International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Journal Européen des Systèmes Automatisés
Vol. 58, No. 2, February, 2025, pp. 345-351
Journal homepage: http://iieta.org/journals/jesa

A Real Case Study of Hybrid System for Enhancing the Energy Production

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https://doi.org/10.18280/jesa.580215

Received: 5 January 2025
Revised: 10 February 2025
Accepted: 16 February 2025
Available online: 28 February 2025

Keywords:
Solar PV system, Hydro plant, PV-Hydro hybrid system, HOMER Pro software

ABSTRACT

The aim of this article was to benefited of pumped storge and photovoltaic (PV) battery storge systems to cover the demand and to propose a program to determine the performance limitation of these two systems. Power grid demand can be satisfied by absorbing the excess power from solar PV array in order to pump the water to the up reservoir also this system was demonstrated for supporting the grid demand from the power. Homer Pro software with optimal energy saving functions has been used. Integration effect of energy resources with different time scales on the hydro-PV systems was studied. It observed that a small failure indices on the measured readings. The results showed the effect of two types on the cost, Stronge capacity and production. Finally, it has been concluded that the first model is more efficient and more economic than the second model.

1. INTRODUCTION

Pumped storage electric power systems use hydroelectricity (PSH), also known as pumped hydroelectric energy storage (PHES), as a kind of hydroelectric energy storage to balance loads. When water is pumped from a reservoir at a lower elevation to one at a higher height, the gravitational potential energy of the water is stored in a PSH system. The pumps are usually powered by inexpensive surplus off-peak electricity. The stored water is released through turbines to generate electricity during times of peak electrical demand. An overview of hybrid renewable energy systems (HRES) is provided in this publication [1]. This kind of system satisfies the current need for new electricity sources by using energy storage and on-pick as a source of such demandable electricity energy off-pick [2].

This is a result of traditional or fossil fuels, which contribute to air pollution and climate change, becoming more and more expensive. Renewable energy sources, such as photovoltaic wind or small-scale hydropower, provide a viable alternative to engine-driven generators for power generation [3]. Photovoltaic technology uses semiconductors to convert solar radiation into DC electricity [4]. PV systems are made up of a number of components, each of which has a distinct function in the solar system. The type of system and its intended use are determined by the components that comprise the system [5]. The technique of using wind to produce mechanical or electrical power is known as wind energy or wind power. using battery-backed hybrid renewable energy systems [6]. In recent years, hybrid power plants have been the focus of an increasing amount of research because, in a variety of situations, they have proven to be effective systems for using renewable resources. Because of the intricacy of the issues encountered and the non-linear nature of some system components, strategies for the operation of hybrid systems are inherently more complex to define and modify than those for non-hybrid systems. The resulting power system's size and functionality may be impacted by the energy available from the various sources, which may exhibit some form of time or space complementarity, or both [7]. To create a clean and environmentally friendly energy source, hybrid energy systems integrate two or more renewable energy sources, such as wind, hydropower, and solar electricity [8].

In this study, HOMER Pro tool is used for assessing the viability of a proposed hybrid PV-pumped storage electricity system at Mosul dam in comparison to the PV-battery system.

Because dam pumped storage station is underground there is always a gathering of groundwater in addition to water leaks that always occur in hydroelectric stations, so a drainage system was designed for this leaked water in order not the station be submersed, and this system consists of four pumps, the capacity of each pump is 450 kilowatts. One pump is sufficient to drain the water, and the rest of the pumps are standby in case of failure of any pump, the other replaces it, and the pump operates ten minutes per hour, so the average daily work of the pump is four hours, and the pump consumes 1800 kilowatts per day, and 657 MWh/yr, in addition to the pumps a constant load of 50kW (lighting, air conditions, TV, fridges…etc.) consuming 1200 kWh/day, so the total load is 3000 kWh/day and its maximum load is 500 kW [9].

This study will compare two models: a PV plant with batteries as an energy storage bank to supply a load, and a PV plant with a hydro pumped storage plant to supply a load. If the load exceeds the minimal load, the PV plant's produced energy is immediately delivered to it; otherwise, the excess power from the PV plant is to be supplied to the energy storage system.

Because of its comparatively high irradiance and relatively moderate temperature as a result of its location, this site is ideal for the development of a renewable energy plant. Figure 1 shows the upper reservoir storage station.

