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Performance Analysis of Genetic Algorithm as a Stochastic Optimization Tool in Engineering Design Problems

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Abstract: **Engineering design problems are complex by nature because of their critical objective functions involving many variables and Constraints. Engineers have to ensure the compatibility with the imposed specifications keeping the manufacturing costs low. Moreover, the methodology may vary according to the design problem.**
The main issue is to choose the proper tool for optimization. In the earlier days, a design problem was optimized by some of the conventional optimization techniques like gradient Search, evolutionary optimization, random search etc. These are known as classical methods.
The method is to be properly Chosen depending on the nature of the problem- an incorrect choice may sometimes fail to give the optimal solution. So the methods are less robust.
Now-a-days soft-computing techniques are being widely used for optimizing a function. These are more robust. Genetic algorithm is one such method. It is an effective tool in the realm of stochastic optimization (non-classical). The algorithm produces many strings and generation to reach the optimal point.
The main objective of the paper is to optimize engineering design problems using Genetic Algorithm and to analyze how the algorithm reaches the optima effectively and closely. We choose a mathematical expression for the objective function in terms of the design variables and optimize the same under given constraints using GA.

Keywords: **Engineering Optimization, Genetic Algorithm, Objective function, convergence, Engineering Application.**

I. INTRODUCTION

Optimization is the process of maximizing or minimizing a function consisting of number of variables under given constraints. It means solving problems in which one seeks to minimize or maximize a real function by systematically choosing the values of real or integer variables from within a set [1,2].

A real world problem may have many feasible solutions. Optimal design is the best possible design out of many feasible designs, generally in presence of a number of inequality constraints.

Various tools are available to reach the optimal solution- classical and non-classical. The non-classical techniques based on soft computing, have now become much popular.

The modern approach is to search and choose the best design method for specific tasks. Engineering optimization deals with the optimal solution in all engineering fields.

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Now use of Design Optimization is rapidly growing in almost all the engineering disciplines [2, 3], like mechanical, civil, electrical, energy and off-shore engineering etc. This is due to the increase of manufacturer's competition and the development of strong and efficient techniques in order to achieve best product against minimum cost [4].

Engineering systems are represented by sophisticated numerical models. They involve several interacting disciplines that must be considered simultaneously to obtain efficient designs [5].

Multidisciplinary optimization problem involve complex systems including subsystems. The main challenges are to develop efficient numerical tools.

Some physical phenomena naturally describe an optimization problem, when the "equilibrium" is attained at the minimum of an energy level [6].

II. GENETIC ALGORITHM

Genetic algorithm has been developed by John Holland, established by Holland and Dejong, and popularized by Goldberg. Several researchers have contributed in many ways on various aspects and applications of Genetic algorithms. GA has found its applications almost in every branch of engineering and still in an area of active research [7].

GA searches the natural genetics. Genetic algorithms (GA) are processed by three operators: reproduction, crossover and mutation. GA creates an initial single population or species by randomly encoded chromosomes where each chromosome representing a possible solution. Encoded chromosomes undergo natural selection for recombination through the crossover operator whereby improved off-springs are generated in successive generations.

Roulette wheel selections for reproduction, single point crossover and probabilistic bit mutation are the basic mechanisms suggested for the operations of the simple Genetic Algorithm. As GA is a stochastic search process a good solution detected in early generations may not be selected for the latter generations (due to genetic drift). This has been referred to as the generation gap. Generation gap may lead the GA to a non-optimal solution. Elitist GA has been suggested to overcome this problem. In case of Elitist GA a solution having high fitness value is copied in the next population thus ensuring the presence of the best solution detected in the final generations. Different Elitist schemes have been suggested. Elitism has both advantages and disadvantages. By forcing the presence of some pre-selected solution strings in the next population, we apply the so called *selection pressure*. Higher selection pressure reduces the variations in the population which may lead to premature convergence of GA. Premature convergence occurs when the population strings become identical before the optimum solution is detected [8].

Crossover is a method of exchanging information between two chromosomes. Most calculus based optimization methods are based on exploitation (hill climbing) of the search space. Random search algorithms allow exploration of the search space. GAs is robust as they find solutions by exploitation and exploration of the hyper planes of the search space. GA exploits through the process of selection and explores through crossover and mutation.

