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Application of PV smart solar system for Agricultural purposes in IRAQ

KEYWORDS

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ABSTRACT *in this work we built a smart PV SOLAR system to be used in Agricultural areas in Iraq. This system is very efficient to be used in urban and far areas. This research deals with the design and simulation of a simple but efficient photovoltaic water pumping system. It provides theoretical studies of photovoltaics and modeling techniques using equivalent electric circuits. The system employs the maximum power point tracker (MPPT). The investigation includes discussion of various MPPT algorithms and control methods. The work decides on the output sensing direct control method because it requires fewer sensors. This allows a lower cost system. Comparisons with the system without MPPT in terms of total energy produced and total volume of water pumped per day. The results validate that MPPT can significantly increase the efficiency and theperformance of PV water pumping system compared to the system without MPPT.*

1.INTRODUCTION:
In this research, a simple but efficient photovoltaic water pumping system is presented.

It provides theoretical studies of photovoltaics (PV) and its modeling techniques. It also investigates in detail the maximum power point tracker (MPPT), a power electronic device that significantly increases the system efficiency.

Water resources are essential for satisfying human needs, protecting health, and ensuring food production, energy and the restoration of ecosystems, as well as for social and economic development and for sustainable development [1]. However, , it has been estimated that two billion people are affected by water shortages in over forty countries, and 1.1 billion do not have sufficient drinking water [2]. There is a great and urgent need to supply environmentally sound technology for the provision of drinking water. Remote water pumping systems are a key component in meeting this need. It will also be the first stage of the purification and desalination plants to produce potable water.

1.1 Water Pumping Systems and Photovoltaic Power:
A water pumping system needs a source of power to operate. In general, AC powered system is economic and takes minimum maintenance when AC power is available from the nearby power grid. However, in many rural areas, water sources are spread over many miles of land and power lines are scarce. Installation of a new transmission line and a transformer to the location is often prohibitively expensive. Windmills have been installed traditionally in such areas; many of them are, however, inoperative now due to lack of proper maintenance and age. Today, many stand-alone type water pumping systems use internal combustion engines. These systems are portable and easy to install. However, they have some major disadvantages, such as: they require frequent site visits for refueling and maintenance, and furthermore diesel fuel is often expensive and not readily available in rural areas of many developing countries.

Good examples include large-scale grid-connected wind turbines, solar water heating, and off-grid stand-alone PV systems [4]. The use of renewable energy for water pumping systems is, therefore, a very attractive proposition.

Windmills are a long-established method of using renewable energy; however they are quickly phasing out from the scene despite success of large-scale grid-tied wind turbines.

PV systems are highly reliable and are often chosen because they offer the lowest life-cycle cost, especially for applications requiring less than 10KW, where grid electricity is not available and where internal-combustion engines are expensive to operate [3].

1.2 Energy Storage Alternatives:
Needless to say, photovoltaics are able to produce electricity only when the sunlight is available, therefore stand-alone systems obviously need some sort of backup energy storage which makes them available through the night or bad weather conditions.

Among many possible storage technologies, the lead-acid battery continues to be the workhorse of many PV systems because it is relatively inexpensive and widely available. In addition to energy storage, the battery also has ability to provide surges of current that are much higher than the instantaneous current available from the array, as well as the inherent and automatic property controlling the output voltage of the array so that loads receive voltages within their own range of acceptability [5].

While batteries may seem like a good idea, they have a number of disadvantages.

The type of lead-acid battery suitable for PV systems is a deep-cycle battery [6], which is different from one used for automobiles, and it is more expensive and not widely available.

Battery lifetime in PV systems is typically three to eight years, but this reduces to typically two to six years in hot climate since high ambient temperature dramatically increases the rate of internal corrosion [4]. Batteries also require regular maintenance and will degrade very rapidly if the electrolyte is not topped up and the charge is not maintained. They reduce the efficiency of the overall system due to power loss during charge and discharge. Typical battery efficiency is around 85% but could go below 75% in hot climate [7]. From all those reasons, experienced PV system designers avoid batteries whenever possible.

For water pumping systems, appropriately sized water reservoirs can meet the requirement of energy storage during the downtime of PV generation. The additional cost of reservoir is considerably lower than that incurred by the battery equipped system. As a matter of fact, only about five percent of solar pumping systems employ a battery bank [7].

