Modeling the Hybrid Battery/Super-Storage System for a Solar Standalone Microgrid

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***Abstract*—**Solar energy systems using various storages are required to be evaluated based on energy requirements and applications. Also, modeling and analysis of storage systems are necessary to increase the effectiveness of combinations of these systems. In this paper, analysis based on the MATLAB software has been analyzed to evaluate the response of the hybrid energy system considering various technologies of renewable energy and energy storage. In the present study, three different simulation scenarios are presented. Simulation output results using software for the first scenario show that the battery is effective in smoothing the overall power demand to the consumer studied during a day, but temporary loads on the grid with high frequencies, effectively cannot be canceled due to the limited response speed of battery control. Simulation outputs for the second scenario using the energy storage system show that sudden changes in demand power are paved by super saving. The majority of these sudden changes in power demand are caused by sewing consumers and receiving variable solar power (due to clouds passing through the solar array). Simulation outputs for the third scenario show the effects of the hybrid system for the same consumer and the output of the solar array, leading to the smallest amount of power demand fed into the grid, as well as demand at peak times. According to the "battery only" scenario, the displacement technique of the peak load has been significantly reduced.

***Keywords*—**Storage system, super storage, standalone, microgrid.

I. Introduction

SOLAR energy systems are required to be evaluated based on the requirements of energy technology applications. Also, modeling and analysis of storage systems are necessary to increase the effectiveness of combinations of these systems.

In the previous researches [1], [2], analysis based on the content software, to evaluate the response of the hybrid system concerning various technologies of renewable energy and energy storage has been analyzed, the response of this allows us to optimize a solar photovoltaic microgrid according to the location scenario when the sun's energy for a microgrid system is optimized. It is considered that hour-by-hour measurements of sun sources are necessary to provide a suitable forecast of electricity generation. Using the collected data, different combinations of energy resources using possible scenarios related to predicted climate information and economic behavior. In many cases, the hardest step is to collect accurate information from the hourly demand of the analyzed microgrid along with the sun data collected from the synoptic station. After collecting the data, which include the latitude and longitude of the microgrid and wind measurement in the region, there can be used to design a microgrid, utilizing the sizing software. To obtain the best solution based on the current net cost, the whole period was studied. In this research, the software is used for designing and sizing the method in the genetic algorithm.

II. History of Case Research in Microgrid Systems

In recent years, many studies have been conducted on the feasibility of using hybrid systems for electricity generation. Below are several of them that have been done for different regions of the world and have achieved good results.

In a sample study, based on renewable energy sources and load data, the technical and economic justification of hybrid wind and photovoltaic and battery power systems to provide the required load for a family in a residential home in Urumqi, China, was carried out using a hybrid optimization model for renewable resources in Homer simulation software [1]. Analyzing solar radiation data for Urumqi province from national organization databases shows that solar radiation in Urumqi city of China ranges from 1.93 kWh/m^2 to 5.92 kWh/m^2/day, with an average of 4.2 kWh/m^2/day. Most solar radiation is for March to September and the lowest is for October to February. Wind speed synoptic data for Urumqi were obtained from the National Aviation and Space Administration database. In this study, it can be observed that wind speed ranges from 3.32 m/s to 3.94 m/s with an average value of 3.61 m/s. Wind speeds are almost higher from September to May than in other months.

In a study, Ngan et al. analyzed hybrid power systems (photovoltaics, wind turbines, and diesel) for a small town in southern Malaysia, Johor, using Homer's software [2]. Homer simulation software was used to determine the technical feasibility of the system and economic analysis, And the feasibility test is designed using hybrid renewable energy systems. The building consists of five laboratories, six lecture

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rooms, 10 offices, and four bathrooms. In general, the main electricity consumption of this building, which is powered by the electricity organization, is related to the power of air conditioning, lighting, computers, and laboratory equipment. The peak need for electricity in the building is 62.5 kWh and the lowest amount is 16 kWh. During the night, the required load reaches its lowest and increases in the hourly range of 8 to 17 due to working hours. Solar radiation data from the National Aeronautics and Astronautics Organization (NASA) are in [3]. The solar radiation ranges from 4.07 to 5.22 kWh/m^2; the average annual solar radiation is estimated to be 4.56 kWh/m^2/ day, while solar radiation is higher for September, October, February, and March than in other months of the year. It is less until Aug. The resolution index is automatically determined by the software. In the software, Homer's output is seven different systems for supplying the building load. Systems include independent diesel systems, hybrid photovoltaic-diesel systems with batteries and without batteries, wind-diesel hybrid systems with and without batteries, and hybrid photovoltaic-wind-diesel systems with and without batteries. Wind cannot be a good economic alternative for electricity supply if a desired area does not have sustainable wind resources. Despite the higher costs for supplying the required electricity, the photovoltaic-diesel system with 80 kilowatts of solar arrays and 40 batteries, and the photovoltaic-wind-diesel hybrid system with 80 kilowatts of solar arrays and 8 wind turbines and 50 batteries, reduce environmental pollution by 30% and 35%, respectively [3].

