Optimal Sizing of an Isolated Hybrid Wind/PV/Battery System with Considering Loss of Power Supply Probability

Sayed Jamal al-Din Hosseini[1], Majid Moazzami[1,2*], Hossein Shahinzadeh[3]
1- Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran.
Email: j.hosseini@sel.iaun.ac.ir
2- Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran.
Email: m_moazzami@pel.iaun.ac.ir (Corresponding author)
3- IEEE Member, Department of Electrical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran.
Email: h.s.shahinzadeh@ieee.org – shahinzadeh@aut.ac.ir

Received: June 2017 Revised: July 2017 Accepted: September 2017

ABSTRACT
In recent years, renewable energy technologies such as wind and solar have had significant growth. The primary purposes of integration of renewable resources are exploitation of free sources of energy as well as environmental advantages. Besides, they can be used close to the consumption centers in order to remove the necessity of high-voltage transmission lines. The use of such renewable sources along with an energy storage in the form of a hybrid system improves the system reliability. The importance of achieving a proper configuration of off-grid hybrid energy systems in order to reduce the implementation cost and improve the continuous supply of the loads as well as system reliability necessitates the employment of powerful software for optimization. Therefore, in the present study, the HOMER software is used to impose the best possible trade-off between cost and reliability (loss of power supply probability (*LPSP*)) for an off-grid hybrid energy system (consists of wind turbines, photovoltaic panels, and batteries) to supply a load in remote areas. The contribution of this work indicates calculating a solution for optimal configuration of hybrid system incorporating both economic and reliability (*LPSP*) aspects using HOMER software. The data of load, solar radiation and definite wind speed for *Kurdeh* village, located in the central district of the *Larestan* city were used. The system costs consist of initial investment, operational and maintenance of equipment and replacement costs. The considered prices are real and the used equipment is available in the market.

KEYWORDS: Hybrid System; Optimal Sizing; *LPSP*; Net Present Cost; Cost of Energy; HOMER Software.

1. INTRODUCTION

Electrical energy is the most common and popular form of energy. The reason of the widespread use of this kind of energy includes the ease of transmission, low emissions, and high efficiency. Due to population scattering, the biggest problem in the use of electric energy is the inaccessibility to the main electricity network in the remote and impassable areas. Moreover, because of the population scattering and the high number of such off-grid consumers, the construction of long transmission lines and connecting them to the network, usually need high costs and in many cases, is not economically affordable. A solution that has been adopted to overcome this problem is the use of independent systems from the electric network. Several energy sources are used in this system for electricity production, including diesel generators, micro-turbines, wind turbine, photovoltaic, etc. [1].

Generally, hybrid systems are used in such networks. The hybrid system consists of a set of electricity generation systems that are fed from different energy sources and are working together in a complementary and combinatorial way. The different modes of the hybrid systems can be selected regard to the location features of the installation area (the intensity of solar radiation, temperature, wind speed, etc.). In off-grid systems, there is a high tendency to exploit renewable energy sources for local supplying due to the non-renewable and finite nature of fossil fuels as well as high prices of them [2].

The wind and solar energies are the most important renewable resources because of their high efficiency and their feature of having no emission of pollutant gases. The wind and solar systems have a significant implication in lowering the electricity price of the off-grid system due to high efficiency, long lifespan, and low maintenance costs. However, the stochastic nature of these types of energies necessitates the utilization of energy storage systems in order to increase the reliability in independent hybrid systems. The optimized design is the most important issue in using an independent system. The optimization of hybrid system supplies the load with the lowest cost and the best reliability [3-4].

