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Optimalsizingofa Hybrid Solar and Wind Energy Micro-Generationsystems and Battery Storage Combination for Armidale NSW, Australia

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ABSTRACT

Intermittency is an apparent characteristic of some renewable energy sources, this specifically applies to solar, wind and tidal renewable sources. Thus, battery storage is a real important element of any hybrid photovoltaic (PV) and wind energy generation systems. As well, sizing ofbattery storageplaysa vital role in achieving an optimal operationofsuch asystem.Emphasis is greatly required to proper sizing of battery storage.Inthiscontext, daily global solarradiationdata and mean daily wind speed for (14) years during the period1997–2010 were meteorologically measured and recordedatArmidale, NSW, Australia. Those data havebeenanalysedtoinvestigatetheoptimal sizeofbatterystoragecapacityfor stand-alone PV and wind energy systems. Several sizingconfigurationshavebeensimulated.Four case studies of Armidale's houses/units with occupancy of (1, 2, 4 and 6) persons are considered to fulfil fifty percent of the average daily electrical load demand of each occupancy category using PV energy system equipped with battery storage. Calculations showed various combinations of capacities of PV energy system and its related battery storage. Optimal size of hybrid PV and wind energy system and relevant battery storage for each occupancy category are conducted based on techno-commercial basis.

KEYWORDS : Batterystorage; energy micro-generation;photovoltaicsystemsolar radiation; wind energy

1. Introduction

Nowadays, renewable energy sources have probable potential to contribute to fulfilpartially 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 asa 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).

Thus, the optimal sizing of a hybrid stand-alone PV and wind system with a battery storage 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 stand-alone PV and wind system design, as well (Hadi Arab,1995).

The main objective of the present study is to determine the optimum capacities of hybrid stand-alone PV and wind energy system and the relevant battery storage capacity that can provide the 50% of the average electricity daily consumption of typical residential buildings of (9, 11.5, 16 and 21) kWh day which is equivalent to occupancy of (1, 2, 4 and 6) persons respectively in Armidale NSW, Australia urban areas. The system sizing and costing optimization is carried out based on the on-site meteorological measured data of solar radiation characteristics.

2. 2. Armidale NSW, Australia

Armidale (30°30'S 151°39'E/ 30.500°S) is a city in the Northern Tablelands, New South Wales, 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.

1. Solar and Wind Data Observations

Solar Irradiance historical data were measured for fourteen years by Armidale Airport Automatic Weather Station which belongs to the Australian Bureau of Meteorology (BOM). Figure 2 presents the estimated solar PV energy in (kWh/m^2 day) of solar irradiance for horizontal surfaces and 45 degrees inclined surfaces.

It is clear that solar radiation values are the highest in Armidale' summer months (November, December and January) and the lowest in Armidale's winter months (May, June and July). Average values of solar radiation on horizontal surfaces ranges from (4.75 kWh/m^2) day to (7.20 kWh/m^2) day, however, for 45 inclination, it ranges from (2.85 kWh/m^2) day to (5.95 kWh/m^2) day. It is easily derived and understood that solar radiation values on horizontal surfaces are higher than those values on inclined surfaces.

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 3 shows the estimated wind energy in (kWh/m2 day) for heights (10, 30, 50 and 70) m above ground level.

Figure 1. Location of Armidale in New South Wales

Source: Google Maps

Figure2. Monthlyaveragedailysolarradiationvalues for measured horizontal(β=0°)andyearlytiltangle surfaces calculated (β=45°) in Armidale NSW, Australia

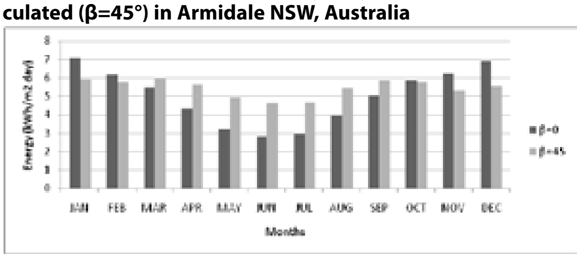
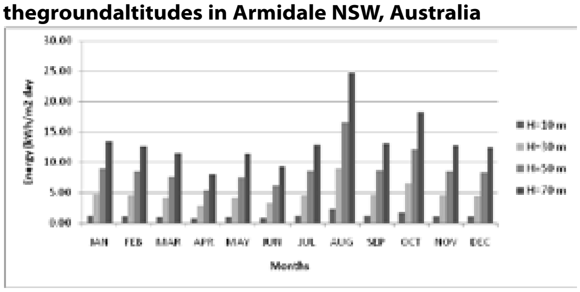


Figure 3 Monthlyaveragedailywindenergy calculated values for heights (H=10, 30, 50 and 70meters) above-thegroundaltitudes in Armidale NSW, Australia



