Technical Assessment for Solar Powered Pumps in IRAQ

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Abstract: IRAQ has been described as having high solar powered irrigation resources. The seasonal changes in climate have a direct effect on the determination of crop water requirements, irrigation schedules and potential of solar energy generation to operate the water pumping. In this study, solar pumping and pressurized drip irrigation systems were theoretically evaluated to estimate the required water requirement (one hectare) for potato planting in the ALKhlis district using calculated climatic data from the ALKhlis Agrometeorological weather station for a period (2013-2017). CROPWAT 8.0 Software was adopted in simulation of crop water requirement. A mathematical modeling of irrigation scheduling processes was carried by using Microsoft Excel worksheets. The pumping system was simulated by using web based Grundfos Product Center tool. The highest average value of 7.6 kWh / m² / month of solar radiation in all monitoring data years in July, while the minimum average value of 2.6 kWh / m² / month in December when the sun is at the lowest point in the atmosphere. The average of peak sun hours corresponding to the time of the pumping system and the highest water intake was observed at eight months, from March to October, is 7.2 hours / day and 5.2 hours/day for January, February, November and December

Keywords: water requirements, drip, irrigation, evapotranspiration, emission, crop, coefficient, conservation, timing, arid, scarce.

1. Introduction
Khalis is a town in Iraq, roughly 15 kilometers northwest of Baqubah. It is the main town of Khalis Arfan District, one of the six districts of the Diyala Governorate. Fossil fuel electricity generation is a significant contributor to fossil related emissions on the environment. As a result, renewable energy production has advanced and is in demand worldwide (Kelley et al., 2010) hence [1]. solar energy is an example of clean energy. There is a significant volume of solar energy flowing into the atmosphere of earth (Sontake and Kalamkar, 2016) [2]. The scarcity of water and electric energy shortage in Iraq due to the increasing demand and lack of irrigation management, it became necessary to use alternative sources of electricity and adopting an effective management for water resources. Efficient water supply control in irrigation agriculture is critical to ensuring the future of food security. Using solar photovoltaic pumping systems, solar energy is now commonly used in irrigation of agriculture in addition to the traditional pumping system which can be operated by electric system. A case study in Jui-Naw of Afghanistan was studied for optimizing irrigation and maximizing net economic return of many crops by using CROPWAT 8.0 model. The results were showed saving in gross irrigation Requirement when applying 10% improvement in...
irrigation efficiency. According to results of crop water requirement (CWR) and irrigation water requirement (IWR), the relative water supply (RWS) at highest values during the hottest months July, August, and September where the crops are suffering from soil deficits due to water shortage. The study demonstrates a scheduling of irrigation and the steps to support the farmers to reduce water wastage in crops irrigation [3]. Some authors used CROPWAT which is a decision support system was developed by Land and Water Development Division of Food and Agriculture Organization (FAO). Many researchers were used CROPWAT software in modeling of planning and management of irrigation. It is a practical tool for standard calculations for reference evapotranspiration, crop water requirements, crop irrigation requirements, development and improvement of irrigation practices and planning of irrigation schedules under varying water supply conditions [4-5].

A 30-kW solar pumping system at Buraydah city in Saudi Arabia for agricultural irrigation by using approach of converting solar radiation values from horizontal surface to tilted surface using the shortest sunny days from real measured data. The proposed system could deliver a 200 m³ of water daily from a well of a 176 m depth according to availability of solar radiation [6]. Another common method in the literature for sizing Solar PV irrigation system by using the monthly average of daily solar insolation data to calculate the associated peak sun hours which is the basis of evaluating the performance of pumping system [7-8].

