International Journal of Scientific & Engineering Research Volume 10, Issue 5, May-2019
ISSN 2229-5518

Genetic Algorithm based Optimization of Power Generation in a Micro-grid System

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Abstract— As the population is increasing, need for energy is also increasing. Nowadays, enormity of energy cannot be denied. Hence it is essential to improve the grid's situational awareness and allow for fast-acting changes in power generation. In such systems, an Energy Management System (EMS) should gather all the required information, solve an optimization problem, and communicate back to each distributed energy resource (DER) for its cor- rect allocation of energy. This paper proposes a metaheuristic optimization method i.e., Genetic Algorithm (GA) to optimally shares the power generation task among a number of DERs. The GA is utilized for minimization of the energy production cost in a micro-grid that includes wind plants, photovoltaic plants, and a combined heat and power system. It shares optimally the power generation for the various load values of a day.

Index Terms— Energy Management System, distributed energy resource, Genetic algorithm, micro-grid, metaheuristic, optimization, combined heat and power.

1 Introduction

Renewable energy is the energy which is derived from a limitless source. Proper utilization of energy resources is a hot debate going these days. Renewable energy resources (RERs) are becoming as prominent alternatives for supplying the growing demand of electrical energy in micro-grids. In power system, a micro-grid is a localized grid including energy resources (DERs), storage devices and loads. A micro-grid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode (A micro-grid can be disconnected from the traditional grid and work autonomously). Literature review shows that the optimization problems related to different fields of micro-grids have been solved by various algorithms. In [1], a memory based genetic algorithm is used to optimize the power generation. The need for renewable energy sources in power generation has been discussed in [2]. In [3] the author has introduced distributed algorithms that share the power generation task in an optimized fashion among the several Distributed Energy Resources (DERs) within a micro-grid. Here the synchronized version of Additive-Increase-Multiplicative-Decrease (AIMD) has been used to minimize a cost utility function of interest in the framework of smart grids. Author in [4] has used artificial fish swarm algorithm to solve the problem of day-ahead scheduling of generation in a mix of renewable energy sources, dispatch able sources and storage.

In micro-grids, initially the load is met by the DERs avoiding long distance transport of energy. This satisfies the small distance producer-consumer paradigm. DERs are used to improve the power system operation by reducing pollutant gas emissions, increasing energy reserve and contributing to ancillary services. In recent years, the attention of smaller investors has been oriented toward entering the energy market especially power generation in micro-grids. As a result, in order to buy their power, consumers are faced with a number of power producers. In such market, there is a strict competition among the power producers to offer energy at the lowest possible prices.

In micro-grids, there is an energy management system (EMS) which performs the balancing task between the produced and consumed energies. Fig.1. shows DERs supplying the load demand. Based on this assumption that at each hour, the available DERs have the ability of supplying the requested power, the EMS is able to select which DER (in which proportion) should be used to provide the requested power. If the aforementioned assumption is not true, the EMS can take energy from the storage systems, virtual power plants (VPPs) and utility grid. It may also make a decision to disconnect some of the loads. In this paper, it is assumed that the requested power is smaller than the power delivered by the available DERs in the micro-grid.

To gain more profit in business, power producers should offer electrical energy at a competitive tariff rate. To achieve this, they must generate electrical power at the possible minimum cost. Evaluation of cost of generation closer to reality and the techniques to reduce the cost so evaluated are of at most importance for economy of generation. Of all techniques, optimal scheduling of generation has gained its own importance in reducing the cost of generation. Due to the com- plexity of power system, load uncertainty, stochastic nature of the power produced by RERs and large number of end-users and DERs, real-time power scheduling and balancing problem is currently a vital and challenging area of research in mi- crogrid environment. Optimal scheduling of generation has been considerably a complex issue and the different types of evolving operating conditions of the system as a whole are adding to the complexity. As such, a lot of research is inspired and different methods of optimal scheduling have been evolved, tested and are being implemented in the convention- al power systems.