In the reference [5], the HOMER software is used to explore the technical and economic feasibility of wind-solar off-grid hybrid systems with batteries and fuel cells storage in Egypt. In [6], the technical and economic viability study of an off-grid hybrid system (micro-hydro / Photovoltaic / biomass and biogas / diesel generator / battery) in the state of Uttarakhand in India is evaluated using the HOMER software. In this article, the optimal structure has been determined based on the lowest cost of energy (COE) and the net present cost (NPC) by considering the maximum contribution of renewable energy and the least amount of harmful greenhouse gas emissions (CO_2). In [7], the particle swarm optimization algorithm (PSO) is employed to optimize the sizing of an off-grid hybrid renewable energy system (HRES) for supplying electricity of a remote area in Kerman. In this article, the optimal structure has been selected based on minimizing the life cycle cost (LCC) and attaining a specific level of reliability (loss of power supply probability (*LPSP*)). The improved genetic optimization algorithm to optimize the wind-solar hybrid system with battery storage is used in [8]. In this study, optimization is done based on a multi-objective function, including life cycle cost (LCC), *LPSP* and embodied energy (EE).

In [9], the preference-inspired co-evolutionary algorithm using goal vectors (PICEA-g) is used to optimize a hybrid system (wind/solar/diesel generator/battery). In this article, the constraints such as the annual cost of the system (ACS), *LPSP* and emission restrictions have been used to optimize the hybrid system. The authors in [10] have used a wind / solar /pump storage hybrid system for electrification of an independent remote load on the network. In this study, in addition to reducing COE, it is tried to minimize *LPSP* index. In references [11-15], the HOMER software is used to optimize hybrid systems. In these articles, in addition to NPC and COE, *LPSP* is also studied.

The main goal of this study is optimal designing of wind and solar hybrid system with battery storage regard to the *LPSP* reliability index to provide reliable electrical energy with minimal cost. Therefore, HOMER software is used. The data of an independent load in the Kurdeh village, Larestan is analyzed for stimulation. Kurdeh is a village in the central district of Larestan city in Fars province of Iran. It is located in the Dehkuyeh village. According to the data provided by the statistical center of Iran, the census results for this remote area in 2011 shows the population of 3353 people (868 families). The following sections of this study will explain the structure of the hybrid system and related constraints. In the last section, it is attempted to describe the simulations and the conclusions are discussed. In the most of the previous similar works, the HOMER software is used in order to only minimize the total operational and investment costs. However, the importance of reliability is described in the literature which is mostly calculated by intelligent algorithms and swarm optimization methods. The novelty of this work emphasizes on using HOMER to optimize the design of hybrid system while the costs are minimized and the reliability is maximized. In this respect, the index of *LPSP* is incorporated in the HOMER software.

2. MODELING OF THE STUDIED HYBRID SYSTEM

The studied hybrid system consists of wind turbines, solar panels, batteries, converters, control and communication equipment. The schematic diagram of the system is shown in Figure 1. In this section, each of these components has been studied, and the appropriate model and technical specifications of each one are presented.

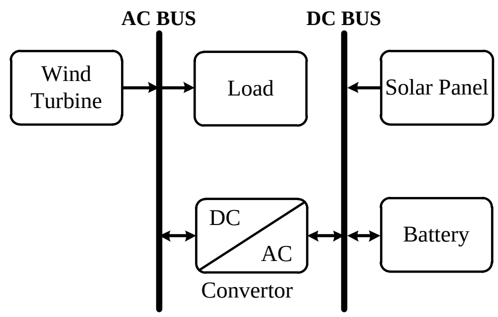

Fig. 1. Studied schematic diagram of the hybrid system.

2.1. Wind Turbine

Wind power, like other renewable energy sources, is an omnipresent energy and is considered as a dispersed and decentralized energy that is almost always accessible. The output power of a wind turbine is calculated by (1) [16]:

$$P_{WT}^{t} = \begin{cases} 0 & v \le v_{ci} \;\; OR \;\; v \ge v_{co} \\ \dfrac{(v - v_{ci})}{(v_r - v_{ci})} P_r & v_{ci} \le v \le v_r \\ P_r & v_r \le v \le v_{co} \end{cases} \tag{1}$$

Where $P_{WT}{}^{t}$ is the output power of the wind turbine at time t, P_r is the nominal power of each wind turbine, v is the wind speed, v_{ci} is the cut-in speed, v_{co} is the cut-out speed, v_r is the nominal speed (rated velocity) of the turbine. The data of utilized wind turbines in this paper is shown in Table 1.