In a study to provide energy for the remote Sheikh Abolhassan village in Binalood, Asrari et al. investigated the usage of hybrid renewable power energy systems [4]. Electricity demand for Sheikh Abolhassan village is provided by Khorasan Regional Electricity Company using a 20 kV 3.7 km line, average electricity demand, and annual peak load, 145 kWh/day, respectively. In the monthly average of solar radiation for the study area, the lowest amount of radiation is observed in December with the amount of 2.38 kWh/m^2/day and the highest amount of radiation is in June with the amount of 7.07 kWh/m^2/day, so the average total radiation for the whole year is 4.79 kWh/m^2/m^2. It is located in the second windy region of the country after Manjil. In this study, Binalood wind data in Khorasan Razavi province were used which were obtained from The New Energy Organization of Iran (SUNA).

Binalood station [5] with an average speed of 6.82 m/s at a height of 40 meters and 6.43 m/s at an altitude of 30 meters has a good wind speed. The homer output is 4 different systems for supplying the mentioned village load. Systems include independent diesel systems, wind-diesel hybrid systems with battery, hybrid diesel systems with battery, and photovoltaic-wind-diesel hybrid systems with battery. The autonomous diesel system with an energy production cost of 0.369 $ per kilowatt-hour has the lowest cost to meet the desired load, but annually it imports large amounts of greenhouse gases into the atmosphere, which poses irreparable risks in the future. Due to the low difference in costs in 4 systems, the use of a system with renewable energy sources seems logical.

In a study, Fazelpour et al. examined the supply of a hotel on Kish Island, using combined energies [5]. The hotel has 125 rooms with annual consumption of 2628,000 kWh. Based on the measures obtained, the hotel's hourly load curves are plotted in different seasons to determine the optimal energy system. The hotel's seasonal load is used. Maximum energy demand, mainly based on summer energy consumption (June to August), is estimated at around 620 kilowatt-hours. Generally, due to semi-arid weather conditions as well as tourist activities, energy consumption in summer is higher than in winter.

Reference [6] presents associate degree improvement framework for the look and operation of a standalone microgrid with electrical and hydrogen masses. Two energy management methods are projected and also the improvement model is resolved victimization particle swarm optimization algorithmic rule. Reference [7] argued that isolated networks that are separated from main electrical grids are viable options to supply remote regions. These networks are called standalone microgrid structures. In [8], a standalone micro-grid system such as a photovoltaic (PV) and wind electricity conversion system (wecs) primarily based everlasting magnet synchronous generator (pmsg) is being designed and controlled. Fuzzy good judgment-based most power factor tracking (mppt) is being applied to a boost converter to manipulate and extract the maximum power to be had for the PV device. The management machine is designed to deliver the specified electricity to a particular load, in all eventualities. The excess power generated via the PV panel is used to rate the batteries when the strength generated by the PV panel exceeds the energy required through the burden.

Reference [8] presents an approach for the optimal configuration of stand-alone hybrid microgrids, while using battery storage systems and diesel generators as backup power supply. The proposed methodology highlights the application of a metaheuristic optimization technique, called the Tunicate Swarm Algorithm (TSA) for the optimal design of the proposed microgrid. A case study is carried out in an oasis located in the southwest of Egypt for a hybrid system consisting of PV panels, wind turbines (WT), battery storage, and a diesel generator. The main target of the proposed methodology is to obtain the optimally installed capacities of the microgrid components while ensuring the minimum energy production cost and satisfying a high-reliability index. The results given in [8] demonstrated that the proposed hybrid microgrid system is a profitable choice for electrification in this region.