Source (Maklad, Glencross-Grant, 2014)

2. Theoretical Analysis

Thepoweroutputfroma solar-windhybridgenerator, Eout, maybeex-pressedas:

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

where S and W representenergycoefficientsandasandawareusedtoac-countforthe sizeandoverallefficiencyoftheindividualsolarandwind-powergenerators, respectively (Sahin,1995; Markvart,1996). Forthephotovoltaic(PV)array, asisdefinedas(Markvart,1996):

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

whereηisthemoduleefficiencyand*A*isthearrayarea.Thisdefinitioncoincideswiththe usual"peakpower"ratingofthearray: if*A*ismeasuredin-m^2,$a_s$isnumericallyequalto thepeakpowerinkW$_p$. Forthewindgeneratorwedefine,

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

where$C_p$isthe(dimensionless)powercoefficient,and*r*istheradiusofthero-tor(Markvart,1996).

Solarandwindenergypotentialsarecomputedperunitsurfacearea(kWh/m^2)for comparisonandcorrelation.Forthesolarpower, S therequired-valuereferstothe inclinedplaneof themodulesthat isusuallycalculated-fromthe meteorologicaldata for a horizontalplane.Inthisregard,theauthorshavedeveloped simpleempirical correlations toestimatethe monthlyaveragedailysolarradiationon atilt surfacefor the cityofIzmir, inTurkey(Ulgen,2002a; Ulgen, 2003).Thewindpower W ismeasuredina-plane perpendicular tothewind direction.Theavailablewindpotentialp-erunitareaperpendicular tothewindstreamisexpressedbythekineticen-ergyfluxduringadayas(Mayhoub, 1997).

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

where W isthewindpoweravailable(kWh/m^2), V isthewind-speed(m/s), ρ istheair density(kg/m^3)and $d_h$isthelengthofaday. The-maingoalindesigningthehybridpowergeneratoristoselecttheoptimum valuesof$a_s$anda_w forminimumcostandtoproduceatotalpoweroutput-tomeetthe demandforpowerthroughout theyear.Assuming thecostto-bealinearfunction ofthe size,thetotalcostofahybridgenerator,C_H,can-bewrittenas(Markvart,1996):

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

where$C_s$and$C_w$representthecostperunitpowerpotentialofindividual-solarandwind powergenerators, respectively. This totalcostisminimized,withtheconstraint

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

where D is theenergydemand.Althoughthedemandofenergyvaries-throughoutthe year,the analysisin thisstudyisbasedontheassumption-of aconstantenergydemandof 82.19kWh/day. The rangeofvalue-s$a_s$and$a_w$thatfulfilsEquation (6) atalltimesofthe yearis alsodeterminedusingtheaveragevalues of D, S and W.

5. Study Area's 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, 2014). 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

Inregards to sizingofa hybrid stand-alone PV and wind systemto fulfil fifty percent of theaverage daily electric demand of residential buildings in Armidale NSW, a simplified calculation method used to determine the size and cost of PV and wind power generators. Following this method, as and aw values are determined taking solar and wind as individual energy sources, respectively. Thehybrid systemsizingforindividualPVandwindenergysystemswith a battery storage isalsocalculatedwith thesamemethodologyandcomparedwiththehybridsystem(Engin,2003).

Table 2. shows the optimized hybrid stand-alone PV and wind system sizing associated with optimal battery storage capacity 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 stand-alone PV system and battery project life time is considered 25 years.

Table 2. Hybrid Stand-alone PV and Wind System with battery optimal size and relevant costing for Armidale NSW.

Occupants	Daily Load	System Components			Total Cost over the project life time (25 Years) in USD		
		Solar PV kW	Wind Turbines kW	Battery	Capital	O&M	Total
1	9	5 kW	3 kW	3kWh	16,000	6,000	22,000
2	11.5	7.5 kW	3 kW	5 kWh	21,000	9,000	30,000
4	16	12 kW	5 kW	10 kWh	25,000	11,500	36,500
6	21	15kW	7.5 kW	15 kWh	30,000	15,000	45,000

Conclusion

In this study, a hybridstand-alone PV and wind system with battery storage was optimized in size and costing using meteorological solar irradiance data, mean wind daily speed and average electrical daily consumption demand for Armidale urban areas.The combination of hybrid stand-alone system and battery storage fulfils the demand of energy over the seasons which have lack of solar radiation and/or non-windy seasons. The results of this study could help residents in Armidale to size and cost their hybrid stand-alone PV and wind system with the proper battery storage size approximately. It is important to mention that due to intermittency and relative inadequacy of solar radiation and wind speed over the daytime and over the seasons in Armidale, battery storage should be considered as a necessary element of the PV and wind system in order to avoid using grid electricity and/or other backups such as diesel generators which is inconvenient in urban areas.

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