Cost Effective Analysis of Variation of Altitude of Wind Turbine System

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Abstract: Renewable power generation plays a vital role in the economic progress of a nation by providing non-pollutant, safe and reasonable energy at affordable cost. Power generation by wind energy is one of the most hopeful solutions, especially in view of its growth and technological advancements. High altitude wind has huge potential as wind speed generally increases with increase in altitude. The amount of energy in high altitude winds and its intermittency depends on the frequency distribution of wind power density. This paper proposes the concept of cost effective analysis on variation in the altitude of hub in wind turbine system (WTS) along with Photovoltaic (PV). This proposed model is simulated for a 24 hours textile show room load in Coimbatore, India using HOMER optimization software. It gives clear analysis of how the production cost is varied by varying the altitude of hub in wind turbine.

Key words: Wind turbine · Hub height · High Altitude

INTRODUCTION

Wind is a clean and inexhaustible source of energy that has been used for many centuries to grind grain, pump water and propel sailing ships and to perform other work [1-4]. Renewable power generation can help countries meet their sustainable development goals through provision of access to clean, secure, reliable and affordable energy. Renewable energy has gone mainstream, accounting for the majority of capacity additions in power generation today. Tens of giga watts of wind, hydropower and solar Photovoltaic capacity are installed worldwide every year in a renewable energy market that is worth more than a hundred billion USD annually. Other renewable power technology markets are also emerging. Recent years have seen dramatic reductions in renewable energy technologies' costs as a result of R&D and accelerated deployment. Yet policy-makers are often not aware of the latest cost data. As wind speed increases, the amount of available energy increases. Therefore, capacity factors rise rapidly as the average mean wind speed increases. The wind generally blows more consistently at higher speeds at greater heights [5]. Major parts of the wind turbine systems are Blades, Nacelle, Rotor Hub, Gear box, Generator, Controller, Tower and Transformer. The turbine

rotor and hub assembly spins at a rate of 10 to 25 revolutions per minute (rpm) depending on turbine size and design (constant or variable speed). The hub is usually attached to a low speed shaft connected to the turbine gearbox. The wind turbine hub height is the height above ground at which the rotor sits. Hub heights typically range between 25m (for smaller wind turbines, 50 kW or less) and 100m (for large, multi-megawatt wind turbines). Wind speeds tend to increase with height above ground [6]. Aim of this work is to find the cost of energy (COE) on variation in the altitude of hub in wind turbine system along with Photovoltaic are simulated for 24 hours residential load using HOMER (Hybrid Optimization Model for Electric Renewable) optimization software.

HOMER: National Renewable Energy Laboratory's (NREL) HOMER has been used as the sizing and optimization software tool. It contains a number of energy component models and evaluates suitable technology options based on cost and availability of resources. In this paper the system sizing [7-9] is carried out using HOMER-optimization and simulation software tool. Analysis with HOMER requires information on resources, economic constraints, and control methods. It also requires inputs on component
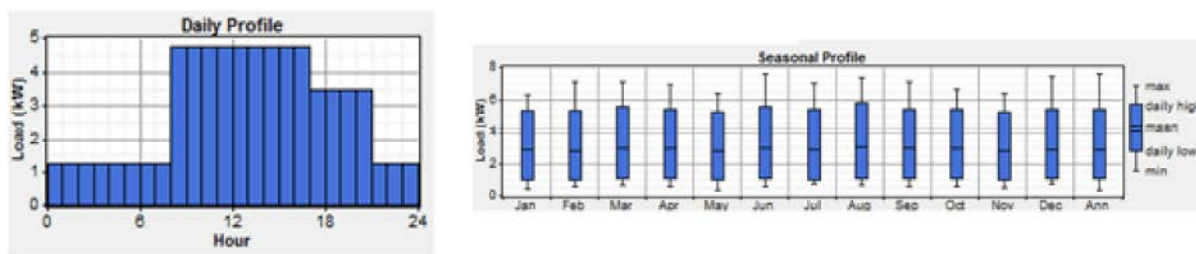

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Fig. 1: Hourly and Yearly Load profile

Fig. 2 Proposed Hybrid System

Table 1: Resource input data

Month	Solar Resource		Wind Resource (m/sec)
	Clearness index	Daily Radiation (kWh/m²/day)	
Jan	0.633	5.46	3.65
Feb	0.634	5.94	3.15
Mar	0.63	6.39	3.29
Apr	0.562	5.93	3.23
May	0.508	5.35	3.81
Jun	0.371	3.87	5.52
Jul	0.355	3.71	5.31
Aug	0.389	4.08	5.02
Sep	0.473	4.83	3.9
Oct	0.475	4.54	3
Nov	0.531	4.65	3.21
Dec	0.597	4.99	4.06

