Solution of Economic Load Dispatch Problem Using Artificial Intelligence Based Advanced Algorithms

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Abstract

Power system evidently, is a complicated task to operate. This study deals with the most common problem of power system i.e., economic load dispatch problem. Economic load dispatch (ELD) is the manipulation of power generated by generating units with a formative arrangement to get more optimal values of cost. The solution of ELD problem require the rearrangement of power being generated so as to provide the required load demand with reduced cost of energy, along with the satisfaction of all the equality and inequality constrains. The principle aim of this study is the liberation of long manual calculations, required in the process of finding the optimal values, and replacing the decisive and calculative element of this complex chore to a rather more advance and comparatively much better suited methods for finding the required end result. This study, as the decisive and calculative element utilizes four methods for finding the optimal values these are Newton Raphson (NR) method, Artificial Bee Colony (ABC) algorithm, Particle Swarm Optimization (PSO), and Cuckoo Search (CS) method. For simulating a network for a small power grid in this study, IEEE-30 bus system has been utilized.

Keywords: Newton Raphson, Artificial Bee Colony, Particle Swarm Optimization, Cuckoo Search Method, Lagrangian Function, Economic Load Dispatch

1. INTRODUCTION

The main problem faced today by the power system engineers is handling the power generated with the growing demand of the consumers. The annual report of 2020 by CEA (Central Electricity Authority) states that the overall 4,871 Mega Units of energy was not met by the overall supply, though it was seen that some parts were receiving energy surplus, the reason might be inefficient power scheduling [1].

Table [1]. Data of Power Consumption and Supplied in India during 2020-21 (CEA) (MU stands for Mega Units.)

Year	Energy Required (MU)	Energy Supplied (MU)	Energy not Supplied	
			MU	%
2020-21	12,75,534	12,70,663	4,871	0.4

Today, modern power system operation is complex than ever. The load requirement mandates maintaining in-range production of voltage and frequency to operate a reliable power production and transmission system. Along with generating sufficient energy, it is needed to keep the cost of producing that energy as low as possible. In the actual energy production and transmission system, the power generation units are not located equidistant from the centre of load and their fuel prices are dissimilar as well [2]. Also under usual operation, the capacity of energy generation is always greater than the amount demanded by the load in addition to losses, leaving a considerable degree of margin for generation scheduling. In the power system, to minimize the operating cost, the first target is the real and reactive power identification during the power production of the energy production unit and finding the power scheduling correspondingly. This statement is implying that a certain power generating unit may provide real and reactive power within a predefined range to provide requisite demand of the load and production of minimized fuel cost. The problem is known as "Economic Load Dispatch" (ELD) [3]. In the designing and the functioning of the power transmission system, Optimal Power Flow (OPF) is considered the most reliable solution for the handling of issues such as Economic Load Dispatch (ELD). Optimal Power Flow is the manipulation and minimization of the losses adjoining in the power production, making the generation of energy more economical by considering some important factors, and considering environmental benefits by reducing the usage of environment-unfriendly compounds. OPF solution produces desired output by adjusting the control variables that are required by the system while also taking the satisfaction of the constraints as well under account [4]. Present computerization for finding the solutions to these problems has become much easier, different algorithms are available today which are capable of running multitudes of tasks in parallel. These methods are generally identified as computer-based mathematical techniques [5]. Different mathematical and computational operations and algorithms are now available, for finding complex, optimized solutions for linearity or non-linearity-based functions as the OPF. Some of the methods like Gradient Method [6], Interior Point Method [7]. Optimal power flow (OPF) is not into consideration of linear or differential problems. So, solving the OPF with the usage of linearly based methods may end up the solution trapped by the local optimum value [8]. During the actual run of the solution, OPF is an extreme nonlinear programming objective containing multiples of hundreds or more variables running along with nonlinear constraints [9]. Since the '60s, the origination of this formulation, multiple optimization methods are proposed and implemented for figuring the effective solution of OPF. Among the most used solutions are; given by Dommel Tinney (the reduced gradient method), and by Carpentier (the differential injection method). Non-linear programming has to solve this problem and a comparison between the execution values of these Algorithms is obtained [10]. Although, these techniques worked as expected previously when the requirements were of only linear or expressly incremental cost curves. Now, solutions for diverse values faced today needs, algorithms that can face, non-linear curves (with valve-point effect and rate limits, etc.), and cost functions with multiple optimum points. These issues make the old methods struggle and get them to stuck on local optimum solutions. To overcome these obstacles, evolutionary algorithms can be used such as Artificial Bee Colony (ABC) Algorithm, Genetic Algorithm, Particle Swarm Optimization, and Cuckoo Search Method. These algorithms can be effectively utilized to solve non-linear functions. These algorithms though not always guaranteed to provide a perfect all usable optimal solution but can provide a near-optimal value [11-18].

