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# Exploring the Synergy of Integration: Assessing the Performance of Hydraulic Storage and Solar Power Integration in Kirkuk City

Edham Hussein Ibraheam[1], Sami Ridha Aslan[1],

[1]Department of Power Mechanics, Kirkuk Technical College, Northern Technical University, Iraq.

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**Corresponding Author:**
Edham Hussein Ibraheam
**Email:**
adham.hussen@ntu.edu.iq

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## ABSTRACT

This research investigates the performance of integrated system combining of hydraulic storage and solar power in Iraq. A photovoltaic-water pumping system was designed to store solar energy in the form of water in tank at a height of 6 mm. The study evaluates the influence of solar radiation level and pumping time in determining the amount of energy stored. During clear days in March, 175 minutes was taken to pump a total of 3400 liters of water in the case of the fixed PV panel, while when using the tracker, the time is reduced to 165 minutes for filling the tank with the same quantity of water due to the increase in the pumping capacity in the case of the tracker. During a cloudy day in the same month, the same quantity of water was pumped in 230 minutes. The stored water was then utilized to generate electricity, with varying flow rates based on the desired power output .The highest produced power was obtained by 42.9 W at a 42 lit / sec water flow rate, and the lowest power obtained by 23.2 W at a minimum water flow rate of 25 lit / sec. Moreover, the system's cost-effectiveness is enhanced by employing a direct current pump which can be used without the need for the inverter or batteries. These findings provide good understanding for the integrating of the hydraulic storage and solar power systems, offering potential solutions for sustainable energy generation in Iraq.

## 1. Introduction

Today's rapidly depleting traditional energy sources and the increasing rise in energy demand and environmental concerns have sparked intense research for new, more efficient technologies. The sun provides the majority of global power usage needs, making solar power a clean and sustainable power source. Utilizing solar power through photovoltaic (PV) generation is a cost-effective option. Street lights, solar panels (an array of photovoltaic cells), and water heaters are being powered by solar energy. This technology has a variety of uses, including in agricultural irrigation systems [1] [2]. Relying on renewable energy sources to power our homes and businesses is crucial in mitigating the effects of climate change and global warming. In addition, renewable energy sources are important for countries with large populations that lack access to the standard energy grid [3] [4]. The fast-depleting conventional energy sources and today’s continuously increasing energy demand in the context of environmental issues have encouraged intensive research for new, more efficient, and green power plants with advanced technology. Since environmental protection concerns are increasing worldwide today, new energy and clean fuel technologies are being intensively pursued and investigated. Most renewable energy from wind, micro-hydro, tidal, geothermal, biomass, and solar are converted into electrical energy to be delivered to the utility grid directly or to isolated loads [5]. Worldwide about 1.5 billion people have no electricity access, and up to one billion more people have no connections to reliable electricity networks [4].

There is still no hope of electricity access in many such remote and rural areas because installing new power substations and transmission lines is not economically feasible due to the geographical constraints in these localities. Mini hydro has gained the highest attraction among renewable energy sources due to its environment-friendly operation [6]. PHP schemes have attracted high attention as the best alternative for electricity production in remote and rural areas. PHP units are easily adapted to the environment without any concerns, such as large water resources storage and population reestablishment [7]. System performance varies significantly during the rainy season [8] [9]. Moreover, these systems' autonomy and cost depend on sizing their component [10]. During this practical study of the photovoltaic water pumping system, we will study the efficiency of the photovoltaic panels and the efficiency of the pump in clear and cloudy weather conditions, as well as the time of filling the tank, and then knowing the amount of energy generated as a result of storage using the hydraulic generator.

## 2. Material and Method

### 2.1 Experimental Setup

The water pumping system was designed, as shown in Figure 1, to take advantage of the photovoltaic energy available during the day to store it in the form of water in an upper tank, where a 665-watt solar panel (all information is in Table 1 ) with an area 3.12 $m^2$ as shown in Figure 3A, and a 280 W DC pump with a voltage of 24 V (all information is in Table 2 ) was used as shown in Figure 3B, a lower tank of 3400 liters instead of a well, an upper tank of the same size with a height of 12.4 m, plastic pipes with a diameter of 1 inch. An MPPT voltage stabilizer was used. A mechanical flow meter with a variable section measures the amount of flow.

