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Developing a Dimensioning Tool for Photovoltaic Water Pumping System

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Abstract

Growing interest in renewable energy worldwide has contributed to the development and the proliferation of solar systems. Many applications are built on solar energy because of the great availability and sustainability of solar radiation. A particular interest is geared toward photovoltaic water pumpingsystem (PWPS) which happens to be very reliable for the supply of drinking water to off-grid areas. However, the sizing of photovoltaic water pumping system has been a great challenge involving intensive mathematical calculations and also long collection of data on solar radiation and weather parameters such as temperature, humidity and others. Notwithstanding, an accurate sizing of the PWPS is very important in the sense that an oversizing can result in heavy financial burden while an under-sizing may not satisfy the targeted population in terms of water need. In view of this, many research works have investigated a reliable and accurate method of measurement. The current paper covers the development of an application tool,using Visual Delphi, based on a mathematical model of sizing photovoltaic water pumping. A database made of different solar panel with their various characteristics as well as data collected from the Retscreen software on weather in West Africa were adopted by the software to ease the dimensioning task. The software was built and tested against existing data to prove its reliability.

Keywords: *Solar water pumping system, dimensioning, software, database, reliability testing*

Introduction

Water resource form an essential part of human needs. The provision of a safe drinking water has become a fundamental reason for sustainable development in every country. There is a great and urgent need to provide an environmentally sound technology for the provision of potable water in remote areas. Solar photovoltaic (PV) system is an attractive complementary energy source deployed alongside diesel pumps in areas with plenty of sunshine where the cost to run power lines is high. In reality, many forms of water pumping system have been in existence for long andsome of the existing methods have utilised varieties of power, namely human energy, animal power, hydropower, wind and solar to achieve water pumping.

Photovoltaic water pumping system (PWPS) however, is an emerging technology characterised by gradually declining costs. The high capital cost of generating electrical power using photovoltaic cells compared to the conventional coal, gas, and nuclear-powered generators have made this method of pumping very uncommon. Despiteits main disadvantage which relate to the cost, PWPS possesses great advantages for instance the non-interruption of the supply due to the great availability of the solar resource, the convenience of exploiting solar resource in remote and uncovered areas by national grid or in desert.

The cost of installing PWPS has become very critical and for that reason, many techniques have been deployed to perform an accurate sizing of the system. The accurate designs demand a manipulation of very complex mathematical equations limiting many designers from adopting them. In reality, many methods are available but few have been adopted. The efficiency of solar systems which depends on some coefficients related to weather and environment are assumed to have higher values whenever the accurate design cannot be carried on. This can have serious impact on the sizing of the system which sometimes result to great oversizing that leadto heavy additional cost of the installation.

To overcome the problem of wrong sizing, many accurate sizing approaches have been developed by scientists (Akihiro, 2005, Narvarte, 2011). The accuracy in designing the mathematical model involved tough mathematical equations that make it difficult for a designer to adopt them. Many people resolve to use simple manufacturer graphs provided together with their pump modules but the disadvantage in doing so is the fact that the solar system may not be properly designed with consideration to weather and other necessary conditions. It is therefore necessary to bring accuracy in the design of solar water pumping system, but it is also important to make this design available to users in a very simple manner by presenting it as an

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application tool or a software. Unfortunately, many models do exist but few application tools have been developed. One of them is the Franklin Electric. This a very powerful software that reduces the cumbersome effort of accurately sizing a photovoltaic water pumping system by providing the possibility to the user to input parameters like volume of water and also to select the geographical area that contains information about the weather. However, it is only focused on the simple water pumping system involving a pump connected to the solar panel with a reservoir. The system does not take in consideration, the possibility of using battery bank or estimating battery size. Also, the results of the software are only limited to the details on the solar panels to be adopted but not actually the details of other components that may be involved, such as battery bank, inverters, and controllers. Moreover, it will be suitable if the software provide a specification on proposed items so that the user may just purchase them directly if possible. Finally a capital cost estimation will also be necessary for the designer to plan ahead the required investment. All these problems consist of gaps in knowledge that were neither filled by the Franklin Electric nor the other solar pump sizing tools including Solarsizer, and Solar Water Pumping Calculator.

