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# An Integrated GA-ABC Optimization Technique to Solve Unit Commitment and Economic Dispatch Problems

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## ABSTRACT

Unit Commitment (UC) and Economic Load Dispatch (ELD) problems are significant research areas to determine the economical generation schedule with all generating unit constraints, such as unit ramp rates, unit minimum and maximum generation capabilities and minimum up-time and down-time. This study proposed a technique for solving the UC and ELD problems using bio-inspired techniques like Genetic Algorithm (GA) and Artificial Bee Colony (ABC) Optimization. The experiments are performed in two phases: UC phase and ELD phase. In the UC phase, a turn-on and turn-off schedule for a given combination of generating units is performed using GA, thus satisfying a set of dynamic operational constraints. During the second ELD phase, the pre-committed schedules are optimized and the optimal load is distributed among the scheduled units using ABC algorithm. The effectiveness of the proposed technique is investigated on two test systems namely, IEEE 30 bus system and ten unit system. Experimental results prove that the proposed method is capable of yielding higher quality solution including mathematical simplicity, fast convergence, diversity maintenance, robustness and scalability for the complex UC-ELD problem.

**Key words:** Unit commitment, economic load dispatch, genetic algorithm, artificial bee colony

## INTRODUCTION

The electric power generated is much larger during day time due to high industrial loads and during evenings and early morning due to residential population usage. Based on the forecasted power requirements for the successive operating day, the generating units are scheduled on an hourly basis for the next day's dispatch which in turn is forecasted for a week ahead. The system operators can now schedule the ON/OFF status and the real power outputs of the generating units to meet the forecasted demand over a time horizon. There may exist large variations in the day to day load patterns, thus enough power has to be generated to meet the maximum load demand. In addition, it is not economical to run all the units every time. Hence it is necessary to determine the units of a particular system that are required to operate for given loads. This problem is known as the unit commitment (Rajan, 2010).

The Economic Load Dispatch (ELD) allocates power to units that are committed thus minimizing the fuel cost. The two major factors to be considered while dispatching power to generating units are the cost of generation and the quantity of power supplied. The relation between the cost of generation and the power levels is approximated by a quadratic polynomial. To determine the economic distribution of load between the various units in a plant, the quadratic polynomial in terms of the power output is treated as an optimization problem with cost minimization as the objective function, considering equality and inequality constraints). The approximate methods include search algorithms such as Artificial Neural Networks (ANN) (Su and Lin, 2000), Genetic Algorithms (GA) (Kazarlis *et al.*, 1996; Swarup and Yamashiro, 2002; Damousis *et al.*, 2003), Tabu Search (TS) (Lin *et al.*, 2002), Simulated Annealing (SA) (Wong and Wong, 1994; Simopoulos *et al.*, 2006), Evolutionary Programming (Juste *et al.*, 1999; Chen and Wang, 2002), Particle Swarm Optimization (PSO) (Zwe-Lee, 2003; Zhao *et al.*, 2006), Ant Colony Optimization (ACO) (Hou *et al.*, 2002), Artificial Immune Systems (AIS) (Panigrahi *et al.*, 2007), Differential Evolution (DE) (Nomana and Iba, 2010), Bacterial Foraging Algorithm (BFA) (Panigrahi and Pandi, 2008), Intelligent Waterdrop (IWD) (Rayapudi, 2011) and Bio-geography based optimization (BBO) (Bhattacharya and Chattopadhyay, 2010a, b) algorithms.

Among these stochastic search heuristics, GA has been popular in solving several optimization problems other than the UC and ELD. Holland (1975) was the first to develop GA and later improved by Goldberg (1989), Davis (1991) and many others. GAs are random parallel search optimization algorithms, inspired by natural selection, genetic recombination and mutation. They have the capability of obtaining optimal results for a problem with constraints with less computational time.

The Artificial Bee Colony (ABC) optimization algorithm developed by Karaboga (2005), is becoming more popular recently, due to the foraging behavior of honeybees. ABC is a population based search technique, in which the individuals known as the food positions are modified by the artificial bees during course of time. The objective of the bees in turn is to discover the food sources with high nectar concentration.

The two optimization problems considered in this study-UC and ELD represent a time decomposed approach to achieve the objective of economic operation. The UC problem deals with a long time span, typically 24 h or a week. The ON/OFF timing of the generating units is scheduled to achieve an overall minimum operating cost. ELD is a problem that deals with shorter time span, typically starting from seconds to approximately 20 min. It allocates the optimal sharing of generation outputs among synchronized units to meet the forecasted load. The cost minimization and the rapid response requirement in real time power systems, necessitate this two step approach. The objective of both the approaches is to minimize the fuel cost with less time of operation, thus meeting the constraints imposed. This study proposes an integrated GA-ABC solution to the UC-ELD problem. The units in the system are switched ON/OFF based on an exhaustive search performed by GA. The ON/OFF schedule is then optimized using the ABC algorithm to dispatch power thus meeting the load without violating the power balance and capacity constraints. The proposed algorithm is evaluated in terms of UC Schedules, total fuel cost, computational time, robustness and solution quality. Experiments were carried out on the IEEE 30 bus and 10 unit test systems including transmission losses, power balance and generator capacity constraints.