Table 1. Specifications of the PV module

| Rated maximum power(Pmax) | 665 W |
|---|---|
| Voltage at Pmax | 38.41 V |
| Current at Pmax | 17.32 A |
| Open-circuit Voltage | 46.09 V |
| Short-circuit current | 18.33 |
| Open Circuit Voltage tolerance | 3% |
| Short Circuit Current tolerance | 4% |

Table 2. Specifications of Water Pump

| Model | LSWQB 24V |
|---|---|
| Max.Flow | 2 $M^3$/H |
| Max.Head | 25 M |
| Power | 280 W |
| Out Let | 1 INCH |
| Voltage | 24 V |

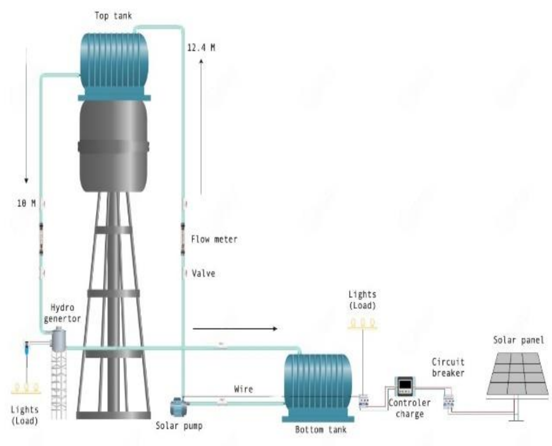


**Figure 1**. Scketch of the experimental test rig

To take advantage of the water storage of solar energy, a generation system was installed consisting of an upper tank with a capacity of 3400 liters at a height of 10 m and a hydraulic generator operating at a voltage of 220 V, as shown in Figure 2. Plastic pipes with a capacity of 1 inch were used, and the amount of flow is controlled using valves Figure 3 explains the parts used in the water storage system at the work site at the Technical Institute / Hawija.

**Figure 2**. Hydraulic Generator

**A**

**B**

**C**

**Figure 3.** The experimental test rig (A)solar panel, tank, and connection wires (B) water pump (C) MPPT

### 2.2 Principle of System Operation

To take advantage of the photovoltaic energy to store water, the water pumping process was carried out during three months in March, April, and May at a certain days, where the pumping process was carried out in clear weather in all months, and during March, the pumping process was also carried out during cloudy weather and at different times to observe the effect of the radiation intensity during these months on the storage time and the amount of flow, as well as calculate the efficiency of the solar panel and the pump with the change of time and the amount of radiation.

To know the efficiency of the hydraulic generator accurately and to get the most benefit from water storage as well as generate the necessary energy only without wasting electrical energy, several methods of generation will be chosen by controlling the amount of water flow from the upper tank through the control valve that was connected to the drainage line. Different water flow rates were chosen, which are (42,35,30,25 lit/min), thus knowing the electrical energy generated at each flow, as it was started from the highest chosen flow rate, 42 lit/min. Then the flow quantities were selected to be suitable for generating electrical energy, and the number of blade cycles to the minimum through which electrical energy is generated. The current and voltage are measured practically using a clamp meter, and thus the board's capacity is calculated using equation (1). Also, the hydraulic capacity of the pump can be found from Equation (2) and its efficiency through Equation (3)[11].

$$P_E = I \times V \quad \ldots\ldots (1)$$
$$P_H = W \times Q \times H \quad \ldots\ldots (2)$$
$$\eta_{gen} = \frac{\text{Out Put Power}}{\text{In Put Power}} = \frac{IxV}{WxQxH} \quad \ldots\ldots (3)$$

Where: $P_E$: The electrical power input to the water pump and out of the hydraulic generator (Watt); I: water pump and hydraulic generator current (Amp); V: water pump and hydraulic generator voltage (volt); $P_H$: Hydraulic power output from the pump and the entrance to the hydraulic generator (Watt); W: Specific weight of water (kg/m$^3$); Q: The amount of water flow from the pump or the amount of water flow from the upper tank of the hydraulic generator (lit/min); H: The total height between the pump and the upper tank after calculating the losses (m) or the height difference between the upper tank and the hydraulic generator device; $\eta_{gen}$: Hydraulic generator efficiency.

