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Prediction of wind speed and wind direction using artificial neural network, support vector regression and adaptive neuro-fuzzy inference system

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ABSTRACT

In this study, three models of machine learning algorithms are implemented to predict wind speed, wind direction and output power of a wind turbine. The first model is multilayer feed-forward neural network (MLFFNN) that is trained with different data training algorithms. The second model is support vector regression with a radial basis function (SVR-RBF). The third model is adaptive neuro-fuzzy inference system (ANFIS) that is optimized with a partial swarm optimization algorithm (ANFIS-PSO). Temperature, pressure, relative humidity and local time are considered as input variables of the models. A large set of wind speed and wind direction data measured at 5-min, 10-min, 30-min and 1-h intervals are utilized to accurately predict wind speed and its direction for Bushehr. Energy and exergy analysis of wind energy for a wind turbine (E-44, 900 kW) is done. Also, the developed models are used to predict the output power of the wind turbine. Comparison of the statistical indices for the predicted and actual data indicate that the SVR-RBF model outperforms the MLFFNN and ANFIS-PSO models. Also, the current energy and exergy analysis presents an average of 32% energy efficiency and approximately 25% exergy efficiency of the wind turbine in the study region.

Introduction

The increasing concern about air pollution, global warming and energy crisis will inevitably result in a transition in energy section from fossil fuel-based mode to renewable and non-polluting mode. Between the renewable energies, the wind energy is more accessible and fairly cheaper [1]. Wind energy is a clean resource and doesn't pollute the air like fossil fuel power stations. In addition, it doesn't produce atmospheric emissions which increase health problems. Power produced by wind turbines (WTs) depends on wind speed and its direction. Due to the importance of short-term prediction of the wind speed for connecting and disconnecting the power to the grid and management of the power, some scholars implemented machine learning algorithms to this target [2–4]. Artificial neural network (ANN) is a kind of machine learning algorithm that is proposed to predict wind speed and its direction [4–11].

Many studies proposed meteorological data, e.g., pressure, temperature, relative humidity and etc., of each region, to predict the wind speed and its direction with ANN [12], [13]. Ref. [13] implemented ANN in order to predict short-term wind speed in Mardin, Turkey. A multilayer perceptron (MLP) neural network was used to predict the wind speed by them. Mean square error (MSE) and correlation coefficient (R) were used as statistical parameters to evaluate the network that these indices were reported respectively by 0.3780 (m/s) and 0.9704. Ref. [14] applied fuzzy modeling technique and ANN to estimate annual energy output of a wind farm. Average wind speed, standard deviation of wind speed and air density of the study region were used as input variables of the models.

Ref. [15] developed an ANFIS model in order to estimate wind turbine power coefficient as a function of pitch angle and tip-speed ratio. It is shown, the proposed ANFIS model can successfully predict the wind turbine power coefficient. In a wind farm near central Taiwan area, radial basis function neural network based on a model with a feedback scheme error, for prognostication of wind speed and produced power, was developed by Ref. [16]. ANN based on multiple local measurements was used to predict wind speed in Eskisehir (Turkey) by Ref. [17]. Forecasting model was developed based on past values of wind speed data, temperature and pressure of the region as input variables. The best performance of the model was obtained in term of RMSE by 0.6940 (m/s).

Ref. [18] developed a generalized regression neural network (GRNN) in order to predict wind speed for the western region of India. The input variables of the model were longitude, latitude, daily horizontal solar irradiance, air temperature, relative humidity, earth temperature, elevation, cooling degree-days, heating degree-days and atmospheric pressure. Also, the GRNN was compared to an MLPNN and

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A	area (m^2)	WD	wind direction
ANN	artificial neural network	z	height (m)
Cp	power efficiency		
cp_a	air specific heat (kJ/kg K)	*Greek Symbols*	
cp_v	vapor specific heat (kJ/kg K)		
$\dot{E}x$	exergy flow rate (kW)	ρ	density (kg/m^3)
$MAPE$	mean absolute percentage error	η	energy efficiency
MSE	mean square error	η_{gb}	gearbox efficiency
m	mass	η_g	generator efficiency
$\dot{m}$	mass flow rate (kg/s)	η_p	power electronics efficiency
P	power (kW)	ω	humidity ratio
$purelin$	linear transfer function	α	constant coefficient
p	pressure (hPa)	Ψ	exergy efficiency
ke	kinetic energy		
R	regression coefficient	*Subscripts/Superscripts*	
RH	relative humidity (%)		
$RMSE$	root mean square error	$dest$	destruction
S	entropy	p	potential
t	time(s)	ch	chemical
$tansig$	hyperbolic-tangent sigmoid	chi	chill
T	temperature (K)	a	air
v	wind speed (m/s)	amb	ambient

the result illustrated that the GRNN is more accurate than the MLPNN.