## MATHEMATICAL FORMULATION

To solve problems related to generator scheduling, numerous trials are required to identify all the possible solutions, from which the best solution is chosen. This approach is capable of testing different combinations of units based on the load requirements (Orero and Irving, 1995). At the end of the testing process the combination with least operating cost is selected as the optimal schedule. While scheduling generator units, the start up and shut down time are to be determined along with the output power levels at each unit over a specified time horizon. In turn the start up, shut down and the running cost are maintained at a minimum. The fuel cost, $FC_i$ per unit in any given time interval is a function of the generator power output as given in Eq. 1:

$$F_T = \sum_{i=1}^{n} F_i(P_i) = \sum_{i=1}^{n} a_i + b_i P_i + c_i P_i^2 \ \$h^{-1} \tag{1}$$

where, $a_i$, $b_i$ and $c_i$ represents unit cost coefficients and $P_i$ is the unit power output.

The start-up cost (SC) depends upon the down time of the unit which can vary from maximum value, when the unit is started from cold state, to a much smaller value, if the unit was turned off recently. It can be represented by an exponential cost curve as shown in Eq. 2:

$$SC_i = \sigma_i + \delta_i * \{1 - \exp(-T_{off} / \tau_i)\} \tag{2}$$

where, $\sigma_i$ is the hot start up cost, $\delta_i$ the cold start up cost, $\tau_i$ the unit cooling time constant and $T_{off}$, is the time at which the unit has been turned off.

The total cost $F_T$ involved during the scheduling process is a sum of the running cost, start up cost and shut down cost given by Eq. 3:

$$F_T = \sum_{t=1}^{T} \sum_{i=1}^{N} FC_{i,t} U_{i,t} + SC_{i,t}(1 - U_{i,t-1}) U_{i,t} + SD_{i,t} \tag{3}$$

where, N is the number of generating units and T is the number of different load demands for which the commitment has to be estimated. The shut down cost, SD is usually a constant value for each unit, $U_{i,t}$ is the binary variable that indicates the ON/OFF status of a unit i in time t. The overall objective is to minimize $F_T$ subject to a number of constraints as follows:

- System hourly power balance is given in Eq. 4, where the total power generated must supply the load demand ($P_D$) and system losses ($P_L$):

$$\sum_{i=1}^{N} P_{i,t} U_{i,t} = P_D + P_L \tag{4}$$

- Hourly spinning reserve requirements (R) must be met. Spinning reserve is the term used to describe the total amount of generation available from all the units synchronized on the system minus the present load plus losses being incurred. This is mathematically represented using Eq. 5:

$$\sum_{i=1}^{N} P_{i,t}^{max} U_{i,t} - (P_D + P_L) = R \tag{5}$$

- Unit rated minimum and maximum capacities must not be violated. The power allocated to each unit should be within their minimum and maximum generating capacity as shown in Eq. 6:

$$P_{i,t}^{min} \leq P_{i,t} \leq P_{i,t}^{max} \tag{6}$$

- The initial states of each generating unit at the start of the scheduling period must be taken in to account
- Minimum up/down (MUT/MDT) time limits of units must not be violated. This is expressed in Eq. 7, 8, respectively:

$$(T_{t-1,i}^{on} - MUT_i)*(U_{t-1,i} - U_{t,i}) \geq 0 \tag{7}$$

$$(T_{t-1,i}^{off} - MDT_i)*(U_{t,i} - U_{t-1,i}) \geq 0 \tag{8}$$

where, $T_{off}/T_{on}$ is the unit off/on time, while $u_{t,\,i}$ denotes the unit off/on {0,1} status

- The principal objective of the economic load dispatch problem is to find a set of active power delivered by the committed generators to satisfy the required demand subject to the unit technical limits at the lowest production cost. The optimization of the ELD problem is formulated in terms of the fuel cost expressed as:

$$F_T = \sum_{i=1}^{n} F_i(P_i) = \sum_{i=1}^{n} a_i + b_i P_i + c_i P_i^2 \tag{9}$$

- Subject to the equality constraint:

$$\sum_{i=1}^{N} P_i = P_D + P_L \tag{10}$$

Subject to the inequality constraint:

$$P_i^{min} \leq P_i \leq P_i^{max} \tag{11}$$

## SOLVING UC-ELD USING GA AND ABC

The methodology used to obtain optimal UC-ELD solution using GA and ABC is shown in Fig. 1. In UC problems, the total capacity of the generators is scheduled to meet the demand without any loss in generation. The most important constraint to be considered is the spinning reserve. Based on the load profile, binary scheduling decisions are made to identify the ON/OFF status of the generating units. The objective of the unit commitment control function is to minimize the total operational cost to meet the load within the study period of 24 h ahead by controlling the start up and shut down timing of the generating units. The available units from the unit commitment solution (GA) are part of the input data for the economic dispatch solution (ABC). With the commitment known, the economic dispatch problem allocates the generation economically to the on-line units while satisfying the demand and system reserve constraints.

**Methodology:** The proposed study includes the state-of-the-art Artificial Bee Colony algorithm combined with Genetic algorithm to solve the combined UC ELD problem. Scheduling of the on/off

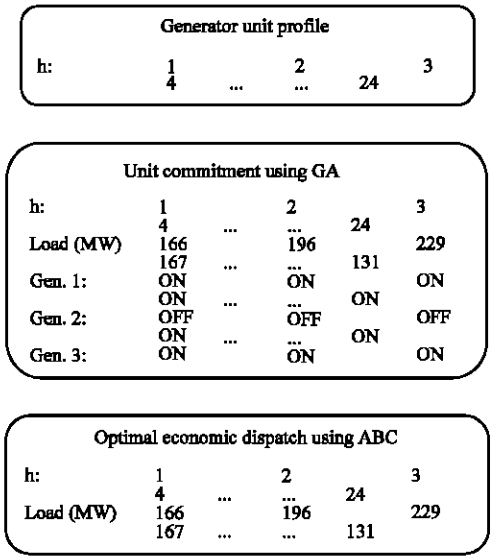

Fig. 1: Coupled UC and ELD solution

status of the generating units in the power system is generated using the Genetic Algorithm. The ELD problem is optimized with the application of ABC algorithm which estimates the power to be shared by each unit that is kept on for the forecasted demand. In this section, the step by step procedure to implement GA-ABC technique for UC-ELD is discussed.

