ECONOMIC GENERATION AND SCHEDULING OF POWER BY GENETIC ALGORITHM

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ABSTRACT

The paper represents a genetic algorithm (GA) solution to the unit commitment problem for power generation in thermal power plant. GAs are general optimization techniques based on principles inspired from the biological evolution, using metaphors of mechanism such as natural selection, genetic recombination and survival of the fittest. A simple GA implementation using the standard crossover and mutation operators could locate near optimal solution. To solve the problem a two layer approach is used, the first layer uses a genetic algorithm to decide the on/off status of the units, and the second layer uses a non linear programming formulation solved by Lagrangian relaxation to perform the economic dispatch while meeting all plant and system constraints. In order to save the execution time the economic dispatch is only performed if the given unit commitment schedule is able to meet the load balance, energy and begin/end level constraints. The simulation results reveal that the features of easy implementation, convergence within an acceptable execution time, and highly optimal solution in solving the unit commitment problem can be achieved.

Keywords: *Unit Commitment, Genetic Algorithm, Generation Scheduling*

1. INTRODUCTION

The main objective of the introduction of competition in the electricity supply industry is to increase efficiency in the production and distribution of electricity, providing better choice to market participants, while maintaining the security and reliability of supply.

The principle objective of the unit commitment (UC) of power system is to schedule the generation units in order to serve the load demand at the minimum operating cost while meeting all plant and system constraints. Generation scheduling involves the determination of startup and the generation levels for each unit over a given scheduling period. The schedule is subject to a number of system and unit constraints.

The general UC problem is to minimize operational cost (mainly fuel cost), transition cost (start-up /shut down cost).

1. The total power output must meet the load demand.
2. Energy constrained must be met.
3. The minimum up and down times of thermal generation unit must be constrained.
4. The generation of each unit must be within its minimum and maximum allowable power output range

The unit commitment problem is defined mathematically as a nonlinear, non-convex, large scaled, mixed integer combinatorial optimization problem, often involving thousand of 0-1 decision values as well as continuous variable, and a wide spectrum of equality and inequality constraints. The optimal solution to such a complex combinatorial optimization problem can be obtained only by global search technique. A number of methods have been proposed previously for solving such a problem and each method has involved one or more difficulties, such as:-

- The high computational time for medium and large scale system may be prohibitive.
- Reliance on heuristic, hence sub optimal solution.
- Difficulty in obtaining feasible solution.

E.g. these methods have included:-

- Priority list method
- Branch and Bound method
- Dynamic programming method

- Lagrangian relaxation method

1. UNIT COMMITMENT PROBLEM FORMULATION

As is true for many systems, an electric power system experiences cycles. The demand for electricity is higher during the daytime and lower during the late evening and early morning. This cyclical demand requires that utility companies plan for generation of power on an hourly basis. The problem is first to decide which of the available units to turn on, and then to determine an economical dispatch schedule of the units. Determining an optimal economical dispatch schedule of a set of generating units to meet a load demand while satisfying a set of operational constraints is called the unit commitment problem (UCP). The following notation is used:

1.1 SYSTEM PARAMETERS

CFi (p): Cost of producing p units of power by unit i

SUi : Start up cost of unit i

u (t) : Load at time t (demand)

1.2 Decision variables

Pi(t) : Amount of power produced by unit i at time t

V*i(t) : Control variable of unit i at time t*

$$v_i(t)=\begin{cases}0 & \text{if unit } i \text{ is off at time } t\\ 1 & \text{if unit } i \text{ is on at time } t\end{cases}$$

1.3 Auxiliary variables:

Xi (t) : Consecutive time that unit i has been up (+) or down (-) at time t

I(x) : Logic function defined by

$$I(x)=\begin{cases}0 & \text{if } x \text{ is false}\\ 1 & \text{if } x \text{ is true}\end{cases}$$

The objective of the standard UCP is to minimize the sum of two cost terms. The first term is the cost of the power produced by the generating units, which depends on the amount of fuel consumed. The second term is the start-up cost of the generating units, which for thermal units, depends on the prevailing temperature of the boilers.