## 3. Results and Discussion

Initially, the changing weather conditions, such as rain, dust, and clouds, were considered when designing the pumping system. Therefore, a solar panel with a high capacity of 665 W was chosen to operate the pump at any time and under any circumstances. An appropriate height sufficient to generate electric power was selected through the hydraulic generator that needs a height of not less than 8 m, as a height of 10 m was chosen at the top of the building, and an upper tank with a capacity of 3400 liters was installed.

The intensity of radiation is considered the main influencing factor for the system and its efficiency, as readings of the radiation intensity were taken for three months, where the difference in radiation intensity was observed between one month and another, as well as between an hour and another, where the highest intensity was observed at the middle of the day at 12 noon, as shown in Figure 4 that shows the intensity of radiation during clear days.

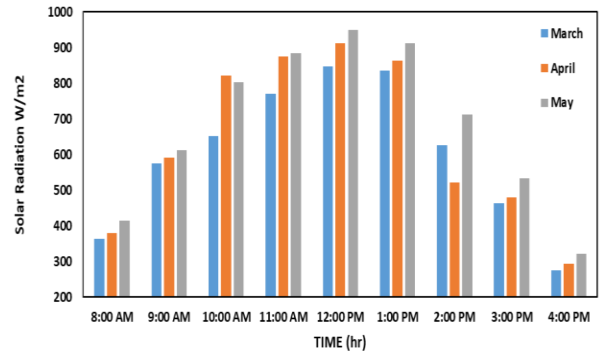


**Figure 4**. The Intensity of Solar Radiation Over Time

Also, readings of the radiation intensity were taken on a cloudy day in March, where it was noticed that the data did not match with the clear days, as it was noted that the highest intensity of the height was at 10 AM with a value of 535 W/m$^2$, and at 12 noon the radiation intensity was 344 W/m$^2$, as shown in Figure 5.

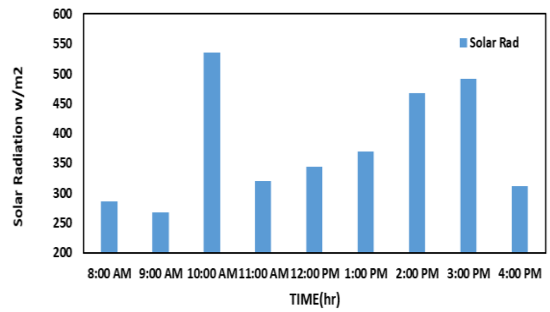


**Figure 5**. The amount of Solar Radiation Intensity with the Time of a Cloudy Day

It was found through the pumping operations and the time required to fill the reservoir that it decreases as the intensity of solar radiation increases. The reason for this is the increase in the energy generated from the solar panels with the increase in the intensity of solar radiation. Figure 6 shows the relationship between the amount of storage and the time between March, April, and May in the condition of the fixed and tracked board.

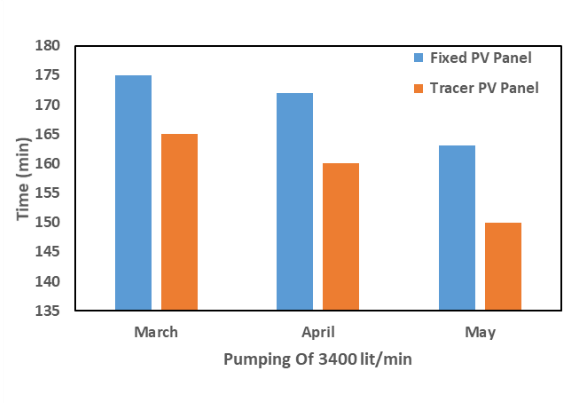


**Figure 6**. The Relationship Between Storage Quantity and Time

Where the maximum hours were chosen to start the pumping operations to obtain the highest efficiency, as well as because the time of filling the tank does not exceed 3 hours on clear days, as the pumping was started at ten o'clock in the morning, and thus the equipped capacity of the pump always remains high. Therefore the pump's efficiency is high, and Figure 7 shows the pump's capacity with time.