Figure 1. Upper reservoir of storage station

Teixeira et al. [10] studied a pump storage of the dam in Braziel were this dam worked to provide drinking water for 60% of the population inside Santa Maria city. They used Homer software program for simulation results, they concluded that for hydroelectric plant with a capacity of 227kW could be operated together with 60kW of PV panels and this combination gave in result to coverage the total load of val de Serra which amount to (260kW) [11].

Ghasempour et al. [12] made a view study of many countries they gave many descriptions and results about hybrid (hydro-PV) system and as follow:

India (2020) generated 1.9 GWh of electricity saved water 942731.5m3 for one year 1.14 MW of solar PV has been used.

Africa (2021), the power generation increased by 58% and water saving reached 743 million m3/year also covered about 1% of the lake.

Morocco (2021), at optimal till angle high energy generated by solar PV [12].

2. SYSTEM DESCRIPTION

To equip the load with electrical power, the photovoltaic plant produces electrical power through the day, surplus electrical energy production is exploited to turn on storage pumping station to left water to upside tank during non-peak times and then uses it to operate the water pumping storage station as a generator to equip electrical energy to the load through period of peak load. Figure 2 shows proposed PV hydro pumped electricity storage system for first model.

Covering the station's internal consumption is considered the first priority for energy produced, which is mainly represented by the sewage network to protect the station from floods because there is always a high percentage of water leakage in the station and it is discharged every hour through the pumps of the sewage system, and the hike energy is utilized charge the batteries.

Figure 3 shows the second model of the PV Batteries storage energy system is depicted.

NASA has determined the solar irradiance data for the site [12]. The site is located at 42°43'29.55" East Longitude and 36°30'50.77" North Latitude, respectively, as displayed by the HOMER Pro tool. Figure 4 shows the relation between monthly solar irradiance over a year, from this figure The average daily irradiance displays an annual average of 5.37 (kWh/m^2/day), while Figure 5 shows the relation between the monthly average ambient temperature over a year.