2.2. Photovoltaic Panel

A phenomenon that generates electricity by light irradiation is called photovoltaic phenomenon, and any system that uses this phenomenon is called photovoltaic system. The equation 2 and 3 declare the estimated generated power of photovoltaic cells [17].

$$P_{PV} = N_s \times N_p \times \frac{G_t}{G_0} \times \eta_{MPPT} \times P_{PV,\text{rated}} \quad (2)$$

$$G_t(\theta_{\text{PV}}) = G_V(t) \times cos(\theta_{\text{PV}}) + G_H(t) \times sin(\theta_{\text{PV}}) \quad (3)$$

Where N_p and N_s are the number of rows and columns of solar panels, G_t is the intensity of solar radiation at time t. $P_{PV,rated}$ is the nominal value of solar power for 1000W/m^2 of radiation per cell. It is assumed that all photovoltaic systems have maximum power point tracking (MPPT) and the efficiency of this system is considered 98%. In this equation, θ_{pv} declares the installation angle of solar panels regard to the benchmark of earth's surface and is considered equal to latitude of the intended region. The characteristics of photovoltaic panels used in this paper are shown in Table 1.

2.3. Battery Model

Batteries have two different applications in a hybrid system: 1- Storing the extra power generated by the system, 2- Providing additional energy requested by the load. The battery status of charge (*SOC*) can be calculated by (4) [18]:

$$SOC(t+1) = SOC(t) + \eta_{Battery} \times \left(P^i_{Battery}(t) / V_{bus}\right) \times \Delta t \quad (4)$$

Where $SOC(t)$ is the amount of energy stored in the batteries in the last day, η_{Battery} is the battery efficiency and $P^i_{Battery}(t)$ is the total power stored in the battery in the same day. Moreover, the battery bank, which has a specified total nominal capacity, is allowed to discharge to a certain level which can be determined by the *DOD* as follows:

$$SOC_{\min} = \left(1 - DOD\right) \times SOC_{\max} \quad (5)$$

Where *DOD* is the maximum level of discharge of battery, SOC_{min} is the lower limit of charging status; SOC_{max} is the upper limit while charging of the battery. The data of battery used in this project is shown in Table 1.

2.4. Converter

Converter indicates the elements that convert direct current to alternating current and vice versa. It should be noted that the type of employed converter is voltage source converter. Hence, the toolbox of convertor is used in HOMER software's interface which functions as both AC/DC and DC/AC convertors. Electric converters do not have moving or rotating components and they have different applications in various power ranges. The data of electric converter that is used in this study is shown in Table 1.

3. RELIABILITY OF THE SYSTEM

The consideration of the real profit of utilized hybrid system in this article (wind/solar/battery) and providing ensured continuous operation of the hybrid system to supply the needed power of consumer necessitate the calculation of system reliability.

Table 1. Technical and economical characteristics of the hybrid systems' components.

Wind Turbine	
Nominal wind turbine power (P_r)	1.5*kW*
Cut-in wind speed (V_{ci})	3*m/s*
Cut-out wind speed (V_{co})	25*m/s*
Nominal wind speed (V_r)	8*m/s*
Wind turbine cost (C_{WT})	*$*4500
Replacement wind turbine cost	*$*4000
Operation and maintenance cost (*O&M*)	50*$/year*
Mechanical efficiency of wind turbine (η_{WT})	85%
Wind turbine lifetime	25 *years*
Photovoltaic	
Nominal *PV* power (P_{PV})	200*W*
PV panel cost (C_{PV})	*$*366
Replacement *PV* panel cost	*$*350
Annual maintenance cost of *PV*	4 *$/year*
PV efficiency (η_{PV})	20%
PV lifetime	25 *years*
Battery	
Battery cost (C_{Ba})	*$*520
Replacement cost of Battery	*$*450
Nominal capacity of Battery	1.2*kWh*
Battery lifetime	10 *years*
Operation and maintenance cost ($C_{O\&M}$)	5*$/year*
Converter	
Nominal Converter Power (P_{Conv})	1*kW*
Converter cost (C_{Conv})	*$*950
Replacement cost of Converter	*$*850
Operation and maintenance cost ($C_{O\&M}$)	10*$/year*
Converter lifetime	15 *years*
Converter efficiency(η_{Conv})	90%