- **Step 1: Input data:** Specify generator cost coefficients, generation power limits for each unit and B-loss coefficients for the test systems. Read hourly load profile of the generators of the systems. Initialize parameters of GA and ABC to suitable values
- **Step 2: Initialize GA's population:** Initialize population of the GA randomly, where each gene of the chromosomes represents commitment of a dispatchable generating unit. The first step is to encode the commitment space for the UC problem based on the load curve from the load profile. For a 24 h schedule 24 binary bits combine to form the chromosome. Units with heavy loads are committed (binary 1) and units with lighter loads are decommitted (binary 0). The population consists of a set of UC schedules in the form of a matrix N×T, where N is the number of generators and T is the time horizon
- **Step 3: Computation of total cost:** The total generation cost for each chromosome is computed as the sum of individual unit fuel cost
- **Step 4: Constraint handling:** The constraints of the UC problem are applied using the penalty factors. This technique converts the primal constrained problem into an unconstrained problem by penalizing constraint violations. The penalty terms are based on the deviation from the constraints and they are chosen high enough to make constraint violations prohibitive in the final solution
- **Step 5: Computation of cost function and fitness function:** The augmented cost function for each chromosomes of population is computed using:

$$F=\sum_{i=1}^{N}FC_i=a_i*P_i^2+b_i*P_i+c_i \tag{12}$$

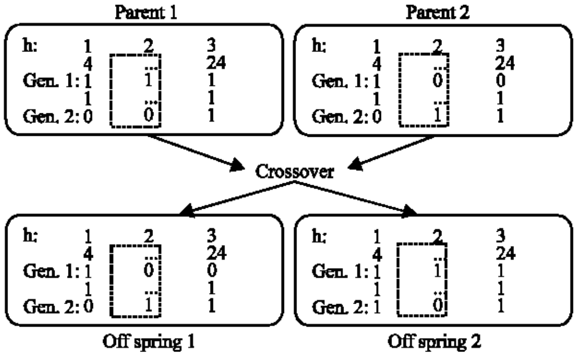

Fig. 2: Crossover operation on UC schedules

where, $a_i$, $b_i$ and $c_i$ represents unit cost coefficients and $P_i$ is the unit power output. The fitness function of chromosomes is calculated as the inverse of the augmented cost function

- **Step 6: Application of genetic operators:** After the computation of the fitness function value for each chromosome of population, crossover and mutation operators are applied to the population and the new generation of chromosomes is generated. A two point crossover technique (Fig. 2) is applied on two parents to generate two offspring. The offspring are evaluated for fitness and the best one is retained while the worst is discarded from the population. The mutation operation is performed by selecting a chromosome with specified probability. The chosen chromosome is decoded to its binary equivalent and the unit number and the time period are randomly selected for the flip bit mutation operation
- **Step 7: Initialize ABC's population:** Randomly initialize a population of food source positions including the limits of each unit along with the capacity and power balance constraints. Each food source includes the initial schedule of binary bits 0 and 1 obtained from GA, analogous to the chromosomes of the randomly generated population. The population now consists of the employed bees. Initialize all parameters of ABC such as number of employed bees, number of onlookers, colony size, number of food sources, limit value and number of iterations

## EMPLOYED BEES PHASE

- **Step 8: Evaluation of fitness function:** The fitness value of each food source position corresponding to the employed bees in the colony is evaluated using:

$$\text{fit}(i) = \sum_{i=1}^{N} FC_i + \rho\left(\sum_{i=1}^{N} P_i - P_D - P_L\right) \tag{13}$$

where, $\rho$ is the penalty factor associated with the power balance constraint. For ELD problems without transmission losses, setting $\rho = 0$ is most rational, while for ELD including transmission losses, the value of $\rho$ is set to 1.

The solution feasibility is assessed by comparing the generated power with the load. The generated power should always be greater than the demand of the unit at time j according to:

$$\sum_{i=1}^{N} P_{ij} * U_{ij} - P_{Dj} \tag{14}$$

where, $P_{ij}$ represents the power generated by unit i at time j (24 h schedule), $P_{Dj}$ is the load demand and $U_{ij}$ represents the on/off status of unit i at time j

- **Step 9: Choose a food source:** The new food source is determined in random by the employed bee by modifying the value of old food source position without changing other parameters, based on Eq. 15:

$$v_{ij} = x_{ij} + \phi_{ij} * (x_{ij} - x_{kj}) \tag{15}$$

where, k ª{1, 2,...., $n_e$} and j ª{1, 2, ... ,D}. Although k is determined randomly, it has to be different from i, $\phi_{i,j}$ is a random number between {-1,1}. It controls the production of neighbor food sources around $x_{i,j}$ and represents the comparison of two food positions visually by a bee. In Eq. 15, as the difference between the parameters of the $x_{i,j}$ and $x_{k,j}$ decreases, the perturbation on the position $x_{i,j}$ gets decreased. Thus, as the search approaches the optimum solution in the search space, the step length is adaptively reduced. This new position is tested for constraints of the ELD problem and in case of violation, they are set to extreme limits. The fitness value for the new food position is evaluated using Eq. 13. and compared with the fitness of the old position. If the fitness of the new food source is better than the old, then the new food source position is retained in the memory. A limit count is also set if the fitness value of the new position is less than the old position. Thus the selection between new and old food positions is based on a greedy selection mechanism