Microgrid power scheduling problem can be solved by different methods addressed in the literature. In [5], a new power scheduling method has been introduced to address the distributed economic dispatch of a microgrid with high renewable penetration and demand-side management. The method tries to minimize the distributed generation (DG) cost, distributed storage (DS) cost, utility of dispatchable loads and worst-case transaction cost. The stochastic availability of DERs is also

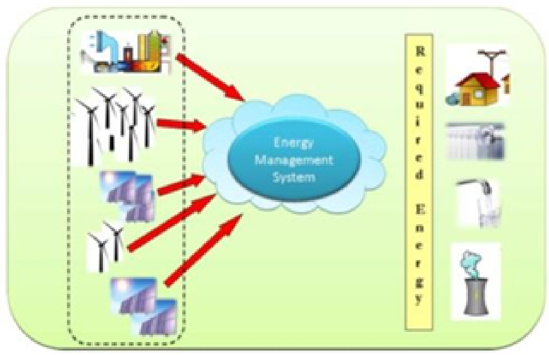

Fig.1.The power demand supplied by all the DERs

considered. In [6], a stochastic microgrid energy scheduling model has been proposed. The main goal is to minimize the microgrid expected operational cost and power loss with respect to the intermittent nature of the RERs. Controllable loads (e.g., plug-in electric vehicles), distributed generators (e.g., micro gas turbines and diesel generators) and storage devices (e.g., battery banks) have been integrated into the microgrid operation

The main contribution of the present study is to propose a meta-heuristic optimization algorithm which is able to auto matically and optimally share the power generation task among the various DERs of a microgrid such that the operating cost is minimised while satisfying the total load demand. The problem of optimising the power generation is a complex and non-linear under various complex constraints, it can be solved by using a meta-heuristic algorithm. Meta-heuristic algorithm includes intensification and diversification. Diversification means to generate different solutions so as to explore the search space on a global scale, while intensification means to focus the search in a local region knowing that a current good solution is found in this region. A good balance between intensification and diversification allow the search to escape from local optima and, at the same time, increases the diversity of solutions.

In this paper, the optimisation is solved by genetic algorithm that automatically shares the power generation task among the available DERs in a way that is fair and distributed. John Holland introduced genetic algorithms in 1960 based on the concept of Darwin's theory of evolution; afterwards, his student David E. Goldberg extended GA in 1989. Genetic Algorithm (GA) is a search-based stochastic optimization technique based on the principles of Genetics and Natural Selection which tries to determine the optimal solution of optimization problems. A microgrid including wind plants, PV plants and CHP has been considered to evaluate the performance of the proposed approach. The effectiveness of GA is evaluated by comparing the results with the results of the other algorithms

2 Problem Formulation

For sharing the requested power among various DERs, EMS faces with a large number of ways. One of the best ways is to minimize the power generation cost. To minimize the genera- tion cost, a quadratic cost function in association with each DER is considered.

$$C_i(P_i) = [\sum_{i=1}^{N_{DER}} [a_i \times P_i^2 + b_i \times P_i + c_i]] \quad (1)$$

Where i is unit number, Ci is the power generation cost ith gen- erating unit during a particular hour the day, Pi is the power generated by ith unit during a particular hour of the day; NDER is the number of Distributed Energy Resources. And a, b and c are non negative cost coefficients of ith generating unit.

2.1 Objective Function

The objective function for minimizing the overall cost of power generation can be defined as

$$Minimize\ OF = [\sum_{i=1}^{N_{DER}} [a_i \times P_i^2 + b_i \times P_i + c_i]] \quad (2)$$

Subject to,

$$\sum_{i=1}^{N_{DER}} P_i = P_l \quad (3)$$

$$P_{i,min} \le P_i \le P_{i,max} \quad (4)$$

Where, P_l is requested power.

In this optimization process, the power generated by each DER is considered as a decision variable. These variables are represented in a vector form as solution, x=[x1 x2 x3 x4 x5 x6]. In this paper, six DERs are considered, i.e. three wind plants, two PV plants and one CHP. So, the solution can be represent as x=[Pwp1 Pwp2 Pwp3 Ppv1 Ppv2 PCHP]. Here Pwp1, Pwp2, Pwp3 are power produced by wind plant 1, wind plant 2, wind plant 3; Ppv1, Ppv2 are power produced by PV plant 1, PV plant 2 and PCHP is power produced by CHP respectively

In optimization problem, adding constraints will increase the difficulty level of the problem. This issue can be handled by converting an optimization problem with equality constraint to an optimization problem without equality constraint. This can be obtained by making use of penalty function.

Hence, the problem can be modified as

$$Minimize\ OF = [\sum_{i=1}^{N_{DER}} [\alpha_i \times P_i^2 + \beta_i \times P_i + \gamma_i]] + P_f \times |\sum_{i=1}^{N_{DER}} P_i - P_l| \quad (5)$$

Where, P_f is the penalty factor.

At each hour, the requested power demand from the load side must be met by available DERs by optimally sharing the power generation task among them. And sum of power gen- eration cost of all the DERs (WP1, WP2, WP3, PV1, PV2, and CHP) present in micrigrid must be minimized.

