Int. J. of Thermal & Environmental Engineering
Volume 1, No. 1 (2010) 15-22

Economic and Environmental Modeling of a Photovoltaic-Wind-Grid Hybrid Power System in Hot Arid Australia

G. Liu, M. G. Rasul*, M. T. O. Amanullah, M. M. K. Khan

Power Engineering Research Group, Faculty of Sciences, Engineering and Health, CQ University, Queensland 4702, Australia

Abstract

Increased concern about energy crisis and environmental issues has revitalized interest in the application of renewable energy technologies. For ensuring steady and continuous electricity generations, a hybrid power system (HPS) including more than one renewable energy elements is introduced. In this paper, environmental and economic analyses are used to discuss the sustainability of a HPS. An investigation is made on small-scale operations of 100kWh per day HPS as a grid-assisted power generation consisting of solar (photovoltaic) and wind energy. A comparison is drawn among the different configurations of a grid-connected HPS operation focusing on environmental and economic impacts. Emissions and the renewable energy generation fraction (RF) of total energy consumption are calculated as the main environmental indicator. Costs including net present cost (NPC) and cost of energy (COE) are calculated for economic evaluation. To simulate long-term continuous implementation of the HPS, the hourly mean global solar radiation and wind speed data of 2007, from Alice Spring ($23.70°S$, $133.88°E$) of Australia, are used as an example of a typical hot arid climate. The monthly solar exposure between 13.31 and 21.3 $MJ/m^2/day$ and mean wind speed of 7.13 m/s in 2007 is considered for simulation The Micropower Optimization Model software HOMER developed by the National Renewable Energy Laboratory, USA is used for simulation. It is found that, for Alice Spring arid climates, the optimum results of HPS show a 64.3% reduction of emissions including CO_2, SO_2, and NO_x. Renewable fraction of the optimized system is 54%. It is also found that the HPS has benefits of cost saving. The reduced NPC and COE are only equal to about 85.3% of energy consumption from standard grid. In addition, through a set of sensitivity analysis, it is found that the wind speed has more effects on the environmental and economic performance of a HPS under the specific climate.

Keywords: *Environment; Economy; Hot Arid Australia; Hybrid Power System.*

1. Introduction

With the rapid escalation in use of fossil fuels, particularly petroleum and its by-products, energy crisis and environmental issues are becoming popular topic. Increased concern about global warming, acid rain and air pollution has revitalized interest in the application of renewable energy resource [1]. Renewable energy technologies are playing important roles in society development, because of its advantages like less emission, less waste, less energy resource use and etc. Generally, in order to ensure stable and reliable power generation, a hybrid power(HRE) system making most efficient use of the different renewable resource is introduced [2].

There are many literatures about renewable energies used and expected to improve the corresponding technical levels in hot arid region [3-6]. Because of the climatic characters of hot arid region, solar and wind energy are the main applications types of renewable energy. Healthcote [3] wrote that the UNESCO Arid Land Research Programme introduced a 15 m diameter rotor working in an average 20 km/h wind could provide 104,000 kWh/yr power, which would support for lighting, water heating, pumping and refrigeration for a village of 100 families. Undoubtedly, future research will discover more efficient and useful ways of using wind energy in arid region. As to solar energy, various systems have been constructed to produce electricity power by massive arrays of photovoltaic cells or reflectors focusing the solar irradiation on to the cells setting on power towers [3]. The use of solar radiation in

* Corresponding Author. Tel.: (+61) 7 49309676;
E-mail: m.rasul@cqu.edu.au

DOI: 10.5383/ijtee.01.01.003

arid lands is also seen as extensive and likely to increase in the future [4]. Some literatures investigated the efficient ways to evaluating renewable energies and reported that there is abundant amount of solar and wind energies available in different arid land. For example, Sabziparvar [5] and Shetaee [6] determined a method of calculating the global solar irradiation through comparing the different methods and taking an example of the data in Iran. It is estimated that Atacama Desert could receive in one year the equivalent of all the fossil fuels used in the mid-1960s [7].

In order to ensure stable and continuous power, a hybrid power system including more than one type of energy component is introduced [8]. In hot arid region, it was seen some researchers studying on the feasibility of using a hybrid power system [9-12]. Mahmoudi et al. [13] investigated the weather data (hourly wind speed and daily solar radiation) for hybrid power system in arid coastal countries. They [13] assessed the feasibility of using HPS (wind + solar) in the Arabian Gulf country of Oman.

However, one of the important problems of HPS's application is that there is no normal, effective and achievable method to assess the environmental and economic performance of a HPS.

This study investigates the environmental and economic performance parameters of evaluating a HPS. Nevertheless, this paper analyzes the environmental and economic benefits of HPS used in hot arid environment. Alice Spring of Northern Territory where is famous hot arid land of Australia, is taken as an example in this study. In this region, the yearly mean rainfall (data of the years 1940 to 2008) is 279.2 mm [14]. The daily temperatures vary by up to 28 °C (82 °F) and rainfalls vary quite dramatically from year to year. In summer, the average maximum temperature is in the highest of 30°C, whereas in winter the average minimum temperature can be 7.5 °C (45.5 °F). These climatic data will be used as the inputs when modeling the long-term implementation of the system.