## ONLOOKER BEE PHASE

- **Step 10: Information sharing between employed bee and onlooker bee:** Once the searching process is completed by the employed bees, they then share all the food source and position information with the onlooker bees in the dance area. The onlooker bee evaluates the information obtained a food source (solution) is chosen randomly based on a probability proportional to the quality of the food source according to:

$$\text{prob}_i = \frac{a * \text{fit}(i)}{\max(\text{fit}) + b} \tag{16}$$

where, a and b are arbitrary constants in the range {0,1} fixed to 0.9 and 0.1 respectively, fit(i) denotes the fitness of the ith generating unit and max(fit) is the maximum fitness value in the population so far. The onlookers are now placed into the food source locations based on roulette wheel selection

- **Step 11: Modification on the position by onlookers:** Similar to the employed bees, the onlooker bees further produce a modification on the position of the food source in its memory using Eq. 15. The greedy selection mechanism is repeated to retain the fitter positions in the memory. Again a limit count is also set if the fitness value of the new position is less than that of the old position

## SCOUT BEE PHASE

- **Step 12: Discover a new food source:** If the solution representing the food source is not improved over defined number of trial runs (limit>predefined trials) then the food source is abandoned and the scout bee finds a new food source for replacement using:

$$P_{ij} = P_{jmin} + rand[0,1] * (P_{jmax} - P_{jmin}) \tag{17}$$

where, $P_{ij}$ and $P_{jmax}$ are the minimum and maximum limits of the parameter to be optimized i.e., the minimum and maximum generation limits of each unit

- **Step 13: Memorize best results:** Store the best results obtained so far and increase the iteration count
- **Step 14: Stopping condition:** Increment the timer counter and repeat steps 8-13 for which the 24 h UC schedules are predetermined through GA. Stop the process if the termination criteria are satisfied, otherwise, continue

## EXPERIMENTAL RESULTS

The main objective of UC-ELD problem is to obtain minimum cost solution while satisfying various equality and inequality constraints. The effectiveness of the proposed algorithm is tested on a six unit IEEE 30 bus system and a ten unit power system. The UC schedules, costs incurred by each unit, fuel cost per h, total fuel costs per day, total computational time and power loss are evaluated. The algorithms are implemented in Turbo C and MATLAB R2008b platform on Intel dual core, 2.4 GHz, 1 GB RAM personal computer. The control parameters for GA and ABC and their settings are shown in Table 1 and 2, respectively.

**Solution for IEEE 30 bus system:** The 6 unit system chosen in this experiment is the IEEE 30 bus system adapted from (Zaraki and Othman, 2009) in which cost coefficients of the generating units, generating capacity of each unit and transmission, loss matrix and 24 h power demand requirements are specified. The test system comprises of 6 generators, 41 transmission lines and 30 buses. The IEEE 30 bus system has a minimum generation capacity of 117 MW and a maximum generation capacity of 435 MW.

Unit Commitment solution is obtained using Genetic Algorithm by applying the control parameters as explained. The on/off status of the six generating units for 24 h load demand are determined and tabulated in Table 3. For each h, load demand varies and hence the commitment

Table 1: GA parameters

| Parameter | Value |
|---|---|
| No. of chromosomes | 6 (IEEE 30 bus) and 10 (Ten unit system) |
| Chromosome size | 24 (h)×No. of generators |
| Number of generations | 2000 |
| Selection method | Roulette wheel |
| Crossover rate | 0.6 |
| Mutation rate | 0.001 |

Table 2: ABC parameters

| Parameter | Parameter value |
|---|---|
| Colony size | 20 |
| No. of food sources | 10 |
| Food source limit | 100 |
| No. of employed bees | 10 |
| No. of onlooker bees | 10 |
| Maximum number of iterations | 500 |