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1.3 The Proposed System:

The experimental water pumping system proposed in this thesis is a stand-alone type

without backup batteries. As shown in Figure 1-1, the system is very simple and consists of a single PV module, a maximum power point tracker (MPPT), and a DC water pump. The size of the system is intended to be small; therefore it could be built in the lab in the future.

The system including the subsystems will be simulated to verify the functionalities.

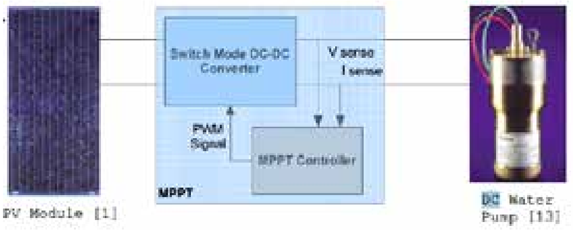

Fig.(1)Blockdiagram of part of the system

1.3.1 PV Module:

There are different sizes of PV module commercially available (typically sized from 60W to 170W). Usually, a number of PV modules are combined as an array to meet different energy demands. For example, a typical small-scale desalination plant requires a few thousand watts of power [6]. The size of system selected for the proposed system is 150W, which is commonly used in small water pumping systems for cattle grazing in rural areas.

1.3.2 Maximum Power Point Tracker:

The maximum power point tracker (MPPT) is now prevalent in grid-tied PV power systems and is becoming more popular in stand-alone systems. It should not be confused with sun trackers, mechanical devices that rotate and/or tilt PV modules in the direction of sun. MPPT is a power electronic device interconnecting a PV power source and a load, maximizes the power output from a PV module or array with varying operating conditions, and therefore maximizes the system efficiency. MPPT is made up with a switch-mode DC-DC converter and a controller. For grid-tied systems, a switch-mode inverter sometimes fills the role of MPPT. Otherwise, it is combined with a DC-DC converter that performs the MPPT function.

1.3.3 Solar Controller:

Analog controllers have traditionally performed control of MPPT. However, the use of digital controllers is rapidly increasing because they offer several advantages over analog controllers. First, digital controllers are programmable thus capable of implementing advanced algorithm with relative ease. It is far easier to code the equation, $x = y \times z$, than to design an analog circuit to do the same [7]. For the same reason, modification of the design is much easier with digital controllers. They are immune to time and temperature drifts because they work in discrete, outside the linear operation. As a result, they offer long-term stability. They are also insensitive to component tolerances since they implement algorithm in software, where gains and parameters are consistent and reproducible [8]. They allow reduction of parts count since they can handle various tasks in a single chip. Many of them are also equipped with multiple A/D converters and PWM generators, thus they can control multiple devices with a single controller.

1.3.4 Water Pump:

Two types of pumps are commonly used for PV water pumping applications: positive displacement and centrifugal [9]. Positive displacement types are used in low-volume

pumps [3] and cost-effective. Centrifugal pumps have relatively high efficiency [9] and are capable of pumping a high volume of water [4]. A typical size of system with this type pump is at least 500W or larger. There is a growing trend among the pump manufacturers to use them with brushless DC motors (BDCM) for higher efficiency and low maintenance [10].

However, the cost and complexity of these systems will be significantly higher. Water pumps are driven by various types of motors. AC induction motors are cheaper and widely available worldwide. The system, however, needs an inverter to convert DC output power from PV to AC power, which is usually expensive, and it is also less efficient than DC motor-pump systems [10]. In general, DC motors are preferred because they are highly efficient and can be directly coupled with a PV module or array. Brushed types are less expensive and more common although brushes need to be replaced periodically (typically every two years) [10].

2.Photovoltaics Models:

2.1Photovoltaic cell:

Photons of light with energy higher than the band-gap energy of PV material can make electrons in the material break free from atoms that hold them and create hole-electron pairs, as shown in Figure 2 . These electrons, however, will soon fall back into holes causing charge carriers to disappear. If a nearby electric field is provided, those in the conduction band can be continuously swept away from holes toward a metallic contact where they will emerge as an electric current. The electric field within the semiconductor itself at the junction between two regions of crystals of different type, called a p-n junction [13].