2. Modeling Framework

Environmental and economic interests are the two of important aspects of sustainability. To evaluate the sustainable performance of a HPS, these two impacts should be considered. The indicators of environmental and economic assessment can be determined by the five relevant meta-criteria: purpose; measurability; representativeness; reliability and feasibility; and communicability [15]. In this study, emissions and renewable fraction are discussed as environmental indicators, and costs are calculated for economic indicators.

2.1. Environmental modeling

2.1.1. Emissions

Emission is widely accepted and understood as an environmental indicator of an energy system. Gaseous emission has many important influences in terms of the choices, integration, and access to energy resources that make up other aspects of long-term sustainability (e.g., energy flow, material flow, and economic efficiency). In this study, the yearly emission of the hybrid power system is simulated.

Emission has representativeness for environmental assessment. The limitations of emission as a comprehensive measure of environmental assessment of a HPS are from the problems associated with capturing and distinguishing all relevant negative impacts on the other aspects of environment, such as water, land and biomass diversity. In addition, emission levels do not embody information of the level of connotative impacts on long-term sustainability and health of life. However, emission is the most important reason for environmental pollution, and it is linked to the main environmental problems as greenhouse effect and acid rain. Thus, emission is used as viable headline assessment for the environmental domain. The calculated result of emission can be reliable and feasible, due to the solar radiation and wind speed data used in the simulation are reliable. They are collected from the local weather station of Bureau of Meteorology, Australia.

Emission of a HPS includes carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Based on the Tokyo Protocol, CO_2 and NO_x are two types of the six main greenhouse gases [16]. Sulfur dioxide is one of the most important reasons for acid rain [17]. Emission is measured as yearly emissions of the emitted gases in kg/yr and emissions per capita in kg/kWh. In this study, the emissions of the HPS will be estimated. The estimating method is based on the User Manual of the Micropower Optimization Model software HOMER [18-19]. Moreover, the feasibility analysis of the system will be confirmed by many literatures mentioned before.

2.1.2. Renewable fraction

Based on the configuration of the HPS, the renewable fractions have representativeness for environmental assessment. This fraction means the proportion of renewable energy generated divided by total energy generated. Therefore, renewable fraction is always seen as an important environmental indictor of a HPS. In this study, renewable fraction means the extent of renewable energy used in a HPS. The greater value of this fraction presents a more renewable energy resource used.

Here, HOMER is used to calculate the renewable fraction of the system. The fraction is in turn divided into two parts based on the two components, namely photovoltaic fraction (f_{PV}) and wind fraction (f_{WG}). These two fractions are calculated by Eq. (1) and (2) [20],

$$f_{PV} = E_{PV} / E_{TOT} \quad (1)$$

$$f_{WG} = E_{WG} / E_{TOT} \quad (2)$$

Where, E_{PV}, E_{WG} and E_{TOT} are respectively the energy generation by photovoltaic, energy generation by wind generator and total energy generation.

2.2. Economic modeling

The HOMER software can simulate the net present cost (NPC) and cost of energy (COE) of a hybrid energy system. The simulation inputs include the initial capital, replacement cost, and operating and maintenance cost of each component of a HPS. NPC means the present value of the costs of investment and operation of a system over its lifetime. NPC is used as a main economic indicator to compare an energy system [21]. COE ($\$/kWh$) is the average cost per capita of useful electricity produced by the system [21]. The NPC is calculated according to Eq. (3) [22]:

$$\mathrm{NPC} = \frac{\mathrm{TAC}}{\mathrm{CRF}} \tag{3}$$

Here, TAC is the total annualized cost, which is the sum of the annualized costs of each system component. The capital recovery factor (CRF) is given by Eq. (4) [22]:

$$\mathrm{CRF} = \frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{N}}}{(1+\mathrm{i})^{\mathrm{N}} - 1} \tag{4}$$

Where, N is the number of years and i is the annual real interest rate.

In sustainability analysis, smaller values of NPC and COE mean a less payment to match the same electricity load. For achieving a sustainable economic efficiency, it is to minimize these two types of cost.

3. System Description

A HPS generally comprises more than one primary renewable power generation components working in parallel with a secondary non-renewable component as a backup system. This study focuses on a photovoltaic-wind-grid hybrid power system. The system has a component of current converter as well. This system does not include a battery for power storage, because the grid has the function of power storage [23]. Fig. 1 shows a general configuration of the HPS system.

HOMER, the micropower optimization model, can simplify the tasks of evaluating designs of grid-connected power systems with a range of applications and elements. Fig. 2 illustrates the proposed scheme as implemented in the HOMER code. The additional information for load, components, energy resources and etc, are explained in the following sections.

