Chapter 5 : Optimal use of resources

This chapter presents the optimal utilization of resources for power generation with its cost estimation. Wind and solar energy resources are considered for the study. The chapter starts with Wind Farm Layout Optimization (WFLO). The WFLO is carried out for (i) constant wind speed in one direction, (ii) constant wind speed in multiple directions and (iii) variable wind speed in one direction. Thereafter, solar field layout optimization is presented for maximizing the power generation, considering shading effect of solar panel, solar elevation angle and panel dimension. An excel based model is developed for optimal use of solar energy within AP and TS. Afterwards, a case study of roof-top solar power generation for a small community, which can be operated stand-alone is presented.

5.1 Wind farm layout optimization

Wind energy has gained significant attention from researchers worldwide. Wind energy conversion system has integration ability with other energy resources. Wind technology is developing rapidly due to its high-reliability and cost-efficiency. This technology can be used as grid-connected mode (where generated power can be supplied to the maingrid), stand-alone mode (where the isolated region can be electrified) or recurrently hybrid mode (where integration happens with a different combination of distributed energy resources). Wind turbine installation was about 487 GW by the end of 2016 worldwide with an increase of 12.5% from 2015. India is fourth in the world with an installed capacity of wind turbine with 28.665 GW in 2016 which is still growing rapidly (Renewable Energy Policy Network for 21st Century (REN21), Renewables Global Status Report 2018). To receive maximum power from the available wind energy potential, it is critical to locate the position of wind turbine in a wind farm. Therefore, researchers use numerical techniques with high-end computers. This problem becomes more complex and nonlinear due to uncertainties associated with wind speed and aerodynamic behaviour of wind. When high wind potential is available and the generation requirement is less, power generation becomes economical and competitive with conventional power generation. Though for a multi-megawatt generation or with limited access to wind, a good number of wind turbines have to be used and the efficiency of wind farm is highly dependent on the positioning of turbines.

In the present study, the effect of wind speed and direction on WFLO is investigated. In addition, wind potential and generation cost are calculated. An algorithm is developed for wind farm performance and optimization for three different scenarios; (i) constant wind speed in one direction, (ii) constant wind speed in multiple directions and (iii) variable wind speed in one direction. A wind farm of 2 km x 2 km is divided into grids of 10 x 10, each grid can have either one turbine or no turbine. The investment cost and the total power extracted are considered optimization variables. Genetic Algorithm (GA) is used for optimizing the wind farm layout.

5.1.1 Turbine modeling

In the present study, wake model was developed by N.O. Jensen (Jensen, 1983) is considered. The wake model was used by numerous researchers to address the wind farm layout optimization problems (Herbert-Acero *et al*., 2014). This model is simple and predicts energy production with high accuracy (Parada *et al.*, 2017). It is influenced by overall momentum conservation in the wake formed along the wind-direction behind the turbine. The study neglects the near-field present just after the wind turbine, and hence the resulting wake is designed as a turbulent wake or negative jet. Since it neglects the influence of tip vortices on the wind parameters, this wake model is suitable for designing problems on the ground that they are only in the far wake region.

The wake at the input of a proposed turbine has radius 'r_0'. The design of turbine is such that the wake radius is proportionately increases along the downstream distance 'x', as the wind wave moves forward. This concurs with the help of Blitz theory. Blitz theory is one of the techniques, used to solve puzzle, such as chess game and this starts with the opening step and followed by solving puzzle step by step. It has been reported in the literature that the net efficiency of a turbine would drastically decrease after placing it in a wind farm with similar other turbines, as a result of wake effect (Parada *et al.,* 2017).

Turbine blades get a part of energy from the movement of a wind inside the turbine. This is the kinetic energy of the wind, being transferred to the blades. Consequently, the blades tend to lower the velocity of the wind, as a result of which, it undergoes a volumetric expansion about the mass acceleration before the blades. To make wake model without considering near turbulence intensity, this effect is presumed to be uninterrupted and linear. The wake effect will tend to surge when multiple wakes happen to apply to one turbine. In this model, it is assumed that the momentum throughout is constant throughout inside of the wake. This is to treat the subsequent wake produced by a wind turbine as a turbulent wake, if the near field behind the turbine is disregarded completely. This approach has been validated by different researchers and reported that Jensen's traditional wake model is more accurate than other models for calculating wake loss. Schematic of Wake model of wind turbine is given in Figure 5.1.

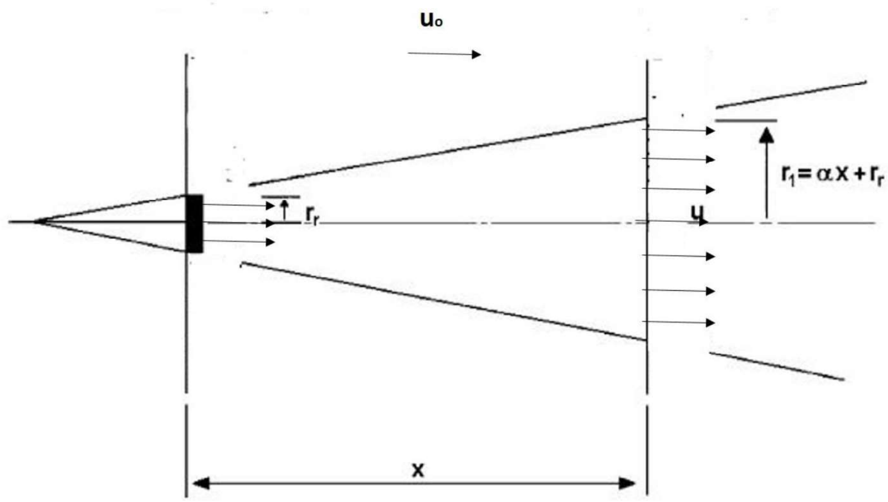

Figure 5.1. Schematic of wake model of wind turbine.

The power produced by a wind turbine is calculated from the given Equations 5.1 (Parada *et al.*, 2017).

$$p_i = \frac{1}{2}\rho A {U_i}^3 C_p \tag{5.1}$$

$$U_i = U_o(1 - U_{def}\frac{A_{overlap}}{A}) \tag{5.2}$$

$$U_0 = \frac{U}{k}\ln\frac{z_j}{z_o} \tag{5.3}$$

where,

U_i = free stream velocity before wind turbine i.

C_p = maximum power coefficient.

z_j = roughness of turbine i,

k = Von Karman constant.

z_0 = surface roughness length.