The uncertainty in energy production from the wind and solar resources during the day will decrease the reliability of the system. Therefore, it is necessary to add an energy storage facility to the above combination of resources to maintain the reliability of the entire system at the desired level, and also to recover the high investment cost of using wind turbines and solar panels significantly. In this article, to evaluate the level of system reliability the *LPSP* index is employed. A reliable power system is a system that has a little loss of power supply probability. The shortage of power supply for the day t, can be calculated via (6) [19]:

$$LPS(\text{t}) = P_{load} \times \Delta t - (P_p \times \Delta t + SOC(t-1) - (SOC_{min}))\eta_{inv} \quad (6)$$

Where P_p is the generated power by the hybrid system, P_{load} declares the load consumption and Δt defines the considered time intervals. Accordingly, *LPSP* for a period of time T respect to the value of $LPS(t)$ can be expressed as in (7). In this equation, T is the operating time of the system.

$$LPSP = \sum_{t=1}^{T} LPS(\text{t}) \Big/ \sum_{t=1}^{T} P_{load}(t) \times \Delta t \quad (7)$$

4. HOMER SOFTWARE

The HOMER software is made and developed by the *US* national renewable energy laboratory (NREL). The HOMER software is used for technical and economic simulation and evaluation of the hybrid systems. This software enables users to compare different design choices based on their technical and economic aspects. It also provides the possibility of applying the changes and uncertainties in the inputs. This software can model the operation of a specific configuration of energy system for each hour of years by determining the possible methods of supplying the demand and evaluating the life cycle cost. In optimization process, the software searches for all different arrangements of electric power supply by considering corresponded limitations in order to achieve the most economical mode of life cycle cost.

In the HOMER software, for modeling a hybrid system consisted of photovoltaic cells and wind turbines, the data of solar radiation and wind speed of the region are inserted into the software. The HOMER software calculates the amount of energy from renewable sources, according to the hourly steps. The HOMER software uses the net present cost (*NPC*) according to (8) for the life-cycle cost. The *NPC* includes the cost of the initial investment, replacement cost, maintenance, fuel, the purchase of electricity from the main grid, penalties resulted from the air pollution, and the sale of electricity to the grid. In the calculation of the *NPC*, costs are considered positive and incomes are assumed to be negative.

$$NPC = \frac{C_{tot}}{CRF(i,T_p)} \quad (8)$$

Where C_{tot} represents the total annual cost, T_p is the lifetime of the project; $CRF\ (i,T_p)$ indicates on the capital recovery factor of investment which can be obtained through (9). In this equation, i shows the real interest rate, and N is the number of years.

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (9)$$

In this article, in the optimization of the studied hybrid system, not only the *NPC* index is considered, but also the reliability index of *LPSP* is taken into account. The solution with the lowest *NPC* and the lowest *LPSP* will be selected as the optimal choice [20-22]. Figure 2 depicts the flowchart of hybrid system optimization procedure in HOMER software.

5. SIMULATION RESULTS OF PROPOSED HYBRID SYSTEM

To study the structure of the proposed hybrid system by HOMER software, the data of wind speed, solar radiation and the load profile of an off-grid load in the *Kurdeh* village in the central district of *Larestan* city is modeled and implemented in the software.

