OPTIMAL POWER FLOW SOLUTIONS USING CONSTRAINT GENETIC ALGORITHM

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ABSTRACT

The objective of the power systems firm is to achieve the maximum profit and customer goodwill by providing reliable and quality power supply. This is a power system operation problem, Optimal Power Flow (OPF) solutions gives operating state which satisfy the objective of the firm. Modern trend used to solve this non-convex, complex OPF problem is Meta heuristic algorithms. This paper deals one of them - Genetic Algorithm (GA), for solving OPF. Performance of the proposed algorithm is tested on the standard test IEEE 30 bus system.

Key words: genetic algorithm; Optimal Power Flow; Newton Raphson power flow.

I. INTRODUCTION

Power system planning and operation needs the power flow analysis. A simple power flow analysis gives needed information but not an optimal. A simple economic load dispatch provides the optimal operating state of the power system but not considering the power balance equations, physical and dependent variables limits. To get the advantage of both, at the same time to confirm the limits of physical and depended variables an Optimal Power Flow (OPF) is evolved. The main objective of the OPF is to find minimum operating cost without violating the limits and be in the secure operating state. Other objective the OPF is to minimize transmission line loss; minimize congestion; minimize nodal real time prices; minimize exhaust emission maximize social welfare; maximize Available Transfer Capacity (ATC). The classical mathematical programming methods to solve the OPF are Linear Programming (LP), Quadratic Programming (QP) and Non Linear Programming (NLP) method are inferior in finding global optimum and high sensitive to initial condition. In order to overcome these drawbacks, meta-heuristic optimization technique has been developed. This paper explains the application of Genetic Algorithm (GA) to solve the Optimal Power Flow. To demonstrate the effectiveness of the developed algorithm standard test case IEEE 30 Bus is considered. The simulation results are proves the GAOPF efficiency.

II. GENETIC ALGORITHM

John Holland and his collaborators invented Genetic Algorithm (GA) in the year 1970s (1). It mimics the Darwin's natural evolution theory. GA is most common algorithm to solve nonlinear, non-convex optimization problem. The optimization problem needs to find best value of control variables in order to minimize or maximize objective function. In constraints optimization problem in addition to objective function the dependent and control variables should be within their limit. GA uses the concept of survival of fitness. Hence it need optimization problem to encoded as GA problem by converting objective function into fitness function and control variables into genes, a chromosome is collection of genes. A different possible value of control variable is called solution space. Minimum of Maximum value of the objective function is present in this space. GA explores this space and finds the global best value.

As like nature optimize the chromosome to the fitness through generation by generation GA tunes the genes (control variables) to the best optimal value through iteration by iteration. A set of chromosome is called population. GA evaluate each chromosome in the population to keeps better chromosome and replace unfit chromosome in each iteration, finally it brings the global optimum value. The procedure for GA is

1. Encoding the objective function,
2. Defining fitness function,
3. Initialize population of individual,
4. Evaluate the fitness of all the individual in the population, 5. create new population by performing crossover and mutation, 6. Evaluate the new population until stooping criteria meet, 7. Decoding the result to obtain the solution of the problem (1). The

three main operation of GA is selection, Cross Over, and Mutation.

A. Encoding

Encoding is the process of converting objective function into the fitness function and decision variable into gene. If the gene is a binary number the problems is called binary coded GA, else if the gene is real number then the problem is called integer coded GA. A set of gene is a chromosome and a set of chromosome is called population. Population size is depends on problem. Initial population is created by generating random values of genes within the solution space. The population size is fixed and does not change till the solution reached.

B. Fitness Function

An appropriate fitness function is vital for the operation of GA [2]. It includes all the objective function and penalty functions. GA evaluates fitness function for each chromosome in the population. Based on the evaluation either the chromosome is selected or replaced by another chromosome.

C. Selection

Selection implements the natural evaluation of survival of fittest according to fitness function. It provides more possibility for reproduction to the high fitness chromosome and tries to remove the low fitness chromosome. The different types of selection schemes are

1. Tournament selection

Based on fitness function best chromosomes are taken into mating pool to provide more opportunity to them by decreasing the tournament size there by increasing the selection pressure.