The Von Karman constant (k) is assumed to be 0.4. Based on practical values, the surface roughness length (z_0) is approximated as 0.3. Equation 5.4 is used to calculate velocity losses and Equation 5.8 is used to calculate turbine thrust coefficient.

$$U_{def} = \frac{2a}{(1+\alpha\frac{x}{r_r}).^2} \qquad (5.4)$$

$$\alpha = \frac{0.5}{\ln\frac{z_j}{z_o}} \qquad (5.5)$$

$$r_1 = \alpha x + r_r \qquad (5.6)$$

$$r_r = r\sqrt{\frac{1-a}{1-2a}} \qquad (5.7)$$

$$C_T = 4a\ x\ (1-a) \qquad (5.8)$$

$$(1-\frac{u}{U_o})^2 = \sum_{i=1}^{N}(1-\frac{U_i}{U_o})^2 \qquad (5.9)$$

$$Maximum\ P = \sum_{i=1}^{N} P_i \qquad (5.10)$$

where,

a = factor of axial induction.

x = downstream distance from the wind turbine that causes the generation of the wake.

C_T = turbine thrust coefficient.

r_1 = wake radius.

α = entrainment constant.

The turbine thrust coefficient C_T and the wake radius r_1 are found to be associated with entrainment constant 'α' and distance x. When several wakes join together, the resulting velocity 'u' can be calculated by equating the kinetic energy difference of the mixed wake to the addition of kinetic energy differences of every individual wake at any point. When a turbine is enclosed incompletely in a wake model, the forces on the turbine blades are irregular. Consequently, the whole turbine will face unstable operation and great turbulence. In this model, it is assumed that the unstable operation due to incomplete coverage will have a negligible effect on the power output of a wind farm. Meanwhile, velocity of the free stream at lower turbines is smaller than that at higher turbines, which may decrease power generation.

5.1.2 Optimization function

Optimization techniques are employed to govern the size of each and every constituent participating in the system problem, so that the final load can be frugally satisfied. Therefore, control variables need to be designed such that they could characterize the size or rating of all influential system constituents. Objective function is to be minimize electricity generating cost. The magnitude of system dependability is expressed by the expected energy not served within every sub-period of operation. Investment cost of wind turbines is based on the number of turbines needs. The total cost per year for the complete wind farm can be calculated using Equation 5.11 (Huang, 2007):

$$cost_{total} = cost_{gen} \times N \times (\frac{2}{3} + \frac{1}{3} e^{-0.00174N^2}) \tag{5.11}$$

where,

$cost_{gen}$ = cost per generator per year.

N = Number of turbines

Wind turbine generates electrical power when the wind speed 'V' is above the specified cut-in speed 'V_{ci}' and is dysfunctional, when 'V' is greater than the cut-out speed 'V_{co}'. However, with $V_r < V < V_{co}$, (V_r being the rated wind speed), a wind turbine generates specified rated power 'P_i' without any increase in power, even though wind velocity increases in that range.

In case of $V_{ci} < V < V_r$, the power output of a wind turbine is expressed by Equation 5.13. Following equations are used for optimization in the study.

$$P_w = 0 \ if \ V < V_{ci} \tag{5.12}$$

$$P_w = aV^3 - bP_r \ if \ V_{ci} < V < V_r \tag{5.13}$$

$$P_w = P_r \ if \ V_r < V < V_{co} \tag{5.14}$$

$$P_w = 0 \ if \ V_{co} > V \tag{5.15}$$

$$a = \frac{P_r}{V_r^3 - V_{ci}^3} \ and \ b = \frac{V_{ci}^3}{V_r^3 - V_{ci}^3} \tag{5.16}$$

$$P_r = \frac{1}{2} C_p \rho A V^3 \tag{5.17}$$

where,

C_p = power coefficient.

p = density of the medium (here, it is air).

A = area of the rotor.

The optimization coefficients used here are as follows:

Total rotor area 'A' is a control variable for the wind turbine model. This value is controlled by the availability of space and project finances. Numerically, 'A' can be found using linear programming algorithm, however turbine modeler can choose the total rotor area based on commercially available wind turbines.

Furthermore, studies are required to investigate variation of wind direction, velocity, and intensity of performance in wind farm before setting it up. The wind farm layout has to be modeled such that maximum energy at the lowest cost can be generated. Also, factor such as topography of the land, wind distribution over the year, type of wind turbine installed and its installation and maintenance cost need to be considered while optimizing the wind farm layout.

5.1.3 Genetic algorithm

Characteristic optimization problem statements are typically addressed by using a mountaineering process, where local gradient is predominant for objective function (Gao *et al.*, 2015). Therefore, a shortcoming representative of this method is the possibility of evaluating just a local optimum, and non-feasibility of determining a global optimum commencing from identical structure. The wind turbine position in a wind farm is a characteristic problem. It is infeasible to solve it precisely and a simple gradient-based technique cannot be used. As for a grid of 10 x 10, there are 2^{100} possibilities of wind turbine positions have to be analyze possible, even if for every grid point option is constrained only to the two likelihoods of either having or not having a turbine at each site. Analysis of these many possibilities far surpasses the competence of any prevalent processor. A genetic search algorithm is one possible method that can be applied to this problem statement to arrive at a solution. It should be noted that gradient-based optimization fundamentally begins from a single point of design space. On the other hand, in simulating a biological-evolution algorithm of a species, the optimization procedure will commence with examining numerous points of configuration space.

The algorithm used here is represented as a flow diagram in Figure 5.2. MATLAB version R2015a was used for modeling the problem statement. Local optimal solutions are completely avoided using GA. Random binary strings are generated as an initial solution. Each generated output string can be considered a particular solution describing the configuration of a wind farm layout. For the GA, selection, crossover, and mutations are the functions which form the basis of optimization to determine the best possible layout. Selection works like a natural selection theory, where the best strings are selected to undergo further operations in the process of optimization. Crossovers and mutations are performed on the strings selected in the first phase. Probabilities for these processes are optimized. Selected strings are arbitrarily crossed in pairs as part of the algorithm, so that it improves the quality of individuals in the next generation in accordance with the cost optimization function. Mutation includes random variation in the solution so that all options of possible solutions are explored and local optima are not determined from the original random binary string. These three steps give a generation of strings optimized and are further subjected to the same process. The non-favourable solutions are reset, when the best solution array is reinitialized to store a new better optimized solution. The algorithm continues until the input generation is reached.