3 Genetic Algorithm

Genetic algorithm is metaheuristic search algorithm used to find the solution of optimization problems with and without constraints. It imitates the process of natural evolution. The flow chart of GA for optimization is shown in Fig. 2. The optimising process in genetic algorithm is as follows:

1. Initialozation: Initially a population is created in a search space, where the population consists of N chro- mosomes. Each chromosome is a solution vector for a given problem. Each chromosome consists of d number of genes which indicates the decision variables. Each chromosome can be represented as xi= [x1i, x2i, x3i, x4i, x5i, x6i] where xdi is chromosome d of gene i. The population will be having such N number of chromo- somes which can be represented in a matrix form as follows:

$$X = \begin{bmatrix} x_1^1 & \cdots & x_6^1 \\ \vdots & \ddots & \vdots \\ x_1^N & \cdots & x_6^N \end{bmatrix} \quad (6)$$

2. Evaluation of objective function value: For N numbers of chromosomes in the population, N number of fitness values are obtained. Each fitness value is calculated by substituting the values of corresponding genes of a chromosome in the fitness function.
3. Selection: Based on the values obtained from fitness function, selection process is carried out. The fitness value indicates the quality of the solution. Here fittest of the individual is selected for producing of next gen- eration. Here, as one of the most popular selection op- erators, roulette wheel approach has been used to select the chromosomes. In roulette wheel, the chromosome with better OF values has more chance of being selected. In this approach, the fittest chromosomes may be included in the mating pool more than one time. More preference will be given to the individuals with better fitness values, allowing them to pass on their genes to the next generation.
4. Crossover: During crossover, two random chromo- somes are selected to produce two new offspring. Crossover operator is applied for the chromosomes in population with probability Pc, while chromosomes with probability (1-Pc) are directly transferred to next generation.

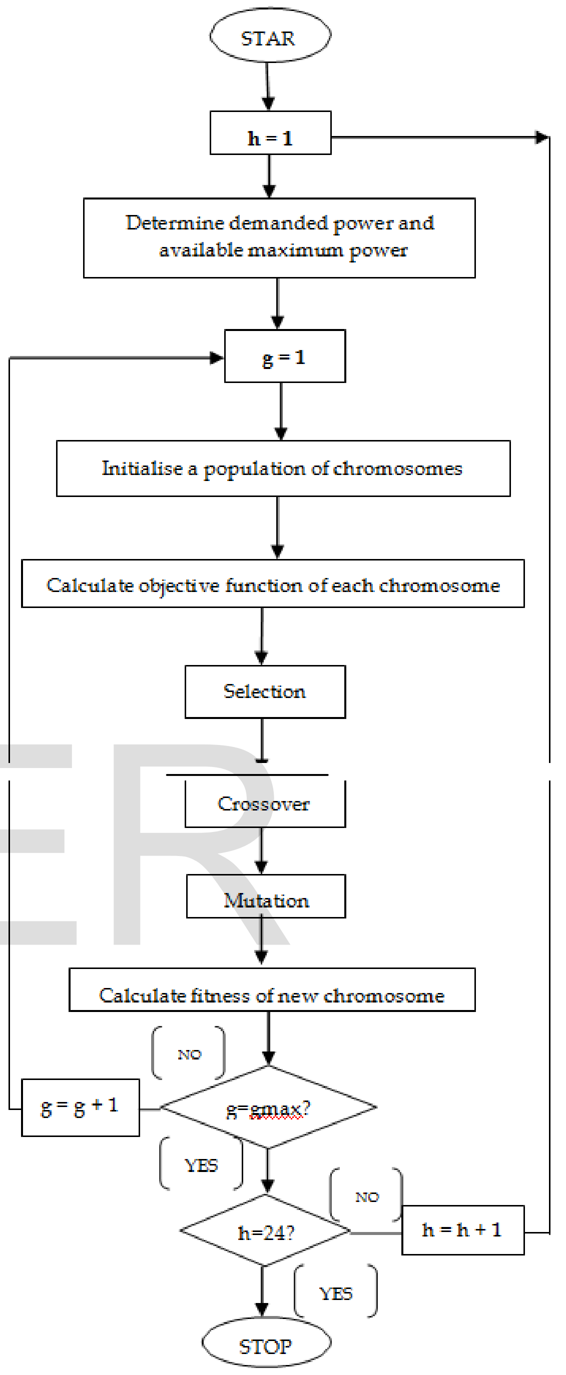

Fig.2.Flow for optimization using Genetic Algorithm

5. Mutation: Mutations are created by randomly changing the gene value of newly generated offspring within the specified range. Mutation is applied with a probability Pm.
6. Evaluating OF for offspring generation: For each chromosome of newly generated population, fitness value is calculated.
7. Formation of new generation: Here the N chromo- somes are selected from the offspring produced and parents with best fitness values. Then the newly gener- ated population will be subjected to operators as men- tioned in step 4 and 5 so as to generate even better so- lution.
8. Stopping conditions: This process continues until it reaches the maximum iteration value. While in some cases, the algorithm is terminated if no further im- provement in the fitness value for the best string is ob- served for a fixed number of iterations, and the best string obtained so far is taken to be the optimal one.