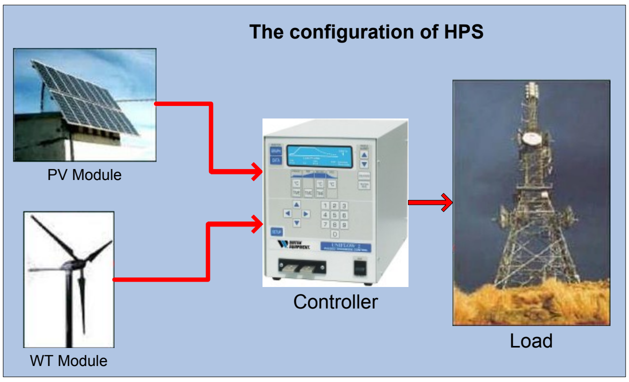


Fig. 1 Configuration of a photovoltaic-wind-grid HPS

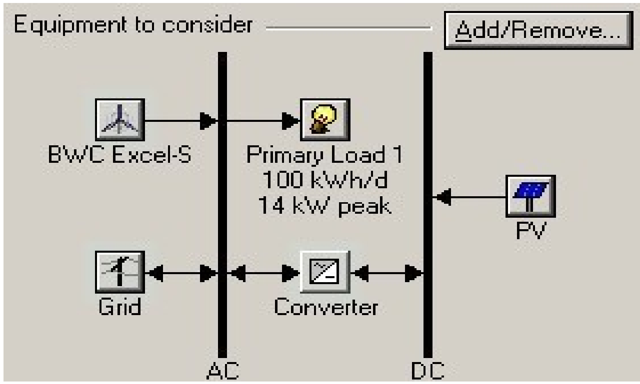


Fig. 2 Scheme of the hybrid system in HOMER code

3.1. Electrical load

An important element of a HPS and any other power generating system is electricity load. Fig. 3 shows the seasonal profile for an assumed load of average value 100 kWh/day. Load shows a bigger value in summer, because air conditioner which is a main electricity consumer is used more frequently in this season. It is seen that there is a peak of monthly mean load in December and January. Fig. 4 shows the daily load profile, the peak occurs between 13:00 and 17:00.

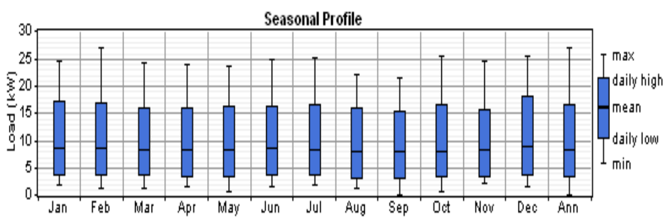


Fig. 3 Average daily load profile for a year

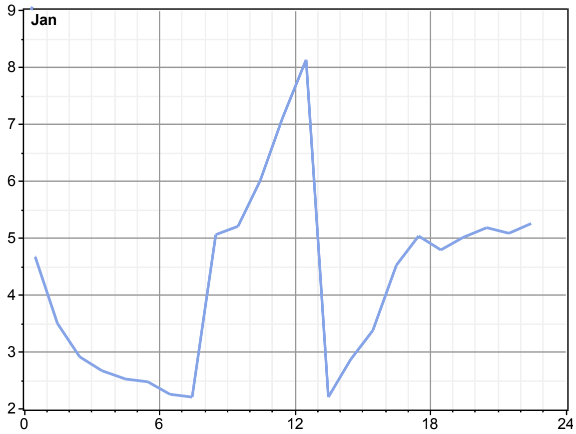


Fig. 4 The daily profile of electricity load (January)

3.2. Renewable energy resources data analysis

3.2.1. Solar energy resources

Daily global solar exposure ($MJ/m^2/day$) derived from satellite data of the weather station of Alice Spring ($23.70°S$, $133.88°E$) for the year 2007 was collected from the Australian Bureau of Meteorology. The solar data shows that the exposure duration is longer than 4516 hours per year. Scaling was done on this data to consider the long-term average annual resource (5.93 $kWh/m^2/day$). HOMER introduces the clearness index from the location (latitude and longitude) information of the site under investigation. Fig. 5 demonstrates the daily radiation in $kWh/m^2/day$ and the clearness index curve over the period of the whole year. The monthly mean solar radiation is between 3.70 and 7.74 $MJ/m^2/day$. The maximum value was seen in December and the minimum one was in July. It is found that Alice Spring region has more solar resource in summer than winter. Considering the annually variations, the sensitivity analysis is done with three values around the mean, which are: 4.5, 5, 5.5, 5.93, 6.5, 7, 8, 10 $kWh/m^2/day$.

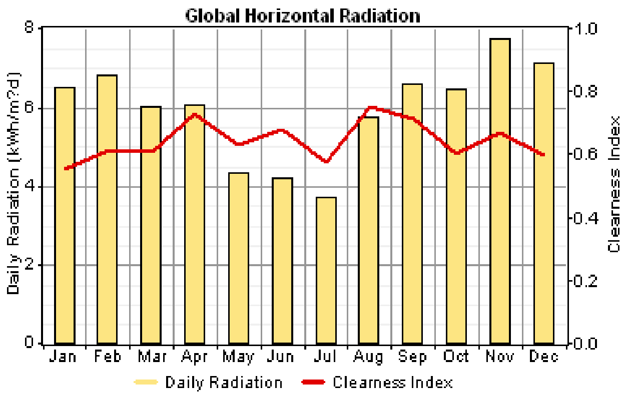


Fig. 4 Average daily global solar radiation data of Alice Spring Airport Weather Station, 2007

3.2.2. Wind energy resources

Three hourly average wind speed (m/s) of the Alice Spring Airport Weather Station is collected from the Australian Bureau of Meteorology. Fig. 6 shows the monthly mean wind speed between 5.72 and 8.56 m/s . Similar to solar resource, wind resource also show more affluence in summer than winter.

