Journal of Engineering and Sustainable Development

Vol. 22, No.06, November 2018
ISSN 2520-0917
https://doi.org/10.31272/jeasd.2018.6.12

DESIGN AND IMPLEMENTATION OF PHOTOVOLTAIC-WATER PUMPING SYSTEM FOR USE IN IRAQ

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Abstract: In this research a well water pumping system utilizing solar cells generated electric power is designed and implemented. We assumed a village located in a remote area of southern Baghdad for providing a quantity of water of 30000lit/day (30m^3/day) to meet the daily needs of the quench and irrigation. Calculations show that the amount of water required can be obtained from a well of water head (15m) by using an array of solar cells that gives a power of (1300W) to submersible pumps capable of raising water by converting electrical energy to a dynamic power. The cost of the pumping system using solar energy is more economical and less expensive than using diesel pumping system. It is recommended to use the present solar energy pumping system in Iraq as it is one of the richest countries with solar power; however, suffers nowadays a scarcity of surface water.

Key words: *Water Pumping, Solar Energy, Solar Cell, Flow, Water Head, Water Well.*

تصميم وتنفيذ نظام ضخ المياه باستخدام الطاقة الشمسية وامكانية أستخدامه في العراق

الخلاصة : تم في هذا البحث تصميم وتنفيذ نظام ضخ مياه الآبار باستخدام الخلايا الشمسية المولدة للطاقة الكهربائية .افترضنا قرية تقع في منطقة نائية في جنوب بغداد لتوفير كمية من المياه تقدر ب (30000lit/day) لتلبية الاحتياجات اليومية للشرب والري .بينت الحسابات التصميمية، أن كمية المياه المطلوبة يمكن الحصول عليها من بئر عمق المياه فيه (15m) باستخدام مصفوفة من الالواح الشمسية تعطي قدرة (1300W) لمضخة غاطسة قادرة على رفع المياه عن طريق تحويل الطاقة الكهربائية إلى طاقة ديناميكية .ان تكلفة نظام الضخ باستخدام الطاقة الشمسية هو أكثر اقتصادا وأقل تكلفة من استخدام نظام ضخ الديزل،لذا فمن المستحسن استخدام نظام الضخ بالطاقة الشمسية في العراق لانه يعتبر أحد أكبر البلدان للتعرض الشمسي، ومع ذلك،فهو يعاني في الوقت الحاضر من ندرة المياه السطحية.

1. Introduction

There is no doubt that the water is very important for all kinds of life; otherwise there is no plant, animal and human life. The decline in water levels is caused by the scarcity of water from Turkey, Iran and Syria to Iraq as these countries set to build dams on Tigris and Euphrates rivers that led to the decline in the amount of water stored in Iraq [1]. Iraq suffers acute water balance because of low water level flowing in the rivers Tigris and Euphrates and their tributaries into Iraqi territory to a great extent, and the phenomenon of drought due to the lack of rain .Therefore, it is needed to find an appropriate solutions and treatments by the exploitation of natural resources

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such as underground water, however, by digging wells and pump lifting water by using different energy sources. This needs water pumping system that can be employed in remote areas. The dependence on solar energy as a source of electrical energy is the best solution. The amount of energy that reaches the earth from the sun is estimated to approximately (1000W/m²). Iraq is one of the richest regions in the world of receiving solar energy; the average solar energy that the earth receives is (5) kilowatts hour per square meter a day [2].

The use of solar energy technology to pump water for irrigation is not new. Solar water pumping has attracted the attention of scientists and engineers since the beginning of the last century. Scientists used a method of converting solar energy into electrical energy to pump irrigation water and published many works on studying the technical and economical factors and climate under different operating conditions in different areas [3-10] . Most researchers concluded the possibility of using solar energy to pump water for irrigation using small size pumping devices that fit small spaces ranging between (2.5 – 5) acres that will be economical in operation. To compete the diesel pumping units the following points are recommended:

- Solar cells power irrigation systems must be used throughout the year.
- Irrigation systems are preferably used to irrigate crops, vegetables and fruits.
- A capacity that is not exceeding (4 kWp) and the size of the farm (2.5 - 5) acres is preferable.
- Preferably using a drip irrigation system because it needs few amounts of water at low pressure.

Now a day, the PV module costs are reduced all over the world. However, the capital cost of a solar photovoltaic water pumping system is still higher than the conventional diesel engines water pumping system. The capital cost of PV water pumping system can be considered as the major barrier for the application of the system in a developing country like Iraq. Therefore, optimization efforts are mainly focused on minimizing the capital cost of the system.

