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Participation of Renewable Energy in Providing Demand Response in Presence of Energy Storage

Ehsan Akbari [1*], Abdul Reza Sheikholeslami [2] and Farhad Zishan[3*]

1. Faculty of Electrical and Computer Engineering, Mazandaran University of Science and Technology, Babol, Iran.
2. Faculty of Electrical and Computer Engineering, Babol Noshirvani University of Technology, Babol, Iran
3. Department of Electrical Engineering, Sahand University of Technology, Tabriz, Iran..

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**Corresponding author: akbari.ieee@gmail.com (E.Akbari), f_zishan99@sut.ac.ir (F.Zishan)*

Abstract
Due to the lack of transmission and distribution network in remote and impassable areas due to the high cost of construction of the transmission line along with the unsuitable geographical conditions, and taking into account the factors affecting sustainable energy production, the use of a hybrid system seems like a sensible solution. Designing hybrid systems in order to respond throughout the year is of paramount importance. In this research work, we investigate the participation of wind turbine, photovoltaic, and hybrid system with demand response in the presence of energy storage. The participation of renewable energy in providing demand response will be presented in three seminars: 1: the role of wind turbine partnership with storage, 2: the role of photovoltaic with storage, 3: hybrid mode with storage. The best ways to generate electricity are sought from three different scenarios to select the best possible case. It can be said that renewable energy is economically competitive with fossil energy, and this energy can be used and implemented along with the distribution networks. While analyzing the participation of different hybrid systems and estimating the cost of optimization, the total price for each unit of energy production, energy storage, Net Present Cost (NPC), and participation in demand supply will be compared. The comparative results show that the hybrid design can have a more appropriate and desirable performance. The HOMER software is used to determine the optimal possible modes for these systems, in the position of 37 degrees latitude and 42 degrees longitude.

Keywords: *Renewable Energy Participation, Demand Response, Energy Storage, Net Present Cost..*

1. Introduction

Utilizers of fossil resources have realistically found that the extraction of fossil resources at the present time will lead to less productivity in the coming days and ultimately depletion of resources in the short term. Among these, the use of renewable energy, i.e. the use of energy sources that are constantly being replaced in comparison with human life expectancy [1, 2], is one of the best solutions for the human beings. Due to easy access and renewable structure, renewable energy is a good alternative to fossil power plants [3]. The lack of electricity network in remote and impassable areas due to the high cost of construction of the transmission line, the feasibility of a hybrid system independent of the network, is a good solution to meet the need for electricity [4-6].
Some of the basic issues and problems are:

- The renewable energy works close to the distribution voltage; because they are close to the point of consumption and provide DC or AC voltage with variable frequency. Therefore, they need power-electronic equipment that can communicate between the network and the load [7].
- The output of renewable energy systems are affected by weather conditions, which are an important issue regarding the connection to the power grid [8].
- The existing power network has several levels of power transmission. Any change in these levels leads to some problems [9].
- Power-electronic equipment improves and adapts the system by converting power from a source to a constant AC frequency. They also provide various ancillary services to the network [10].

In Ref. [11], the optimal size of a renewable energy system is examined in a Bangladesh case study system. In this work, an overview is provided using the Homer software for optimal planning of hybrid systems. The use of these resources has led to reduced costs and reduced pollution. Ref. [12] presents the production management analysis of a battery-independent photovoltaic system. In Ref. [13], a hybrid system including photovoltaic, wind turbine, and battery is economically evaluated. In Ref. [14], the hybrid system (wind, solar, and hydrogen system) is investigated. The purpose of this method is to achieve a high reliability of the whole system along with lower cost compared to the previous hybrid systems. In Ref. [15], various case studies examine the economic and technical benefits of providing local reactive power for renewable energy.

In Ref. [16], a comprehensive storage control strategy is proposed, which includes an economic control model and an efficient control model.

