# Hydro Pump Storage System Driven by PV System for Peak Demand

SUHIB A. ABU TAHA, MOHAMED R. GOMAA*, SOHAIB AL-MA'ASFEH
Mechanical Engineering Department,
Faculty of Engineering,
Al-Hussein Bin Talal University,
MA'AN, JORDAN

*Abstract:* - Nowadays there are increasing demands for the electricity also the rapid improvement in the technology and urbanization that increases energy consumption daily, in the other hand there are many research to find an optimal and economical storage system for the renewable energy that can reduce the demand on the fossil fuel , also reduce the emission and save the environment in this report we review some applications and methods related to the Integrated between the photovoltaic system with pumped hydro storage system the first application in the residential building , the second one in the arid area and the third one in the farms above methods or applications used to minimize cost and reduce emission by reduce dependency on fossil fuel, that's occur by use the system contains of Photovoltaic (PV) system with pumped hydro storage ,the major components of the systems used are PV panels, upper reservoir and lower reservoir, control center or inverter, pump, turbine and connected to public grid or diesel generator the results of the above methods show that the integration between photovoltaic system and pumped hydro system is applicable and sufficient ,the proposed hybrid systems can assist in reducing operation cost, reduce in consuming fossil fuel and make cost saving by an average of 50%.

*Key-Words:* - Pumped hydro storage; Residential buildings; Distributed energy storage; Photovoltaic generation; arid area.

Received: June 9, 2021. Revised: February 18, 2022. Accepted: March 20, 2022. Published: April 28, 2022.

## 1 Introduction

In those days, the rapid improvement in technologies increases energy consumption. Furthermore, the excessive use of fossil fuels affects the environment [1]. Hence, it is urgent to utilize renewable energy (RE) with high electricity consumption [2].

As we know, photovoltaic systems can provide an inexhaustible source of energy. Still, solar energy is not continuous during the day because it is affected by the weather and radiation, indicating that an independent photovoltaic system cannot ensure a stable power supply for the whole day. The energy storage system has been investigated to complement the available PV energy and shift peaks. Energy storage systems can store surplus power from the PV system and generate power when the sunlight is not effective. So, modern energy storage technologies bring many advanced methods such as pumped hydro storage (PHS) [3-10].

Recently almost 90% of the country's energy demand has been met from fossil fuels [11-15]. However, the total renewable energy share of solar, wind, or hydropower energy sources is rising due to the government commitment, and currently, it's reaching 12% [16]. However, despite the increase in the country's power generation capacity, it's still not in a position to adequately meet the overall energy demands of all the customers connected to the grid without making strategies like demand-side management, Time-of-Use tariff, or optimal management of available energy storages [17]. For the consumers in the residential, commercial, and industries, this matter is most evident and apparent in the high cost of electricity during peak pricing periods, and it can be up to four times the cost of electricity in off-peak periods; based on the demand sectors as well as the seasons [18].

Residential buildings in large cities have a significant source of power consumption. The high demands for electricity from the population are tremendous pressure on the public grids, leading to a peak load period of electricity consumption accompanied by an unstable power grid supply [19].

The previous studies show that the initial cost for this system is high compared with others, but on the other hand, it has the optimal solution that represents a lower environmental impact; in the domain of irrigation, there is integration between the hydro and electrical stations utilized that incorporate PV systems and precipitation trends analysis was proposed [20].

The current paper introduces pumped hydro storage system applications, results review, comparison, and conclusion of the pumped hydro system.

## 2 Different Application of Pumped Hydro Storage System Integrated with Photovoltaic in Different Areas.

Section two will review applications for integrating the hydro energy storage system and other systems in three different areas residential buildings, small farms, and arid areas.

### 2.1 Residential Buildings-Prefeasibility Study of a Distributed Photovoltaic System with Pumped Hydro Storage for Residential Buildings

The residential houses have a natural height drop and always have an available roof area. Still, we must consider two major things the building's load-bearing capacity and the maximum available roof area [19].