As the mutation rate is increased mutation becomes more disruptive (explorative) until the exploitative effects of selection are completely overwhelmed. A low mutation rate on the other hand, allows the algorithm to exploit a particular hyper plane. Setting the mutation rate high allow the algorithm to explore different hyper planes. Crossover also helps exploration. But, the amount of exploration through crossover is also dependent upon the selection. With increased selection pressure, crossover can hardly bring any difference in the child population. Increased exploitation by selection leads to decreased exploration by crossover.

A single allele mutation of an individual can also be thought of as a local search (exploitation) in an area surrounding that individual in a multidimensional space. When the GA converges prematurely a higher mutation rate can be helpful.

Many real life problems, especially of engineering, are characterized by several goals. Each of these goals belongs to the optimum of an objective function to be optimized. Most of the cases, the objective functions are in conflict. A common approach to deal with this kind of problems is to amalgam multi objective functions into a single one by giving different weighing factors to different objectives and then solving the weighted objective function. One can select the most dominant feature as the objective function and other as constraints. The designer must give the priority to each objective function according to their merits [7, 8].

For a multi objective optimization, the problem is stated as given below:

Minimize $\overline{f} = \left\{ f_1(\overline{x}),\ f_2(\overline{x}), \ldots\ldots\ldots\ldots f_m(\overline{x}) \right\}^T$ --------- [1]

Subject to:

$\overline{g} = \left\{ g_1(\overline{x}),\ g_2(\overline{x}), \ldots\ldots\ldots\ldots g_n(\overline{x}) \right\}^T \leq \{0,\ 0,\ \ldots\ldots\ldots 0\}^T,$ --------- [2]

Where, $\overline{x} = \{x_1,\ x_2, \ldots\ldots\ldots\ldots x_k\}^T$ --------- [2a]

In GA, although the binary coded algorithm can be better explained by biological heredities there exist some problems such as, discretization and code conversion in solving continuous optimization. Various crossover and mutation techniques have been developed for real coding of Genetic algorithm. One of the simplest crossover techniques is the arithmetic crossover where the child chromosomes are produced as follows.

$$C_1 = \lambda P_1 + (1-\lambda) P_2$$
$$C_2 = \lambda P_2 + (1-\lambda) P_1, \quad [3]$$

where $0 < \lambda < 1$, P_1, P_2 are the parents and C_1, C_2 are the children.

