Active Power Dispatch Planning Using Differential Evolution Algorithm

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***Abstract*—Economic Load Dispatch is an integral part of power system generation planning and it is of utmost importance for the electrical utilities and power engineers to explore this area in short and long term planning scenarios. Load demand requirements subjected to economic feasible solutions matching voltage profile, power demand, minimization of losses, voltage stability and improve the capacity of the system is the need of the hour. Optimization techniques based on evolutionary computing, artificial intelligence, search method finds their applications in the area of economic load dispatch planning to reach global optimal solution for this multi-decision, multi-objective combinatorial problem subjected to different constraints. In this paper, Differential Evolution based algorithm has been proposed to solve economic dispatch problem. Unlike other heuristic algorithms, Differential Evolution possesses a flexible and well-balanced mutation operator to enhance and adapt the global and fine tune local search. The Differential Evolution algorithm starts by initialization in first iteration. The next step is mutation where addition, subtraction and multiplication are done to achieve target population from donor population starting with initial count. Mutation operator in general works well within bandwidth of 0 to 1. Similarly, crossover is benchmarked in this slab to promote the promising results. Exponential cross over is chosen for recombination. Recombination results in trial version of generated population vector for next generation. The suggested technique is tested on IEEE 25 bus system. Test results are compared with other techniques presented in literature. Test results appeals for further investigation of differential evolution in active load dispatch problem.**

***Index Terms*—differential evolution (DE), Unit commitment (UC), economic dispatch (ED)**

I. Introduction

The economic dispatch (ED) problem is one of the most important areas of today's power system. The purpose of the ED is to find the optimum generation among the existing units, such that the total generation cost is minimized while simultaneously satisfying the power balance equations and various other constraints in the system. Below are the suggested techniques in the literature.

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Amudha A. *et al* [1] solved unit commitment problem using worst fit algorithm considering the effect of reserve on profit basis .Bavafa M. *et al* [2] implemented a hybrid approach based on lagrange algorithm with evolutionary and quadratic programming for short thermal unit commitment considering ramp rate constraint. Catalao J. S. *et al* [3] proposed a profit based unit commitment with constraints of emission limitation. A trade off has been done between profit and emission in order to assist decision makers. Chang G.W. *et al* [4] proposed a mixed integer linear programming method for unit commitment optimization. This approach is suitable for both traditional and deregulated environment. Christober C. *et al* [5] coined an algorithm based on genetic algorithm to minimize the total operating cost. It uses standard reproduction, cross over and mutation operators for the optimization. Christober C. *et al* [6] proposed a neural network based tabu search for unit commitment optimization which is more efficient than conventional tabu search. Christober C. *et al* [7] presented approach based on evolutionary programming simulated annealing method considering cooling and banking constraints for cost minimization. Fei L. and Jinghua L. [8] designed algorithm based on local search which combines interior search method for large power system. Ganguly D. *et al* [9] proposed a new genetic approach based on parallel system to handle impossible solution in an organized fashion for thermal unit commitment. Barquin J. [10] proposed an algorithm for self unit commitment for day ahead market based on simple bids. Iguchi M. and Yamashiro S. [11] implemented an efficient scheduling method for hydro-thermal units considering the account of transmission network. It consists of different stages and constraints are relaxed at every stage and transmission losses are calculated at every stage. Im T.S and Ongsakul W. [12] implemented an Ant colony search algorithm based on new co-operative agent approach for economic dispatch and unit commitment. Jenkins L. [13] implemented four hybrid algorithms based on simulated annealing, local search, tabu search, dynamic programming and genetic algorithms and compared the cost with earlier literature. Klir J. *et al* [14] presented different fuzzy techniques for optimization. Gonzalez J. G and Kuan E. *et al* [15] implemented an algorithm for

