CHAPTER-VII

Optimal planning of renewable distributed generation

7.1. Introduction

With the progressing exhaustion of fossil fuel energy sources, the limitation of available transmission corridors and the gradual increase in the global temperature, the rapid development of renewable distributed generation system has been observed around the world. The concept of renewable distributed generation arises from the distributed power generation with renewable energy sources (Labis et al., 2011). This came to force because of its environmental benefits and onsite power generation flexibility to improve the reliability and quality of power. With their advantages, this is a top priority in making of energy policy over worldwide. Penetration of renewable distributed generation units is helpful for postponing transmission investment, reducing primary energy consumption, decreasing the emission of greenhouse gases, and, hence, alleviating global warming (Hung et al., 2013). Due to increasing penetration of the renewable distributed generation in a distribution system, the optimal planning of the renewable distributed generation units in the distribution system is increasingly important.

The need for more flexible electrical systems, changing regulatory and economic scenarios, energy savings and environmental impact are providing impetus to the development of renewable distributed generation system, which is predicted to play an important role in the future power system (Khamis et al., 2013). One of the important applications of renewable distributed generation system is the utilization of the small-modular residential or commercial onsite generation units. The renewable distributed generation technology can be chosen so that they satisfy the customer's load demand at minimum cost all the time. A proper management strategy is important for both better system efficiency and endurance of power grid integration systems (Blake et al., 1962).

A small-scale renewable energy based energy conversion system ranged from 1 kW to 50MW can define as renewable distributed generation system (Electric Power Research Institute, January 1998). This can be used as an alternative or upgradation of conventional power generation system. The motivation of setting up of power generation units in this system is customer-centric and near to customers. The renewable distributed generation units become directly integrated to power distribution systems to fulfill the randomly distributed demand with more reliability. For the reason of reliability, renewable distributed generation units would be interconnected to the same transmission grid as central stations (Atwa et al., 2009). Over the conventional power generation system, it becomes a valuable alternative for the industrial, commercial and residential purpose (Wolsink, 2012). This leads complexity in the planning of the economic power dispatch to get optimal solution among different alternatives.

The reasons behind the high penetration of renewable distributed generation in modern electricity market are:

- Renewable distributed generation system can fulfill required load demand by installing multiple numbers of units with different capacity at the desired location or near to demand sites and develop a new upgraded power system with minimal transmission and distribution losses.
- We can easily assemble renewable distributed generation units anywhere for power generation.
- Due to decentralization of power system, the renewable distributed generation has a great advantage to set up its unit in the demand region. Thus, it gives the flexibility to install as per consumers demand.

- Renewable distributed generation helps in "peak load shaving" and demand-side management.
- In the case of emergency and system outages, renewable distributed generation can be used as on-site standby to supply electricity.
- Renewable distributed generation provides system stability, supply the spinning reserve required and also provides transmission capacity release.
- At a ground level, it's easy to find a location for set up of the small unit compared to the large unit.
- It helps to harness the regional potential of renewable energy sources.

For the use of renewable distributed generation units at a large scale, it is advisable to take its impact in the system at the planning level. Distribution system engineers should analyze future impact of renewable distributed generation system in modern smart grid integrated system (Ochoa and Harrison, 2011).

In energy planning, it involves identification of suitable location (technically, economically and environmentally), selection of best equipment (highly reliable and efficient), digitally interconnected through the smart grid system. Because of all factors measure in the financial term, the financial measure becomes the higher priority for the planner (Molderink et al., 2010). Improvement of the living standard and increasing population has increased consumption level of electricity. In the modern era, electricity has been the brightness of human being, without this life of human will be dark or we can say, we can't imagine a life without electricity in the recent technological era. Increasing stochastic demand for electricity will require better investment strategy to cope up with the uncertainty (Abdullah et al., 2014). For the long-term planning (more than one year), a planner will have the best strategy to optimize their resources or reduce losses to fulfill the load demand in environment friendly condition. By using renewable distributed generation technology as an investment strategy, a planner can reduce power losses and can manage the uncertainty of load demand and variable renewable energy sources.

When we are considering for renewable distributed generation system and its impact on the distribution system, our prime concern should be optimal planning of renewable distributed generation system, because unplanned renewable distributed generation system by decision maker may cause losses and decreasing reliability level (Atwa and El-Saadany, 2011). Proper selection of tools and techniques will make able planner choose best optimal value among multiple alternatives for optimal planning of renewable distributed generation system to minimize project cost and satisfy all the constraints (Begovic et al., 2001, January). At planning level planner or decision maker should plan for long-term along with short-term plan rather than only short-term plan or the quick result. So that, they can achieve their long-term goal with the assessment of the future impact of renewable distributed generation penetration in electricity market with present design and technology. Future planning along with short-term planning will also minimize future failure and give more stability to the power generation system. We all know future becomes completely unpredictable, we can just some guess or assumptions about our experience. Therefore, under stochastic future demand, power generation should match the demand fluctuation and get optimal power flow.