The weather station is 10.4 meters height above ground surface. The rotors of the modern wind machines are placed at heights varying between 50-100 meters, so this data was calculated at 100 meters hub height using boundary layer low [24]:

$$\frac{\overline{U}(z)}{\overline{U}(H)} = \frac{\log_e\left(\frac{z}{z_0}\right)}{\log_e\left(\frac{H}{z_0}\right)} \tag{5}$$

z_0 is the surface roughness lengths defined by Table 1.

Table 1 Typical Surface Roughness Lengths [24]

Type of terrain	Roughness length z_0 (m)
Cities, forests	0.7
Suburbs, wooded countryside	0.3
Villages, countryside with trees and hedges	0.1
Open farmland, few trees and buildings	0.03
Flat grassy plains	0.01
Flat desert, rough sea	0.001

The average wind speed became 7.31 m/s at 100 meters height, while at 10.4 meters it was only 3.82 m/s . Fig. 6 demonstrates that the wind speed mainly distributes between 4 m/s and 8 m/s . As seen from the figure, the wind has shortage during June, July and August. Fig. 7 demonstrates wind speed data fitting a Weibull distribution with a scale parameter k=1.79 and a shape parameter c=7.95 m/s .

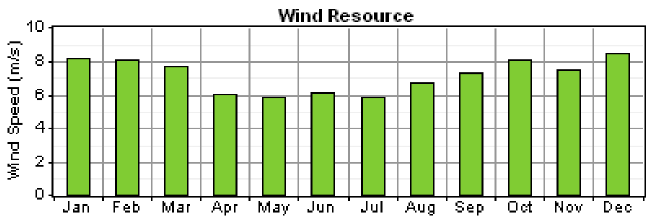


Fig. 6 Average monthly wind speed data of Alice Spring Airport Weather Station, 2007

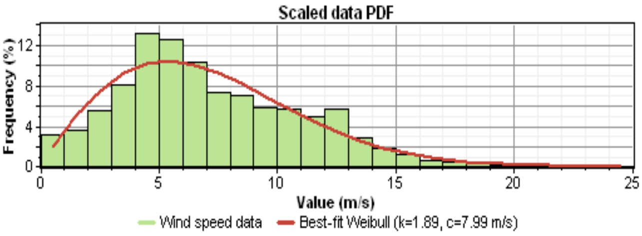


Fig. 7 Wind speed probability distribution function

Consequently, based on the renewable energy resource data of 2007, solar and wind energy in Alice Spring are abundant in summer but relatively less in winter. It can be forecasted that the hybrid power system needs more grid electricity as complementarities.

3.3. Components details

The energy system components are photovoltaic modules, wind turbine, grid, 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 as simulating conditions. All the parameters are shown in Table 2.

3.3.1. Photovoltaic arrays

Photovoltaic array is an expansive component in such a system. The initial cost of photovoltaic arrays commonly vary from $ 4.00 to $ 5.00 per watt [25, 26]. As to an optimistic system, the costs of installation, replacement and maintenance of a 1 kW solar energy system are taken as $ 5,000 and $ 4,000. Sizes of photovoltaic arrays vary 0, 1, 2, 3, 4, 5, 6 and 7 kW.

3.3.2. Wind turbine

The power generated by a wind turbine which is an important component of the system should be more than the average electrical load. Therefore, according to the load data discussed above, the average load is around 40 kW. Thus, BWC Excel-R turbine produced by Bergey Windpower is used. Its performance curve is shown in Fig. 8. The rated power of this wind turbine is 7.5 kW.

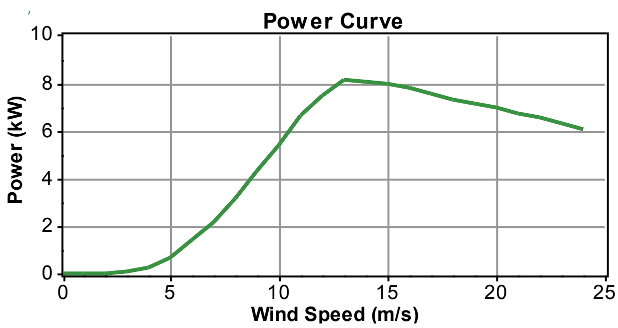


Fig. 8 The power curve of BWC Excel-R

3.3.3. Grid

Grid plays a role of a backup power component in the HPS. When the renewable energy resource is not enough to meet the load, the electricity from the grid is consumed. As mentioned in section 3, the grid element replaced of battery component [23].

3.3.4. Power converter

Converter exists in the system which DC components serve an AD load or vice-versa. The HOMER software considers a converter as inverter (DC to AC), rectifier (AC to DC), or both. For 1 kW facility, the installation and relacement costs are taken as $ 800 and $ 750 respectively [27]. Seven sizes of converter (0, 2, 4, 6, 8, 12 and 16 kW) are taken in the model. Its lifetime is considered as 25 years with an efficiency of 90%.