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unit commitment optimization considering the complete network modeling and bender method is employed to decompose the problem into integer and continuous variables. Larsen T. J. *et al* [16] developed a model based on sequential time step. It decomposes the problem at every time step and is solved by free marked model. Liang R.H. and Kang F.C.[17] proposed an extended mean field annealing neural network approach to solve short term unit commitment problem which is tested on Taiwan power system. Liao G.C. and Tsao T. P. [18] introduced hybrid algorithm based on fuzzy logic, tabu search and genetic algorithm to solve short term unit commitment results in reduction in computation time. Liao G.C. and Tsao T. P. [19] implemented an algorithm based on genetic algorithm and Meta Heuristic method for unit commitment problem. It includes genetic algorithm, fuzzy logic and simulated annealing to determine shutdown and startup schedule. Maojun L. and Tiaosheng T. [20] proposed a modified genetic algorithm with three genetic operators called Gene Complementary Genetic Algorithm. Momoh J. A. and Zhang Y. [21] proposed a unit commitment method based on adaptive dynamic programming algorithm. Nagrath and Kothari [22] presented different aspects of power system analysis. Norhamim *et al* [23] presented a approach for cost minimization based on unit commitment and economic dispatch in large scale power system and comparison has been done with lagrange algorithm. Senjyu Pappala V.S. and Erlich I. [24] proposed a new approach based on adaptive particle swarm optimization. It results in reduction in no. of decision variables. Park J. D. *et al* [25] proposed an algorithm based on the effect of economic dispatch and consideration of ramp constraints. It reduces the generation level of less efficient units by commiting additional units or by economic dispatch. J. D. *et al* [26] did the stochastic analysis based on uneven load demand on hour basis with the consideration of hit rate of units. Raglend I. J. *et al* [27] proposed an algorithm including operational, power flow and environmental constraints to plan secure and economic generation schedule. Rampriya B. *et al* [28] proposed a method in deregulated power system based on lagrangian firefly algorithm for profit based unit commitment. Saber A. Y. *et al* [29] introduced algorithm based on fuzzy adaptive particle swarm optimization approach. It tracks continuously changing solutions. Sadati N. *et al* [30] proposed a technique based on particle swarm fusion with simulated annealing for unit commitment optimization. It performs two functions unit schedule and economic dispatch. Seifi H. [31] presented different issues in power system planning. Senjyu T. *et al* [32] implemented an algorithm based on genetic algorithm for large scale unit commitment with the consideration of new genetic operator and unit integration technique. Senjyu T. *et al* [33] presented a genetic algorithm based on unit. Characteristics classification. Numerical results for system of up to 100 units are compared to previously reported results. Simopoulos D. N *et al* [34] implemented an enhanced simulated annealing algorithm for unit commitment problem combined with dynamic economic dispatch. Sriyanyong P. and Song Y. H. [35] proposed a hybrid algorithm based on Particle Swarm Optimization and Lagrange and performed on various 4 and 10 unit systems. Vasan H. P [36] presented hopefield neural network approach for unit commitment and economic dispatch problem. Wang B. *et al* [37] implemented algorithm for rescheduling of units in fuzzy logic. They proposed a heuristic algorithm called local convergence averse binary particle swarm optimization to solve the unit commitment problem. Wang M. *et al* [38] proposed a technique considering various constraints for the optimization of unit commitment. It uses the combination of dynamic programming with economic dispatch and comparison with lagrange algorithm has been done. Woods and Woolenberg [39] shared different scenarios of operation and control of power system. Zheng H. and Gou B. [40] designed new algorithm based on ON-OFF unit schedule by using lagrange algorithm which is superior than dynamic programming. Zhu [41] presented different optimization methods of power system. Navpreet Singh Tung *et al* [42], [43] introduced various unit commitment aspects. Hamid Boujeboudja [44] proposed real coded genetic algorithm for unit commitment problem.

II. Problem Formulation

The ED problem may be expressed by minimizing the fuel cost of generator units under constraints. Depending on load variations, the output of generators has to be changed to meet the balance between loads and generation of a power system. The power system model consists of n generating units already connected to the system.

