Chapter 7 : Summary and Conclusions

In this chapter, summary of results and conclusions of the research work are presented. The salient features of the work are highlighted. Scope for future work is also presented.

7.1 Summary of results

Prediction and mapping of wind speed

The Artificial Neural Network (ANN) model was developed and optimized to predict the wind speed. The predicted wind speed was then mapped over Andhra Pradesh (AP) and Telangana State (TS) using Geographic Information System (GIS) approach. Effects of meteorological parameters, such as temperature, pressure and relative humidity on wind speed prediction were studied. The meteorological parameters taken here were monthly mean values, measured at ground stations. These data were obtained for 28 sites over a period of 20 years from the India Meteorological Department (IMD), Pune. Three ANN models with different input parameters were designed, trained and tested to predict the wind speed accurately. These three models were optimized for varying neurons in the hidden layer. The Mean Absolute Percentage Error (MAPE) and Mean Squared Error (MSE) were calculated to evaluate the performance of the model. It was found that ANN model with relative humidity as an input parameter and six neurons in hidden layer gives a better prediction of wind speed, which was then considered for further study. The overall mean MAPE values for an optimum network of three cases were 5.31, 2.16, and 6.38, respectively. The ANN model with six neurons in one hidden layer and relative humidity as an input parameter (Case-2) was found to be the best model in this study. The MAPE value and MSE value for four test locations were calculated as 2.02, 2.19, 2.42, 2.01 and 0.0164, 0.0184, 0.0226, 0.0132, respectively. The study has shown that the ANN model has an acceptable accuracy in predicting wind speed, since the correlation coefficient

(R-value) of 0.9611 was attainted for the test data. The best model was considered to predict the wind speed in different locations in AP and TS. The predicted wind speed from the model was analyzed and mapped using GIS approach. The monthly mean maps of wind speed were generated in the forms of contour with an interval of 0.5 m/s. The contour map was plotted for each month separately. It was found that AP and TS has high average wind energy potential, especially in May, June and July as 6.628, 7.723, and 7.278 m/s, respectively, and less in October, November and December as 3.82, 4.0 and 3.97 m/s, respectively. The ANN model was also developed and validated with historical data of wind speed at Anantapur district in AP, which has high wind potential. The model was validated using monthly mean wind speed during the year 2009 and 2013. The average MAPE value for the year 2009 and 2013 were 3.91 and 4.29, respectively and found to be in acceptable range. Hence, the model was also used to predict the monthly mean wind speed for the year 2016 and 2017.

Based on yearly and monthly maps three different regions (North-East, South-West and West) were identified, which have higher wind potential and wind speed more than 4 m/s. In North-East region, there are three districts: Srikakulam, Vizianagaram and some parts of Visakhapatnam. This region has highest wind speed in the range of 6 to 11 m/s. In spite of high wind speed, this region has large coastal area and uneven terrains, which are not favorable for wind farm installation. It is observed that onshore wind turbine has a very good scope in this region. The South-West region with two districts Anantapur and Kurnool, where the wind speed is in the range of 5 to 11 m/s and has considerably flat terrains to install wind farms. The West region with two districts Medak and Ranga Reddy, has the wind speed in the range of 4 to 8 m/s. This range of wind speed is more than the cut-in speed for most turbines. Additionally, Land Use and Land Cover (LULC) analysis was carried out to estimate the available ideal land for wind farms in the region of higher wind speeds. Anantapur district has the highest barren land, which could easily be used for wind farm installations.

Thus, the developed ANN model can be used to predict wind speed at any location within AP and TS. The developed contour maps have a good visualization of wind energy potential and it can help researchers/decision makers to locate regions of high wind potential to design wind farms. This study also indicates that ANN model is a useful tool for predicting any meteorological parameters, if sufficient historical data is available.

