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Sizing and Costing Optimisation of a Typical Wind/PV Hybrid Electricity Generation System for a Typical Residential Building in Urban Armidale NSW, Australia

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ABSTRACT: This study investigates the wind and solar electricity generation availability and potentiality for residential buildings in Armidale NSW, Australia. The main purpose of this study is to design an appropriate wind-PV hybrid system to cover the electricity consumption of typical residential buildings of various occupancy rates and relevant various average electrical daily consumption. In order to do achieve that, monthly average solar irradiance monthly average wind speed historical data observed at weather station belongs to the Australian bureau of meteorology in Armidale town over a fourteen years period from 1997–2010. Simulation of solar photovoltaic panels and wind turbines were conducted to obtain the optimal hybrid system sizing and best efficient with lowest cost. Correlations between the solar and wind power data were carried out on an hourly, daily, and monthly basis. It is shown that the hybrid system can be applied for the efficient and economic utilization of wind and solar renewable energy sources.

Keywords: Hybrid system; wind energy; photovoltaic energy; Armidale NSW; renewable energy; system optimisation
JEL Classifications: C1; C2; C3; C6; C9

1. Introduction

Nowadays, renewable energy sources have probable potential to contribute to fulfil partially to the energy increasing demands worldwide as such sources are reliable and inexhaustible to a great extent. Recent researches show an increasingly evident that renewable energy technologies do have a strategic role to play in the achievement of the goals of sustainable economic development and environmental protection (Sayish, 1999; Wrixon, 1993). The development of renewable energy technology is currently booming as important if the world is to move towards a green and sustainable approach of generating energy. However, various obstacles face the rapid development of such technologies. A major obstacle is the commercialization of (Elliot, 2000). Currently, existing renewable energy technologies in the energy market cannot provide a reliable source of the entire energy demand of any country all over the world (Ediger, 1999). Although, the fact that the environmental concerns and limited energy sources are promoting renewable energy as a potential alternative to fossil fuels. Thus, at this time, renewable energy can be complementary to fossil fuels, and can be used effectively alone or in combinations of two or more renewable energy sources (e.g., wind and solar). Thus, all renewable options should be pursued in tandem (Wrixon, 1993).

Photovoltaic solar energy and wind energy conversion systems have been widely used for electricity supply in remote and isolated locations far from the electricity public distribution network. These systems provide a relatively reliable source of electricity generation and operate in an unattended manner for extended periods of time if they are properly sized, designed and maintained. However, these systems does suffer from the natural fluctuating attributes solar and wind energy sources, this fluctuation have to be addressed and solved during the initial stages of the hybrid system design (Sahin, 1995; Markvart, 1996). The cost of the individual system is a function of its power size.

Thus, the optimal sizing of a hybrid system is a far important aspect of system efficient functionality. Several factors, such as climatic data, system's component costs, and the temporal distribution of the electric load have to be taken into consideration in the hybrid system design, as well (Hadi Arab, 1995).

The applicability and optimum design of the wind/PV hybrid systems have been approached and examined by various several researchers (Sahin, 1995; Markvart, 1996; Hadi Arab, 1995). However, the optimal design for wind-PV hybrid power systems is dependent and closely related to place of application. Therefore, the main objective of the present study is to determine the optimum solar/wind combination of a hybrid wind and solar system that can provide the electricity needs of typical residential buildings of 9, 11.5, 16 and 21 (kWh day) in Armidale NSW, Australia as a half average daily consumptions of 1, 2, 4 and 6 occupants respectively. The system sizing and costing optimization is carried out based on the on-site measured data of solar and wind energy characteristics.

