TECHNO- ECONOMIC CONFIGURATION FOR HYBRID RENEWABLE ENERGY SYSTEMS IN ISOLATED AREA IN ALGERIA

AMARA MOHAMED, MEZIANE RACHID
Faculty of Technology, University of Saida,
B.P. 20000, Saida, Algeria, amara_moham@yahoo.fr

ABDELKADER ZEBLAH
University of Sidi Bel Abbes,
B.P. 22000, Sidi Jillali, Sidi Bel Abbes, Algeria,azeblah@yahoo.fr

Abstract: *This work proposes the use of a hybrid PV-Wind diesel system in order to determine the optimal configuration of renewable energy in isolated area in Algeria and to compare the cost of production of solar and wind energy with its annual yield relevant to different configurations of a rural area in Tindouf regions of Algeria. The paper reports of the results of the techno - economic optimization study of the solar-wind diesel hybrid with storage of the battery. The first objective of this study is to estimate the appropriate dimension of autonomous hybrid solar -wind diesel with battery storage that guarantee the energy autonomy of the consumer with the lowest cost of energy. The HOMER software is used as a sizing and optimization tool. Sensitivity analysis with wind speed data, solar radiation level, diesel price and the cost from different components. An isolated city of 230residents with an energy consumption of 709 kWh per day and a peak power of 66 kW was considered autonomous load. The results show that for the rural area of Tindouf, a hybrid solar -wind diesel generator system is the most suitable solution in terms of economic performance and pollution. The cost of production for this configuration proved to be cheaper and more environmentally friendly than the energy produced by the other configurations.*
Key words: *Techno-economical, Renewable energy, hybrid system, HOMER software.*

1. Introduction

Algeria encourages research on the renewable energy program for the development of a national industry that will optimize the different Algerian potentials (human, physical, scientific, etc.). Research is an essential element in the acquisition of technologies, the development of know-how and the improvement of energy performance For Algeria [1]. The acceleration of the acquisition and use of the technology is indispensable, in particular with regard to the development of solar photovoltaic, solar thermal and wind power. Algeria's geographical location allows it to play an important role in the implementation of renewable energy technology in northern Africa and to provide sufficient energy for its own needs and even to export such projects to other countries. Indeed, the integration of renewable energies into the national energy mix constitutes a major challenge for the preservation of fossil resources, the diversification of electricity production methods and the contribution to sustainable development in the renewable energy development program 2011- 2030 adopted by the government In February 2011[1,2].

Within of the national electrification policy; the major programs of supply of electricity in isolated areas of the southern Algeria have been launched, financed by the government and carried out by the group SONELGAZ. The development of these programs led to the economic and social opening in these areas and access to commercial energy. The installed capacity supplying isolated south areas has increased from 281 MW in 2000 to 352 MW in 2012[3]. The electricity demand characterized by early sustained growth, with a ratio higher than 10% by year. The first step was the development of an experimental program of 20 isolated villages of southern Algeria by photovoltaic systems with a total capacity of 0.5 MW. The second program of the same size was launched in 2011; it consists of a supplementary program to support growth for the electrification of 16 villages in southern Algeria with photovoltaic systems from individual kits with a total capacity of 3 MW. Another program has been launched, which includes the implementation of 65 projects. In this context, it is expected to develop a total capacity of 45 MW until 2020 in isolated areas, with photovoltaic systems or diesel/wind or diesel/photovoltaic hybrid plants in the existing Diesel power plants [2,3].

The objective of renewable energy development in Algeria is to achieve by 2020 a share of 6% of these energies (including cogeneration) in the national energy mix. The introduction of renewable energies leads to a greater exploitation of the available potentialities, a greater contribution to the reduction of CO_2, a bigger contribution to the reduction of CO_2, a reduction of the share of fossil fuels in the national energy balance sheet, a development of national industry and Job creation [2-4].

2. Energy sources

Selection of energy resources is very important for a design of the energy system. In our study, wind and solar energy are enough for power generation. As gas reserve may perish within a decade, diesel is used as the fuel for power generation from fossil fuels.