In this paper, PVsyst software is used for design and simulation of solar photovoltaic water pumping system. The solar data, well characteristics, water demand and storage tank size are input to PVsyst.

2. Theoretical Calculations of the System

For the purpose of system design calculation, the first factor to know is the water required per day. Then the size of the pump and the amount of energy required from the cells of solar modules and the characteristics of the water source have to be determined. To complete the design requirements, we calculate the value of total dynamic head (TDH), which determines the minimum point in the well for static water level to the highest point that water reaches. Figure 1 shows a schematic diagram of a photovoltaic - submerged centrifugal pump system.

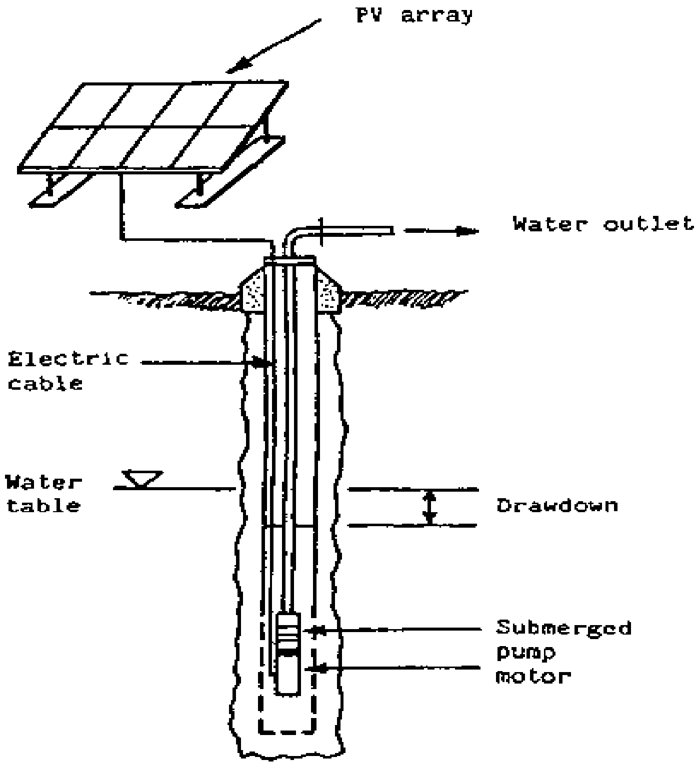

Fig.1 A schematic diagram for photovoltaic- submersible centrifugal pump system.

Suppose that the daily average amount of water needed for a village assumed at the south of Baghdad, homes about (100) people and have a cattle of about (50) Cows and covers an area of agricultural land of (5) acres, is about (30000) liters per a day (30 m^3/day). The rate of exposure of the solar day is approximately (5) Sun hr, then the flow rate will be about (6000) L/h [11].

Assume that, water static level = 15 m, drawdown level = 3 m, static discharge level= 2m, allowance for friction =10% *20 = 2 m,
Then: the total dynamic head (TDH) equals (22) m. The required hydraulic and array energies can be determined using equations (1) and (2) [11]:

$$\text{Hydraulic energy}\left(\frac{\text{Wh}}{\text{day}}\right) = \frac{\text{Water required} \times (\text{TDH})}{\text{Coversion factor}} \quad (1)$$

Where the Conversion factor = 367

$$\text{Array energy} = \frac{\text{Hydraulic energy}}{\text{Pump system efficiency}} \quad (2)$$

The load is determined by using equation (3):

$$\text{Load}\left(\frac{\text{Ah}}{\text{day}}\right) = \frac{\text{Array energy}}{\text{Nominal voltage}} \quad (3)$$

Results of the pre- calculations from above equations show that the pump should have the following specifications: Static head of (15m), flow (6000 L / h), solar panels array voltage (180 Vdc), current drawn (7.2 A), and the required power output of solar panels (1300 W).

3. System Design and Simulation

In this research, PVsyst 4.3 [12] software has been used to simulate the solar photovoltaic water pumping system. During the design and simulation process of PV pumping system, it is assumed that the solar panels are not shaded with free horizon and the simulations are performed based on the maximum possible annual water demand. The pump and solar panels are selected from the PVsyst software database to meet the maximum possible annual demands. The main design and simulation input parameters are listed in the Table 1.

Table 1. Simulation input parameters.