Outlier correction algorithm, wavelet and extreme learning machine were implemented to estimate wind speed data by Ref. [19]. Forecasting wind speed data by a novel method based on Weibull distribution was done by Ref. [20]. They developed a model based on Weibull and Gaussian probability distribution functions to estimate short-term wind speed data. The model was trained with recorded wind speed data of 2014 in Ankara (Turkey) and the developed model provided better forecasting compared to Weibull model. Also, some studies concentrated on the time-series wind speed prediction [21–23]. This forecasting model uses the past value of measured wind speed data in order to predict the wind speed in the future.

Support vector machines (SVMs) are classification and regression techniques, which optimize its structure based on the input data. These techniques for the first time have been introduced by Vapnik [24]. In recent years, SVM was successfully employed on classification tasks in

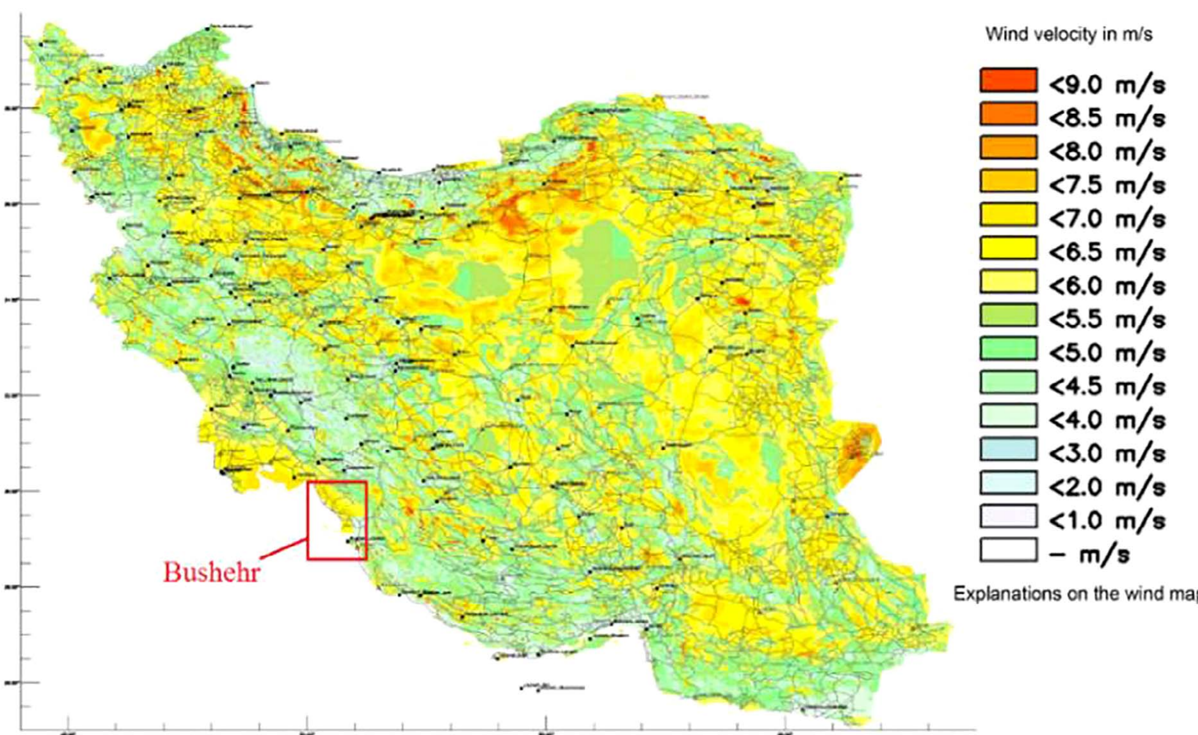

Fig. 1. Wind map of Iran.