2.1. Solar potential in Algeria

The geographical situation of Algeria is one of the largest solar reserves in the world. The hours of daylight almost on all Algeria exceeds 2.000 hours yearly and reaches 3.900 hours (highlands and Sahara). The energy received daily on a horizontal surface of 1m2 is 5 kWh on most of the nation that is around 1.700 kWh/m2 per year in the north and 2.263 kWh/m2 per year in the southern part of the country [2, 4, 12].The table 1. Gives the capacity energy from the sun in Algeria in figures and broken down by locality.

Table 1
Algerian sun capacity in terms of sunshine hours and energy received.

Regions	Coastal regions	Highlands	Sahara
Area (%)	4	10	86
Average duration of sun exposure (h/year)	2650	3000	3500
Average energy received (Kwh/m2 /year)	1700	1900	2650

In photovoltaic system solar cells or panels are used to convert sunlight directly into electricity. The monthly averaged global radiation data has been taken from NASA (National Aeronautics and Space Administration) and clearness index is a measure of the clearness of the atmosphere, has an average value of 0.843 for Tindouf. Table 2 provides the data of clearness index and daily radiation for Tindouf [4, 5, 6,14].

Table 2
Solar Irradiation in Tindouf

Month	Clearness index	Daily radiation KW/m2/d
January	0.379	3.810
February	0.461	4.790
March	0.588	6.180
April	0.706	7.200
May	0.804	7.760
June	0.843	7.840
July	0.809	7.630
August	0.704	6.980
September	0.586	6.050
October	0.477	4.940
November	0.398	4.020
December	0.337	3.340

2.2. Wind data

In Algeria the average wind speed varies from one season to another. It is also likely to be affected by general weather patterns and the time of day it is not uncommon for a site to have a certain number of days of relatively strong winds and that these days are followed by others of lower winds. The wind also exhibits short term (seconds to minutes) variations in speed and direction. The wind speed data at Tindouf is recorded at 20 m height. Table 3 shows the monthly average wind speed around the year at Tindouf [2, 4,13].

Table 3
Wind Speed at 20 m Height in Tindouf

Month	Wind speed m/s
January	3.2
February	5
March	5.2
April	5.6
May	4.7
June	5.1
July	4
August	4.2
September	4
October	3.9
November	3.6
December	3.5
Annual average	3.77

The distribution of wind speed's probabilities at Tindouf is obtained applying the mathematical expression of Weibull's function [7, 15-16], and it is defined by the following formula:

$$f(v)=(k/c) 〚(v/c)〛^{(k-1)} \exp 〚(v/c)〛^{k} \quad (1)$$

Where k is the shape parameter describing the dispersion of the data and c is the scale parameter (with units of speed (m/s))The two parameters $c$and $k$are related to the average wind speed by the following relation:

$$\bar{v} = c\Gamma(1/k+1)[〚(v/c)〛^{k}] \quad (2)$$

Where Γ is the gamma function to fit a Weibull distribution of measured wind data.

3. HYBRID SYSTEM

The systems hybrid usually integrates renewable energy sources with fossil fuel generators (diesel) to provide electrical power. Proposed hybrid system configuration is depicted in Fig 1. They are generally independent of large centralized electric grids and are used in isolated areas. In these systems it is possible for the individual power sources to provide different percentages of the total load. For instance, the solar panels are producing low levels of electricity, the wind generator compensates by producing a lot of electricity. Naturally, to use a wind generator effectively requires a location with a good wind regime. Balancing the power sources to achieve the highest level of system performance takes thorough research. Resource assessment and location must be assessed to determine sizing for optimized performance [7, 8, 17-20].

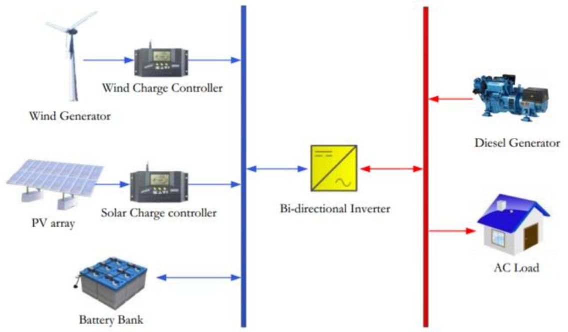

Fig.1. Hybrid system

4. Description of the Tindouf system

4-1. Site Location

The location of this village in Algeria is illustrated in Fig 2 by a red circle. We chose an isolated village not connected to the classic energy distribution networks is equipped with all the devices to provide comfort to the occupants. The site we have chosen belongs to the south western of Algeria zone (Tindouf) located at 439 m of latitude and whose geographical coordinates are: latitude: 27 ° 40'6 "N, longitude: and longitude 8° 09 ' 8 "E [5, 6].