2. PROBLEM FORMULATION

The MW generation is allotted to the required MW demand on the particular regional grid as allocated by the Load Dispatch Centre. Load Dispatch centre for each load manipulates frequency and voltage of its own to match parallel with other generating stations and provide the required MW load demand along with the consideration of losses [11]. OPF's main task is the control variable identification that reduces the objective quadratic function related to the power output of all the generators. The mathematical formulation:

2.1. *Problem Objective*

Fuel cost-cutting with the output considered as the Real Power;

$$f = \sum_{i=1}^{NG} a_i Pg_i^2 + b_i Pg_i + c_i (\$ / h) \tag{1}$$

A single quadratic function is used to express the cost of fossil fuel used by each fuel-fired generator; the only problem is the discontinuity in the change of fuel [6]. Hence, the use of a Piecewise quadratic equation is appropriate here. Power Output with respect to fuel Cost is given by [12]:

2.2. *System Constraints*

This study follows the underneath stated equality and inequality constraints [13]:

2.2.1 Equality Constraints

$$\sum_{i=1}^{NG} Pg_i - \sum_{i=1}^{NB} Pd_i - Ploss = 0 \qquad (2)$$

$$Pg - Pd - Vi\sum_{j=1}^{NB} Vj[Gij\cos(\delta i - \delta j) + Bij\sin(\delta i - \delta j)] = 0 \qquad (3)$$

Where, i = (1… NB). NB is the number of buses. P_g is the generated real power. P_d is the actual power demand. G_{ij} and B_{ij} are conductance and susceptance respectively of the line between buses i and j.

$$P_L = \sum_{j=1}^{n}\sum_{i=1}^{n} P_i B_{ij} P_j \qquad (4)$$

Where Bij are the elements of loss co-efficient matrix B. The Lagrangian function for the above problem of economic load dispatch.

$$L(Pg_i, \lambda) = f(P_g) + \lambda(Pd + Ploss - \Sigma Pg_i) \qquad (5)$$

2.2.2 Inequality Constraints

Generator Constraints: The output power from the generation unit lies in between their maximum and lowest values:

$$Pg_i^{\min} \le Pg_i \le Pg_i^{\max} \;\_\_\_(i = 1, 2 \ldots NG) \qquad (6)$$

3. SOLUTION METHODS

3.1. *Newton Raphson (NR) Method*

Named after Isaac Newton and Joseph Raphson, it had been the most used approach which is adopted as it is flexible enough to formulate power flow algorithms used for the optimization of power systems. The concept of finding optimization of any non-linear function using gradient and Hessian matrix and Newton's iterative technique together comprise the given approach. The solution for the optimal power flow by NR method requires the creation of the Lagrangian function as shown below

$$L(z) = f(x) + \mu^T h(x) + \lambda^T g(x) \qquad (7)$$

Where Z = [x μ λ]^T, μ and λ are vectors of Lagrangian multipliers. A gradient which is Partial Derivative's vector of a Lagrangian function is then defined as follows:

$$\nabla L = [\frac{\partial L(z)}{\partial z}] \qquad (8)$$

The Hessian matrix is the second derivative of the Lagrangian function, is then defined as follows:

$$H = \nabla^2 L(z) = [\frac{\partial^2 L(z)}{\partial z_i \partial z_i}] \qquad (9)$$

The gradient of the Lagrangian function is equated to zero and finds the solution vector. At this point, the Hessian matrix should be positive definite (Eigenvalues of the Hessian matrix at that point must be positive) to ensure that the solution point is the most optimum.

3.1.1 Steps of NR Method

After calculating the Hessian & Gradient, OPF is attained using the iteration algorithm of Newton's.

Step 1: OPF operation starting, Initial guess vector, z (Generator's power output & all the Lagrange multipliers).

Step 2: Evaluation of ∇f , if ∇f =0, estimated λ corresponds to the optimum solution and depending on the sign, λ is increased or decreased.

Step 3: Gradient Calculation by Equation... (7)

Hessian of the Lagrangian by Equation... (8)

Step 4: Solving the following expression.

$$[H]\Delta z = \nabla L(z) \qquad (10)$$

Step 5: Renew the solution.