III. Research Method

The design parameters of solar energy systems are performance parameters that are used to determine reliability and feasibility, allowing the system designer to design the appropriate system according to the specific application. Some of the parameters used in this research are introduced in Table I. This article, is to find the optimal size of a solar-battery/ ultracapacitor array for a microgrid independent of the national grid using a genetic algorithm proposed by [8] to minimize the overall costs of the microgrid including installation costs and meeting the demands for network load at all times with optimal reliability. Fig. 1 represents the schematic of a microgrid independent of the PV -battery hybrid system.

TABLE I
COMPARISON OF DIFFERENT TYPES OF ENERGY STORAGE

Type	Acidic-lead	Lithium-ion	Ultracapacitor
Cell Voltage	2 volts	3.7V	2.75-2.3V
Energy density (Wh/kg)	50-30	200-75	10-5
Power density (W/kg)	300-75	300-150	Up to 10,000
Performance time	10> S	10> S	1> S
Continuous Discharge Time	h10-1 s	h10 -1 s	1ms-1h
Working cycles per hour	2000	>1000	100000
Advantages	High capacity, high energy density	High energy density	High power density, quick response
Disadvantages	Low power density, low working cycle	Small, hard capacity for wide-scale applications	Low energy density, expensive

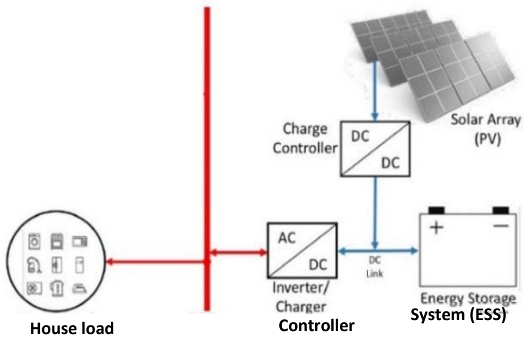

Fig. 1 Microgrid independent of PV-energy storage ESS

IV. MICROGRID SOLAR SYSTEMS USING ESS

A grid-connected solar system using ESS is necessarily used in areas where grid power is not reliable, but the grid produces energy essentially through the use of high-power steam generators heated by coal, natural gas, or nuclear fusion, but due to the work table program, usually in communities, experiences in the network. Grid study has shown that demand and load on the network in the early morning and evening are the highest for residential applications. In the meantime, solar panels convert solar optical energy (photons) from the sun to electricity through the PV effect between silicon panel intersections. Although solar radiation reached its peak in the middle of the day, it is unable to meet the high demand for the network. Energy storage is required to smoothly distribute energy from these sources. In the case of ESS grid failure operation, the energy storage system provides backup electricity to provide consumers with electricity. An ESS system in the solar microgrid connected to the grid for rapid and emergency support and shifting during peak load (reducing consumer energy) by shifting from peak hours to non-peak hours is commonly used.

Comparison of ESS Technologies

Various ESS technologies have advantages and disadvantages based on their applications, Table I represents a comparison of the three ESS technologies in question. Lead-acid batteries have high power density; however, they have lower cycles (life) due to high energy density, on the opposite side, ultracapacitors have higher power density but lower energy density in classification between lead-acid batteries and ultracapacitors. The performance time of acidic-lead and lithium-ion is under 10 seconds whereas the performance time of super-storages is less than 1 second.

V. THE CONCEPT OF THE PROPOSED HYBRID SYSTEM

In this paper, we explain a method for modeling a battery-ultracapacitor hybrid system as specified in Fig. 2. This design will allow the system to be much more efficient at maintaining the available solar power and depreciating according to the type of consumer. By sensing the power of the network, an ESS system will be able to provide a suitable output power to help reduce the load on the delivery grid.

In the ESS modeling, batteries typically support high-energy but less power grid loads, on the other hand, super-storages can support the demand from high-current grid loads despite storing less energy. In this paper, energy constraints are modeled using power integration with saturation limits. The lower limit determines the minimum capacity and the upper limit determines the maximum capacity of the system. If the system reaches a low saturation limit, the permissible output power will be zero. If the system reaches the upper limit, the permissible input power will be zero. ESS power constraints are controlled by the simultaneous resolution of the simple dynamic equations with numerical saturation limits, which have minimum and maximum constant values, the power reference of the battery storage system is controlled by the lower-transition filtered version, from the demand for home power. On the other hand, super-storages entail higher power density but lower energy density. Lithium-ion batteries are classified between acidic-lead batteries and ultracapacitors. The impulse response of these two 1st order filters in the Laplace domain are represented by (1) and (2).