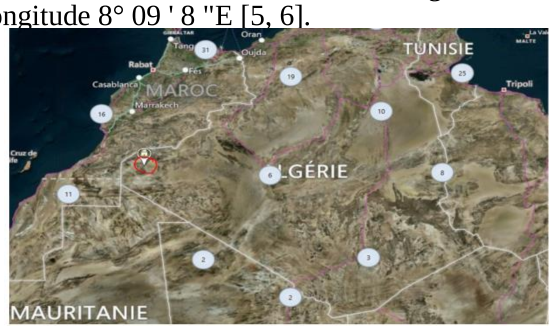

Fig. 2. Google Map position of Tindouf.

4-2. DATAINPUT

4-2-2 - Electrical Load

The load profile is based on a rural area with 230 families. Table 4 shows the load profile of selected houses [9, 13-14,25]. The simulation process of the chosen hybrid system was analyzed to see if the use of the feed system will be possible or not. It is important to note that these houses presented in the example study are isolated and not connected to the grid, the additional objective was to see the effect of using the hybrid system to supply them with electrical energy.

The daily load of this village is 709 KWh per day, the daily load of a household is 66 KWh per day, and therefore the system load built by HOMER simulates the power supply for a sum of houses that can reach 230 households [9, 21, 22].

Table 4

The load consumed by a household.

	Power (W)	Time (h /d)	Consumption (Wh/d)
Adult room	11	4	44
Children's room	22	5	110
living room	22	6	132
corridor	22	2	44
bathroom	22	2	44
toilet	11	1	11
kitchen room	11	7	77
Refrigerator	120	12	1440
Television	75	7	525
fan	100	4	400
various	100	2	200
Total (Wh/d)			3027

4-2-3 Wind turbine

A BERGEY EXCEL 10 model wind turbine was used with rated power 10 kW AC. The rotor diameter is 7m and tower height is 26 m or 30m freestanding lattice and the lifetime 15 years cut-in speed for this wind turbine is 2.2 m/s, which can be observed in the power curve shown in Figure 3. This turbine initially costs 20000$ [10,16].

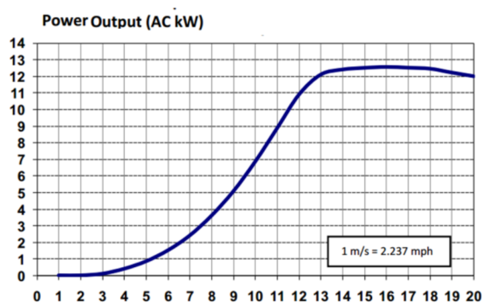

Fig.3. Power curve for Bergy Excel 10 wind turbine.

4-2-4 PV panel

The PV panels used here cost 1500 $/kW. Most of the PV panels come with a lifetime of 20 years, although they most likely last longer. For energy storage, Hoppecke 100Pzs1000 batteries with nominal capacity of 1000h were used in the analysis [11, 23,25].

4-2-5 Diesel generators

Diesel generator is used in the study as base load server. In this work, diesel generator Lapel is considered [8, 11, 21]. The initial capital is1500$, replacement cost 1500$ and O&M cost is 0.50 $/hr .The generator operating lifetime is defined around 15000 hours and the minimum load ratio is 30%. The diesel generator size is considered from 0 kW to 40 kW on 5 kW intervals.

4-2-6 Converter

To generate sufficient power, converters are necessary; the price of the converters is given by the HOMER software [11, 12, 24].The conversion efficiency of both inverter and rectifier are considered as 90% and the lifetime of converter is 15 years. The sizing of converter is considered from 0 kW to 45 kW at 5kW interval, while the relative conversion ratio of AC and DC is considered 100%.

