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Analysis of fixed tilt and sun tracking photovoltaic–micro wind based hybrid power systems

Sunanda Sinha, S.S. Chandel *

Centre for Energy and Environmental Engineering, National Institute of Technology, Hamirpur 177005, Himachal Pradesh, India

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ABSTRACT

In this study fixed tilt and sun tracking photovoltaic based micro wind hybrid power systems are analyzed along with determining the optimum configurations for a 6 kW_p roof mounted micro wind based hybrid system using fixed and tracking photovoltaic systems to enhance the power generation potential in a low windy Indian hilly terrain with good solar resource. The main objective of the study is to enhance power generation by focusing on photovoltaic component of the hybrid system. A comparative power generation analysis of different configurations of hybrid systems with fixed tilt, monthly optimum tilt, yearly optimum tilt and 6 different sun tracking photovoltaic systems is carried out using Hybrid Optimization Model for Electric Renewables. Monthly and seasonal optimum tilt angles determined for the location vary between 0° and 60° with annual optimum tilt angle as 29.25°. The optimum configurations for all sun tracking systems except for the two axis tracking system is found to be 7 kW_p photovoltaic system, one 5 kW_p wind turbine, 10 batteries and a 2 kW_p inverter. The optimum configuration for two axis tracking system and two types of fixed tilt systems, is found to be a 8 kW_p photovoltaic system, one 5 kW_p wind turbine, 10 batteries and a 2 kW_p inverter. The results show that horizontal axis with monthly adjustment, horizontal axis with daily adjustment, horizontal axis with continuous adjustment and two axis tracking system generate 4.88–26.29% more energy per year than the existing fixed tilt photovoltaic system. The cost of energy is found to be more for two axis tracking than all tracking systems and fixed tilted photovoltaic system. However, two axis tracking is found to be more advantageous than other systems despite higher costs to maximize power output of the hybrid systems. The methodology followed can be applied to improve the power generation potential of photovoltaic–micro wind based hybrid systems for any location worldwide.

1. Introduction

Solar and wind energy sources are being utilized for generating electrical power in recent years. The hybrid systems utilizing both solar and wind resources simultaneously improves the system efficiency, power reliability and minimizes the energy storage requirements. Such a system is therefore more advantageous than either a solar or wind based system [1]. However, in order to utilize the solar and wind resources efficiently and economically, optimum sizing of the hybrid system with lowest cost of energy has to be carried out [2]. Climatic parameters like solar radiation [3], wind speed [4], and air temperature for the location of interest are important for efficient utilization of renewable sources.

The solar radiation data have to be accurate as pointed out by Quej et al. [5] and the detailed data on wind speed are important in the design of wind based systems and wind farms [6]. Apart from the renewable energy based studies the climatic parameters are also important in meteorological research [7] and other applications like irrigation, agriculture studies [8], and weather forecasting [9]. The renewable energy based hybrid systems can achieve considerable fuel savings in comparison to conventional fossil fuels and are found to be viable for roof mounted urban and remote locations by various researchers namely Shiroudi et al. [10] for Iran, Bawah et al. [11] for Saudi Arabia, Suresh Kumar and Manoharan [12] for India and Ismail et al. [13] for Palestine.

The building sector is another potential area where hybrid systems can be used to minimize conventional and fossil fuel based energy consumption and CO_2 emissions [14]. The roof mounted wind turbines which are at higher elevation are exposed to higher wind speeds as compared to ground based ones and generates more energy [15]. Thus wind based hybrid systems have the

* Corresponding author. Tel.: +91 9418011957; fax: +91 1972 223834.
E-mail addresses: chandel_shyam@yahoo.com, sschandel2013@gmail.com (S.S. Chandel).

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Nomenclature

G_b	beam radiation (kW/m^2)
G_d	diffuse radiation (kW/m^2)
G	global horizontal radiation on the earth's surface averaged over the time step (kW/m^2)
A_i	anisotropy index
G_0	extraterrestrial horizontal radiation averaged over the time step (kW/m^2)
ρ_g	ground reflectance, which is also called the albedo (%)
R_b	ratio of beam radiation on the tilted surface to beam radiation on the horizontal surface
f	factor used to account for 'horizon brightening'
β	slope of the surface (°)
Y_{pv}	rated capacity of the PV array, meaning its power output under standard test conditions (kW)
f_{pv}	PV derating factor (%)
G_T	solar radiation incident on the PV array (kW/m^2)
T_c	PV cell temperature in the current time step (°C)
α_p	temperature coefficient of power (%/°C)
$G_{T,STC}$	incident radiation at standard test conditions (1 kW/m^2)
$T_{c,STC}$	PV cell temperature under standard test conditions (25 °C)
$C_{ann,tot}$	total annualized cost of the system ($/yr)
$E_{prim,AC}$	AC primary load served (kW h/yr)
AC	alternating current
CEEE	Centre for Energy and Environmental Engineering
CRF	capital recovery factor
DC	direct current
EFT	existing fixed tilt
H.P.	Himachal Pradesh
HACA	Horizontal Axis, continuous adjustment
HADA	Horizontal Axis, daily adjustment
HAMA	Horizontal Axis, monthly adjustment
HAWA	Horizontal Axis, weekly adjustment
HOMER	Hybrid Optimization Model for Electric Renewables
i	interest rate (%)
MOT	monthly optimum tilt
N	number of years
NIT	National Institute of Technology
PV	photovoltaics
R_{proj}	project lifetime (yr)
YOT	yearly optimum tilt