Table 2 Technical data and study assumptions of photovoltaic, wind turbine, grid and converter.

Description	Value/Information
Photovoltaic	
Capital cost	$ 4000/kW
Life time	20 years
Operation & maintenance cost	$ 3200/kW
Size	0,1,2,3,4,5,6,7 kW
Wind Turbine	
Model of wind turbine	BWC Excel-R
Hub height	100 m
Capital cost	$ 27,500
Life time	30 years
Operation & maintenance cost	$ 25,000
Size	0,1,2
Grid	
Electricity Price	0.3 $/kWh
Emission factors (CO_2)	632 g/kWh
Emission factors (SO_2)	2.74 g/kWh
Emission factors (NO_x)	1.34 g/kWh
Converter	
Capital cost	$ 800/kW
Life time	25 years
Operation & maintenance cost	$ 750/kW
Size	0, 2,4,8,12,16 kW

4. Results and Analysis

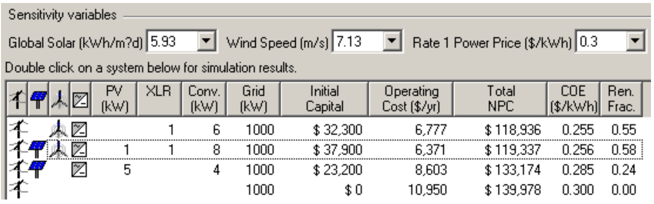
The results of optimal systems and the sensitivity analysis are provided in this study. Considering the electricity price fixed at 0.3 $\$/kWh$, the photovoltaic-wind-grid system can be varied to identify an optimal system type for Alice Spring region. In this software the optimization and sensitivity results will be presented in the forth coming paragraphs.

4.1. Optimization results and analysis

Given the specific wind speed (7.13 m/s), solar irradiation (5.93 $kWh/m^2/day$) and grid electricity price (0.3 $\$/kWh$), the optimization results of the system are summarized in Fig. 9.

In this case, a wind power system seems to be most feasible economically with a minimum total net present cost (NPC) of 114,130 $ and a minimum cost of energy (COE) of 0.255 $\$/kWh$. This is due to the abundant wind energy resource in Alice Spring. In addition, the COE of wind turbine generator is more economical than solar array modules.

Moreover, Fig. 9 shows that when renewable fraction was 58% the NPC is $ 119,337 and the COE is 0.256 $\$/kWh$. This Fig. also indicates that the economic performance of the optimized photovoltaic-wind-grid system is quite similar to the wind-grid system. The reduced NPC and COE are just equal to 85.3% of a standard grid power system. This photovoltaic-wind-grid case has greater renewable fraction (0.576) meaning the bigger proportion of renewable energy electricity generations.


Sensitivity variables
Global Solar (kWh/m²d) 5.93 | Wind Speed (m/s) 7.13 | Rate 1 Power Price ($/kWh) 0.3
Double click on a system below for simulation results.

PV (kW)	XLR	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	1	6	1000	$ 32,300	6,777	$ 118,936	0.255	0.55
1	1	8	1000	$ 37,900	6,371	$ 119,337	0.256	0.58
5		4	1000	$ 23,200	8,603	$ 133,174	0.285	0.24
			1000	$ 0	10,950	$ 139,978	0.300	0.00

Fig. 9 The optimization results of the HOMER simulation

The cost of the standard grid and the optimized photovoltaic-wind-grid system, are compared in Table 3. Obviously, the photovoltaic-wind-grid system is more economical, while the NPC and COE of the standard grid system are $ 139,978 and 0.3 $\$/kWh$. Table 4 shows the emission of the standard grid system and the optimized system. As the main greenhouse gas, the emission of carbon dioxide from standard grid is 23,068 kg/yr, while the optimized system exhausts only 8,230 kg/yr which means 64.3% reduction. Meanwhile, the sulfur dioxide and nitrogen oxide emissions of the photovoltaic-wind-grid system are equal to less than 36% of a standard grid system. Fig. 10 shows that the cost summary of each components of photovoltaic-wind-grid system. The most costs are for the wind turbine.

Table 3 Cost comparison between standard grid and photovoltaic-wind-grid system

Types of Costs	*Standard grid*	*PV-wind-grid system*
NPC (kg/yr)	*139,978*	*119,337*
COE ($\$/kWh$)	*0.3*	*0.256*

Table 4 Emissions comparison between standard grid and photovoltaic-wind-grid system

Pollutant (kg/yr)	*Standard grid*	*PV-wind-grid system*
CO_2	*23,068*	*8,230*
SO_2	*100*	*35.7*
NO_x	*48.9*	*17.5*

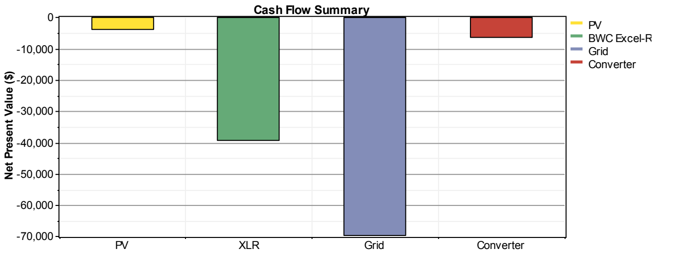


Fig. 10 Cost summary of the photovoltaic-wind-grid system

The electricity consumption from grid component is important. In the optimized photovoltaic-wind-grid system, the grid component costs the most money ($ 69,749), while the photovoltaic-gird system just costs $ 3,876. This is caused by the renewable energy components do not need any more cost for energy resource, but the grid component does. The wind component and the converter cost of $ 39,313 and $ 6,400 respectively.