In this research work, a system model is proposed to rigorously study the renewable distributed generation issues regarding accuracy and efficiency of having a system model based on the net project cost. The system model has the potential to explain the costs significantly. However, developing the system model imposes studying minimization of the total cost of the system. Thus, it is important that the problem of minimizing the costs as well as serving the load of the renewable distributed generation be investigated.

This study assumes the renewable distributed generation system is seeking optimal planning to minimize net project costs using the evolutionary genetic algorithm (GA). Renewable distributed generation could operate independently with the smart grid, but they are usually assumed to be connected through power electronics to the smart grid. The renewable distributed generation in this study is assumed to be interconnected to the smart grid and can purchase power from utility providers when the power generation is insufficient to meet the load demand. There is a daily income to the renewable distributed generation planner when the generated power exceeds the load demand.

Our optimization model incorporates an explicit cost minimization criterion applied to the renewable distributed generation architecture. The formulation in this work seeks the most economical generation to satisfy the load demand and the constraints. The problem is decomposed into several stages, starting with building the system model which is an important stage to understand the problem. The next stage is to use the algorithm developed. This algorithm optimizes the grid integrated renewable distributed generation system to minimize the net project cost. Based on input data, including electrical loads and, technical and cost specifications of renewable distributed generation equipment, the algorithm determines the optimal flow of power required to meet the electrical load demand in the most economical fashion.

Furthermore, the algorithm determines at each iteration the optimum utilization of the available renewable energy resources, such as wind speed, as they are the inputs to the model. If the produced power from the wind turbine is less than the load demand, then the algorithm goes to the next stage which is the use of the conventional power source according to the load and their cost function. On the other side, if the produced power from the wind turbine is more than load demand, then the algorithm goes to the next stage which is the surplus power supplied to the conventional power source according to the power generation and their cost function.

Evolutionary methodology GA is the generalization of the pattern search algorithm. Evolutionary methods are intended for the black box optimization problem. They are derivative-free methods in the sense that they do not compute nor even attempt to evaluate derivatives. Some applications of an optimization or heuristic technique based methodology to identify the optimal placement of renewable distributed generation can be found in Tan et al., (2013). An evolutionary programming (EP) based technique has been presented for the optimal placement of distributed generation units energized by renewable energy resources (wind and solar) in a radial distribution system in Khatod et al., (2013). In Whitley, (1994) work evolutionary genetic algorithm is applied to the optimization management problem of the renewable distributed generation system.

7.2. System Description

For dealing with the optimal planning of the renewable distributed generation system, we used Weibull distribution and Lognormal distribution for the wind turbine generation uncertainty and load demand uncertainty, respectively. To get the optimal solution, we used the evolutionary GA methodology to solve the objective function. This methodology will give us the best optimal solution for renewable distributed generation planning with consideration of uncertainty of power generation and load demand without violation of the constraints. Growing industrialization and digitalization of technology, like smart grid, is playing a new role in increasing demand for electricity and dependence over renewable distributed generation system.

Figure-7.1 shows economic dispatch of power with renewable distributed generation system under stochastic environment. Use of the wind and solar renewable energy sources makes unpredictability in the generation along with randomly distributed load demand. The smart grid helps to operate optimal power flow with digital information sharing.

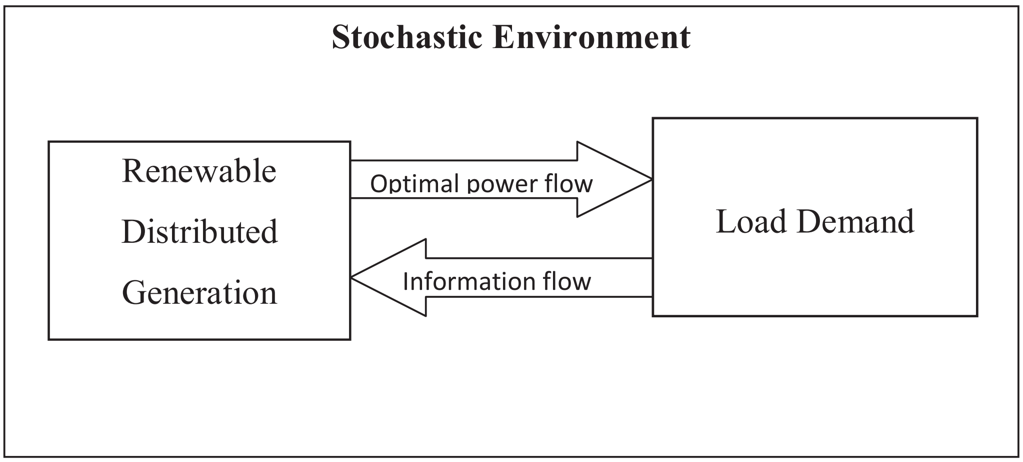

Figure 7.1: Energy flow balance between demand and supply in stochastic environment

In this work, we are considering two steps to get the final optimal renewable distributed generation planning in stochastic system: the first step to get possible scenarios associated with different renewable distributed generation units and characterized by the proper probability distribution demand-supply, and second step application of GA methodology to get the best optimal solution from the number of iteration for optimal renewable distributed generation planning.