4 Simulation Results

To evaluate the performance of GA for optimally sharing the demanded electrical power among DERs, a microgrid includ- ing three wind plants, two PV plants and one CHP is consid- ered. In such system, there are six decision variables, namely, generated power of wind plant 1, wind plant 2, wind plant 3, PV plant 1, PV plant 2 and CHP. Here the optimization prob- lem is solved for different load values during 24 hours of a day. The Table 1 shows the load values for 24 hours which is depicted in the graph of Fig. 3. It is assumed that at each hour, the available DERs have the ability of supplying the requested power.

The data for these DERs is extracted from[1]. The rated capacity of wind plants, PV plants and CHP is 750 kW, 200 kW and 1000 kW, respectively. The maximum available power from each DER is illustrated in Fig. 4. Here the available power of CHP system has not been shown since CHP can produce 1000 kWh at each hour. Table shows the cost coefficients for each DER present microgrid. At each hour EMS should collect the information of maximum available power of each DERs and the load demand. EMS will then use this information to calculate the optimal values for all DERs, then send this information of correct allocation of energy DERs.

TABLE 1
LOAD VALUES AT EACH HOUR

Hour	1	2	3	4	5	6
Load(kW)	1471	1325	1263	1229	1229	1321
Hour	7	8	9	10	11	12
Load(kW)	1509	1663	1657	1643	1643	1652
Hour	13	14	15	16	17	18
Load(kW)	1666	1639	1642	1640	1676	1920
Hour	19	20	21	22	23	24
Load(kW)	2214	2328	2328	2327	2174	1903

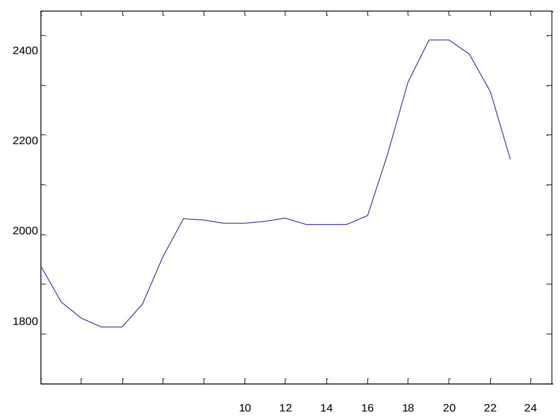

Fig.3. Maximum power generation of each DER during 24 hours of the day.

While evaluating the optimal values using genetic algorithm, the values considered for various paramiters are as follows:

Population size = 100, maximum number of generations = 100, crossover probability = 0.9 and mutation probability = 0.05.

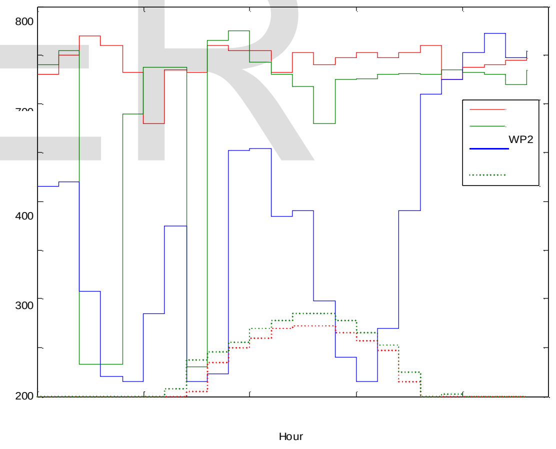

Fig.4. Maximum power generation of each DER during 24 hours

The optimal value of each DER which satisfies the load at minimum cost is shown in the Fig.5. The total cost of power generation for each hour of the day is shown in the Fig.6.

Fig.7. compares the power generation by DER and the demanded at each hour of the day. The results have been obtained by MGA. It is seen that the power balance equation has been satisfied since the generation is in accordance with the requested power.