The SolarSizer is used to calculate the require size of a solar system including battery bank size. It can also be used to calculate the output of a planned solar system. The panel can be fixed or mounted on either a two-axis tracker or a single-axis tracker. The program includes a data base of insolation and temperature data for 291 siteswithin the United States, Guam, San Juan, Puerto Rico, and Bocas del Toro, Panama. The solarsizer software does not cover West Africa countries like Togo Republic, Benin Republic and Cote d'Ivoire. However, these areas have a great potential of solar resources and need a solar water pumping system even more than developed countries because the grid system is very limited in these developing countries.

Furthermore, the Solar Water Pumping Calculatoris an online application that also estimates parameters for a solar system. It is very limited in terms of input parameters. The software present approximate figures and recommendations on the pumping system and gives an idea of the budget needed to implement it.

It is in spite of the difficulty of the gaps in knowledge enumerated above that this paper proposes the development of an application tool with Visual Delphi to easily provide an accurate sizing of solar water pumping system. This will reduce the user's effort of going through complex mathematical equations but at the same time,it will consider all possible parameters on weather and environment to carry an accurate design and finally provide to the user with the size of each components and possibly their specifications for the system designed.

Methodology

The method consists of two part: the review of the adopted analytical method of sizing PWPS and the implementation of the application tool with visual Delphi.

According to Acakpovi & al. (2012), the power peak which is the main determinant in the sizing procedure can be given by the formula (1):

$$P_P = \left(\frac{G_{ce}}{[1-\gamma\cdot(T_c - T_{cref})]\cdot G_{dm}}\cdot\frac{C_H}{\eta_{MP}}\right)\cdot Q \cdot H_T \quad (1)$$

with

$$C_H = \frac{\rho.g}{3600} \quad (2)$$

η_{MP}: Efficiency of motor-pump system

G_{dm} : Average irradiation in the considered area (Wh/m^2/day).

G_{ce} : Irradiation under normal conditions (1000 W/m^2).

Tcref = 25^{o}C

Tc: Average temperature in the considered location

γ is the temperature coefficient of cell; For mono-silicon module, γ varies from 0.004 to 0.005 /°C. For poly-silicon module, γ varies from 0.001 to 0.002/°C

E_H :hydraulic energy per day (Wh/day)

H_T : total hydraulic head (m)

ρ :water density (1000 kg/m^3)

g : acceleration due to gravity (9,81m/s^2)

Q: volume of water pumped per day (m^3/day)

In the same paper, the total hydraulic head was evaluated as shown by the flowchart in figure 1 below.

The flowchart depicts a method of hydraulic loss evaluation which is based on the analysis of flow through the pipe. A criteria established by Reynold help to characterise the type of flow and determine the equivalent friction accordingly. Three cases have been distinguished according to the flowchart.

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Journal of Advances in Science and Technology Research (JASTER), Volume 1, Number 1, March 2015, pp4-11

