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A Hybrid Intelligent Algorithm to Solve the Unit Commitment Problem

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Abstract

Generation unit's commitment is a large complex decision making problem due to many difficulties such as multiple constraints, variety of unit's specification and different fuel used. In this work a hybrid intelligent technique is produced by genetic algorithm seeded by LaGrange multiplier method to solve the unit commitment problem for a ١٠ units large dimension network system using multiple mitigation techniques. This is to reduce the adverse impacts of the difficulties mentioned above. The solution results in an optimal operation schedule during a ٢٤ hours load profile serving a load demand in addition to a required spinning reserve.

Keywords: ***Unit Commitment, Hybrid Intelligence, and Genetic Algorithm***

Introduction

The Unit commitment (UC) is recorded is a complex challenging task by power system researchers, many traditional optimization techniques are dedicated to solve the UC problem, these techniques includes dynamic programming [١] , mixed-integer programming (MIP) [٢] and unit de-commitment [٣]. Intelligent techniques like fuzzy logics [٤] are also powerful techniques in finding fast and accurate UC problem solution.

This paper implements a new hybrid intelligent algorithm to find the optimal on/off schedule for a set of Generation Units (GU) during a certain load profile which is defined as a unit commitment problem [٥].

Most of traditional methods face difficulties like :-

١. Multiple constrains complex problem that must not be violated while finding the solution.
٢. Large dimension that increase significantly depending on how many GU to be committed, network size and the decision stages that is the number of overall load durations to be served.

The solution schedule is not an instant decision taken to cover instantaneous disturbance in load demand, the GU must be committed to overcome a long time load profile, cover network losses and improve service availability and stability by a spinning reserve in the next hours or days.

Genetic Algorithm (GA) seeded by optimization techniques is used successfully by developers to find the optimal solution for such large dimension complex problem. The efficiency of GA is attributed to high accuracy results approaching the optima and the ability of parallel search that can be applied to complex optimization problems.

Problem Formulation

The objective of UC problem is to minimize the sum of two terms, first is the generated power, which is related to fuel consumption, the second is start up cost which is for thermal GU's depending on prevailing boiler thermodynamic parameters. Hence, the problem can be formulated in objective function as:

$$Minimize\ \sum_{t=1}^{T}\sum_{i=1}^{N}[C_{Fi}\left(P_g i(t)\right) vi(t) + C_{Si}(t)] \qquad (١)$$

where $P_g i$ is the amount of power produced by unit i at interval t,

C_{Fi} is the cost of producing P_g units of power by unit I,

$vi(t)$ control variable of unit i at interval t (٠ if unit i is off at interval t ,١ when on),

$C_{Si}(t)$ start up cost of unit i,

t is time in h and equal to ١،٢،٣…T,

i is unit number and equal to ١،٢،٣…N,

The objective equation is subjected to the following constraints:

١. Load demand and spinning reserve

$$\sum_{i=1}^{N} vi(t) P_g i^{max} \geq P_d(t) + r(t) \qquad (٢)$$

Where $P_d(t)$ is the load demand at interval i,

$r(t)$ is the spinning reserve including network power loss

٢. Capacity limits

$$vi(t) P_g i^{min} \leq P_g i(t) \leq vi(t) P_g i^{max} \qquad (٣)$$

٣. Minimum Up/Down time

$$vi(t) \geq I\left(1 \leq k_i(t-1) \leq t_{up} - 1\right) \qquad (٤)$$

$$vi(t) \leq 1 - I(1 - t_d \leq k_i(t-1) \leq -1) \qquad (٥)$$

Where $k_i(t)$ is the consecutive time that unit i has been up(+) or down (-) for interval t,

$I(x)$ logic function equal to ٠ if k_i is false and ١ if true,

t_{up} is the minimum time that the unit needs to be on in order to turn off,

t_d is the minimum time that the unit must stay down before committed again.

Hybrid Intelligent Algorithm

Unit *State* (S) can be represented by binary ١ if a unit is committed or binary ٠ if not, for GU set the state is subjected to the number of generation units, as an example state ١١١٠ indicate that units ١،٢ and ٣ are committed while unit number ٤ is not.