5. System analysis and simulations

The Hybrid optimization is used for designing standalone electric power systems that employ some combination of wind turbines, photovoltaic panels, or diesel generators to produce electricity (Fig 4). The simulation process of different sizes of photovoltaic panels, wind turbines, power converters, and batteries were used and the most economical system was selected after running the simulations several times. The search space for the optimization process is shown in Table5. There were 8 sizes for PV panels, 8 sizes for wind turbines, 9 sizes for diesel generators ,8 sizes for batteries, and 8 sizes for power converters. Zero is included in the search space of each component for more optimal results.

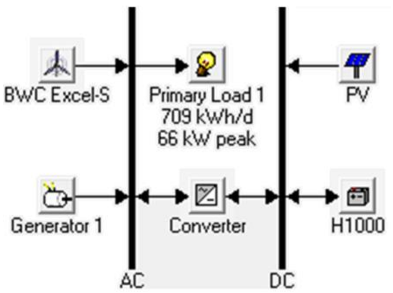

Fig.4. Configuration of hybrid PV/generator system in HOMER software

Table 5
Search space of different components.

PV panels (kW)	Wind turbine	Diesel generator	Batteries	Converter
0	0	0	0	0
30	12	5	4	14
60	16	10	8	20
90	20	15	12	30
120	24	20	16	40
150	28	25	20	50
190	32	30	24	60
220	36	35	26	70

5.1. Components details

The energy system components are photovoltaic modules, wind turbine, battery, and power converter. This study develops a suitable assembly of the key parameters such as photovoltaic array power, wind turbine power curve, battery storage and converter capacity to match the predefined load. For economic analysis, the cost including the initial capital, replacement cost, and operating and maintenance cost are considered in simulating conditions. All the parameters are shown in Table 6.

Table 6
Components details.

Components	Parameters	value	Unit
PV module	Rated capacity Capital cost Replacement cost Operation and maintenance cost Lifetime year	1 1500 1200 15 20	KW $ $ $/year year
Batteries	Capital cost Replacement cost Operation and maintenance cost Minimum battery life Nominal capacity	900 900 9 8 1000	$ $ $/y Year h
Converter	Capital cost Replacement cost Operation and maintenance cost Lifetime year Capacity relative to inverter	1000 1000 10 15 100	$ $ $/year Year %
Diesel generator	Capital cost Replacement cost Operation and maintenance cost Lifetime year Rated capacity	1500 1500 0.5 15000 10	$ $ $/year h KW
Wind turbine 240VAC, 60 Hz	Capital cost Replacement cost Operation and maintenance cost Lifetime year Rated capacity	20000 10000 7000 15 10	$ $ $/year Year KW

5.2. Simulation.

The economic study is performed on the HOMER software; it allows us to compare the financial and technical constraints on the use of the different systems. HOMER is a software application developed by the National Renewable Energy Laboratory in the United States. This software application is used to design and evaluate technically and financially the options for off-grid and on-grid power systems for remote, stand-alone and distributed generation applications. It allows you to consider a large number of technology options to account for energy resource availability and other variables.

Table 7
Optimum solution for hybrid renewable energy system.

	Configuration	PV (KW)	Wind	Diesel (KW)	Battery H1000	Converter (KW)	Initial Capital$	Total NPC $	COE ($kW/h)
System1	PV wind+diesel	150	16	25	336	60	794.900	1275.208	0.386
System2	wind + diesel	0	36	35	432	70	881.300	1567.587	0.474
System3	PV +diesel	220	0	35	384	70	798.100	1660.641	0.502
System4	PV +wind	220	40		624	70	1371.600	1886.825	0.571

HOMER simulations were performed to find the best possible solution. Three kinds of component cost were examined in the system analysis: capital cost, replacement cost, and operating and maintenance cost.

6. Result at and discussion

6.1. Optimal system

The optimization results of hybrid renewable energy system using HOMER software are shown in table 7. Wind Solar hybrid system with battery, inverter and generator have the lowest total net present cost at 1275.208$ and cost of electricity of 0.386 $ per Kwh.
For this combination it is observed that PV array produce 205,975Kwh per year(about 40%),generator wind produce 287 ,812 Kwh per year(about 57%) and diesel generator produce 15,301 Kwh per year(about 3% of total) . The consumption is about 509,088Kwh per year as shown in Figure 5.