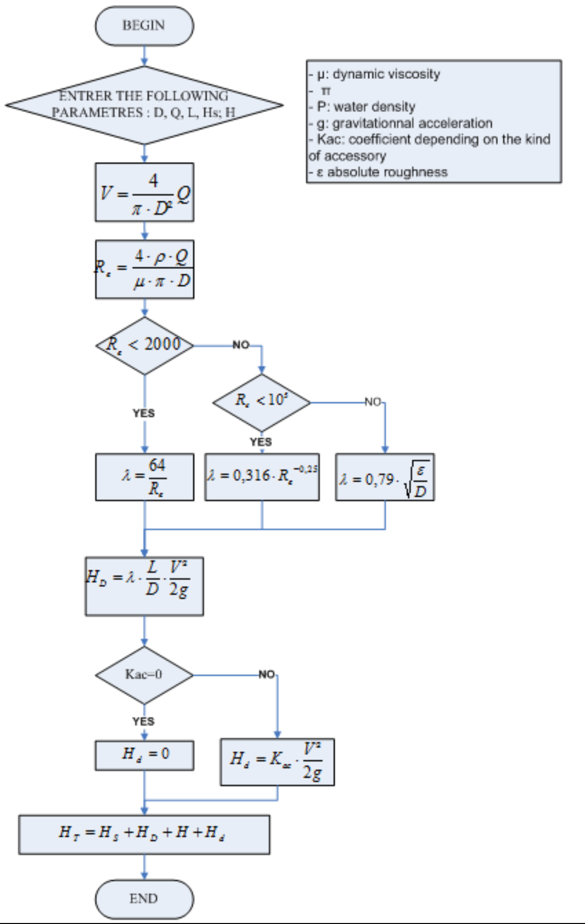


Figure 1: Method of calculation of total hydraulic head

For $R_e < 2000$, the friction coefficient is determined by Poiseuil law: $\lambda = \frac{64}{R_e}$

For: $2000 < R_e < 10000$, the friction coefficient is determined by Blasius law: $\lambda = 0.316 \cdot R_e^{-0,25}$

For $R_e > 10000$, the friction coefficient isdetermined Blench law: $\lambda = 0.79 \cdot \sqrt{\frac{\varepsilon}{D}}$

Based on the analytical model briefly described above, an application tool has been developed with Visual Delphi.

A Waterfall approach have been adopted as System Development Life Cycle (SDLC). Figure 2 depicts the waterfall sequence.

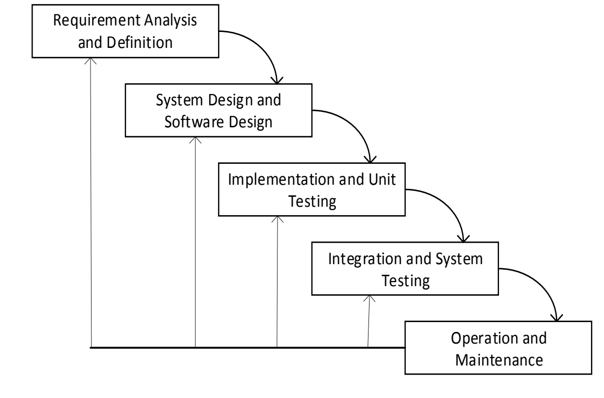


Figure 2: Waterfall model

This model, also referred to as a linear sequential life cycle model was chosen due to the fact that, it is straightforward, simple to understand and use, and the amount of resources required to implement this model is minimal.

Data structures and models used in developing effective system's architecture follow three types of diagrams namely.

- Flowchart
- Database model

These two diagrams have been used to design the data models and structures in this paper and the paragraphs below show their description.

Flowchart

The flowchart in figure 3 shows the operation the software through all its steps. At the start, the tool gives the possibility to the user to choose between "start a new project" or to consult the "catalogues".The catalogues contain specifications on the following components: PV modules, batteries, controllers, inverters and pumps. The selection of any of these components brings its specifications as stored in the database.