1.2 FUEL COST

For a given set of N committed units at hour t, the total fuel cost, at that particular hour, is minimized by economically dispatching the units subject to the following constraints:

a) The total generated power must be equal to the demand (also called load).

b) The power produced by each unit must be within certain limits (minimum and maximum capacity).

This problem is called Economic Dispatch (ECD) and it can be stated as follows (the subscript t is omitted for simplicity):

$$\min CF = \sum_{i=1}^{N} CFi(Pi)$$

1.3 OPERATING COST

$$CFi(Pi) = a_i P_i^2 + b_i P_i + c_i$$

Where,

a_i, b_i, and c_i are the unit constants.

subject to:-

1) $$\sum_{i=1}^{N} Pi = u$$

2) $$P_i^{min} \le P_i \le P_i^{max}$$

1.4 START-UP COST

The start-up costs relate to turning a unit on. If the thermal unit has been off for a long period, a cold start-up cost will be incurred. If the unit has been recently turned off (temperature of the boiler is still high), a hot start-up cost is applied.

$$S(t)=\begin{cases}S_c & \text{if } -x(t) \le t_{cold\ start}\\ S_h & \text{otherwise}\end{cases}$$

Start-up costs are incurred only when a transition from state off to on occurs, which can be expressed as follows:

CS(t)= S(t) V(t) (1-V(t-1)

1.5 OBJECTIVE FUNCTION

Consequently, the objective function of the unit commitment problem for N generating units and T hours can be written as follows:

$$\min \sum_{t=1}^{T}\sum_{i=1}^{N} \left[\; CFi\ (\ Pi(t)\ Vi(t) + CSi(t) \;\right]$$

Subject to the constraints:

a) Demand:

$$\sum_{i=1}^{N} Vi(t)\ Pi(t) = u(t) \qquad t=1,\ldots\ldots,T$$

b) Capacity limits:

$$Vi(t)\ Pi^{min} \le Pi(t) \le Vi(t)\ Pi^{max}$$

c) Minimum up- and down time constraints

$$Vi(t)=1 \quad \sum_{j=ts}^{t-1} Vi(t) \geq \text{Min Up Tim}_i$$

$$Vi(t)=0 \quad \sum_{t=td}^{t-1} (1-Vi(t) \geq \text{Min Dwn Tim}_i$$

Where,

i index of units

t index of time steps

N number of units

CF(Pi) operating cost of unit i($. MW/h)

u(t) system load demand at time-step t

P_i^{min} minimum power that can be generated by unit i (MW)

P_i^{min} maximum power that can be generated by unit i (MW)

SUi start-up cost ($./MW)

The total amount of power available at each hour must be greater than the load demanded.

2. METHODOLOGY OF THE PROBLEM SOLUTION

2.1 BASIC FUNCTION

The solution of the unit commitment of thermal power station is developed by a software program in MATLAB. The software program is developed in two layers, first layer is used to calculate the economic power dispatch, operating cost of each unit and the total cost of the power generation of the randomly selected schedules of the units at time t which meets the system load demand at the time t on the station, and the second layer of the programming to obtain the best schedule of units at time t by genetic terminology. The thermal unit commit object is executed for each chromosome of the population. As noted in the flowchart, the decision variable of the cost function is decomposed into integer on/off variables and the continuous real power outputs. The former ones are coded in binary strings which are embedded the minimum up/down-time constraint. The latter are determined by an economic dispatch program after checking and evolution of load balance, energy, and begin/end level constraints.

2.2 FLOW CHARTS FOR THE PROBLEM SOLUTION

The developing a software programming flow chats are given below for the unit commitment problem.