As previously mentioned, there are uncertainties associated with the optimal planning of renewable distributed generation system in the modern power system. Given this background, we considered Weibull distribution for wind speed and Lognormal distribution for load demand distribution. First, a mathematical model is developed with minimization of the renewable distributed generation investment cost, operation, and maintenance cost; power purchased cost of the grid and maximizes savings of internal consumption and revenue of surplus power supplied back to the grid. To get solve, a Monte-Carlo simulation embedded GA approach is developed to solve the developed model.

7.3. System components

Getting of the economic power dispatch, the importance of trend analysis of load demand and power generation variability has been considered. Load demand and power generation profile have been estimated through the past years data of BHU campus.

7.3.1. Stochastic wind power output

Optimal planning of renewable distributed generation at BHU campus gets optimized with the wind turbine as the best alternative. Estimation of hourly distributed power generation at BHU campus through wind turbine needs the prediction of stochastic wind speed distribution. Hourly wind speed distribution has been studied by multiple researchers. The fitness of hourly distributed wind speed data with theoretical probability density function differs in previous researches and shows regional distribution profile of wind speed. We studied hourly wind speed distribution of BHU campus with data of NREL (India Solar Resource Data: Hourly Data and TMYs), after the statistical analysis of hourly wind speed data; it shows Weibull distribution is the best-fitted probability density function. Probability density function of the Weibull distribution is given as (Papoulis and Pillai, 2002)

$$P(v < v_i < v+dv) = P(v > 0)(k/c)(v_i/c)^{k-1} e^{-(\frac{v_i}{c})^k} dv \quad (7.1)$$

Where c is the scale parameter of the Weibull distribution, with units equal to the wind speed units, k is the unitless Weibull shape parameter, v is the wind speed, v_i is a particular wind speed, dv is an incremental wind speed, $P(v < v_i < v+dv)$ is the probability that the wind speed is in between v and v+dv and, $P(v > 0)$ is the probability that the wind speed exceeds zero.

The cumulative density function of Weibull distribution is given as,

$$P(v<v_i) = P(v>=0)\{1-e^{-(\frac{v_i}{c})^k}\} \qquad (7.2)$$

Where $P(v < v_i)$ is the probability that the wind speed is less than v_i, and $P(v >= 0)$ is the probability that the wind speed equals or exceeds zero.

From the equation-7.1 graph of power output of wind generating units vs. wind speed is

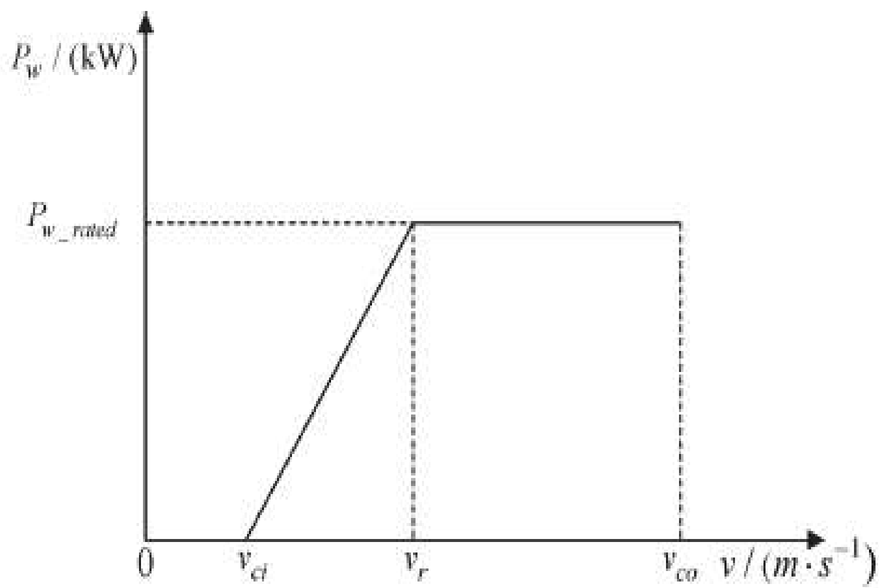

Figure 7.2: Wind turbine output from available wind speed (Ackermann, 2005)

Based on the known probability distribution function of the wind speed, the relationship between the output power of a wind generating unit and the wind speed (Ackermann, 2005) can be formulated as

$$P_w = \begin{cases} 0, & 0 \le v \le v_{c_i} \\ P_{w_{rated}} \frac{v - v_{c_i}}{v_r - v_{c_i}}, & v_{c_i} \le v \le v_r \\ P_{w_{rated,}} & v_r \le v \le v_{c_o} \end{cases} \quad (7.3)$$

Where v is the wind speed at the hub height of the wind turbine; v_{c_i}, v_{c_o}, and v_r are, respectively, the cut-in wind speed, the cut-out wind speed, and the rated wind speed respectively and $P_{w_{rated,}}$ is the rated output power of the wind turbine.