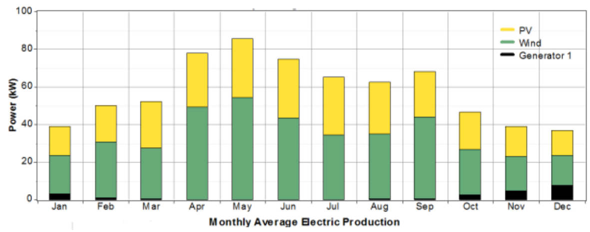

Fig.5. Electricity production by wind, solar PV and diesel generator.

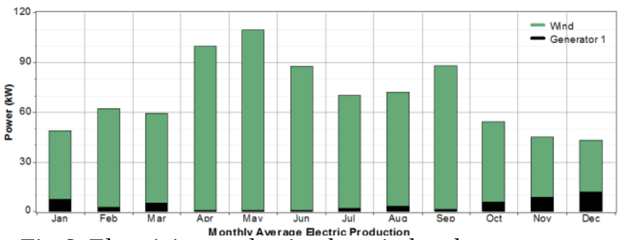

Fig.6. Electricity production by wind and generator.

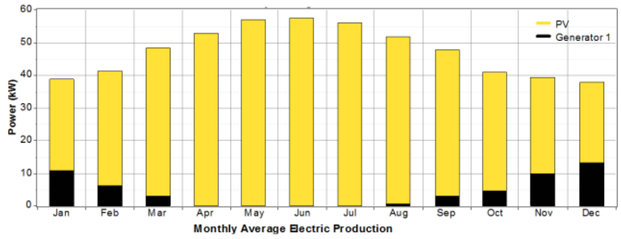

Fig.7. Electricity production by solar PV and diesel generator.

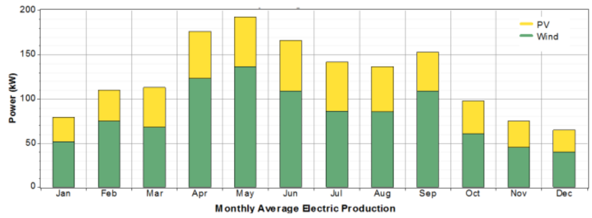

Fig.8. Electricity production by wind and solar PV

Figures 6, 7, and 8 show the contribution of different sources in the power supply. The most optimal system is the fourth system.
System 2: Energy wind supplies (96%) and diesel provides (04%) of the load demand.
System 3: Solar energy provides (91%) and wind provides (09%) of the load demand.
System 4: Solar energy provides (34%) and wind provides (66%) of the load demand.

6.2. Economic analysis.

The system is analyzed according to the cost of electricity (COE) of the system. Other factors which influence the analysis are capital cost, operating cost, renewable energy factor, total Net present cost (NPC) and diesel consumption rate.
Figure 9 show the capital cost, replacement cost, operation and maintenance cost and Fuel cost of different configuration of the system.

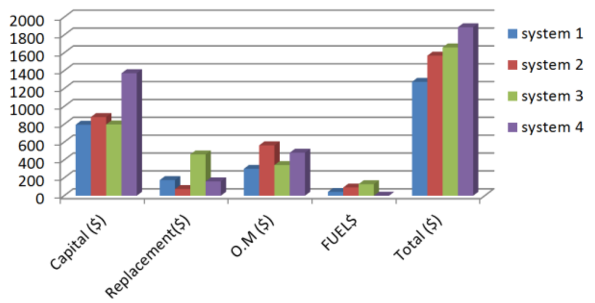

Fig.9. Net present Cost of different systems

6.3. Environmental analysis.

For the environmental analysis of the hybrid system, HOMER evaluates emissions of air pollutants. Table 8 summarizes the total emission of pollutants in the four cases examined systems.

Table8
Emission of air pollutants.

Emission of air pollutants(kg/year)	Sys 1	Sys 2	Sys3	Sys 4
Carbon dioxide	13.37	21.70	33.00	0
Carbon monoxide	33	53.6	81.5	0
Unburned hydrocarbons	3.66	5.93	9.02	0
Particulate matter	2.49	4.04	6.14	0
Sulfur dioxide	26.9	43.6	66.3	0
Nitrogen oxides	295	478	727	0

6.4 Comparison of the results using Homer and genetic algorithm.

The Genetic Algorithm method is based on the cost minimization of the objective function by considering annual average wind speed and solar radiation. The result was obtained after 320 iterations (Fig.10). Table 8 shows a comparison between Homer software and the genetic algorithm method for the total cost optimization. The comparison between the two methods shows that the best cost is obtained by the software Homer.