In Ref. [17], a new model is proposed for optimal design and power management of a renewable energy. In Ref. [18], the term smart grid refers to the modernization of the electrical network including the integration of various technologies such as distributed generation, communication systems, and storage devices that operate in network and island-connected modes. In Ref. [19], considering the reliability criterion, a model is presented for calculating the optimal size of the energy storage system in a renewable energy. The larger the (energy storage system), the higher the investment costs, while the lower the cost of operating the micro-grid. In Ref. [20], a stable energy distribution for the micro-grid is performed in a power system. The results show that this current configuration works in the shortest possible time and stabilizes the network. In Ref [21], electricity demand is fully met despite systemic constraints.

According to the results of the presented researches, it can be said that:

- Backup power supply (BPS) to provide power to sensitive loads such as special industrial units during network power outages and improve the level of reliability.
- On the other hand, in New networks of different renewable energies can exist, which are also in close proximity to each other, may cause to prevent loads from multiple grids of the same power or prevent.
- Load supply separately from the network for remote areas, which is very expensive due to geographical barriers to power supply to them through the network.
- Minimizing the peak by providing the required load power during peak hours.
- Boosting the system voltage in rural and remote areas connected to the network.
- Combined production of heat and electricity in order to achieve a higher efficiency in energy consumption.
- Providing part of the required power in the base load.
- Postponing the construction and development of the network.
- Reducing environmental pollution, especially for the products based on renewable energy.
- Preventing the increase of network capacity and reducing electrical losses in the transmission and distribution sector.
- Increased penetration of energy sources that rely on heavily on renewable energies and are located near loads; in addition to reducing the operating costs of causal units, it prevents the construction of new retrofits or transmission lines to supply loads.

In this research work, we will try to make an effective and strong source of economic and geographical information for the construction of power plants as a strategic document and it can be used for the development of the country. The participation of micro-grids in providing demand response will be presented in three seminars. Therefore, the micro-grid has three operating modes: grid-connected mode, island mode, and transient between these two modes. In all modes, the generated energy can be used to supply local loads.

Therefore, in this research work, renewable energy will be connected to the network, and will provide part of the load. The simulation will be performed in the HOMER software, which is optimization software and also receives geographical area information online.

2. Renewable energy structure

The overall structure of the renewable energy is shown in figure 1 as an example. The renewable energy is connected to the main network through a common coupling point. The generation unit is responsible for generating electricity, and includes two types of rotary and inverter sources [20]. The rotary type includes AC motors, gas, and diesel turbines, while the inverter type includes photovoltaic, fuel cells and wind turbines, etc. Both of them must have electronic-power converters as interfaces. The power level of the units is from the low range of 5 KW to 100MW (Figure 2).

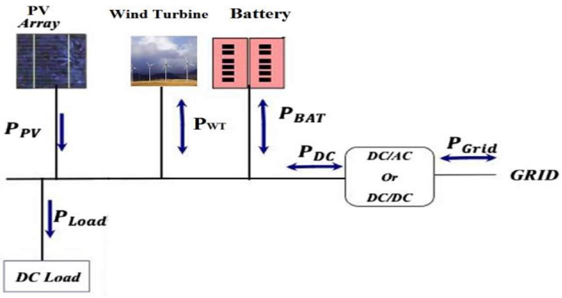


Figure 1. Overall structure of renewable energy.

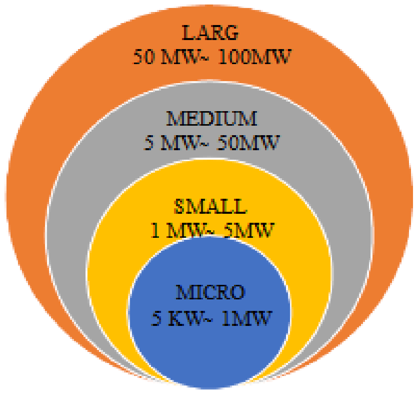


Figure 2. Power level of renewable energy.

Scattered production sources such as photovoltaic and wind turbines are inherently fluctuating in nature. On the other hand, it is always possible to change the load in the power system, so the existence of energy storage resources is necessary for the system stability and power injection during peak hours when the system is faced with a shortage of production capacity, and the imbalance between production and consumption is high [22].