Other authors were used the monthly average of solar radiation on tilted surface of the worst month throughout the year in sizing the solar PV array required to satisfy the operating power of the pumping system. [9]. The data of the worst monthly average solar radiation and the maximum monthly demand of water was used to calculate the size of solar PV array [10]. Another approach was used the worst daily data of solar radiation collected over the inclined surfaces of solar modules and the system efficiency in design of solar PV pumping system [11]. A developed a simple algorithm depends the monthly average of global horizontal irradiance only was used for designing of solar PV pumping system [12-13]. The frequently used method by the farmers to supply the water for irrigation is not optimal and causes water wastage in addition to hardly control the amount of water to individual plants to achieve ideal growth. The query that emerges is how much water should be added to a given field, and when? A rational, economic and technically realistic solution of electrical power shortage and scarcity of water needed for crop irrigation in the most rural areas of Iraq was studied in the present study. The alternative suggested is to develop a solar-powered drip irrigation system that satisfies the required water requirement for crop irrigation. The system's portion includes Solar panels, 3-Phase Solar Inverter, Solar Power Submersible Pump, Water Supply Level Switches, Automated Irrigation Control, and Pressure Drip Irrigation[19-20].

Figure 1. Description of System for photovoltaic water pump.
2. Research Method

The proposed Solar Pumping System will supply the water from a well to a Pressurized Drip Irrigation for supplying the crops with required water for irrigation. The irrigation applications were controlled of by using soil sensors. Mathematical model was used to evaluate the CW required using CROPWAT8.0 Software, while Grundfos Product Centre-based sizing software was used to model the solar Pumping System.

The research study the following:

- Estimation of Crops Water requirement and required water for irrigation scheduling.
- Analysis the required Water for irrigation of the adopted crops with respect to soil moisture.
- Estimation the surface solar pumping sizing according to monthly Water requirements.
- Design of drip irrigation system.
- Technical evaluation of total irrigation system.

![Figure 2. show the plant of potato crop.](image)

![Figure 3. Layout of drip irrigation system.](image)
3. Study Area Data
The study area Al-Khalis district / Diyala governorate is located at (Latitude 33.75N, Longitude 44.62E) at middle of Iraq. The climate data used have been collected from AlKhalis Agrometeorological weather station/ agriculture ministry in Iraq as shown in the Figure 4. The average monthly measured data were arranged for a period (2013-2017) as shown in the Table 1. The suggested agricultural land is one Hectare (10000m2) planted with seasonal crops of Potatoes (100% of total land).

Figure 4. Study area (Al- Khalis district) latitude 33.75N, longitude 44.62E [14].

Table 1. Agro- meteorological data of station AL- Khalis [14].

| Month | R mm | TM C° | Tm C° | Hav. % | WS km/day | SRt Mj/m2/m | Et˳_avg mm/day | Et˳_tot mm/month |
|-------|------|-------|-------|--------|-----------|-------------|---------------|-----------------|
| Jan   | 20.3 | 15.834| 4.082 | 66.94  | 140.486   | 10.136      | 1.606         | 49.74           |
| Feb   | 15.3 | 19.602| 5.694 | 58.806 | 137.030   | 13.466      | 2.486         | 70.18           |
| Mar   | 9.96 | 24.42 | 9.686 | 52.557 | 159.494   | 17.004      | 3.772         | 116.92          |
| Apr   | 26.3 | 30.786| 13.354| 43.833 | 146.88    | 20.742      | 5.268         | 158.02          |
| May   | 4.4  | 36.63 | 19.262| 36.238 | 155.52    | 21.574      | 6.546         | 202.946         |
| Jun   | 0    | 41.256| 23.146| 27.437 | 167.443   | 24.372      | 7.93          | 237.934         |
| Jul   | 0    | 44.542| 25.614| 27.516 | 162.777   | 23.37       | 8.162         | 253             |
| Aug   | 0    | 44.792| 24.688| 28.815 | 135.820   | 21.57       | 7.228         | 224.092         |
| Sep   | 1.16 | 40.36 | 20.71 | 33.505 | 116.985   | 19.05       | 5.49          | 165.775         |
| Oct   | 5.32 | 32.614| 15.292| 43.209 | 111.110   | 14.1175     | 3.546         | 115.97          |
4. Modeling of Water Requirement System

4.1. Estimation of Crop Water Requirements (CWR)

The water requirement for the irrigation system arises from an assessment of the water needed to achieve optimum crop production. CROPWAT 8.0 is a software program for the calculation of crop water requirements (CWR) according to climatic, crop and soil data [15]. It was used to calculate the evapotranspiration and crop coefficient at growing stages of the crop. A mathematical modeling was applied in irrigation requirements (IR) calculation and irrigation management scheduling using Microsoft Excel worksheets. The measured climatic data (temperature, humidity, wind speed, sunshine, Rainfall data, crop and soil data) for five years (2013-2017) from Al-Khalis Agrometeorological weather station. The data was modified by MS excel worksheet to calculate evapotranspiration (ETo) using the Penman-Monteith formula in CROPWAT 8.0 software. It was used for determination of (CWR), irrigation schedules for Potato using the following input parameters in calculations. Planting date 15 September [16].