Prediction and mapping of solar potential

A Feed-forward with Back-Propagation Neural Network (FBPNN) based predictive model was developed for estimating solar potential within AP and TS. The predicted solar potential was then mapped using GIS approach. The developed ANN model was optimized for varying number of neurons in the hidden layer. The input to the model was meteorological data along with the location (latitude, longitude, and altitude) and month. The model was trained to give solar radiation as an output parameter. The meteorological data for 28 different locations were used to develop the model. The model was trained with data of 20 locations and validated with 4 locations. Remaining data of 4 locations were kept aside and not used for model development, which was finally used to test the model for its accuracy. To evaluate performance of the model, MAPE value was calculated. Nine neurons in one hidden layer has been found giving least MAPE value for all four test location in this study. The average MAPE value for test location is 2.16. The developed model has an error less the 2.5%, which can be considered as good accuracy. The R-value attained by the model was 0.98745 for test data. The model can be considered to estimate solar radiation at any locations within AP and TS with high accuracy. The ANN model was also developed and validated with historical data of solar radiation at Thumkunta village in TS, which receives high solar radiation. The ANN model was validated for monthly mean solar radiation during the year 2009 and 2013. The average MAPE value for the year 2009 and 2013 were 1.95 and 3.72, respectively which is in acceptable range. Hence, the model was used to project the monthly mean solar radiation for the year 2016 and 2017.

The predicted solar radiation was then analyzed and mapped for yearly and monthly mean solar radiation using GIS approach with an interval of 0.1 kWh/m^{2}day. The contour map was plotted for each month separately. These maps give a better visualization of solar potential in AP and TS, which would help the decision makers to find ideal locations for deployment of solar fields. The yearly and monthly maps of solar potential were used to identify the regions with higher solar potential. It has been observed that solar radiation is high in the West region (Kurnool, Anantapur, YSR, Chittoor, Adilabad, Nizamabad, Karimnagar, Medak, Ranga Reddy and Mahbubnagar) which decreases towards the East regions of AP and TS. The west region has solar radiation in the range of 4 to 6.6 kWh/m^{2}day. It is found that the highest solar radiation is available in April and the lowest in August. To estimate the area of suitable land types for installing PV panels, the LULC analysis was carried out. Two types of land were considered for solar field development, such as built-up land and barren land. Effective area for PV installation in both types of lands was calculated using several factors, such as type of man-made structures, strength of the structures, shading effect, etc. Ranga Reddy district is found to have highest area for PV installation.

Optimal use of wind potential

The Genetic Algorithm (GA) was used for wind farm layout optimization. Actual wind speed data measured at 10-meter height was obtained from IMD, Pune. The prediction and mapping of wind potential within AP and TS showed that Anantapur district has maximum wind potential and hence identified as an ideal location for setting up wind farms. The yearly average wind speed at Anantapur is 8.95 m/s. The monthly mean wind speed varies from 14.62 m/s in November to 4.88 m/s in May. A wind farm of 2 km x 2 km was considered for the optimization problem. A program based on GA was used to optimize the position of wind turbine in a wind farm for maximizing the power generation with minimum cost. The wind farm was divided into grids of 10 x 10. Each grid can have one turbine or can be empty. Algorithm was considered to determine the optimal locations of wind turbine in the wind farm for three scenarios: Scenario-1 constant wind speed in one direction, Scenario-2 constant wind speed in multiple directions and Scenario-3 variable wind speed in one direction. These investigations helped to study the effect of variation in wind speed on the optimum number and positioning of wind turbines in a wind farm. It was observed that the optimum number of wind turbines decreases with an increase in wind speed. For the first scenario, the optimal number of turbines were 19 and for the second scenario, the optimum number of wind turbines were 16. If 19 turbines were considered in the wind farm, the average theoretical power generated would be 183.55 MW with a wind speed of 8.95 m/s, maximum theoretical power generated would be 343.15 MW in November with a wind speed of 14.62 m/s and minimum theoretical power generated would be 29.8 MW in May with a wind speed of 4.88 m/s. The present algorithm is also compared with the previous studies and better fitness value is observed.

