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Design and Construction of Hybrid Solar-Wind System used for Irrigation Projects

KEYWORDS

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ABSTRACT *This work deals with the design and implementation of a solar-wind system used to irrigate the agricultural Iraqi areas in the far and desert areas. The wind and solar resource in this area was analyzed in order to establish the system's expected energy output over a year. The water balance was also considered to establish how much water can be collected, and if it will satisfy the garden's requirements. It was subsequently possible to suggest two specific pumps that can be used for the system.The results of this analysis show that the system cannot be standalone. The collectable water will not be enough to satisfy the system's requirements for 6 months of the year. It is also clear that the modules and generator are oversized for the system, and that the wind contribution is significantly smaller than that from the modules. In conclusion, other applications, such as fans for room ventilation, are suggested to make use of the excess energy therefore increasing the system's efficiency.*

1.INTRODUCTION:

The use of solar energy for powering the pumps of a drip irrigation system was investigated. A solar-wind system was considered since this was size of plot that being distributed to farmers for food crop production. The pumping power requirement for drip irrigation was calculated and the associated solar-wind panel area to meet these needs was determined. The design considered several factors including the crop, 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. The work showed encouraging good results for the farmers. Small areas, 3-5 square meters which is a small percent of the total land area, would be needed for housing the panels and thus the associated cost would not be very high. The work provided a premise for further studies to be conducted.

Solar-wind powered pumping for crop irrigation has been suggested as an application, as it is an energy intensive activity that is well suited for implementation with renewable energy sources [1]

Advocated a method for sizing these "photo-irrigation" schemes. The method consisted of three main stages:

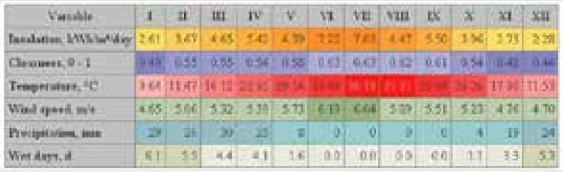
1. Determination of the irrigation requirements of the specific estate according to the characteristics of its soil-type and climate.
2) A hydraulic analysis of the pumping system.
3) A determination of the peak photovoltaic power required to irrigate the estate taking into account the overall yield of the photovoltaic-pump-irrigation system.

According to [2] this method was suitable for determining the size and thus viability of these solar powered irrigation systems since the cost of photovoltaic (PV) systems is fairly high. Not only is the viability looked at in terms of the cost of PV systems but also the land area required for implementation. The investigated the maximum areas which could be economically irrigated [3]. Similar work done [4] suggested that PV irrigation was technically and economically feasible, provided that there was enough land available for the solar array.

Specific studies have looked at using PV systems on small farms [4] and previous feasibility studies evaluated either the economic feasibility or the technical feasibility of PV irrigation. Most of the studies were system size-specific and location-specific. Studies focusing on systems with power requirements on the order of 1 kW have been conducted for sites in Iraq, Jordan and India [5]). Most of the literature concluded that PV irrigation is both technically feasible for very small systems in the order of one acre [6]

In this project, the choice of designing a hybrid system, although motivated by the nature of the equipment available, could prove to be the perfect solution, given that Reading is not renowned for being particularly sunny or windy. At the same time, the idea of recycling collected rainwater to use in the irrigation and grey water systems represents a further step towards sustainability that is definitely worth considering, especially in locations where clean drinkable water is scarce.

Figure(1) shows the annually distribution of solar-wind energy at Baghdad.



Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m²/day	2.61	3.47	4.65	5.43	4.39	7.22	7.03	6.47	5.50	3.96	2.73	2.38
Clearness, 0 - 1	0.49	0.55	0.55	0.54	0.58	0.63	0.63	0.62	0.61	0.54	0.42	0.46
Temperature, °C	9.64	11.47	16.12	21.95	28.54	[illegible]	[illegible]	[illegible]	[illegible]	26.26	17.96	11.53
Wind speed, m/s	4.65	5.06	5.32	5.39	5.73	6.13	6.04	5.09	5.51	5.23	4.76	4.70
Precipitation, mm	29	26	30	25	8	0	0	0	0	4	19	24
Wet days, d	6.1	5.5	4.4	4.1	1.6	0.0	0.0	0.0	0.0	1.1	3.3	5.3

Fig. (1)The solar-wind distribution at Baghdad

Figure(2)shows the daily solar-wind energy at Baghdad.

