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Photovoltaic based Irrigation System Software

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Abstract: Photovoltaic is a technology in which solar radiation is converted to electrical power, that is, direct current. The use of photovoltaic as power source for water pumping activities is one of the promising areas in photovoltaic application. The objective of this study is to develop a software that can be used as guidelines for developing suitable photovoltaic based irrigation system. This study presents the design and the technical requirements of a photovoltaic powered water pumping system for irrigation. The design of the photovoltaic system is based on the estimation of the water requirement, pumping system selection and sizing, photovoltaic arrays sizing, load matching design, along with the meteorological data of the site location. Java language was employed in the development of the software.

Key words: Photovoltaic, solar water pumping system, simulation software

INTRODUCTION

The sun is an unlimited energy source and it is also cleaner and less hazardous compared to the conventional energy sources. Photovoltaic (PV) is a technology in which the solar radiation is converted to electrical power. PV has demonstrated its effectiveness and holds great promise in electrical generation for various applications especially in remote areas, since the extension of the national electricity grid to these remote villages is not an economically viable option (Al-Douri and Al-Sabounchi, 2003; Al-Sabounchi *et al*., 2004). These applications include stand-alone power systems for residential houses (Abdul-Aziz and Shafie, 2008; Ibrahim *et al*., 2006), emergency telephones, water pumping and streets lighting.

Ghoneim (2006) has studied the performance of photovoltaic powered water pumping system in the Kuwait climate. The life cycle cost evaluation that is carried out lead him to conclude that PV powered system is less expensive than the cost of conventional system.

Antonia and Diniz (2008) studied the implementation of photovoltaic rural-school electrification program for the southern state of Minas Gerais in Brazil. Part of the project is the Rural PV Communal Centres Electrification Program. The water pumping systems that were set up provide an average of 10,000 L day^{-1} for 100 inhabitants per community.

A study by El-Tous *et al.* (2008) on the applicability of PV systems with particular application to water pumping and refrigeration systems under the local climate conditions of Jordan has shown that the use of sun tracking system with the PV arrays is efficient and significant for enhancing electrical power generation for the developed system, which in turn would benefit the Jordanian isolated communities away from the national grid.

Al Douri and Al-Sabounchi (2003) has designed and successfully implement a pilot PV system to pump drinking water from a water well in a residential complex north of Mousel city in Iraq. An experimental investigation by Omar and Makhomo (2008) on the short terms results and evaluation of a remotely monitored PV water pumping system support the evidence that PV pumping can compete with diesel water pumping under specific head and flow conditions.

Photovoltaic powered water pumping system is in a way similar to any other pumping systems, except the power source is solar energy. PV water pumping system consists of PV arrays, power regulator, motors, pumps, water tank and batteries. PV arrays are fixed mounted, or placed on trackers to increase pumping time and volume.

The successful implementation of a PV water pumping system (El-Tous *et al*., 2008; Al-Sabounchi *et al*., 2006; Omar and Makhomo, 2008) has lead to the possible consideration of a PV powered irrigation system.

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This study presents a possible design of a photovoltaic powered irrigation system. Fundamentally, the design will make use of the traditional concepts of PV water pumping system sizing in order to determine the technical requirements for operating a PV powered irrigation system.

SYSTEM REQUIREMENT

A water pumping system consists of three main components; the PV array, the direct current (DC) motor and the pump along with an additional power controller as shown in Fig. 1.

Each component has its own operating characteristics, which are; the I-V characteristics for the PV array and DC motor and the torque speed characteristics for the motor and pump. The DC motor drives the pump whose torque requirements vary with the speed at which it is driven. The motor is operated by the power generated from the PV arrays whose I-V characteristics depend non-linearly on the solar radiation variations and on the current drawn by the DC motor. The solar cell modules can only provide maximum power at specific voltage and current levels. Since, the maximum power varies with radiation and temperature, a DC-DC converter known as maximum power point tracker is used to continuously match the output characteristics of the PV array to the input characteristics of a DC motor.

Figure 2 illustrates the PV based irrigation system under consideration. In this system, a water tank instead of batteries is used to store water for usage at night or during cloudy moments. As shown in the diagram, the area of the agricultural field to be powered by PV is 3 ha. PV arrays will be connected directly to a power regulator from which power will be delivered to pump the load. Pumps are to be mounted on a fixed base to decrease the effect of vibrations. They should also be located as near as possible to water source which is assumed to be water stream that will act as an abundant water source. During normal operation, water will be pumped directly from the water stream into the storage tank with the specified flow rate.