Optimal use of solar potential

Predicted monthly mean solar radiation within AP and TS was used to investigate cost effective solar power generation. Thumkunta village in TS was taken as study location for optimizing the solar field. The shading effect of solar panels was considered for power generation using solar elevation angle along with its tilt angle. If the shadow of one solar panel falls on another panel, it reduces the incident solar radiation. Moreover, if solar panel kept apart enough to avoid the shading effect, it will end up in improper use of the available space. Therefore, the available space needs to be utilized effectively to maximize cost-effective power generation. Solar panel of 100 W with a dimension of 1.03 x 0.67 m was considered to investigate the solar power generation. India's per capita energy consumption (1075 kWh per annum) and average family size of 4.9 were considered for estimating the energy demand. Based on the shading effect and solar elevation angle, the minimum row spacing was observed to be 0.354 m. The effective horizontal module width was calculated using the tilt angle and observed to be 0.641 m. Also, the width of one row was calculated as 0.995 m. With these findings, a solar field of 60 m x 50 m can have maximum of 60 rows and 47 panels in one row. For annual average solar radiation, it has been found that the solar park can generate 1483.32 kWh/day. Based on power generated, the requirement of battery and inverter with the total cost for a given specification are calculated.

An excel based model was developed for solar field optimization for AP and TS, but it could be used for any geographical location by changing the solar elevation angle and azimuth correction angle. Other parameters based on the specific requirement, can be changed in the excel sheet and result can be obtained from the result page of the model. This model gives output as module row spacing, row width, number of solar panels, expected power generation (kWh/day), number of batteries, and number of inverters. This model is easy to use and will help prefeasibility check. This module takes solar radiation value, PV panel specifications and available space as input parameters. To estimate the electrical component (battery and inverter) and initial capital cost, their specifications with cost has to be added in the excel model.

New development of 120 housing was considered based on Hyderabad Metropolitan Development Authority (HMDA) act. Energy demand of the society was calculated based on the need of essential appliances in 2 BHK flat. Available roof-top and roadside area were taken for solar power generation. Monthly energy demand and energy generation was compared for the society. It has been found that solar power generation is more than demand in most of the months and power generation is less in June, July, August, and September, due to lower availability of solar radiation. The annual average power generation is 2430.12 kWh/day, which is 88.72% of the power demand without considering the losses in power supply.

IRES for microgrid operation

Integrated Renewable Energy System (IRES) for microgrid system was developed to meet the electrical demand of Thumkunta village. The electrical energy demand was considered for 100 existing houses for the analysis. Different energy generation units, such as photovoltaic (PV), wind, diesel, and biogas along with energy storage units, such as batteries and fuel cell were investigated to meet the energy demand. Seven scenarios (realistic as well as futuristic) with different combination of energy sources and storage system were designed and investigated using HOMER software based on their Levelized Cost of Energy (LCOE) supply and Net Present Cost (NPC). The futuristic scenarios considered fuel cell along with wind and/or solar generation system. The minimum LCOE for the best futuristic scenario was observed as 62.1 Rs./kWh, whereas, realistic scenarios consider the PV, solar, wind and biogas as generation systems and have minimum LCOE as 14.49 Rs./kWh.

The proposed IRES approach, which included PV, wind, li-ion battery, biogas, and DC-AC, gave the least LCOE as 14.49 Rs./kWh without considering any existing subsidy. This IRES has a renewable factor of 100% (PV 85%, wind 4% and biogas 11%) and the reliability of this system is 100%. Based on the results of all the seven scenarios, policy interventions were proposed, which included reduction in taxes, subsidies on PV panels and wind turbines along with carbon abatement cost. The existing subsidies from Central Government (MNRE) and State Government on rooftop PV system as 30% and 20%, respectively were considered. In addition to this, subsidy of 20% on wind turbine and reduction in taxes on solar panel and wind turbine were also proposed. These considerations led to a reduction the LCOE to 11.8 Rs./kWh, besides grid emission factor of coal-based power plant (0.98 tCO_2/MWh) and carbon abetment cost (\$46/tCO_2). This reduced the LCOE to 8.6 Rs./kWh, which is close to the cost of conventional power supply to HT consumers. In addition, cost of each component of microgrid considered in the present analysis was for one unit from a retail vendor. If the development of microgrid is done at a larger scale, the various component of microgrid could be taken directly from the manufacturer at a lower price for bulk purchase, which would further reduce the investment in initial capital cost as well as the LCOE. Another finding of this study is the integration of biogas in the IRES approach in the Indian context.