Table 2: Cost Input

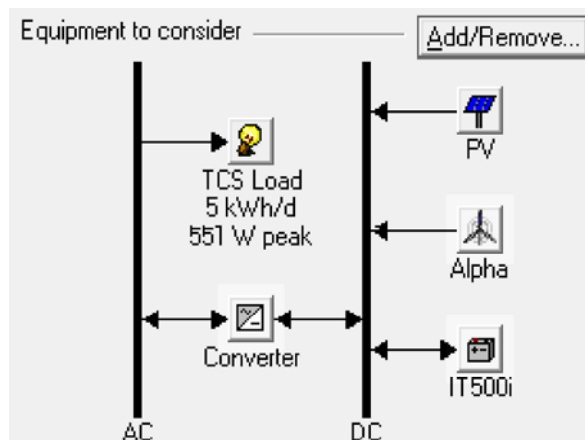| Components	Rating	Quantity	Cost
PV Panel	1kW	1	1,00,000.00
Wind Turbine	Alpha2.7 2.7kW	1	2,73,000.00
Battery	Exide iT 12V/150Ah	1	15,400.00
Converter	96V/5VA	1	52,500.00

types, their numbers, costs, efficiency, longevity, etc. Sensitivity analysis could be done with variables having a range of values instead of a specific number. A case study has been analyzed in Coimbatore, India by considering two power sources such as 1kW Photovoltaic, 2.7kW Wind turbine system, solar inverter and battery storage. Fig. 2 shows the HOMER schematic diagram of the hybrid renewable electric system showing all components.

Load Profile: Cited location for this paper is Coimbatore, India. Its latitude is 11.59°North and longitude 76.07°E respectively. The load profile is based on basic loads like light, fan, Television, CFL, Decorative lamps, LCD Computers, CCTV and Music System. A small base load of 1.225kW occurs throughout day and night. The total daily load average is 5kW/day. The varying daily and yearly load profiles are shown in Fig. 1.

Resource Input: The daily average solar radiation for this location is 4.972 kWh/m²/day and daily average clearness index is 0.508. The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions and a low value under cloudy conditions [11]. The monthly average wind speed for the test location is 3.935m/sec. Monthly average solar insolation data and wind speed for the selected location is shown in Table 1.

Cost Input: HOMER performs comparative economic analyses on a generation power system. The costs objective function is the Total Net Present Cost of the system, which includes the costs of the investments plus the discounted present values of all future costs throughout the total life of the installation. We assume that the life of the system is the life of the PV panels which are the elements that have a longer lifetime [12]. The proposed plan life time is considered to be 25 years with an annual interest rate of 8%. Individual cost of installed system components are shown in Table 2.

Proposed Model: The proposed and simulated hybrid renewable system model consists of a Photovoltaic, wind turbine system and battery as a back-up and storage system with various altitude of wind turbine system (Fig. 2). The project lifetime is estimated to 25 years.

Simulation: We perform the simulation to obtain the optimum power system configuration on variation in the altitude of hub in wind turbine system along with Photovoltaic that meets the above said load profile. The considered altitudes of wind turbine systems are 10m, 20m, 30m and 40m. HOMER model has been used as the sizing and optimization software tool. It contains a number of energy component models and evaluates suitable technology options based on cost and availability of resources [10-16].

Analysis of Simulation Results: The simulation result allows only feasible solution with their increasing in number of cost and eliminates all other infeasible possible solutions. Also simulation performs the number of parameters displayed against sensitivity variables to identify optimal solution for energy system. According to the optimal solution the total energy required to satisfy the load demand by the hybrid combination. Wind velocities increase at higher altitudes due to surface aerodynamic drag (by land or water surfaces) and the viscosity of the air. The variation in velocity with altitude, called wind shear, is most dramatic near the surface. Typically, the variation follows the wind profile power law, which predicts that wind speed rises proportionally to the seventh root of altitude. Doubling the altitude of a turbine, then, increases the expected wind speeds by 10% and the expected power by 34%.

