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Wind speed prediction in the mountainous region of India using an artificial neural network model

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ABSTRACT

Measured wind speed data are not available for most sites in the mountainous regions of India. The objective of present study is to predict wind speeds for 11 locations in the Western Himalayan Indian state of Himachal Pradesh to identify possible wind energy applications. An artificial neural network (ANN) model is used to predict wind speeds using measured wind data of Hamirpur location for training and testing. Temperature, air pressure, solar radiation and altitude are taken as inputs for the ANN model to predict daily mean wind speeds. Mean absolute percentage error (MAPE) and correlation coefficient between the predicted and measured wind speeds are found to be 4.55% and 0.98 respectively. Predicted wind speeds are found to range from 1.27 to 3.78 m/s for Bilaspur, Chamba, Kangra, Kinnaur, Kullu, Keylong, Mandi, Shimla, Sirmaur, Solan and Una locations. A micro-wind turbine is used to assess the wind power generated at these locations which is found to vary from 773.61 W to 5329.76 W which is suitable for small lighting applications. Model is validated by predicting wind speeds for Gurgaon city for which measured data are available with MAPE 6.489% and correlation coefficient 0.99 showing high prediction accuracy of the developed ANN Model.

1. Introduction

Renewable energy sources have the potential to meet the energy needs of a country if exploited efficiently resulting in economic development due to reduced dependence on fossil fuels. Among renewable energy sources wind energy is becoming one of important sources of power generation [1] as a wind power plant with no fuel consumption, has low operating costs. The capital cost of a wind power plant has also become comparable with conventional power plants depending on the site and the type of wind electric generator. Wind is being utilized in 103 countries for power generation with total installed capacity of 318.5 GW by the end of 2013 and is forecasted to provide 30% of the world's electricity by 2030 [2]. Wind energy is becoming the largest source of electricity in a number of countries. At present wind power contributes close to 4% to global electricity demand. The installed capacity of wind power in Asia is now the same as that of Europe (119 GW) and is expected to overtake Europe in 2014 and can become the biggest wind power continent. The highest growth rates of wind energy are in Latin America and in Eastern Europe. Chile has shown the highest growth rate of 76% among all countries and Morocco in Africa has shown a second highest growth of 70%. China with a total capacity of 91.3 GW is the leading wind market. India ranks fifth amongst the wind-energy-producing countries of the world after USA, China, Germany and Spain. Wind power share in the electricity supply in some countries is as follows: Denmark (34%) which produces one third of its electricity from wind turbines, Spain (21%), Portugal (more than 20%), Ireland (more than 16%), Germany (9%) and Japan produces around 10% of its electricity from wind power. About one million small wind turbines have been installed worldwide by end of 2013 and wind capacity is expected to grow by more than 700 GW by 2020. In a recent study. Onea and Rusu [3] have identified good wind energy potential in the north-western side of the Black Sea.

In India renewable energy remains a small fraction of the total installed capacity although it has over 150,000 MW of exploitable renewable potential. Renewable energy sources excluding large hydro power currently accounts for 13.86% of India's overall installed power capacity i.e. 228721.73 MW which is expected to become 21136.3 MW by March 2014. Wind Energy holds the major

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Nomenclature

ANN	artificial neural network
C-WET	Centre for Wind Energy Technology
LM	Levenberg–Marquardt
MAPE	mean absolute percentage error (%)
MNRE	Ministry of New and Renewable Energy
NASA	National Aeronautics and Space Administration
P_{wind}	monthly mean wind power (W)
R	correlation coefficient
RMSE	root mean square error
WS	wind speed (m/s)
$WS_{i(ANN)}$	predicted wind speed for i day (m/s)
$WS_{i(measured)}$	measured wind speed for i day (m/s)

Symbols

n	total number of input and output pairs
ρ	air density (kg/m^3)

portion of 66.7% of total Renewable energy capacity of 31707.2 GW and continues as the largest supplier of clean energy [4]. The Indian Government has set a target of adding 18.5 GW of renewable energy sources during the 12th five year plan (2012–2017) out of which 11 GW is estimated from wind and 4 GW from solar and 3.5 from GW other renewable energy resources. Thus, wind energy is highly preferred alternative as compared to conventional sources of power but India has not still exploited its full wind potential. Keeping in view the vast wind potential, an autonomous research and development institution Centre for Wind Energy Technology (C-WET) has been established by Indian Ministry of New and Renewable Energy (MNRE) at Chennai.