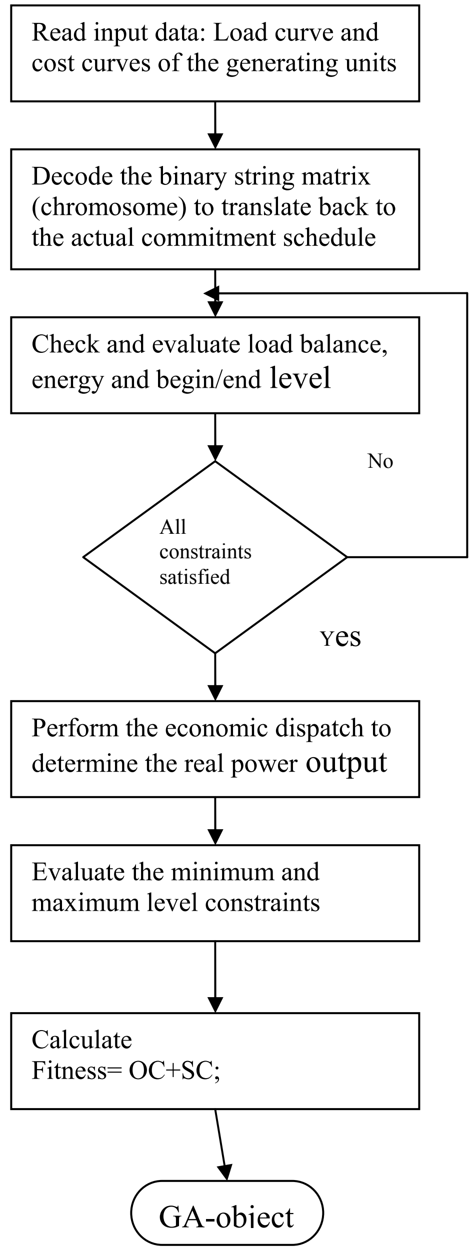

Fig.2.1 Flowchart of the thermal commitment object

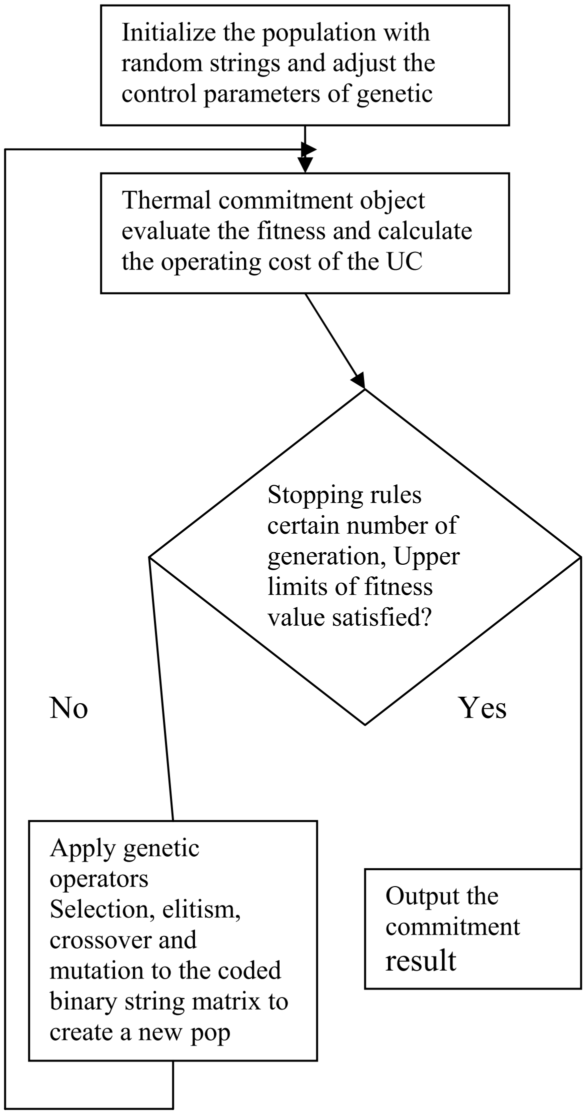

Fig.2.2 Flow chart of the GA- object

2.3 CODING SCHEME OF THE UNIT COMMITMENT

The binary variables Vi,t to be determined in the unit commitment (UC) problem denote the on/off – states of the unit I at time step t, where two index variable, I for the unit and t for the time step, are involved. Hence, the decision variable V is expressed as a two dimensional matrix of elements Vi,t with the row indexed by unit i and the column by time step t. if the actual binary decision variables V were directly employed in the genetic algorithm(GA), the operation of the selection, crossover(recombination), and the mutation on the current feasible solutions (i.e. solution with all constraints satisfied) would almost all yield infeasible solution (i.e. solution with at least one constraint violated) in the next generation, in particular the minimum up/down time constraints. As a result, the search process becomes very inefficient for the GA to achieve the optimal or near optimal solution.

The proposed coding scheme translates the decisions variables V into their binary string binary representation Uc, also in a matrix form. The minimum up and down time constraints are integrated in the representation. As shown in fig each row of the matrix stands for the coded operating states of the one generating unit during the H time step periods. A row of the matrix is divided into several substrings, e.g. s_{i1}, s_{i2}, s_{i3}.....................for the i^{th} row. Each of the substrings, indicates one operating state on (with leading bit of 1) or off (with leading bit of 0) and the number of time steps, for which the on state (or off state) lasts. This number is obtained by summing the time steps, which are indicated by the decimal value of the bits following the leading bit and the minimum up time (or down time).

The length of the substring n_i for unit I is given by following the function.

$n_i = [\log_2 (n_{i\,max})]$ for $n_{i\,max} > 1$

$n_i = 1$ otherwise

Where $n_{i\,max}$ max (minimum up time, minimum down time)

And [x] is the greatest integer less than or equal to x.

For example, unit i have a minimum up time of 2 time steps and a minimum down time of 4 time steps. Then the substring length n_i for unit I is three bits. The substring **1**|01 denotes that the unit is in up state and up state lasts for three time steps, i.e. 1 time step (indicated by the binary value 01) plus a two time step minimum up time. Similarly, the substring **0**|11 means that the unit i is an off state for seven time steps (indicated by 11) plus a 4 time step minimum down time.