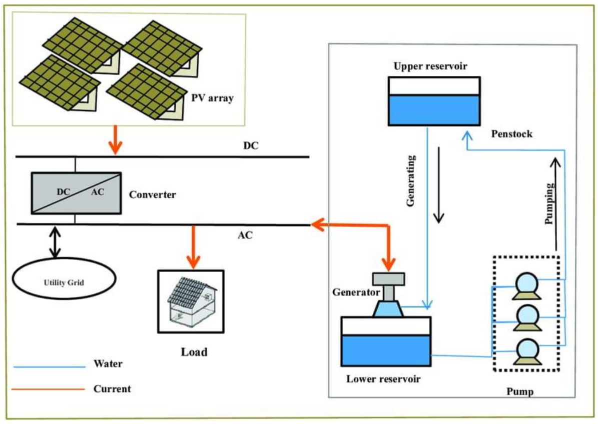

Figure 2. Proposed PV hydro pumped electricity storage system

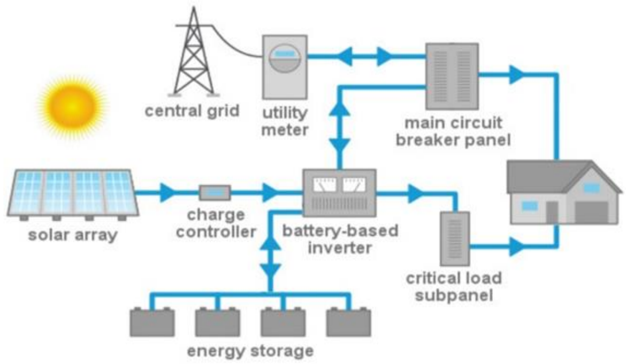

Figure 3. Proposed PV Batteries storage electricity system

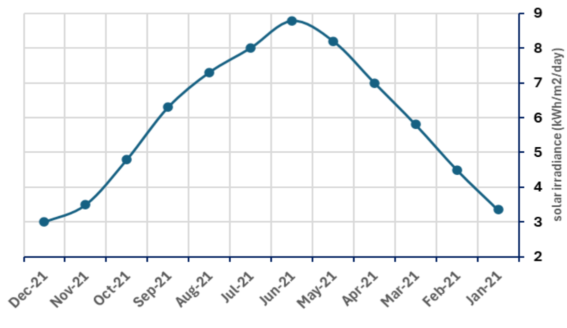

Figure 4. Monthly average solar irradiance

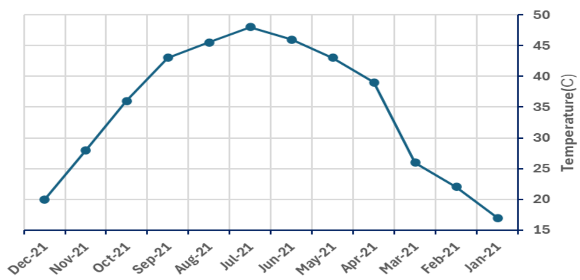

Figure 5. Monthly average ambient temperature

3. HYDROELECTRIC ENERGY PRODUCTION EQUATION

Because of large size of the hydroelectric power station, the overall value of electrical energy that can be product from water is given by:

$$P(\mathrm{kW}) = Q.g.h.\eta \quad (1)$$

where,

P: the generated power in kW.
Q: water flow rate in m^3/sec.
g: gravitational acceleration (9.81 m/s^2)
h: average height in m.
η: overall efficiency.

The above equation shows how the flow volume and fall height affect the electricity production in a hydropower station.

To obtain a high water level, the water tank must be placed at the highest level allowed for the generating unit.

Geographic considerations, such as river bottom elevation, water volume, and other environment stipulation, affect the peak height of the water tank. According to the whole amount of electricity to be generated, the position of the energy production unit ability be changed. To obtain the greatest amount of water, energy production units are often established at grades lower than the circumference earth grade, so their site is as well exposed to geographical constraints [1].

4. PHOTOVOLTAIC SYSTEM

PV arrays are made by connecting multiple solar cells in parallel and series to form solar modules. Short-wave radiation is captured by these cells, which convert it into direct current energy. The total annual energy contribution (*Epv*) of the solar array is calculated using Eq. (2) [2]:

$$Epv = Ypv.\ PSH.\ Fpv.\ 350\ \text{day/year} \quad (2)$$

where,

Ypv: maximum capacity of PV arrays in kW.
PSH: peak sun hour (h).
Fpv: PV derating factors.

The derating factors are included loses of wire, air temperature, dust, and various elements on the energy output of the solar array. The relationship between anticipated and actual output, commonly referred to as PV efficiency, is the derating factor.

HOMER Pro tool is used to determine the total energy, number of PV modules, batteries, and pumped storage units in order to evaluate solar PV systems. Solar PV systems are available in a variety of configurations and power output ranges. It is necessary to establish the first stage's total energy consumption and daily sunlight hours in accordance with the location [7-11].

5. LOAD CHARACTERISTIC

The PV plant is designed to supply a load consists of two parts, the first one is constant load of 50 kW (lighting, air conditions, TV, fridges…etc.) consuming 1200 kWh/day, the second one is a constant load but it does not operates all the time, it is a pump of 450 kW operates ten minute per hour consuming 1800 kWh/day so, the total load is 3000 kWh/day and its maximum load is 500 kW. Figure 6 shows the load curve of this load.

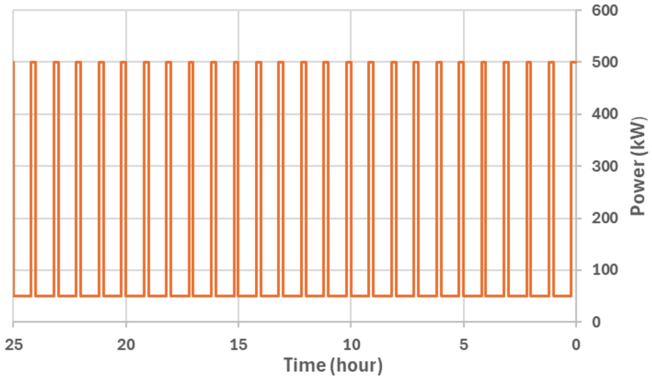

Figure 6. Load curve

6. PUMPED STORAGE PLANT MODELING

Upper tank capacity and average head are the very important factors for designing pumping systems [3]. In this test, the Tigris River is considered the bottom tank and its level is at an altitude of 300 metres.

A-Generator case

The turbo generator output during vacuum mode is written as follows:

$$P_T(t) = \eta_T \rho g h.\ q_T(t) \quad (3)$$

where,

η_T: the total efficiency.
$q_T(t)$: the flow rate of water.