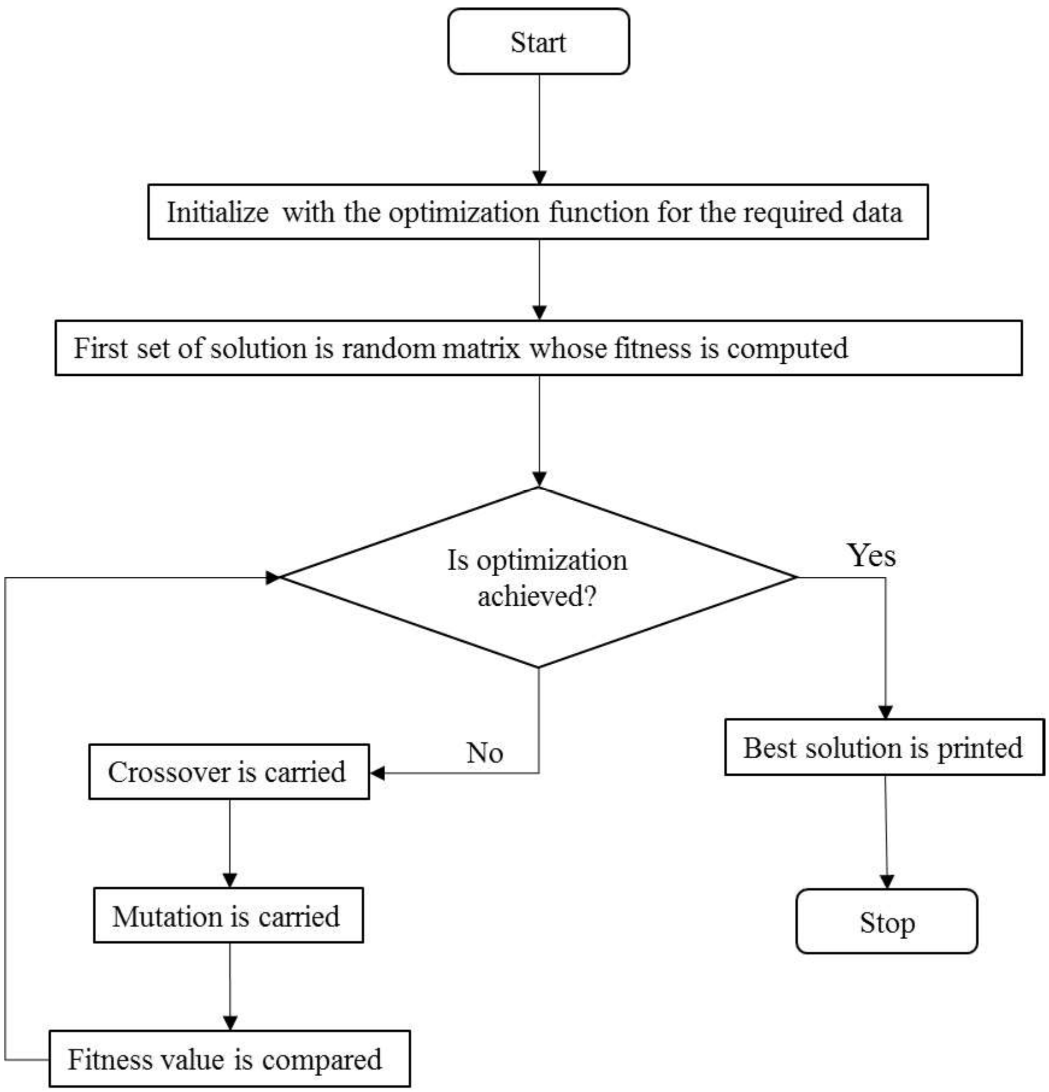

Figure 5.2. Genetic algorithm used for WFLO.

First, the algorithm would generate an arbitrary ‘m’ x ‘n’ matrix with binary inputs including strings representing wind farm layouts, where ‘m’ indicates string individuals in the optimized generation and ‘n’ would be optimal and potential locations for the turbine. The values of ‘m’ and ‘n’ are determined before the code runs, as 10 to have a grid of 100. In each string of the optimized solution of algorithm, binary ‘0’ and ‘1’ are defined as absence and presence of turbine at that location respectively. After obtaining fitness values and power generation values with an objective function, algorithm chooses only those layouts that would yield comparatively better results according to the objective function. Afterward, mutations and crossovers take place to create one complete generation that is optimized until the number of generations required is reached. Basically, the algorithm handles only the position selection of wind turbines.

5.1.4 Data analysis

Ideal locations for wind farm installation within AP and TS are identified using the methodology discussed in Chapter 3. Anantapur district with latitude 14.5833^o and longitude 77.6333^o in AP is found to have highest wind speed as well as availability of suitable type of land for wind farm installation. For representation, a contour map for the month of April is shown in Figure 5.3. In this study, monthly mean wind speed at Anantapur over the last 20 years is used and the variation of wind speed is shown in Figure 5.4. Optimization of wind farm layout is carried out 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.

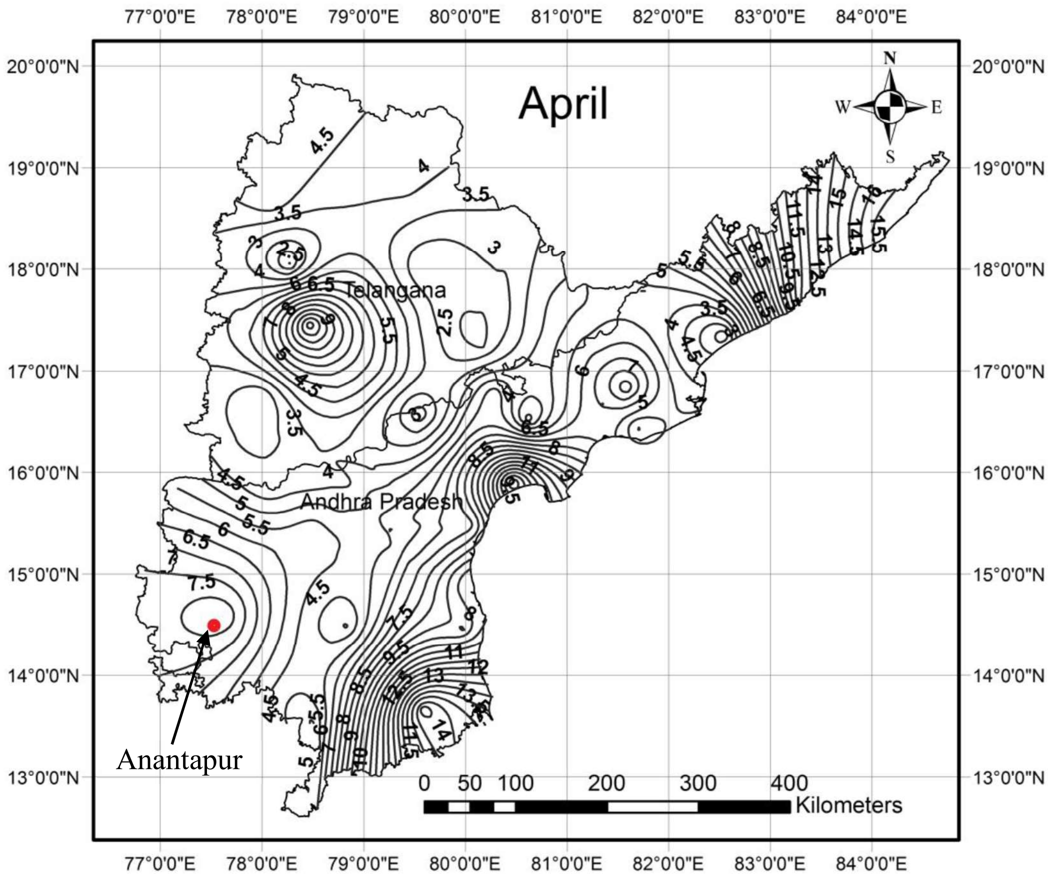

Figure 5.3. Map of wind speed for the month of April.

