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Design of DC Solar Water Pump for Farmers in the Kurdistan Region of Iraq

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Abstract. This study will focus on the Kurdistan region of Iraq. Irrigation is an essential of agriculture, and the process of irrigation takes place by transfer of water from water source to farm. However, energy is the main aspect to consider when carrying out the irrigation process. Due to shortages of electricity and the high cost of diesel, there are difficulties in meeting the demands of irrigation. In this study, solar energy is considered as one way to design a solar water pump that can be used on farms in the Kurdistan region of Iraq. Photovoltaic solar panels have been assessed as a way to provide a successful solar water pump system with a minimum cost. The weather conditions for Duhok city in Kurdistan have been analysed to assess the solar water pump system for local use. The outcome of this study revealed that the solar water pump is applicable and can provide many benefits for the use of clean and renewable energy to transfer water from a water source to farms in the Kurdistan region of Iraq. A proposed design system with cost analysis is provided as an outcome of this study.

Keywords: solar energy, solar water pump, photovoltaic, dc water pump.

INTRODUCTION

Solar energy has been used widely in the world as an alternative source of clean energy to operate various applications. These applications can be used in both domestic and commercial sectors. Basically, any system that is required to provide a service and meet the user's needs is considered in terms of its performance, energy consumption and effect on the environment [7, 8]. The water solar pump system is one of the commercial systems that can be used to transfer water from the water source to another spot [9, 10].

Irrigation is necessary for growing different types of vegetables and fruits and [11, 12]. However, in some areas irrigation is not easy to access because of the shortage of electricity and the high cost of diesel, affecting both the economy and agriculture in the Kurdistan region of Iraq. Many studies have attempted to modify and improve disparate applications in different sectors such as Mahmood, Buttsworth [13], Musa, Mahmood [14], Abdulkareem, Musa [15], Mahmood, Buttsworth [13], Mahmood [16], Mahmood [17], Mahmood [16] but, the solar water pump system still needs much improvement before it can be considered for local cities in Iraq.

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There is a wide range of water pumps that can be used for irrigation, for example the Low Lift Pump (LLP), Shallow Tube Well (STW), and Deep Tube Well (DTW) [18, 19]. However, these types of water pumps use either diesel or electricity which are not available in some areas. However, solar energy can be transferred to Direct Current (DC) using the Photovoltaic Solar Panel (PV) [20]. The photovoltaic solar panel has a crucial role to serve off grid and to protect the environment [21]. In addition, the photovoltaic solar panel has low cost of maintenance, operation and labour compared with a diesel electricity generator. The solar water pump system is an alternative system that can be used in remote villages and other areas in Iraq where electricity is not available.
Although there have been many studies focusing on solar systems and photovoltaic solar panels, there is insufficient information about the design of solar water pump system that can be used in Iraq. This study also provides a database for the new technology and innovation for the future research and investigation. Cost analysis based on local market availability is also considered and presented in this study.

TECHNOLOGY OF THE SOLAR WATER PUMP

The solar water system using a photovoltaic solar panel is used in communities where the grid power is not available including rural and remote villages. In developing countries, the technology of solar water pumps is providing many benefits that serve the local community. Some of these benefits are: improvement of people’s quality life, reduction of energy consumption, use of clean and safe energy sources, and finally, the provision of remote energy sources. The technology works based on semiconductor technology that has ability to convert sunlight and /or solar incident array into electricity [22-24]. The proposed design for DC solar water pump system consists of a photovoltaic solar panel, pump, battery, and controller. It is not a complex system and is easy to build. Figure 1 shows a schematic diagram of the proposed DC solar water pump system.