2. Armidale NSW, Australia

Armidale (30°30′S 151°39′E/ 30.500°S) is a city in the Northern Tablelands, New South Wales (NSW), Australia (Burr, 2002). Armidale is located on the Northern Tablelands in the New England region about midway between Sydney and Brisbane at an altitude ranging from 970 metre at the floor of the valley to 1,110 metres above sea level at the crests of the hills (Burr, 2002). Armidale has a cool temperate climate with the majority of rain falling in the summer months. Armidale's elevation results in a mild climate, with pleasant warm summers, extended spring and autumn seasons, and a long cold winter with some frosty nights. Figure 1 shows the location of Armidale in regional NSW. Generally, rural/regional Australia are rich of the following renewable energy sources such as solar, wind, geothermal, biomass and hydropower, however, further works needs to be done to prove the above findings feasibility against existing traditional electricity generation based on fossil fuel (Maklad, 2014a)

Figure 1. Location of Armidale in New South Wales

Source: Google Maps

3. Solar and Wind Data Observations

Solar Irradiance data and wind speed historical data were measured for fourteen years by Armidale Airport Automatic Weather Station which belongs to the Australian Bureau of Meteorology

(BOM). Figure 1 presents the estimated solar PV energy in (kWh/m2 day) of solar irradiance for horizontal surfaces and 45 degrees inclined surfaces.

Figure 1. Monthly average daily solar radiation values for measured horizontal (β = 0°) and yearly optimum tilt angle surfaces calculated (β = 45°) in Armidale NSW, Australia

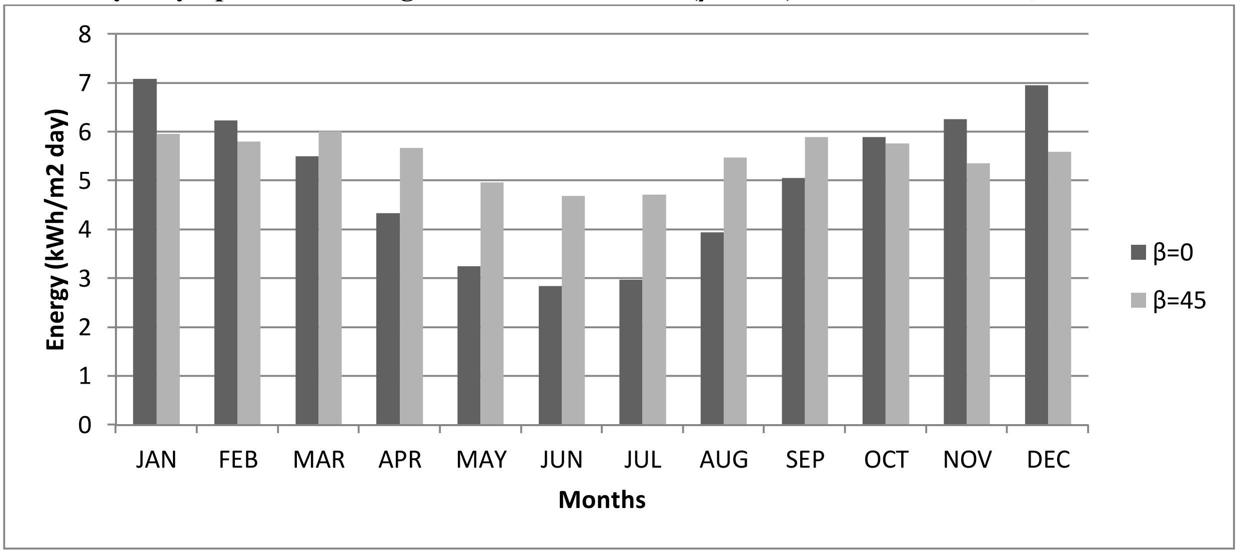
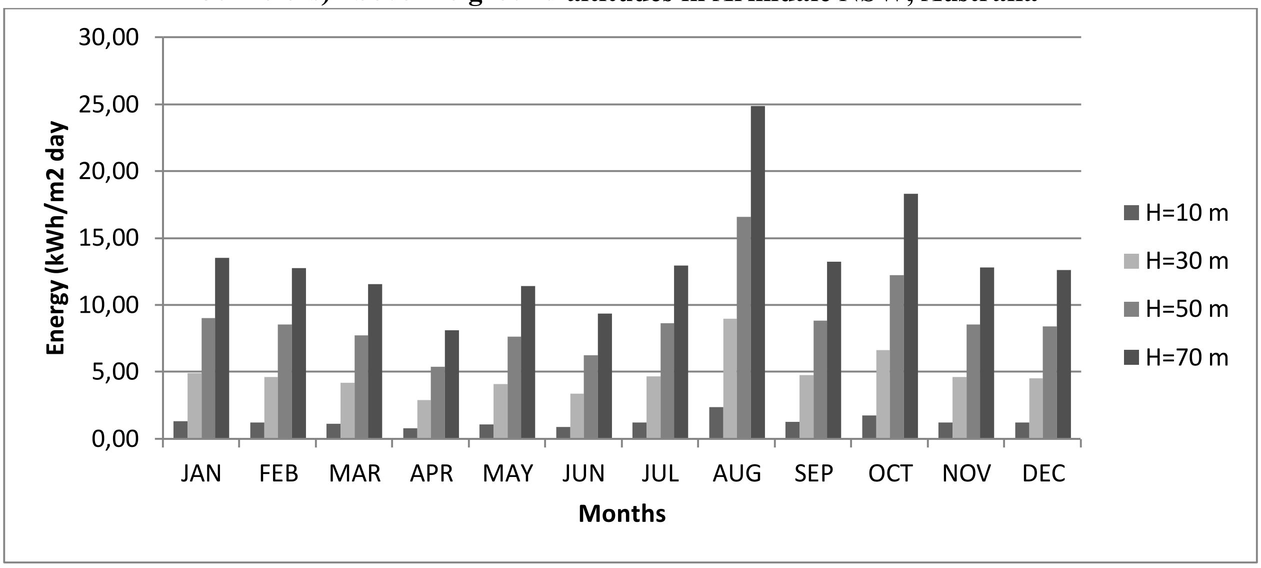