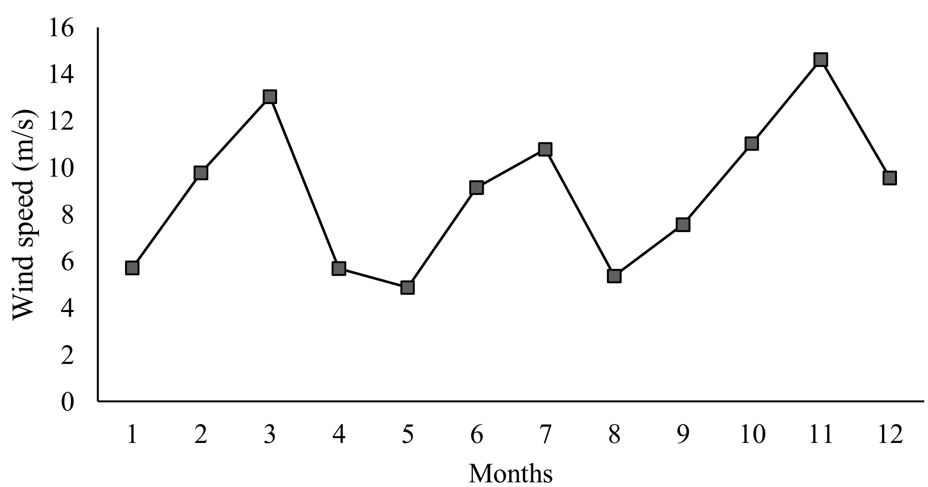

Figure 5.4. Monthly average wind speeds at Anantapur.

5.2 WFLO results

Input parameters for optimizing wind farm layout is given in Table 5.1.

Table 5.1. Input properties for WFLO.

Hub height	60 m
Rotor diameter	40 m
Thrust coefficient	0.88
Ground roughness	0.3 m
Wind velocity (Yearly average)	8.95 m/s
Axial induction factor	0.330
Entrainment factor	0.094

5.2.1 Constant wind speed in one direction

In case of constant wind speed in one direction, it is assumed that the wind is flowing only from the front of turbines. The proposed algorithm is used to optimize a wind farm layout in Anantapur district of size 2 km × 2 km with wind speed measured at the ground station. There are total 100 grids in 4 km^2 area. Each grid is of 200 m x 200 m and can have only one turbine. So, there is a possibility of installing maximum 100 turbines. The simulation results are obtained for yearly average wind speed of 8.95 m/s. The cost objective function to be minimized, which includes turbine investment, operation and maintenance cost per kW installed. Figure 5.5 shows the behavior of fitness curve, as a function of generation for a yearly average wind speed. It can be noted that the fitness value converges before 400 generations. It was found that for a constant wind speed in one direction, the best solution would accommodate less than 19 turbines. Optimized wind farm layout is presented in Figure 5.6.

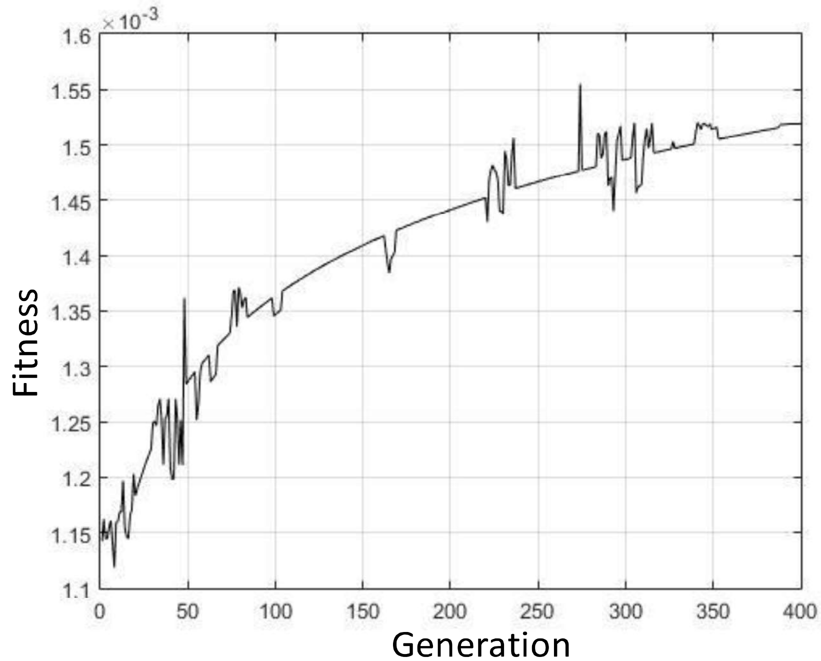

Figure 5.5. Fitness curve with respect to generation for one direction wind.

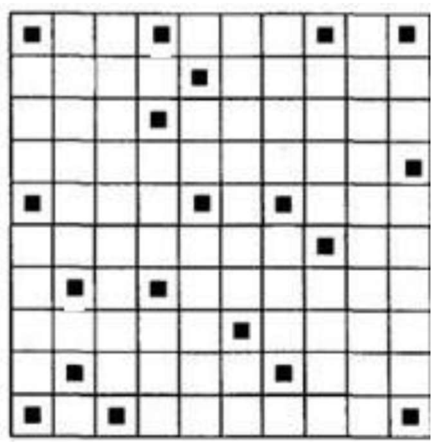

Figure 5.6. Optimization result for wind farm layout for one direction wind.

5.2.2 Constant wind speed in multiple directions

In case of constant wind speed in multiple directions, wind direction is assumed to be diagonal to the farm. Therefore, the wind has components in both the directions, parallel and transverse to the turbine. For multiple directions, yearly average wind speed is taken for wind farm optimization problem. It is observed from a single direction wind speed that there is not much difference in numbers of turbine or power generation. The behavior of the fitness function becomes stable and converge before 400 generations. The result for this optimization was approximated to 16 turbines. The multidirectional optimized windfarm layout at Anantapur district with annual average wind speed of 8.95 m/s is shown in Figure 5.7. The current algorithm was also applied and compared with previous reported studies for a 2 km × 2 km wind farm with 100 grids as shown in Table 5.2. For comparison, similar input parameters, such as the average wind velocity of 12 m/s and grid size of 0.2 km are used in the present study. It is observed that the fitness value obtained in the present study is lowest amongst the reported studies. It indicates that the proposed GA model gives better results for WFLO.