- Period of crop life 130 days.
- Expected Harvesting date 22 January.
- Planning of Planting area with Potatoes is one Hectare (10000 m²)
- Row spacing of plant lines is 80cm.
- Spacing between plants along the row is 25 cm.

The term of evapotranspiration (ET) is a term consisting of water lost from soil by evaporation and crop transpiration (vaporization of liquid water contained in plant tissues) processes which occur simultaneously. The water lost from the soil by evaporation is too much when the crops as small and decrease when the crops are covering the soil surface and the transpiration become the mean cause of water loss. It is expressed in (mm/day) as depth.

The calculations of ETo [mm/ day] include determination of reference crop evapotranspiration which represents the evapotranspiration from a standardized vegetated surface (grass) at standard climatological records of sunshine, temperature, humidity and wind speed. The characteristics of the hypothetical reference crop at height of 0.12 m, a fixed surface resistance rs=70 s m⁻¹ and an albedo of 0.23, ra aerodynamic resistance [s m⁻¹]. The equation of ETo gives insight of evapotranspiration at different periods of the year, regions and crops and expressed as following [15]:-

\[
ETo = \frac{0.408 \Delta (R_n-G) + \frac{900}{k_2} \left(\frac{1}{x_e-x_a}\right)}{\Delta + \gamma (1+0.34\theta_x)}
\]

Where \(ETo\) reference evapotranspiration is calculated in [mm day⁻¹], \(R_n\) net radiation at the crop surface [MJ m⁻² day⁻¹], \(G\) soil heat flux density [MJ m⁻² day⁻¹], \(T\) mean daily air temperature at an altitude 2
mheight [°C], \( u_2 \) wind speed at 2 m height [m s\(^{-1}\)], \( e_s \) saturation vapour pressure [kPa], \( e_a \) actual vapour pressure [kPa], \( e_s - e_a \) saturation vapour pressure deficit [kPa], \( D \) slope vapor pressure curve [kPa °C\(^{-1}\)], \( g \) psychrometric constant [kPa °C\(^{-1}\)].

Grometeorological stations measured all environment variables for ET0 determination, which depends on wind direction, solar radiation, air temperature, and relative humidity. The actual crop evapotranspiration (ETc) at the area can be obtained from the following equation after calculating the ETo (mm / day).

\[
ET_c = K_c \times ET_0
\]  

(2)

Where ETc Crop evapotranspiration in mm/day, \( K_c \) = crop coefficient, the average value of crop coefficient (\( K_c \)) varies according to crop life stages.

The relationship between the measured crop evapotranspiration (ETc) with the calculated ETo, is crop coefficient (\( K_c \)). It is the differences in the crop canopy (\( K_p \)) and aerodynamic resistance relative to the hypothetical reference crop are accounted for within the crop coefficient. The \( K_c \) factor serves as an aggregation of the physical and physiological differences between crops and the reference definition [17-18].

\[
K_c = \frac{ET_c}{ET_0}
\]  

(3)

The peak CWR in mm/day can be less than the peak ETo value when less than 100% of the area is planted in the cropping pattern. If the maximum cropped area is 80%, the peak CWR is shown as less than the peak ETo.

4.2. Calculation of Irrigation Water Requirement (NIR)

The net quantity of water required to present at the crop root zone to satisfy the optimal growth of crop through different growing stages which supplied by irrigation and rain falling to avoid crop water stress. It is the difference between the Crop evapotranspiration under standard conditions (ETc) and the Effective Rainfall contributions throughout the same time step. If Irrigation requirement is neglect the soil water contribution to the crop and expressed as \([17-18]\).

\[
NIR = (ET_c - ER)
\]  

(4)

ER = Effective Rainfall (mm)

5. Design of Pressurized Drip Irrigation system

This research uses a pressurized drip system and Optimum working pressure and emitter discharges to ensure that the soil absorption rate remains constant on the soil surface without water. The drip irrigation from Netafim™ Company model ARIES™ TWD 22125, INTEGRAL Dripper was chosen for modeling in this research work. This system offers the chance for on-surface multi seasonal row crops and Permanent sub-surface multi seasonal row crops.