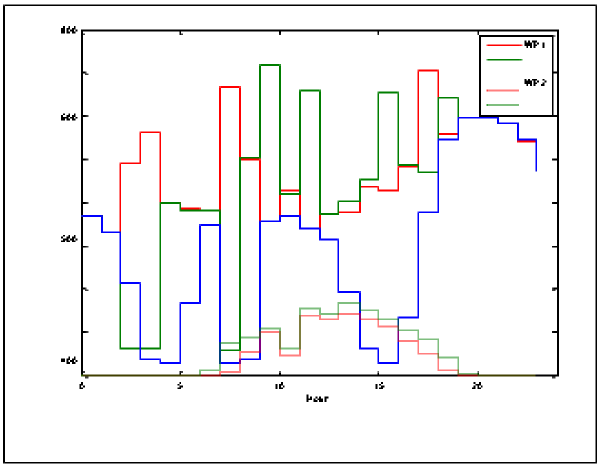

Fig.5. Optimal power scheduling of DER obtained by GA

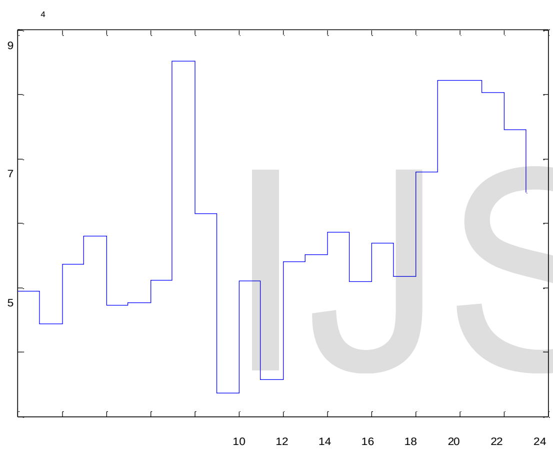

Fig. 6..Total cost of powe generation at each hour

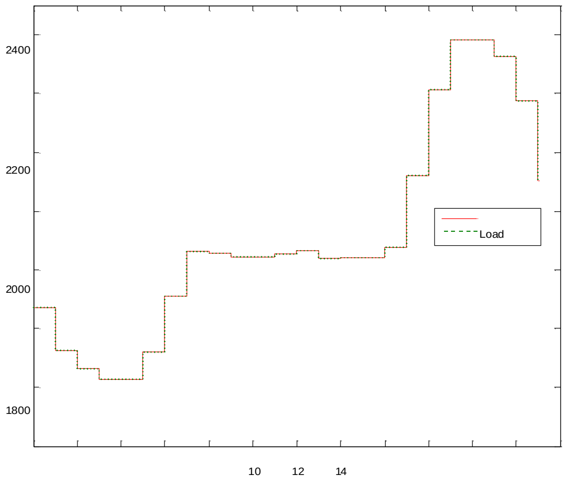

Fig. 7. Comparision of load and total power generation

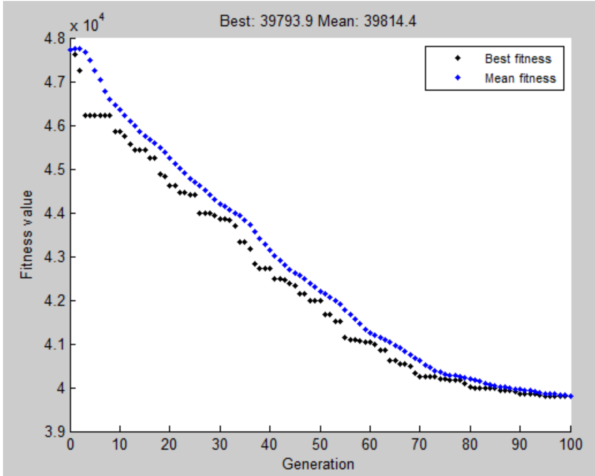

Fig. 8.. Convergence of GA solution.

Fig.8. Illustrates the convergence process of the genetic algorithm for solving the optimization problem for the load at hours 1 i,e 1471 kW.

5 Conclusion

In this paper ev evolutionary based Genetic Algorithm is used for optimal allocation of load among three wind plants, two PVplants and one CHP, such that the generation cost is mini- mised while satisfying certain operational constraints. Here it is assumed that the power generation forcast data of all the wind and PV plants and load load forcast data are collected by energymanagement system. Here CHP is producing a constant power at each hour. From the results obtained by genetic algorithm opti- mization technique, it is found to be effective in matching the generation and the load. Its ability to reduce the cost of genera- tion by searching for the cheaper sources within the search space and allocate major share of generation to them is also shown

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