7.3.2. Load Demand Uncertainty

Load demand uncertainty is the major challenge in optimal planning of renewable distributed generation. Getting of the optimal planning of renewable distributed generation systems, we have to get analysed for load demand uncertainty. In a case of BHU campus, hourly load demand data has been taken from EWSS centre to know load demand profile at BHU campus. Hourly power consumption Pattern at BHU campus has been statistically analyzed. Hourly load demand distribution data of BHU campus shows fitness with a Lognormal distribution. Lognormal probability distribution function with μ as location and σ as scale parameters is given by (Papoulis and Pillai, 2002)

$$\ln(x; \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} exp\left[-\frac{(\ln x - \mu)^2}{2\sigma^2}\right] \quad (7.4)$$

Lognormal CDF is written as

$$LN(x; \mu, \sigma) = \frac{1}{2}\left[1 + \text{erf}\,(\frac{\ln x - \mu}{\sigma\sqrt{2}})\right] \quad (7.5)$$

7.4. Mathematical Model

Here we developed a mathematical model of optimal renewable distributed generation planning. The output of this model is the optimal configuration of the renewable distributed generation system taking into account the technical performance of supply options, locally available energy resources, load demand characteristics, start-up cost, operating and maintenance costs, and daily purchased–sold power tariffs. Figure-7.1 illustrates the optimization model when its inputs are:

- Load demand of the BHU campus.
- Data of best alternative to locally available renewable energy source: These include wind speed (m/s) as shown in Figure-7.2.
- The technical and economic performance of supply options: These characteristics include, for example, power curve for the wind turbine.
- Start-up costs.
- Operating and maintenance costs: Operating and maintenance costs must be given to all generators.
- Daily purchased and sold power tariffs.

7.4.1. Objective Function

The major concern in the design of a mathematical model that represents optimal planning of renewable distributed generation system is the optimal power flow to match demand-supply variability. Investment cost, operation and maintenance cost and cost of power purchased from grid should be minimized. In-installation area power consumption from renewable distributed generation and surplus power sale back to the grid should be maximised. Therefore, for economic dispatch of power objective function formulated as

$$min\, f = C_1 + C_2 + C_3 - C_4 - C_5 \tag{7.6}$$

$$C_1 = \left(\frac{(1+d)^Y - 1}{d(1+d)^Y}\right)\left(\frac{d(1+d)^L}{(1+d)^L - 1}\right) S^G C^G \sigma^G \tag{7.7}$$

$$C_2 = \sum_{y=1}^{Y} \frac{\tau}{(1+d)^y} \sum_{h=1}^{H} P_{y,h}^G \tag{7.8}$$

$$C_3 = \sum_{y=1}^{Y} \frac{\lambda}{(1+d)^y} \sum_{h=1}^{H} P_{y,h}^P \tag{7.9}$$

$$C_4 = \sum_{y=1}^{Y} \frac{\delta}{(1+d)^y} \sum_{h=1}^{H} P_{y,h}^S \tag{7.10}$$

$$C_5 = \sum_{y=1}^{Y} \frac{\lambda}{(1+d)^y} \sum_{h=1}^{H} P_{y,h}^D \tag{7.11}$$

$$min\, f = \left(\frac{(1+d)^Y - 1}{d(1+d)^Y}\right)\left(\frac{d(1+d)^L}{(1+d)^L - 1}\right) S^G C^G \sigma^G + \sum_{y=1}^{Y} \frac{\tau}{(1+d)^y} \sum_{h=1}^{H} P_{y,h}^G + \sum_{y=1}^{Y} \frac{\lambda}{(1+d)^y} \sum_{h=1}^{H} P_{y,h}^P - \sum_{y=1}^{Y} \frac{\delta}{(1+d)^y} \sum_{h=1}^{H} P_{y,h}^S - \sum_{y=1}^{Y} \frac{\lambda}{(1+d)^y} \sum_{h=1}^{H} P_{y,h}^D \tag{7.12}$$

7.4.2. Subject to Constraint

1) *Number of installation units:*

$$0 \le \sigma^G \le \sigma^{G\max} \tag{7.13}$$

2) *Generation capacity:*

$$0 \le P_{y,h}^G \le P_{y,h}^{G\max} \tag{7.14}$$

3) *Demand limit:*

$$0 \le P_{y,h}^D \le P_{y,h}^{D\max} \tag{7.15}$$

4) *Power purchased from the grid:* The main utility balances the difference between the load demand and the power generation output of renewable distributed generation

units. Therefore, there is a cost to be paid for the purchased power whenever the generated power is insufficient to cover the load demand.

