A Hybrid ABC-GA Solution for the Economic Dispatch of Generation in Power System

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ABSTRACT
The power system optimization is one of the most important aspects of power engineering with respect to cost. The running cost of the thermal power plant is high. The main objective of this paper is to minimize the total fuel cost of the thermal power plant. Economic dispatch is the optimal allocation of power to various generating units satisfying power system constraints such that the minimum overall fuel cost is achieved. This paper proposes a novel heuristic hybrid optimization method designed to solve the economic dispatch problem in power systems. The proposed methodology improves the overall search capability of two powerful heuristic optimization algorithms: Artificial Bee colony (ABC) and Genetic Algorithm (GA). Here, the minimum fuel cost of thermal power plant with six generators is determined using a hybrid ABC-GA technique and is proved to give less cost than GA and ABC. The proposed technique is implemented using optimization toolbox in the MATLAB environment.

General Terms
Objective Function, Equality Constraints, Transmission Constraints, Generation Limit Constraints, Ramp Rate Limit Constraints, Prohibited Operating Zones (POZ) Constraints.

Keywords
Economic Load Dispatch (ELD), Artificial Bee Colony (ABC), Genetic Algorithm (GA), Hybrid Model.

1. INTRODUCTION
Economic dispatch of generation in power systems is one of the most important optimization problems. The fuel cost component is still the major part of the variable cost of electricity generation, which directly influences the electricity bills. Economic dispatch aims at allocating the electricity load demand to the committed generating units in the most economic or profitable way, while continuously meeting out the physical constraints of the power system. Various mathematical programming methods and optimization techniques have previously been applied for the solution of ELD. Techniques such as Lagrange multipliers [1], linear programming [2], quadratic programming [3] and dynamic programming [4] have been used to solve the ELD problem. ELD problems are usually hard for traditional mathematical programming methodologies because of equality and inequality constraints. Genetic Algorithm (GA) [5] is one of the best optimization techniques that are used to solve the ELD problem. GA proves to be efficient in finding the near global optimal solution. The main drawback in the solution obtained by GA is the premature convergence. Thus, hybrid solutions [6] and [7] are proposed to solve this complex optimization problem. This paper proposes a hybrid optimization technique that combines Artificial Bee Colony (ABC) with Genetic Algorithm to solve ELD problem and it is proved to give the best optimal solution. This approach is flexible in adding more number of constraints with minimum transformation. The main advantages of the optimization tool proposed are reduced computational time and the robustness of the solution.

2. ECONOMIC DISPATCH PROBLEM FORMULATION
The main objective of the economic dispatch of generation in power systems is to determine the output of each generating unit based on the committed generation for the next dispatch interval such that the total generation cost is minimized, while continuously satisfying the system constraints.
The formulation of the economic dispatch problem as a single-objective optimization problem is adopted in this paper and two specific components of the optimization system are:

- Formulation of the objective function
- Formulation of the constraints

2.1 Objective Function
A convex thermal generation function is a quadratic approximation of the incremental cost curves that could include the operation maintenance cost and is of the form given by eq. (1).

$$F_{total}(P,t) = \sum_{i=1}^{n} a_i + b_i P_i(t) + c_i\left(P_i^2(t)\right) \qquad (1)$$

where,

$F_{total}(P,t)$: total generation cost,
a_i, b_i and c_i : fuel cost coefficients of unit 'i',
$P_i(t)$: output power of the i^{th} unit,
n : number of generators in the system, all reported at the dispatch period 't'.

2.2 Constraints
2.2.1 Equality Constraints
The total electric power generation has to meet the total electric power demand and the real power losses. Hence,

$$P_{Loss}(t) + P_D(t) - \sum_{i=1}^{n} P_i(t) = 0 \qquad (2)$$

where,

$P_D(t)$: load demand for the dispatch period t,
$P_{Loss}(t)$: transmission losses associated with the power flow for the dispatch period 't'.

2.2.2 Transmission Constraints
The transmission power losses can be computed through power flow computation (DC or AC approach). However, for simplification of the problem, the total transmission loss is approximated either as a quadratic function of the power output of generating units (known as *Kron's loss formula*) or through a simplified linear formula. The quadratic representation of the *Kron's loss formula* adopted in this paper is expressed as in eq. (3).

$$P_{Loss}(t) = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i(t)B_{ij}P_j(t) + \sum_{i=1}^{n} B_{i0}P_i(t) + B_{00} \quad (3)$$

where,

B : Transmission loss coefficient matrix.