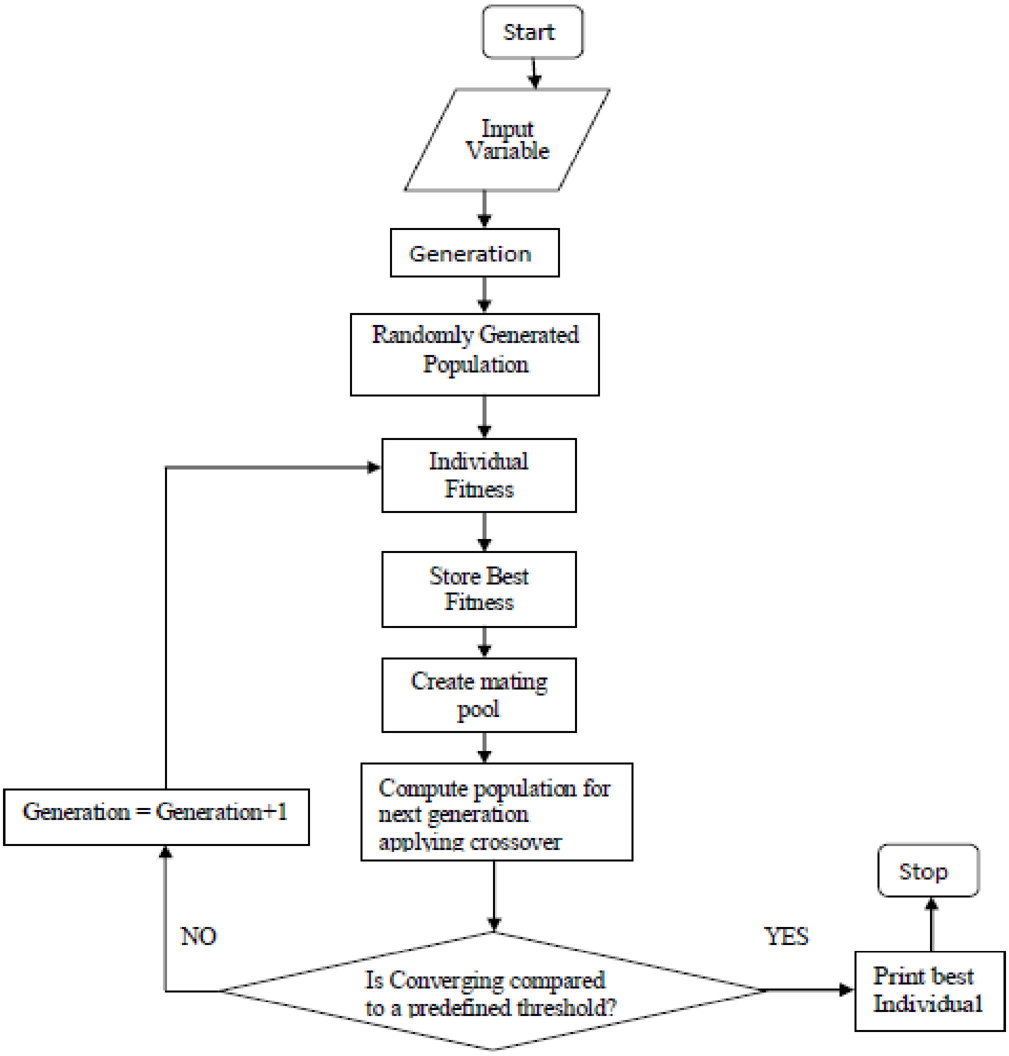

Fig.1. Flow chart for genetic algorithm

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III. THE OPTIMIZING FUNCTION

Objective function given below has been taken arbitrarily. It may be taken as the mathematical expression for cost function of some electrical equipment, having four variables with upper and lower bounds. The function is to be optimized by Genetic Algorithm having four variables:x_1, x_2, x_3 and x_4.It has been found that the optimal values of the variables are 1.6, 4, 10, 5 respectively and the minimum value of the objective function is 257.3199999999998 ≈ 257.32. The objective function is given as:

$$y = 100(x_1^2 - x_2) + (1 - x_1)^2 + x_1 + x_3x_4 - x_3/x_4$$

Mathematical programming techniques or MATLAB software can also be used for finding out the optimal solution [9, 10]. Several authors have made use of GA or its improved for reaching the optimum solution for a design problem [11, 12].

IV. RESULTS

The results are given below in tabular form, which shows the convergence:

Table-1

Generation	**f(x)**	Generation	**f(x)**
1	727.330	29	260.844
2	484.650	30	259.191
3	479.441	31	259.191
4	358.179	32	258.469
5	298.915	33	258.469
6	298.915	34	258.468
7	298.760	35	258.468
8	298.760	36	258.462
9	298.760	37	258.462
10	298.760	38	258.462
11	298.760	39	258.462
12	298.760	40	258.461
13	280.372	41	258.459
14	279.993	42	258.459
15	270.090	43	257.898
16	270.090	44	257.895
17	270.090	45	257.895
18	270.09	46	257.895
19	268.791	47	257.891
20	268.791	48	257.891
21	268.791	49	257.350
22	262.859	50	257.350
23	262.747	51	257.329
24	260.844	52	257.329
25	260.844	53	257.329
26	260.844	54	257.324
27	260.844	55	257.324
28	260.844	55	257.324

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The graphical plot of generation is given in fig. 2