6. Results and Discussions

6.1. Solar Irradiation in The Study Area

Figure 5. shows the radiation of solar distribution for AL-Kahlis city. Over all the years of tracking data the highest amount of solar radiation was measured in July. The estimated average daily solar radiation levels at December month when the sun is at its lowest point in the atmosphere.
The mean of Peak Sun Hours (PSH) for studied area was found to be 7.2 hours/day and 5.2 hours/day for four months (January, February, November, and December) per year from March to October as shown in Figure 6. It's important to analyses the solar pumping system's operating hours efficiency.

Figure 5. Solar radiation over selected area's horizontal surface.

Figure 6. Normal regular Global radiation on the horizontal and inclined surface of Kalis field.
6.2. Results of water requirement

The values of the calculated evapotranspiration (ETo) and the measured values. It seems both values tendencies to be very close in values. The adopted theoretical formula of the Penman-Monteith formula is reflecting the real values of evapotranspiration (ETo). The maximum values of water lost from soil by evaporation and crop transpiration occur simultaneously when the environmental temperature is high through the summer months than the other months throughout the year as in Figure 7. The increased value of ET is indicating more water need for crop requirements at hot months.

![Evapotranspiration Graph](image_url)

**Figure 7.** Measured and calculated of evapotranspiration at Al-Khalis area.

The crop coefficient Kc of Potatoes were varied from 0.5 at initial growing stage and increasing gradually till it reach maximum value 1.14 at middle-season stage. The crop needs maximum quantity of water for growing development and middle-season stages, then decrease at the harvesting or late-season stage. The variation caused due to changing in vegetation area and ground cover by plants of Potatoes. It reflects the crop transpiration and soil evaporation in deferent environmental of crop growing as shown in Figure 8.
7. Modeling of solar Pumping System

The solar pumping system was modeled by using web based Grundfos Product Center tool. The concept includes selection the suitable pump according to:

Where total daily or hourly required water (25 m³/hour), total dynamic head 78 m including the well depth. The hydraulic power that required for pump operation is calculated by the following equation:

\[
P_m (\text{kW}) = \frac{\rho (\text{kg/m}^3) \times g \left(\frac{m}{g} \right) 	imes Q \left(\frac{m^3}{h} \right) \times TDH (m)}{\text{motor–pump efficiency(ηpump–motor)} \times 3.6 \times 10^6}
\]  

Eff.pump = pump efficiency (0.734) from performance curve. Eff.motor = electric motors efficiency (0.8) from performance curve.

\[
P_m (\text{kW}) = \frac{1000 \left(\frac{\text{kg}}{\text{m}^3} \right) \times 9.81 \left(\frac{\text{m}}{\text{g} \cdot \text{s}^2} \right) \times 25 \left(\frac{\text{m}^3}{\text{h}} \right) \times 78 (m)}{0.734 \times 0.8 \times 3.6 \times 10^6} = 9 \text{ kW}
\]

\[
P (\text{kW}) = \frac{9 \text{ kW}}{0.745 \text{ HP/kw}} = 12 \text{ HP}
\]

7.1. Pump selection

The optimum way of choosing the solar pump on the basis of performance curve that depends on manufacturer’s specifications, which relate the pumping head versus the quantity of flow rate on H-Q graph, as in Figure (9) at different speeds of operation. Solar pump model Grunf0z type SP 30-9 with 80 m head and maximum flow rate of 25 m³/h (417 L/min or 6.945 L/s) was chosen. The 3-phase motor power of the selected pump is 9.2 Kw with compounds motor pump efficiency (eta) of 57.3%. The rated voltage is 3*(220-230) V. The rated current: 38.5-39.0 A and power factor: 0.81-0.77.
7.2. Inverter Design and Selection
Grunfoz type RSI Low voltage range 3x220VAC. Maximum MPP Voltage DC 400 V. The solar panels orientation was done towards south facing with no significant shading to achieve full sun exposure.