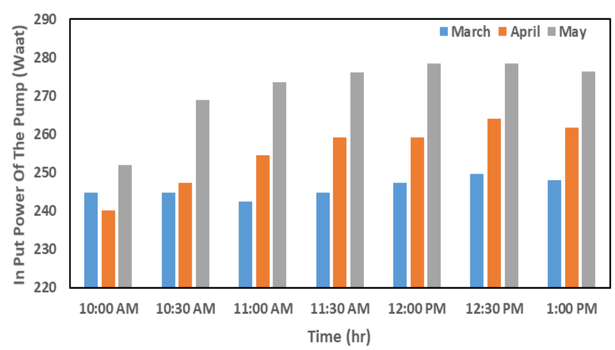


**Figure 7**. Pump Capacity Over Time

During cloudy days, the pumping process was carried out starting from eight o'clock in the morning. Thus, the amount of power entering the pump is directly proportional to the amount of radiation, despite the variation in the radiation intensity value, as the pump's lowest capacity was recorded with a value of 132 W when the value of solar radiation was 270 W/ $m^2$. The amount of flow was 12 lit /min at eight o'clock in the morning when the system started working. However, the amount of radiation is not high. However, our choice of a relatively large plate compensated for the lack of radiation intensity and produced enough capacity for us to operate the low radiation intensity due to clouds, dust, or rain, as shown in Figure 8.

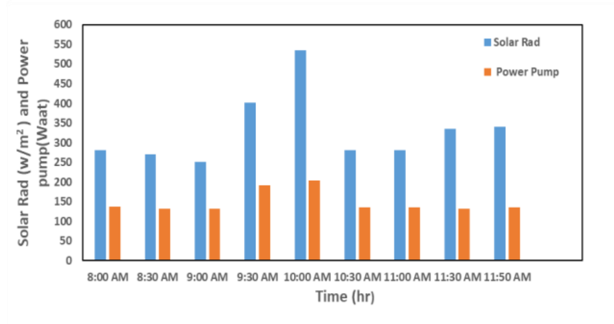


**Figure 8**. Pump capacity and solar radiation with time during cloudy weather

After performing the process of pumping water and storing the photoelectric energy in the form of water in the upper tank, the advantage of the water storage will be considered to generate electric power by draining the water smoothly to the hydraulic generator device, as the height of the upper tank from the generator is 10 m. we will conduct several generation methods by controlling the flow of water flowing smoothly from the upper tank. The control method is done through the control valve linked to the Drainage line. Different flows were chosen, which are (42,35,30, and 25 lit/min), thus knowing the electrical energy generated at each flow, as it was started from the highest possible flow, 42 lit/min. Then the flow quantities were selected that could generate electrical energy, and the number of blade cycles to the minimum through which electrical energy is generated. The highest value of the discharge was 42 lit/min, so the resulting power was 42.9 W, and the time to discharge it was 81 minutes, while when setting the flow to an amount of 35 lit/min, the resulting power was 35.7 W and the time to discharge it was 97 minutes. Minutes, and at the lowest possible flow, the device can reach sufficient cycles for generating 25 lit/min. The resulting power was 23.2 W, and the emptying time was 136 minutes, as shown in Figure 9. The power values were obtained through Equation No. 1 after measuring the current and voltage values practically by means of a clamp meter.

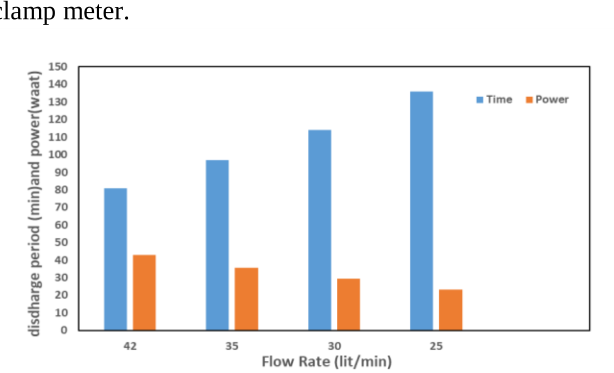


**Figure 9**. Discharch and Power produced by the hydraulic generator with time

Figure 10 indicates that the current and the generated voltage relationship is also directly proportional to the amount of flow. At a 42 lit/min flow, the measured voltage value was 130 V, and the measured current was 0.33 A. It was measured by connecting electrical loads, and lamps were used and measured by a clamp meter at 35 lit/min flow. The values of voltage and current were respectively (122 V, 0.29 A), and at a flow of 30lit/min, the values of voltage and current were respectively (110 V, 0.26 A), and at a flow of 25 lit/min, the values of voltage and current were respectively (102 V, 0.22 A).