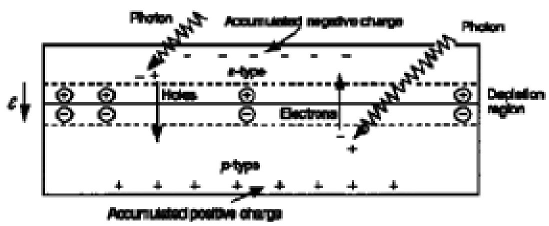

Fig.(2) Illustration of the p-n junction of PV cell [14] showing hole-electron pairs created by photons

The PV cell has electrical contacts on its top and bottom to capture the electrons, as shown in Figure (3). When the PV cell delivers power to the load, the electrons flow out of the n-side into the connecting wire, through the load, and back to the p-side where they recombine with holes [16]. Note that conventional current flows in the opposite direction from electrons.

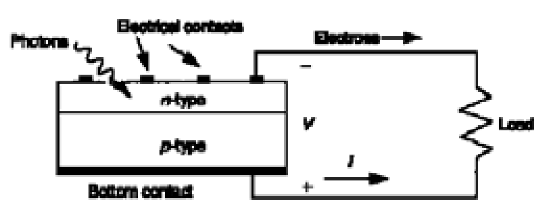

Fig.(3) Illustrated side view of solar cell and the conducting current [16]

Figure (4) shows that current and voltage relationship (often called as an I-V curve) of an ideal PV cell using the simplest equivalent circuit model.

The PV cell output is both limited by the cell current and the cell voltage, and it can only produce a power with any combinations of current and voltage on the I-V curve. It also

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shows that the cell current is proportional to the irradiance.

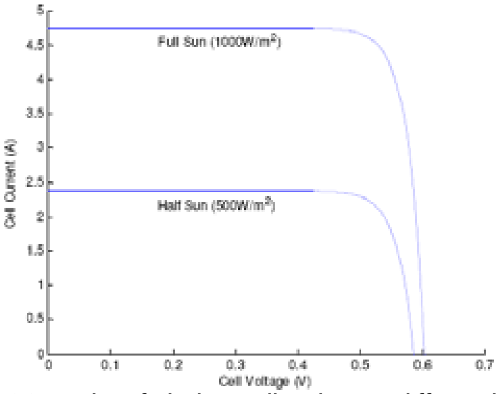

Fig.(4) I-V plot of ideal PV cell under two different levels of irradiance (25oC)

2.2Photovoltaic module:
A single PV cell produces an output voltage less than 1V, about 0.6V for crystallinesilicon (Si) cells, thus a number of PV cells are connected in series to archive a desired output voltage. When series-connected cells are placed in a frame, it is called as a module.

Most of commercially available PV modules with crystalline-Si cells have either 36 or 72 series-connected cells. A 36-cell module provides a voltage suitable for charging a 12V battery, and similarly a 72-cell module is appropriate for a 24V battery. This is because most of PV systems used to have backup batteries, however today many PV systems do not use batteries; for example, grid-tied systems.

Furthermore, the advent of high efficiency DC-DC converters has alleviated the need for modules with specific voltages. When the PV cells are wired together in series, the current output is the same as the single cell, but the voltage output is the sum of each cell voltage, as shown in Figure(5).

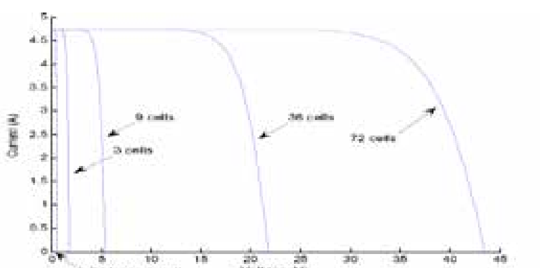

Fig.(5) PV cells are connected in series to make up a PV module

Also, multiple modules can be wired together in series or parallel to deliver the voltage and current level needed. The group of modules is called an array.

The solar panels used in our work are as shown in Figure(6) and its characteristics are shown in table (1) shown below.