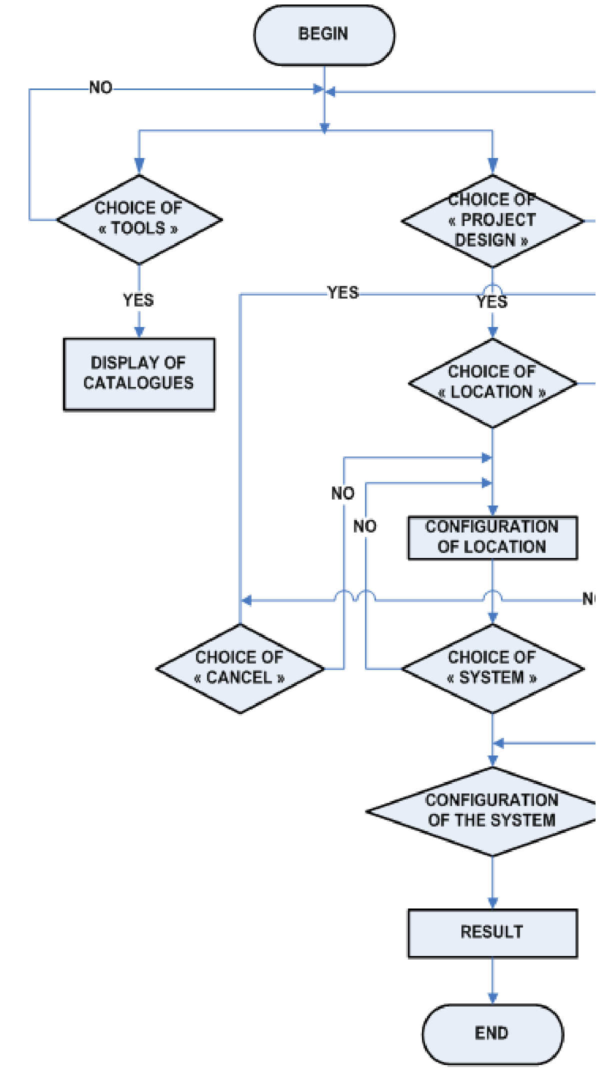


Figure 3: Flowchart showing the structure of the application tool

Three main steps are involved in using the software to size a photovoltaic system namely: "location", "configuration of the system" and "result".

- The location session helps to define the following parameters: solar irradiation, temperature, latitude and longitude in the considered region. A database on all regions in Ghana has been built to this effect with information coming from the Retscreen international software. As a result, the user will only have to select the desired location and all the parameters listed above will be implicitly selected from the software's database.
- The "system" session provide a platform for the user to insert his information about the system to be designed and all necessary parameters to achieve as illustrated by the figures below.
- The "results" session provide a comprehensive result on the sizing of the various components of the system. Necessary specifications are provided per components and those available in the database are proposed to the user. Also a capital course estimate is provided.

In summary, nine different files were programmed in Delphi version seven (7)and two databases in Microsoft Access 2008. All of these files help to design the software which was named PVPSAA systems.

Database model

Figure 4 shows thestructure of the software database which contains eight tables with their respective arrays and links as described below:

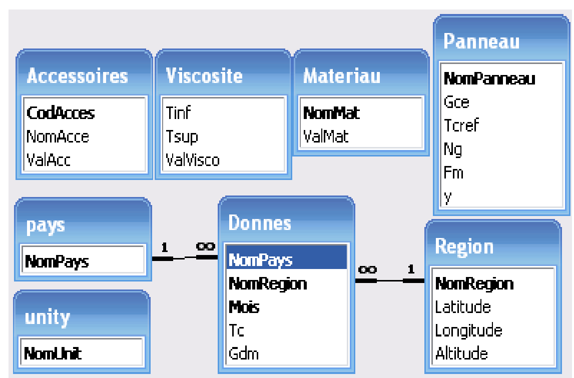


Figure 4: Database model of the PVPSaa

1. Solar panel: This table provide necessary specifications for the choice of solar panel.
2. Material and Accessories: These tables provide necessary friction coefficient Kac that follows special materials as shown in the table 1 below:

Table 1: Coefficient Kac of commonly used accessories

Accessories	Coefficient K_{ac}
Junction from the tank to the pipeline	0.5
Junction from the pipeline to the tank	0.1
Elbow 45°	0.35 to 0.45
Elbow 90°	0.50 to 0.75
Object which have the form of T	1.5 to 2
Control valve (open)	3

3. Viscosity: It provide viscosity value for different types of flow selected by the user
4. Country, Unit, Region, Data: This table contain the information on weather grouped per countries and regions.

Result and Analysis

Figure 5 shows the home page. The background picture reflect solar radiation on earth. The size of all the pages is fixed and defined in the event “Onshow” of Visual Delphi. The picture type was « Bitmap » and the picture was automatically drawn by using the “Oncreate” event of Visual Delphi.