2.2.3 Generation Limit Constraints
For stable operation, the real power output of each generator is restricted by lower and upper limits as in eq. (4).

$$P_i^{min} \le P_i(t) \le P_i^{max} \quad (4)$$

where,

P_i^{min} : minimum active power output of unit 'i',

P_i^{max} : maximum active power output of unit 'i'.

2.2.4 Ramp Rate Limit Constraints
Increasing or decreasing the output generation of each unit is restricted to an amount of power over a time interval due to the physical limitations of each unit. The generator ramp rate limits change the effective real power operating limits as given by equations (5) and (6).

$$\max\left(P_i^{min}, P_i(t-1) - DR_i\right) \le P_i(t) \quad (5)$$

$$P_i(t) \le \min(P_i^{max}, P_i(t-1) + UR_i) \quad (6)$$

where,

$P_i(t-1)$: output power of generator in the previous dispatch,

DR_i : ramp-down rate limit of unit 'i',

UR_i : ramp-up rate limit of unit 'i'.

2.2.5 Prohibited Operating Zones (POZ) Constraints
Modern generators with valve point loading have many POZs [8]. Therefore, in practical operation, when adjusting the generation output P_i of unit, the operation of the unit in the prohibited zones must be avoided. The feasible operating zones of unit can be described as in equations (7), (8) and (9).

$$P_i^{min} \le P_i(t) \le P_{i,1}^{LB} \quad (7)$$

$$P_{i,j}^{LB} \le P_i(t) \le P_{i,j}^{UB} \quad (8)$$

$$P_{i,NP_i}^{UB} \le P_i(t) \le P_i^{max} \quad (9)$$

$(j=2,3,\ldots,NP_i)$

where,

P_{ij}^{LB} : lower boundary of POZ_j of unit 'i',

P_{ij}^{UB} : upper boundary of POZ_j of unit 'i'.

3. ABC-GA FOR ELD PROBLEM
This paper focuses on the solution of ELD problem with various power system constraints, employing a hybrid method that incorporates favourable features of two powerful optimization algorithms namely ABC and GA.

3.1 Artificial Bee Colony Foraging Behaviour
ABC is an optimization technique used to solve ELD problems [9] and [10]. The variables are bounded to the limits to find the optimal decision variables and to optimize the objective function.

3.1.1 Random Solution Generation
Food sources which are in their proximity are selected by the employed bees when they move to a new location. Each employed bee associated with a food source is responsible for nectar extraction from it. The random solution generated by ABC is given by eq. (10).

$$P_i(t) = P_i^{min} + rand(0,1) * \left(P_i^{max} - P_i^{min}\right) \quad (10)$$

for $\forall\, i \in [1,2,3, \ldots n]$

In equation (10), 'rand (0, 1)' represents a random number between 0 and 1.

In order to satisfy the equality constraint, solve for slack bus power (P_1) from eq. (2) and replace it with the randomly chosen P_1.The solution is represented in matrix form as in eq. (11).

$$X_i = [P_1 P_2 P_3 P_4 P_5 \ldots P_n] \quad (11)$$

Similarly, the food source is the set of all randomly selected solutions which satisfies all the defined constraints. The food source is defined by $[X_1 X_2 X_3 X_4 \ldots . X_n]$.

3.1.2 Evaluation of Fitness of Solutions
The food sources are ranked based on the quality and quantity of their nectar. Similarly, fitness is assigned to each solution, which represents the goodness of each solution. The fitness for this minimization problem is given by eq. (12).

$$fitness = \frac{1}{1 + F_{total}(P,t)} \quad (12)$$

3.1.3 Employed Bee Phase
Each solution is handled by an employed bee and the employed bee searches for the food source in their neighbourhood and if a better food source is found, it discards its previous food source and starts exploiting the new food source until it explores a better food source. Similarly, a mutant solution is generated for each solution using its randomly selected neighbour and the parameter to be changed.