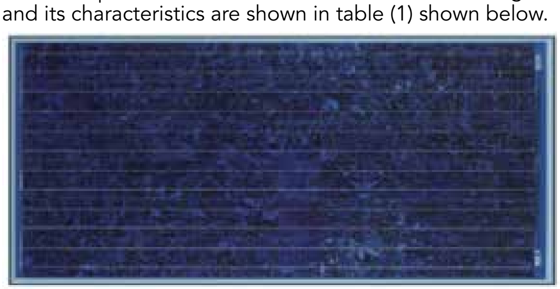

Fig.(6) Picture of BP SX 150S PV module [1]

Electrical Characteristics	
Maximum Power (P_{max})	150W
Voltage at P_{max} (V_{mp})	34.5V
Current at P_{max} (I_{mp})	4.35A
Open-circuit voltage (V_{oc})	43.5V
Short-circuit current (I_{sc})	4.75A
Temperature coefficient of I_{sc}	0.065 ± 0.015 %/ °C
Temperature coefficient of V_{oc}	-160 ± 20 mV/ °C
Temperature coefficient of power	-0.5 ± 0.05 %/ °C
NOCT	47 ± 2°C

Table(1) Electrical characteristics data of PV module taken from the datasheet [1]

The strategy of modeling a PV module is no different from modeling a PV cell. It uses the same PV cell model. The parameters are the all same, but only a voltage parameter (such as the open-circuit voltage) is different and must be divided by the number of cells.

The model consists of a current source (Isc), a diode (D), and a series resistance (Rs).

The effect of parallel resistance (Rp) is very small in a single module, thus the model does not include it.

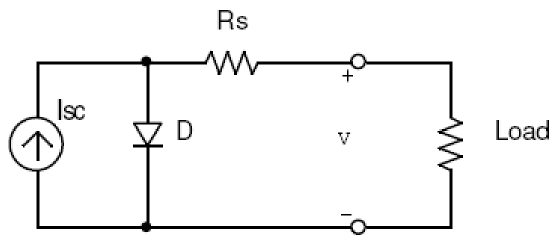

Fig.(7) Equivalent circuit used of the solar cell

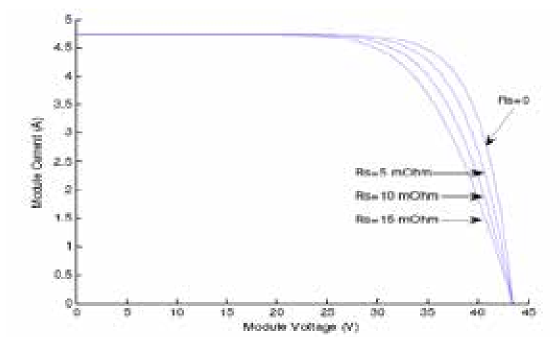

Fig.(8) Effect of series resistances (1KW/m2, 25°C)

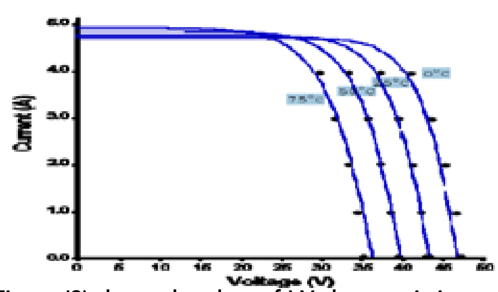

Figure (9) shows the plots of I-V characteristics at various module temperatures of the solar cells used in the practical part of the research. The figure shows good correspondence between the data points and the simulated I-V curves.

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Fig.(9) I-V curves of the PV module at various temperatures(1KW/m2, 25°C)

2.3 The I-V Curve and Maximum Power Point:

Figure(10)shows the I-V curve of the PV module used . A PV module can produce the power at a point, called an operating point, anywhere on the I-V curve. The coordinates of the operating point are the operating voltage and current. There is a unique point near the knee of the I-V curve, called a maximum power point (MPP), at which the module operates with the maximum efficiency and produces the maximum output power.

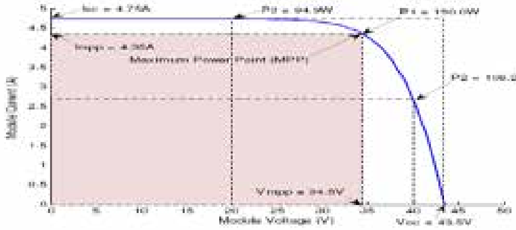

Fig.(10) I-V curve of the solar PV module (1KW/m2, 25°C)

The power vs. voltage plot is overlaid on the I-V plot of the PV module, as shown in Figure (11). It reveals that the amount of power produced by the PV module varies greatly depending on its operating condition. It is important to operate the system at the MPP of PV module in order to exploit the maximum power from the module.