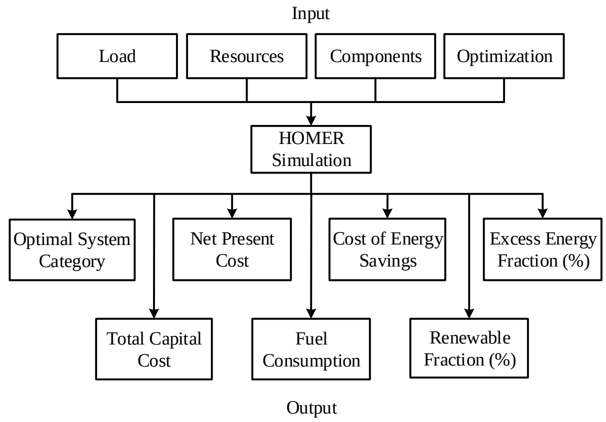

Fig. 2. The hybrid system optimization procedure in HOMER software [23].

Kurdeh village is a district of *Larestan* city, located in Fars province, in longitude of 54 degrees 20 min and latitude of 27 degrees 40 min at an altitude of 806 meters above the sea level. The data of wind speed and solar radiation are provided in average hourly records from 1st January to 31th December 2015 by the meteorological agency and can be seen in Figures 3 and 4. It should be noted that wind speed is measured at the height of 40 meters**.** The power dispatch and the studied load consumption are also measured hourly at the same time in 2015 and are shown in figure 5.

Technical and economic analysis of hybrid systems by HOMER software needs modeling the project by inputting the detailed information of each component of the project including photovoltaic cells, wind turbines, batteries, converters, as well as parameters such as longitude and latitude of the site, the useful life of the project, the average annual interest rate, the rate of solar radiation and wind speed, environmental pollutant emissions, the amount of load consumption etc. Then the most optimal design of the hybrid system will be proposed. In the simulation process, the HOMER software simulates all possible states, and then sorts them according to the *NPC* and finally introduces a feasible configuration with the lowest *NPC* as the optimum arrangement. In this article, the optimal economic structures of the hybrid system are shown in Table 2 in different reliability ranges (*LPSP* = 0.01~0.05) while the costs corresponding to hybrid energy system is calculated based on consideration of lifetime of 25 years and annual interest of 10%. During the lifespan of the project, solar panels and wind turbine will be usable (available) and do not need to be replaced.

In order to better understand the results of simulation for each of the hybrid system components, the simulation is carried out with the minimum and maximum daily electric load of 20~30 kWh/d and the different reliabilities of *LPSP*=0.01~0.05 which are displayed in the figures 6 to 9.

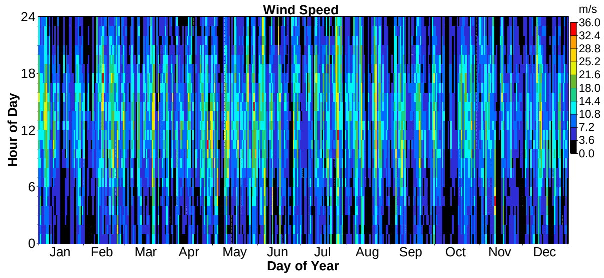

Fig. 3. Annual wind blowing curve at the studied site.

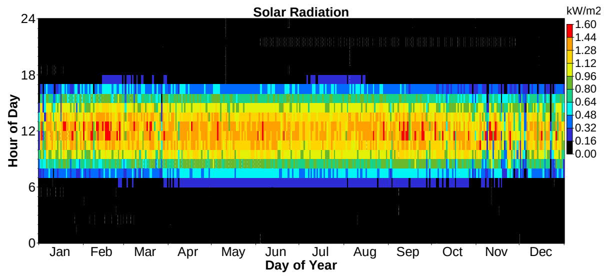

Fig. 4. Annual solar radiation curve at the studied site.

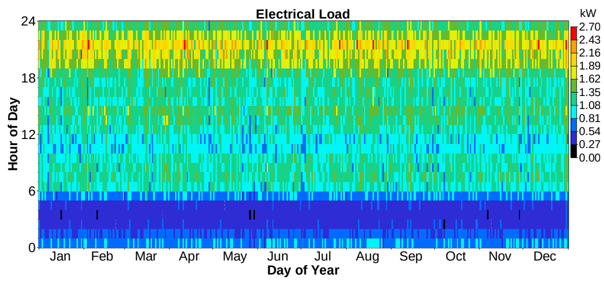

Fig. 5. Annual consumption load curve.