A random variable of all 'n' variables is chosen and a neighbour of all n-1 neighbours is chosen randomly and a mutant solution is produced using eq. (13).

$$P_{k\,mutant} = P_k(i) + (P_j(i) - P_k(i)) * (2 * rand - 1) \quad (13)$$

where, 'i' and 'j' are randomly chosen parameter and neighbour respectively.

A greedy selection between the mutant and original solutions takes place resulting in the discard of least fit solution. This process of selection is repeated for each solution. The solution whose mutant is less fit increases its trial and may lead to dissertation of the food source if the trial exceeds a threshold limit.

3.1.4 Onlooker Bee Phase

The onlooker bees in the hive detect a food source by means of the information presented by the employed foragers. A food source is chosen with the probability which is proportional to its food quality.

A random number is chosen which represents the expectancy of the onlooker bee and is compared with probability of a solution (food). If the solution meets the expectancy of the onlooker, then it moves to exploit the food source and becomes an employed bee and corresponding employed bee of food source retires. The new employed bee starts exploring the neighbourhood and repeats the employed bee's behaviour. If the expectancy is not reached then the onlooker chooses other food source (solution) with different expectancy until it becomes employed. The above procedure repeats till all the onlooker bees get employed to food source. The food source with highest probability will be chosen maximum and the one with least probability is discarded more times.

3.1.5 Scout Bee Phase

The scout bee is to explore the search area and it is often represented by a randomly generated solution. It will replace an employed bee if its trials of mutation exceed a threshold limit. The scout will encourage the exploration of unexplored area of the search space.

The best solution and fitness values are memorized for all iterations. The above process is repeated for maximum number of iterations and the result at the end will ensure a global minimum or maximum.

3.1.6 ABC Algorithm

- Generate 'n' random solutions within boundaries of the system using eq. (10).
- Calculate the objective function and the fitness of each solution.
- Store the best fit as Pbest solution.
- A mutant solution is formed using a randomly selected neighbour using eq. (13).
- Replace $P_{k\,mutant}$ by P_k, if the mutant has higher fitness or lower fuel cost of generation.
- Repeat the above procedure for all the solutions.
- Probability of each solution is calculated using eq. (14),

$$\text{Probability}(i) = a * \text{fitness}\frac{1}{\text{max}}(\text{fitness}) + b \qquad (14)$$

where, a+b=1.

- The solution P is selected if its probability is greater than a random number
  If (rand<probability (i))
  Solution is accepted for mutation
  Else
  Go for next solution
  Counter is incremented until the counter value becomes half of the population.
- Again the best 'Pbest' is determined.
- Replace a P by random P, if its trial counter exceeds threshold.
- Repeat the above for maximum number of iterations.
- Pbest and F(Pbest) are determined which represents the best solution and the global minimum of the objective function.

3.2 Genetic Algorithm Foraging Behaviour

The main idea behind GA is to improve a set of candidate solutions for a problem by using several genetic operators inspired from genetic evolution mechanisms observed in real life. It combines the Darwin's Survival of the Fittest principle with genetic operation, abstracted from the nature to form a robust mechanism that is very effective at finding optimal solutions to complex real world problems.

The genetic operators are selection, crossover and mutation. The selection operator selects the best member from the population which survives. The crossover operator generates two new individuals (offsprings) from two parent solutions, based on certain rules such as mixing them with a given probability. The mutation operator randomly changes a part of an individual with a certain probability.

3.2.1 Genetic Parameters

Genetic parameters manipulate the performance of GA. The genetic parameters are population size, crossover rate and mutation rate.

3.2.1.1 Population Size

The efficiency and performance of GA are affected by population size. Smaller value of population size results in poor performance i.e., it leads to premature convergence. Large population covers more solution space and prevents premature convergence to local minima. Also, large population needs more evaluation per generation and may slow down the convergence rate.

3.2.1.2 Crossover Rate

It is the rate at which the process of crossover is applied. The number of strings that undergo crossover can be depicted by a probability called crossover probability. Higher probability introduces new strings quickly into the population. If it is too high, high performance strings are eliminated faster than the improvements produced by selection. Lower probability may cause stagnations due to lower exploration rate.

3.2.1.3 Mutation Rate

It is the probability at which mutation occurs. It increases the diversity of the population. Lower probability prevents any bit position from getting trapped at a single value, whereas higher rate results in random search.