B-Pump case

When PV capacity exceeds the demand of energy. The rate of water pumping is represented by the battery charging rate. Since the pump receives its energy closely from the photovoltaic panels, it can be represent the water flow proportion drawn from the lower tank as follows [13]:

$$Q_p(t) = \frac{\eta_p . P_{PVp}(t)}{\rho . g . h} \quad (4)$$

where,

P_{PVP}: input power.
ρ: water density (1000 kg/m^3).
η_ρ: overall pumping efficiency.

C-Upper reservoir

The amount of water stored in the upper reservoir (UR) at time t is affected by:

$$Q_{UR}(t) = Q_{UR}(t-1)(1-\alpha) + \int_{t-1}^{t} q_P(t)dt - \int_{t-1}^{t} q_T(t)dt \quad (5)$$

where,

α: Evaporation and leakage loss, can be compared to the self-discharge of a battery.

These losses have been ignored in this analysis for simplicity. The amount of water in the higer reservoir can be represent the state of charge (SoC). Thus, the SoC of a storage system is given:

$$\mathrm{SoC}(t) = \frac{Q_{UR}(t)}{Q_{URmax}} \tag{6}$$

The following limitations also apply to the overhead tank water volume:

$$Q_{URmin} \leq UR \leq Q_{URmax} = V_{UR} \tag{7}$$

where,

Q_{URmin} : lower limit of U.

Q_{URmax}: higer limit of U.

V_{UR}: capacity of reservoir (m^3).

The minimum storage capacity, QURmin is zero in this paper [14]. The Tigris River can be considered as a lower tank in this analyze, which can to a large extent reduce the cost of constructing a pumped storage system.

The number of days of autonomy can be calculated depending on the size of the UR and the probable power s in the UR:

$$n_{day} = \frac{E_C}{E_{load}} = \frac{\eta_t . g . V_{UR} . \rho . h}{E_{load}} \tag{8}$$

where,

E_C: upper tank capacity(J).

E_{load}: daily load consumption (kWh).

7. HYBRID SOLAR-HYDRO ENERGY PLANTS

Hybrid energy generation is a process which includes two or many plant of various energies, these generators are utilized in isolated networks, so synergison are taken in order to provide technical and economic advantages. The hybrid energy generation system consists of three basic parts, namely, switching, series and parallel hybrid system [15]. In this work, the hybrid system debated is a renewable power resource that come from hydropower and solar. Parallel connection is used because they have advantages of continuity and do not depend on each other. Figure 7 shows the configurations of hybrid PV and hydropower plants.

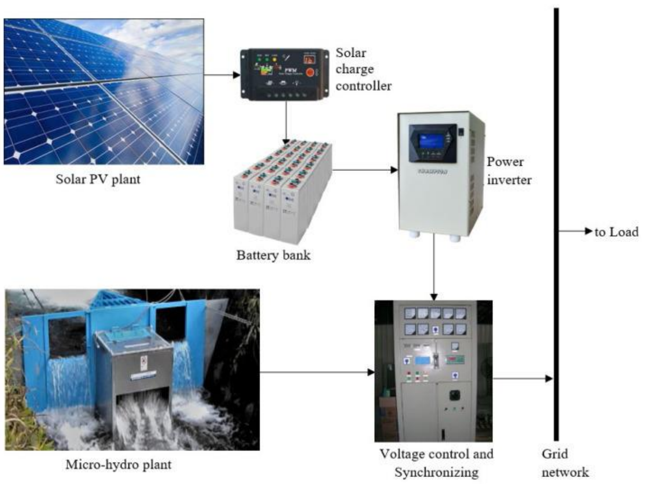

Figure 7. Hybrid (PV and hydro) power plant configuration

7.1 Micro-hydro power plant

The hydropower plant is a pollution-free and environmentally friendly renewable energy product. The plant converting water energy to move a water turbine, which in turn operates a generator to generate electrical power. Hydroelectric power is one of the ancient forms of power used in the world, as it has been used on a small scale since the beginning of the twentieth century. The construction of the Fox River Wheel in Wisconsin was the first use of hydroelectric power in 1882.

The capacity of micro-hydropower plant is less than 100Kw. The state of hydroelectric water than used as a resource for electricity production which has a certain high and flow capacity. The generated electricity by this small plant depends greatly on the water discharge and the hight of the waterfall [16].