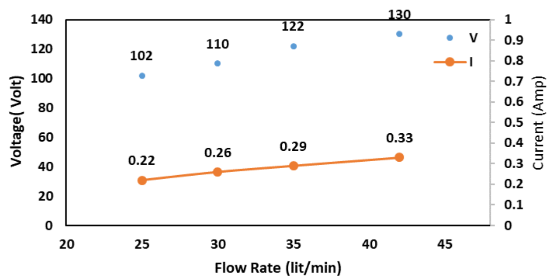


**Figure 10**. Amount of voltage and current generated by the hydraulic generator with the water flow rate

Figure 11 indicates that the efficiency of the hydraulic generator is proportional to the increase in the amount of flow. At the highest flow of 42 lit/min, the efficiency of the hydraulic generator was 72.46%, and at the flow of 35 lit/min, the efficiency was 69.17%. At 30 lit/min flow, the efficiency efficiency was 63.8%. At the lowest flow rate of 25 lit/min, the efficiency was 58.98%, as it was observed through this that the greater the fluid flow quantity and speed, the more efficient the hydraulic generator, where the efficiency values were obtained from Equation No. 3.

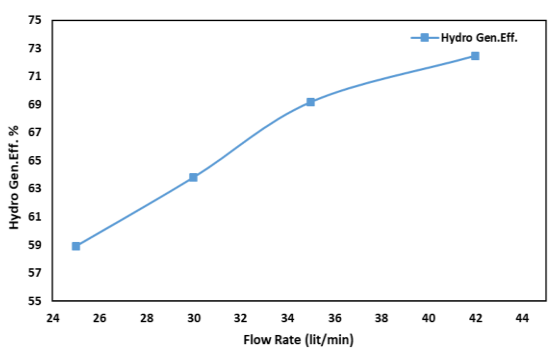


**Figure 11**. Efficiency of the hydraulic generator with the water flow rate

When calculating the cost of the solar energy-water storage system designed in this research, the cost is summarized as a basic cost only, and there is no investment cost. The feasibility of using solar energy systems at the expense of the diesel system to reduce the cost in the long term, and the solar energy system is environmentally friendly. When calculating the total efficiency of the system, we compared the equipped capacity of the pumping system with the power produced by the hydraulic generator and found that it is 7.4%, which means that it is an acceptable initial efficiency because it is considered an additional benefit with the benefit of storage for irrigation and the provision of drinking water to remote villages.

## Conclusion

Solar energy is the most abundant and least expensive of all conventional energy sources. Through our research, the system of storing solar energy in the form of water was studied and benefited from the presence of light during the day, and then benefited from the storage to generate electric power through the hydraulic generator during the absence of solar radiation such as at night, as well as benefiting from the storage for irrigation and drinking water for remote areas. The results of this study showed that the greater the discharge intensity, the greater the productive capacity. The highest value of the discharge was 42 lit/min, so the resulting power was 42.9 W, and the time to discharge was 81 minutes, while when setting the flow to 35 lit/min, the resulting power was 35.7 W and the time to dischargewas 97 minutes. At the lowest possible flow, the device can reach sufficient cycles for generating 25 lit/min. The resulting power was 23.2 W, and the discharch time was 136 minutes. It is recommended to use the present solar energy pumping system in Iraq. During clear weather, the amount of radiation falling increases, and thus the amount of pumping increases, and thus the pumping period decreases to fill the tank with a capacity of 3400 liters. Besides, the proposed system does not need too much maintenance in operation and does not contaminate the environment.

Accordinglym it is recommended to use the water available during the pumping process to cool the solar panels because a solar panel temperature of more than 25 degrees Celsius reduces the efficiency of the solar panel and thus reduces the system's efficiency.

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