The monthly energy yield of each component of the photovoltaic-wind-grid system is shown in Fig. 11. Implementing under the specific electricity load (100 kWh/day), the photovoltaic array produces 1,811 kWh/yr (f_{PV} =4%). The wind turbine module produces almost 54% (24,275 kWh/yr) of the system's total energy production (45,306 kWh/yr). In another word, the wind generation fraction f_{WT} of this system is 54%. In this system, the grid purchases share of 42% (19,220 kWh/yr) of the total energy production.

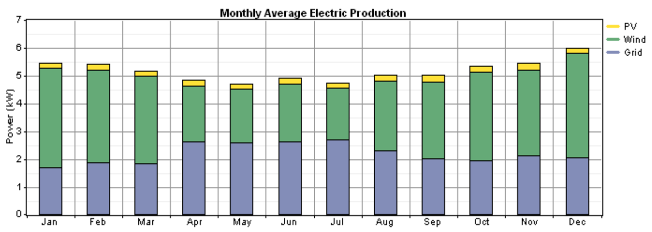


Fig. 11 Monthly power generation

4.2. Sensitivity results and analysis

Sensitivity results are analyzed to study the impacts of variation in the solar irradiation and wind speed on the performance of the HPS. The simulation software simulates the long-term implementation of the hybrid system based on their respective search size for the predefined sensitivity values of the components. The emissions, renewable fraction, NPC and COE are simulated based on the three sensitivity variables: wind speed (m/s), solar irradiation ($kWh/m^2/day$), and grid electricity price ($\$/kWh$). For all of the sensitivity values HOMER simulates all the systems in their respective predefined search space. The long-term implementation of every possible system configuration was simulated for one year period (from Jan 1st 2007 to Dec 31st 2007).

In this study, the sensitivity variables of solar irradiation are defined as: G=4.5, 5, 5.5, 5.93, 6.5, 7, 8, 10 $kWh/m^2/day$, while wind speed are: v=6, 6.5, 7, 7.13, 7.5, 8 m/s . Moreover, the grid electricity price is also defined as a sensitivity variable (P=0.15, 0.2, 0.3, 0.4 $\$/kWh$). A total of 192 sensitivity cases were tried for each system configuration. The simulation time was 17 minutes and 11 seconds on personal computer with Intel CORE Duo Processor of 2.97GHz and 4 GB RAM.

The feasibility of the system is analyzed through the sensitivity results in terms of solar irradiation, wind speed and grid electricity price. Here, the feasibility of hybrid power system is analyzed based on emission reduction and cost saving. This type of sensitivity analysis of the systems provides information that a particular system would be optimal at certain sensitivity variables [28]. The photovoltaic-wind system is feasible when the grid electricity price more than 0.3 $\$/kWh$. Under this condition, the RF can be between 0.55 and 0.65. A photovoltaic-wind-grid system is feasible when global solar irradiation is more than 5 $kWh/m^2/day$ and the grid electricity price is more expansive than 0.3 $\$/kWh$. Its RF can reach between 0.59 and 0.63. When the grid electricity price is constant at 0.3 $\$/kWh$, the photovoltaic-wind system is feasible when the global solar irradiation is more than 5 $kWh/m^2/day$ and the wind speed is between 6.0 – 6.75 m/s . RF varies around 0.55.

Based on the optimization results, wind energy production shows a bigger proportion of energy generation than solar. While the solar power occupies less than 5% of the total energy generation, wind power occupies approximately half. Therefore, the wind energy resource has more impacts on the implementation. Fig. 12-15 reflect the cost, renewable fraction and emissions variation dependent on the sensitivity variable wind speed. The NPC and COE of the hybrid power system (the configuration is undefined here) reduces when the wind speed increase from 6.0 m/s to 8.0 m/s . Simultaneously, as seen in Fig. 13, renewable fraction rise sharply from 0.24 to 0.48 (when wind speed increases from 6.0 m/s to 6.5 m/s), and then steadily increases to 0.63 at slower rate. As shown in Fig. 14 and Fig. 15, the main emissions of carbon dioxide, sulfur dioxide and nitrogen oxide decrease 63 per cent.