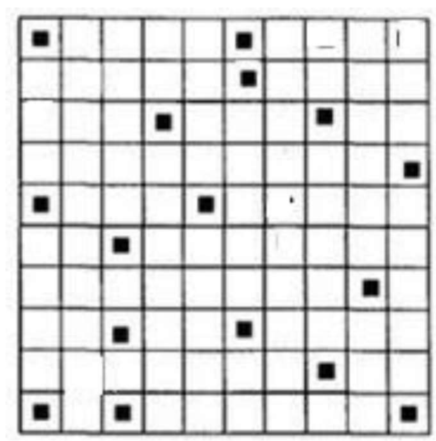

Figure 5.7. Optimization result for wind farm layout for multiple wind directions.

Table 5.2. Comparison of the present algorithm with previous works.

Studies	No of turbines	Fitness value ($x10^{-3}$)
Grady *et al*. (2005)	30	1.544
González *et al*. (2010b)	30	1.544
Mosetti *et al*. (1993)	26	1.620
Pookpunt and Ongsakul (2013)	30	1.544
Present study	30	1.530

5.2.3 Variable wind speed in one direction

In case of variable wind speed in one direction, estimated wind speed for each month at study location is taken separately and wind farm optimization is carried out. Wind speed is in the range of 4.88 to 14.62 m/s. Table 5.3 shows variation of the number of turbine with respect to the monthly mean wind speed for a wind farm of 2 km × 2 km.

Table 5.3. Optimum number of wind turbines and theoretical power generation for monthly mean wind speed.

Month	**Monthly mean wind speed (m/s)**	**Optimum No. of turbines**	**Theoretical power generation (MW)**
January	5.72	22.00	55.36
February	9.78	19.00	239.63
March	13.04	17.00	507.28
April	5.69	22.00	54.53
May	4.88	22.00	34.51
June	9.16	19.00	196.44
July	10.78	17.00	287.20
August	5.37	22.00	45.80
September	7.57	19.00	110.96
October	11.03	17.00	307.53
November	14.62	17.00	715.63
December	9.56	19.00	223.93

It can be noted that for similar size of wind farm, the optimum number of turbine decreases with increase in wind speed. Optimum number of turbines is 22 for the minimum wind speed of 4.88 m/s and 17 for the maximum wind speed of 14.62 m/s. The average of optimum number of turbine for all months is 19.33, which is closer to the optimum number of turbines for yearly average wind speed. If 19 turbines are considered in a 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. Optimized wind farm layout for monthly mean wind speed is presented in Figure 5.8.

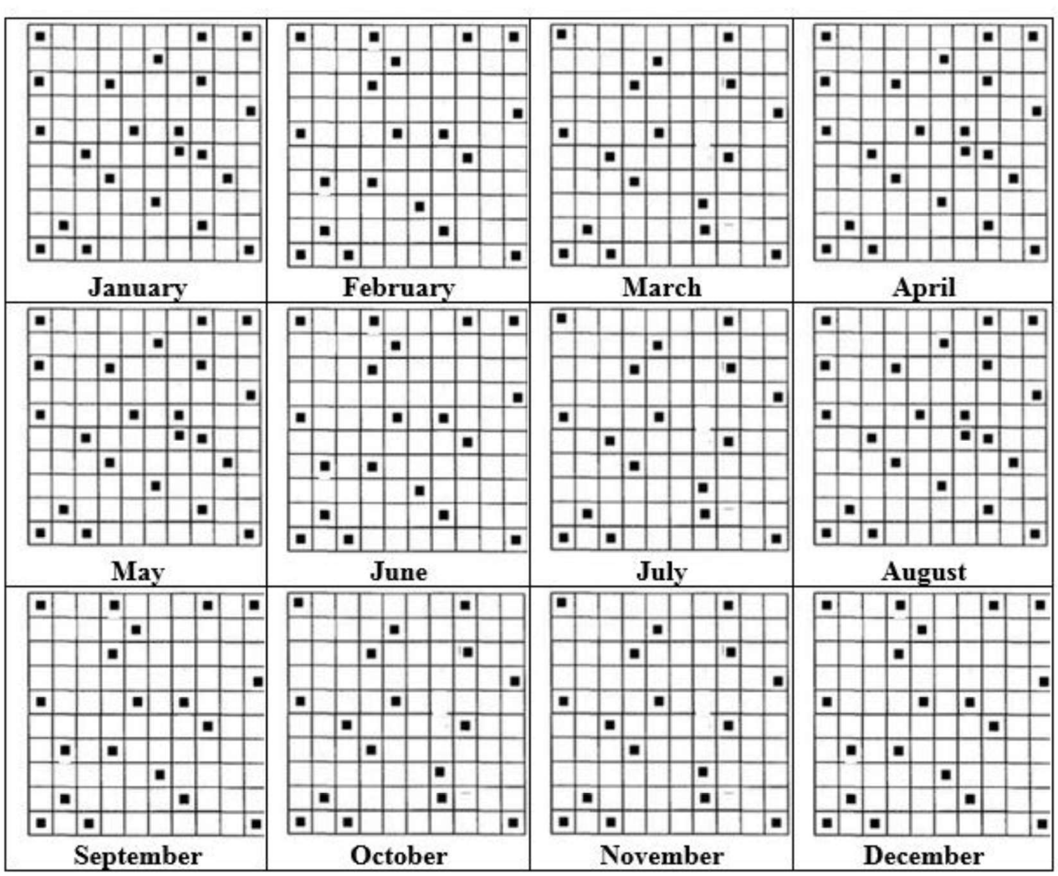

Figure 5.8. Optimized wind farm layout for monthly mean wind speed with one direction.

5.2.4 Cost and power generation

The operation and maintenance costs of Rs. 120/kWh throughout the lifetime of a wind turbine is assumed in the present study (European wind energy association report, 2009). In this study the cost of land is not considered while calculating the cost of energy generation. Also, the lifetime of a turbine is assumed to be 20 years, while approximating the cost of maintenance. The power output from selected turbine was calculated using Equation 5.14 and Equation 5.17, since the average velocity measured is above the rated speed but below cut off speed. For maximum power generation, the optimum number of wind turbines that can be installed is 19 for average wind speed. For a power coefficient, C_p as 1, density of air as 1 kg/m^3 and rotor swept area equal to the rotor diameter gives 183.55 MW of power at Anantapur for a 2 km x 2 km wind farm.