Step 6: If this value is not obtained $||\Delta z|| < \epsilon$ go back to Step 2.

3.2. *Artificial Bee Colony (ABC) Algorithm*

The ABC algorithm comes under the category of Swarm-Based Optimization Algorithms (SOAs). In SOAs instead of having one direct solution, various iterations of different solutions are contemplated for the optimum solution [14]. The Artificial Bee Colony algorithm imitates the resource-gathering tactics of Honey Bees shown in figure 1. In this algorithm there are three artificial bee groups [15]:

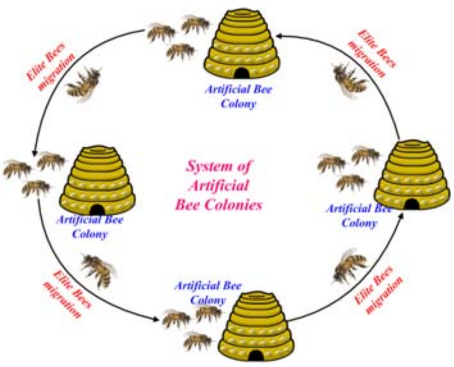


Figure 1: Artificial Bee Colony

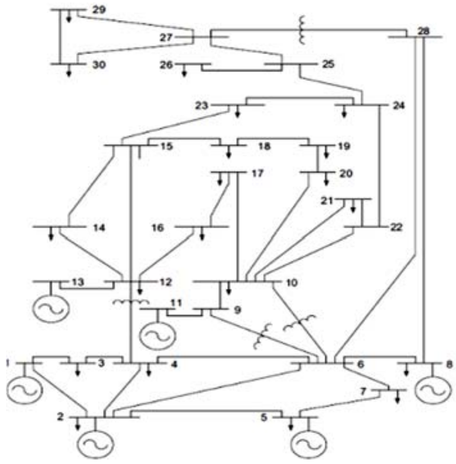


Figure 2. SLD of IEEE-30 bus system

Employed Bees: - Partial colony is distributed as the employed bee. The count of employed bees is the same as the number of resources in the system. Employed bees are responsible for resources, their details, and memorization. **Onlooker Bees:** - The other half of the colony contains the onlooker bees. Onlooker bees get their details about the present or discarded resources from the employed bees and select any one of the resources at random. **Scout Bees:** - These are the bees associated with the abandoned food sources. They are responsible for finding new food sources.

3.2.1 Optimization Algorithm

Step 1: Initialization: In a D dimensional problem space, a population solution is selected randomly. (X_i = 1,2,3………. D).

Step 2: Reproduction: A random food source is chosen by the artificial onlooker bee according to the expectation of that resource's provability, P_i [16].

$$P_i = f_i t_i \Big/ \sum_{n=1}^{N} f_i t_n \qquad (11)$$

fiti = fitness value of the solution, i = nectar amount of food source, N = number of resources = number of employed bees. For deciding a possible food position from the previous memories following expression is used.

$$V_{ij} = X_{kj} + \phi_{ij}(X_{ij} - X_{kj}) \qquad (12)$$

k = {1,2… D} and j = {1,2… N} are randomly chosen indexes.

ϕ_{ij} = randomly selected from -1 or 1.

Step 3: Replacement of Bee and Selection: After several cycles, if a source is not providing enough or is not improving to be more providing, the source is then abandoned. The number of cycles required to abandon a food source is labeled as the "limit" for desertion [17]. Left out food source is denoted by Xi and j = {1,2… N}, new food that is discovered replaces the place of the earlier Xi. The operation is defined as:

$$X_i^j = X_{min}^j + rand(0,1) * (X_{max}^j - X_{min}^j) \qquad (13)$$

When a new possible food source is found Vij, it is analyzed by the virtual bees and after judging the new food source's produce comparison is conducted between the old one and the new one. Only if the newly found resource is found to be more productive and preferable than the last one, it is decided to keep the food source as actively retained in the memory.

3.3. *Particle Swarm Optimization (PSO) [13]*

Invented by J. Kennedy and R. C. Eberhart in 1995, Particle Swarm Optimization is an algorithmic technique that simulates the social & psychological information gathering and extrapolation methods of birds and fish. It simulates how information is gathered by people in real life by communicating with different social groups and individual people hence collecting their social beliefs and opinions. PSO behaves like a person where it converges to a decision by the experience it had gathered along with others' experiences and its knowledge as well.