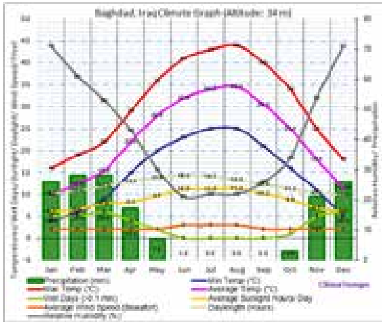


Fig.(2)the graphs of solar-wind energy during the year at Baghdad.

1.1The system components:

1.1.1The PV modules:

The test consisted in measuring the current-voltage characteristic for every module and comparing it with the manufacturer's curve. To achieve this, the current and voltage from the module were measured through different levels of resistance, at a constant level of irradiance. The measurements had to be taken quickly to minimize variations in the irradiance. [7]

Equipment:

9 PV modules
1 Variable resistor 0 – 35.6 Ω
1 Sampling resistor 0.005 Ω
1 Potential divider 11.78 and 120 kΩ
1 Scientific CR10X data logger
1 Semiconductor solarimeter 14.77 μV/W m-2

1.1.2 Wind generator:

The generator was set up outside on the Meteorology Field Site and connected to charge a battery. This location was chosen because it is where wind speed and direction measurements are taken every 5 minutes. The current and voltage from the wind-charger were measured in order to plot current against wind speed and power (obtained as current × voltage) against wind speed and compare standard graphs. [8]

Equipment:

1 Rutland 910 wind generator on a 1.79 m stand
1 12 V 75 Ah deep cycling battery
1 Sampling resistor 0.005 Ω
1 Potential divider 11.78 and 120 kΩ
1 Campbell scientific datalogger
Various wiring and connectors
Various wiring and connectors

Figure (3) shows the PV system circuit. This was done because the datalogger only measures voltages up to 1000 mV. The potential divider is used to make the measurement one order of magnitude smaller than its true value. The current cannot be measured directly, therefore a sampling resistor was introduced and the voltage measured across it used to obtain the current.

The datalogger was programmed to take measurements of the three variables stated above every 1/8 of a second. The experiment consisted in exposing one module at a time to sunlight, connecting it to the circuit and varying the resistance from 35.6 to 0 Ω. The resistance could be varied over a period as short as half a minute in order to have as little variation as possible in the incoming solar radiation. [9]

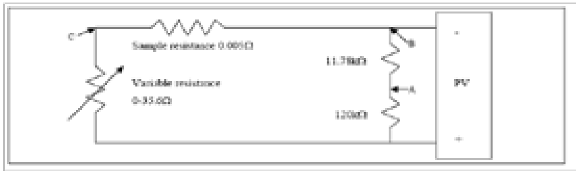


Fig.(3) PV logging system circuit

Once the data was collected, it was converted in values of irradiance, voltage and current using calibration constants that were calculated at the start of the experiment.

It was then possible to choose the data set with the least variation in solar irradiance and plot current against voltage to obtain the I-V characteristic for each module. The experiment was carried out once on a sunny day and once on a cloudy day to obtain results at two different levels of irradiance. [10]

The I-V characteristics of all the other modules show the same features as described above and despite the temperature issue, all the modules appear to be working properly and therefore can be used for the system.

