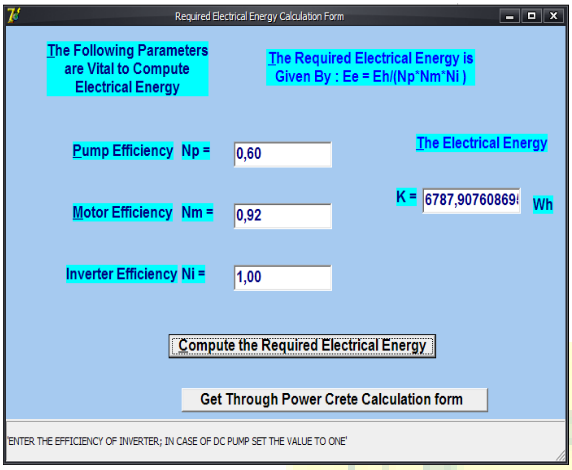

Figure 8:Form4 for Electrical Energy Computing

By clicking this button with caption "Compute the required electrical energy ", the required electrical energy is compited and result is displayed in a reserved box. Note however, that in DC pumping system the inverter efficiency should be put equal to one. This is mentioned at the bottom of the form the efficiency of the photovoltaic modules is affected significantly by the temperature elevation and semiconductor material such as mono-crystalline silicon which presents a negative power temperature coefficient. Often PV system are operated at temperature conditions that differs from that of STC and consequently, the efficiency varies. To take into consideration the influence of temperature on electrical performances of PV system a new correction formula is suggested and is given as in [5].

$$\aleph_{noc} = \aleph_{STC} * \left(1 - K_{Tp} * \left(T_c - T_{ref}\right)\right) \quad (6)$$

Where $\aleph_{STC}$ is STC efficiency, K_{Tp} power factor coefficient, T_c is the cell temperature and T_{ref} is the reference temperature.

Several correlation formulas exist to determine the temperature of the solar cell under real operation conditions. Attempt was made to express cell temperature in function of module efficiency at STC and cell absorptance α and module transductance t at any irradiance level as in [6]

$$T_c = \left(T_{NOCT} - T_{ambNOCT}\right) * \left(\frac{G_T}{800}\right) * \left(1 - \frac{N_c}{2\alpha}\right) + T_{amb} \quad (7)$$

Where G_T is the incident irradiance, T_{NOCt} is ambient temperature when the cell is at T_{NOCT}.

An more simpler proposed correlation is given as in [7].

$$T_c = \left(T_{NOCT} - 20°C\right) * \left(\frac{G_T}{800}\right) \quad (8)$$

In Algeria semi-arid the cells temperatu re is in the range of 70°C is often recorded and therefore modules efficiency drops to 8.34%.

To energize the pump Isofoton photovoltaic modules are selected. Table IV briefly, outlines their main features at STC Conditions.

TABLE V: MAIN FEATURES OF I-130-S/24 ISOFOTON MODULES

Current at maximum Power (A)	3.76	Efficiency	10.4 %
Voltage at maximum Power (V)	34.8	TC of Pmax	-0.44%/°K
ISC (A)	3.94	TC of VOC	-0.35%/)K
VOC (V)	43.2	TC of Isc	0.048¨/°K
Power Crete (Watt)	130		

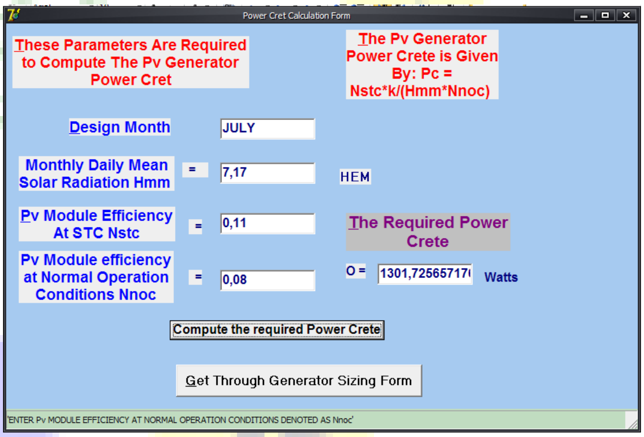

Figure 9: Form5 to Compute Required Power Crete

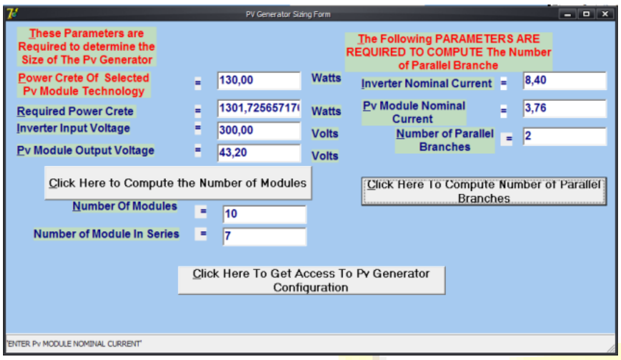

Figure 10: Form6 for Preliminary PV Sizing Form

in the next step of the design procedure the size of the photovoltaic generator is determined and the the number of modules in series and the number of parallel branch are also determined.