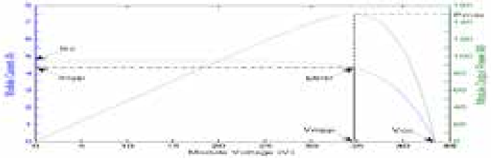

Fig.(11) I-V and P-V relationships of solar PV module (1KW/m2, 25°C)

3.The solar tracker:

This part discusses the I-V characteristics of PV modules and loads, matching between the two, and the use of DC-DC converters as a means of MPPT. It also discusses the details of some MPPT algorithms and control methods, and limitations of MPPT.

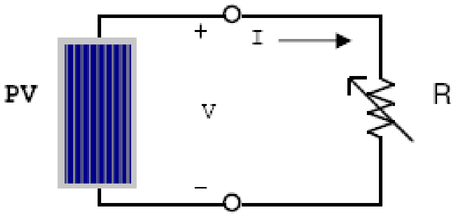

Fig.(12) PV module is directly connected to a (variable) resistive load

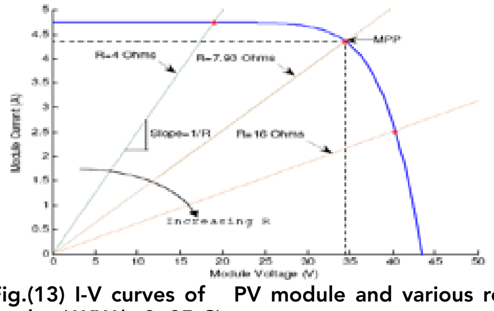

Fig.(13) I-V curves of PV module and various resistive loads (1KW/m2, 25°C)

3.1 I-V Characteristics of DC Motors:

Many PV water pumping systems employ DC motors (instead of AC motors) because they could be directly coupled with PV arrays and make a very simple system. Among different types of DC motors, a permanent magnet DC (PMDC) motor is preferred in PV systems because it can provide higher starting torque. Figure (14) shows an electrical model of a PMDC motor.

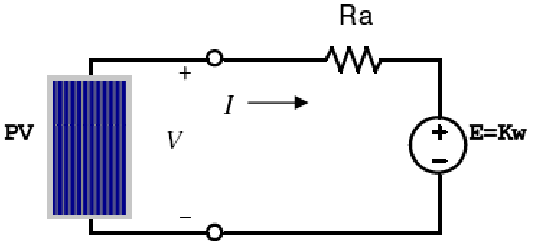

Fig.(14) Electrical model of permanent magnet DC motor

A a simple type of PV water pumping systems uses a direct coupled PV-motor setup. This configuration has a severe disadvantage in efficiency because of a mismatched operating point, as shown in Figure (15). For this example, the water pumping system would not start operating until irradiance reaches at 400W/m2. Once it starts to run, it requires as little as 200W/m2 of irradiance to maintain the minimum operation.[8]

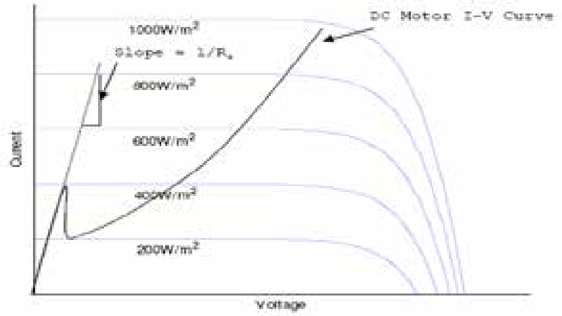

Fig.(15) PV I-V curves with varying irradiance and a DC motor I-V curve

3.2 The DC-DC Converter:

The heart of MPPT hardware is a switch-mode DC-DC converter. It is widely used in DC power supplies and DC motor drives for the purpose of converting unregulated DC input into a controlled DC output at a desired voltage level [17]. MPPT uses the same converter for a different purpose: regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer.

As shown in Figure (16), the impedance seem by PV is the input impedance of the converter (Rin). By changing the duty cycle (D), the value of Rin can be matched with that of Ropt. Therefore, the impedance of the load can be anything as long as the duty cycle is adjusted accordingly.[9]

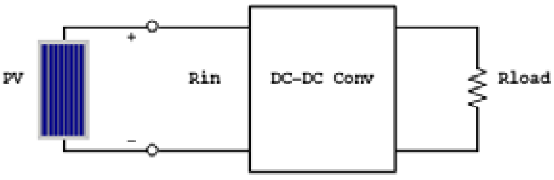

Fig.(16) The impedance seen by PV is Rin that is adjustable by duty cycle (D)

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3.3 The irrigation system used and the moister sensors used:

Figure(17) shows aphotograph for irrigation systems designed and implemented in this work.