The altitude is the elevation above mean sea level. Altitude affects air density, which in turn affects wind turbine output. HOMER therefore considers the altitude when calculating the output of the wind turbine. According to the ideal gas law, air density is given by the following equation (13):

$$\rho_0 = \frac{P}{RT} \tag{1}$$

Where

ρ = air density [kg/m^3],
P = pressure [Pa],
R = gas constant [287 J/KgK],
T = Temperature [K]

When calculating the output of the wind turbine at the specified altitude, the power output obtained from the wind turbine power curve by the air density ratio. Using the ideal gas law, the air density ratio can be expressed as follows:

$$\frac{\rho}{\rho 0} = \frac{P}{P0} \left[\frac{T0}{T} \right] \tag{2}$$

where: P_0= standard pressure [101, 325 Pa], T_0= standard temperature [288.16K]

Altitude affects both pressure and temperature, temperature decreases linearly with altitude according to the following equation:

$$T = T_0 - BZ \tag{3}$$

where: B = lapse rate [0.00650 k/m], Z = altitude [m]

Using the assumption that temperature decreases linearly with altitude, the air pressure can be shown to depend on the altitude according to the following equation:

$$P = P_0 \left(1 - \frac{Bz}{T_0} \right)^{g/RB} \tag{4}$$

where: g = gravitational acceleration [9.81 m/s2]

By substituting these equations for P and T into the equation defining the air density ratio, we get the following equation for the air density ratio:

$$P = P_0 \left(1 - \frac{Bz}{T_0} \right)^{g/RB} \tag{5}$$

On the right hand side of the above equation, only z, the altitude, is not constant [23-25]. So with the assumptions we have used, the air density ratio is a function of altitude alone. In this paper we consider four different hub altitudes. i.e. 10m, 20m, 30 m and 40m for 5kWh/day, 551w load profile for simulation. The Table 3 shows the summary of results for variation in the altitude of hub in wind turbine system.

The above mentioned result proposes the cost effective analysis on variation in the altitude of hub in wind turbine system along with Photovoltaic.

When WTS hub altitude is 10m and 2kW Photovoltaic, 1 no. alpha2.7 wind turbine and 6 nos. exide batteries are used, the production is 3,491 kWh/year. If 1,825 kWh/year power is used the remaining 1,295 kWh/year power becomes excess [17-25].
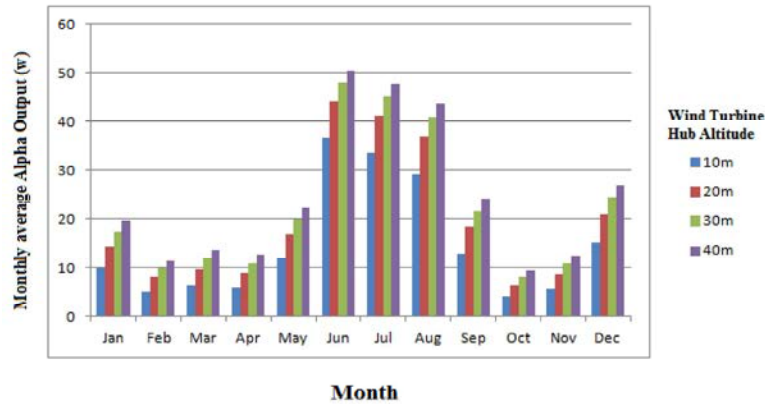
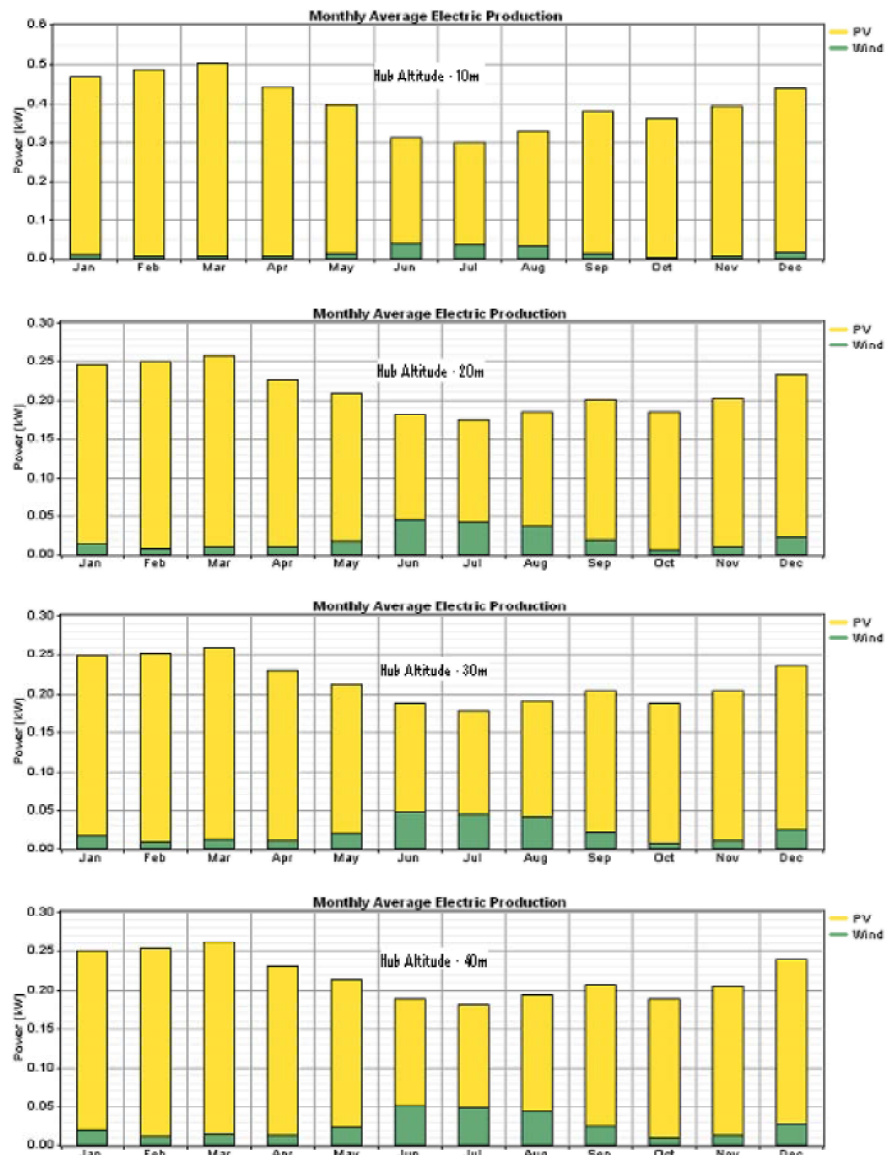Fig. 3: Monthly wind energy production Vs different hub Height