We have in this study two reservoirs; the upper reservoir (UR) should be covered with the roof as much as possible to keep a space for walking and operation and prevent water from evaporating. The upper reservoir will be made with a closed cover style, and then the photovoltaic system should be fixed on the upper pool closed cover to utilize the roof area. The top surface of the upper reservoir is designed and has a vent hole. This can help maintain the air pressure balance when the water level changes. The penstock of the PHS system is fixed vertically against the wall of the residential building. Also, it is connected to the lower reservoir, which locates down in the basement.

Referring to the figure below figure Fig. 1, The residential building is a power consumption center equipped with photovoltaic panels to generate power. It uses pumped hydro storage for energy storage [8]. The system work of this study as the PHS system used to store the PV system's extra power by using the pumping water to UR, then it can be utilized the energy stored when PV power is not available. The system must be compact because of the limited mounting space, so a PAT device is applied where the pump and a generator are integrated. The control in this system is not working as an inverter, but it also controls and is responsible for the electricity distribution; if we have excess electricity. The system can also distribute it to the grid with repayment; when the power from the PV-PHS system is insufficient and does not comply with the demands, it can also get supply from the grid [19].

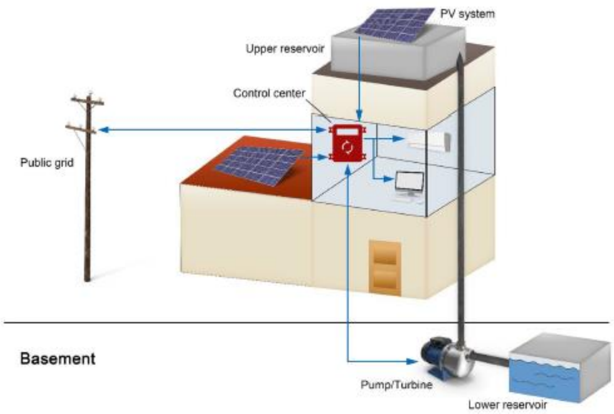


Fig. 1. The system configuration of a grid-connected PV-PHS system.

Referring to Fig. 2, which shows the flow chart of the control logic, the operation principle is the brain of the proposed photovoltaic system with hydro pump system, the input parameters, for example (PV system power generation, water volume for pump, and the amount of trading electricity), must be defined before starting the program for control logic, there are two branches for the flowchart the first one is when the PV system generates more electricity load than required during the day, and the second one when the PV system cannot generate electricity or the household is lacking energy during the night or rainy days. The study has presented two case studies: one villa and the second apartment building. The results reveal that the operation principle combined with the system proposed in this study shows a better effect on apartment buildings than villa buildings because of the building height and load demand. It is clear that, the residents of the apartment building can employ the PHS system to supply energy more effective during peak power periods, and the residents of the villa building need to be powered by the grid after 6 pm for most of the year, that's leading to an increase in cost [19].

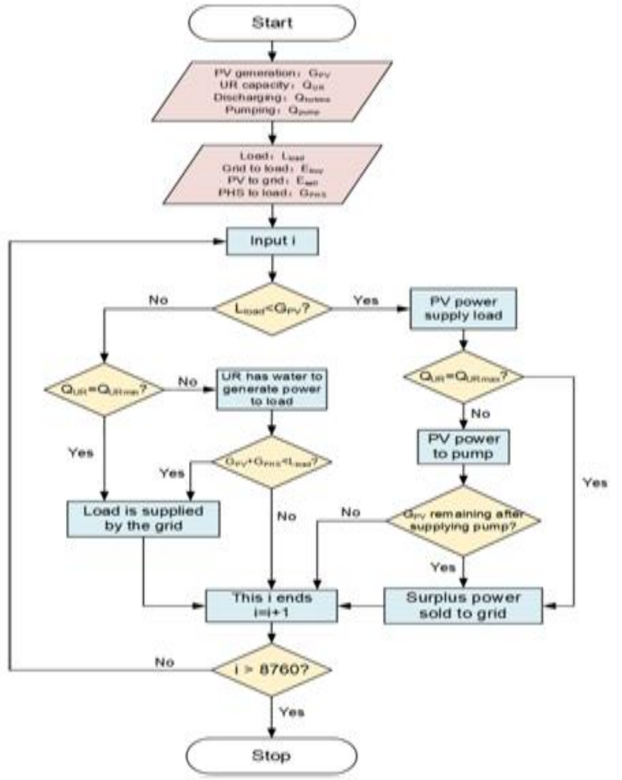


Fig. 2. The flow chart of operating the PV-PHS system.