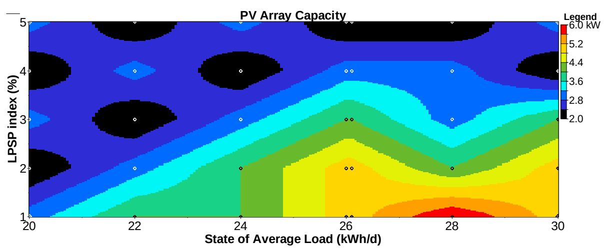

Fig. 6. Solar panel sensitivity analysis curve.

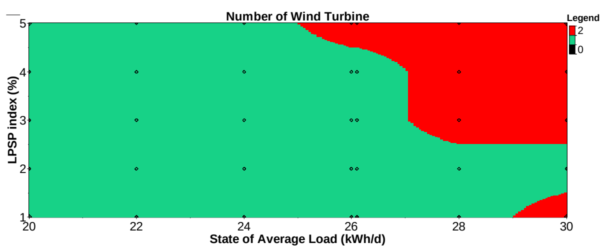

Fig. 7. Wind turbine sensitivity analysis curve.

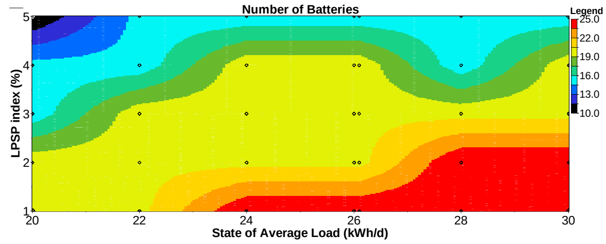

Fig. 8. Battery sensitivity analysis curve.

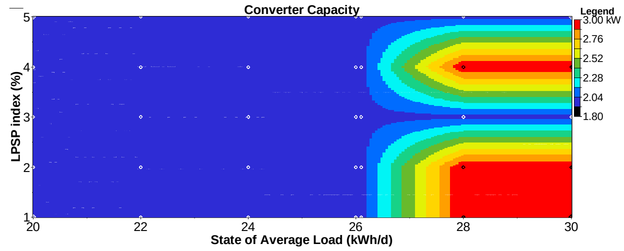

Fig. 9. Converter sensitivity analysis curve.

As it can be seen in Figures 6 to 9, by increasing the amount of *LPSP*, the number and the size of equipment of hybrid system become lower, which reduces the net present cost (*NPC*) of the system. Since in this system, the reliability index (*LPSP*) in the range of 0.01~0.05 is allowed, hence, in order to achieve the most economic combination the *LPSP* value is considered to be 0.05. In this case, in the condition of the average electrical load of the system (26 *kWh/d*), the most optimal energy system by proposed method consists of 2*kW* photovoltaic cells, 2 wind turbines with the capacity of 1.5*kW*, a 2*kW* electric converter and 15 batteries. According to the performed simulation, the wind turbine generates 19509 *kWh/yr*, within a year that accounts for 83% of the generation of the hybrid system. The photovoltaic panels also will generate 4005 *kWh/yr*, within a year which shows the contribution of 17% in the hybrid system generation.

6. CONCLUSION

The aim of this study is to provide a new method for finding an optimal combination of a hybrid system including renewable energies. Regard to the need of reducing investment costs in designing hybrid systems and having better competitiveness with similar fossil-based hybrid systems, the existence of a powerful tool for determining proper configuration is necessary. Therefore, in this article, for optimum design and simulation of the hybrid system, the HOMER software is used. In optimization process, not only the costs are reduced, but also some aspects of reliability (*LPSP*=0.01~0.05) are taken into consideration. The results show that in *LPSP*=0.05, the number and the size of hybrid system equipment are less than other possible scenarios, which reduce the net present cost (*NPC*) of the system. Therefore, the optimum configuration of the hybrid system according to proposed method consists of 2*kW* photovoltaic cells, 2 wind turbines with the capacity of 1.5*kW*, a 2*kW* electric converter and 15 batteries. In this combination of resources, the share of 83% of the generation is provided by the wind turbines and the rest of required generation (17%) are satisfied by photovoltaic panels.