On the other hand, if the substring length is one bit, in particular for contracts and storage power stations, each bit in the corresponding row of the matrix directly represents the schedule of the unit in each time step of the H time steps period. Since we considers an one day UC problem in time steps with a length of one hour, i.e. 24 time steps for a day (H=24), therefore,24 bits are given for each row of the matrix Uc. Figure in order to cope with contract and storage power station units. After decoding, if the corresponding actual commitment schedule covers a period longer than H time steps, the scheduling interval beyond is ignored for further evaluation.

Furthermore, to consider the initial status of generating units (on/off time before the study period), the first substring has twofold indications depending on whether the initial on time (or off time) constraint. If the constraint has been satisfied, the first substring represents an on or off operating state (denoted by the rest of bits). Otherwise, the leading bit is ignored (i.e. it means the same state as the initial one by default), and the other bits imply the number of time steps the on state (or off state) carries through as well as the minimum up time (or down time) minus the initial on time (or off time).

For genetic operations the N X H matrix is converted into a 1 X H*N matrix which represents a coded chromosome. After the processing by the binary strings can be easily decoded back to the actual decision variable. For instance, after decoding, the binary string of unit i is translating back to the actual commitment schedule.

The decoded actual commitment schedule of the units is used to perform the economic dispatch and to calculate the fitness value.

2.4 ECONOMIC DISPATCH

The economic dispatch is a computational intensive part, therefore, to save execution time the economic dispatch is only performed if the given unit commitment schedule is able to meet the load balance, energy, and begin/end level constraints. The economic dispatch problem can be defined as finding the optimal combination of power outputs that minimize the total operating cost while satisfying the given constraints. The some of the power outputs must equal the total load demand and the power output of an individual unit must be within it's respecting operating limits. Additionally, primary constrain groups, i.e. fuel consumption constraints, and secondary constraint group, i.e. energy constraints, must be met. A constraint group covers a certain time period.