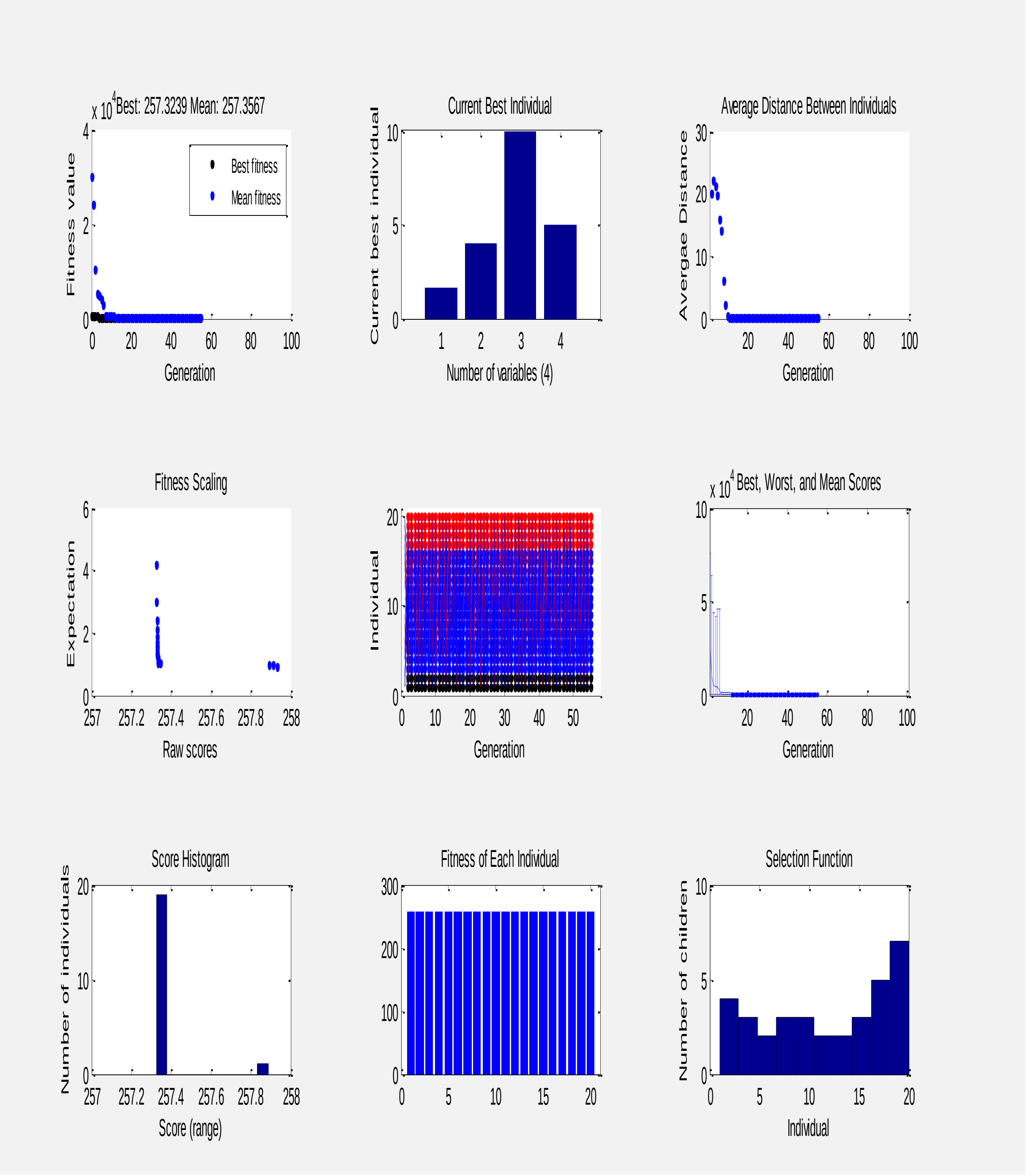

Fig.2. Graphical plot of generation

V. CONCLUSION

The mathematical expression which has been optimized in this paper may be taken as the objective function- it may be the cost function of some electrical equipment.

The main objective in this paper is focused on the Genetic Algorithm a non-classical stochastic tool for optimization- how efficiently and effectively it can optimize when applied to an engineering design problem.

It may be observed from the table of convergence and the graphical plot that GA reaches the optimal solution very fast and steady, creating so many generations and uses large search space.

Engineering Design problem requires global minima; otherwise optimization cannot give fruitful result on which the vale of the objective function depends.

It can be very much effective for mass production. So, Genetic Algorithm may be chosen as one of the best tools for optimizing an engineering design problem.

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