Fig.(17) The photograph of the designed system.[10]

The moister sensors are moisture sensors are highly sensitive devices that check the humidity present in a certain product be it house paint or soil or coffee beans. The moisture sensors are designed to estimate soil volumetric water content based on the dielectric constant (soil bulk permittivity) of the soil. The dielectric constant can be understood in layman terms as the soil's ability to transmit electricity. If the water content of the soil is high then the dielectric constant will also be high. The reason behind this surge in dielectric constant is that the dielectric constant of water is way higher other soil components including air. Thus by measuring the dielectric constant one can find out the predictable estimation of water content. Using soil moisture sensors in combination with an automatic irrigation system can work wonders watering the plants. The irrigation system will get started once the moisture sensor detects that the dielectric constant of the soil is below the optimum standards. They will stop automatically once the sensor detects the standard has been reached again.

Fig.(18) moister sensor

There are two types of moisture sensors which are typically used for measuring soil moisture. The most widely used sensor is called capacitance which tells how much water is available for usage. Since the volume of available water in the soil is directly related to soil's texture, every time a sensor is installed, it needs to be calibrated which can turn out be a very time consuming process. In order to use sensor as an effective agricultural tool , they need to be placed strategically placed throughout the field to provide a correct reading of the soil in each farmer's field.

Soil moisture sensors can prove to be a great agricultural tool if used in the right way and with the right infrastructure. Combining with an automatic irrigation system can out the need of setting up the timing for the watering the crops or plants. All you need to do is to pair your moisture sensors with the automatic irrigation system. Whenever the sensor will determine the level of moisture falling behind the regular standard, it will trigger the irrigation system and will stop it once the moisture reaches the standard level. Figure(19) shows capacitance moister sensor.

Fig.(19) Capacitance moister sensor

Figure(20) shows Modeled Vs. actual battery current. The regime A and E in the figure represents negligible battery current because battery at this stage was fully charged and power for irrigation was directly supplied by the PV array. The regime B and F represents the negative battery currents which means that produced power was less than the load demand and irrigations were applied by consuming the stored energy during these phases. The regime C and G represents the phases when irrigation was not practiced so battery current was just due to self-discharge of the battery bank. Regime D represents an early morning phase when irrigation was not started yet but produced current was used to charge the batteries. In contrast, regime H represents a phase where irrigation was started early in the morning so produced power was used for both supplying power for irrigation and charging the battery bank simultaneously. Battery current was chosen for validation because battery model considers the power production, load requirement and controller models for estimating the battery power and ultimately battery current. Thus validation of the battery model also endorses the accurate functioning of the other models. [11]

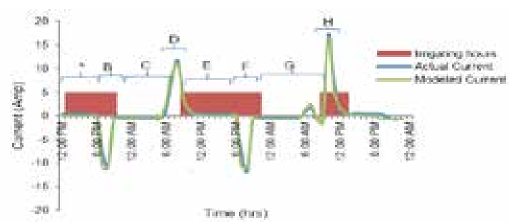

Fig.(19) shows Modeled Vs. actual battery current[12]

4.Design and implementation:

This paper looked at using land use statistics, types of grains grown, water consumption, yearly rainfall, available water resources and availability of solar insolation in the area to design the solar powered irrigation system. The design considered was for the pumping requirement for drip irrigation systems. The designated plot size was used to calculate the irrigation requirements and thus the solar area necessary to determine the feasibility of implementing PV irrigation systems.

4.1 Analysis:

The analysis involved:

Determining the area for implementing the solar powered irrigation scheme, Choosing the crop, Determining the water requirement for that crop and showing the water deficit during the dry season,

Determining the storage area required for the water deficit,

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Calculating the pumping power required, and Calculating the solar panel array area required

4.2Determining the storage area required for the volume of water : Using the information from the last section, the water deficit for this period would be 4613.58m3. Hence, the storage volume required for the dry season for hot pepper is 4,613.58m3.

The larger the area of the water storage area, the less is the depth required of the water storage area. This results in less power requirement for pumping and distribution due to the lower pump head. But the evaporation rate of water from the water storage area would increase, so hence the water storage area should be covered to reduce this evaporation rate. This can be covered via the solar panel array required. For this study a storage area of 22m in length by 22m in width and 10m in depth (H) should be adequate to store this required volume.