The ED problem can be expressed as.

A. *Fuel Cost Model*

$C(P_{Gi}) = \Sigma\,(a_i * P_{Gi}{}^2 + b_i * P_{Gi} + c_i)$Rs where i=1…..N

B. *B. Constraints*

- $\Sigma P_{Gi} - P_D - P_L = 0$
- $P_{Gi,min} \le P_{Gi} \le P_{Gi,max}$ where i=1,2……N

C. *Minimization*

Total Operating Cost=C

D. *Transmission* Losses

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{Gi} B_{ij} P_{Gj} + \sum_{i=1}^{N} B_{0i} P_{Gi} + B_{00}$$

III. Differential Evolution

The Differential Evolution (DE) [45] algorithm was introduced by Storn and Price in 1995. DE is a version of an evolutionary algorithm which operates in continuous search spaces. DE is based on four main steps:

Initialization, mutation, recombination and selection. While the initialization step is only compiled in the initial iteration,the other three steps take place in each iteration. All individuals pass through these operations.

The chromosomes of an individual are built up of real valued genes, $X_{p,q,r}$ (where q is the index of the parameter, p is the index of the individual and r shows the generation number), each of which maps to the parameters of the problem to be optimized.

All individuals in the population, called the *target vectors*, go through the phase of mutation and recombination. There are several mutation operators. One f the most commonly used forms of these operators, the DE/rand/1 method, chooses three different vectors from the population and creates a mutant vector from these, called the *donor vector*, through the equation given below.

$$V_{i,g} = X_{r0,g} + Q(X_{r1,g} - X_{r2,g})$$

Q (step size) takes values in the range (0, 1). Next Step is recombination. The aim of the recombination operation is to create a different vector based on the donor and the target vectors.

The parameters of this vector are taken from the target vector when a uniformly distributed random number is greater than a predefined *cross over* value; otherwise, it is taken from the donor vector [45] as shown:

$$U_{j,i,g} = \begin{cases} V_{j,i,g} & if\left(rand_j(0,1) \le Cr\, or\; j = j_{rand}\right) \\ X_{j,i,g} & otherwise \end{cases}$$

There are two proposed ways to implement this step: binomial and exponential. The binomial crossover operation evaluates each parameter in a vector separately; however in the exponential crossover operation after (randj (0, 1) ≤ Cr) becomes true for the first time, the remaining parameters are taken from the donor vector as a block. The exponential crossover operator is chosen in this study. Cr (crossover) takes values in the range [0, 1]. The vector that is created through the recombination step is called the *trial vector*. In the selection step, either the target vector or the trial vector is chosen for the next generation as shown below.

$$X_{i,g+1} = \begin{cases} U_{i,g} & if\left(fitness\left(V_{i,g}\right) \le fitness\left(X_{i,g}\right)\right) \\ X_{i,g} & otherwise \end{cases}$$

These steps continue until an optimal solution is found or a predefined number of maximum iterations has been reached.

IV. Active Power Dispatch Using Differential Evolution

A. Variables

Power Generation (PG) and cost coefficients (a, b, c) of units with objective function as fuel cost, quadratic in nature. Power Generation variable should be initialized as starting point for DE algorithm.

B. Constraints

Equality Constraints: Power Generation-Power Demand-Power losses=0(P_G-P_d-P_L)

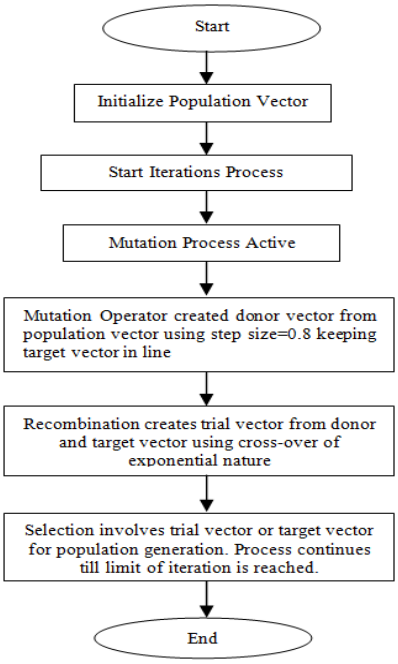
In-Equality Constraints: Power Generation should be between minimum and maximum limit of power generation.