2. Truncation selection

In this low fitness chromosome is removed from the mating pool. Then the fittest chromosome are ordered based on their fitness values

3. Linear Ranking selection

All individual chromosomes are ranked based on the fitness. The selection probability is linearly assigned to the individuals according to their rank

4. Exponential Ranking selection

It differs from linear ranking selection only in that the probability of the ranked individuals is exponentially weighted.

5. Elitist selection

Keeping some best chromosome into the next generation without modifying it to ensure more opportunity for reproduction is called elitism. It is used in combination with other selection scheme.

6. Roulette Wheel selection

The probability of selection individual chromosome is proportional to its fitness value. This is the simplest selection scheme.

D. Crossover

Crossover is the process of interchanging information (genes) among the parents in the mating pool. The crossover can be classified as single point, tow point and multi point crossover. In single point crossover after specified point the genes of the two parents are interchanged. In two point crossover the genes in between two specified point are interchanged.

E. Mutation

Mutation is the process of toggle the specified bit in a gene of the chromosome. In real valued encoding, the gene is replaced by a random value in the solution space. Mutation is required for divergent search in the solution space. The probability of mutation is very less as compared to crossover.

F. Stopping criteria

GA improves problems' solution iteration by iteration and the iteration has to be stopped either the problem is converged or iteration reached its maximum value. Stopping of iteration is important to provide solution for time complexity.

III. OPF PROBLEM FORMULATION

Optimal Power Flow problem is a minimization problem which is stated as follows. The objective is to minimize the generation cost

$$\text{Min } C_t = \sum_{i=1}^{ng} \alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2 \qquad [1]$$

Where,

C_t = Total generation cost

α, β, γ = Cost coefficients of the generator

P_{Gi}, Q_{Gi} = Active and Reactive power generation of i^{th} generator

ng = Total number of generators

Subject To:

Equality constraints

$$\sum_{i=1}^{ng} P_{Gi} = P_D + P_L \quad [2]$$

$$\sum_{i=1}^{ng} Q_{Gi} = Q_D + Q_L \quad [3]$$

Where,

P_D, Q_D = Active and Reactive demand

P_L, Q_L = Active and Reactive loss

Inequality constraints

$$V_{i\,(\min)} \le V_i \le V_{i\,\max} \text{ for i=1 to Nbus} \quad [4]$$

$$P_{G\,(\min)} \le P_{Gi} \le P_{Gi\,(\max)} \text{ for i=1 to ng} \quad [5]$$

$$Q_{G\,(\min)} \le Q_{Gi} \le Q_{Gi\,(\max)} \text{ for i=1 to ng} \quad [6]$$

$$t_{i\,(\min)} \le t_i \le t_{i\,(\max)} \text{ for i=1 to Ntrans} \quad [7]$$

Where,

Vi = Voltage at i^{th} bus

ti = Transformer tap position

Nbus = Number of buses

ng = Number of generators

Ntrans = Number of transformers

Nbr = Number of branches

IV. CONSTRAINT GENETIC ALGORITHM FORMULTION

In this research paper, the Constraint Genetic Algorithm (CGA) is used to get the solution for the OPF problem. The objective function itself is a Minimization problem and need not to convert minimization into maximization problem as such in earlier published research papers [3]. Control and depended variables used in the problem are integer, so the integer coded CGA is implemented in the research work. For the selection process roulette wheel selection procedure is used, for crossover, single point crossover and for stopping maximum iteration stopping criteria is implemented