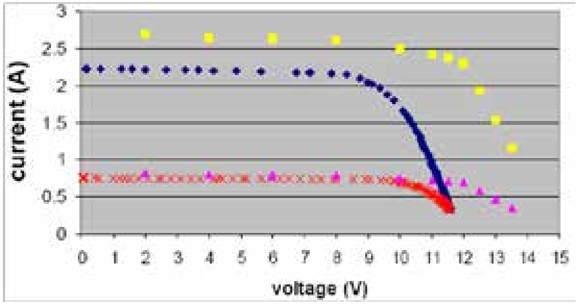


Fig.(4)The I-V characteristics for the solar model

The full graph of the wind turbine used in this work is shown in figure (5), this however show a significant amount of scatter because of the great variability of wind speed with time. In order to compare the experimental results with the manufacturer's data only a few points were taken from the two graphs. [11]

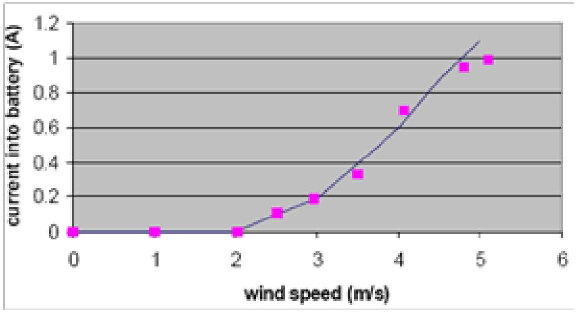


Fig.(5) The wind speed vs current of the turbine used

The objectives of this project were:

1. To create a crop specific irrigation scheduling software package to relieve the producer of the daily tedium of scheduling irrigation.
2. Test the irrigation scheduling software using a simulator for various crops, pumping rates, and soil water holding capacities with weather data collected at sites throughout the upper Great Plains. [12]
3. Determine the effectiveness of the irrigation scheduling software in preventing yield reduction for corn.
4. Determine the effect that increased pumping rate has on the number of days below the minimum allowable balance for a given soil type at a particular site.

1.2 Soil Moisture:

Basing the irrigation decision solely on soil moisture measurements has been practiced by growers for years and also debated by researchers. More recently, and [1] attempted to quantify the measurement uncertainty of some commercially available granular matrix, electro conductivity, and time-domain reflectometry sensors. The researchers concluded due to the large amount of scattering that occurred over time that scheduling irrigations with these three instruments should not be done without first considering the high amount of uncertainty associated with their measurements. A study conducted in Colorado implemented over 8,500 acres of irrigated fields with neutron probe access tubes, tensiometers, electrical resistance blocks, and continuously recording data loggers with visual displays [2]. They determined that soil and crop rooting variability make it nearly impossible to precisely calibrate the moisture sensors and that using absolute numeric thresholds output by these sensors had its limitations. They recommended a system that continuously displays the relative changes in soil moisture. The same general recommendation was given by[13]

Another approach to estimating the soil moisture content in a field is by using an ET equation that is adjusted periodi-

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cally by soil moisture sensors. [14] attempted to determine the frequency in which the field soil moisture balance that is calculated using ET estimates should be corrected with soil moisture measuring devices.

They found that corrections should be made at least monthly and preferably semimonthly.

ET Estimation:

Scientific irrigation scheduling relies on the ability to accurately estimate evapotranspiration (ET). This equation requires daily weather values of maximum and minimum temperature, average wind speed, average relative humidity, and total solar radiation.

This method was selected because of its overall reliability, acceptance by the scientific community, and the ability to transfer crop coefficients to other alfalfa referenced ET equations. [15]

$$ET_r = \frac{0.408\Delta(R_n - G) + \gamma\frac{1600}{T+273}\mu_2(e_s - e_a)}{\Delta + \gamma(1 + 0.38\mu_2)} \quad \text{................................(1)}$$

where,
ET_r - reference evapotranspiration [mm d^{-1}],
R_n - net radiation at the crop surface [MJ m^{-2}],
G - soil heat flux density [MJ m^{-2}],
T - mean daily air temperature at 2 m height [°C],
u_2 - wind speed at 2 m height [m s^{-1}],
e_s - saturation vapor pressure [kPa],
e_a - actual vapor pressure [kPa],
$e_s - e_a$ - vapor pressure deficit [kPa],
Δ - slope vapor pressure curve [kPa $°C^{-1}$],
γ- psychrometric constant [kPa $°C^{-1}$]