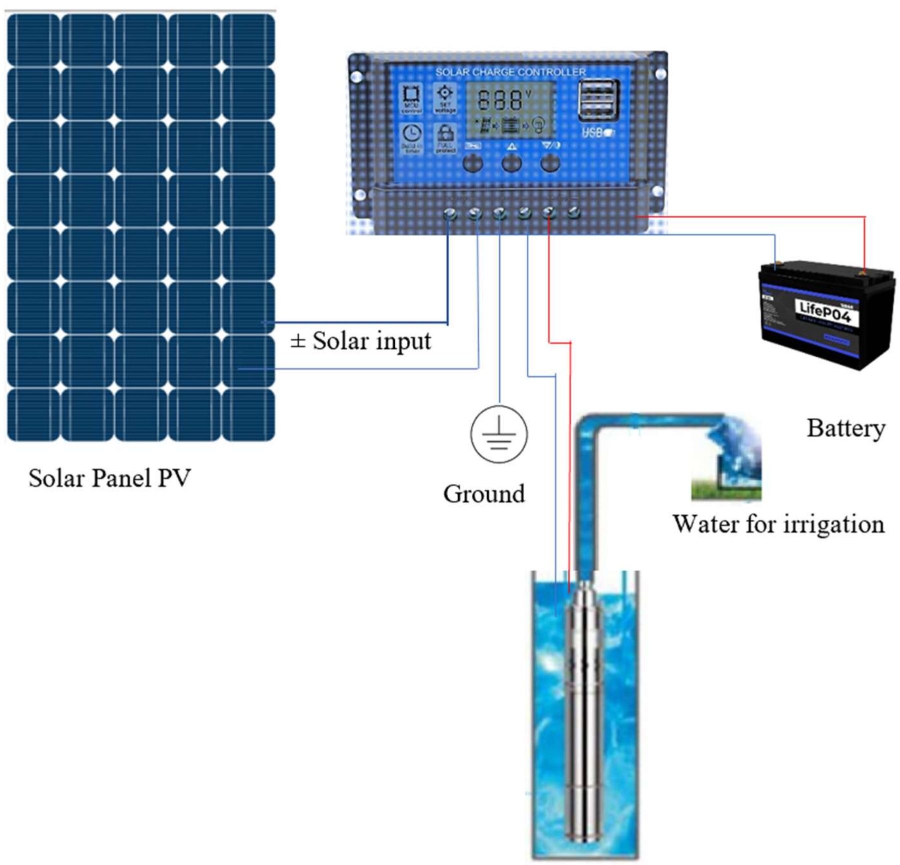

FIGURE 1. Schematic diagram of solar pump system.

Components of Solar Water Pump

The proposed design of the DC solar water pump is focused on reliable service and less cost. A direct current (DC) motor can be used to run the pump easily. It does not require the installation of an invertor to change the current phase from the direct current (DC) into alternating current (AC). A 750-watt DC motor is a proposed motor for the solar water pump which can be operated using 12V.

Photovoltaic array (PV)

It is the essential component that converts the solar energy to electricity. There are three types of PV namely: Amorphous, Polycrystalline, and Monocrystalline Silicon [25-27]. The available efficiency for those types of PV is 7%, 15% and 17%, respectively [21, 28, 29].

Water pump

There are three main types of water pump that can be used for irrigation purposes. These types can be classified based on their application into submersible pump, surface pump and floating pump [30-32]. The submersible pump is a proposed pump that can be used to meet the irrigation needs in the Kurdistan Region of Iraq.

Motor for pump

A wide range of motor types is available in AC and DC in the market plus the permanent magnet, synchronous and asynchronous[33-35]. For this study, DC motor is selected as it does not need the invertor to operate, and it also reduces the cost of the system.

Controller

The controller is a device that delivers power from PV to load and battery [36, 37]. It comes in two categories: pulse-width modulation (PWM) and maximum power point tracking (MPPT) [38-40]. The PWM has a lower cost compared with MPPT because of the difference in design and technology. The PWM reduces the current gradually to regulate the flow of electricity to the battery and is therefore the best option for small applications. While, the MPPT has multiple functions such as controlling, monitoring and adjusting the input to regulate the current solar system [41]. To achieve a better and more successful design, MPPT is suggested for use in the current proposed design.
A special design for the solar water pump for farmers is performed after intensive investigation the ability to operate and install the system in the Kurdistan region of Iraq. The proposed design system consists of five main components, as shown in Table 1. Table 1 lists the components and description of the solar water pump.

TABLE1. Specification and characteristic of the solar water pump.