2.5 CALCULATION OF FITNESS VALUE

The fitness of a solution V is evaluated as the total production cost. Fitness (V) = Total_fuel_cost

+Total_start_up cost (V)

To evaluate the total fuel cost of a given solution V, the optimal value of P needs to be determined by solving T different(one at each hour) economic dispatch sub-problem. An economic dispatch sub-problem consists of economically dispatching those units whose entries in V are equal to "1". Using the lagrangian multiplier, the economic dispatch sub-problem at hour t can be solved.

Assuming that the fuel cost can be modeled by a quadratic function (Wood and Wollenberg 1996), the fuel cost of producing p units of power using generating unit I is found by:

$CFi\ (Pi) = a_i P_i^2 + b_i P_i + c_i$ ($/**MW)**

The coefficient terms are determined by a price of the fuel ($/Mbtu) and the amount of fuel required per unit of power generated (Mbtu/MW).To find the optimal values of the generated power of each unit, described in (Wood and Wollenberg 1996), is used to solve this system of equations. The procedure has complexity is as follows:

1. Input the values of a, b, c
2. For i=1 to N

   2.1 Calculate $\frac{dCFi(Pi(t))}{dPi(t)}$

   2.2 Equals them for each unit and find equations
3. Total demand is equals to the sum of generating power of each unit
4. Calculate Pi(t).

Once the optimal values of Pi(t) are found, the total fuel cost is computed by adding the fuel cost of all generating units over the time horizon T. the total startup cost is calculated by adding the start up costs of those units tat change their states from "0" to "1".

2.6 GENETIC OPERATIONS

For unit commitment of thermal power station genetic operations applied are as follows:

- Parent selection
- Crossover
- Mutation

2.6.1 PARENT SELECTION

Tournament selection is used for selecting parents with the first parent better of two solutions in tournament and the second parent uniformly randomly chosen from the population.

2.6.2 CROSSOVER

After choosing the parents from the population crossover operator and obtain the deficient results. Applying a simple crossover operator to parent X and Y, obtaining offspring Z, works as follows:

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Single point Crossover Operator Procedure

1. Set parent X to have fitness(X) > fitness(Y).
2. Randomly choose a bit number in the binary string
3. Divide the parent X on to the bit number, W1, W2
4. Same procedure is used for the parent Y.
5. Now add the off strings of the parents in that manner for creating the Childs

For child1 = X [W1] Y [W2]

For child1 = Y [W1] X [W2]

Now step 1 of the crossover is repeated for the child, if the fitness value of any child in generation is not satisfied then that child drops from the population and second go to the next generation.

The crossover operator defined above transfers more genes from the parent with the better fitness value. Figure shows an example of the crossover operator.

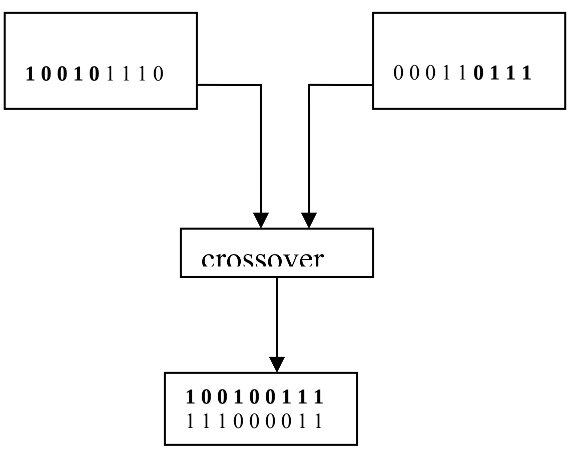

Fig.2.3 Crossover operator

2.6.3 MUTATION

A standard mutation operator, where a bit of an off spring with flipped with 0.001, is used. With the small probability, randomly chosen bits of the offspring genotypes change from '0' to '1' and vice versa as shown in fig.