Eliminating the need for wind speed and humidity measurements may be advantageous because the sensors themselves are much less reliable than sensors for solar radiation and temperature. It also could reduce costs and allow the weather monitoring system to be more economical to the farmer. [16]

$$ET_r = 0.0102(T_m + 3.36)R_s \quad \text{..............................(2)}$$

where,
T_m – average daily temperature (°C)
R_s – solar radiation (MJ m^{-2})

The ETr values were also multiplied by a plant available water coefficient (Ka)derived [5].

$$ET_r = 0.0102(T_m + 3.36)R_s \quad \text{........................(3)}$$

where,
K_a – plant available water coefficient
AW – available water (%)

As the available soil water is depleted, the water left within the pore space becomes bound more tightly to the soil particles. Therefore, as the percentage of soil water decreases, so does the value of the coefficient as illustrated in Figure (.6) shown.

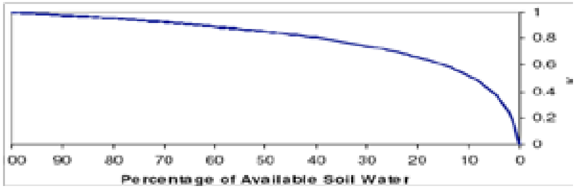

Fig.(6) Ka values as percentage of available soil water decreases from left to right.

The full graphs are shown in figure (7) shown , this however show a significant amount of scatter because of the great variability of wind speed with time. In order to compare the experimental results with the manufacturer's data only a few points were taken from the graphs. [17]

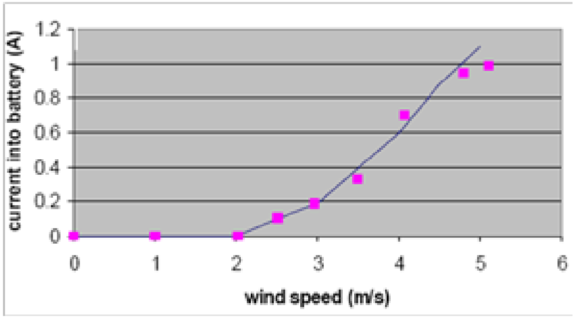

Fig.(7) The wind speed vs the current into the battery

Figure(8) shows the relationship of wind turbine power against the battery current.

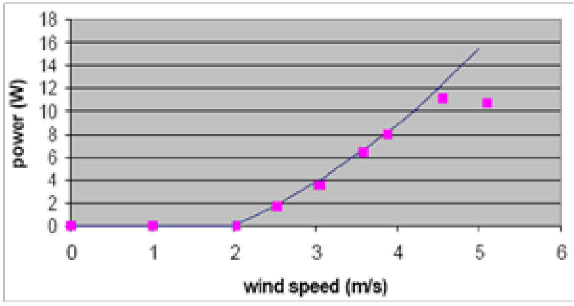

Fig.(8) wind speed vs power

The manufacturer's graphs in fact, do not have very high resolution and the measured wind speeds did not exceed 5 m/s, reading errors will therefore be more significant because the actual values are small.

The scatter is also partly influenced by the variation in the terminal voltage of the battery, however this was not measured during the experiment therefore it is impossible to assess to what extent it influences the results.

Overall, it is possible to say that the generator is working to specification and can therefore be used for the irrigation system. [17]

2.Solar and Wind data:

In order to calculate the amount of electrical energy produced it is necessary to know the solar irradiation hitting the surface of the PV modules. The 30 year average data in hours of bright sunshine was converted using approximate relationships as shown before , in order to obtain monthly average irradiation values on the module's surface. The results of this analysis is shown in Fig.(9)