potential to make a significant impact on rooftop electricity generation worldwide, which needs to be explored [16,17].

The technical and economic feasibility of a renewable energy based hybrid system has to be established based on wind and solar resource potential for the location of interest as shown in feasibility analysis by Essalaimeh et al. [18] for solar and wind hybrid system under Jordanian climatic conditions and Adaramola et al. [19] for PV–wind–diesel hybrid system for application in remote areas of southern Ghana. Currently there is a widespread adoption of various types of hybrid energy systems in rural, urban locations as well as in built environment in a number of countries including India.

Bhattacharjee and Acharya [20] studied harnessing of wind resource along with solar energy through hybrid technology in a low windy location in a north-east Indian state of Tripura where grid connectivity is not a feasible option, Bhakta et al. [21] investigated the techno-economic analysis of standalone PV/wind hybrid system and found it as a viable option. But the north-western Himalayan region of India is still not in focus for such systems, which is considered in the present study. Sinha and Chandel [22] studied the prospects of solar photovoltaic–micro-wind based hybrid power systems in western Himalayan state of Himachal Pradesh in India for the first time. The study location Hamirpur, lies in western Himalayan region, has a good solar resource but low wind resource.

A photovoltaic(PV)–micro wind hybrid system consisting of 1 kW$_p$ PV system and 5 kW$_p$ micro wind turbine was installed in 2011 on the roof top of Centre for Energy and Environmental Engineering (CEEE), National Institute of Technology, Hamirpur (NIT-H), Himachal Pradesh, India for educational and research purposes. The system is able to meet the partial electrical load of the CEEE building, but in continuous cloudy and non-windy days the system is unable to meet the entire load demand. The system faces these problems, as the minimum PV shared and maximum wind shared rooftop small hybrid power generation unit was installed without optimization and detailed meteorological resource analysis as measured data at the location was not available at that time. Later with installation of automatic weather station at CEEE the measurement of solar and wind resource data was carried out.

In order to identify the appropriate configuration for a hybrid system, optimization of the system has to be done as per resource at the location, electric load demand and components of the system. The present study is focused on maximization of power generation by photovoltaic system component of the hybrid system. In order to maximize power generation by fixed PV system, the panel tilt angle has to be optimized for capturing maximum solar radiation falling on the panels. This angle is site specific as it depends on the daily, monthly and yearly solar radiation for the location of interest. Yadav and Chandel [23] in an extensive review of various tilt angle determination methods have shown that in order to gain maximum energy, the optimum tilt angle for solar photovoltaic systems needs to be determined accurately for a particular location. Yan et al. [24] investigated PV array performance at different tilt angles and orientations in Brisbane, Australia by utilizing the yearlong recorded data which provided valuable information to PV applications for the study location. Despotovic and Nedic [25] determined yearly, biannual, seasonal, monthly, fortnightly, and daily optimum tilt angles of solar collectors in Belgrade, Serbia for which the solar radiation on the collector surface was maximum for a specific period. The results show that placing the panels at yearly, seasonal and monthly optimum tilt angles, would yield increasing yearly amount of collected energy by factor of 5.98%, 13.55%, and 15.42% respectively. Hussein et al. [26] investigated the performance of mono-crystalline silicon type PV at different tilt angles and orientations based on the meteorological conditions of Cairo, Egypt and found optimum tilt angle ranging from 20° to 30° with south facing orientation. These studies show that in order to maximize PV output, the modules must be optimally tilted for every location.

Another strategy is to use sun tracking PV systems to maximize power generation. Mehrtash et al. [27] demonstrated the energy performance of solar tracking photovoltaic systems in Canada, with four different tracking systems: fixed horizontal, fixed tilted, single-axis and dual-axis tracking. The study shows that dual-axis tracking array provided best performance over a year. Alexandru [28] in a comparative analysis between the single-axis and dual-axis tracking PV systems in Romania, concluded that a single axis tracking system is preferable for the region based on technical