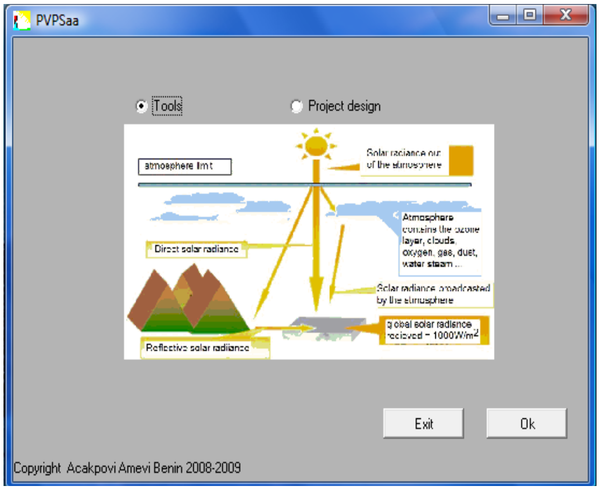


Figure 5: Home page of the PVPSAA

Two radio buttons: “Tools” and “Project design” are provided on the home page. Two other push buttons are also provided, namely “Exit” and “Ok”. Once the radio button « tools » is chosen, a click on the « ok » button will open the page illustrated by figure 6. However, « exit » button will close and completely exit the software because it is programmed with the “Onterminate” procedure of Delphi.

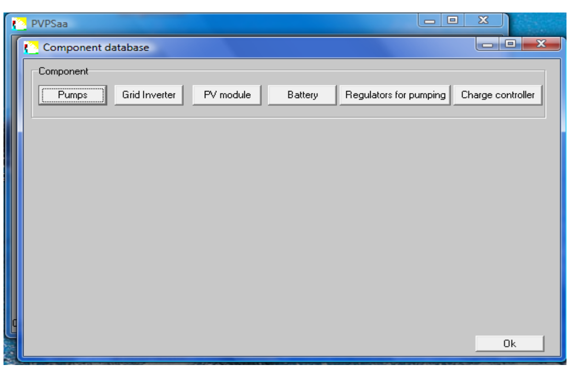
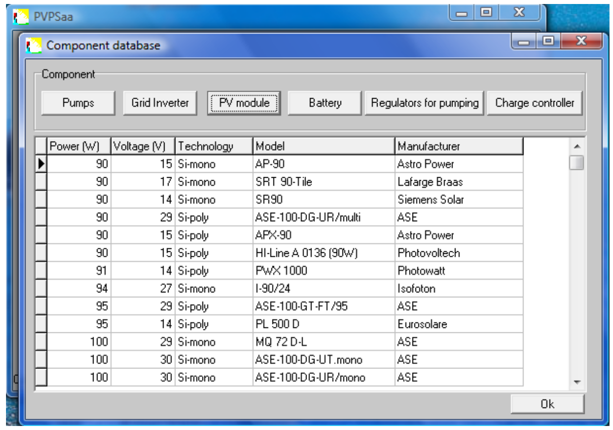


Figure 6: Access to catalogues

Catalogues of various solar system components including pump, PV module, grid inverter, battery, charge controller and MPPT converter have been provided. For example, figure 7 shows catalogue on PV module after the click on the radio button « PV Module »



Power (W)	Voltage (V)	Technology	Model	Manufacturer
90	15	Si-mono	AP-90	Astro Power
90	17	Si-mono	SRT 90-Tile	Lafarge Braas
90	14	Si-mono	SR90	Siemens Solar
90	29	Si-poly	ASE-100-DG-UR/multi	ASE
90	15	Si-poly	APX-90	Astro Power
90	15	Si-poly	HI-Line A 0136 (90W)	Photovoltech
91	14	Si-poly	PWX 1000	Photowatt
94	27	Si-mono	I-90/24	Isofoton
95	29	Si-poly	ASE-100-GT-FT/95	ASE
95	14	Si-poly	PL 500 D	Eurosolare
100	29	Si-mono	MQ 72 D-L	ASE
100	30	Si-mono	ASE-100-DG-UT.mono	ASE
100	30	Si-mono	ASE-100-DG-UR/mono	ASE

Figure 7: PV module catalogue

On the other hand, the choice of « project design » on the home page will lead to the proper sizing of the photovoltaic pumping system starting from the page shown in figure 8.