The wind resource assessment in India has been carried out using measured data at 729 wind monitoring stations spread in various parts of the country. The 233 wind monitoring stations have shown a wind power density of 200 W/m^2 or more at 50 m above ground. C-WET has estimated the wind potential of India as around 49,130 MW at 50 m above ground level and as per new survey 102,788 MW at 80 m above ground level [5]. The wind power potential is estimated by assuming only 2% of land availability in 10 states of India and 0.5% in hilly states. This potential is likely to be further revised with the identification of actual land for wind farms and more refined detailed analysis.

In India total wind power generation is contributed by states of Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat, Maharashtra and Rajasthan. The wind resources fall in low wind regime and wind power density ranges from 250 to 450 W/m^2. **Gujarat** and **Tamil Nadu** states are leading in onshore wind energy installations, with **Tamil Nadu** accounting for 50% of the countries installed wind energy capacity. Gujarat has shown spectacular growth in this sector with a number of wind turbine manufacturers located in the state. India is now focusing on the growth of offshore wind energy as the country has a vast coastline with potential sites to set up large wind farms. MNRE is planning to setup an Authority to conduct studies on the potential of offshore wind energy in India. However, little attention is given to identify wind potential in mountainous regions of the country. Himachal Pradesh is one of such regions located in western Himalayan region of India which need to be explored for wind energy applications along with solar power generation.

C-WET is carrying out wind resource assessment through 154 wind monitoring stations setup in 17 states of the country as on May 31st 2014. Some of these new stations have been established in some north-east hill states but the western Himalayan state of Himachal Pradesh is not included which indicates that hilly regions are not on priority list at present. The region has large hydro potential and is supplying surplus power to various states but the state has also good solar resource. There is need to assess the wind potential of the state in order to identify potential applications.

C-WET has estimated the wind potential in Himachal Pradesh (H.P) as 20 MW and 64 MW at 50 m and 80 m heights respectively however this potential is not validated as yet by measured data. C-WET has recently identified state wise targets for implementation of wind resource assessment in uncovered new areas at 100 m level in 500 locations including H.P where there is a plan to establish 12 stations at 100 m height. However, there is a further need to determine the wind potential in the region with improved accuracy for possible integration of solar and wind power generation with hydro power plants.

Krishnadas and Ramachandra [6] have estimated wind potential of Himachal Pradesh using wind data from National Aeronautics and Space Administration (NASA). However, the uncertainties in NASA measured satellite data are found to vary from 6 to 12% [7]. Chandel et al. [8] have carried out a wind resource assessment study of different locations of the state of Himachal Pradesh using Energy Pattern Factor (EPF) method. In another study, Chandel et al. [9] have carried out the wind characteristic assessment for a location in western Himalayan region using Wind Atlas Analysis and Application Program micro scale model.

Although, the measured wind data for most locations in the state of Himachal Pradesh are not available at present yet there is a good potential for a number of wind energy applications. Therefore, there is a need to develop reliable wind speed prediction models so as to identify possible wind energy applications in the region. With this objective an artificial neural network (ANN) technique is used in the present study for the prediction of wind speed for different locations in the mountainous western Himalayan state of Himachal Pradesh, India along with a case study to understand the potential applications.

The paper is organized as follows: a background of wind speed prediction using ANN models is given in Section 2; description of different locations of Himachal Pradesh is given in Section 3; data used and methodology are given in Section 4; the results are presented and discussed in Section 5 and conclusions in Section 6.

2. Background of ANN method for wind speed prediction

Wind speed prediction models are becoming more relevant in view of fast propagation of wind power generation worldwide for wind characterization, resource prediction and forecasting. Researchers have used different prediction models worldwide as the wind data are not available for most of the sites of interest [10–13].

Mabel and Fernandez [14] used ANN technique for prediction of wind energy output of wind farms in Muppandal, Tamil Nadu, India. The ANN model utilized average wind speed, relative humidity and generation hours as input variables and wind energy as output variable. The root mean square (RMSE) error for testing the model is 0.0065. Monfared et al. [15] proposed fuzzy logic and neural network for wind speed prediction for Rostamabad in northern Iran and found that with proposed method, the fuzzy rule base becomes less and fast learning process can be achieved with neural network. Çam et al. [16] used ANN model for predicting wind speed and wind power in seven regions of Turkey. The input variables are longitude, latitude, altitude, height and corresponding output is wind speed and wind power. The RMSE for testing regions varies from 0.00527 to 0.01904. Sfetsos [17] compared feed forward, recurrent neural networks, Adaptive Neuro-Fuzzy Inference Systems and Neural