7.2 Solar energy in Iraq

Iraq lies around latitude lines 29˚5' - 37˚22'N and longitude lines 38˚45'-48˚45'E, with area of 435052km^2. Figure 8 shows Solar radiation map in Iraq. Northern Iraq contains many mountainous, and the occurrence of sunny days is unsimilar to the other country regions. In winter, Iraq center includes a plain between the two principal water ways of Euphrates and Tigris rivers, this region receives more sunlight than the north. A very clean atmosphere is finding in the southern region [17].

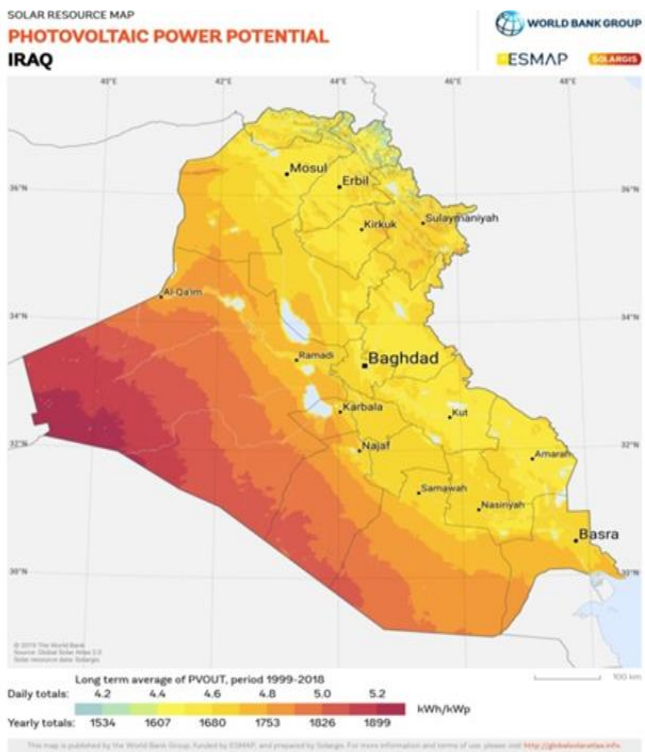

Figure 8. Solar radiation map of Iraq

8. OPERATION STRATEGIES

The first balance relationship for basic power is represented by the electricity that utilized by the solar panels being used directly for the load when the demand is equal to or less than the PV power or used for pumping water when the requestis greater than the PV power generation [18].

Considering the aforementioned limitations, Figure 9 illustrates the flowchart of overall system's operating approach.

The algorithm describes how to manage photovoltaic and hydro-turbine energy generation, respectively. The power produced by PV can be used to supply the load or to pump water to the overhead tank. The priority is to cover the load. When the PV power output exceeds the lower load value the PV power supply the load directly, if the PV power less than the load and the upper reservoir level greater than its minimum value, the turbine starts supplying the load. If the upper tank level is less than its minimum value, the pump starts pumping water to the upper reservoir exploiting the PV generated power which could not meet the load and the load must be supplied from the grid [19].

Figure 10 below provides a flowchart of the HOMER simulation.