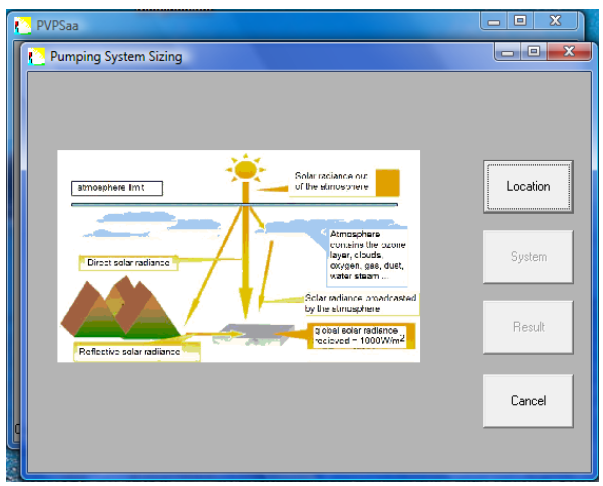


Figure 8: First step in sizing

At this level, the user has to configure respectively the Location and the system itself. Also the system can provide results after been configured.Figure 9 shows the page on the configuration of location.

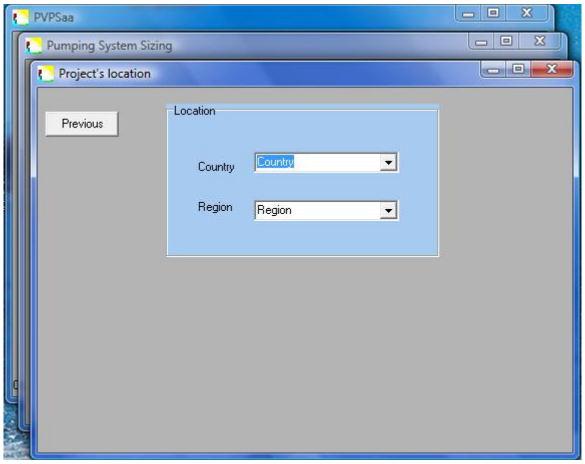


Figure 9: Location of the installation

The dropdown box « Region » is empty until a choice of country has been made. Once the dropdown box country is clicked on, a list of five countries including Togo, Benin, Ghana, Nigeria, Cote d'Ivoire, appear as shown in figure 10.

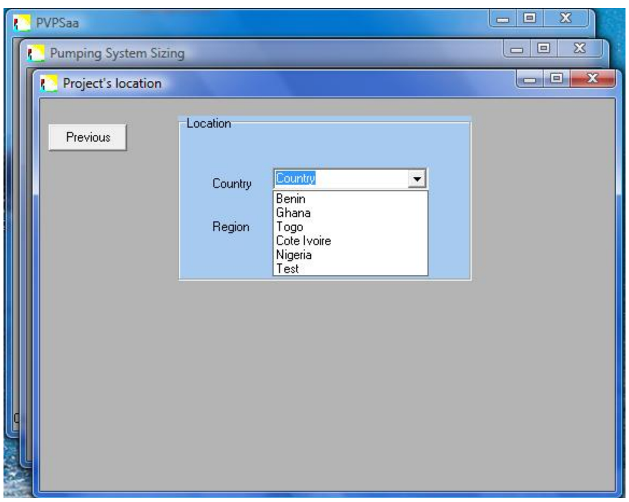


Figure 10: Choice of country

In fact, the first version of this software is limited to five countries. Updates will include more countries. When a country is chosen the dropdown box « Next » shows the list of regions of the chosen country but it is important to know that this subdivision into regions is related to some parameters like altitude and longitude which are automatically downloaded once the region is selected. Figure 11 and 12 illustrate this process.