3. Demand response renewable energy and demand response planning model

Demand response has been modeled, and is a priority in many recent papers. References [23, 24] in these papers are devoted to production planning in the presence of DPRs. In reference [25], DR is a model as a quadratic function of both converter demand and reactive power. It is worth noting that reactive power avoids changing from a certain level to specific converter power consumption. Reference [26] focuses on the demand-side management of MGs with respect to ESSs. Also the optimal control of the island micro-grid frequency has been performed by the PID controller in the presence of the micro-grid in the references [27, 28].

Optimizing the Net Present Cost of the micro-grid is essential for its useful life. The system life is assumed to be 25 years, which is equal to the longest component life. The total current net cost of the system is as described in equation (1) [29-33]:

$$\mathbf{Tcost} = \mathbf{NPC_{PV} * N_{PV} + NPC_{WT} * N_{WT} + NPC_{B} * N_{B} + NPC_{Inverter} * N_{inverter}} \quad (1)$$

so that NPC is the net current cost and N is the equivalent number or capacity.

The decision variables are the capacity of renewable wind and solar sources. The capacity of a programmable energy storage system is defined over a period of time.

The decision variables include problem constraints including operational and physical constraints on components, energy balance, production resource constraints, equipment capacity, energy storage constraints, and adequate reliability of consumption load supply.

Depending on the production capacity and load consumption capacity, the battery bank can be charged or discharged. This section presents the relationship between battery capacity and charging and discharging power. Battery input capacity can be positive or negative depending on the charging or discharging function:

$$\mathbf{P_B = P_{WT} + P_{PV} - \frac{T_L}{\eta}} \quad (2)$$

In this relationship, P_B is battery, T_L represents the total consumed load in the moment, and η is the efficiency of the converter. If P_B = 0, then the capacity of the battery bank remains unchanged. Due to the fact that charging and discharging the battery banks at the same time is not possible, some restrictions on these processes are considered to prevent a reduction in the useful life of each battery.

The net present cost of the whole system is considered as a criterion for economic evaluation. The total cost of each component k is determined by equation (3):

$$\mathbf{T_k = IC_K + RC_K + OM} \quad (3)$$

IC_K : Initial cost (purchase, installation, and commissioning), RC_K: replacement cost, OM: operation cost and maintenance.

Capital Recovery Factor (CRF) is used to convert the initial cost to the annual cost:

$$\mathbf{CRF = \frac{i(1+i)^n}{(1+i)^n - 1}} \quad (4)$$

i , interest rate, and n is the system life. The initial annual cost of equation (5) is determined:

$$\mathbf{AIC_k = IC_K * CRF} \quad (5)$$

To calculate the total net cost:

$$\textbf{Total cost} = \frac{T_k}{CRF} \quad (6)$$

f the network in question has N consumers, each consumer tries to reduce his energy consumption for the next H hour compared to the previous hours by using load management and control of different parts. The energy of each subscriber is expressed as follows [34]:

$$q_n = (q_n^1, \dots, q_n^H) \quad (7)$$

$$\sum q_n = E_n \quad (8)$$

During each day and night, each subscriber, having information on the consumption of other subscribers and manufacturers, seeks to find a time when energy consumption is lower, which confirms the results obtained from the simulation of peak load reduction. [35]:

$$PLR = \frac{\sum_{i=1}^{N} l_i^T}{\frac{1}{T}\sum_{i=1}^{N} E_i} \quad (9)$$

where l_i^T is the energy consumption of each subscriber, E_i is the total energy consumption of each subscriber, and T is the duration in one day, i.e. 24 hours.

4. Implementation of Studied System

The proposed system is designed by the HOMER software. This software is provided by the International Renewable Energy Organization. It can be used to measure hybrid systems based on the net present cost. In fact, the HOMER software allows us to examine the effect of changing a variable on the entire system. This software requires data from energy sources such as the type of system components, the number of components, costs, efficiency, lifespan, economic constraints, and control methods. The technical and economic specifications of the renewable energy components are according to tables 1 to 4.