3.2.2 Step By Step Procedure

- Initial strings are randomly generated.
- Generated string is converted in the feasible range using eq. (15).

$$P_i(t) = P_i^{min} + \frac{\left(P_i^{max} - P_i^{min}\right) * Pm_i}{2^l - 1} \qquad (15)$$

where,

Pm_i : decimal-coded value of the binary string,

l : length of the string.

- Fitness of each chromosome is calculated according to the cost function and the cost function is sorted and those with the lowest cost function are selected for the next generation.
- Selected chromosomes are considered for the crossover operation.
- After the crossover operation, the new offsprings are considered for the mutation operation.

- Fitness of each new offspring is calculated and are sorted in the ascending order. The lowest cost function means better fitness. So, the offsprings with the lowest cost function values are selected for the next generation.
- Process is repeated upto the maximum number of iterations.

3.3 ABC-GA Hybrid Algorithm

In this approach, ABC algorithm is run until the stopping criterion for ABC is met. Here, the stopping criterion is maximum number of iterations. Then, the optimal values of individuals generated by the ABC are given to the GA as its starting point. Then GA is run to find the optimal power values and the minimum fuel cost of generation.

3.3.1 Pseudo-Code

1) Run ABC
2) Generate optimal values for all individuals
3) Pass these individuals to GA as starting points
4) Run GA till stopping criterion is met.

4. RESULTS AND DISCUSSION

The proposed hybrid algorithm is used to minimize the total fuel cost of IEEE six unit test system. This test system is subjected to constraints like equality constraints, transmission constraints, generation limit constraints, ramp rate constraints and POZ constraints. The data of 6 unit system [11] is given in tables 1 and 2. The power demand of 6 unit system is 1263 MW. The loss coefficients with the 100 MVA base capacity are given below:

$$B_{ij}= \begin{matrix} 0.0017 & 0.0012 & 0.0007 & -0.0001 & -0.0005 & -0.0002 \\ 0.0012 & 0.0014 & 0.0009 & 0.0001 & -0.0006 & -0.0001 \\ 0.0007 & 0.0009 & 0.0031 & 0 & -0.0010 & -0.0006 \\ -0.0001 & 0.0001 & 0 & 0.0024 & -0.0006 & -0.0008 \\ -0.0005 & -0.0006 & -0.0010 & -0.0006 & 0.0129 & -0.0002 \\ -0.0002 & -0.0001 & -0.0006 & -0.0008 & -0.0002 & 0.0150 \end{matrix}$$

$B_{0i} = 1.0e^{-03}$*[-0.3908 -0.1297 0.7047 0.0591 0.2161 -0.6635]

$B_{00} = 0.056$

The programs are implemented in MATLAB environment.

ABC control setting: Colony size=20; food number= (colony size)/2=10; trial limit=100; maximum number of cycles for foraging=1000.
GA control setting: Population size=20; crossover probability=0.8; mutation function is constraint dependent.
Fig. 1 shows the power generation of six generating units and the total fuel cost of the system using GA. In this method, GA starts it search randomly.

For hybrid technique, ABC algorithm is run until the stopping criterion is reached. The result obtained from ABC matlab code is shown in fig. 2.
The power values of six generators, determined using ABC approach are fed to GA as its initial values. Then, this hybridised GA is run to obtain the best optimal result. The fuel cost obtained from the proposed hybrid method is shown in fig. 3. The fitness value in the graph represents the total fuel cost of the system and the generation represents the number of iterations.

Table 1. Fuel cost coefficients and capacities of generating units

No.	a $/MW^2 hr	b $/MW hr	c $/hr	P_{min} (MW)	P_{max} (MW)
1	0.0070	7.0	240	100	500
2	0.0095	10.0	200	50	200
3	0.0090	8.5	220	80	300
4	0.0090	11.0	200	50	150
5	0.0080	10.5	220	50	200
6	0.0075	12.0	190	50	120

Table 2. Ramp rate limits and prohibited operating zones of generating units

No.	P_i^0 MW	UR_i MW/hr	DR_i MW/hr	Prohibited zones MW
1	440	80	120	[210 240], [350 380]
2	170	50	90	[90 110], [140 160]
3	200	65	100	[150 170], [210 240]
4	150	50	90	[80 90], [110 120]
5	190	50	90	[90 110], [140 150]
6	110	50	90	[75 85], [100 105]