2.6.4 POPULATION SIZE AND INITIALIZATION

A genetic algorithm is a population based search technique that derives at power from the fact that it advances its search based on feedback obtained from a number of potential solution to the problem, each searching a different regions of the search space at the same time. The initial population of solutions is usually generated randomly, although sometimes the search can benefit from inclusion of good previous solutions, if available, but this must be done with utmost care, since lack of sufficient diversity in the initial population can easily result in premature convergence. The size of the population is one of the major GA control parameters. A number of theoretical and empirical studies provide guidelines on the choice of appropriate population size. However there are no empirical formulae linking the population size to other GA variables or any problem specific parameters. In this dissertation the population size is chosen as a function of string length, and the value used has been set after a number of empirical trials.

2.6.5 PARENT REPLACEMENT METHOD

In moving from one generation to the next, the old population should be replaced by the newly created offspring population in some optimal way that keeps the search for better solution on the appropriate track. This step is important for the GA because it determines the degree of exploitation of the new search material in the advancement of the search for the optimal solution. Sometimes, it is good to keep track of the best solution obtained so far as the optimization progresses. This is achieved in GA by an "elitist" strategy that retains intact a copy of the best solution in successive generations

2.7 EVALUATION OF CURRENT POPULATION

At the beginning of algorithm an initial population of size p is randomly generated. Then parents are chosen from the initial population to procreate a new population of p solutions through out crossover and mutation. The off spring are set in competition for survival with the current population using a probabilistic version.

The contest for survival is as follows:-

Replacing current population procedure

1. Define X as a member of the current population and Y as an off spring.
2. for each member X do
   2.1 Select a randomly a member Y from the off spring
   2.2If fitness(Y) < fitness(X)
   Add X to the new generation
   Else
   Add Y to the new generation
   2.3 Remove X from current population
   2.4 Remove Y from eligible off spring
3. And for

So, the solution of the unit commitment problem by genetic algorithm gives the most optimal schedule of the units for required load demand at the time t.

3. SIMULATION AND RESULTS:

The calculated power system consists of ten thermal generation units. There are three generation system P1, P2, P3 has been tested. They have been given P^{max}, P^{min}, a_0, a_1, a_2, t_{up}, t_{down} and load demand.

4. INPUT PARAMETERS

For the unit commitment problem, the influences of respective control parameters on the performance of the GA are examined further. Using the load demand in table 5.2, table 5.5, table 5.8 for the test problem P!, P2 and P3 and control parameter listed below and get the performance of the GA is evaluated accordingly. The parameters which are varied include population size, the selection method, recombination (crossover), and mutation rate.
Following parameters are chosen as basis:
Selection method: Tournament
Recombination: Simple point crossover
Mutation method: Constant mutation rate = .004
Number of individual =10

TEST RESULTS

Problem	N	Search space	LR Cost($)	GA cost($)	
				Best	worst
P1	10	1.7E72	551278	541656	555997
P2	10	1.7E72	566107	565866	571336
P3	10	1.7E72	59485	59882	60977

5. CONCLUSION AND FUTURE SCOPE:

A genetic algorithm solution to the unit commitment problem has been presented. The GA is most advantageous for the larger unit systems. Simulation results reveal that optimal tuning of GA parameter to guarantee fast convergence and a highly optimal solution is difficult and depends on the studied unit commitment problem. Additionally, the GA is a random search technique whereby, however, the search is guided by the objective function (e.g. operating cost function).

A basic advantage of the GA solution is the flexibility provides in modeling both time dependent and coupling constants. Another advantage is that GA is can be very easily converted to work on parallel computers. A disadvantage of GA is that, since they are stochastic optimization algorithm, the optimality of the solution they provide can not be guaranteed, however, our results indicate difference between worst and best GA provided solution is very small. Another disadvantage of GAs unit commitment algorithm is the high execution time. However, with the progress in the hardware of parallel computing both disadvantage of the GA unit commitment algorithm will soon be eliminated.

The following aspects are being identified for further research in the area of GA unit commitment determination:-

1) The research must be done on high complex hydro system, considering hydraulic coupling of hydro station.
2) The program can be further improved in a number of ways. One of them is add functionality some or all of the constraints that were ignored in the initial problem formulation, second is the transmission losses.

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