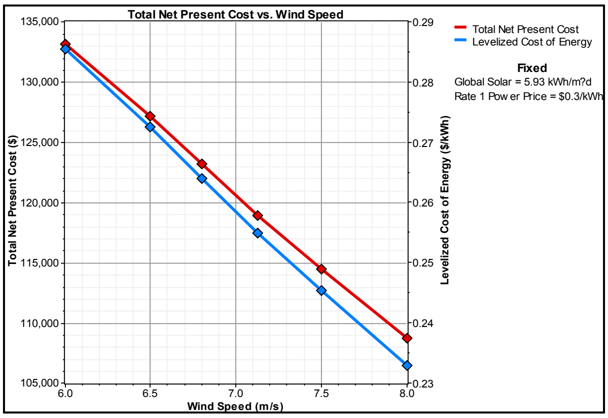


Fig. 12 The relationship between cost and wind speed

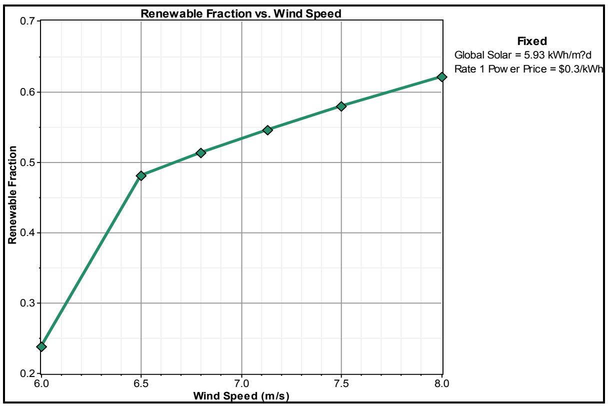


Fig. 13 The relationship between RF and wind speed

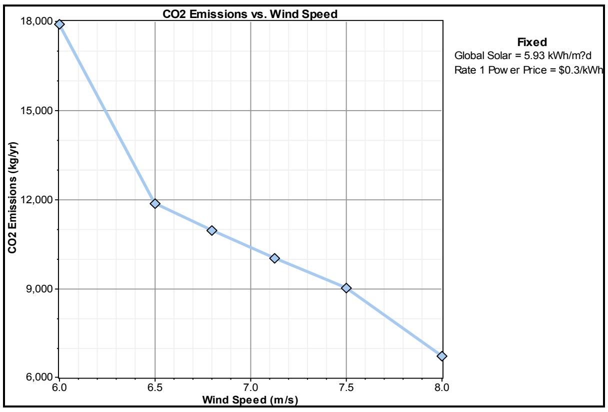


Fig. 14 The relationship between CO2 emissions and wind speed

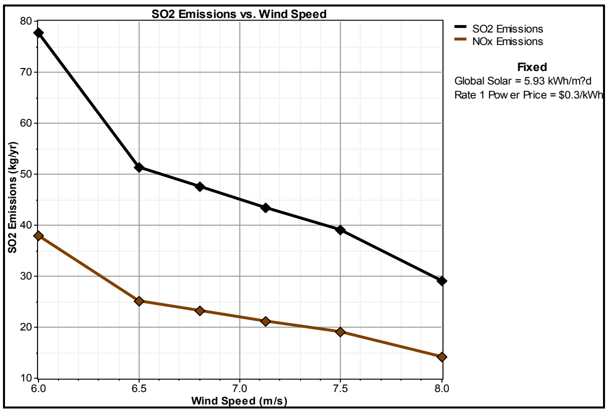


Fig. 15 The relationship between SO_2 (NO_x) and wind speed

5. Conclusion

The economic and environmental performance parameters of a photovoltaic-wind-grid hybrid power system in hot arid Australia are calculated through modeling the system. This study collected the local meteorological data of solar and wind energy resources from the weather station of Alice Spring where a typical hot arid region is. The mean solar irradiation was G=5.93 $kWh/m^2/day$ and wind speed was 7.13 m/s in the year of 2007. The electricity load of the system was defined as 100 kWh per day. The hybrid power system is sized by using the software HOMER to meet the requirements of emission reduction and cost saving. The optimized HPS, including a BWC Excel-R wind turbine and a photovoltaic module of 1 kW. It is capable to reduce the COE to 0.256 $\$/kWh$, while the standard grid electricity was 0.3 $\$/kWh$. The application of such system also decreases the emissions of CO_2, SO_2 and NO_x to less than 40% of the standard grid power system. In addition, the sensitivity analysis indicates that photovoltaic-wind-grid system is feasible under the Alice Spring's local climatic conditions. The increasing value of wind speed leads to the reduction of NPC, COE and CO_2, SO_2 and NO_x emissions of the system reduces. The renewable fraction grows up with the increasing wind speed and solar irradiations.

References

[1] Bevan, E., *An assessment of renewable energy for the UK*. Vol. 1. 1994, London: HMSO.

[2] Saheb-Koussa, D., M. Haddadi, and M. Belhamel, *Economic and technical study of a hybrid system (wind-photovoltaic-diesel) for rural electrification in Algeria*. Applied Energy, 2009. 86(7-8): 1024-1030. http.dx.doi.org/10.1016/j.apenergy.2008.10.015

[3] Heathcote, R.L., *The arid lands: their use and abuse*. 1983, Hong Kong: Longman Group Limited.

[4] Daniels, F., *Direct use of the sun's energy*. Amer. Scientist, 1967. 55: p. 15-47.