Table 1. Photovoltaic specifications.

Nominal capacity	1 kw
Initial cost	1000$/unit
Placement cost	800$/unit
Maintenance cost	10$/year
Useful life	25 years

Table 2. Wind turbine specifications.

Nominal capacity	1 kw
Initial cost	1300$/unit
Placement cost	700$/unit
Maintenance cost	130$/year
Useful life	25 years

Table 3. Battery bank specifications.

Nominal capacity	1.2 kw
Initial cost	400$/unit
Placement cost	2500$/unit
Maintenance cost	4$/year
Useful life	5 years
Efficiency	85%

Table 4. Converter Specifications.

Nominal capacity	1 kw
Initial cost	500$/unit
Placement cost	400$/years
Maintenance cost	50$/unit
Useful life	15 years
Efficiency	90%
Interest rate i	6%

Daily load profile in figure (3) and seasonal load profile is shown in figure (4). The information for this load is given in table (5).

Table 5. Load information

	Scaled
Average (kWh/d)	72.7
Average (kW)	175
Peak (kW)	0.415
Load factor	1.744

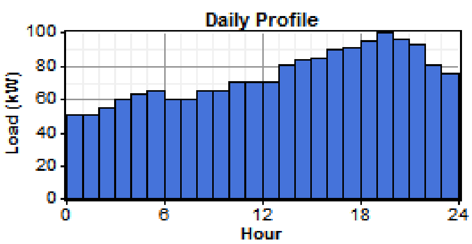


Figure 3. Daily load profile.

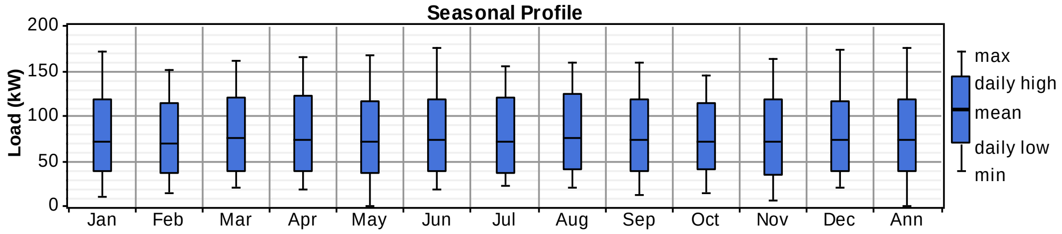


Figure 4. Seasonal load profile.

The results will be simulated and discussed in three scenarios:

- Partnership of photovoltaic with storage
- Partnership of wind turbine with storage
- Hybrid mode partnership with the storage

4.1. Photovoltaic models with storage

Sensitivity studies are performed using solar radiation data and panels cost, and output parameters are expressed as functions of these variables. It will be possible to determine the optimal system for any area whose sunlight is known. The simulation model in the HOMER software is shown in figure 5. The geographical location and also the longitude and latitude of the region, the average amount of solar energy radiation during the period under study is according to figure 6. The average annual radiation intensity is 4.8 Kwh/ m2 /d. The proposed sizes for photovoltaic are 100,200,300,400,500,500 kW. The following results are obtained after running the homer program, which can be seen in figure 7. As it can be seen in figure 7, the most economically optimal case for the system in question is the first option shown in the set of answers. With the operation of 100 kW photovoltaic, the Net Present Cost (NPC) will be $985674 during the 25-year operation period. The investment cost for each component is shown in figure 8. The cost price for each unit of energy production is 120 $/kwh for this system.

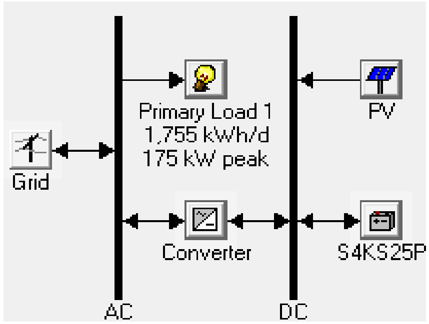


Figure 5. Model of photovoltaic connected to network.