Table 3: UC schedule and simulation results of IEEE 30 bus system

| | | | Distribution of load among units (MW) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour | $P_D$ (MW) | UC schedule | P1 | P2 | P3 | P4 | P5 | P6 | FC (\$ $h^{-1}$) | $P_L$ (MW) | CT (sec) |
| 1 | 166 | 1 0 1 1 0 1 | 127.5694 | 0 | 16.8065 | 10.0000 | 0 | 12.0000 | 440.1445 | 3.594 | 1.1076 |
| 2 | 196 | 1 0 1 1 1 1 | 146.5167 | 0 | 17.9747 | 10.0000 | 10.0000 | 12.0000 | 536.1842 | 4.723 | 1.0296 |
| 3 | 229 | 1 0 1 1 1 1 | 177.8214 | 0 | 19.8959 | 10.0000 | 10.0000 | 12.0000 | 647.4068 | 6.942 | 1.092 |
| 4 | 267 | 1 1 1 1 1 0 | 178.5283 | 49.4499 | 19.9576 | 10.0000 | 10.0000 | 0 | 739.8022 | 9.126 | 1.2792 |
| 5 | 283.4 | 1 1 1 1 1 0 | 190.0662 | 51.9525 | 20.671 | 10 | 11.7666 | 0 | 797.9324 | 9.315 | 1.404 |
| 6 | 272 | 1 1 1 1 1 0 | 182.0526 | 50.2146 | 20.1748 | 10.0000 | 10.5298 | 0 | 757.3698 | 9.281 | 1.2480 |
| 7 | 246 | 1 1 1 1 1 0 | 161.9778 | 45.8594 | 18.9389 | 10.0000 | 10.0000 | 0 | 667.6495 | 7.551 | 1.3416 |
| 8 | 213 | 1 1 1 1 1 0 | 135.9869 | 40.2272 | 17.3418 | 10.0000 | 10.0000 | 0 | 559.6873 | 5.382 | 1.2948 |
| 9 | 192 | 1 1 1 1 0 0 | 127.3354 | 38.3524 | 16.8031 | 10.0000 | 0 | 0 | 492.6694 | 4.744 | 1.1388 |
| 10 | 161 | 1 1 1 0 0 0 | 114.5305 | 31.8619 | 15.0000 | 0 | 0 | 0 | 380.8370 | 3.924 | 1.1544 |
| 11 | 147 | 1 1 0 0 0 0 | 115.3473 | 32.0374 | 0 | 0 | 0 | 0 | 354.6159 | 3.848 | 1.0764 |
| 12 | 160 | 1 1 0 0 0 0 | 126.0940 | 34.3632 | 0 | 0 | 0 | 0 | 392.6121 | 4.572 | 1.0608 |
| 13 | 170 | 1 1 0 0 0 0 | 134.3637 | 36.1536 | 0 | 0 | 0 | 0 | 422.5712 | 5.173 | 1.0452 |
| 14 | 185 | 1 1 0 0 0 0 | 146.7730 | 38.8414 | 0 | 0 | 0 | 0 | 468.7035 | 6.144 | 1.0764 |
| 15 | 208 | 1 1 0 0 0 0 | 165.8119 | 42.9677 | 0 | 0 | 0 | 0 | 542.2269 | 6.795 | 1.0764 |
| 16 | 232 | 1 1 1 0 0 0 | 170.4652 | 43.9784 | 18.3997 | 0 | 0 | 0 | 600.2674 | 7.433 | 1.0764 |
| 17 | 246 | 1 1 1 0 0 1 | 172.0470 | 44.3208 | 18.5055 | 0 | 0 | 12.0000 | 646.5408 | 7.733 | 1.1544 |
| 18 | 241 | 1 1 1 0 0 1 | 168.1061 | 43.4662 | 18.2631 | 0 | 0 | 12.0000 | 630.0239 | 7.353 | 1.0452 |
| 19 | 236 | 1 1 1 0 0 1 | 164.1655 | 42.6118 | 18.0209 | 0 | 0 | 12.0000 | 613.6592 | 6.982 | 1.1232 |
| 20 | 225 | 1 1 1 0 0 1 | 155.4983 | 40.7330 | 17.4882 | 0 | 0 | 12.0000 | 578.1920 | 6.195 | 1.1076 |
| 21 | 204 | 1 1 1 0 0 1 | 138.9585 | 37.1495 | 16.4728 | 0 | 0 | 12.0000 | 512.5230 | 5.808 | 1.0608 |
| 22 | 182 | 1 1 1 0 0 1 | 121.6404 | 33.4001 | 15.4112 | 0 | 0 | 12.0000 | 446.5949 | 4.516 | 1.0764 |
| 23 | 161 | 1 1 1 0 0 1 | 104.6233 | 29.7181 | 15.0000 | 0 | 0 | 12.0000 | 386.4189 | 3.414 | 1.0140 |
| 24 | 131 | 1 1 1 0 0 0 | 89.7472 | 26.5022 | 15.0000 | 0 | 0 | 0 | 297.4318 | 2.494 | 1.0140 |

of the units also varies. From the Table 3 , it is clear that the unit P1 is ON (binary 1) for 24 h because this unit generates power with minimum fuel cost as the value of coefficient ‘a’ is minimum for this unit.

Units P5 and P6 is OFF (binary 0) for most of the h because the value of fuel cost coefficient is the maximum for these two units and hence the operating cost to generate power using these units is expensive when compared to other units. Thus the Unit Commitment using GA provides a cost effective solution by choosing the appropriate units for the forecasted load demand. The optimized ELD solution for 24 h obtained using the ABC algorithm is also presented in Table 5. In ELD using ABC algorithm, the load sharing by each unit is uniformly distributed rather than allocating full load to a single unit. Thus stress in the generators can be avoided since none of the units is generating its maximum capacity. The real power output generated by units P1 to P6 are graphically depicted using Fig. 3. Unit P1 contributes a power of 3516.027 MW, P2 generates 834.1613 MW, P3 delivers 336.1257 MW, 90 MW is contributed by unit P4, unit P5 shares a load of 72.2964 and 120 MW of load is generated by unit P6. Thus from the analysis, it is clear that unit P1 generates maximum power per day and unit P5 generates the minimum power.

The objective of the UC-ELD problem includes minimization of total fuel cost and computation time. The minimum operating cost is 297.4318 \$ $h^{-1}$ for a load demand of 131 MW at the twenty fourth h. Similarly, the maximum fuel cost (797.9324 \$ $h^{-1}$) is incurred during the fifth h for a load demand of 283.4 MW. The total operating cost to generate power from the IEEE 30 bus system per day (24 h) is 12912.06 \$. The total time for the algorithm to execute is called as the computation

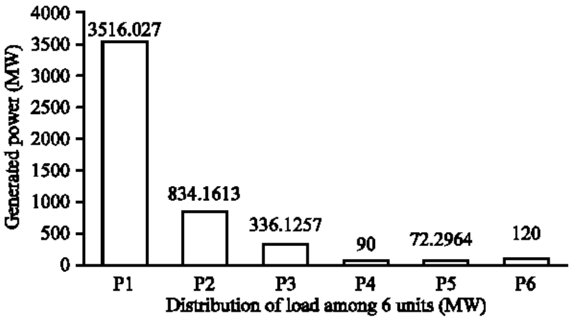

Fig. 3: Contribution of power per unit using ABC for six unit system

Table 4a: Commitment of Units using GA and Dispatch using ABC for Ten unit test system