This water will then be distributed for irrigation as desired. This tank is used as a replacement for storage batteries thus reducing excessive cost to the PV system. However, a small set of batteries shall be used to supply power for automatic valves, sprinklers and for the auxiliary load. The two main factors that will identify the size of the pump motors as well as the PV arrays are the daily water demand and the irrigation need.

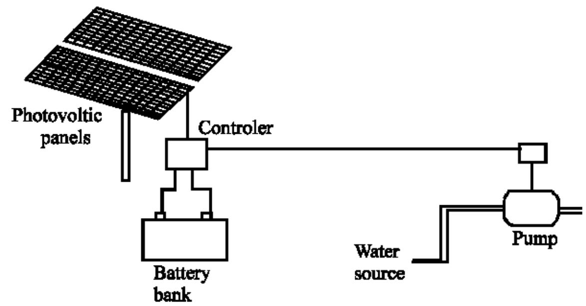

Fig. 1: PV Irrigation system

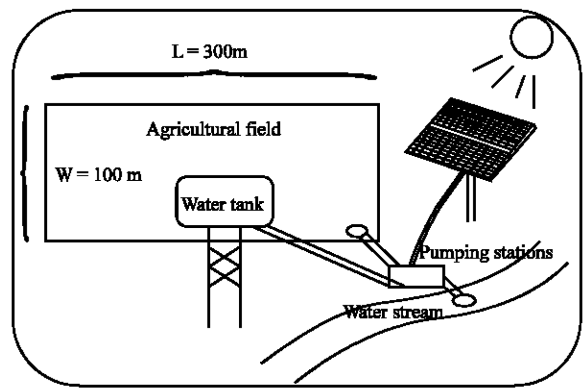

Fig. 2: Proposed PV based Irrigation system

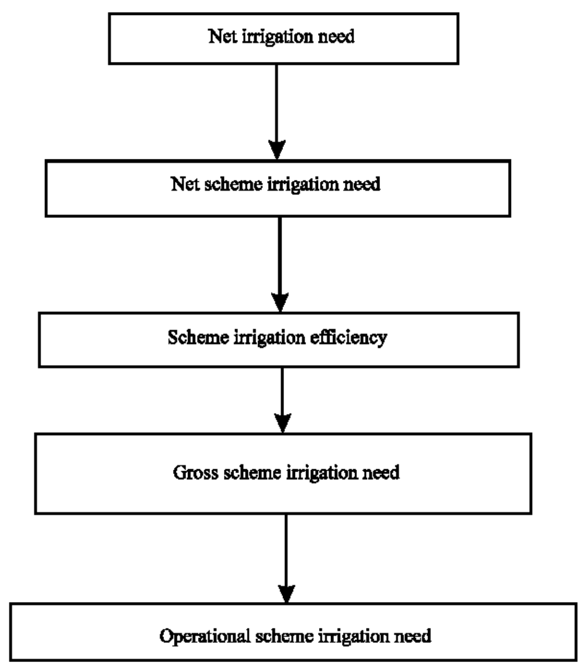

Fig. 3: Flowchart for estimation of water demand

Estimating the water demand: The flowchart used to estimate the demand is given in Fig. 3.

The estimated daily water requirement in liter per day takes into consideration (1) the climate (2) the area of the land and (3) the number of days and hours irrigation takes place.

Estimating the pumping requirement: The pumping requirements are based on the following assumptions; (1) water reservoir is very large and located 20 m underground and (2) the worst case peak sun hours is 6 h. The hydraulic power (HP) of the pump is given as:

$$HP = \frac{3.66\times10^{6}(\text{L day}^{-1})\times h}{(PT)(PTF)(\eta)} \quad (1)$$

Where:

h = Effective height
PT = Pumping time
PTF = Pumping time factor is the ratio of the actual time the pump operates each day to the peak sun hours
n = Wire to water efficiency

Effective height, (h=height x pipe friction losses) is the distance from water surface to the delivery point. Piping friction should also be considered, which in most designs, the value is about 5% of the total effective height. In addition, the height also depends on the type and diameter of pipe used. The pumping time in most cases is nothing but the peak sun hours. The wire to water efficiency is the efficiency of the combination of the motor and the pump and is specified by the pump manufacturer. The hydraulic power is then converted to electrical power using:

$$\text{Power (p)} = HP \times 746 \text{ W} \quad (2)$$

The total current is then calculated from Eq. 2 using Eq. 3 given as:

$$\text{Current} = \frac{\text{Power}\times(\text{Degradation factor})}{\text{Motor voltage}} \quad (3)$$

Estimating auxiliary load: Most of the agricultural activities are usually carried out in rural or remote areas. Due to this, the farmers would require some form of small cabins as temporary accommodation. Thus, the design should also incorporate the load analysis of the accommodation. The cabin will have items such as lights, a DC television, refrigerator and water pump.