Possibility chart takes all the possible paths from starting state at t=١ to the final state at $t=T$, the total number of candidates paths is equal to

$$(2^N - 1)^T \tag{٦}$$

Possibility trajectory matrix (PTM) it is a matrix that contain only the *viable states* (*Vs*) at each time interval, the viable states are the states that cover load demand, losses and spinning reserve, i.e

$$\text{If } P_g^{max} S(t) \geq P_d(t) \quad S = V_s \text{ is viable} \tag{٧}$$

The PTM can be illustrated from the possibility chart in such that each column will be modified to contain only viable states V_s and eliminate the un-wanted states for each time interval. This procedure is named *column modifier technique*, implementing this technique leads PTM containing many zeros and can be treated as sparse matrix.

Genetic algorithm chromosome X is represented in binary represents the states (solution) from PTM to schedule the units successfully.

$$X_i^j\{Vs(1),\ldots,Vs(T)\} \tag{٨}$$

where i=١،٢,, selected number of chromosome (n_c)

j=١،٢,,decided number of generation (n_g)

Although X is Represented in binary, to save computer memory and achieve faster execution time an alternative coding program is developed to code the individuals in decimal. Then a predefined number of chromosomes (individuals) is generated for specific number of generations depending on problem complexity to obtain the optimal solution. The generation is performed by randomly selected trajectories from the PTM (initial population) that represents the candidate's viable states that cover the study time horizon. For further reduction in problem size and complexity a *population modification* is required. This modification is implemented on the PTM by eliminating any individuals/trajectories that cannot satisfy conditions in equations ٢،٤ and ٥ and regenerating individuals until all the states are viable and satisfy equations ٢،٤ and ٥. Then a *selection* of best chromosomes based on fitness evaluation is performed to initiate the system for the genetic algorithm operators.

Fitness=total fuel cost +startup + shutdown cost

$$f_s = f(X_i^j) + C_s \tag{٩}$$

To evaluate fuel cost and the optimal value of *P* a program is coded based on LaGrange method to economically dispatch only units that are included in the viable states of candidate's trajectories [٥]. The economic dispatch program will act as a sub program each time one needs to estimate the fitness (minimum fuel cost) producing the maximum generated power.

Probability of chromosome is also evaluated to measure the ability of single chromosome for being propagated (survived) to next generation compared with all individuals in the generation as follows:

$$P_r(X_i^j) = f_s / F_T \quad , \text{ Where } F_T = \sum_1^{nc} f_s(i) \tag{١٠}$$

Elitism mechanism [٦] is an important technique for this work activated by searching and passing the highest fitness individual in each generation to the next generation before implementing GA operators to guarantee that good solutions will not be lost through GA operation.

Then the selected individuals will be copied into the next generation and regeneration will stop when n_g is reached. Then a *crossover* and *mutation* [٧] operations is implemented based on *roulette-wheel* parent selection to produce individuals with higher fitness. Figure ١ shows the process flow chart.

Test System and Results

The hybrid intelligent algorithm is tested on a ١٠-units system for a ٢٤h time period [٨]. Investigating possibility chart shows that there is a ١,٧٢٦E٧٢ possible candidates paths which is an enormous amount of possibilities that cannot be studied to find the optimal one using traditional methods. Implementing column modifier technique illustrates the PTM with ٦٨٪ reduction in size due to elimination, where n_g and n_c are selectable and could be changed by developer depending on problem complexity in achieving the optimal solution. Furthermore, each generation will be tested and modified using population modification technique to ensure that it contains only viable states trajectories. Best selection is performed on best fitness and probability to initiate the GA operators.

The optimal solutions for the particular load profile is shown in figure ٢, this figure shows the optimal on/off schedule for the ١٠ GU's that achieve optimal power generated and satisfy power demand with least fuel cost, each unit generation is within the designed capacity and finally the sequence of operation satisfies the unit time constraints which is the most complex constrain to satisfy. The solution shows that at minimum load (h=١) only ٤ units is required to cover the demand, the best set of GU's at this particular hour is (١،٢،٣,٤). At maximum load (h=١٢) the optimal solution to cover the demand is to operate all the ١٠ units.