Table 2. The optimized configuration results by HOMER software in different reliabilities.

Optimization Parameters	*LPSP* & Load=26kWh/d				
	0.01	0.02	0.03	0.04	0.05
Photovoltaic (kW)	5	5	4	3	2
Number of Wind Turbine	1	1	1	1	2
Number of Battery	25	20	20	20	15
Converter (kW)	2	2	2	2	2
Total Capital Cost ($)	28550	25950	24120	22290	22360
Total Net Present Cost (NPC) ($)	37073	33470	31318	29125	28142
Total O&M Cost ($/yr)	295	270	250	230	235
Operating Cost ($/yr)	939	828	793	753	637
Cost of Energy (COE) ($/kWh)	0.432	0.394	0.37	0.347	0.338
PV Production (kWh/yr)	10013	10013	8011	6008	4005
Wind Production (kWh/yr)	9754	9754	9754	9754	19509

REFERENCES

[1] Aktas, Ahmet, Koray Erhan, Sule Ozdemir, and Engin Ozdemir. **"Experimental investigation of a new smart energy management algorithm for a hybrid energy storage system in smart grid applications,"** *Electric Power Systems Research*, Vol. 144, pp. 185-196, 2017.

[2] Shahinzadeh, Hossein, Gevork B. Gharehpetian, S. Hamid Fathi, and Sayed Mohsen Nasr-Azadani. **"Optimal Planning of an Off-grid Electricity Generation with Renewable Energy Resources using the HOMER Software,"** *International Journal of Power Electronics and Drive Systems 6*, No. 1, pp. 137, 2015.

[3] Shahinzadeh, Hossein, Mohammad Moien Najaf Abadi, Mohammad Hajahmadi, and Ali Paknejad. **"Design and Economic Study for Use the Photovoltaic Systems for Electricity Supply in Isfahan Museum Park,"** *International Journal of Power Electronics and Drive Systems* 3, No. 1, pp. 83, 2013.

[4] Shahinzadeh, Hossein, Alireza Gheiratmand, Jalal Moradi, and S. Hamid Fathi. **"Simultaneous operation of near-to-sea and off-shore wind farms with ocean renewable energy storage,"** In *Renewable Energy & Distributed Generation (ICREDG), 2016 Iranian Conference on*, pp. 38-44. IEEE, 2016.

[5] Rezk, Hegazy, and Gamal M. Dousoky. **"Technical and economic analysis of different configurations of stand-alone hybrid renewable power systems–A case study,"** *Renewable and Sustainable Energy Reviews 62*, pp. 941-953, 2016.

[6] Bhatt, Ankit, M. P. Sharma, and R. P. Saini. **"Feasibility and sensitivity analysis of an off-grid micro hydro–photovoltaic–biomass and biogas–diesel–battery hybrid energy system for a remote area in Uttarakhand state, India."** *Renewable and Sustainable Energy Reviews 61*, pp. 53-69, 2016.

[7] Askarzadeh, Alireza, and Leandro dos Santos Coelho. **"A novel framework for optimization of a grid independent hybrid renewable energy system: A case study of Iran,"** *Solar Energy 112*, pp. 383-396, 2015.

[8] Abbes, Dhaker, André Martinez, and Gérard Champenois. **"Life cycle cost, embodied energy and loss of power supply probability for the optimal design of hybrid power systems,"** *Mathematics and Computers in Simulation 98*, pp. 46-62, 2014.

[9] Shi, Zhichao, Rui Wang, and Tao Zhang. **"Multi-objective optimal design of hybrid renewable energy systems using preference-inspired coevolutionary approach,"** *Solar Energy 118*, pp. 96-106, 2015.