4.3 Calculating the pump power required and the solar panel area assumptions were made.

These are Periods of maximum demand for water will coincide with periods of maximum solar radiation, hence the pumping time will be equivalent to the number of hours of peak solar radiation (Kelley et al., 2010; Cuadros et al., 2004). The land is flat; hence the pumping power required would be to pump the water from the depth of the pond to the level of the land. The pond is covered and minimal evaporation would take place. The water in the pond was of good quality, and hence no water treatment processes were considered .

The pumping power required was calculated using the Equation 1.

$E_H = \rho g Q H/3600$……………………………1)

where,

E_H is the daily energy required to pump a volume Q to an elevation H

ρ is the density of water, 1000 kg/m3

g is the gravitational constant, 9.81 m/s2

Q is the total daily flow of water required for water deficit

We take into account:

Energy losses due to friction of the water in the irrigation system, R;

The fraction of the day during which solar radiation is above the threshold at which the pump starts to work Gd> Gthreshold;

The yield, μG, of the photovoltaic generator;

The yield, μI, of the AC/DC converter; and

The yield, μMB, of the pump.

Then, the maximum energy required from the photovoltaic generator, Eel, will be:

$E_{EL} = E_H + R/G_d\ \mu_G\ \mu_I\ \mu_{MB}$ ………………………2)

where,

E_{el} is the maximum energy required from the photovoltaic

$R = 10\%\ E_H$

$\mu_G = 0.85$; $\mu_I = 0.90$; $\mu_{MB} = 0.43$; $G_d = 0.95$

Hence, $P_P = E_{el}/h$ ………………………………………….(3)

where,

P_p is the power required for water pumping h is the number of hours of peak sun per day

Now, $A_S = P_P/I_P\eta_{sa}$

where,

A_s is the required solar panel array area

I_p is the average amount of solar radiation incident on a panel during the peak sunshine hours, 1000W/m2

η_{sa} is the efficiency of the solar array and its electronics, <14%

For a good polycrystalline module, the efficiency is expected to be 14 %. The overall array efficiency depends on many factors and will be lower than the module. For the purposes of this paper, 12% will be used.

The averaged insolation on a horizontal surface was studied. The analysis shows that the power requirements for drip irrigation can be met with quite a small area of solar PV in the order of 3-5m2, or 0.06-0.07% of planted area.

5.DISCUSSION AND CONCLUSION:

This study presents a simple but efficient photovoltaic water pumping system. It models each component and simulates the system required . The result shows that the PV model using the equivalent circuit in moderate complexity provides good matching with the real PV module. Simulations perform comparative tests for the two MPPT algorithms using actual irradiance data in the two different weather conditions. The algorithm shows narrowly but better performance in terms of efficiency compared to the P&O algorithm under the cloudy weather condition. Even a small improvement of efficiency could bring large savings if the system is large. However, it could be difficult to justify the use of algorithm for small low-cost systems since it requires four sensors. In order to develop a simple low-cost system, this thesis adopts the direct control method which employs the P&O algorithm but requires only two sensors for output. This control method offers another benefit of allowing steady-state analysis of the DC-DC converter, as opposed to the more complex state-space averaging method, because it performs sampling of voltage and current at the periodic steady state. The model a DC pump motor, and then the model is done. It performs simulations of the whole system and verifies functionality and benefits of MPPT.

Simulations also make comparisons with the system without MPPT in terms of total energy

produced and total volume of water pumped a day. The results validate that MPPT can significantly increase the efficiency of energy production from PV and the performance of the PV water pumping system compared to the system without MPPT.

79Physical implementation of the system remains for future research. It may involve implementation of: a DSP or a microcontroller, a method of supplying power to the controller, signal conditioning circuits for A/D converters, a driving circuit for Power-MOSFET, a Cúk converter, and a water level sensor that detects when the water reservoir reaches full. It may also involve performance analysis on the actual system and comparisons with simulations.

Some of the factors were taken into consideration to calculate the pumping requirement and thus the solar panel area included the crop chosen, the size of the planting region, the number of peak sun hours, the efficiency of the solar array and its electronics, the pumping elevation and the pump efficiency. These factors would thus affect the feasibility of such systems.

This study showed encouraging results for the use of solar panels in terms of the area required to house them to be used to generate power for the pumping requirement for drip irrigation.

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