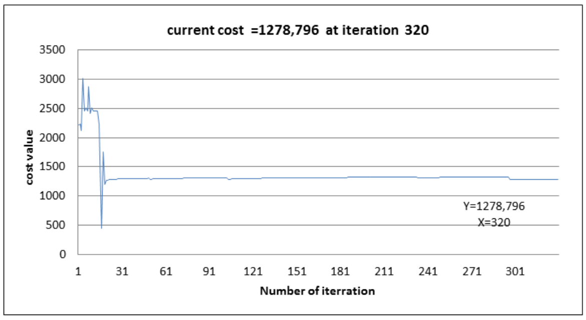

Fig.10. Optimization of the Objective function using GA

Table 9 shows a comparison between the Homer software and the genetic algorithm method for the total cost optimization. The comparison between the two methods shows that the best cost is obtained by the Homer software.

Table 9
Cost comparison using Homer and GA.

Technique	Total NPC $
Homer	1275.208
Genetic Algorithm (GA)	1278.796

7. Conclusion

The study clearly shows that the different configurations of the systems and equipment were analyzed by HOMER software and it was found that the lowest cost of energy (0.388 $ / kWh) with the lowest NPC (1.283.559$) was observed with the solar-wind diesel system. The highest energy cost ($ 0.571 / kWh) with the highest NPC (1.886.825 $) was observed with the solar-wind system. There is an increase in the CO2 production rate of (33.008 kg / year) with the solar-diesel system. Higher than that of the solar-wind-diesel system, a minimum CO2 (13.375kg / year) is produced in this system. With regard to CO2 production and future load demand, the optimized wind-PV-diesel hybrid system is more cost effective in terms of Net Present Cost (CNP) and Energy Cost (COE).