Parameters	Simulation input values
Water requirement per day	30.00 m³/day, one day autonomy.
Total dynamic head	22 m
Water storage tank volume	$30 m^3$
Pump depth	26 m
Borehole diameter	15 cm
Pipe length	30 m
Array tilt angle	35º
Azimuth	0º
Solar panels type	Model: JWP205, si-poly, Manuf. JuraWatt.205W.
Pump type	Model: SQF5A-6-MPPT, 900W, 30-300V, Manuf. Grunfos.
Power conditioning	(MPPT) controller

The inputs of this software are monthly average solar irradiation, average daily water demand, well depth characteristics, selection of PV modules and pump. The simulation process on PVsyst software operates on hourly values. The main simulation results for the site are shown in Table 2.

Table 2. Simulation results for the system.

Parameters	Simulation results
PV size	205 Wp, 7 modules in series and 1 in parallel.
Total area	$11.6 m^2$.
Pump power	900 W, 30-300V DC.
Water pumped annually	$10215.3 m^3$.
Energy at pump	1489kWh.
System efficiency	68.1% (system efficiency or performance ratio).
Pump efficiency	43.8%.
Water pumped	Average $28.37 m^3$/day and minimum $24.2 m^3$/day in January.
Missing water	7.0%
Maximum loss of load within the year	21.82% in January

According to the simulation result shown in Table 2, the selected PV size and pump power is able to provide 93.2% of water need for the village site. From November up to February there is a reduction of water supply, during the month of January there is a significant water supply reduction 21.82% due to the lack of solar energy falling on the solar panels, but in August there is 1.5% water supply reduction.

Figure 2 shows the energy balance of the proposed solar Photovoltaic water pumping system, as can be observed from the figure, the unused energy is low, and the system and collection losses are seems lower. This is because, the system is designed based on the maximum possible water production volume within the year.

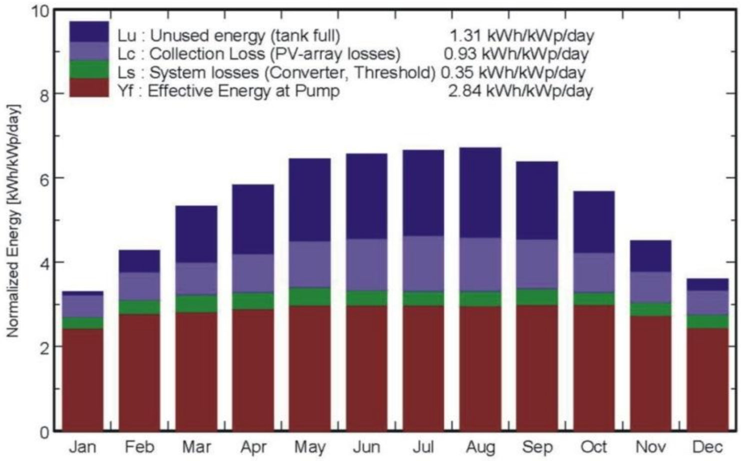

Fig. 2 Energy balance of the SPV water pumping system.

Figure 3 shows the linear relationship between the flow rate and available energy at the pump. In addition, this figure indicates that how the size of pump depend on available power. If the available power at the pump varies the size of the pump or the flow rates also vary. Therefore, maximum power point tracking (MPPT) controller with perturbed and observe algorithm play a great role for adjusting the size of the pump according to the available power at the pump.

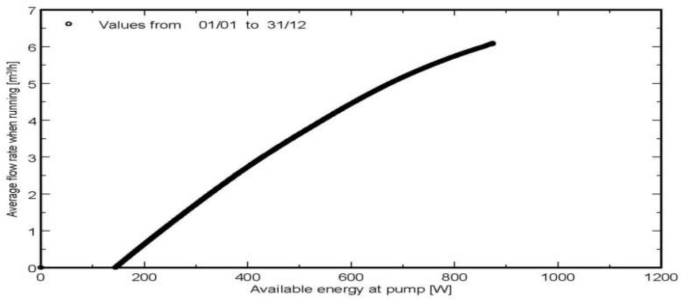

Fig. 3 Simulated Flow – Power characteristic graph of the pump.