NO.	Components	Description	Size
1	Solar panel	Convert solar to electricity	$P = 750\ W$ $N = 5\ panels$ $A = 1.65\ m^2$
2	Motor pump	Pump water from source to farm for irrigation.	DC 750 W 56 litter / min
3	Controller	control, monitor and adjust the input to regulate the current of solar system	MPPT
4	Battery storage	Storage for energy.	12000 Wh Time : 4 hours $V.B = 12\ volt\ \ 100/120\ \ Ah$
5	Tank	Storage for water.	$V = 10.6\ m^3$ liter $= 10600$ L

Performance Analysis

Duhok city is the northern capital city of the Kurdistan Region of Iraq. Its latitude and longitude are 36.867 ºN and 42.948 ºE, respectively. The elevation of Duhok is 509 m above the sea level [42]. Weather data including sunrise time to sunset time have been considered to estimate daytime length for Duhok city. According to the outcome of the research study provided by Yousif [43], Sparavigna [44] and Müller-Stach, Weinzierl [45], daytime length is estimated for this study to identify the longer day time during 2021 as following,
Hour angle is estimated as following,

$$\omega = \frac{360^o}{2\pi} \arccos\ (-\tan\varphi\,.\tan\delta) - 90^o \quad (1)$$

$$\delta = \arcsin(0.4\,.\sin(\frac{2\pi n}{365})) \quad (2)$$

Where the n is number of days. Then sunrise can be estimated as following,

$$z = 90^o - \frac{360^o}{2\pi} \arccos(\frac{\sin\delta}{\cos\varphi}) \quad (3)$$

Figure 2 presents the sunrise and sunset for Dohuk city in year 2021. The longer daytime is identified in range starting in May and ending in beginning of August.

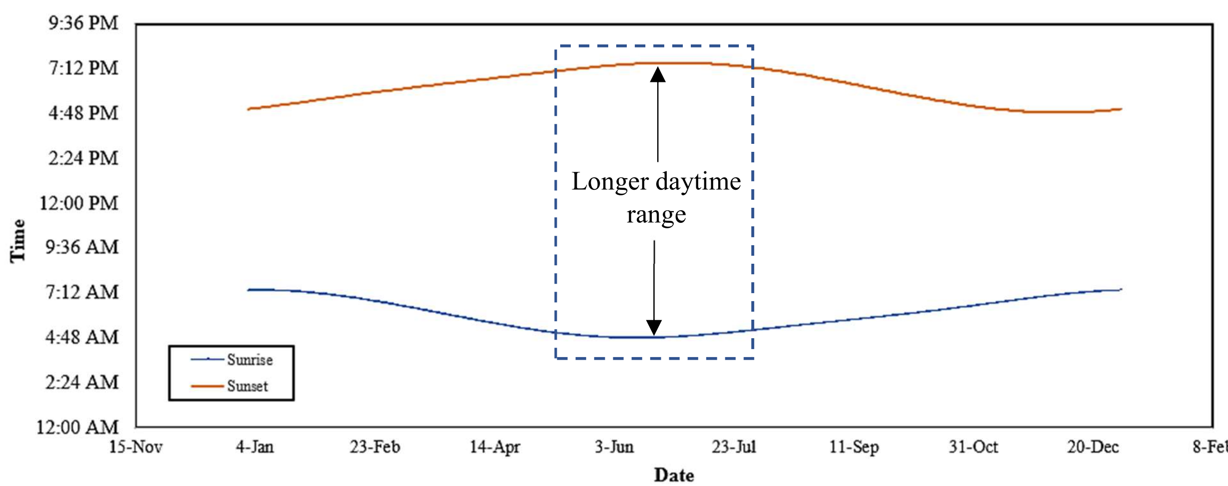

FIGURE 2. Sunset and sunrise during 2021 for Dohuk city.

Sollumis [4] provides virtual useful information about the direction of sunset, noon and sunrise for any provided location. The website can be accessed through the site https://www.sollumis.com/index2021.html, on Google Map. The electrical output is a function of the efficiency and area, the electric output can be estimated by following equation [46].

$$E_{out} = \tau_{PV}\ A\ I_{array} \quad (4)$$

Where τ_{PV} is the efficiency of the photovoltaic and it is a function of temperature and radiation incidents. The electrical efficiency is affected by temperature. Many studies have investigated the effect of temperature on electrical efficiency, which can be estimated as follows [47].

$$\tau_{PV} = \tau_{PR}[1 - \beta_R(T_C - T_R) + \gamma log_{10} I_{PV}] \quad (5)$$