## 2.2 Arid Areas- Hybrid DG-PV With Groundwater Pumped Hydro Storage for Sustainable Energy Supply in Arid Areas

The present study develops a model for the optimal operation of a hybrid diesel-photovoltaic system by using the groundwater in pumped hydro storage, that used to reduce the electricity cost, also minimize the power produced from the DG, the generated power flow from the photovoltaic and stored by PHS used to convert into electrical potential energy of the stored water in the reservoir, and provide variable load demand as well as the availability and provided from solar resources, this system applicable in small farming activities where groundwater is extracted, therefore, the resources and facilities made available in arid area farms can be efficiently used with the proposed system. In this proposed study, the total load from the photovoltaic system during the time of the day from the solar resource. The photovoltaic supplies the pump for storing the water in the reservoir for future power generation by the turbine and hydro-generator set. The diesel generator is also used to provide the load or supply the pumped hydro storage. However, the total output power from the diesel generator is the control variable to be minimized. The diesel generator can be used in many cases, like when there is not enough energy from the photovoltaic and the pumped hydro system to supply the load when the reservoir needs to fill state condition. The photovoltaic resource is not practical, and when the reservoir requires to be filled up before a peak power demand, most of the photovoltaic system's power is used to supply the load. Referring to the figure below, Fig. 3, which shows the proposed application, the main power flows related to the hybrid system can be graphically represented [20].

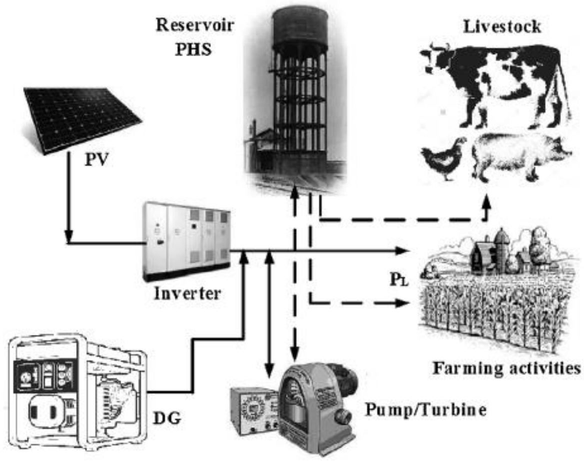


Fig. 3. Schematic diagram of the PV-DG with pump hydro storage system.

In this system, the best control model for the operation cost reduction of the hybrid photovoltaic-diesel hybrid system integrated with pumped hydro storage by used groundwater has been improved; this proposed system takes into account the non-constant of the diesel engines fuel consumption curve in the objective function as well as significant constraints, like the operation exclusive power flow and the final fixed state condition of the pumped hydro storage water level [20].

## 2.3 Farms-Optimal Operation Scheduling of Grid-Connected PV With Ground Pumped Hydro Storage System for Cost Reduction in Small Farming Activities

The proposed system is a model that is used to reduce the operation cost of a grid-connected PV system integrated with hydro and PHS. This proposed system can be used in small farming activities, where boreholes are already presented for supplying water. Therefore, the resources and facilities available on the farms can be efficiently used for the proposed system. Fig. 4 shows the operation of the proposed system first load PL supplied by PV and the excess energy used for a water pump that pumped the water from the borehole to the upper reservoir. The use of stored energy when the solar resource is unavailable by the turbine, also the system is connected to the grid we can use it when the electricity price is low, after generated power by the pico turbine pump, turbine-generator PT-G, the water is returned to the underground, that's lead that borehole with its reservoirs is as an energy storage system [21].