4. The Practical Side

To achieve an array of solar panels to generate (180V) voltage , (7.2A) current and the overall power of the solar array around (1300W) , solar panels manufactured by

JuraWatt company type (JWP.205W, si-poly) are selected [13]. These produce at standard conditions (7.49A) current, (27.4V) voltage and the max. power is (205W).Seven panels are connected in series to obtain the required voltage, current and power. A platform to install the panels is used that has the ability to change manually the angle of inclination from the horizon to face the sun and with two sites, in summer at an angle (35 ˚) and in winter at an angle (45 ˚). The curves of solar exposure in Baghdad (Fig.4) show that the severity of radiation is up to (6.55 Sun) in June [2].

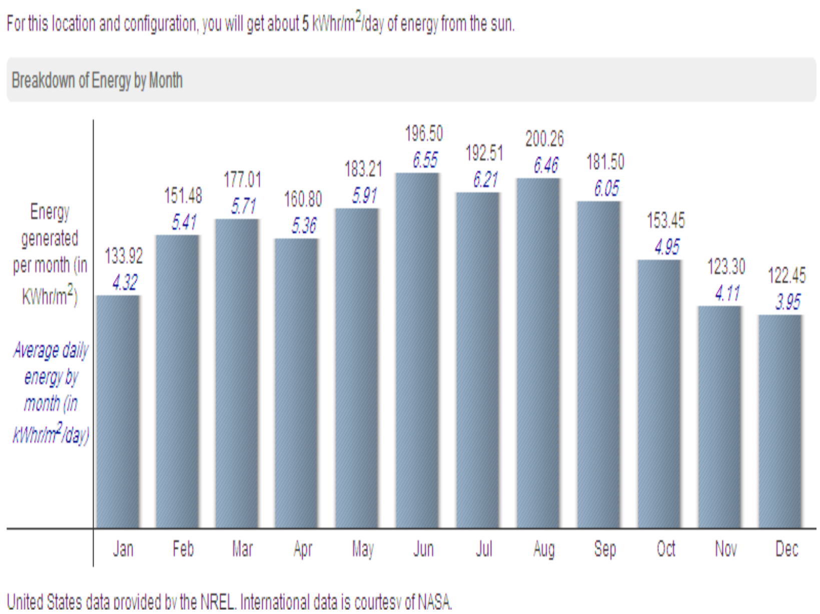

Fig. 4 Solar exposure for Baghdad city throughout the year [2].

The general specifications of the solar array are illustrated in Fig.5, which shows the curves of current –voltage at multiple solar exposures (G) which are extracted from equation (4) for the photovoltaic array based on the electrical equivalent circuit for solar cell shown in Fig.6 [14]:

$$Va = Vt \times \ln\left(\left(G \times Is - \frac{Ia}{Io}\right) + 1\right) - Rs \times Ia$$

$$Va = 11.564 \times \ln\left(\left(G \times 8.1 - \frac{Ia}{8.1\times10^{-9}}\right) + 1\right) - 2.394 \times Ia \qquad (4)$$

Where, Va : array voltage , Vt : thermal voltage ,G : solar insolation ratio, Is : array short circuit current, Ia : array current, Io : reverse saturation current and Rs is series resistor.

The water well is designed and implemented at a diameter of (6) inches and at a depth of about (30m).Submersible pump (Grundfos-SQF5A-6) [15] working in the centrifugal principle with the built-in microprocessor MPPT (maximum power point tracking) controller is chosen to extract water from the well which has the specifications that it can receive DC voltage between (30V -300V), operates at power (900W), head

(10-30 m) and of flow rate of (7.4 – 4.4 m^3/h). Figure 7 shows the electrical layout of the pump.