| Hour | $P_D$ (MW) | Combination of committed units | Distribution of load among units (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 |
| 1 | 1036 | 1001011001 | 470 | 0 | 0 | 234.095 | 0 | 159.946 | 130 | 0 | 0 | 55 |
| 2 | 1110 | 1001110000 | 470 | 0 | 0 | 257.092 | 240.407 | 159.201 | 0 | 0 | 0 | 0 |
| 3 | 1258 | 1110000001 | 470 | 416.391 | 331.955 | 0 | 0 | 0 | 0 | 0 | 0 | 55 |
| 4 | 1406 | 1101010011 | 470 | 460 | 0 | 222.923 | 0 | 159.606 | 0 | 0 | 64.025 | 55 |
| 5 | 1480 | 1110100010 | 470 | 460 | 318.064 | 0 | 212.915 | 0 | 0 | 0 | 38.383 | 0 |
| 6 | 1628 | 1110110001 | 470 | 394.246 | 339.825 | 0 | 223.314 | 160 | 0 | 0 | 0 | 55 |
| 7 | 1702 | 1111010001 | 470 | 402.954 | 340 | 293.883 | 0 | 160 | 0 | 0 | 0 | 55 |
| 8 | 1776 | 1111100000 | 470 | 460 | 339.627 | 279.204 | 240.331 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1924 | 1111110001 | 470 | 460 | 326.478 | 227.114 | 242.837 | 159.766 | 0 | 0 | 0 | 55 |
| 10 | 2072 | 1111111000 | 470 | 459.998 | 339.999 | 299.956 | 232.011 | 159.997 | 129.994 | 0 | 0 | 0 |
| 11 | 2146 | 1111111100 | 470 | 17.998 | 339.934 | 294.912 | 242.494 | 155.950 | 130 | 120 | 0 | 0 |
| 12 | 2220 | 1111111011 | 469.99 | 60 | 340 | 285.782 | 243 | 160 | 130 | 0 | 76.227 | 55 |
| 13 | 2072 | 1111111000 | 470 | 459.993 | 339.985 | 297.149 | 243 | 160 | 129.999 | 0 | 0 | 0 |
| 14 | 1924 | 1111110001 | 470 | 460 | 326.478 | 227.114 | 242.837 | 159.766 | 0 | 0 | 0 | 55 |
| 15 | 1776 | 1111100000 | 470 | 460 | 339.627 | 279.204 | 240.331 | 0 | 0 | 0 | 0 | 0 |
| 16 | 1554 | 1110101000 | 470 | 457.197 | 340 | 180.127 | 0 | 0 | 130 | 0 | 0 | 0 |
| 17 | 1480 | 1110100010 | 470 | 460 | 291.209 | 0 | 217.877 | 0 | 0 | 0 | 52.761 | 0 |
| 18 | 1628 | 1110110001 | 470 | 394.246 | 339.825 | 0 | 223.314 | 160 | 0 | 0 | 0 | 55 |
| 19 | 1776 | 1111100000 | 470 | 460 | 339.627 | 279.204 | 240.331 | 0 | 0 | 0 | 0 | 0 |
| 20 | 2072 | 1111111000 | 470 | 459.998 | 339.999 | 299.956 | 232.011 | 159.997 | 129.994 | 0 | 0 | 0 |
| 21 | 1924 | 1111110001 | 470 | 460 | 326.478 | 227.114 | 242.837 | 159.766 | 0 | 0 | 0 | 55 |
| 22 | 1628 | 1110110001 | 470 | 394.246 | 339.825 | 0 | 223.3137 | 160 | 0 | 0 | 0 | 55 |
| 23 | 1332 | 1100100111 | 470 | 460 | 0 | 0 | 238.4479 | 0 | 0 | 81.7608 | 51.5469 | 55 |
| 24 | 1184 | 1100001111 | 470 | 460 | 0 | 0 | 0 | 0 | 109.4633 | 85.4916 | 28.9867 | 55 |

time. The value of computation time for GA-ABC paradigm to compute the solution for 24 h forecasted load profile is 27.0972 sec and the mean time per h is 1.129 sec.

**Results of ten unit system:** The second case study consists of a Ten-unit test system adapted from (Park *et al.*, 2010). The input data includes the generator limits, fuel cost coefficients, transmission loss matrix and load profile for 24 h. The minimum generating capacity of the system is 690 MW and the maximum generating capacity is 2358 MW. The UC results obtained using GA for 24 h load profile is tabulated in Table 4a and b. Here, unit P9 is the most expensive unit and

Table 4b: Computational results using ABC for Ten unit test system

| H | $P_D$ (MW) | FC (\$ $h^{-1}$) | $P_L$ (MW) | CT (s) |
|---|---|---|---|---|
| 1 | 1036 | 25756 | 26.0664 | 5.3508 |
| 2 | 1110 | 27053 | 33.4014 | 3.0732 |
| 3 | 1258 | 30911 | 30.6888 | 2.8392 |
| 4 | 1406 | 35756 | 51.1058 | 2.9172 |
| 5 | 1480 | 36269 | 39.0882 | 3.1980 |
| 6 | 1628 | 39422 | 28.7674 | 2.9640 |
| 7 | 1702 | 41828 | 39.6586 | 2.9796 |
| 8 | 1776 | 42974 | 26.323 | 3.0420 |
| 9 | 1924 | 46922 | 34.386 | 3.0264 |
| 10 | 2072 | 49463 | 39.9106 | 2.9658 |
| 11 | 2146 | 52094 | 50.5946 | 1.3728 |
| 12 | 2220 | 53903 | 64.4348 | 3.1356 |
| 13 | 2072 | 49636 | 56.2536 | 2.9952 |
| 14 | 1924 | 46922 | 34.386 | 3.0576 |
| 15 | 1776 | 42974 | 26.323 | 2.8548 |
| 16 | 1554 | 37088 | 46.6424 | 2.7144 |
| 17 | 1480 | 36066 | 23.7192 | 2.7768 |
| 18 | 1628 | 39422 | 28.7674 | 2.9952 |
| 19 | 1776 | 42974 | 26.323 | 3.3072 |
| 20 | 2072 | 49463 | 39.9106 | 3.0108 |
| 21 | 1924 | 46922 | 34.386 | 3.0576 |
| 22 | 1628 | 39422 | 28.7674 | 2.9952 |
| 23 | 1332 | 34325 | 49.466 | 3.0420 |
| 24 | 1184 | 30407 | 49.8848 | 2.8392 |