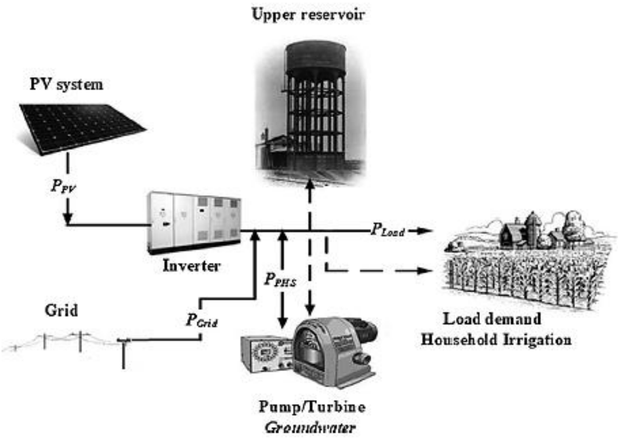


Fig. 4. Set-up of the studied microgrid.

The main goal of the proposed system is to minimization of electricity costs, and as per the results can be implemented in small farming activities, in which we have already boreholes for supplying water in this system, a hybrid system that consists of solar PV which is integrated with PHS are used that reduce the electricity cost in a dynamic electricity pricing environment. The optimal flow of power from the different energy sources to the load is determined by the fluctuating price of electricity, the load requirements, the reservoir state of water stored, and the solar resource. Those are the control parameters to be optimized with the aim of minimizing the power consumed from the grid. The optimization problem can be solved through linear programming. The simulation results can provide the impact and benefit of the proposed system on the electricity cost reduction of small loads in the farming sector [21].

## 3 Comparison Between Studied Applications

Table 1 shows studies conclude that there are several applications for using hydro pump storage, such as residential buildings (apartments and villas), arid areas, and farms. The difference between the systems used and how it reduces the daily electricity cost and the developed system reduces the power produced from the grid or diesel generator. The simulation results show that the proposed system can achieve a high potential for energy cost saving.

For the first application, a residential building that is used for apartment and villa, the results show that the operation principle combined with the system proposed in this study has a better effect on apartment buildings than on villa buildings due to the height and load demand, the apartment building can use PHS system more sustainably through peak power periods than resident villa building which needs to powered by grid after six pm for most of the year that leading to increasing cost, also as mentioned in the above table, this system used control center which is used for distribution of electricity. It converted DC to AC, not unlike the other two applications, with only an inverter. Also, this system used the public grid as stand by a source of energy; this system was used for powering electrical equipment. For the second application, arid areas, this system reduces the environmental emission by reducing dependency on the diesel generator and reducing fossil fuel consumption. This system used the underground as the lower reservoir, different from other applications used for livestock farming activity. For the third application, the farm's area, this system uses to minimize the cost of electricity for the proposed farming activities. This system uses the borehole to supply water as a lower reservoir, which is different from other applications. This system is used for load-demand household irrigation.

**Table.1.** Comparison between studied Applications [19-23]

| No. | Item | Application #1 | Application #2 | Application #3 |
|---|---|---|---|---|
| 1 | Proposed System Location | Residential Building | Arid Area | Farms |
| 2 | Major Components | PV panels, Reservoir (upper and lower), Control center, Pump, Turbine, and Public Grid. | PV panels, Reservoir (upper and underground water), Inverter, Pump, Turbine, and Diesel generator. | PV panels, reservoir (upper and borehole for supplying water), Inverter, Pump, Turbine, and grid. |
| 3 | Duty/Stand by Energy Source | PV Panels/ Electricity Grid | PV Panels/ Diesel Generator | PV Panels/ Electricity Grid |
| 4 | Reservoir Proposed | Concrete or Steel Upper and Lower Reservoir | Concrete or Steel Upper Reservoir and | Concrete or Steel Upper Reservoir and Borehole for |

| | | | | |
|---|---|---|---|---|
| | | | Underground Water as Lower Reservoir | Supplying Water as Lower Reservoir |
| 5 | Control System for The Energy Supply | Control center | Inverter | Inverter |
| 6 | Function For Control System for The Energy Supply. | Controls The Distribution of Electricity and Convert DC to AC | Only Convert DC to AC | Only Convert DC to AC |
| 7 | Cost Saving | Between 46%-76% | Almost 71% | Nearly 50% |
| 8 | Application | Electrical Equipment's | Livestock Farming Activity | Load Demand House Hold Irrigation |