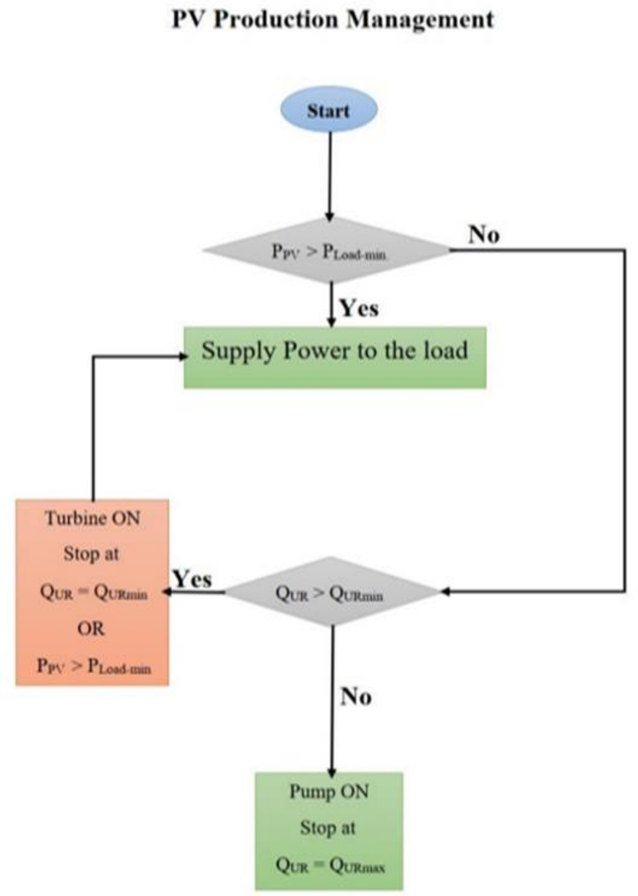

Figure 9. Flowchart of plant operation

The National Renewable Energy Laboratory in the United States (NREL) developed the hybrid optimization model for electric renewables (HOMER) as a computer model to assist designers in creating sustainable energy systems for grid connected and standalone projects and to make it simpler to evaluate methods for generating power through a variety of combinations [20]. Using the HOMER Pro software version 3.14.2, a comparison between to models of PV plant have been done to supply the load as follow. Homer pro. Software the optimal system configuration selected according to minimum excess electricity percentage, lowest net cost (NPC) and levelized cost of power (LCE). The optimization objectives were reliability maximization, cost minimization, energy production, environmental impact reduction, operation flexibility and load matching. In Homer pro, constrains included, load demand, minimum and maximum load generation, operational limits, storage technical and operational [21].

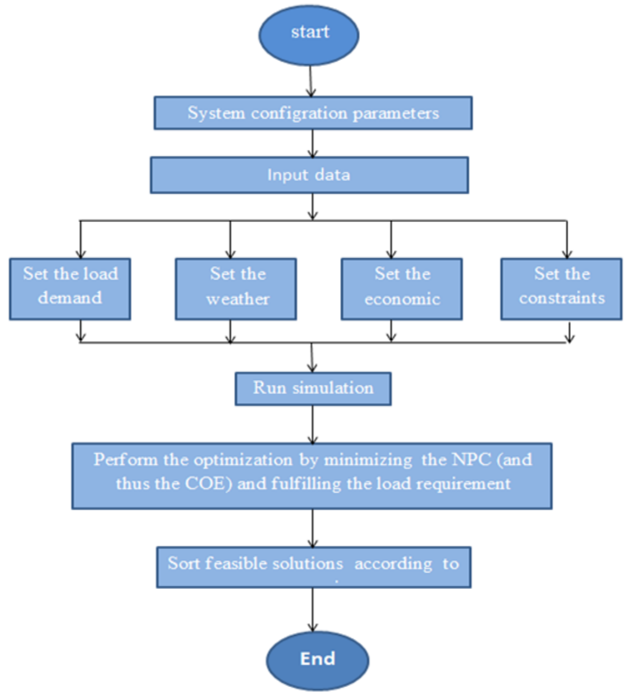

Figure 10. Flowchart of HOMER simulation process

A. PV-Pumped Storage System

An off-grid PV power system with pumped storage system is designed to supply a load of 3000 kWh/day, PV panels of 500 watt was used and a pumped storage system of 245 kWh was used which has a reservoir of 1000 m^3 and effective head of 100 m and discharge flow rate of 0.0231 m^3/sec. Figure 11 shows the schematic of this system.

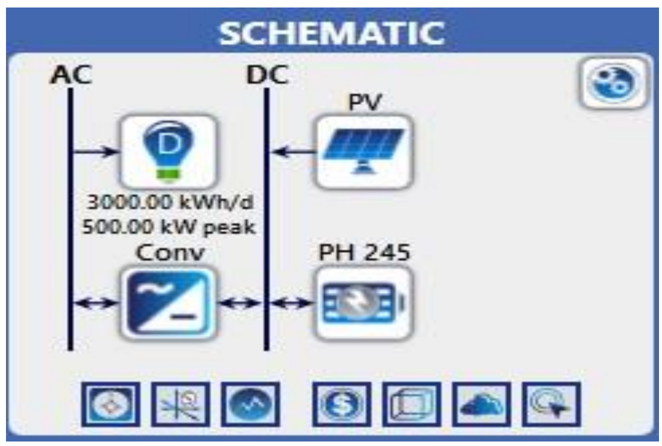

Figure 11. Schematic system of PV-Pumped storage system

The simulation of the system as shown in Table 1 showed that for supplying the load a PV plant of 804 kW capacity (1608) panels produce 1,278,540 kWh/year or 3502 kWh/day and 20 units of pumped storage system with nominal capacity of 5083 kWh which has an autonomy of 40.7 hour are required.

where,

NPC: Net present cost

COE: Cost of energy

B. PV-Batteries System

An off-grid PV power system with batteries energy storage system is designed to supply a load of 3000 kWh/day, PV panels of 500 watt was used and a battery storage system of 1kWh of 12Vand 83.4 Ah. Figure 12 shows the schematic of this system. The results are shown in Table 2, and Table 3 shows a comparison between two types of storge system.