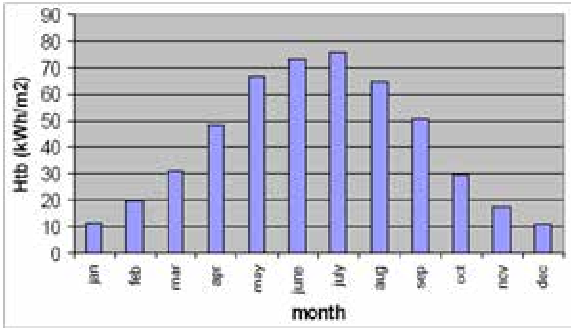

Fig.(9) Solar resource on the module surface

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Wind speed is constantly varying and a wind generator produces a different amount of power depending on the speed to the power of three therefore, in order to assess how many Joules are produced in a given period, it is necessary to know the frequency distribution of the wind speed. This may be done in the assumption that the actual distribution of wind speeds at a given site does not vary significantly from year to year. The monthly average wind speeds for 2014 were compared with the 30 year averages to check that 2014 was not significantly different from the average (Fig. 10).

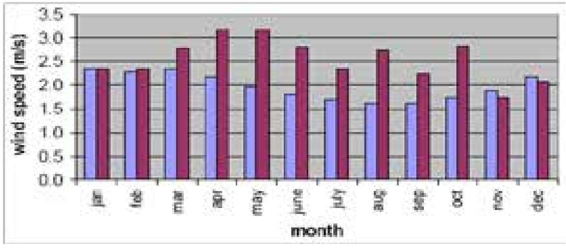

Fig.(10) Average monthly wind speed comparison

The values of water collected and required for each month were plotted together to show the overall water balance of the system (Fig. 11).

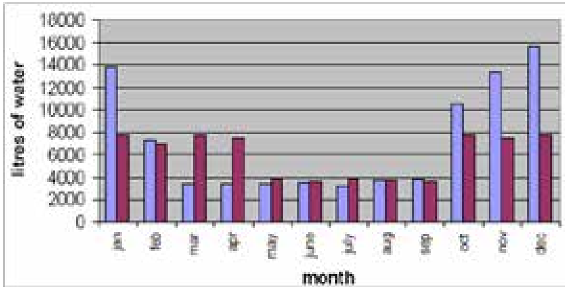

Figure (11) Comparison between amount of water required and amount available from collection.

From this graph it is clear that, a part from September, during the irrigation period (May-Sep.), the water required is always slightly greater than the water collected. This means that the irrigation system will never fulfill the plant water requirements. The balance is only slightly negative most of the time (with exception of July), therefore only a small amount of water will have to be obtained form a mains supply, which is already available on the roof.

In the winter the collected water is much greater because the evaporation does not exceed the rainfall over the garden, therefore runoff can be obtained from a greater surface area.

3.Energy output:

3.1.Solar energy:

Once the average solar irradiation incident on the modules' surface was calculated, it was possible to calculate the theoretical energy output of the PV array. Each module has a Watt peak rating of 34 Wp therefore the array of 12 modules will have a rating of 34×12 = 408 Wp. From this the rated energy output can be calculated as follows:

output(Wh) = rating(Wp) ×irradiation(kWh /m2) ....(3)

In order to account for losses in the system, such as connection losses, battery charge/discharge losses etc, a performance ratio for the system has to be considered. This can be assumed to be 55%. Therefore the new formula will be:

output (Wh) = rating(Wp) × irradiation (kWh/ m2) × = 408× × H β t × 0.55 rating ....(4)

The results of these calculations are plotted in Fig. (12) is shown.

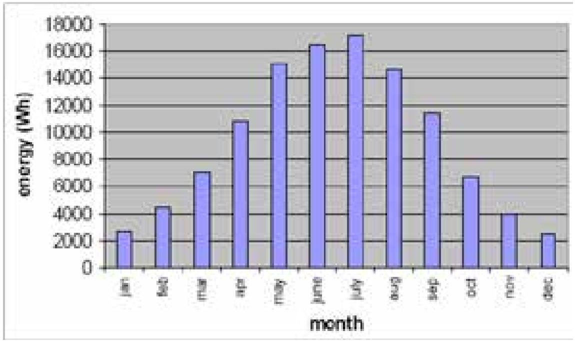

Fig.(12) Potential energy output from the solar system

3.2 Wind energy:

The energy output for each month could subsequently be calculated as follows:

$$output(Wh) = \sum_{u=0}^{n} P_u(W) \times t_u(h) \quad ....(5)$$

where :

u is the wind speed interval Pu is the rated power at a given wind speed and tu is the frequency in number of hours for which the wind speed is within u.