In this work the algorithm is designed to produce a multi-solution output, in our case the output is ١٠ best solutions, then optimal solution is chosen after comparison, this solution is ranked as the optimal solution compared with ٩ near-optimal options with relatively smaller fitness among the GA ٥٠th generations as shown in figures ٣. Figure ٤ shows the fitness evaluation and selection convergence to the optimal value during the GA generations. The execution time to give the optimal solution for our test system was ١٧ seconds.

Conclusions

Finding optimal unit commitment problem solution is a challenging task involving many difficulties regarding complexity and large scale of the problem. Many mitigation techniques have been developed in this work to reduce the adverse impacts of studying large-scale unit commitment problems, these techniques are:

١. Column modifier.
٢. Chromosome way of representation and coding.
٣. Population modification.
٤. Selection basis.

٥. Elitism.

The developed techniques in addition to seeding GA intelligent technique with LaGrange multiplier method give fast, high accuracy, optimal multi solutions to the unit commitment problem. This enables the researchers to study complex power systems with large number of generation units for a long time period quickly and efficiently. Furthermore, the multi solutions property shows technique's versatility improvement result in expanding the search rule.

This work is the starting point of a more reliable and fast methods to undertake power system complex problems and will be followed by further investigations, improvements and developments.

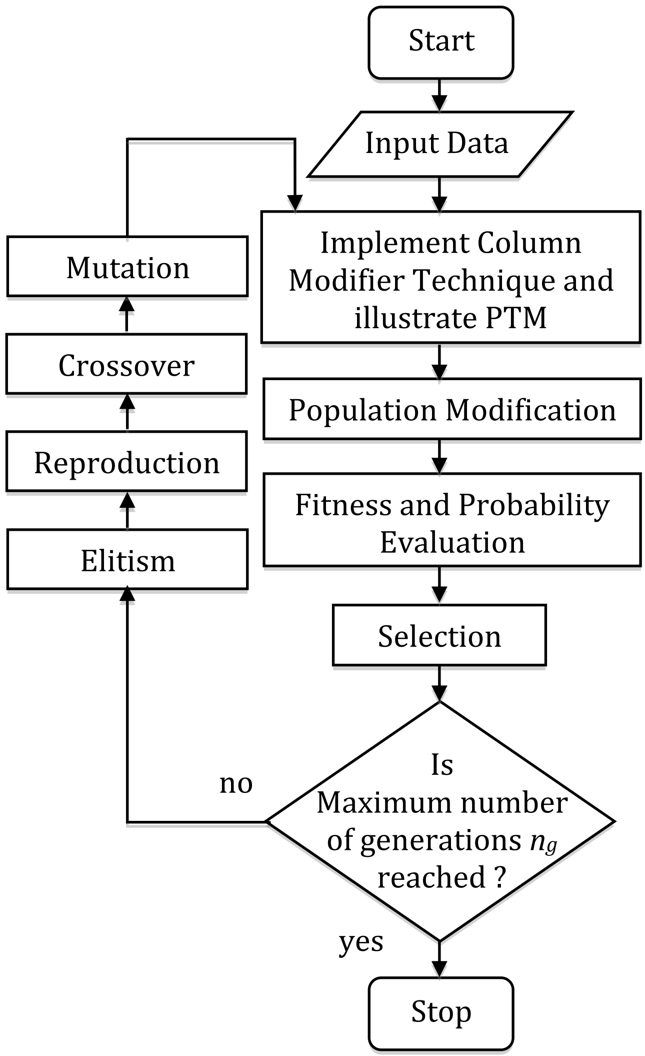
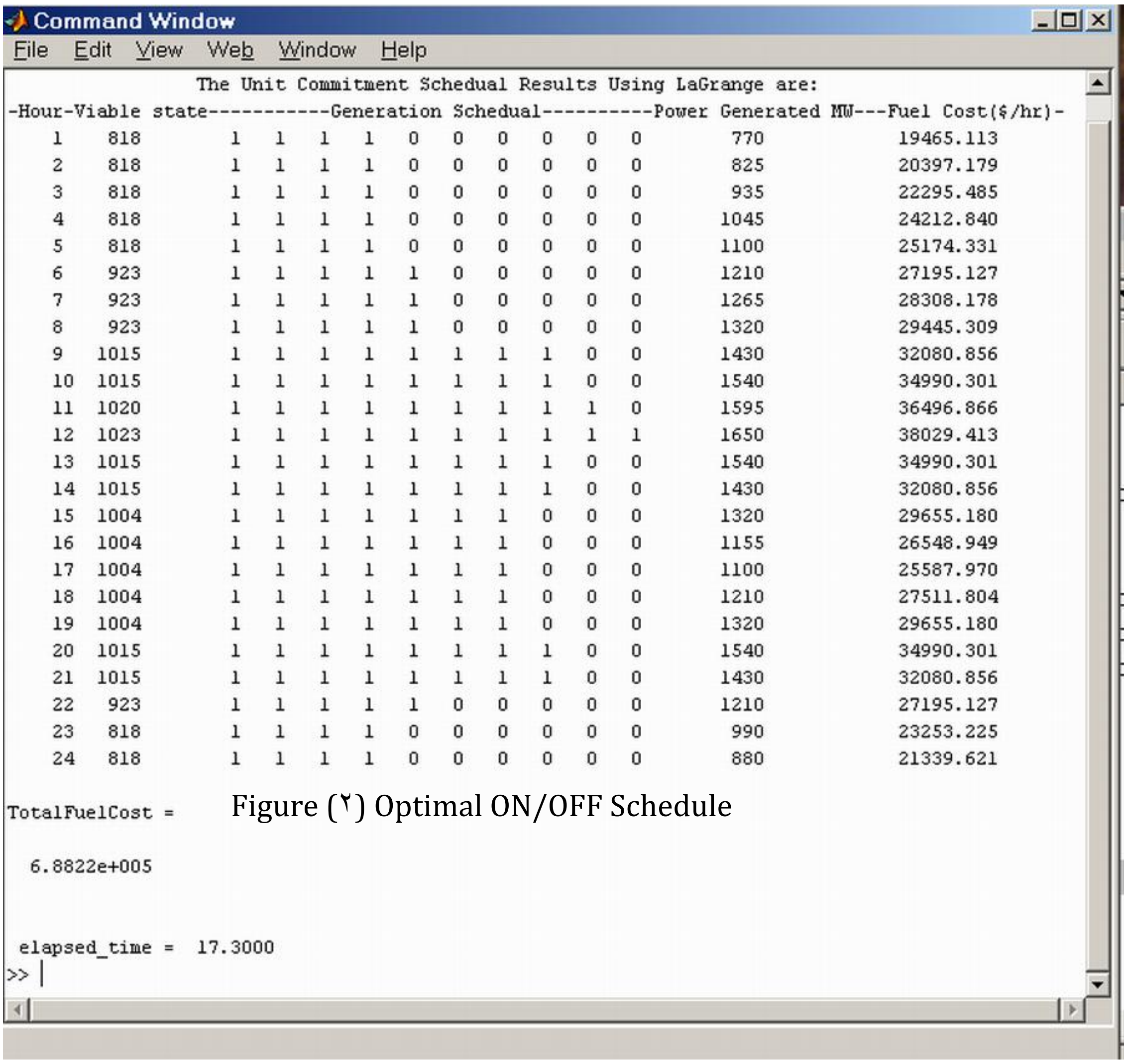


Figure (١) Hybrid Intelligent Algorithm



Command Window

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The Unit Commitment Schedual Results Using LaGrange are:

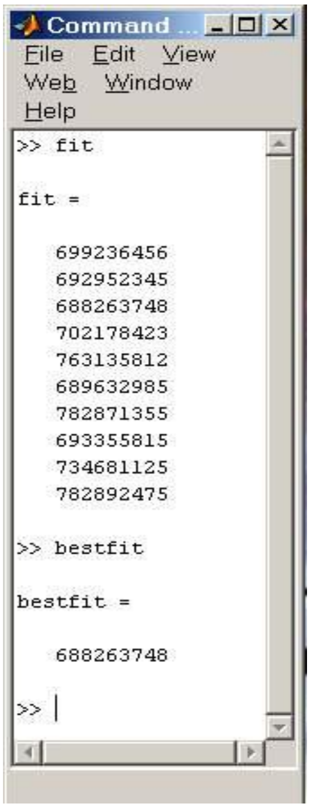
Hour	Viable state	Generation Schedual										Power Generated MW	Fuel Cost($/hr)
1	818	1	1	1	1	0	0	0	0	0	0	770	19465.113
2	818	1	1	1	1	0	0	0	0	0	0	825	20397.179
3	818	1	1	1	1	0	0	0	0	0	0	935	22295.485
4	818	1	1	1	1	0	0	0	0	0	0	1045	24212.840
5	818	1	1	1	1	0	0	0	0	0	0	1100	25174.331
6	923	1	1	1	1	1	0	0	0	0	0	1210	27195.127
7	923	1	1	1	1	1	0	0	0	0	0	1265	28308.178
8	923	1	1	1	1	1	0	0	0	0	0	1320	29445.309
9	1015	1	1	1	1	1	1	1	1	0	0	1430	32080.856
10	1015	1	1	1	1	1	1	1	1	0	0	1540	34990.301
11	1020	1	1	1	1	1	1	1	1	1	0	1595	36496.866
12	1023	1	1	1	1	1	1	1	1	1	1	1650	38029.413
13	1015	1	1	1	1	1	1	1	1	0	0	1540	34990.301
14	1015	1	1	1	1	1	1	1	1	0	0	1430	32080.856
15	1004	1	1	1	1	1	1	1	0	0	0	1320	29655.180
16	1004	1	1	1	1	1	1	1	0	0	0	1155	26548.949
17	1004	1	1	1	1	1	1	1	0	0	0	1100	25587.970
18	1004	1	1	1	1	1	1	1	0	0	0	1210	27511.804
19	1004	1	1	1	1	1	1	1	0	0	0	1320	29655.180
20	1015	1	1	1	1	1	1	1	1	0	0	1540	34990.301
21	1015	1	1	1	1	1	1	1	1	0	0	1430	32080.856
22	923	1	1	1	1	1	0	0	0	0	0	1210	27195.127
23	818	1	1	1	1	0	0	0	0	0	0	990	23253.225
24	818	1	1	1	1	0	0	0	0	0	0	880	21339.621

```
TotalFuelCost =

  6.8822e+005


 elapsed_time =  17.3000
>>
```

Figure (٢) Optimal ON/OFF Schedule



Command ...

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```
>> fit

fit =

   699236456
   692952345
   688263748
   702178423
   763135812
   689632985
   782871355
   693355815
   734681125
   782892475

>> bestfit

bestfit =

   688263748

>>
```

Figure (٣) Selecting Optimal Solution Between ١٠ Near-Optimal Ones

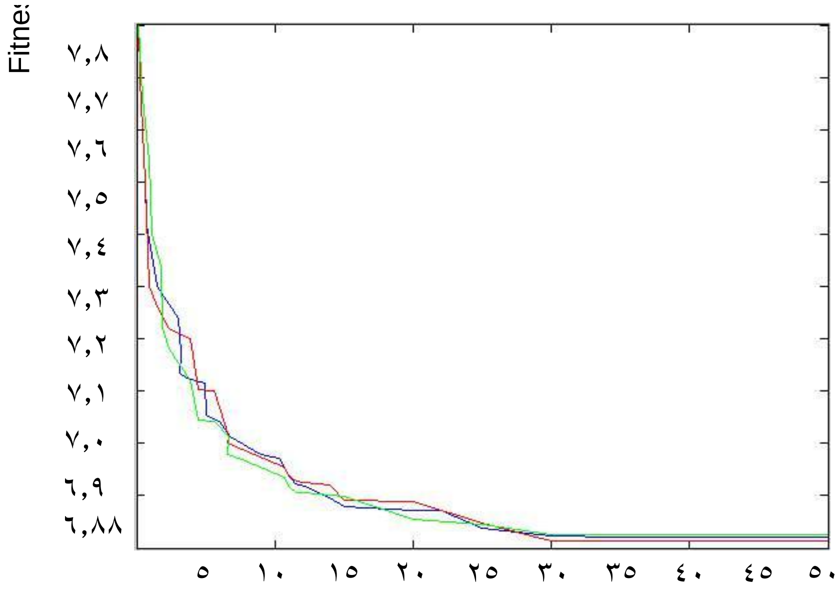

Figure (٤) Fitness Vs. Number of Generation

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