[5] Sabziparvar, A.A., *A simple formula for estimating global solar radiation in central arid deserts of Iran.* Renewable Energy, 2008. **33**(5): p. 1002-1010. http.dx.doi.org/10.1016/j.renene.2007.06.015

[6] Sabziparvar, A.A. and H. Shetaee, *Estimation of global solar radiation in arid and semi-arid climates of East and West Iran.* Energy, 2007. **32** (5): p. 649-655. http.dx.doi.org/10.1016/j.energy.2006.05.005

[7] Hills, E.S., *Arid lands: A geographical appraisal*. 1969, London: Mehuen & Co Ltd.

[8] Saheb-Koussa, D., M. Haddadi, and M. Belhamel, *Economic and technical study of a hybrid system (wind-photovoltaic-diesel) for rural electrification in Algeria.* Applied Energy, 2009. **86**(7-8): 1024-1030. http.dx.doi.org/10.1016/j.apenergy.2008.10.015

[9] Shaahid, S.M. and I. El-Amin, *Techno-economic evaluation of off-grid hybrid photovoltaic-diesel-battery power systems for rural electrification in Saudi Arabia-A way forward for sustainable development. Renewable and Sustainable Energy Reviews*, 2009. **13**(3): p. 625-633. http.dx.doi.org/10.1016/j.rser.2007.11.017

[10] Shaahid, S.M., et al., *Potential of autonomous/off-grid hybrid wind-diesel power system for electrification of a remote settlement in Saudi Arabia*. Wind Engineering, 2004. **28**(5): p. 621-628. http.dx.doi.org/10.1260/0309524043028127

[11] Elhadidy, M.A. and S.M. Shaahid, *Feasibility of hybrid (wind+solar) power systems for Dhahran, Saudi Arabia*. Renewable Energy, 1999. **16**(1 -4 pt 2): p. 970-976.

[12] Shaahid, S.M. and M.A. Elhadidy, *Wind and solar energy at Dhahran, Saudi Arabia.* Renewable Energy, 1994. **4**(4): p. 441-445. http.dx.doi.org/10.1016/0960-1481(94)90052-3

[13] Mahmoudi, H., et al., *Weather data and analysis of hybrid photovoltaic-wind power generation systems adapted to a seawater greenhouse desalination unit designed for arid coastal countries*. Desalination, 2008. **222**(1-3): p. 119-127. http.dx.doi.org/10.1016/j.desal.2007.01.135

[14] *Australia's Arid Lands*. 2005 29th, Nov 2005 [cited 2009 5th, Nov]; Available from: http://www.cazr.csiro.au/contacts.htm.

[15] Hak, T., B. Moldan, and A.L. Dahl, *Sustainability indicator: A scientific assessment*. 2007, Washington: Island Press.

[16] Hare, B., *Guide to the Kyoto Protocol*, G. International, Editor. 1998, Climate Policy Director: Amsterdam.

[17] Lang, Y. *Acid Rain*. 2009 [cited 2009 Dec, 8]; Available from: http://en.wikipedia.org/wiki/Acid_rain.

[18] *HOMER - Getting Started Guide for HOMER Version 2.1*. 2005, National Renewable Energy Laboratory, Operated for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy.

[19] *Using the HOMER Model in Air Quality Analysis*, P. Lilienthal and T. Lambert, Editors. 2004, National Renewalbe Energy Laboratory: Colorado.

[20] Celik, A.N., *Techno-economic analysis of autonomous PV-wind hybrid energy systems using different sizing methods.* Energy Conversion and Management, 2003. **44**(12): p. 1951-1968 http.dx.doi.org/10.1016/S0196-8904(02)00223-6

[21] Beccali, M., et al., *Energy, economic and environmental analysis on RET-hydrogen systems in residential buildings.* Renewable Energy, 2008. **33**(3): p. 366-382. http.dx.doi.org/10.1016/j.renene.2007.03.013

[22] Dalton, G.J., D.A. Lockington, and T.E. Baldock, *Feasibility analysis of stand-alone renewable energy supply options for a large hotel.* Renewable Energy, 2008. **33**(7): p. 1475-1490 http.dx.doi.org/10.1016/j.renene.2007.09.014

[23] Camerlynck, J., *Modelling of renewable energy system in the maldives*. 2004, Utrecht University: Netherlands.

[24] Burton, T., et al., *Wind Energy Handbook*. 2001, West Sussex: John Wiley & Sons, Ltd. http.dx.doi.org/10.1002/0470846062

[25] *Solar Module Price Highlights: October 2009*. 2009 [cited 2009 28th October]; Available from: http://www.solarbuzz.com.

[26] *Product details: Solar photovoltaic*. 2009 [cited 2009 28th October]; Available from: http://www.auzion.com.

[27] Khan, M.J. and M.T. Iqbal, *Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland.* Renewable Energy, 2005. **30**(6): p. 835-854. http.dx.doi.org/10.1016/j.renene.2004.09.001

[28] Rehman, S., et al., *Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant.* Renewable and Sustainable Energy Reviews, 2007. **11**(4): p. 635-653. http.dx.doi.org/10.1016/j.rser.2005.05.003