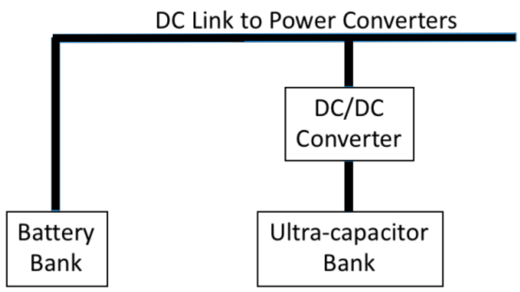

Fig. 2 Hybrid battery maintenance system/super-storage

In (1), H_{LP} is the low-transition filter which is used as a battery power reference, H_{HP} high-pass filter which is used as a supersaver power reference and ω_c is the amplify frequency of filters, the cutoff frequency for both filters is fixed on the number 0.01 Hz.

$$H_{LP}(s) = \frac{w_c}{s + w_c} \quad (1)$$

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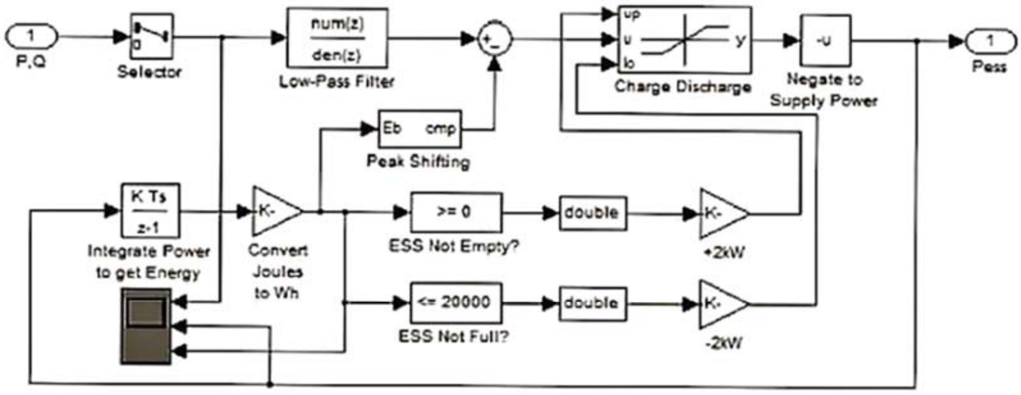
$$H_{HP}(s) = \frac{s}{s + w_c} \quad (2)$$



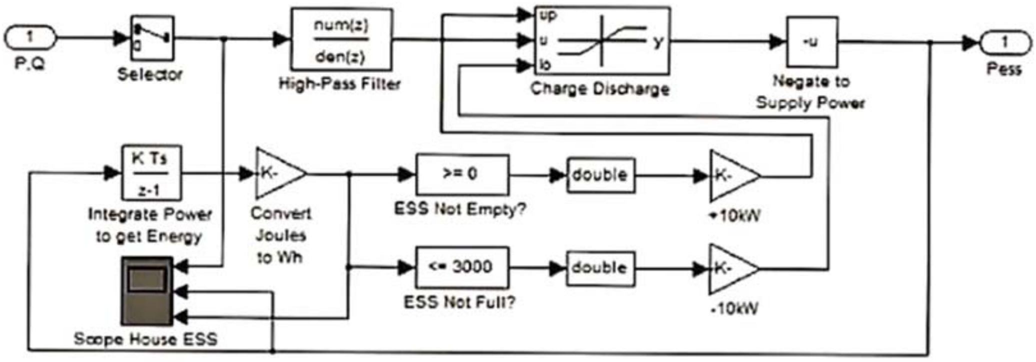


Fig. 3 Modeling (a) battery (b) super-storage

VI. Discussion and Conclusion

A. The Results of Modeling Different Scenarios of Production Source/Consumers

To confirm the analysis of the proposed ESS system control strategies, a solar microgrid system is simulated with daily consumer power demand, as shown in Fig. 4 and a 2 kW solar installation courier as shown in Fig. 5. To observe the effects of the ESS system on the demanded household power, three different simulation scenarios are presented:

- Scenario 1: A house with a solar PV and battery-feeding system
- Scenario 2: A house with an ultracapacitor and solar PV feeding system
- Scenario 3: A house using an ESS battery hybrid system and ultracapacitor plus solar PVs

In each case, the main household power demand is compared to the desired demand for the network, which combines household power, solar power, and compensated power of the ESS system.