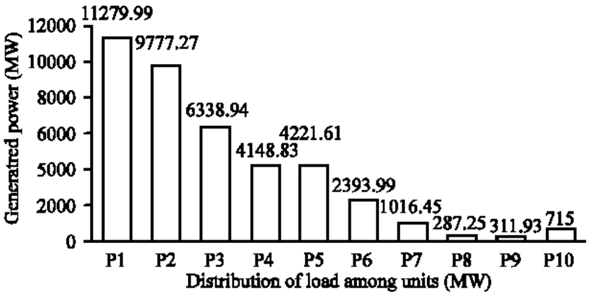

Fig. 4: Contribution of power per unit using ABC for ten unit system

hence it is kept OFF during most h of the day. Unit P1 is kept ON for the entire day because it has the minimum fuel cost coefficients and hence it also generates the maximum power per day. Unit P8 is the most expensive unit with a fuel cost coefficient of 0.0048 (\$/W-$h^2$). For units P2, P3, P6 and P7, maximum generation limit is allocated for all load demands. For units P4, P5, P8 and P9, the load sharing is allotted based on the load demand and combination of units in ON state. For each load demand in the 24 h load profile, the power generated by each unit varies according to their fuel cost function, generating limits and also the UC schedule. Thus different power is shared by each unit throughout the day which is graphically presented in Fig. 4. Unit P1 generates a load of 11279.99 MW per day whereas unit P8 shares a load of only 287.2524 MW per day.

Table 5: Comparative analysis of ten unit test system

| | | EPSO-GM | ADHDE | | ABC | | Proposed | |
|---|---|---|---|---|---|---|---|---|
| H | Demand (MW) | FC ($ $h^{-1}$) | FC ($ $h^{-1}$) | $P_L$ (MW) | FC ($ $h^{-1}$) | $P_L$ (MW) | FC ($ $h^{-1}$) | $P_L$ (MW) |
| 1 | 1036 | 28511.54 | 29574 | 16.26 | 30445 | 13.56 | 25756 | 26.0664 |
| 2 | 1110 | 30373.73 | 31330 | 16.66 | 30949 | 13.84 | 27053 | 33.4014 |
| 3 | 1258 | 33282.83 | 35145 | 15.99 | 34022 | 17.33 | 30911 | 30.6888 |
| 4 | 1406 | 36429.45 | 38981 | 18.4 | 37389 | 22.57 | 35756 | 51.1058 |
| 5 | 1480 | 37672.97 | 39935 | 19.32 | 39017 | 23.83 | 36269 | 39.0882 |
| 6 | 1628 | 41415.96 | 43455 | 25.64 | 42091 | 28.08 | 39422 | 28.7674 |
| 7 | 1702 | 43115 | 44572 | 30.22 | 43714 | 31.83 | 41828 | 39.6586 |
| 8 | 1776 | 44375.06 | 46477 | 32.47 | 45368 | 37.48 | 42974 | 26.323 |
| 9 | 1924 | 48576.93 | 50808 | 35.76 | 49466 | 41.47 | 46922 | 34.386 |
| 10 | 2072 | 52039.39 | 53626 | 43.73 | 53331 | 49.4 | 49463 | 39.9106 |
| 11 | 2146 | 54036.43 | 54943 | 46.83 | 54919 | 51.57 | 52094 | 50.5946 |
| 12 | 2220 | 55636.69 | 57176 | 49.94 | 56920 | 58.87 | 53903 | 64.4348 |
| 13 | 2072 | 51834.41 | 53397 | 43.32 | 52615 | 49.39 | 49636 | 56.2536 |
| 14 | 1924 | 48215.01 | 49927 | 38.72 | 49134 | 44.35 | 46922 | 34.386 |
| 15 | 1776 | 45505.05 | 46782 | 35.56 | 45554 | 38.56 | 42974 | 26.323 |
| 16 | 1554 | 40209.21 | 41208 | 26.95 | 40673 | 29.58 | 37088 | 46.6424 |
| 17 | 1480 | 38157.08 | 40128 | 24.22 | 38584 | 27.03 | 36066 | 23.7192 |
| 18 | 1628 | 41496.73 | 43226 | 27.74 | 42070 | 31.31 | 39422 | 28.7674 |
| 19 | 1776 | 44635.63 | 46344 | 30.99 | 45512 | 37.55 | 42974 | 26.323 |
| 20 | 2072 | 51905.56 | 54438 | 43.74 | 52811 | 51.51 | 49463 | 39.9106 |
| 21 | 1924 | 47954.14 | 49742 | 39.62 | 48776 | 46.53 | 46922 | 34.386 |
| 22 | 1628 | 41555.34 | 42735 | 27.28 | 42512 | 32.92 | 39422 | 28.7674 |
| 23 | 1332 | 34863.14 | 35931 | 17.5 | 35619 | 21.62 | 34325 | 49.466 |
| 24 | 1184 | 31893.85 | 32492 | 14.57 | 31887 | 17.64 | 30407 | 49.8848 |

From Fig. 4, it can be observed that unit P1 shares the maximum load of the total load demand per day and P9 shares the minimum power of the total demand. The total fuel cost to generate each load demand and the respective computational time is given in Table 4b. For a minimum load demand of 1036 MW, the fuel cost is 25756 $ $h^{-1}$ and the fuel cost is 53903 $ $h^{-1}$ for the maximum load demand of 2220 MW during the twelfth h. The total fuel cost to generate a power of 40108 MW per day is 977972 $. The computational time of the algorithm for generating the schedule for 24 h is 72.5106 seconds and the average time per h is 3.02 sec.