Fig. 4: Photovoltaic and Wind Turbine Monthly average Production with different Hub altitude

Table 3: Simulation Results

WTS Hub Altitude	Optimal Configuration	Capacity	Power Production (kWh/year)	Cost of Energy (INR/kWh)
10m	PV	2kW	3,362	75.95
	Alpha 2.7	1No.	130	
	ExideiT500i	6 Nos.		
	Total	3,491		
	Consumption	1,825		
	Excess Electricity	1,295		
20m	PV	1kW	1,681	73.58
	Alpha 2.7	1 No.	172	
	ExideiT500i	24 Nos.		
	Total	1,853		
	Consumption	1,809		
	Excess Electricity	11.1		
30m	PV	1kW	1681	72.93
	Alpha 2.7	1 No.	198	
	ExideiT500i	24 Nos.		
	Total	1878		
	Consumption	1825		
	Excess Electricity	16.3		
40m	PV	1kW	1681	58.70
	Alpha 2.7	1 No.	216	
	ExideiT500i	12 Nos.		
	Total	1897		
	Consumption	1825		
	Excess Electricity	20.2		

The power production is 1,853 kWh/year when the wind turbine height is 20m and 1kW PV and 1 no. alpha2.7 with battery are utilised. This combination generates 1,681 kWh/year of power and WTS generates 172 kWh/year of power and excess electricity is 11.1 kWh/year.

When 1kW PV is combined with alpha2.7 WTS and 24 nos. exide batteries, the power production is 1,878 kWh/year. If 1,825 kWh/year power is consumed, 16.3 kWh/year power remains unused. The cost of energy is 72.93 INR/kWh for the altitude of 30m. Fig. 3 shows monthly average electric production from wind turbine with variation in hub altitude (10m, 20m, 30m and 40m).

The cost of energy is the least when the altitude increases to 40m. PV production is almost the same. In this optimum combination totally 1,897 kWh/year (1,681 kWh/year by PV and 216 kWh/year by alpha27 WTS) of power is generated. Fig. 4 shows the total (pv and wind) monthly average electric production with four different hub altitudes.

CONCLUSION

With the help of HOMER simulation, the cost of energy production is calculated for a textile show room load. This cost analysis data concludes that the cost of energy is the least i.e. 58.70 INR/kWh when the altitude increases to 40m. Alpha wind turbine minimizes the cost by producing more power of 216kWh/year when the altitude increases to 40m. Totally (1,681 kWh/year by 1kW PV and 216kWh/year by alpha) 1,897kWh/year of power is generated and the excess of 20.20 kWh/year power can be connected to grid. Although initial cost of PV-Wind Hybrid system is high, it produces electricity at least cost with increase in altitude of wind turbine and environment free.

