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Prediction of hourly solar radiation in Abu Musa Island using machine learning algorithms

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ABSTRACT

Accurate forecasting of renewable energy sources plays a key role in their integration into the grid. This study proposes machine learning algorithms to predict the hourly solar irradiance. Forecasting models were developed based two types of the input data. The first one uses local time, temperature, pressure, wind speed, and relative humidity as input variables of the models (N_1); the second one is the time-series prediction of solar irradiance (N_2) (forecasting models only use from past time-series solar radiation values to estimate the future values). For this purpose, multilayer feed-forward neural network (MLFFNN), radial basis function neural network (RBFNN), support vector regression (SVR), fuzzy inference system (FIS) and adaptive neuro-fuzzy inference system (ANFIS) are developed. The results demonstrated that for the N_1, SVR and MLFFNN models have the maximum performance to predict the solar irradiance with R = 0.9999 and 0.9795, respectively. For the N_2, SVR, MLFFNN and ANFIS models have reported the correlation coefficient more than 0.95 for the testing dataset.

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1. Introduction

There is a growing global demand for energy, but also for reduced strain on the environment. Considerable investments were made in alternative energy research worldwide recently. Growing demand for environment-friendly energy makes renewable energy development and production a sound investment for the future (Izadyar et al., 2016). Solar energy is a kind of the renewable energy that is obtained from the sun. The energy of the sun is converted to the thermal or electrical form the energy (Vi et al., 2012). The solar energy is distributed over a wide geographical region and the cost of this energy is stable for the long-term in the future with low maintenance costs. An important feature to design required photovoltaic systems is predicting solar energy, that machine learning algorithms are currently, the most popular for this target (Hossain et al., 2017). Several studies were proposed machine learning algorithms to predict solar irradiance in different world-wide regions (Martín et al., 2010; Alzahrani et al., 2014; Sharma and Kakkar, 2017; Ibrahim and Khatib, 2017).

Ref. (Yaiici and Entchev, 2016) designed an ANFIS model for predicting the performance parameters of a solar thermal energy system. It was considered 10 inputs and 8 outputs to develop the ANFIS model. Input and output membership functions (MFs) were considered as Gaussian and Linear, respectively. The results demonstrated that the ANFIS model can successfully predict the targets with mean relative errors less than 1% (for the stratification temperatures) and 9% (for the solar fractions). Time-series prediction of the solar irradiance after sunrise was done by Ref. (Hirata and Aihara, 2017). They proposed the recently derived infinite-dimensional delay coordinates to predict the solar irradiance after sunrise. It was obtained that the examined short-term time series prediction had effectively predictively skills.

A neuro-fuzzy method was developed by Ref. (Jović et al., 2016) to investigate solar radiation. They used four parameters that were mean sea level, dry-bulb temperature, wet-bulb temperature, and relative humidity in order to estimate the parameters influence on the solar radiation prediction. Their results demonstrated that dry-bulb temperature and relative humidity were the most dominant factors for the solar radiation prediction. Daily global solar radiation using neuro-fuzzy system was predicted by Ref. (Mohammadi et al., 2015). An ANFIS model was developed by using day of the year (n_{day}) as the only input of the model. Long-term measured data for Tabass (Iran) was used to train and test the model. It was reported that the mean absolute percentage error (MAPE), mean absolute bias error (MABE), root mean square error (RMSE) and correlation coefficient (R) to be 3.9569%, 0.6911 MJ/m^2,

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0.8917 MJ/m^2 and 0.9908, respectively.

Ref. (Olatomiwa et al., 2015a) used support vector machine-firefly algorithm-based model for global solar irradiance prediction. They used meteorological data (sunshine duration ($\overline{n}$), maximum temperature (T_{max}) and minimum temperature (T_{min})) as inputs of the network in order to estimate solar radiation. The developed model was compared to an artificial neural network (ANN) and genetic programming (GP) and the results illustrated that the developed model works better than ANN and GP models. Ref. (Olatomiwa et al., 2015b) developed an ANFIS model for forecasting solar radiation in Nigeria. This investigation was done by using a series of measured meteorological data that were monthly mean minimum temperature and maximum temperature, and sunshine duration obtained from a meteorological station located in Iseyin, Nigeria. They achieved correlation coefficient for the train and test data respectively with 0.8544 and 0.6567.

Daily solar radiation prediction in a warm sub-humid environment with different soft-computing techniques was done by Ref. (Quej et al., 2017a). They used ANFIS, SVM, and ANN in order to forecast the solar radiation and obtained that SVM with requirements of daily maximum and minimum air temperature, extraterrestrial solar radiation, and rainfall has better performance than the other techniques. A comparison between improved empirical models and ANFIS for forecasting solar radiation was done by Ref. (Zou et al., 2017). In their work, the ANFIS model was compared with Expanded-Improved Bristow-Campbell Model (E-IBCM) and Improved Yang Hybrid Model (IYHM) to forecast daily global solar irradiance in China. Daily sunshine duration, precipitation, relative humidity, air pressure and daily minimum/mean/maximum temperatures were considered as input variables of the network. The results demonstrated that the ANFIS model provided the better performance compared with the empirical models.