PV array sizing: The method used in sizing the PV arrays is the amperage method. The total average amp-hour per day is obtained from load sizing stage to give the required current. This value is calculated using:

$$A = \frac{C\times n\times P\times(W_{dc}\div 7)}{P_{ce}\times V} \quad (4)$$

Where:

A = Amp-Hour Load per day
C = AC–DC check
n = Quantity of equipment
P = Rated power (watt)
H = Hours used
W_{dc} = Number of days each week the load will be used
P_{ce} = Power conversion efficiency

This value is then multiplied by a factor of 1.2 to compensate for any losses that may occur. Total amp-hours is then divided by the average sun hours per day for user's area to get the required total solar array ampere as given in the formula below:

$$DC = \frac{\sum A\times 1.2}{PS} \quad (5)$$

Where:

DC = Design current (Amp)
PS = Peak sun h day^{-1}

The PV modules is then calculated using:

$$Mod = \frac{DC}{Mod_{der}\times I_{mod}} \quad (6)$$

Where:

Mod = PV modules
DC = Design current
n = Quantity of equipment
Mod_{der} = Module derate factor
1_{mod} = Rated module current

Estimating the tilt angle of PV modules: There are two parameters that are involved in calculating the tilt angle. They are; the latitude of the site (L) and the declination of the sun (D). The declination of the sun is the latitude at which the sun is directly overhead at solar noon. This varies from 23.2° North latitude on the summer solstice to 23.5° South latitude on the winter solstice. The equation for calculating the declination (D) for any day is:

$$D = 23.5^0 \sin[\frac{360(284 + m)}{365}] \quad (7)$$

where, m is the day number counted from January 1st.

The tilt angle (A), the angle between the panel and the horizontal plane, is calculated as:

$$A = L - D \quad (8)$$

Where:
L = Latitude of site
D = Declination for a particular day number m

All of these components will be used in the development of the PV based irrigation software.

SOFTWARE DEVELOPMENT

The main objective of the software is to assist the user on the size and type of PV system that is needed. A user friendly graphical user interface is displayed upon logging on to the system. The main screen consists of two parts, basic input and auxi-inputs part. The basic input part allows the user to key in the data required for sizing the water pumping system, PV panels and water tank. In addition, the user also needs to provide the type of climate according to the location. At the moment, six climate types are included in the software; humid tropical climate, monsoon wet season, monsoon dry season, semi-arid wet season, semi-arid dry season and arid climate. The corresponding L sec^{-1} will be calculated based on the type of climate selected.

The user needs to input field area in terms of hectare. This step is very crucial for sizing the water pump, since the size of the pump is proportional to the area of the field. In addition, the user is required to give the expected irrigation days per week along with the expected irrigation hours per day. User will also provide the estimation of how high, in meters, would the pump be required to lift the fluid. The location button refers to the location of the user based on the availability of irradiance data for the location. There are six main locations in Sudan and one for Malaysia.

The auxiliary inputs will be used to estimate the load that is required by the farmer. It is assumed that he will need at least a cabin to stay during his working days. All the equipments and electrical load are assumed to be DC loads. The user need to provide the rating for his loads in term of power and current as well as the number of operating h day^{-1}. The water pump is added to provide for user's water needs, but this can be neglected if he gets the water supply from the main water tank. Upon clicking the 'display output' button, a new window that displays the calculations will then pop up.

This new window will show the number of PV arrays and its size, total PV array price, circuit breaker size, pump and water tank size. A graph of the monthly solar pattern for the selected location is also shown on the screen. The location as well as the respective latitude of the user is shown at the bottom of the screen. The tilt angle of the PV module is also displayed. In this project, it is assumed that the angle of positioning the PV modules should be changed four times a year, in mid of February, April, August and October.

CONCLUSION

In this project, software for PV based irrigation system is developed. The development of the software is based on the fundamental calculations such as water demand, pump size, auxiliary load analysis and PV module sizing. This software is able to act as a guide for the user to decide on the installation of a PV system since initial cost of a PV system is high.

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