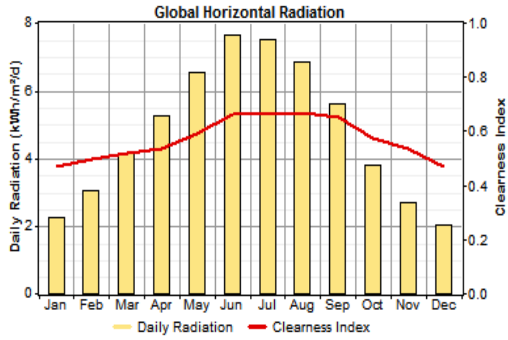


Figure 6. Chart of solar radiation.

PV (kW)	S4KS25P	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
100	100	100	1000	$ 190,000	62,243	$ 985,674	0.120	0.24
100	100	200	1000	$ 240,000	64,307	$ 1,062,066	0.130	0.24
200	100	100	1000	$ 290,000	61,688	$ 1,078,580	0.132	0.42
200	100	200	1000	$ 340,000	62,095	$ 1,133,787	0.138	0.42
100	100	300	1000	$ 290,000	66,370	$ 1,138,433	0.139	0.24
200	100	300	1000	$ 390,000	64,158	$ 1,210,154	0.148	0.42
100	100	400	1000	$ 340,000	68,433	$ 1,214,800	0.148	0.24
100	500	100	1000	$ 350,000	68,448	$ 1,224,996	0.150	0.24
300	100	200	1000	$ 440,000	62,379	$ 1,237,416	0.151	0.54

Figure 7. Optimal results for photovoltaic system.

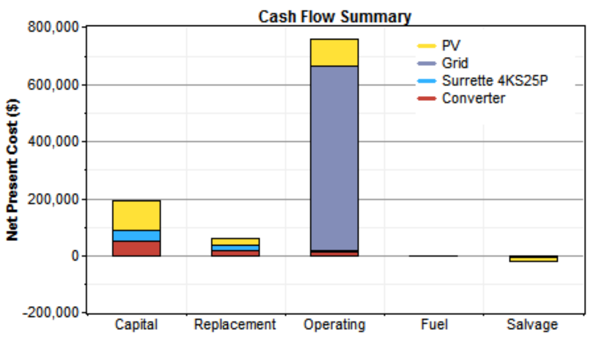


Figure 8. Investment cost for each component of the photovoltaic connected to grid.

The participation of the photovoltaic in supplying the load is given in table 6. 24% is supplied by the photovoltaic and 76% by the grid. The amount of electricity generated by photovoltaic from the proposed load is shown in figure 9.

figure 10 also shows the amount of sunlight received in different months and at different times. The amount of energy stored in the battery is charged in almost all seasons, as shown in figure 11.

Table 7. Participation of wind system in load supply.

Production	kWh/yr	%
PV array	155.948	24

Grid purchases	505.302	76
Total	661.250	100

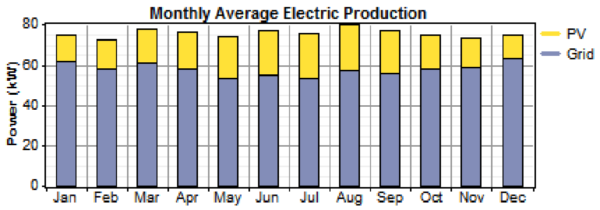


Figure 9. Electricity generation rate by PV and grid during one year.

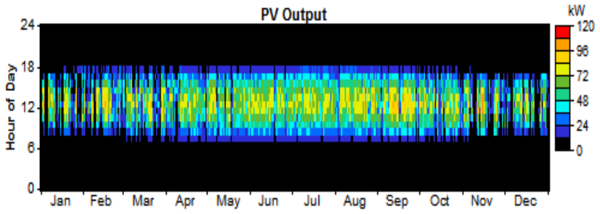


Figure 10. Amount of solar energy received in 24 hours a day.