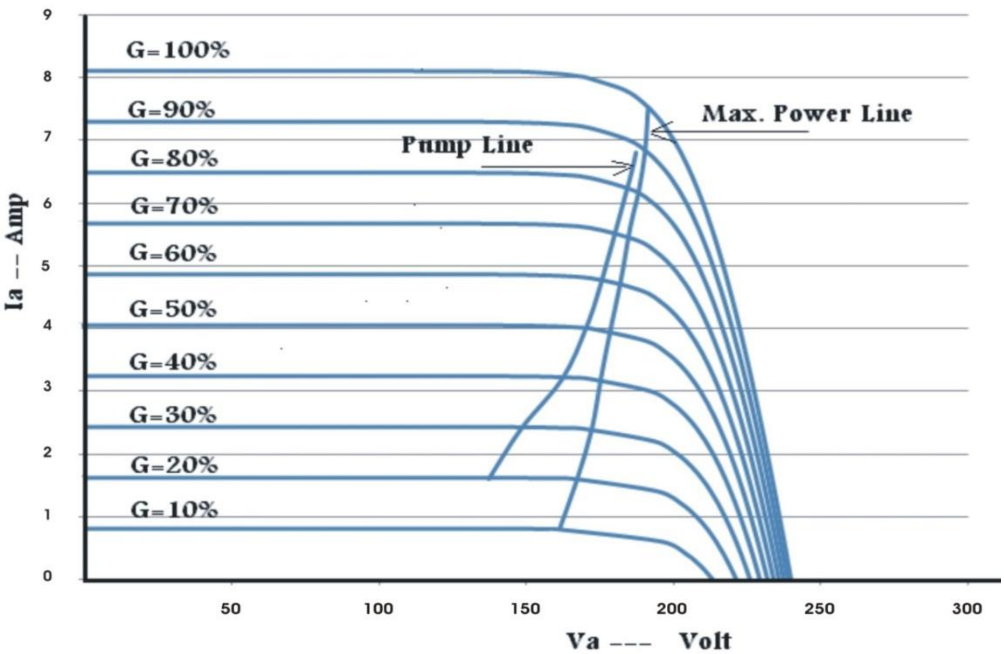

Fig. 5 The compatibility of the measurable pump load line with the simulated maximum power line of solar array. Va: Solar array voltage, Ia: Solar array current, G: Solar insolasion ratio.

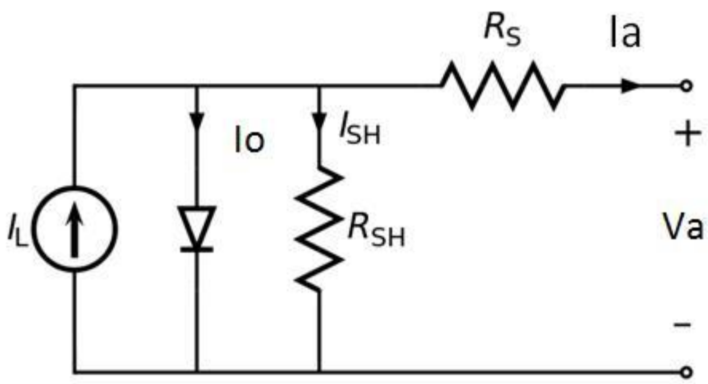

Fig. 6 Equivalent electrical circuit of solar cell.

After the completion of installation the system has been run in a suitable atmosphere where the sky was clear. A tank with a capacity of ($1m^3$) is used and filled with water, a digital stopwatch is used to record the value of flow rate of lift (15m) .The voltage and current of the pump are measured, and the results are shown in Fig.8, this demonstrates the characteristics of the flow with the power derived from the solar array.

The practical results show a good matching of the measurable pump load line with the simulated maximum power line of the solar array that means good performance ratio (68.1%) for a coupling between the solar cells array and the centrifugal pump system, as shown above in Fig. 5.Also the measurable Flow – Power characteristic curve of the submersible pump as shown in Fig.8 has a clear matching with the specifications and shape of the simulated relation shown in Fig.3.