5.3 Solar power generation optimization

Solar energy is another reliable renewable energy resource, which can easily be integrated into a microgrid. Among all renewable resources, solar energy is one of the cheapest resource and technology is advanced enough for commercial power generation. Solar power generation capacity in India is increasing rapidly. India was seventh in the world for an installed capacity of solar power with 9 GW in 2016. The solar power generated reached up to 26 GW end of September 2018, which is almost eight times the solar power generated in 2014. To maximize cost-effective power generation from solar radiation, the placement of solar panels need to be optimized for shading effect. Solar panels cast their shadow on surrounding panels, which reduces the amount of incident energy and consequently the output. However, if sufficient arrangements are made to increase the gap between the panels, the number of solar panels for a given area of land comes down, in result the output gets reduced. Hence a tradeoff is required. If the solar panels of amorphous silicon cells are used instead of crystalline silicon cells, the effect of shading can be minimized. However, this type of solar panels are not manufactured in India. The Government of India provides subsidy only on domestically manufactured solar panels. Therefore, within India domestically manufactured solar panels must be used for reducing the cost of electricity generation. Another parameter which maximizes the solar power generation is its tilt angle. An excel based model is developed to optimize and evaluate the solar power generation, which can be operated in stand-alone or grid-connected mode.

5.3.1 Data analysis

This study deals with the design of solar component of a hybrid system. For designing a solar field, main requirements are solar radiation data and energy demand data at a given location. Ideal locations for solar field are identified using maps of solar radiation and the land use land cover analysis, as discussed in Chapter 4. Thumkunta village in Ranga Reddy district, TS is considered ideal location for setting-up a solar field. Thumkunta village with latitude 17.44^{o} and longitude 78.49^{o} is located in Ranga Reddy district, in the region with higher solar potential. This district also has the highest built-up area, which can be utilized for roof-top PV installation.

Figure 5.9 shows the variation of monthly mean solar radiation over 20 years. The annual mean solar radiation available is 5.26 kWh/m^2/day. India has per capita energy consumption as 1075 kWh per annum (Government of India, Annual Report on Electricity consumption, 2015-2016) with an average family size of 4.9. Therefore, the energy consumption per annum per households is 5268 kWh.

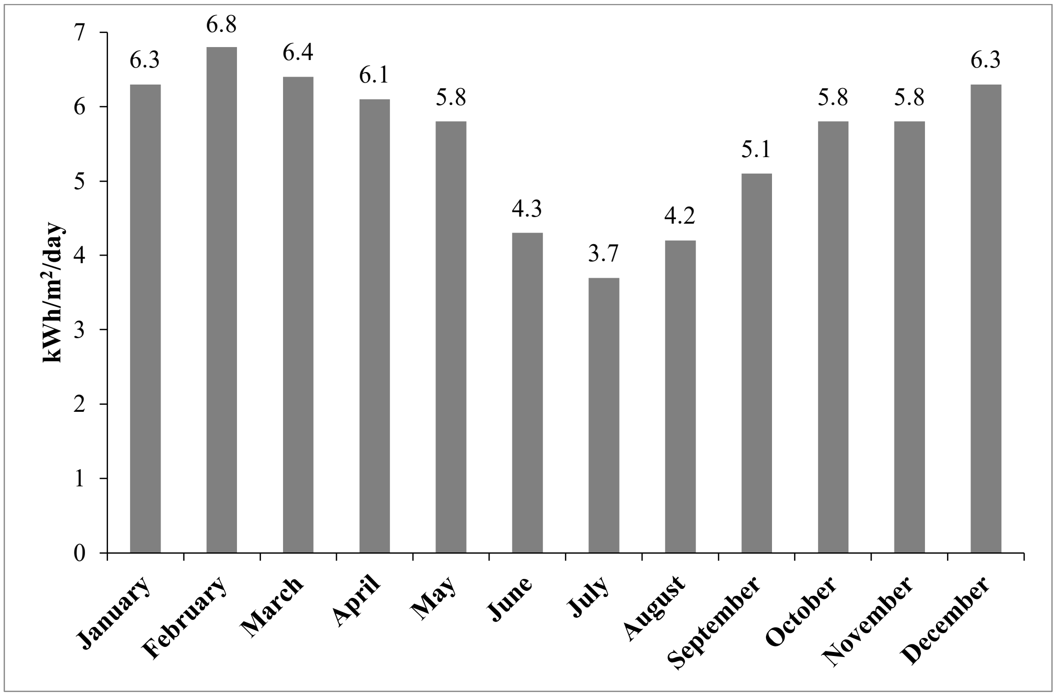

Figure 5.9. Monthly mean solar radiation at Thumkunta village.

5.3.2 Modeling of solar power generation

Solar power generation has been modelled for maximum power generation with minimum cost by considering the shading effect of solar panels. In this study, energy requirement for 100 households is considered, which means solar field is expected to generate 526 MWh per annum with daily energy requirement of 1.4 MWh. While modeling, days of autonomy is considered one day.

Specification of PV modules

There are several manufacturers of solar panels in India with rated power output in the range of 100 to 260 W. A few of them are Luminous, Sukam, Microtek, etc., as given in Table 5.4. For this study, a panel of 100W from Luminous is considered, which has length and width of 1.03 and 0.67 m, respectively.

Table 5.4. Solar panel specifications.

Wattage (W)	Length (m)	Width (m)	Thickness (m)	Price (Rs)	Manufacturer
250	1.67	1.01	0.05	16000	Luminous
100	1.03	0.67	0.04	4800	
250	1.00	1.00	0.010	15000	Sukam
150	1.00	1.00	0.010	12000	
100	1.00	1.00	0.010	9250	
40	1.00	1.00	0.010	3700	
260	1.64	0.99	0.035	14000	Microtek
250	1.64	0.99	0.035	12650	
150	1.49	0.67	0.035	7500	

5.3.3 Solar field layout optimization

Optimum row spacing (i.e. minimum spacing between two successive rows of solar panels) has to be estimated to avoid the shading effect of one panel over the other. This calculation is carried out on the basis of physical dimensions of a solar panel and solar elevation angle, depending on geographical location. For a non-tracking solar panel, the optimum tilt angle should be equal to latitude angle, which is 17.44^0. The schematic of module row spacing is shown in Figure 5.10. Figure 5.11 shows the sun path (University of Oregon, Solar Radiation Monitoring Laboratory (UO, SRML)) to estimate solar elevation angle and azimuth correction angle at a given location. Minimum elevation angles are observed in winter solstice, 21 December. If the minimum elevation angle is used to calculate inter-panel spacing, it would ensure maximum possible spacing between the panels. Solar elevation angle of 18^0 is estimated for 21 December at 8 am or 4 pm (Point C in Figure 5.11). Azimuth correction angle is observed as 55^0 (AB/2, in Figure 5.11).