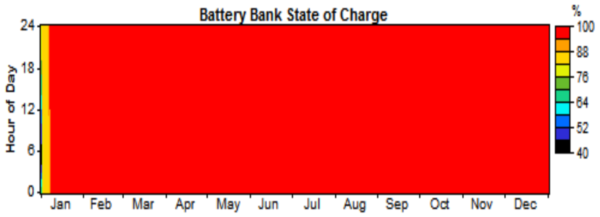


Figure 11. Amount of energy stored by photovoltaic.

4.2. Wind turbine model with storage

In this model, instead of the photovoltaic, there is a wind turbine, which can be seen in figure 12 schematically. A 250 kV turbine has been used to generate the desired electrical power. figure 12 also shows the wind speed profiles in different months. The production characteristic curve is shown in figure 14. The number of proposed sizes for wind turbines is 5. The following results are obtained after the implementation of the program, which can be seen in figure 15. With the operation of wind turbine, NPC will be $1308464 during the 25-year operation period. The investment cost for each component is shown in figure 16. The cost price for each unit of energy production is 170$/kWh for this system. The participation of the wind system in supplying the load is given in table 7. 35% is supplied by the wind system and 65% by the grid. The amount of electricity generated by wind system from the proposed load is shown in figure 17. The amount of energy stored in the battery in the presence of a wind turbine is shown in Figure 18. It can be seen that energy storage is also not complete due to the lack of power generation for the months of January and February. Figure 18 shows the amount of solar energy received in 24 hours a day. The amount of energy stored in the battery in the presence of a wind turbine is shown in figure 19. It can be seen that energy storage is also not complete due to the lack of power generation for the months of January and February.

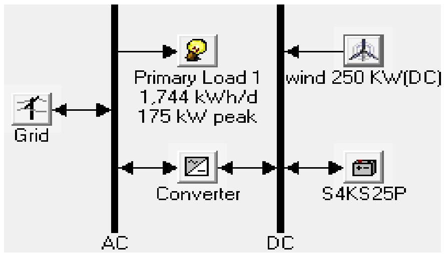


Figure 12. Model of wind system connected to network.

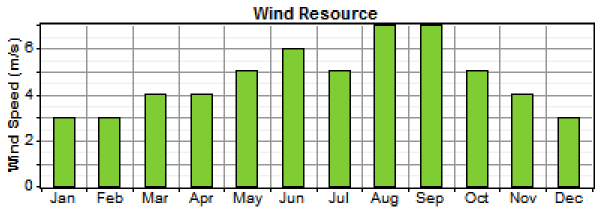


Figure 13. Wind speed profiles in different months.

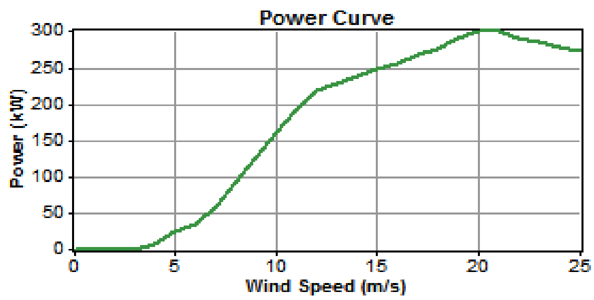


Figure 14. Characteristic curve of wind turbine production.

FL250	S4KS25P	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
1	100	1000	1000	$ 541,300	65,645	$ 1,380,464	0.170	0.35
1	500	1000	1000	$ 701,300	71,902	$ 1,620,449	0.199	0.35
	100	1000	1000	$ 540,000	85,832	$ 1,637,217	0.201	0.00
1	800	1000	1000	$ 821,300	76,597	$ 1,800,464	0.221	0.35
1	900	1000	1000	$ 861,300	78,167	$ 1,860,539	0.229	0.35
	500	1000	1000	$ 700,000	92,065	$ 1,876,897	0.231	0.00
	800	1000	1000	$ 820,000	96,742	$ 2,056,683	0.253	0.00
	900	1000	1000	$ 860,000	98,302	$ 2,116,629	0.260	0.00
1	100	2000	1000	$ 1,041,300	86,271	$ 2,144,138	0.263	0.35
1	500	2000	1000	$ 1,201,300	92,528	$ 2,384,123	0.293	0.35

Figure 15. Optimal results for wind system.