## 4 Conclusion

The main goal of the previous studies is to minimize cost and reduce emissions by reducing dependency on fossil fuels that are occurred by using the system containing PV system with pumped hydro storage and integrated with an electricity grid or diesel generator. The previous systems can reduce the pressure of the power grid or diesel generator during the peak period. The users of the above applications can store surplus electricity instead of selling it to the grid, which reduces the load on the grid compared with the grid-connected systems without energy storage. The previous systems show a significant reduction in using electricity and diesel generator, showing that cost-saving by an average of more than 50%. The system proposed on the farms and in the arid area shows that the developed model effectively utilizes underground water resources available on site. The system proposed in the arid area can use the pumping system available on the site to store energy in a PHS scheme.

*References:*

[1] Ma T, Javed MS. Integrated sizing of hybrid PV-wind-battery system for remote island considering the saturation of each renewable energy resource. Energy Convers Manage 2019; 182:178–90.

[2] Javed MS, Song A, Ma T. Techno-economic assessment of a stand-alone hybrid solar-wind-battery system for a remote island using genetic algorithm. Energy 2019; 176:704–17.

[3] Xu X, Hu W, Cao D, Liu W, Chen Z, Lund H. Implementation of repowering optimization for an existing photovoltaic-pumped hydro storage hybrid system: A case study in Sichuan, China. Int J Energy Res 2019.

[4] Mohamed R. Gomaa, Mohsen Ahmed, Hegazy Rezk. Temperature distribution modelling of PV and cooling water PV/T collectors through thin and thick cooling cross-fined channel box. Energy Reports 8 (2022), 1144-1153. doi.org/10.1016/j.egyr.2021.11.061.

[5] Hani Al-Rawashdeh, Ahmad O. Hasan, Hazem A. Al-Shakhanbeh, Mujahed Al-Dhaifallah, Mohamed R. Gomaa, and Hegazy Rezk. Investigation of the Effect of Solar Ventilation on the Cabin Temperature of Vehicles Parked under the Sun. Sustainability 2021, 13(24), 13963. https://doi.org/10.3390/su132413963.

[6] Mohammad Shalby, Ahmed Elhanafi, Paul Walker, David G. Dorrell, Ahmad Salah and Mohamed R. Gomaa. Experimental Investigation of the Small‑scale Fixed Multi‑chamber OWC Device. Chinese Journal of Mechanical Engineering (2021), 34:124. https://doi.org/10.1186/s10033-021-00641-9.

[8] Mohammed AlJuhani, Mohamed R. Gomaa, Talal S. Mandourah, Mowffaq M. A. Oreijah. The Environmental Effects on the Photovoltaic Panel Power: Jeddah Case Study. Journal of Mechanical Engineering Research and Developments (2021), 44 (6), pp. 251-262. https://jmerd.net/06-2021-251-262/

[9] Mohammad Al-Dabbas, Ali Alahmer, Amer Mamkagh, Mohamed R. Gomaa. Productivity enhancement of the solar still by using water cooled finned condensing pipe. Desalination and Water Treatment 2021, 213, 35-43. https://doi.org/10.5004/dwt.2021.26711.

[10] Mohamed R. Gomaa, Hegazy Rezk. Passive Cooling System for Enhancement the Energy Conversion Efficiency of Thermo-Electric Generator. Energy Reports 6 (2020) 87–692. https://doi.org/10.1016/j.egyr.2020.11.149.