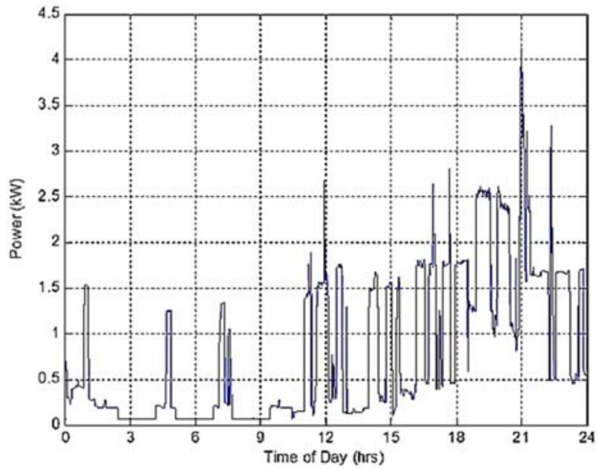


Fig. 4 An example of the demand for power consumption for household use

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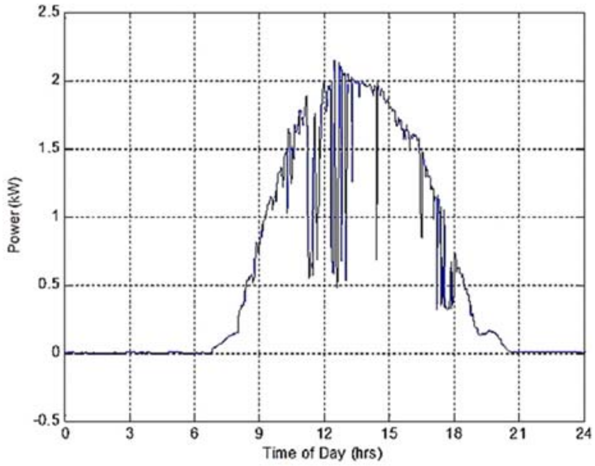

Fig. 5 A solar power absorption sample within 24 hours

TABLE II
PARAMETERS OF MICROGRID SYSTEM SIMULATOR WITH ENERGY STORAGE

Parameter	Amount
Home power demand at the peak point	3 kW
Absorption of solar power at the peak point	2 kW
Battery energy storage capacity	20 kWh
Battery courier power	2 kW
Cloud Storage Energy Storage Capability	3 kWh
The power of the cloud storage courier	10 kW

B. Scenario 1: A House with a Battery Storage system Plus Solar PVs

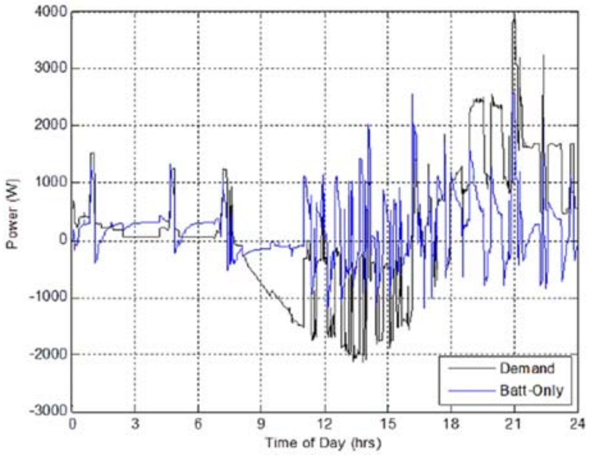

Fig. 6 Home power demand using battery-only storage

From Fig. 6, the behavior of battery control is observed in removing peak points from 700 to 1700 hours. The battery charges and discharges by and to the network, to provide peak. To conclude that the installation of solar PVs, when the battery is deprecated to the grid during the night, was larger than the limit power hours throughout the day. By reducing the power demand during peak hours, it is very helpful to reduce the cost of consumer operation, depending on the size of the PV installation system and the size of the house in this simulation. In conclusion, the installation of solar PVs, when the battery is deprecated to the grid during the night, was larger than the limit.

C. Scenario 2: A House with an Ultracapacitor Source Plus Solar PVs

Simulation outputs for the second scenario are observed using cloud storage in Fig. 7. In this situation, it seems that sudden changes in power demand are smoothed by the supersaver, most of these sudden changes in power demand are caused by the swirling of consumers at home and the output of transient solar power (due to clouds passing through the solar array) as in Fig. 7. It can be seen that cloud storage is unable to shift the average demand out of peak times at night. Due to the limited capabilities of storage, a control method should be used.