Where τ_{PV} is the efficiency of photovoltaic panel at cell temperature T_R = 25 ºC, β_R is the temperature coefficient, usually in the range from 0.004 /ºC to 0.005/ºC [46]. T_C is the cell temperature, T_R is the reference temperature. The average hourly irradiation incident of the photovoltaic solar panel is I_{PV}. Then the radiation intensity coefficient is defined by . The value of the radiation intensity coefficient can be assumed to be zero [48, 49]. That assumption reduces Equation 5 to,

$$\tau_{PV} = \tau_{PR}[1 - \beta_R(T_C - T_R)] \quad (6)$$

Then by adding and subtracting the ambient temperature to the temperature term, the electrical efficiency for the photovoltaic panel can be estimated as follows [46].

$$\tau_{PV} = \tau_{TR}\left[1 - 0.9\,\beta\left[\frac{I_{PV}}{I_{PV,NT}}\right](T_{C,NT} - T_{A,NT}) - \beta(TA - TC)\right] \quad (7)$$

Average incident solar radiation, minimum and maximum temperature during the 2021 year for Duhok city have been obtained from the Word weather (https://www.worldweatheronline.com/duhok-weather/dahuk/iq.aspx). Figure 3 presents the average solar radiation for twelve months for 2021. The maximum solar radiation was obtained in July. However, from January to December the solar radiation variation started from 1.8 kW .h /m^2. day and then increased to reach the maximum value of 6.5 kW. h /m^2.day in July and going down to 1.7 kW. h / m^2. day in December. While the average high temperature 42 ºC and average low temperature 3 ºC were recorded in January and July during the year 2021, respectively. Figure 7 presents the temperature contour of the high and low temperature variation during the year 2021 [50].

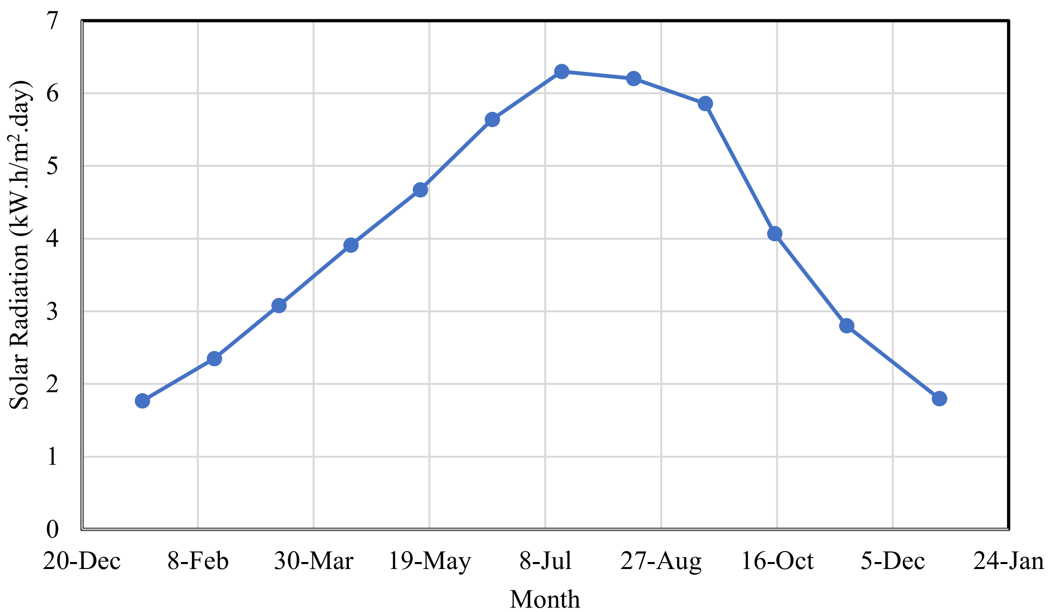

FIGURE 3. Average solar radiation for Duhok city during year 2021.