$$\text{Fitness Function} = \sum_{i=1}^{ng} F_i(P_{Gi}) \quad [8]$$

The hard limited constraints are implemented using the following equation

$$Gene = Gene_{min} + \eta\ .(Gene_{max} - Gene_{min}) \quad [9]$$

Where,

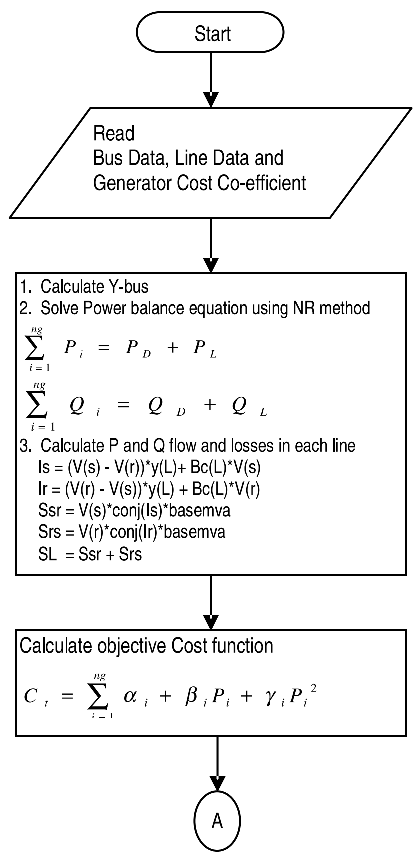
F_i (P_{Gi}) - quadratic fuel cost function of generators

$Gene_{max}$ - Gene maximum limit

$Gene_{min}$ - Gene minimum limit

η - Random number within [0 1]

The standard IEEE 30 bus test system (4) has SIX generators including slack bus. Generators real powers excluding slack bus, generators bus voltages, and transformers tap positions are taken as control variables (Genes). All these genes are combined and called chromosome, and a population has set of chromosomes (3). The fitness function is a cost equation as given in equation [1]. The constraints from equation [2] to [7] are taken as hard constraint and the gene values are constraint within the limits. MATLAB 7.10 software is used to develop the program. The flowchart for the developed CGA algorithm is given below.