[11] Caetano Tara, Bruno Merven, Energy System and Economy-wide Implications of a Rapid Transition to Decarbonized Energy in South Africa, World Institute for Development Economic Research (UNU-WIDER), 2017 No. 039.

[12] Ali Alahmer, Hegazy Rezk, Wail Aladayleh, Ahmad O. Mostafa, Mahmoud Abu-Zaid, Hussein Alahmer, Mohamed R. Gomaa, Amel A. Alhussan, and Rania M. Ghoniem. Modeling and Optimization of a Compression Ignition Engine Fueled with Biodiesel Blends for Performance Improvement. Mathematics 2022, 10, 420. https://doi.org/10.3390/math10030420.

[13] Ahmad O. Hasan, Ahmed I. Osman, Ala'a H. Al-Muhtaseb, Hani Al-Rawashdeh, Ahmad Abu-jrai, Riad Ahmad, Mohamed R. Gomaa, Tanmay J. Deka, David W. Rooney. An experimental study of engine characteristics and tailpipe emissions from modern DI diesel engine fuelled with methanol/diesel blends. Fuel Processing Technology 220 (2021) 106901. https://doi.org/10.1016/j.fuproc.2021.106901.
[14] Mohamed R. Gomaa, Ramadan J. Mustafa, Mujahed Al-Dhaifallah, Hegazy Rezk. A Low-Grade Heat Organic Rankine Cycle Driven by Hybrid Solar Collectors and a Waste Heat Recovery System. Energy Reports 6 (2020) 3425–3445. https://doi.org/10.1016/j.egyr.2020.12.011.
[15] Hani A. AL-Rawashdeh, Mohamed R. Gomaa, Ramadan J. Mustafa, Ahmad O. Hasan. Efficiency and Exergy Enhancement of ORC Powered by Recovering Flue Gases-Heat System in Cement Industrials: A Case Study. International Review of Mechanical Engineering (I.RE.M.E.) 2019, 13(3), 185-197. https://doi.org/10.15866/ireme.v13i3.16713.
[16] Randall Spalding-Fecher, Mamahloko Senatla, Francis Yamba, Biness Lukwesa, Grayson Himunzowa, Charles Heaps, Arthur Chapman, Gilberto Mahumane, Bernard Tembo, Imasiku Nyambe, Electricity supply and demand scenarios for the Southern African power pool, Energy Policy 101 (2017) 403–414.
[17] K. Kusakana, Optimal power flow of a Battery/Wind/PV/Grid hybrid system: case of South Africa, Smart Energy Grid Design for Island Countries, Springer International Publishing, 2017, pp. 447–465.
[18] B.P. Numbi, S.J. Malinga, Optimal energy cost and economic analysis of a residential grid-interactive solar PV system-case.
[19] Ma T, Yang H, Gu W, Li Z, Yan S. Development of walkable photovoltaic floor tiles used for pavement. Energy Convers Manage 2019; 183:764–71.
[20] Bhattacharjee S, Nayak PK. PV-pumped energy storage option for convalescing
performance of hydroelectric station under declining precipitation trend. Renewable Energy 2019; 135:288–302.
[21] Shaoquan Lin, Tao Ma, Muhammad Shahzad Javed. Prefeasibility study of a distributed photovoltaic system with pumped hydro storage for residential buildings. Energy Conversion and Management ,222, (2020) ,113199. https://doi.org/10.1016/j.enconman.2020.113199.
[22] Kanzumba Kusakana, Hybrid DG-PV with groundwater pumped hydro storage for sustainable energy supply in arid areas. Journal of Energy Storage 18, (2018), 84–89. https://doi.org/10.1016/j.est.2018.04.012.
[23] Kanzumba Kusakana. Optimal operation scheduling of grid-connected PV with ground pumped hydro storage system for cost reduction in small farming activities. Journal of Energy Storage 16, (2018), 133–138. https://doi.org/10.1016/j.est.2018.01.007.

## Contribution of individual authors to the creation of a scientific article (ghostwriting policy)
**All are equal**

## Sources of funding for research presented in a scientific article or scientific article itself
**No funding sources**