Climate data for Duhok, Iraq [hide]													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	20 (68)	27 (81)	30 (86)	34 (93)	38 (100)	41 (106)	45 (113)	46 (115)	44 (111)	39 (102)	31 (88)	24 (75)	46 (115)
Average high °C (°F)	11 (52)	14 (57)	19 (66)	24 (75)	32 (90)	38 (100)	42 (108)	41 (106)	37 (99)	29 (84)	20 (68)	13 (55)	27 (80)
Daily mean °C (°F)	7 (45)	10 (50)	14 (57)	18 (64)	25 (77)	31 (88)	34 (93)	34 (93)	29 (84)	22 (72)	14 (57)	9 (48)	21 (69)
Average low °C (°F)	3 (37)	5 (41)	9 (48)	13 (55)	18 (64)	23 (73)	27 (81)	26 (79)	21 (70)	15 (59)	8 (46)	6 (43)	15 (58)
Record low °C (°F)	−4 (25)	−6 (21)	−1 (30)	3 (37)	6 (43)	10 (50)	13 (55)	17 (63)	11 (52)	4 (39)	−2 (28)	−2 (28)	−6 (21)
Average rainfall mm (inches)	101 (4.0)	120 (4.7)	111 (4.4)	70 (2.8)	38 (1.5)	0 (0)	0 (0)	0 (0)	1 (0.0)	10 (0.4)	57 (2.2)	108 (4.3)	616 (24.3)
Average precipitation days	9	9	10	9	4	1	0	0	1	3	6	10	62
Average snowy days	1	0	—	0	0	0	0	0	0	0	0	—	—
Average relative humidity (%)	60	53	46	39	23	15	13	15	17	28	42	62	34

FIGURE 4. Maximum and minimum temperature during year 2021.

Basically, the input power of the PV array can be estimated as follows [51],

$$P_{array} = I_{array} A \quad (8)$$

Where I_{array} is the solar radiation (W/m^2), A is the effective area of the PV (m^2).
Then as the pump needs power to be operated the output power of the PV can be estimated as follows,

$$P_{array,out} = V I \quad (9)$$

Where V is the DC operating voltage (V), I is the DC operating current (A).

The hydraulic power for the pump (P_{hyd}) is the required power to operate the pump and lift a certain volume of water through a required head, which can be calculated as follows,

$$P_{hyd} = d . g . Q . H \quad (10)$$

Where the d is density of water (kg/m^3), g is the gravity (m/s^2), Q is the discharge of water (m^3/s) and finally H is the head (m).
The overall system efficiency (E_{all}) indicates to the overall system performance to convert the solar energy into water delivery. This parameter can be estimated as follows,

$$E_{all} = (P_{hyd} / P_{array}) 100\% \quad (11)$$

Figure 5 presents the variation of the efficiency of the solar photovoltaic panel with the solar radiation, and it indicates that there is a direct relationship between the efficiency and solar radiation, confirming the possibility of using the photovoltaic with a satisfactory performance.

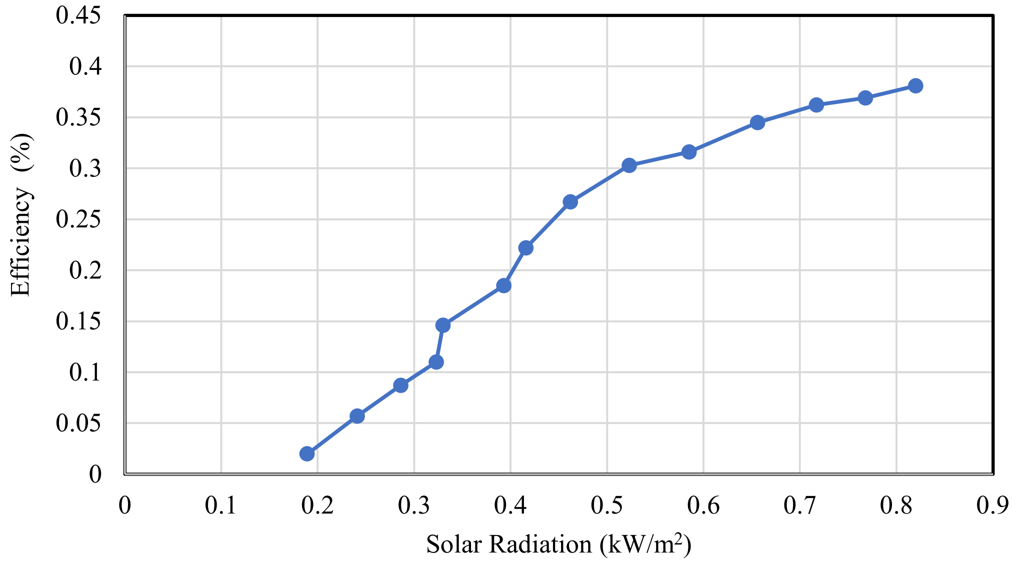

FIGURE 5. Efficiency variation with the solar radiation.