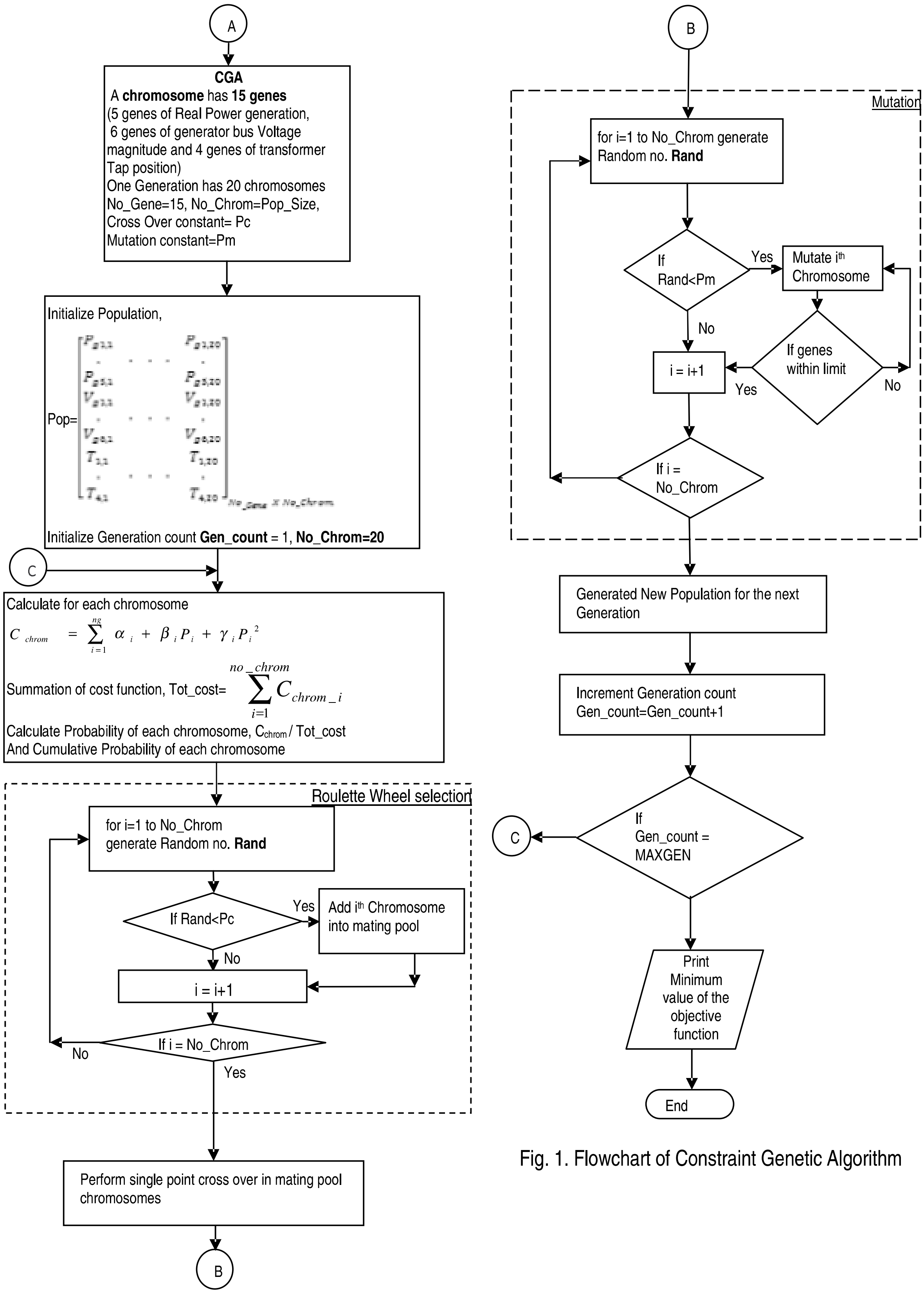


Fig. 1. Flowchart of Constraint Genetic Algorithm

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V. TEST RESULTS

Effectiveness of the developed CGA is validated with the help of standard IEEE 30 bus system. This system has 6 generators including slack bus generator, 4 transformers, 2 injected MVAR and 41 transmission line. Five candidate of real power, Six candidate of voltage magnitude and Four candidate of transformer tap position are taken as control variables (genes). These 15 genes form a chromosome. The population size of 80 is considered and stopping criterion is maximum number of iteration. In the work 200 iterations (3) is taken as maximum number of iteration. The input data for the algorithm is given below. Table I, gives the fuel cost, minimum and maximum real power generation limit of the 6 generators (4). Table II, gives limits on all 30 bus voltages and 4 transformers tap positions (3). Generator buses are known as PV bus and Load buses are known as PQ bus.

Table 1. Generator Cost Coefficients

Gen. No	Real Power Generation Limit (MW)		Cost Coefficients		
	Min	Max	α	β	γ
1	50	200	0	2.00	0.00375
2	20	80	0	1.75	0.01750
3	15	50	0	1.00	0.06250
4	10	35	0	3.25	0.00834
5	10	30	0	3.00	0.02500
6	12	40	0	3.00	0.02500

Table 2. Limits on Variables

Type of Variable	Description	Lower Limit (PU)	Upper Limit (PU)
Control	Transformer Tap Position	0.90	1.10
Control	PV bus Voltage	0.95	1.10
Dependent	PQ bus Voltage	0.95	1.05

From the fitness function equation [8], cost of generation is calculated with the help cost coefficients form table I. Versatile load flow analysis, Newton-Raphson (NR) method is used to find the real power generation and cost of generation from equation (1) for the IEEE 30 bus system it is 875.448$/hr.

The developed CGA optimal power flow solved by 80 chromosomes, each chromosome gives one solution as shown in figure 3. The lowest cost generations by the chromosomes are selected using roulette wheel selection, then crossover and mutation operations are carried to get better chromosome for the next iteration. The iteration is stopped after 200th iteration to get final cost of generation is shown in figure 2. Cost of generation is reduced to 805.453 $/hr. The cost saving of 69.995$/hr is achieved.