In order to make the monthly output comparable with that calculated for the solar system it was necessary to consider losses in battery charge/discharge. A reasonable assumption for this was considered to be a loss of about 25%.

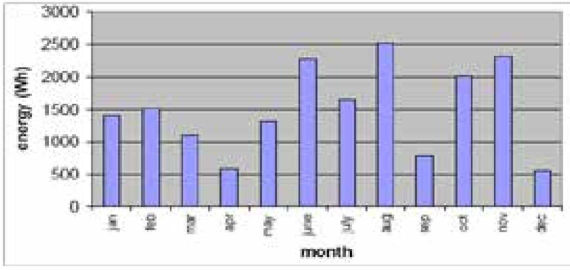

Fig.(13) Potential energy output from the wind system (2014 data)

It is clear here that even in a windy month, the generator will only produce about 2 kWh, which is just about as much as the lowest monthly PV array output. This is because most of the time, the wind speed ranges between 0 and 3 m/s. Therefore for a lot of the time the generator will not be producing any power because it does not start generating until the wind speed is above 2 m/s. Once it is considered that 2014 was windier than average, the significance of the wind component in the long term decreases even more.

3.3 Total energy:

The sum of the solar and wind output for each month gives the total output that could be expected from the system on average (Fig. 14). When looking at the two components, it appears very clear that the solar contribution is far greater than the wind contribution and it is responsible for the trends in output throughout the year, as shown by the shape of Fig. (14). The output will range between 2 and 18 kWh a month, with the maximum being in July and the minimum in December.

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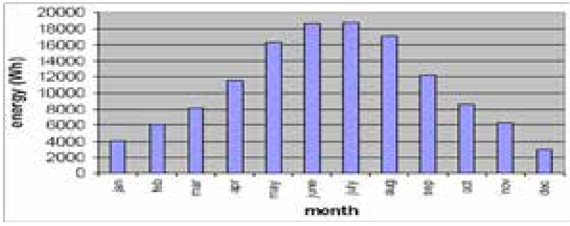

Fig.(14) Total potential energy output(solar+wind)

4. System Design and Calculations:

The solar system will consist of 4 strings in parallel, each of 3 PV modules in series. This arrangement will allow the highest charging efficiency as well as meaning that if one of the modules fails, only its string will fail and not the whole array. The wind generator will be in parallel with the PV array and they will both charge the two batteries, connected in series. The batteries are then used to power the two pumps that are connected in parallel so they can run at different currents. Fig. (15) shows the circuit diagram of the electrical side of the system.

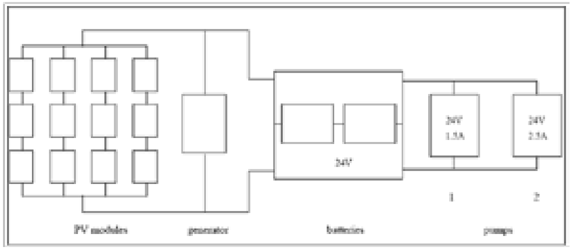

Fig.(15) System diagram

Once it was established that the equipment was working to specification, the first step was to assess the availability of the main resources for the irrigation system. This consisted in establishing the amount of solar irradiation and wind speed available on site as well as the amount of water that could be collected. It was then possible to calculate the amount of energy obtainable from the PV array and the wind generator. With the above information and the plant water requirements two pumps were chosen for pumping the water up to the header tanks and for delivering it to the plants.