A variation of the discharge for the DC solar water pump is considered as there is a varation in solar radiation. Figure 6 presents the direct relationship between the discharge and solar radiation, confirming that the discharge of the DC solar water pump increases when the solar radiation is increased. So, based on the weather data of Duhok, the DC solar water pump will be operated safely and effecintly.

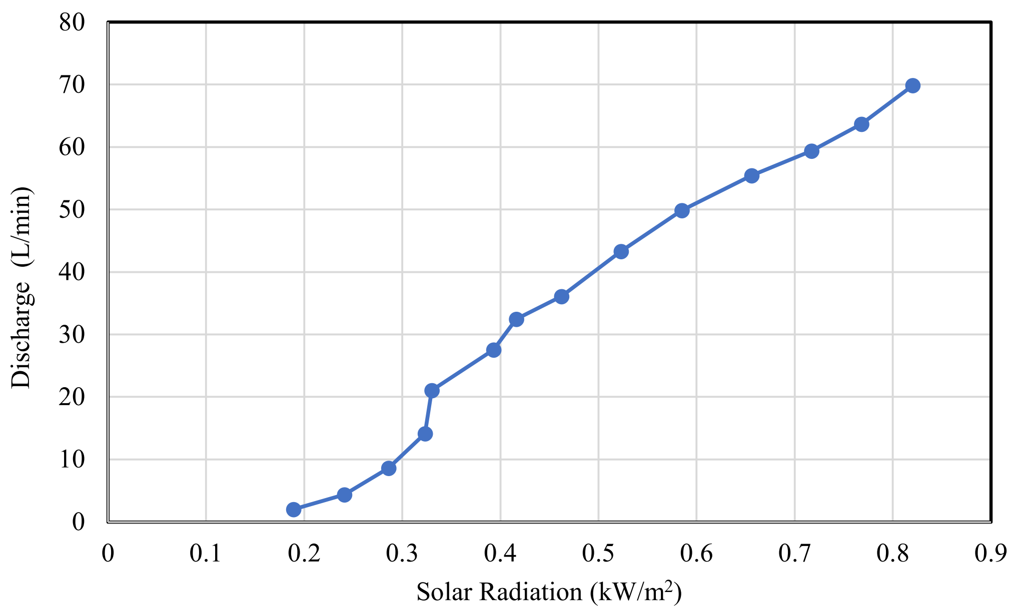

FIGURE 6. Discharge variation with the solar radiation.

Cost Analysis

A solar water pump using Monocrystalline Silicon, DC motor, MPPT, and battery is proposed and assessed. Locally it is the best option to reduce using diesel and electricity in irrigation and it is an efficient way to be applied in countryside. The cost of the main components to build the solar water pump system is less than cost of diesel as there are no repair and maintenance costs. The DC solar water pump is flexible to use wherever it is required and is easy to install. In addition, it has lower costs compared with other solar systems as it does not need an invertor to run the motor on AC mode. Based on local markets and availability, Table 2 shows the individual and total cost of the solar water pump system.

TABLE 2. Cost of the solar water pump system.

NO.	Components	type	Cost / unit	Total
1	Solar panel	Monocrystalline Silicon	$ 0.24 per watt	$ 180
2	Motor pump	DC motor pump	$ 0.068 per KW	$ 51
3	Controller	MPPT	$ 50	$ 50
4	Battery	12000 Wh	$ 30	$ 30
5	Tank	1000 L	$ 30	$ 30
		Overall cost		$ 341

CONCLUSION

The DC solar water pump system provides the most efficient way for farmers in the Kurdistan region of Iraq to irrigate their crops. This study demonstrates that the new technology of using DC motor in the solar water pump system for irrigation purposes in the Kurdistan region of Iraq is suitable. The system components have been defined so as to build an efficient solar water pump system. The weather data, including sunrise and sunset of local area is sufficient to operate the solar water pump system at maximum efficiency. Solar radiation has a significant effect on the discharge and efficiency of the solar water pump. The discharge of the DC solar water pump increases when the solar radiation is increased. The advantages of the solar water system are the reduction of the dependence on diesel and electricity, together with low maintenance and repair costs. It will have a lower cost compared with other solar systems as it does not need an invertor to run the motor on the AC mode. The DC solar water pump is flexible to use wherever is required and easy to install. Cost analysis has been completed based on local markets and availability. Consequently, the overall cost of the dc solar water pump system is around $341 which is a low cost compared with other systems.

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