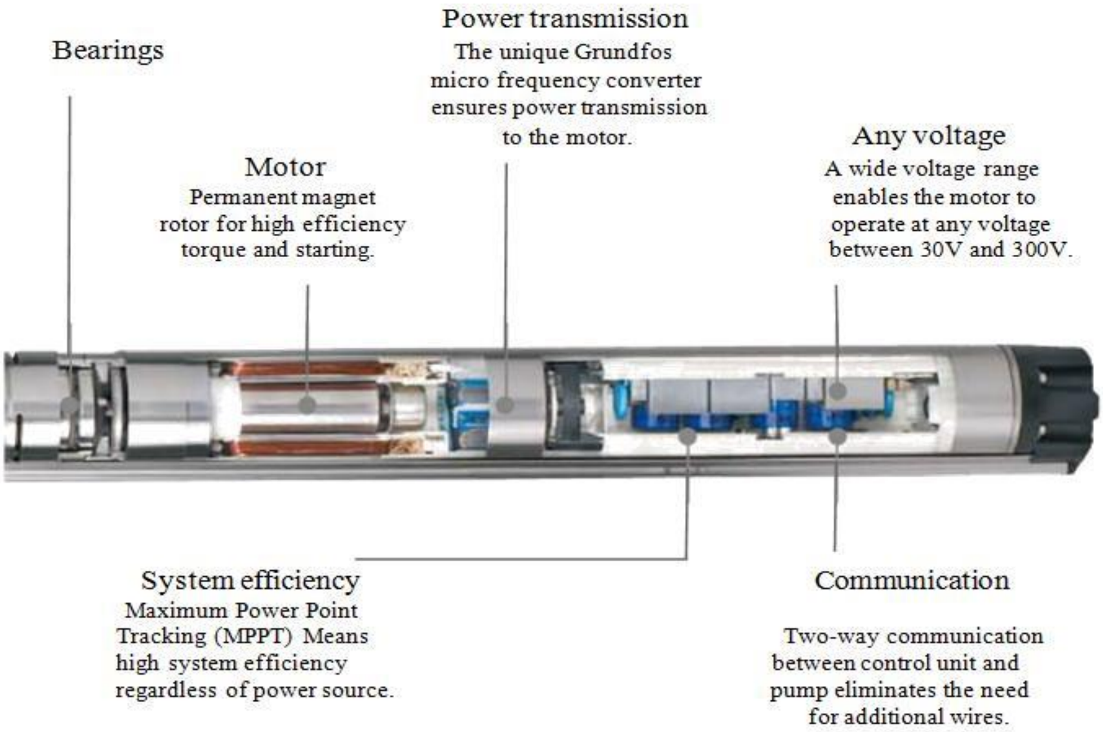

Fig. 7 The electrical layout of Grundfos-SQF5A-6 pump [15].

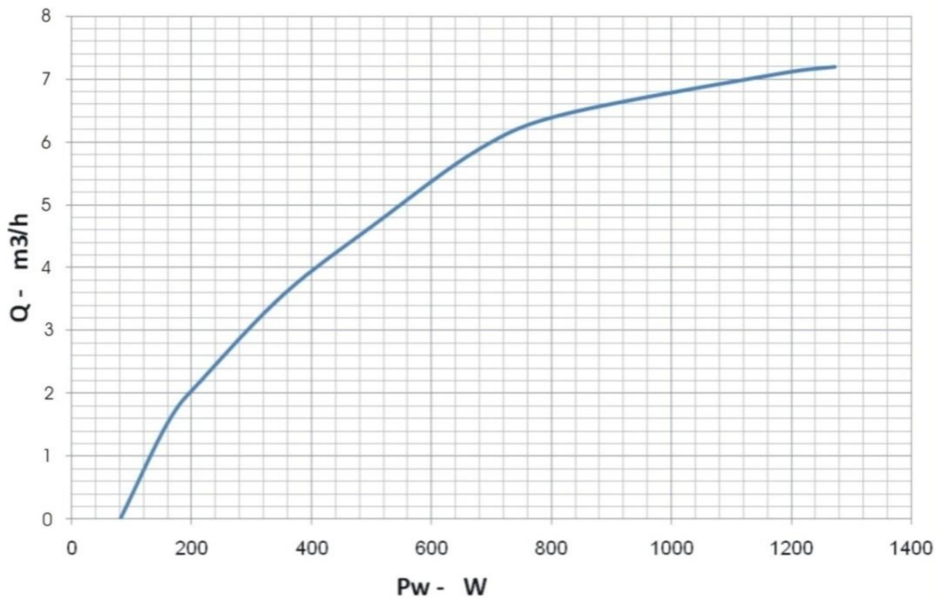

Fig. 8 Measurable Flow – Power characteristic curve of the submersible pump.

Figures 9, 10, 11 and12 show images for the practical installation system of solar array, structure, submersible pump and well water respectively.

Fig. 9 An image for the Solar cells array (JuraWatt.205W).

Fig. 10 An image shows the Installation platform for solar panels.

Fig. 11 An image for the submersible pump (Grundfos-SQF5A-6).

Fig.12 An image for the water well with it's accessories.

5. Conclusions

The performance of the solar cells pumping system designed, simulated and implemented here, indicates the acceptable matching between the practical results and theoretical calculations. The results show a good matching of the measurable load line with the simulated maximum power line of the solar array. Also the measurable Flow – Power characteristic curve of the submersible pump has a clear matching with the specifications and shape of the simulated relation, that means good performance ratio

(68.1%) for a coupling between the solar cells array and the centrifugal pump system. It is recommended to use the present solar energy pumping system in Iraq; as Iraq is one of the richest countries with solar power, however, suffers nowadays a scarcity of surface water. Beside, the proposed system does not need too much maintenance in operation and does not contaminate the environment .As for long life cycle operation; the proposed solar pumping system is more economical and easier to deal with.

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