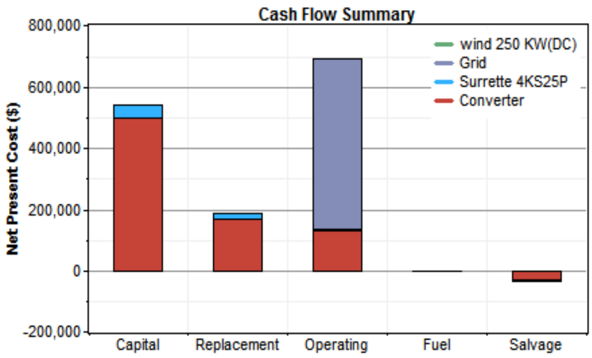


Figure 16. Investment cost for each component of e wind system connected to grid.

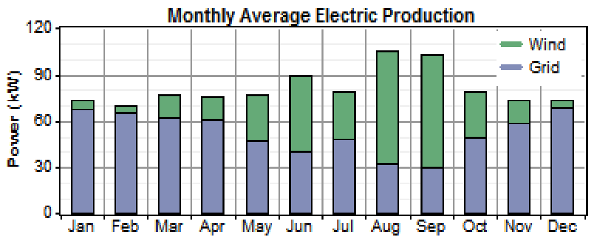


Figure 17. Aamount of electricity generated by wind turbines and grids during one year.

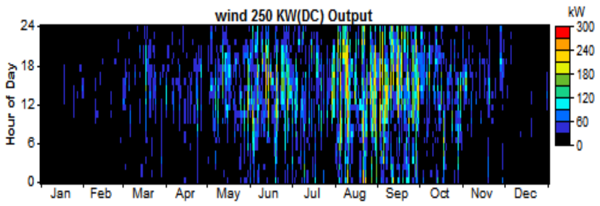


Figure 18. Amount of wind energy received in 24 hours a day.

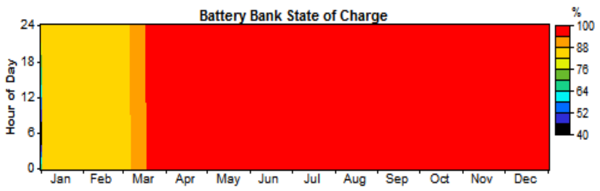
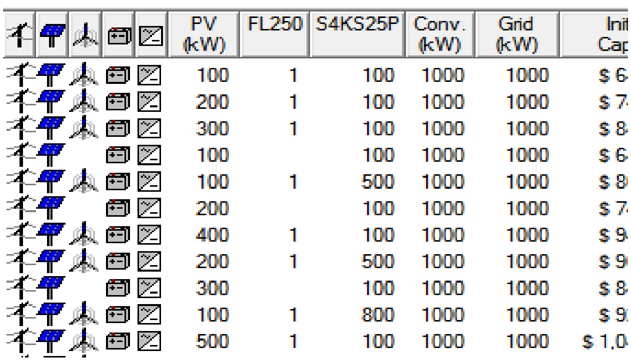


Figure 19. Amount of energy stored by wind system.



PV (kW)	FL250	S4KS25P	Conv. (kW)	Grid (kW)	Init Cap
100	1	100	1000	1000	$ 6
200	1	100	1000	1000	$ 7
300	1	100	1000	1000	$ 8
100		100	1000	1000	$ 6
100	1	500	1000	1000	$ 8
200		100	1000	1000	$ 7
400	1	100	1000	1000	$ 9
200	1	500	1000	1000	$ 9
300		100	1000	1000	$ 8
100	1	800	1000	1000	$ 9
500	1	100	1000	1000	$ 1,0

Figure 21. Optimal results for hybrid system.

Table 6. Participation of photovoltaic in load supply.