$$P^{P}_{y,h} = max\left(P^{D}_{y,h} - P^{dg}_{y,h}, 0\right) \quad (7.16)$$

5) *Power supplied to grid:* There is income because of sold power when the power generated is higher than the load demand. It is possible that there will be no sold power at all.

$$P^{S}_{y,h} = max\left(P^{G}_{y,h} - P^{D}_{y,h}, 0\right) \quad (7.17)$$

Indices

y	Planning year
h	Operating hour

Parameters

S^{G}	Wind turbine size
C^{G}	Cost of wind turbine
σ^{G}	Number of wind turbine installed
Y	Planning year
L	Operating life of wind turbine
H	Total number of hours in a year
d	Discount rate
τ	Operation and maintenance cost per unit
λ	Per unit cost of power purchased from the grid
δ	Per unit cost of power supplied to the grid
$P^{G}_{y,h}$	Total power generation in y year for h hour
$P^{D}_{y,h}$	Load demand in y year for h hour
$P^{P}_{y,h}$	Power purchased from the grid in y year for h hour

$P_{y,h}^{S}$	Surplus power supplied to grid in y year for h hour
$\sigma^{G\max}$	Maximum number of wind turbines
$P_{y,h}^{G\max}$	Total power generation capacity limit in y year for h hour
$P_{y,h}^{D\max}$	Maximum load demand in y year for h hour

Decision Variables

σ^{G}	Number of wind turbines
$P_{y,h}^{G}$	Power generated in y year for h hour
$P_{y,h}^{D}$	Load demand in y year for h hour

7.5. Methodology

In this work evolutionary GA methodology has been used to solve the optimization problem. Computational work makes GA more important in implementation process (Whitley, 1994). The implementation of GA starts by randomly generating an initial population of possible solutions. For every solution, a value of renewable distributed generation is chosen between 0 and maximum limit, fixed by the planner on the ground of economic and technical justifications; then, some renewable distributed generation units are randomly chosen until the total amount of power installed reaches the renewable distributed generation maximum capacity level assigned. At this point, the renewable distributed generation units are randomly located among the network nodes, and the objective function is evaluated and verifying all the constraints; if one of them is violated the solution is penalized. Regarding the population size, the best results have been found.

Once the initial population has formed, the genetic operators are repeatedly applied to produce the new solution. In particular, a classical "reminder stochastic sampling without replacement" scheme has been adopted for the selection operator, and a "uniform crossover" has been chosen by which each vector's element is swapped with probability 0.5. For the mutation operator, all the vector elements are mutated, with a small mutation probability, choosing a different value in the defined alphabet. If one constraint is violated on the total amount of renewable distributed generation exceeds the maximum level of renewable distributed generation capacity, the new solution is penalized.

Finally, according to the GA “steady state” typology, the new population is formed comparing old and new solutions and choosing the best among them. The algorithm stops when the maximum number of generation is reached or when the difference between the objective function value of the best and the worst individuals becomes smaller than a specified value.

The presented optimization procedure permits the definition of the optimal planning of renewable distributed generation in a given network among different non-inferior solution produced by the application of the GA methodology. This way of proceeding may be very useful because it allows the planner to be aided by a software tool, able to take into account quickly and precisely all possible combinations in real size cases, but it does leave to the decision maker the control on the process to make the final decision.

Evolutionary techniques are a preferable technique to optimize complex problem in a computational world. GA is also such computational optimization technique generated from evolutionary techniques. This technique termed GA was formulated first by Holland, (1992). GA is non-comprehensive search technique used to determine among other things the global optima of a given function that may not be subject to constraints. This uses a procedure to evaluate the problem inspired by the biological science. Biological science and experiment say only those can survive which can better adapt the environment and only that can pass their genes to succeeding generations. The process of search in GA is stochastic and usually does not give the exact location of optima compared to some other gradient-based optimization techniques which do. Application of GA work over a set (population) of possible solutions (individuals) of a generic problem applying selection and reproduction criteria to generate new solutions (offspring) with information enclosed in the solutions (parents) from which they originated. For the better solution, there are more possibilities of reproducing and passing on genes to the offspring. This study proposes a methodology of GA technique to get optimal planning of renewable distributed generation in distribution networks. For this, first we will go for application of GA; after that, we will derive objective function and lastly will put some constraints.

7.5.1. System Modelling Simulation Using Genetic Algorithm

The modelling equations described above form the simulation algorithm, which is used to verify whether a solution derived by the Genetic Algorithm based cost function minimization procedure fulfils the load power requirements during the whole planning year. The corresponding flowchart is depicted in Figure-7.3. The algorithm input data set consists of the hourly mean values of wind speed and the load power requirements during the planning year and the specifications of the system requirements, while it is executed with a time step of 1 h.