REFERENCES

1. Bolonkin, A., 2004. Utilization of Wind Energy at High Altitude, Proceedings of the International Energy Conversion Engineering Conference at Providence, Rhode Island, 16-19 August 2004. AIAA-2004-5705, AIAA- 2004-5756, USA. http:// arxiv.org/ ftp/physics/papers /0701 /0701114. pdf.

2. Gipe P., 1998.Wind Power, Chelsea Green Publishing Co., Vermont.

3. Thresher, R.W., 1999. Wind Technology Development: Large and Small Turbines, NRFL.

1. Renewable Energy Technologies: Cost Analysis Series, 2012. Irena Working Paper, Volume 1:Power Sector, Issue:5/5, 'Wind Power.

2. Homer manual.

3. Elhadidy, M.A. and S.M. Shaahid, 2004. Role of hybrid (wind + diesel) power systems in meeting commercial loads. Renewable Energy, 29(12): 109-18.

4. Nema Pragya, R.K. Nema and Saroj Rangnekar, 2007. Integrated Design approach for stand alone PV-solar and wind hybrid energy system: For Rural electrifications. International conference on advance energy systems (ICAER-2007) held at IIT Bombay, pp: 354-359.

5. http:/www.motorola.com

6. Dufo-López, R., 2005. Bernal-Agustín JL. Design and control strategies of PV-Diesel systems using genetic algorithms. Solar Energy, 79(1): 33-46.

7. www.nrel.gov/homer.

8. Nema Pragya and R.K. Nema, 2007. Saroj Rangnekar, sizing and methodology of pvsolar/ wind hybrid energy systems' national conference of power electronics & intelligent control held at Malaviya National Institute of technology Jaipur (rajasthan), India, pp: 291-294.

9. Türkay, E., Selection of Optimum Hybrid Stand Alone Systems, Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10).

10. Balachander, K. and A. Amudha, XXXX. Energy Audit and Renewable Energy System Modelling' "Middle East Journal of Scientific Research, 23(7): 1305-1313.

11. Cairo University, 2010. Cairo, 19-21, 994-1000.

12. Cotrell, J. and W. Pratt, 2003. Modeling the Feasibility of Us-ing Fuel Cells and Hydrogen Internal Combustion En-gines in Remote Renewable Energy Systems, NREL/ TP-500-34648.

13. Archer Cristina, L. and Ken Caldeira, 2009. Global Assessment of High-Altitude Wind Power Energies, 2: 307-319.

14. Balachander, K. and Dr. P. Vijayakumar, 2013. Modeling, Simulation and Optimization of Hybrid Renewable Energy Systems in Technical, Environmental and Economical aspects (Case Study: Pichanur Village, Coimbatore, India), International Journal of Applied Environmental Sciences, 8(16): 2035-2042.

15. Burton, T., D. Sharpe, N. Jenkin and E. Bossanyi, 2001. Wind energy handbook; John Wiley and Sons: Chichester, U.K., pp: 617.

16. Stull, R., 1988. An introduction to boundary layer meteorology; Springer: New York, NY, USA, pp: 670.

17. Chen, W. and E. Lui, 2005. Handbook of structural engineering; CRC Press: Boca Raton, FL, USA, pp: 17-68.

18. Stensrud, D., 1996. Importance of low-level jets to climate: A review. J. Clim., 9: 1698-1711.

19. Kung, E.C. and P.H. Chan, 1981. Energetics Characteristics of the Asian Winter Monsoon in the Source Region. Mon. Weather Rev., 109: 854-870.

20. Cadet, D.¸ 1979. Meteorology of the Indian summer monsoon. Nature, 279: 761-767.

21. Archer, C.L. and M.Z. Jacobson, 2007. Supplying baseload power and reducing transmission requirements by interconnecting wind farms, J. Appl. Meteorol. Climatol., 46: 1701-1717.

22. Renewable Energy Technologies: Cost Analysis Series, 1: (5)5.

23. Alexander Bolonkin, 2011. Smart Grid and Renewable Energy, 2011, 2, 75-85 doi:10.4236/sgre.2011.22010 Published Online May 2011 (http:// www.SciRP.org/ journal/ sgre) Using of High Altitude Wind Energy.

24. Manyonge, A.W., R.M. Ochieng, J.M. Shichikha and F.N. Onyango, 2012. Mathematical Modelling of Wind Turbine in a Wind Energy Conversion System: Power Coefficient Analysis, Applied Mathematical Sciences, 6(91): 4527-4536.

25. Bolonkin, A.A., 2001. Method of Utilization a Flow Energy and Power Installation for It,USA Patent Application 09/946,497 of 09/06/2001.