Although the system designed here is not perfectly sized, the idea behind it is very valuable and could be developed further on an even smaller scale. An average terraced house garden, consisting mainly of lawn and a few flowerbeds could probably be irrigated satisfactorily by a system similar to the one described here. A single water butt could be used to collect rainwater and a correctly sized PV module could produce enough to power a small drip irrigation system. In such a situation the system would probably work more effectively without battery storage given the perfect coupling between solar resource and irrigation requirements.

On the other hand, on a large scale hybrid solar-wind irrigation systems could prove to be very successful. The solar component would produce energy when the water needs to be delivered to the plants during dry periods, while the wind component would probably produce more energy when it rains and water needs to be collected and pumped to a storage tank.

The parameters that are known and are to be considered in the choice of this pump are as follows:

- The pump will have to work on DC current and at 24 V.
- The static head is 5 m an estimated 10% is added to take into account for friction losses in the pipe (dynamic head), therefore the total head will be 5.5 m.
- The maximum amount of water to be pumped in a day is 750 l, required to fill the header tanks when it is empty.
- The minimum energy available to the pump is that calculated before for December and it is equal to 2,980 Wh. This pump at 24 V can run at a pressure of 30 psi and at a current of 2.5 A . The power requirement will be 24×2.5 = 60 W.

$$time(h) = \frac{156.25(l)}{3(l/m)} \times \frac{1(h)}{60(m)} = 0.87h \qquad \text{.................................(6)}$$

so the rated energy required in a day will be:
output = 60W × 0.87h = 52.2Wh / day ....(7)

assuming a 75% pump efficiency the energy required will be:
52.2/0.75 = 69.6 Wh/day.

If for the whole of September the pump were to work at its maximum, which is a considerable overestimation,

$output_{max}$ = 69.6W × 30days = 2088Wh.................(8)

Even assuming that in the same month pump were also used at its maximum, the maximum energy required would still be less than the minimum energy available.

$Output_{max}$ = 2088Wh + 2232Wh = 4320Wh < 12181Wh ....(9)

This assumption is contradictory because it would mean that at the same time there would be maximum rainwater collected as well as maximum irrigation required, which is impossible, given that they complement each other. However it is just to demonstrate that it can be safely expected that the pump requirements will always be satisfied by the system. Knowing that the system runs on 24 V and assuming a battery charging/discharging efficiency of 75% it was possible to calculate the charge going into the batteries daily.

$$charge(Ah) = \frac{P(Wh)}{24(V)} \times 0.75 \qquad \text{.........................(10)}$$

5. DISCUSSION:

A solar-powered center pivot irrigation system may be precisely evaluated in terms of its reliability and economic viability for any given location using the developed reliability assessment model customized for the site specific operating (PV sizing, irrigation system specifications, management strategy chosen in the light of recommendations i.e. frequent light irrigations) and meteorological conditions considering the crop selection and minimizing the total dynamic head guidelines. The holistic approach has a great potential for its worldwide adoption due to ever growing interest in replacing conventional non-renewable energy resources application in irrigation sector with environment friendly PV technology, which is becoming increasingly affordable. Since the potential of a solar-powered pivot irrigation system is limited by the high initial cost causing financial difficulties during the payback period of the system. Therefore, policies for providing loans on easy conditions and installments, insuring crops, and giving subsidies by the government agencies may prove very beneficial to cope with the challenge. The financial support by the government will help in rapidly promoting the long lasting, environment friendly, and reliable renewable energy technology application in irrigation sector. This work looked at the feasibility of planting grains and gardens using drip irrigation for water requirement. It specifically investigated using solar power for the pumps to be used for irrigation. The results indicate that using solar power for the pumps required is feasible in terms of the solar panel area to be housed. One of the concerns regarding the use of solar panels for producing power is the amount of panels required and the area they would occupy. In the case of agriculture this is especially important since it directly impacts the area that would be left for planting. This work showed that only a small percentage would be required on the two-acre plot for the panels. This demonstrates the feasibility and application of using solar PV to provide energy for the pumping requirements for drip irrigation.

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 of grains and gardens.

REFERENCE

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