According to the above power production and load consumption calculations, the resulting battery capacity is calculated

• If $P^G_{y,h} = P^D_{y,h}$ then the power generation matched with load demand.

• If $P^G_{y,h} > P^D_{y,h}$ then the power surplus $P^S_{y,h} = P^G_{y,h} - P^D_{y,h}$ is supplied to grid.

• If $P^G_{y,h} < P^D_{y,h}$ then the power deficit $P^P_{y,h} = P^D_{y,h} - P^G_{y,h}$ required to cover the load energy requirements is purchased from the grid supply.

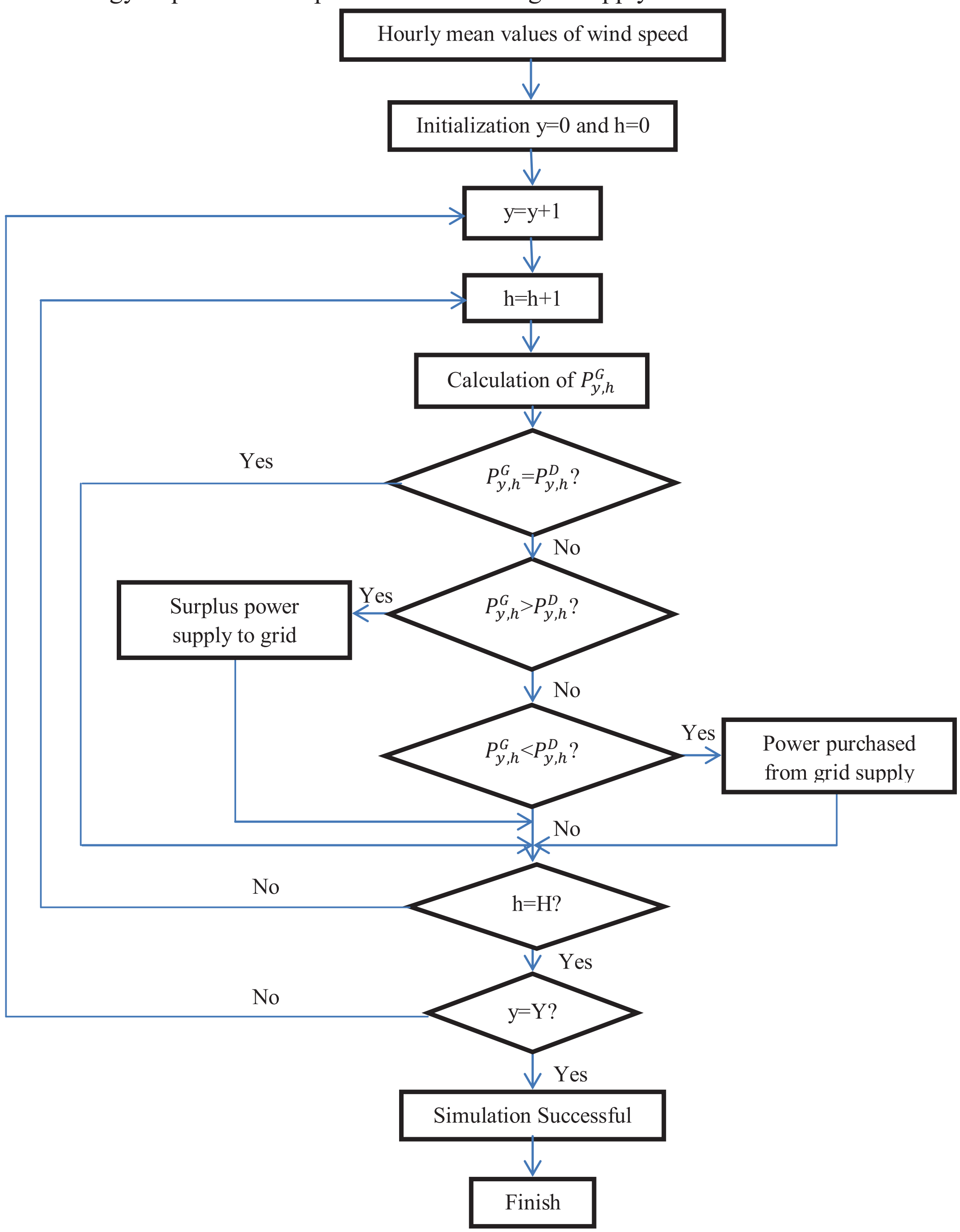

Figure 7.3: Flowchart of the algorithm

In the first phase, we will randomly generate an initial population of possible solutions. In the second phase, we will apply the genetic operators to produce the new solutions. A flow chart of the GA has been shown in Figure-7.4. In this research work we implemented genetic operators that have been (Deb, 2001):