[10] Ma, Tao, Hongxing Yang, Lin Lu, and Jinqing Peng. **"Optimal design of an autonomous solar–wind-pumped storage power supply system,"** *Applied Energy 160*, pp. 728-736, 2015.

[11] Ma, Tao, Hongxing Yang, and Lin Lu. **"A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island,"** *Applied Energy 121*, pp. 149-158, 2014.

[12] Belmili, Hocine, Mourad Haddadi, Seddik Bacha, Mohamed Fayçal Almi, and Boualem Bendib. **"Sizing stand-alone photovoltaic–wind hybrid system: Techno-economic analysis and optimization,"** *Renewable and Sustainable Energy Reviews 30*, pp. 821-832, 2014.

[13] Rehman, Shafiqur, Md Mahbub Alam, Josua P. Meyer, and Luai M. Al-Hadhrami. **"Feasibility study of a wind–pv–diesel hybrid power system for a village,"** *Renewable Energy 38*, No. 1, pp. 258-268, 2012.

[14] Kalinci, Yildiz, Arif Hepbasli, and Ibrahim Dincer. **"Techno-economic analysis of a stand-alone hybrid renewable energy system with hydrogen production and storage options,"** *International Journal of Hydrogen Energy 40*, No. 24, pp. 7652-7664, 2015.

[15] Rezzouk, H., and A. Mellit. **"Feasibility study and

sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of Algeria," *Renewable and Sustainable Energy Reviews 43*, pp. 1134-1150, 2015.

[16] Shahinzadeh, Hossein, Mohammadreza Matin, Seyed-Saeed Seyed-Barzani, G. B. Gharehpetian and A. A. Khodadoost Arani. **"Integrated Operation of Thermal Power Plants and Wind Resources using Glowworm Swarm Optimization Algorithm,"** *In 2016 1st International Conference on New Research Achievements in Electrical and Computer Engineering* (*ICNRAECE*), IEEE, 2016.

[17] Shahinzadeh, Hossein, Alireza Gheiratmand, S. Hamid Fathi, and Jalal Moradi. **"Optimal design and management of isolated hybrid renewable energy system (WT/PV/ORES),"** In *Electrical Power Distribution Networks Conference (EPDC), 2016 21st Conference on*, pp. 208-215. IEEE, 2016.

[18] Isa, Normazlina Mat, Himadry Shekhar Das, Chee Wei Tan, A. H. M. Yatim, and Kwan Yiew Lau. **"A techno-economic assessment of a combined heat and power photovoltaic/fuel cell/battery energy system in Malaysia hospital,"** *Energy* 112, pp. 75-90, 2016.

[19] Shahinzadeh, Hossein, Majid Moazzami, Mehrdad Abbasi, Hossein Masoudi, and Vahid Sheigani. **"Smart design and management of hybrid energy structures for isolated systems using biogeography-based optimization algorithm,"** In *Smart Grids Conference (SGC),* pp. 1-7, IEEE, 2016.

[20] Shahinzadeh, Hossein, Majid Moazzami, S. Hamid Fathi, and Gevork B. Gharehpetian. **"Optimal sizing and energy management of a grid-connected microgrid using HOMER software,"** In *Smart Grids Conference (SGC),* pp. 1-6. IEEE, 2016.

[21] Olatomiwa, Lanre, Saad Mekhilef, A. S. N. Huda, and Olayinka S. Ohunakin. **"Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria,"** *Renewable Energy* 83, pp. 435-446, 2015.

[22] Hossain, Monowar, Saad Mekhilef, and Lanre Olatomiwa. **"Performance evaluation of a stand-alone PV-wind-diesel-battery hybrid system feasible for a large resort center in South China Sea, Malaysia,"** *Sustainable Cities and Society* 28, pp. 358-366, 2017.

[23] Erdinc, O., and M. Uzunoglu. **"Optimum design of hybrid renewable energy systems: Overview of different approaches,"** *Renewable and Sustainable Energy Reviews* 16, No. 3, pp. 1412-1425, 2012.