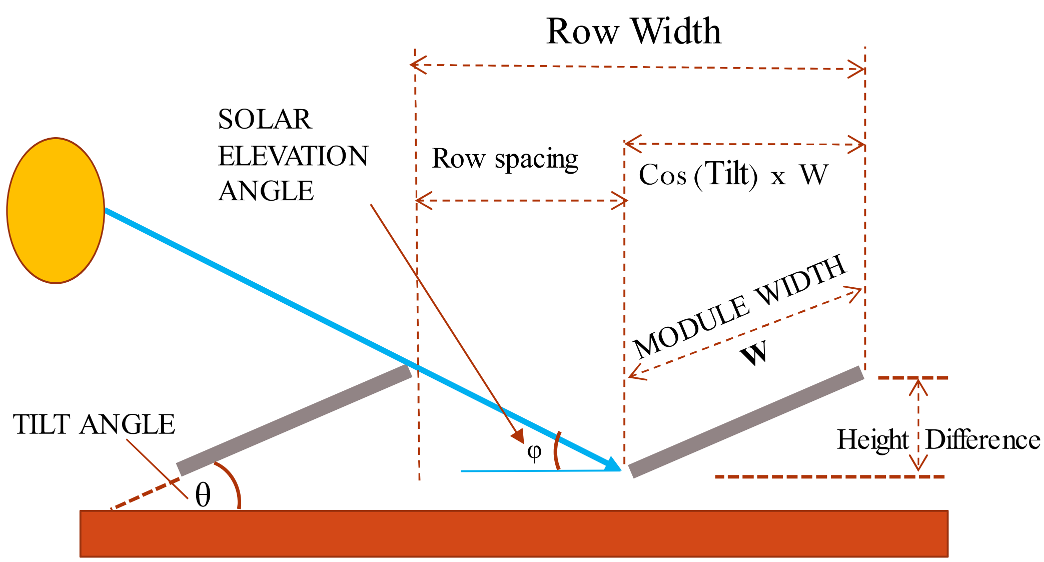

Figure 5.10. Schematic of module row spacing considering shading effect.

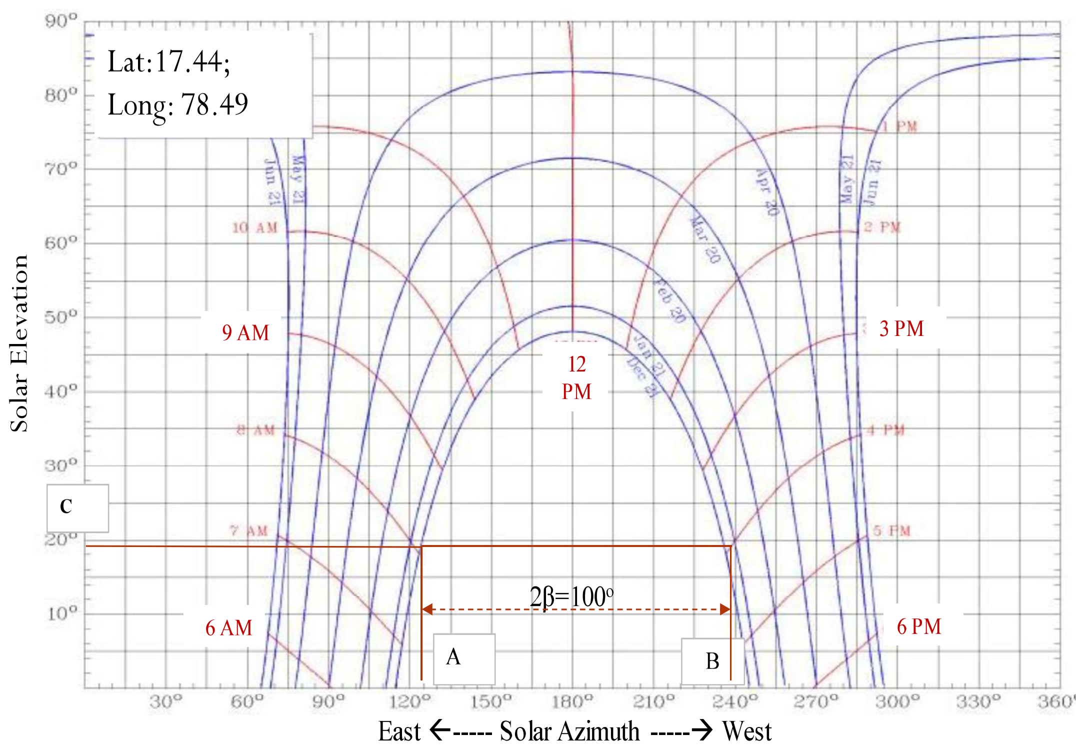

Figure 5.11. Graph of solar elevation angle and solar azimuth at Thumkunta village (UO, SRML).

The module row spacing is calculated based on various parameters, such as tilt angle, module width, solar elevation angle, and height difference, as shown as Figure 5.10. Minimum module row spacing is found out using azimuth correction angle. Based on the minimum module row spacing and effective horizontal width of one module, and overall row width is calculated. Hence, the minimum module row spacing and row width are calculated as 0.354 m and 0.995 m, respectively. Details of calculation steps are given in Appendix V.

Optimum number of solar modules for a given field

To meet the demand of 1,443 kWh/day, several dimensions of solar field are considered for the calculation. It has been found that a solar field of 60 m x 50 m will generate the required energy. A gap of 1 m between 2 successive trails of solar panels is provided to help easy movement for maintenance purposes. Therefore, the optimum number of rows and number of solar panels in one row are found to be 60 and 47, respectively, which can accommodate maximum 2,820 number of solar panels. Details of this calculation are given in Appendix V.

Solar power generation for a given field

Annual average solar radiation available at Thumkunta village is 5.26 $kWh/m^2/day$. The solar panel considered for this study has a rated capacity of 100 W. Panel generation factor is assumed to be equal to the available solar radiation. Therefore, the amount of power generated in one day (i.e. panel generation factor multiplied by panel wattage and number of panels) is observed to be 1483.32 kWh/day. This generated power could meet the daily energy requirement of 100 households. There is a general observation that 30% of the total energy generated by the solar panels is lost to the environment (Khatri, 2016). Considering this loss, the energy required from the solar field would be 1876 kWh/day, which can be generated with a solar field of 60 m x 63 m.

Requirement of an electrical component (Inverter and Battery)

The solar panel generates DC power, which needs to be stored and converted to AC power. Therefore, battery and inverter are required. Specifications of inverter and battery are given in Table 5.5. The maximum open circuit voltage of a considered solar panel is 12 V. Therefore, the required number of inverters and batteries are 245 and 1527, respectively, as shown in Appendix V.

Table 5.5. Specifications of inverter and battery.

Inverter specifications	Power of Inverter (KW)	1.5
	Max. Open circuit Voltage (V)	80
Battery specifications	Nominal voltage (V)	12
	Depth of discharge	40%
	Efficiency	90%
	Capacity (Ah)	150
	Life of a battery	4 years

Financial aspect of solar power

Total capital investment has been calculated based on market cost of each component. There are three main components: panel, inverter, and battery. The cost of solar panel, inverter, and battery considered here are Rs 4800/-, Rs 35000/- and Rs 13200/-, respectively. The number of solar panels, inverters and batteries required in the above scenario are 2820, 245 and 1527 units, respectively, which costs Rs 4.22 Cr.