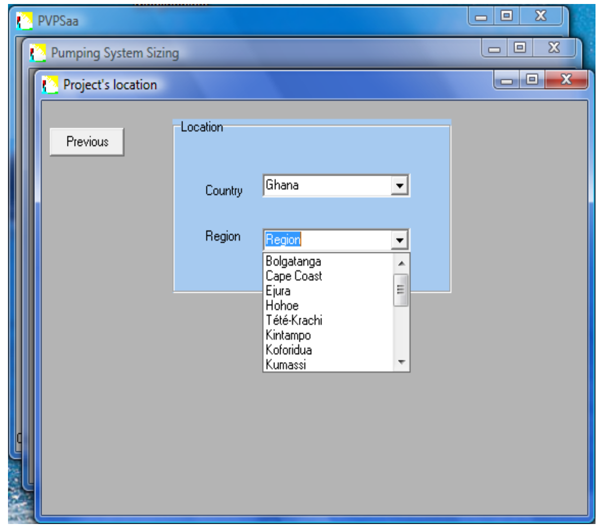


Figure 11: Choice of region

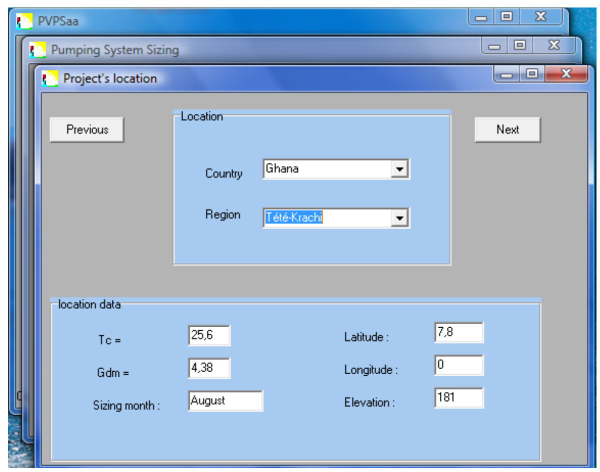


Figure12: Downloading of data

Once the location selected with its parameters as shown in figure 12, the next action is to go back and select the button system. A click on "system" brings the six different optionsfor configuring the solar water pumping system as illustrated in figure 13.

After selecting any of the six configurations shown in figure 13, a page comes up for their configuration. For instance, the sixth option which include « battery, inverter and tank » is configured and illustrate as shown in figure 14

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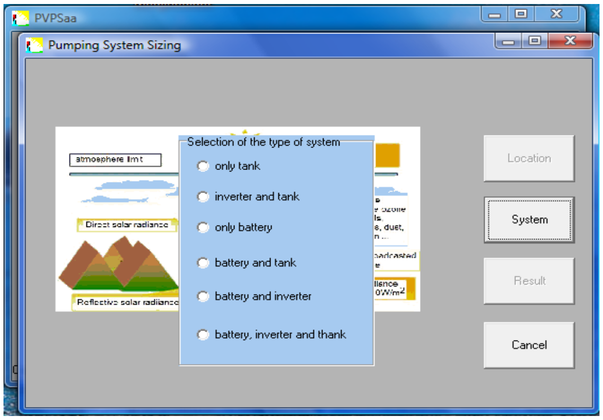

Figure 13: **Choice of the type of system**

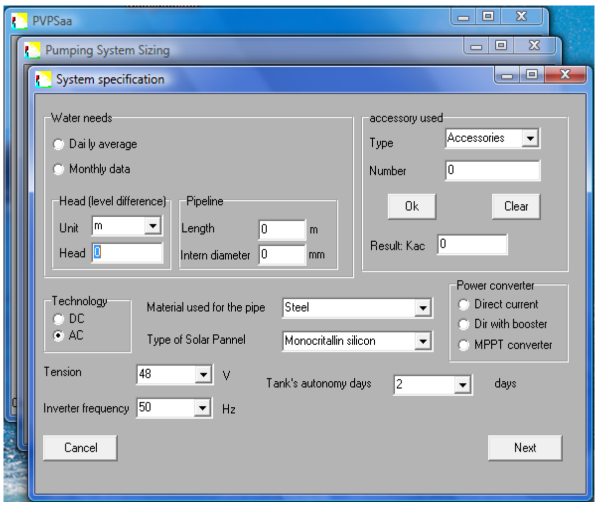

Figure14: Configuration of the system

At this stage, the user must insert data in the software in order to configure the system correctly. Avolume of water is needed, which an essential parameter for the sizing can be inserted by choosing « Monthly data » as shown by the figure 15.