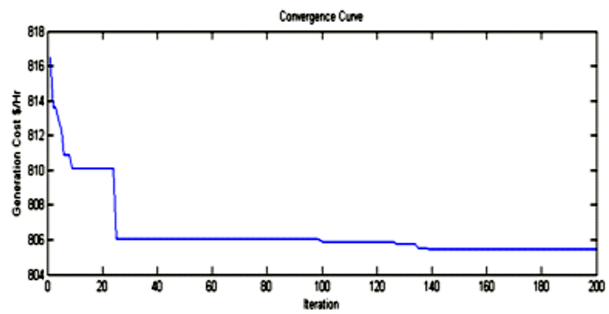

Fig. 2. Convergence Curve

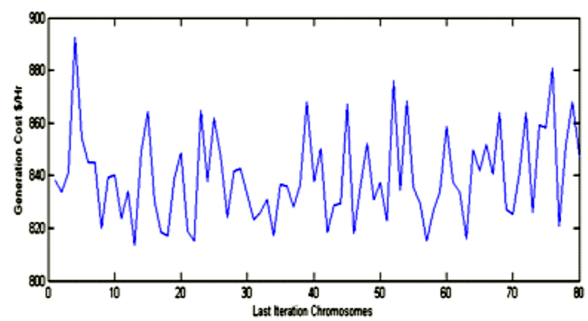

Fig. 3. Generating Cost of Individual Chromosomes in last iteration

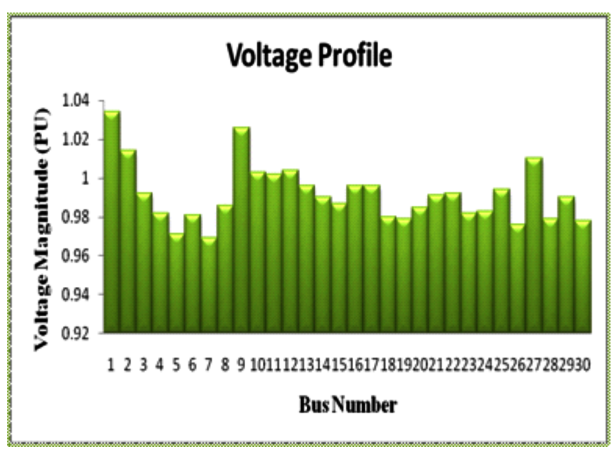

Fig. 4. Voltage Profile: V1 max = 1.034, V7min = 0.969 in PU

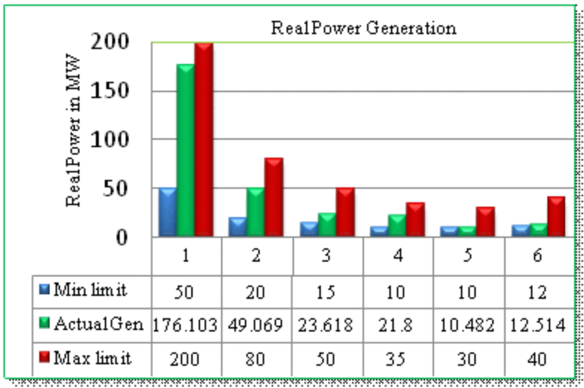

Fig. 5. Generators Real Power generation with respect to its limits

Figure 4, shows the voltage magnitude of all the buses in the system. Bus 1, is slack bus has maximum voltage of 1.034 per unit (PU) load bus 7, has minimum voltage of 0.979. The maximum and minimum voltage is within the limits specified in the table II. This guarantees the developed CGA application to OPF.

Figure 5, is a bar chart shows the real power generation of all the 6 generators. Blue (first) bar shows the minimum limit, Green (second) bar shows actual generation of each generator and Red (third) bar shows maximum limit of the generators. Slack bus generates maximum power 176.103 mega watt (MW) and 5th generator in the system generates minimum power of 10.482 MW. This bar chart also guarantees that the generation is within the limits specified in table I. Total real power demand in the system is 283.4MW, total real power losses is 10.186 MW and total real power generation is 293.586 MW which satisfy the equality constraint given by equation [2].

VI CONCLUSION

Optimal Power Flow (OPF) is a nonlinear nonconvex problem, conventional techniques like NR method is inferior to find best (global) optimal value. Meta heuristic techniques are superior in finding global optimal value. In this research paper one such meta heuristic technique, constraint genetic algorithm (CGA) used to solve OPF. Prime importance of OPF is to reduce the generting cost and to satisfy all equality and inequality constraints. For IEEE 30 bus standard test system CGA results shows saving in cost 69.995 $/hr. Equality constraint of power balance equation is satisfied, to take care this NR method power flow in used as a subset in the algorithm. The results also guarantees control variables and dependent variables are within their limits.

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BIOGRAPHIES

C.N. Ravi is a Research Scholar in Sathyabama University. He received M.E. in Power System Engineering, and B.E. in Electrical and Electronics Engineering, from B.S.A. Crescent Engineering College, Anna University, Chennai, in the year 2006 and from Crescent Engineering College, University of Madras, Chennai, in the year 1999, respectively.

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