5.4 Excel-based model for optimal utilization of solar potential

Based on the above optimization, excel-based model has been developed to evaluate a solar field to maximize its cost-effective power generation. This model is developed using the data for AP and TS, but it can be used for any geographical location after correcting solar elevation angle and azimuth correction angle. These angles can be calculated for any specific location and imported in the model. Other parameters based on the specific requirement, can be modified in the excel sheet and result will be estimated, which can be obtained from the result page of the model. Snapshots of this model are given in Appendix VI. This model is easy to use and will help to check the feasibility of a solar power plant. This model takes solar radiation value, PV panel specifications and available area to install solar panels as an input to estimate the optimum number of solar panels, their layout and expected power generation per day. To estimate the electrical component (battery and inverter) and Initial Capital Cost (ICC), their specifications with cost have to be entered in the excel model. The model can also be modified as per any specific requirement. The same excel based model has been used to evaluate solar potential for a small society of 120 households as discussed below.

5.4.1 Estimation of electrical load for a small semi-urban community

New development of 120 housing is considered based on Hyderabad Metropolitan Development Authority (HMDA) act. 2 BHK flats are assumed for an urban housing society. Each flat has a carpet area of 1000 feet^2 (approx. 92.9 m^2). Each housing block made up of 3 floors and 4 flats on one floor is considered. Total land area of one floor is therefore equal to 4000 ft^2 (371.6 m^2). There is a general assumption that total construction area is 1.5 times the total carpet area. Thus, the total land area of one block would be 6000 ft^2 (557.4 m^2). The housing society is made up of 10 such blocks. The Government regulations are used while allocating land to different uses (plotted area, road area, and open area) in this housing society, whereby the total area of the housing society would be 90000 ft^2 or 8361 m^2 (Table 5.6). Out of the available areas, area composition of the housing society is presented in Table 5.8. 100% of the plotted area and 30% of the road area are considered for solar panel installation, which is equal to 6131 m^2. 20% of the available area has to be left as side space and for other space needs as required handling and cleaning. Therefore, the effective area for solar panel installation would be 4905 m^2, which can be assumed a solar field of 70 m x 70 m.

The power requirement for this society has been estimated based on the commonly used appliance in a family, as given in Table 5.7. Total power required for given appliances works out to 17.56 kWh. This consumption is then modified by adding 30% for miscellaneous appliances, such as mixer, grinder, mobile phone charging, microwave oven, water purifier, etc. Hence, the power requirement per day per family would be 22.828 kWh. As there are 120 families, each with four members, the per capita energy consumption works out to 2083 kWh/annum and the total power consumption for 120 family work out to 2739.24 kWh/day.

Table 5.6. Area composition for the society of 120 housing.

Land distribution	Area in sq-ft	Area in sq-m	Percentage
Plotted area	60000	5574	67%
Road area	20000	1858	22%
Open area	10000	929	11%
Total society area	90000	8361	100%

Table 5.7. Estimation of power consumption per day for a 2BHK house for 4 persons.

Appliance	Quantity	Unit power (in Watts)	Number of hours (1 day)	Total (Wh)
CFLs	7	15	12	1260
Tube lights	4	30	6	720
Fans	4	50	18	3600
Washing machine	1	500	2	1000
Refrigerator	1	150	24	3600
Telivision (19")	1	70	4	280
Computer	1	275	4	1100
Air cooler	2	100	10	2000
Water geyser	1	2000	2	4000
			Total	17560

5.4.2 Assessment of roof-top solar power

The excel-based model is used to assess the roof-top solar power generation to meet the estimated energy demand of new development, consisting of 120 housing, other parameters being the same as that of previous calculation. For annual average solar radiation available at Thumkunta village, number of solar panels, batteries, and inverters required are 4620, 2501 and 401 units, respectively. This roof-top solar power system can generate 2430.12 kWh/day. This generated power can meet 88.72% of the energy demand. Deficit power required can be met by installing additional solar panels in available barren land or by using a backup diesel generator or from the main grid. Further, the developed model is used to evaluate the solar power generation using monthly mean radiation and is compared with monthly power required, as shown in Figure 5.12.

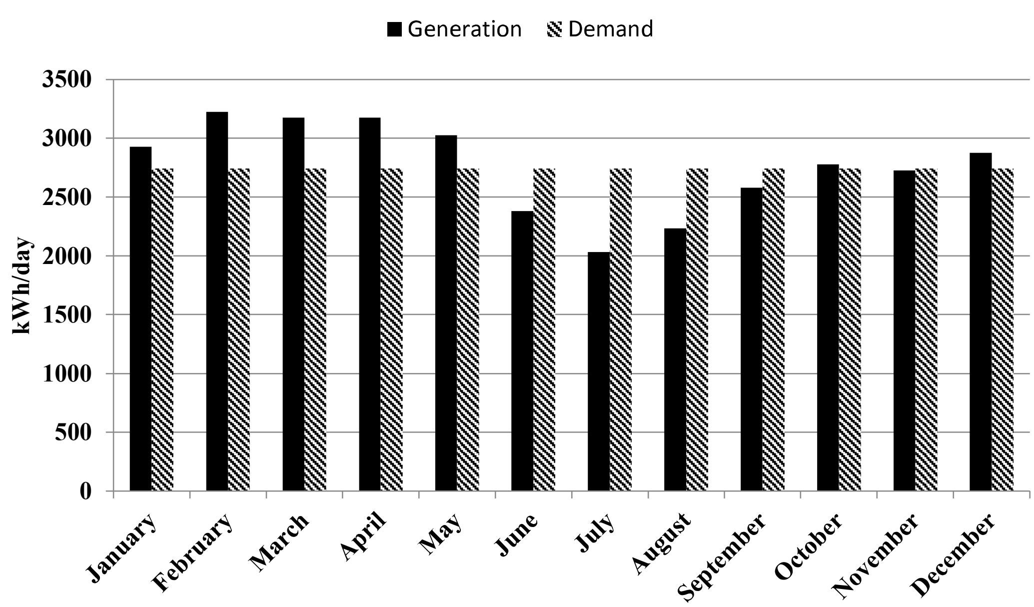

Figure 5.12. Comparison of monthly power demand and power generation.

5.5 Summary

A program based on GA is proposed to optimize the position of wind turbines in a wind farm using a wake model, for maximizing power generation with minimum cost. Three different wind conditions are analyzed: constant wind speed in one direction, constant wind speed in multiple directions and variable wind speed in one direction. Effect of variation in wind speed on the optimum number and positioning of wind turbines in a wind farm are investigated. It has been observed that the optimum number of wind turbine decreases with an increase in wind speed. Thereafter, solar field has been optimized for positioning of solar panels in a solar field by considering the shading effect of solar panels and solar elevation angle along with the tilt angle. Finally, excel based model is developed for optimization of solar field.

Next chapter discusses development of optimal integrated renewable energy system for stand-alone microgrid, which includes different combinations of distributed energy sources, storage systems and energy demand.