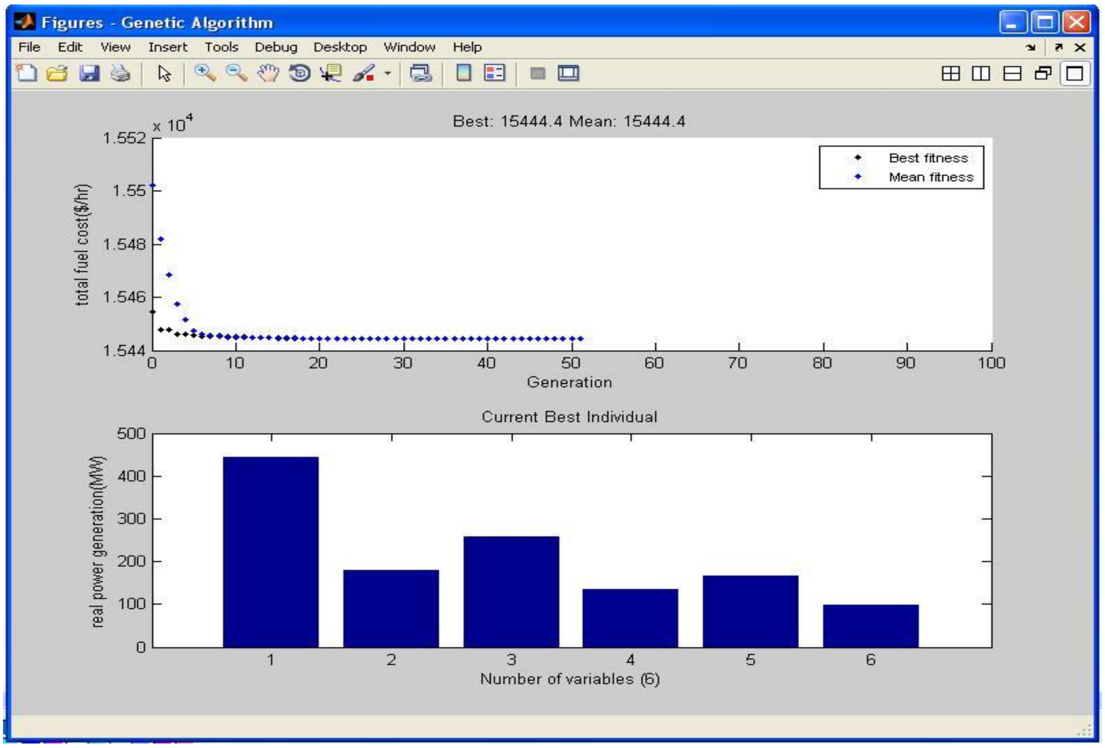

Fig 1: Solution of ELD for the considered 6 unit system using GA

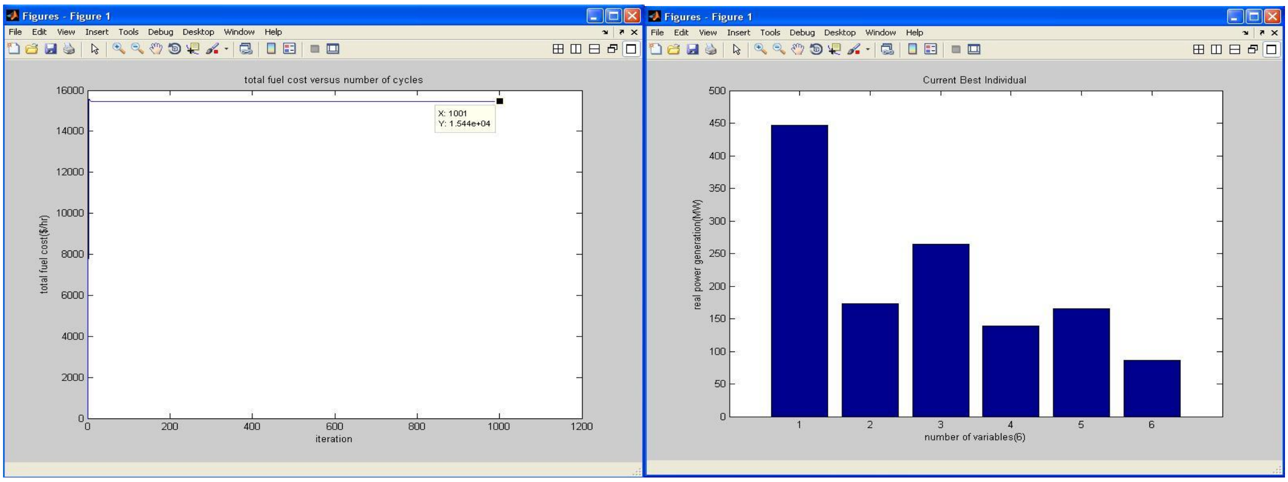

Fig 2: Solution of ELD for the considered 6 unit system using ABC

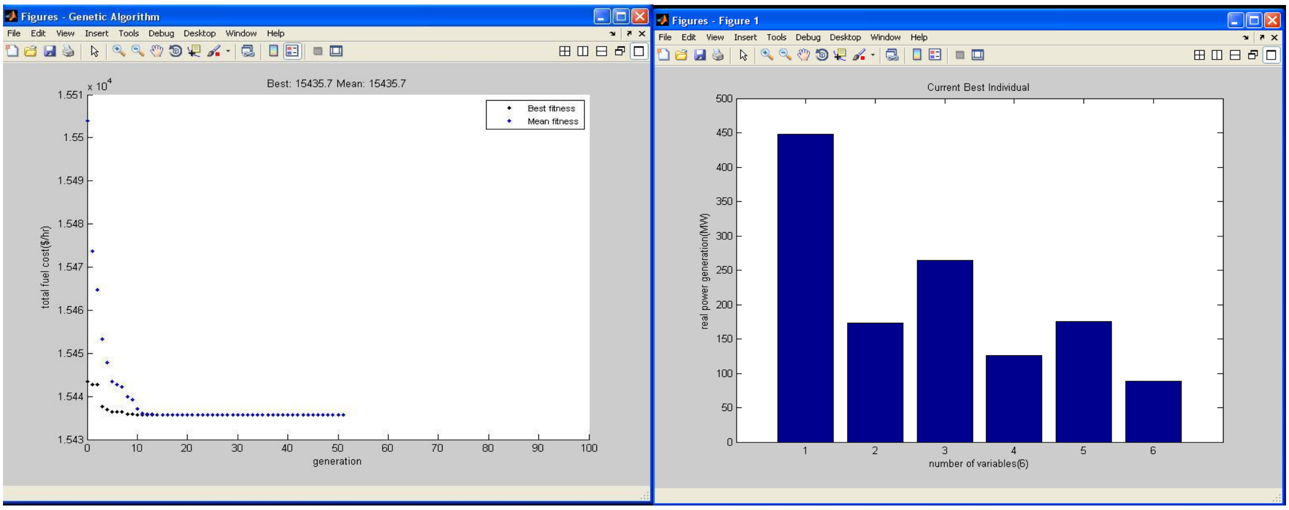

Fig 3: Convergence characteristics of fuel cost using hybrid ABC-GA

Table 3. Economic Dispatch comparison for 6 generator test system for the power demand of 1263MW

	GA	ABC	ABC-GA
P_1 MW	443.569	447.0688	448.302
P_2 MW	178.329	173.1805	173.317
P_3 MW	257.598	263.9225	264.743
P_4 MW	134.177	139.0512	125.889
P_5 MW	165.354	165.5762	174.832
P_6 MW	96.874	86.6164	88.918
P_{Loss} MW	12.8322	12.4157	12.3
F_{total} $/hr	15,444.4	15,443	15,435.7

Table 3. shows the comparison of ELD problem using GA, ABC and hybrid ABC-GA methods which implies hybrid ABC-GA produces a lower fuel cost of 7.3$/hr than ABC and 8.7$/hr lower than GA. It is found that the proposed hybrid approach gives the best optimal values.

5. CONCLUSION

This paper has formulated and implemented the hybrid ABC-GA algorithm and it is proved to improve the optimization of ELD problem. This work can be extended to higher unit system. Also, this can be applied for multi-objective optimization problem.

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