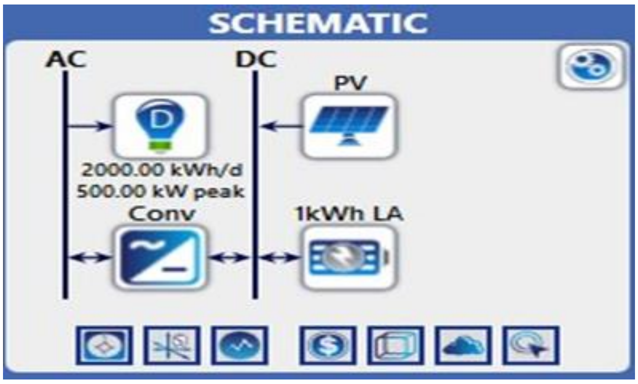

Figure 12. Schematic system of PV-Batteries system

Table 1. The main results of PV-Pumped storge system

Category	Parameter	Value
Architecture	Ph 245	20
	Pv (kW)	804
Cost	NPC ($)	$1.22M
	COE ($)	$ 0.0495
PV	Production (kWh/yr)	1,278,540
	Quantity	20.0
Ph 245	Autonomy (hr)	40.7
	Nominal capacity (kWh)	5,083

Table 2. The main results of PV-Battery storage system

Category	Parameter	Value
Architecture	1kWh (LA)	3400
	Pv (kW)	603
Cost	NPC ($)	$1.98M
	COE ($)	$ 0.120
PV	Production (kWh/yr)	958,192
	Quantity	3,400
1kWh LA	Autonomy (hr)	24.5
	Nominal capacity (kWh)	3,403

Table 3. A comparison between two types of storage systems

Type / System Functions	PV-Pumped Storage	PV-Battery
PV plant capacity	804kW	603kW
Storage capacity	5083 kWh	3043kWh
PV Production	1278 MWh/yr	958 MWh/yr
Autonomy hours	40.7	24.5
Net Present Cost	1.22 M$	1.98M$
Cost of Energy	0.0495$	0.120$/kWh

The first model is more efficient and more economic than the second model due to the lower cost of power COE and net present cost NPC of the first model and the autonomy hours of the first model is greater than the second model by 16.2 hours. As well as the upper reservoir of Mosul dam is already constructed which is reducing the cost significantly.

The advantages of pumped storage systems are the facilitates in the integration of other renewable sources like hydro and PV are storing the excess energy from these sources and improving overall electricity generation efficiency. But the disadvantages of this type are some limitations like, environmental impacts, site suitability requirements and high initial costs. From overall above the advantages of PV pumped storage system is better than the battery storge system but the last has good feature and less limitation as compared with PV pumped storge system.

9. CONCLUSIONS

This work pupesed on adequate sizing and operation of a PV storage and battery storge systems in order to give firmness to PV power generation, the proposed system model described with indicating its corresponding indicators and parameter.

The set point of the power has been adjusted for each month of the year. According to the expected PV production, the aim was to generation a constant source with high capacity credit.

From the first model CPV pumped storge showed that a PV plant capacity of 804 kW and 20 units of pumped storge turbine rating 245kW with total capacity of 4900kW and a reservoir 2000m3at a head 100m has been required to cover the load, because the upper reservoir head of Mosul dam is 330m led to reduction in the turbine capacity by 3.33 ratio, so the new capacity must be around 484.84 kW and the minimum efficiency was 75% therefore the turbine capacity will be 2 MW and the maximum discharge flow rate is 0.462m/sec.

Form the second model PV battery storge system showed that the PV plant capacity of 603kW and a batteries storge system of 3400kW consisting of 3403 pcs of 12V, 83Ah required to cover the load.

Using Study hydropower plants to utilize gravity for electricity generation,

- Constructing pumped storage systems location to be more cost effective by using prefabricated structure steel modules.
- Closed loop pump storage system design to reduce environmental impact.

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