References

1. Ministry of Energy and Mines.,Satinfo sonelgaz group company.: *Renewable energy and energy efficiency program*. In: Renewable Energies of Algeria, edition. 2011, March. 2011, p. 8-14.
2. Minisry of energy.,Mining.: *guidelines to renewable energies edition 2007.* In: New and Renewable Energies of Algeria, Edition. 2007, p.12-16.
3. Medreg., European Union. : *Assessements of mechanisms to integrate RES in isolated electricity systems in medreg countries*. In: Meditterranean Energy regulator, November. 2013, p. 17-27.
4. Centre de la technologie de l'énergie de CANMET., Ressources naturelles Canada.: *RETScreen International.* In*:* Modèle RETScreen pour projets de petite centrale hydroélectrique*, Canada, 2004.*
5. Google map of Algeria.: *Satellite Images of Algeria.* In: 2016 maplandia.com.
6. Paul W. Stackhouse, Jr., William S. Chandler., Taiping Zhang. : *Surface meteorology and Solar Energy (SSE) Release 6.0 Methodology.* In: NASA Langley Research Center, Version 3.2.0, June. 2. 2016, p 1-72.
7. D.saheb-koussa.,M.koussa.,Nourredine.Said.: *prospects of wind-diesel generator-battery hybrid power system: a feasibility study in Algeria*. In: Journal of Wind Energy, Vol. 2013, July. 2013, p. 1-8.
8. Nachida. KASBADJI. MERZOUK.: *Evaluation du Gisement Energetique Eolien Contribution a la Determination Du Profil Vertical de la Vitesse du Vent en Algerie*. In : these de doctorat 2006, l'universite abou bekr belkaid de tlemcen, algeria. 2006.
9. D.saheb-koussa.,M.belhamel.,k.benferhat.: *Contribution a l'etude theorique du Comportement d'un systeme hybride (eolien-photovoltaïque- diesel) de production d'electricite sans interruption.* In: Afrique science, vol. 05, Jan. 2009, pp. 23 – 38.
10. A Bergey Wind Power Company Manual.: *owner's manual bergey excel 10 grid-intertiewind turbine & powersync II inverter*. In: Bergey EXCEL 10 Turbines, Rev. 1, March. 2011, p. 1-3.
11. T. Lambert., P. Gilman., and P. Lilienthal.*: The Micropower System Modeling with HOMER. In*: HOMER Energy,USA, July. 2011, p. 4-24.
12. Madhav. S. T., Bhupendra. Gupta., Veerendra. Kumar., Mukesh. Pandey.: *optimization of hybrid renewable energy system (2mwh/d) for sustainable and economical power supply*. In: International Journal of Engineering Research & Technology (IJERT), vol. 1, august. 2012, p. 1-8.
13. A. K. Pradhan., S. K. Kar., M. K.Mohanty.: *Off-Grid Renewable Hybrid power Generation system For a Public Health Centre in Rural Village*. In: International Journal of Renewable Energy Research, Vol. 6, 2016, p. 282-288.
14. Lanre. Olatomiwa., Saad. Mekhilef., A.S.N. Huda., Olayinka S. Ohunakin.*: Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria.* In: Elsevier Renewable Energy, Vol. 83, April. 2015, p. 435-446.
15. Md. Mustafizur Rahman., Md. Mohib-Ul-Haque Khan., Mohammad Ahsan Ullah., Xiaolei Zhang., Amit Kumar.: *A Hybrid Renewable Energy System for a North American off-grid Community*. In: Elsevier Energy, Vol.97, December. 2016, p. 151-160.
16. Getachew Bekele., Gelma Boneya.: *Design of a Photovoltaic-Wind Hybrid Power Generation System for Ethiopian Remote Area.* In: Energy Procedia 2nd International Conference on Advances in Energy Engineering (ICAEE). Decembre. 2011, p1760-1765.
17. Wei Zhoua., Chengzhi Lou., Zhongshi Li., Lin Lu., Hongxing Yang.: *Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems.* In: Elsevier Applied Energy, Vol. 87, septembre. 2010, p. 380-389.
18. Paul W. Stackhouse, Jr., William S. Chandler., Taiping Zhang.: *Surface meteorology and Solar Energy (SSE) Release 6.0 Methodology.* In: NASA Langley Research Center, Version 3.2.0, June 2. 2016, p 1-72.
19. Yousif El-Tous., Saleh Al-Battat., Sandro Abdel Hafith.: Hybrid *wind-Pv grid connected power Station case study Al Tafila, Jordan.* In*:* International Energy & Environment Foundation, VOL. 3, 2012, p. 605-6016.
20. Hongxing Yang., Lin Lu., Wei Zhou.: A *novel optimization sizing model for hybrid solar-wind power generation system.* In: elsevier Solar Energy, Vol. 81, Decembre. 2007, p. 76-80.
21. Deepak Kumar Lal., Bibhuti Bhusan Dash., A. K. Akella.*: Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER for the Study Area.* In: International Journal on Electrical Engineering and Informatics, Vol. 3, August. 2011, p. 307- 325.
22. S. Bahramara., M. Parsa Moghaddamn., M.R. Haghifam.*: Optimal planning of hybrid renewable energy systems using HOMER: A review.* In: elsevier Renewable and Sustainable Energy Reviews, Vol.62, May.2016, p. 609–620.

23. Sayedus Salehin., M. Tanvirul Ferdaous, Ridhwan M. Chowdhury.,Sumaia Shahid Shithi., M.S.R. Bhuiyan Rofi., Mahir Asif Mohammed.: *Assessment of renewable energy systems combining techno-economic optimization with energy scenario analysis.* In: Elsevier Energy, Vol. 112, June. 2016, p. 729-741.
24. Shiplu. Sarker.: *Feasibility analysis of a renewable hybrid energy system with producer gas generator fulfilling remote household electricity demand.* In: Elsevier Renewable Energy,Vol. 87, Novembre. 2016, p. 772-781.
25. Nima Izadyar., Hwai Chyuan Ong., Wen Tong Chong., Juwel Chandra Mojumder.,K.Y. Leong.: *Investigation of potential hybrid renewable energy at various rural areas in Malaysia.* In: Elsevier Journal of Cleaner Production, Vol. 139, July. 2016, p. 61-73.