Production	kWh/yr	%
PV array	250.903	35
Grid purchases	458.212	65
Total	709.115	100

4.3. Hybrid system model with storage

In this model, instead of the solar system, there is a wind turbine, which can be seen in figure 20 schematically. The optimal hybrid results are shown in figure 21. With the operation of hybrid system, NPC will be $1437552 during the 25-year operation period. The investment cost for each component is shown in figure 22. The cost price for each unit of energy production is 177$/kWh for this system. Table 8 shows the hybrid system participation in the proposed load supply. Figure 23 shows the amount of electricity generated by the hybrid system and the grid over a year. The amount of energy stored in the battery is charged in almost all seasons, as shown in figure 24. Table 9 compares the proposed systems for the target area. According to the results of the three scenarios, the combined solar-generator-battery system has a higher priority than other systems due to having the minimum cost of energy production and the final net cost.

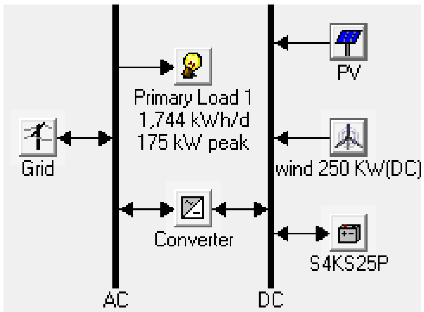


Figure 20. Model of a network-connected hybrid system.

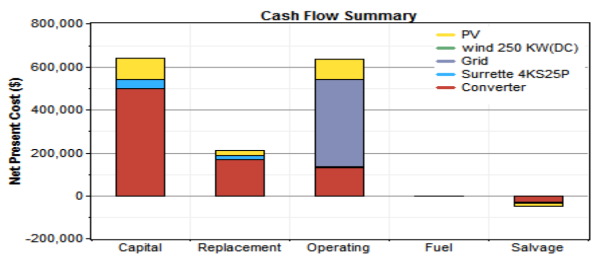


Figure 22. Investment cost for each component of a network-connected hybrid system.

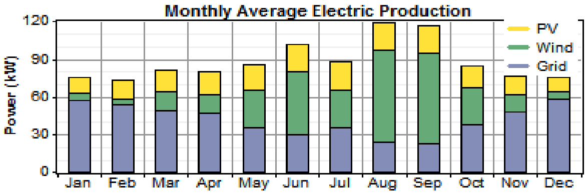


Figure 23. Electricity generation rate by hybrid system and network during one year.

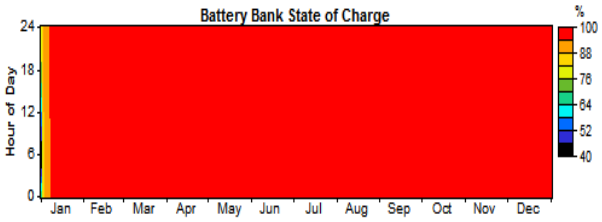


Figure 24. Aamount of energy stored by wind system.

Table 8. Hybrid system participation in e proposed load supply.

Production	kWh/yr	%
PV array	155.948	20
Wind turbine	250.903	33
Grid purchases	364.285	47
Total	771.136	100

Table 9. Comparison of proposed systems.

Type of system	Participation in load supply	Net Present Cost	energy saving	Cost price for each unit of energy generation
photovoltaic	24%	$985674	95%	0.120/kwh$
Wind	35%	$1380464	75%	0.170/kwh$
Hybrid	55%	$1437552	95%	0.177/kwh$

5. Conclusion

Based on the results obtained from the analysis of the three proposed systems, the following results were obtained. Photovoltaic: To operate 100 kW, participation in load supply by 24% photovoltaic with the lowest. Wind: 250 kW wind turbine, participation in load supply by 35% photovoltaic with the average net present cost. However, energy storage is low, and also there is relatively a high energy consumption in this scenario. Hybrid: 100 kW photovoltaic and 250 kW wind turbine, participation in 55% load supply with a higher net present cost. According to the results obtained, it can be said that the operation of photovoltaic and hybrid system is cost-effective, and has a higher priority for implementation.

6. References

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