For estimating the monthly average daily global solar radiation in Baghdad (Iraq), one model based on ANN was developed by Ref. (Rasheed et al., 2014). The network was developed based mean air temperature, maximum and minimum air temperature, relative humidity and sunshine duration. The results illustrated that the predicted solar radiation data were in good agreement with the measured values and the developed model successfully predicted the monthly mean daily global solar radiation for Baghdad city. Ref. (Quej et al., 2017b) proposed a day of the year-based (DYB) models for predicting the solar radiation in six cities located in the Yucatán Peninsula, Mexico. It was developed a new Gaussian DYB model in order to estimate daily solar radiation. The results presented that the developed model has good performance in all seasons, including in the rainy season.

Ref. (Renno et al., 2016) developed two models based on ANN for predicting the direct normal irradiance (DNI) and the global radiation (GR) for a solar application to a residential building. For each ANN models, a multilayer perceptron (MLP) was trained. To evaluate the performance of the models the MAPE, RMSE and determination coefficient (R^2) were proposed. The best ANN configuration to predict the GR was obtained with MAPE = 4.57%, RMSE = 160.3 Wh/m^2 and R^2 = 0.9918 and this values for the DNI were respectively equal to 5.57%, 17.7 w/m^2 and 0.994.

Ref. (Chiteka and Enweremadu, 2016) implemented ANNs to predict the global solar radiation in Zimbabwe. The geographical data of latitude and longitude and meteorological data of humidity pressure, clearness index and average temperature were used as inputs variables of the model. The best ANN structure was obtained with 10 neurons in the hidden layer and a tansig transfer function for the input and output layers was proposed by them. The network achieved a determination coefficient (R^2) of 99.894%.

Between renewable energy resources, solar energy has a high potential in Iran. This country with 300 clear sunny days for a year and average 2200 kWh/m^2/year solar radiation is especially important to use solar systems (Najafi et al., 2015). In the south of Iran there are several Islands that because of remarkable potential of the solar energy in these regions, it is proposed to use solar energy systems for providing the electrical energy. Prediction of the solar radiation is useful for grid operators in order to make decisions of grid operation, as well as, for electric market operators. In addition energy producers and to negotiate contracts with financial entities or utilities that distribute the produced energy also use of this solar prediction. Hence, authors have been encouraged to use machine learning algorithms in order to predict the solar radiation in Abu Musa Island that is located in the south of Iran.

The main contribution of this study is to developed machine learning algorithms in order to predict the hourly solar radiation in two separate networks. The N_1 uses four meteorological data and local time for estimating the solar radiation. The N_2 is a time-series prediction of solar radiation in which the network uses the past values to estimate the future values. For the N_1, this study provides a comparison between the MLFFNN, SVR, FIS and RBFNN in order to obtain the better one. For the N_2, a comparison between the MLFFNN, SVR, FIS and ANFIS models is reported. For the first time, in the current study, three types of ANFIS model are developed to predict the time-series hourly solar radiation. Although this study is developed to predict the hourly solar radiation for Abu Musa Island, the results of this study can help to select the optimum model of machine learning algorithms in order to estimate the hourly solar radiation for other geographical areas.

2. Methodology

2.1. Case study

Production of electrical energy in most countries is done by the fossil fuel resources (Khosravi et al., 2017). But these resources gradually decrease per year. So, replacing this resource with the renewable energy resources has been taken into consideration (Danish et al., 2017). Despite Iran's vast reserves of hydrocarbons, but this country is potentially one of the best regions for solar energy. The prediction of solar radiation on the collectors is essential for photovoltaic generation plant in enhancing the usage of solar energy for electrical production scheme. The goal of this study is forecasting the solar irradiation for Abu Musa Island (Longitude: 55.03° and Latitude: 25.87°) that is located in the south of Iran. Fig. 1 represents the variation of the solar radiation (a) and temperature (b) for 7 years in the case study zone (the data were provided by NASA (NASA-SSE, 2017)). The amount of the global horizontal irradiance for this zone is 2069 kWh/m^2 for one year. The average daily solar radiation and temperature are approximately 6 kWh/m^2 and 29°C respectively for this region.

2.2. Proposed networks

Two type of networks were designed to predict the solar irradiance in the study zone. The first network (N_1) is to predict the solar irradiance with five inputs that are pressure (hPa), temperature (K), wind speed (m/s), relative humidity (%), and local time (hour) as the inputs of the model. The second network (N_2) is based on the time-series prediction of the solar irradiance. Fig. 2 represents the N_1 and N_2 that have been considered to predict the solar radiation in this study. For evaluation of the predicted data, correlation coefficient (R), root mean square error (RMSE), and mean square error (MSE) were selected. These statistical parameters help to find the best performance for the developed models that are given in Appendix B.

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