7.3. PV array Sizing and Selection of PV module
The PV module was selected due to few reasons that are worth to mention, its performance, warranty and high efficiency. Thus, choosing solar modules type SW 290 - 300 MONO from Solar World Company with technical specifications in Table 2.

| Performance Under Standard Test Conditions (Stc) * |
|--------------------------------------------------|
| Maximum power                                   | $P_{\text{max}}$ | 300 Wp  |
| Maximum power point voltage                     | $V_{\text{OC}}$  | 4.0 V   |
| Open circuit voltage                            | $V_{\text{mppt}}$| 32.6 V  |
| Short circuit current                           | $I_{\text{SC}}$  | 9.83 A  |
| Maximum power point current                     | $I_{\text{mppt}}$| 9.31 A  |
| Module efficiency                               | $\eta_{\text{m}}$| 17.89 % |

The number of panels to be wired in series and parallel can be determined by following equation.

Total No. of modules = Pump power (k W) ÷ [Peak power/module× Inverter efficiency] = 9200 k W ÷ (300 V×0.98) = 30 modules

Maximum modules per series string = $V_{\text{mppt}}$, max, inv.÷$V_{\text{OC}}$/module = 400 V ÷ 40 V/module = 10 modules
No. parallel strings = Total No. of modules/ Maximum modules per series string = 30/10 = 3 string
Maximum current array = No. parallel strings × Impp/module = 9.31A × 3 = 27.93A

7. 4. Sizing results of solar pumping system

- Total water production per year: 73800 m³, average water production per day: 202.1 m³/day
  And the average water production per watt per day: 9.4 Liter/Wp/day.
- Solar module configuration:
  Number of solar modules in series: 10, in parallel: 3, Solar array rated power: 9 kW
  Solar array rated volts: 326 V
  Tilt angle: 33 deg.
- Cables and pipes:
  Pump cable length: 33 m, Pump cable size: 4 mm², Total cable loss: 1.6 %, Pipe Length: 30 m
  Pipe diameter: 103.38 mm, Friction loss: 0.6 m

Figure 10 indicates the monthly efficiency of pumping water from the well to the drip irrigation system for watering the potato field. Maximum water supply at June is 226 m³/day and at December is a minimum of 163.8 m³/day. Maximum daily water supply occurs in June where the highest water demand is in the summer season in the driest months.

The additional areas that could be irrigated in days that no need for irrigation of planted area with Potatoes crop as calculated and shown in the Figure (11). Since the water required for irrigation is not constant as one value due throughout plant growing stages, due to variation of evaporation from soil and transpiration from potato plants, a variation in irrigation intervals (days) and the consumed time of each application in hour/day. For this remembered reason, the additional areas that can be irrigated simultaneously in same period of potato planting are varies from minimum 4.3 hectares at September month to maximum area of 6 hectares at January month. This is an attractive encouragement point for adopting solar PV pumping system with using drip irrigation technology.
The adopted drip irrigation system design with solar pumping showed that the supplied water will be adequate for required water that need for plants consuming in the root zones in all growing stages as shown in the Figure 12.

![Supplied water/plant vs Consumed Water/Plant graph](image)

**Figure 12.** Plant stages

### 8. Conclusions

1. The planting time of any crop is affected by the variation of soil moisture continent at root zone throughout different growing stages of plants. The crop water requirement, soil texture and soil moisture content must be taken as crucial parameters in the design of irrigation system.

2. The solar pumping sizing based on H-Q performance curve which insure the system operation at maximum flow rate of 25 m$^3$/h at pump capacity of 9.2 Kw with compounds motor pump efficiency (eta) of 57.3%. The rated voltage is 3*(220-230) Volt of proposed water pumping system.

3. The suggested irrigation system of one hectare of potatoes crop would be able to provide water to irrigate additional areas varies from minimum 4.3 hectares at September month to maximum area of 6 hectares at January month.

4. This procedure is an attractive encouragement point for adopting solar PV pumping system with using drip irrigation technology.

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