3.4.1 Steps of PSO.

Step 1: Initialization: Each Particle is represented as ‘i’ and every ‘i’ represents every solution for the to be optimized function. Also, as a vector representing a decisive variable, Xi.

$$X_i = X_i^{min} + rand(\,) * X_i^{max} + X_i^{min}) \qquad (14)$$

i = 1, 2, 3, …… NP, (NP is the number of particles.)

Step 2: Velocity of Particles: PSO algorithm always gives priority to the most adequate swarm and provides access towards analytically better regions of the solution space.

$$v_{ij}^{t+1} = wv_{ji}^{t} + c_1R_1\{Pbest^t - X^t\} + c_2R_2\{Pbest^t - X^t\} \qquad (15)$$

V_{ij} = velocity of j^{th} member

j = member of i^{th} particle

i = number of particle at t iteration

Gbest = global best position

Pbest = local best position

Step 3: Inertial Weight: w represents the inertial weight.

$$w = w^{max} - \frac{(w^{max} - w^{min}) * iteration}{max\ iteration} \quad (16)$$

R_1 & R_2 represent the random numbers produced between 0 & 1.

C_1 & C_2 has a range of 0 to 4. Although, they are adjusted as C_1+C_2 = 4 or C_1= C_2 = 2.

Step 4: Solution Vector: Velocity 'v' is added further after every generation of iteration.

$$X^{t+1} = X^t + v^{t+1} \quad (17)$$

3.4. *Cuckoo Search Method [13]*

Introduced by Xin-She Yang in 2009, this algorithm mimics the brooding pattern of Cuckoo birds. With a lesser number of control variables, this algorithm has the potential to easily handle the optimization of any non-linear functions effectively [18]. This method has already been applied and tested for finding discrete multi-variable OPF solutions.

3.4.1 Steps of Cuckoo Search Method

Step 1: The first population is generated randomly within the limits of control parameters. After that 'Levy flight' operation is applied to the first wave of the population.

$$X_i = X_i^{min} + rand(\,) * X_i^{max} + X_i^{min}) \quad (18)$$

(i = 1, 2, 3…. NP) 'i' is the number of eggs.

Step 2: Levy flights operator describes the phonetic flying or swimming order of manner of the cuckoo birds.

$$X^{t+1} = X^t + \alpha \oplus Levy(\lambda) \quad (19)$$

The variance of step size 'α' is between 0.1 to 0.4 [12].

Step 4: The number of cuckoos and nests are taken as constants.

Step 5: Per cuckoo single or multiple eggs are selected and are dumped at randomly chosen nests.

Step 6: The quality of nests ensures the propagation to the next generation.

Step 7: Probability of identification by the parent is given by Pa whose value ranges in between [0, 1].

4. RESULTS AND DISCUSSION

In this study, IEEE-30 bus standard test system environment is used to test the efficiency of the proposed algorithm in the active power dispatch with 5 generator buses, 1 as a slack bus, and 24 load buses with 41 transmission lines. A comparative analysis of the results obtained by all the algorithms is also given in Table [2]. Table [2] shows that before optimization, the total cost of generation was 916.29 $/hr for the demand of 283.00 MW. After optimization by the NR method as a conventional optimization method the total cost of generation is reduced to 869.68 $/hr. and ABC algorithm as an AI method resulted into least cost by 805.70 $/hr. The Fitness curve for the cost optimization using the ABC algorithm is given in figure 3.

Table [2] Effectiveness of proposed algorithm in economic active power dispatch

S. No.	Parameters	Before optimization	Optimized values by			
			NR method	PSO	CS	ABC
1	Pg1	102.62	177.07	137.547	120.727	185.05

2	Pg2	80.00	48.06	54.039	64.445	46.98
3	Pg3	50.00	20.77	40.234	49.618	20.45
4	Pg4	20.00	22.18	31.580	12.835	14.89
5	Pg5	20.00	12.23	16.989	29.998	11.84
6	Pg6	20.00	12.00	12.700	15.741	15.41
7	Total Gen. (MW)	**292.12**	**292.31**	**293.08**	**293.36**	**294.62**
8	Total Cost ($/h)	**916.29**	**869.68**	**829.543**	**824.069**	**805.70**