- Selection: For giving birth to the next generation this procedure is applied to select the individuals that participate in the reproduction process. The "remainder stochastic sampling without replacement" scheme has been adopted, whereby we calculated the number of selections of each in following ways: the expected individual count values are calculated as a fraction between the objective function values of the individuals and the average of objective function values of the whole population. Then integer parts of the expected numbers will assign, and fractional parts will be treated as probabilities.
- Crossover: Crossover is derived from the natural phenomenon of mating, but refers most specifically to genetic recombination, in which the genes of two parents are combined in more or less random fashion to form the genotype of a child.
- Mutation: While the crossover operation generates new combinations of genes, and therefore new combinations of traits, mutation can introduce completely new alleles into a population. It has been widely recognized that mutation is the operators that create completely new solutions while selection and crossover serve to explore variants of existing solutions while eliminating bad ones. All the vector elements are mutated, according to a small mutation probability.

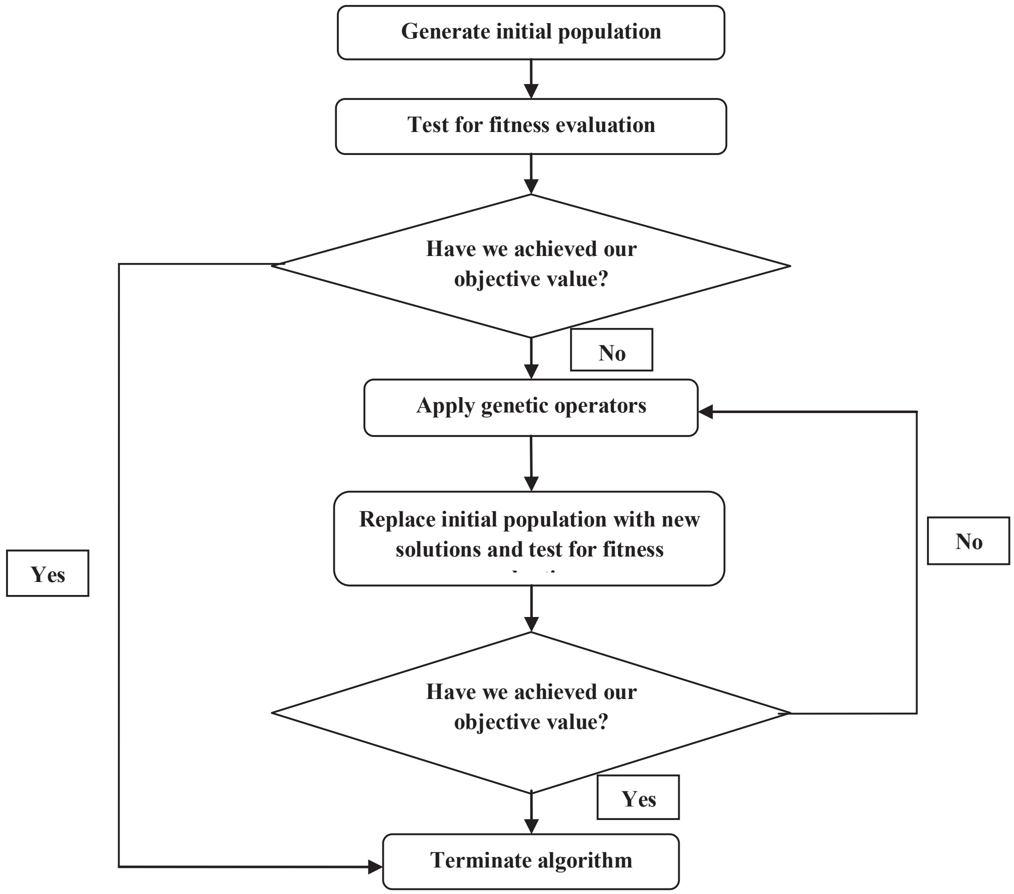

Figure 7.4: Schematic representation of GA

7.5.2. Solving steps

A Monte Carlo simulation embedded GA approach is employed to solve the optimization problem. The fitness function is formed by the objective function and penalty constraints together (Deb, 2001).

The detailed solving steps are as follows.

Step I: Specify some parameters, including N_S, and the ones associated with the GA, such as the population size N_P, the crossover probability P_C, and the mutation probability P_M, and the maximum-permitted generation number N_C.

Step II: Randomly generate N_P chromosomes and check their feasibilities with Monte Carlo simulation.

Step III: Update the N_P chromosomes by crossover and mutation operators according to the specified probabilities P_C and P_M, and check their feasibilities again with Monte Carlo simulation.

Step IV: Calculate the objective function value of all such chromosomes produced.

Step V: Calculate the fitness value of each chromosome regarding the objective function value.