The number of modules is obtained by dividing the total required watt Crete by that of selected PV modules and is expressed as follows.

$$N_M = P_c / P_{cM} \qquad (9)$$

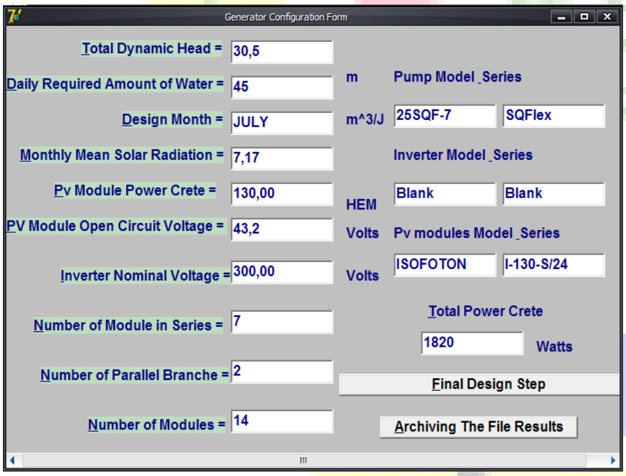

Figure 11: Form7 Final Design and Sizing PV System Components

The number of modules that should be connected in series is obtained from the ratio between pump and PV module nominal voltages and is given by:

$$N_{MS} = \frac{V_{PNom}}{V_{MNom}} \qquad (10)$$

The number of parallel branch is expressed as the ratio between pump current and module nominal currents as follows:

$$N_{MS} = \frac{V_{PNom}}{V_{MNom}} \qquad (10)$$

The number of parallel branch is expressed as the ratio between pump and modules nominal currents as follows;

$$N_{PB} = \frac{I_{PNom}}{I_{MNom}} \qquad (11)$$

In the final form the number of modules is recalculated in such way to satisfy both current and voltage compatibility constraint and the resulting total power Crete is alsqo recalculated. This form also displays all design steps results.

H. Results and Discussion

Finally, the input and output information of the design process is archived in a text file format ready for printing action. Typical obtained text file is given below. The file is divided into three blocks, the first one comprises personal information on user for whom the solar pumping system is designed and sized. The second blocks reserved to archiving the explored site hydraulic and solar resources. The site is where the solar pumping system is to be mounted. The third and fourth block holds respectively the characteristics of the selected pump and modules technology and the final PV generator configuration.

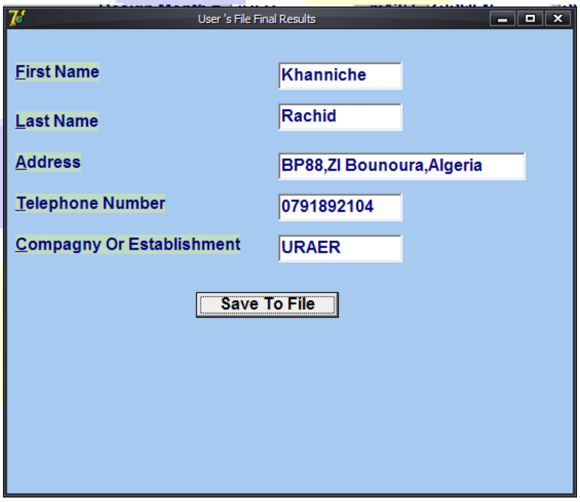

Figure 12: Form 8 Archiving of Design Results

USER PERSONAL DETAILS
First Name Khanniche
Last Name Rachid
Address BP88, ZI Bounoura, Algeri
Telephone Number 0791892104
Company Or Establishment BP88,ZI Bounoura, Algeria
SITE SOLAR AND HYDRAULICS Characteristics
Total Dynamic Head = 30·5 m
Daily Required Amount of Water = 45 m^3/d
Design Month = JULY
Monthly Mean Solar Radiation = 7·17 PSH
SOLAR PUMP SERIES AND MODEL
Pump Model & Series 25SQF-7SQFlex
PV GENERATOR SIZING AND CONFIGURATION
PV Module Power Crete = 130·00 Watt
PV Module Open Circuit Voltage = 43·2 Volts
Pump Nominal Voltage = 300·00 Watts
Number of Module in Series = 7
Number of Parallel Branch = 2

Number of Modules = 14

PV modules Model & Series ISOFOTONI-130-S/24

Total Power Crete 1820 Watts

III. Conclusions

In conclusion a simple straightforward and yet efficient procedure is described to optimize sizing a solar pumping system. This procedure is implemented through specially developed software equipped with a a visually appealing GUI. This GUI is simple and allows to users to interact with intuitively. It is enthusiastically accessible to moderate and advanced users alike. The effectiveness of the proposed sizing procedure is strengthened by a typical case study treating the case of sizing a DC solar pumping system in arid and semi-arid areas. However, the developed software can be applied to size general purpose pumping system anywhere in the globe. The implementation of this software to typical case of a given site in Algeria semi-arid revealed that to pump 30.5 m^3 of water from a depth of 45 m a total of 1820 Watt Crete is required. The PV generator is to be composed of fourteen !odules having 7x2 configuration south oriented and tilted at an angle equal to that of site latitude in our case Ghardaia latitude() to maximize the conversion rate. The modules are mono-crystalline of Isofoton Company. As further works more computing forms are to be included in design steps specially the one which deals with water requirement and site solar irradiation resource. Moreover, this software will be enhanced with a database that enables system components easy selection.

Acknowledgment

I am grateful to Applied Research Unit on Renewable Energy, URAER, Ghardaia, Algeria , where this work was carried out.

Finally, I acknowledge the comments and advice offered by my colleagues.

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