Figure 2 shows the estimated wind energy in (kWh/m2 day) for heights (10, 30, 50 and 70) m above ground level. In this study, mean wind velocity data was measured daily by Armidale Airport Automatic Weather Station under the authority of the Australian Bureau of Meteorology (BoM). Observed wind velocity data during the period (1994-2010) were obtained at 10 metres above ground level with an anemometer. These data were used to investigate the wind power potential of this region. Figure 2 shows the monthly mean wind velocity in Armidale region during the period 1994 to 2014. The highest monthly mean wind velocity of 7.83 m/s occurred in September 2003, while the lowest mean wind velocity of 2.89 m/s occurred in March 1999. The mean annual wind velocity in the period from 1994 to 2010 was 5.30 m/s (Maklad, Glencross-Grant, 2014).

Figure 2. Monthly average daily wind energy calculated values for heights (H = 10, 30, 50 and 70 meters) above the ground altitudes in Armidale NSW, Australia



Source: Maklad and Glencross-Grant (2014)

4. Theoretical Analysis

The power output from a solar-wind hybrid generator, $E_{out,}$ may be expressed as:

$$E_{out} = S_{a_s} + W_{a_w} \quad (1)$$

where S and W represent energy coefficients and a_s and a_W are used to account for the size and overall efficiency of the individual solar and wind power generators, respectively (Sahin, 1995; Markvart, 1996). For the photovoltaic (PV) array, a_s is defined as (Markvart, 1996):

$$a_s = \lambda A \quad (2)$$

where η is the module efficiency and A is the array area. This definition coincides with the usual "peak power" rating of the array: if A is measured in m^2, a_s is numerically equal to the peak power in kW_p. For the wind generator we define,

$$a_w = C_p(\pi r^2) \quad (3)$$

where C_p is the (dimensionless) power coefficient, and r is the radius of the rotor (Markvart, 1996).

Solar and wind energy potentials are computed per unit surface area (kWh/m^2) for comparison and correlation. For the solar power, S the required value refers to the inclined plane of the modules that is usually calculated from the meteorological data for a horizontal plane. In this regard, the authors have developed simple empirical correlations to estimate the monthly average daily solar radiation on a tilt surface for the city of Izmir, in Turkey (Ulgen, 2002a; Ulgen 2002b; Ulgen, 2003). The wind power W is measured in a plane perpendicular to the wind direction. The available wind potential per unit area perpendicular to the wind stream is expressed by the kinetic energy flux during a day as (Mayhoub, 1997).