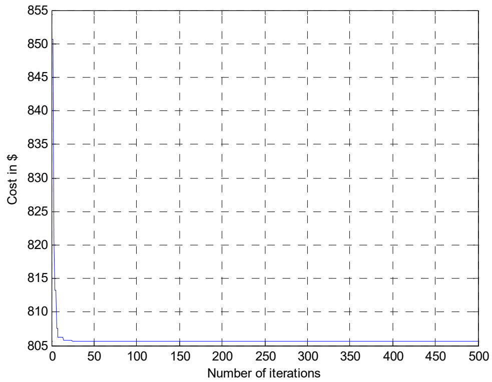
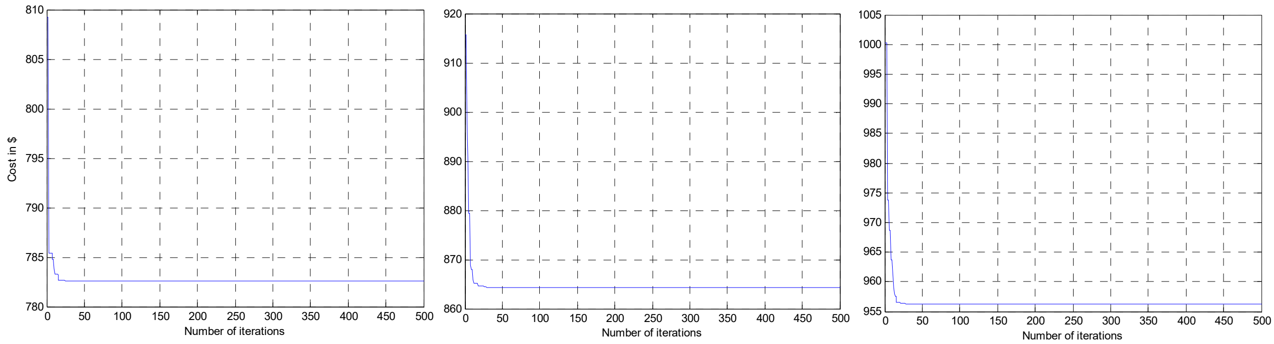


Figure 3. Fitness curve for generation cost optimization by ABC algorithm

Table [3] gives the relative comparison of generator scheduling for different demands of the IEEE 30 bus system and shows the optimized quantity of active power generation for the system. Here, the proficiency of the proposed algorithm is tested for three cases of different load demands i.e., 275MW, 300MW, and 325MW. ABC algorithm resulted in minimum fuel cost in the each case and the fitness curve for these three cases has been shown in figure 4.

Table [3]. Optimal scheduling of generators for different load conditions

S. No.	Parameters	Power Demand (MW)								
		PD= 275			**PD= 300**			**PD= 325**		
1	Un-opt. Total Cost ($/h)	838.45			947.28			1005.74		
Optimal scheduling of generators by										
		PSO	**CS**	**ABC**	**PSO**	**CS**	**ABC**	**PSO**	**CS**	**ABC**
2	Pg1	165.07	114.84	155.69	180.06	178.35	177.49	197.08	197.89	199.45
3	Pg2	48.06	62.88	46.71	51.21	50.89	52.42	52.92	49.8	44.72
4	Pg3	20.77	42.20	20.39	21.86	23.45	21.34	22.47	23.46	25.19
5	Pg4	22.18	18.64	34.87	29.35	27.96	29.75	33.25	27.50	21.67
6	Pg5	12.23	26.21	11.57	14.67	15.47	12.78	16.01	19.81	23.69
7	Pg6	12.00	17.26	14.13	13.59	14.12	16.58	14.87	17.75	20.63
8	Total Gen.	280.31	282.03	283.36	310.74	310.56	310.38	336.52	335.97	335.38
9	Opt. Total Cost ($/h)	**798.68**	**791.08**	**782.62**	**898.46**	**871.96**	**864.32**	**976.27**	**961.23**	**955.39**



(a) (b) (c)

Figure 4. Fitness curve by ABC algorithm for demands a) 275 MW, b) 300MW, c)325 MW.

5. CONCLUSION

In this paper, a conventional technique i.e., Newton Raphson along with comparatively recent techniques i.e. Artificial Bee Colony (ABC) algorithm, Particle Swarm Optimization (PSO), and Cuckoo Search (CS) method has been used to solve the problem of ELD. All the algorithms are enacted on MATLAB software and eminently applied to reduce the cost of real power generation by optimized relocating the power generating units with subjecting to load balance equation as equality constraint. The stated techniques had been tested on the standard test environment of the IEEE-30 bus system with different cases of power demand. In the case of power demand 283 MW, the conventional method of optimization minimized the fuel cost by 5.06% compared with power flow solutions. In comparison of this ABC algorithm as an recent technique of artificial intelligence resulted into highest cost saving by 12.10%. The proposed algorithm proved its efficiency in the reduction of fuel cost of power generation in all the cases of power demand under study.

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