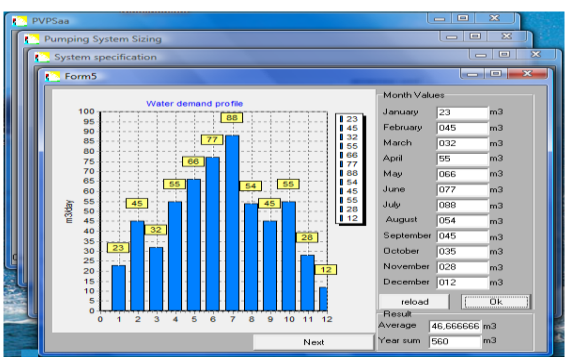

Figure 15: Insertion of monthly data on volume of water needed

The average water demand can also be inserted directly by clicking on the « Daily data ».

It is essential to emphasize that some parameters are fundamental for the sizing and for this reason they cannot be put to zero. They mainly consist of static head, the internal diameter and length of the pipeline, the flow and the system voltage. Figure 16 shows a good configuration of photovoltaic water pumping system.

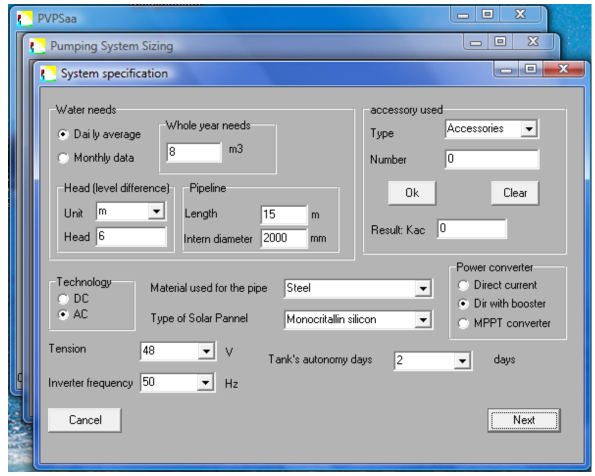

Figure16: Example of System configuration

When the configuration is set, « Next » button helps to compile the sizing and to access the result page as shown in figure 17. The results essentially consist of the basic parameters that will help select the appropriate components. Some of them include the peak power, the system voltage and current, the battery capacity and the required volume for the tank. Moreover, the software proposes as result, some components chosen from catalogue in line with the specification provided by the analytical model.

Finally, a cost assessment model was introduced to help estimate the capital cost of installation. The details on the cost are provided when we click on the button « Details on the total cost ».

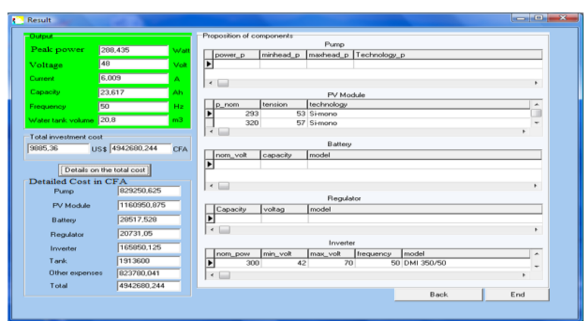

Figure 17: Results page

Conclusion

In summary, this paper dealt with the design of an application tool using Delphi 7 programming software. The programming mainly consist of a first part that handled the mathematical equations of sizing photovoltaic water pumping systems, and the other part of the programming involved the use of database. Due to the volume of data tobe stored in the database, Delphi 7 database was abandoned and rather Microsoft Access 2008 was used to create the two databases. The first database contains data about weather for each country involved in the actual version of the software and some other data which are the input parameters of the system. The second database contains some catalogues on each component that is included in the design of the system. The created software, named PVPSAA provides the essential data for the choice of components such as peak power, capacity of batteries, system current for the choice of regulator and approximate tank volume. It also provides some specifications on components based on its catalogues. Finally, an estimation of investment cost is made with a full detail on the expenditures. While relying on a very rigorous and reliable analytical model the PVPSAA tremendously reduces the effort of the designer and minimizes losses in the design due to inaccurate estimation of basic parameters. It is henceforth recommended for industrial applications as well as manufacturers of solar water pumping system. For future works, an enriched database can be built and the software can be extended to the sizing of other solar systems.

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