$$W = \frac{1}{2}\rho d_h V^3 \quad (4)$$

where W is the wind power available (kWh/m^2), V is the wind speed (m/s), ρ is the air density (kg/m^3) and d_h is the length of a day. The main goal in designing the hybrid power generator is to select the optimum values of a_s and a_W *for* minimum cost and to produce a total power output to meet the demand for power throughout the year. Assuming the cost to be a linear function of the size, the total cost of a hybrid generator, C_H, can be written as (Markvart, 1996):

$$C_H = C_s a_s + C_w a_w \quad (5)$$

where C_s and C_W represent the cost per unit power potential of individual solar and wind power generators, respectively. This total cost is minimized, with the constraint

$$D \leq S_{a_s} + W_{a_w} \quad (6)$$

where D is the energy demand. Although the demand of energy varies throughout the year, the analysis in this study is based on the assumption of a constant energy demand of 82.19 kWh/day. The range of values a_s and $a_W$that fulfils Equation (6) at all times of the year is also determined using the average values of D, S and W.

5. Study Area Details

The study area is a virtual single storey house with a living area, kitchen, toilet and laundry area, the study will deal with a one, two, three and four bedroom houses which are typically to be occupied by one, two, four and six occupants respectively. The typical relevant electrical loads are lighting, kitchen appliances (electrical fridge, electrical stove with oven, toaster), a television, two computers/laptops, electric water heating (operating all the year) and electrical air conditioning to be operated in (almost 8 months/annually) (Maklad, 2014b). A typical electrical consumption pattern for such a house in urban Armidale is seasonally categorized as shown in Table 1.

Table 1. Extracted from AGL electricity provider in Australia data for Armidale NSW, Australia

Season	Months	1 Occupant		2 Occupants		4 Occupants		6 Occupants	
		Total kWh	Avg. Daily kWh	Total kWh	Avg. Daily kWh	Total kWh	Avg. Daily kWh	Total kWh	Avg. Daily kWh
Winter	Jun–Jul-Aug	1700	18	2255	23	3160	32	4070	42
Spring	Sept-Oct-Nov	1150	13	1440	16	2020	22	2600	29
Summer	Dec-Jan-Feb	1300	15	1630	18	2280	25	2940	33
Autumn	Mar-Apr-May	1100	12	1380	15	1930	21	2490	27

Source: Maklad (2014)

6. Results and Discussion

In the sizing of the hybrid system for covering the average daily electric demand of residential buildings in Armidale NSW, a simple method used to determine the size and cost of wind and PV power generators. Following this method, as and aw values are determined taking solar and wind as individual energy sources, respectively. The system sizing for individual PV and wind energy systems is also calculated with the same methodology and compared with the hybrid system (Engin, 2003).

Table 2 shows the optimized hybrid system sizing and relevant costing for residential buildings occupants 1, 2, 4 and 6 would typically consume average daily electric load of 9, 11.5, 16 and 21 kWh day as their half daily consumption, respectively. The proposed hybrid systems project life time is considered 25 years.

Table 2. Hybrid system optimal size and relevant costing for Armidale NSW

Occupants	Daily Load	Hybrid System Components				Total Cost over the project life time (25 Years) in USD		
		Wind Turbines kW	Solar PV kW	Battery	Converter	Capital	O&M	Total
1	9	2 x 3kW	7.5 kW	10kWh	15 kW	21,150	6,250	27,400
2	11.5	3 x 3kW	10 kW	15Kwh	20Kw	30,100	8,000	38,100
4	16	2x5kW	15 kW	20Kwh	25kW	45,750	10,000	55,750
6	21	1x10Kw+1x5kW	20kW	25kWh	35kW	60,750	13,750	74,500

7. Conclusion

In this study, a hybrid system consisting of both solar and wind electricity generation systems was optimized in size and costing using meteorological solar irradiance and wind data obtained on energy supply and demand. The cost of the hybrid system for a typical residential building of a 15 kWh average daily electric was determined and found to be less costly than those of the individual PV systems and individual wind systems. This hybridising process fills the need of energy over the seasons which have lack of solar and/or wind by complementing each other source. The results of this study could help residents in Armidale to size and cost their hybrid systems approximately. Different options of funding and financing are still open for households to investigate and make a decision, as well, excess generated electricity by such a hybrid system feed in grid tariff is one of the influencing factors affecting the system payback period.

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