Step VI: Select the chromosomes in the current population by the roulette wheel method.

Step VII: Repeat IV-VII for N_C times.

Step VIII: Select the best chromosome found in the above solving procedure as the optimal solution of the renewable distributed generation system.

7.6. A case of BHU campus

7.6.1. Test system

The test network used for the verification of the proposed algorithm is the BHU campus test feeders. The distribution system includes an optimal number of renewable distributed generation units in their network. The substation is expected to connect the remainder of the system to the smart grid. As per annual demand pattern, we can setup optimal generation capacities to fulfill our demand without any interruption. There are two feeders of power supply at BHU campus for better control of power distribution. EWSS centre is using 133kVA capacities of both the feeders.Here we planned for the smart grid integrated renewable distributed generation for the 5-year planning horizon. The technology used here is wind turbine with the assumed characteristics.

The proposed methodology has been tested in radial distribution systems with different characteristics. The topology of an actual existing grid uses, as a part of the Northern grid in the Indian power distribution network, which sometimes suffers from under voltages, overflows and frequency deviations due to insufficient power generation reserve. The northern grid network is a part of the interconnected Indian power distribution network with other four interconnected regional grid networks. The operation of the interconnected network is dependent on the principle that each partner is responsible for its network. All per-unit quantities used in this study are based on 50 kW capacity limit of each renewable distributed generation unit. This system consists of smart grid connected 500 kW capacities of renewable distributed generation units as of maximum 10 generation units can be installed. The loads are located unevenly hourly basis for BHU campus for a year. A case of BHU campus has considered this problem. We have taken input data in Table-7.1 for optimal planning of smart grid integrated renewable distributed generation at BHU campus. Computation work has done in Java programming language. The Intel Core2Due 2.26 GHz processor used to find out all the computations of the mathematical model.

7.6.2. Results and discussions

The proposed algorithm is implemented in Java programming language and found 4488579711.87 as optimal solution of the objective function with the population size of 50 and passing 10 iterations. It took each iteration on an average 28 sec to run. The noteworthy is that the proposed approach in this research work is considered as a planning-based, but not an operational-base decision making. As a result, regarding the placement procedure as a decision making in the planning horizon, timing issues and the execution times of the presented scheme are not the concern. Moreover, referring the relevant literature on the optimization algorithms, it can be concluded that the GA method is among the fastest ones which also ensures the global optima of the optimization problems (Deb, 2001).

Table-7.1: Input Data

d	0.1	τ	0.67 (INR/kWh)
Y	5 (year)	λ	4 (INR/kWh)
L	20 (year)	δ	4 (INR/kWh)
S^G	50 (kW)	$\sigma^{G\max}$	10
C^G	2000 (INR/kW)	$P_{y,h}^{G\max}$	486 (kW)
H	8760 (hour)	$P_{y,h}^{D\max}$	11.4 (MW)
N_P	10	N_C	50
P_C	0.7	P_M	0.3

After getting solved of the objective function without violating any constraint in this problem, we get the optimal solutions as shown in Table-7.2. Objective function value, net project cost, is 4488579711.87 for the 8 number of wind turbines to be installed in the planning area. Total operation and maintenance cost is 197508.40 for the planning period. The total cost of power purchased is 4495033838.16 for the high demand period and total cost saved by self-consumption is 1915289.02, whereas there is no surplus power supplied to the grid.

Table-7.2: Optimal Solutions

Particulars	**Optimal Solutions**
Number of wind turbines	8
Initial setup cost	356211.51
Total operation and maintenance cost	197508.40
Total cost of power purchased	4495033838.16
Total cost saved by self-consumption	1915289.02
Total revenue generated with surplus power supplied to grid	0.0
Net project cost	4488579711.87

7.7. Conclusion

The liberalization of electricity sector taking globally to contribute in creating new attractive opportunities for the utilities in power generation sector. The presence of renewable distributed generation introduces the new problem of power generation and distribution planning that the unavoidable uncertainties make more complex to be managed. This research work has dealt with a procedure based on evolutionary GA methodology to establish the fittest solutions for optimal planning of the renewable distributed generation system in a distribution network under stochastic demand-supply of power without violation of the constraints. A model development to determine the optimum project cost of the renewable distributed generation concerning demand and supply requirement is constructed and presented. The economic dispatch problem includes uncertainty of wind speed distribution in generation source for the renewable distributed generation. From the results, it is clear that the optimization works very well and delivers optimal power flow taking into account the cost function. The effectiveness of the suggested approach is confirmed through the agreement between the optimized settings and the output from the algorithm. The responses are affected by several variables including power generation, investment cost and maintenance costs sold and purchased tariffs, and of course, the actual power demand. The results show the capability of the proposed model and the proposed algorithm to achieve both reductions in the total project costs and matching the demand-supply variability. Evolutionary GA optimization technique made a good selection to get the optimal solution.