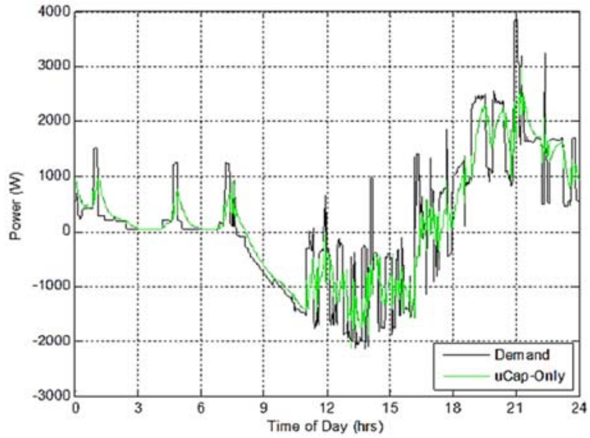

Fig. 7 Home power demand using cloud storage source

D. Scenario 3: A house with an ESS hybrid system plus solar PVs

Fig. 8 shows the effects of the ESS hybrid system for the same consumer and the output of the solar array. The combined topology of ESS leads to the smallest amount of power demand fed into the grid, in addition, demand at peak times, similar to the "battery-only" scenario, has been significantly reduced by the use of the peak load displacement technique.

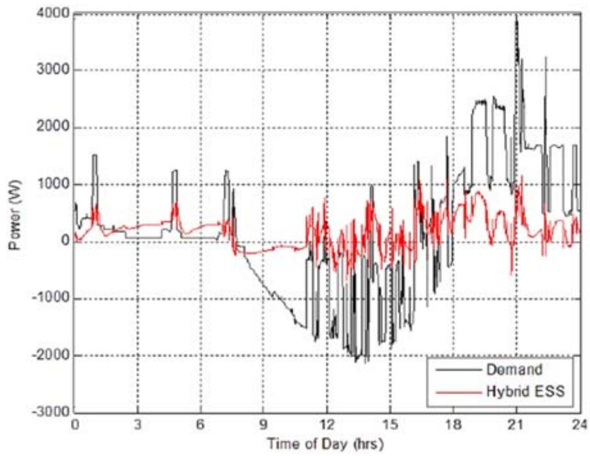

Fig. 8 Household power demand using a hybrid storage system

REFERENCES

[1] Li C, Ge X, Zheng Y, Xu C, Ren Y, Song C, Yang C. (2013). "Techno-economic feasibility study of autonomous hybrid wind/PV/battery power

Open Science Index, Energy and Power Engineering Vol:17, No:2, 2023 publications.waset.org/10012948.pdf

system for a household in Urumqi, China", Journal of Energy, Vol. 55, pp. 263–272.

[2] Ngan MS, Tan CW. (2012). "Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia". Renewable and Sustainable Energy Reviews; Vol. 16, No. 1, pp. 634–647.

[3] Surface meteorology and solar energy. http://eosweb.larc.nasa.gov/sse/ (accessed on 01.08. 2021).

[4] Asrari A, Ghasemi A, Javidi MH (2012). "Economic evaluation of hybrid renewable energy systems for rural electrification in Iran-A case study". Renewable and Sustainable Energy Reviews, Vol. 16, pp. 3123–3130

[5] Fazelpour F, Soltani N, Rosen MA (2014). "Feasibility of satisfying electrical energy needs with hybrid systems for a medium-size hotel on Kish Island, Iran", Journal of Energy, Vol. 73, pp. 856-886.

[6] Mah, A.X.Y., Ho, W.S., Hassim, M.H., Hashim, H., Ling, G.H.T., Ho, C.S. and Ab Muis, Z., (2021). Optimization of a standalone photovoltaic-based microgrid with electrical and hydrogen loads. Energy, 235, p.121218.

[7] Al-Quraan, Ayman, and Muhannad Al-Qaisi. 2021. "Modelling, Design and Control of a Standalone Hybrid PV-Wind Micro-Grid System" Energies 14, no. 16: 4849. https://doi.org/10.3390/en14164849

[8] Mahesh, A., Sandhu, K. S. (2020). "A Genetic Algorithm Based Improved Optimal Sizing Strategy for Solar-Wind-Battery Hybrid System Using Energy Filter Algorithm". Journal of Frontiers in Energy, Vol. 14, No. 1, pp. 139–151.

Open Science Index, Energy and Power Engineering Vol:17, No:2, 2023 publications.waset.org/10012948.pdf