**Comparative analysis:** Table 5 presents a comparison of the total cost and power loss obtained from proposed GA-ABC algorithm with that of Enhanced Particle Swarm Optimization with Gaussian Mutation (EPSO-GM), Ant Directed Hybrid Differential Evolution (ADHDE) and ABC techniques. It is observed that the proposed method yields better results than the compared state-of-the-art methods, thus satisfying all the constraints considered in this work. Losses during h 8, 10, 14, 15, 17, 18, 19, 20 and 21 are comparatively less than the loss obtained through ADHDE and ABC methods. The total fuel cost of the 10 unit system obtained through the proposed method is also compared as shown in Table 6 with EPSO-GM (Sriyanyong, 2008a,b), ADHDE, ABC (Hemamalini and Simon, 2010), EP (Attaviriyanupap *et al.*, 2002), SQP (Attaviriyanupap *et al.*, 2002), EP-SQP (Attaviriyanupap *et al.*, 2002), MHEP-SQP (Victoire and Jeyakumar, 2005a), PSO-SQP (Victoire and Jeyakumar, 2005a), PSO-SQP (Victoire and Jeyakumar, 2005b), DGPSO

Table 6: Total fuel cost comparison for ten unit system

| Technique | Fuel cost ($ $h^{-1}$) |
|---|---|
| EPSO-GM | 1023691.11 |
| ADHDE | 1062372 |
| ABC | 1043378 |
| EP | 1048638 |
| SQP | 1051163 |
| EP-SQP | 1031746 |
| MHEP-SQP | 1028924 |
| PSO-SQP | 1030773 |
| PSO-SQP(C) | 1027334 |
| DGPSO | 1028835 |
| EPSO | 1023772.46 |
| Proposed | 977972 |

(Victoire and Jeyakumar, 2005c) and EPSO (Sriyanyong, 2008a,b) methods. The minimum cost obtained so far in literature was 1023691.11 $ $h^{-1}$ (EPSO-GM technique) which is higher by 45719.11 $ $h^{-1}$ than that obtained through GA-ABC method.

**Summary of results:** From the analysis of the results obtained by applying the GA-ABC algorithm to the Six-unit and the Ten-unit system, it can be concluded that the algorithm provides optimal solution to the Unit commitment and Economic Load Dispatch problem in terms of solution quality, robustness and algorithmic efficiency are summarized in this section.

Solution quality is justified based on the optimizing parameters that include total operating cost and the execution time. Robustness of an algorithm can be evaluated by testing the developed technique on different input cases. Results obtained to the UC-ELD problem reveals that the technique is highly robust as it generates optimal solution for different test cases. Robustness of an algorithm can also be judged through repetitive runs in order to verify the consistency of the algorithm. To measure the robustness, the frequency of convergence to the minimum cost at different ranges of generation cost with fixed load demand is recorded. Experimental results show that the frequency of convergence for a 6 unit system and a 10 unit system using GA-ABC, towards the optimal fuel cost was 30 out of 30 trial runs for all power demands.

Algorithmic efficiency can be thought of as analogous to engineering productivity for a repeating or continuous process in order to minimize time taken for completion to some acceptable optimal level. The most frequently encountered and measurable metric of an algorithm is the speed or execution time. In addition to yielding optimal solution in terms of minimum fuel cost, the algorithm was tested for efficiency in terms of the time taken for completion of the MATLAB code with the sub-functions used. The convergence of an algorithm is determined by the number of iterations required to generate an optimal solution. Since convergence rate is proportional to the execution time of the algorithm, it highly influences the algorithmic efficiency of a technique. The efficiency of GA-ABC technique was 91.45% for a six unit test system and 94.80% for a ten unit system.

## CONCLUSION

Unit Commitment (UC) and Economic Load Dispatch (ELD) problem has a significant influence on secure and economic operation of power systems. Optimal commitment scheduling and dispatching can save huge amount of costs to electric utilities thus improving reliability of operation. This study presents a novel approach based on GA and ABC for solving the Unit Commitment and Economic Load Dispatch problem. The algorithm is based mainly on ABC algorithm, whereas the GA method is used to generate new members in the population to guide the search towards the optimal solution. The use of genetic scheme improves the performance of coding the combination of units and to arrange the ON/OFF status of the units. PSO is used for power output estimation and to locate the global optimal solution by fine tuning the search process. The implementation is tested on IEEE 30 bus and ten unit test systems. The results proved the effectiveness of the algorithm for UC-ELD problems with reduced production cost. In addition, GA-ABC technique provides optimal solution in terms of total fuel cost, execution time, mean cost and algorithmic efficiency. In future, efforts will be taken to impose complex real time constraints to the UC-ELD problem that include spinning reserves, emission constraint and network security on the UC-ELD problem. This application can also be solved using new optimization techniques like Stud Genetic Algorithm, Population-based incremental learning, Intelligent water drop algorithm, Bio-Geography based algorithm and hybrid combination of these paradigms.

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