Pradhan Mantri Ujjwala Yojana (PMUY) was launched by Government of India on May 1st, 2016 to provide LPG gas connection to the families, which relied on firewood, coal, dung-cakes etc. for cooking purposes. As of December 2018, 58 million households were given LPG connection under PMUY and have a target to provide LPG connection to 80 million households by 2019. This will lead to additional availability of domestic and agro waste for power generation. This waste can very easily be used in biogas generator for generating electricity. Since the biogas generator is the most cost effective resource, it can help to reduce the levelized cost of energy supply further to make IRES implementation competitive.

7.2 Conclusions

Based on the objectives of the study and subsequent summary of results, following are the important conclusions:

- This study indicates that relative humidity is the most influencing parameter among the recorded meteorological parameters such as temperature, pressure and relative humidity, for predicting the wind speed. Prediction of wind speed and solar radiation from the developed ANN model has least error (less than 5%) with five and nine neurons in hidden layers, respectively.

- It is found that Anantapur and Kurnool districts in South-West region have high wind speeds in the range of 5 to 11 m/s. In the West region, Medak and Ranga Reddy districts have high wind speed in the range of 4 to 8 m/s. Moreover, Anantapur and Kurnool districts have highest barren land available in the region, therefore these districts are most suitable for installing wind farms.
- The solar radiation is observed to be maximum in the western districts (Kurnool, Anantapur, YSR, Chittoor districts in AP and Adilabad, Nizamabad, Karimnagar, Medak, Ranga Reddy, Mahbubnagar districts in TS) in the range of 4 to 6.6 kWh/m^{2}day. Built-up land area is found to be high (1179.92 km^2) in Ranga Reddy district. Hence, this district is recommended for installation of roof-top solar systems.
- It is observed that a 2 km x 2 km wind farm in Anantapur district could generate approximately 183.55 MW of power with an annual average wind speed of 8.95 m/s. The present study highlights, for cost effective power generation in a given size of wind farm, the optimum number of wind turbines decreases with increase in wind speed. Moreover, a 60 m x 50 m solar field can generate 1.4 MWh/day with average solar radiation of 5.26 kWh/m^2/day in Anantapur district. It is observed that it can meet the energy demand of 100 households.
- The investigation of seven different IRES scenarios concludes that the IRES which includes PV, wind, and biogas, gives the LCOE as 14.46 Rs/kWh without any subsidy or policy interventions. The feasibility analysis of IRES is carried out considering policy intervention along with the carbon abatement cost. Therefore, the LCOE reduces to 8.6 Rs/kWh, which makes it a sustainable option for the study region.

7.3 Specific contributions

The specific contributions of the study are:

1. The thesis is a maiden attempt to identify regions with higher solar and wind energy potentials; and to identify available land areas to harness these resources within AP and TS.
2. The ANN model is developed and optimized for accurate prediction of wind speed and solar radiation, which can be used to predict wind speed and solar radiation at any location within AP and TS, where measured data is not available.
3. Predicted wind speed and solar radiation are mapped for the entire region using GIS approach. It is easy to interpret and can save the time of decision maker to estimate the potential and identify ideal locations of wind and solar energy system within AP and TS at local level.
4. Wind farm layout optimization is proposed using GA for better positioning of wind turbines in a wind farm.
5. An approach is proposed using an excel based model for maximum use of solar potential, considering shading effect and solar elevation angle.
6. An approach for development of integrated IRES is proposed, considering available local and futuristic energy sources.
7. The present work is a ready reckoner for decision makers to achieve higher penetration of solar and wind resources within AP and TS.

7.4 Further scope of work

A few directions for enhancing this research further are as follows:

- The methodology described here can be tested and adopted in other regions.
- A grid-connected microgrid can also be investigated and compared in this region.
- Real-time meteorological data and real-time demand can be used to refine the developed models.