Variables in constraints should be incorporated in differential evolution algorithm.

C. Stopping Criteria

It can be maximum limit of iterations or any other benchmark for optimum solution.

Flow Chart of DE



V. Simulation Results

This proposed approach is tested on IEEE 25 bus system [44]. Simulation results are achieved and compared with other techniques presented in literature.

TABLE I. Power Generation, Total Cost and Computational Time Using DE

PG1(MW)	212.2441
PG2(MW)	122.7887
PG3(MW)	140.3052
PG4(MW)	27.258
PG5(MW)	268.3662
Cost($/hr)	2009.3145
Time(Sec)	7

TABLE II. Results Comparison with Other Techniques [44]

Parameters	DE	RCGAs	BCGAs	BFGS
PG1(MW)	212.2441	213.68	206.72	211.30
PG2(MW)	122.7887	127.46	121.64	126.30
PG3(MW)	140.3052	141.93	151.82	151.29
PG4(MW)	27.2958	29.53	33.21	71.24
PG5(MW)	268.3662	258.86	258.05	211.31
Cost($/hr)	2009.3145	2010.8	2011.0	2029.3
Time(Sec)	7	1.6	4.78	0.0

TABLE III. DE Algorithm Parameter Setup for Optimal Solution

Iterations	Step Size	Cross Over	Number of Populations	Best Value
10	0.8	0.8	20	2009.5464
20	0.8	0.8	20	2009.3383

30	0.8	0.8	20	2009.3186
40	0.8	0.8	20	2009.3149
50	0.8	0.8	20	2009.3145
60	0.8	0.8	20	2009.3146

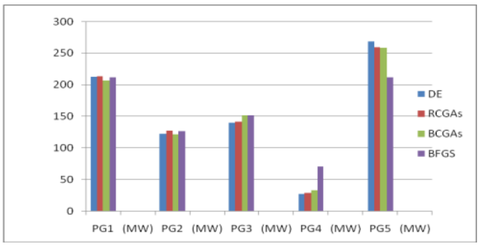


Figure. 1. Power generation comparison

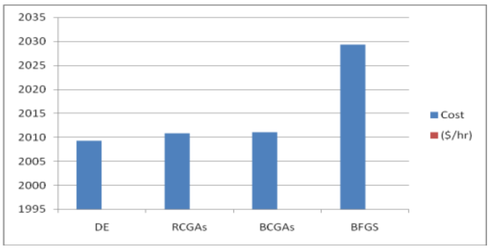


Figure. 2. Comparison of total operating cost

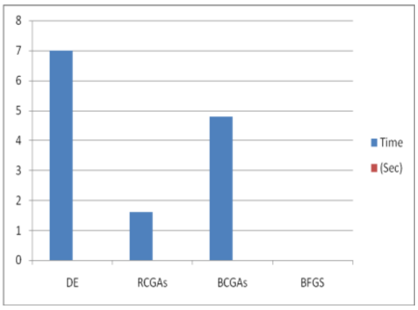


Figure. 3. Comparison of CPU computation time

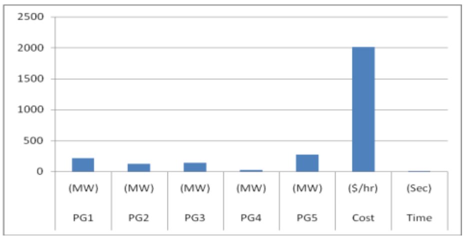


Figure. 4. Parameter's analysis using DE

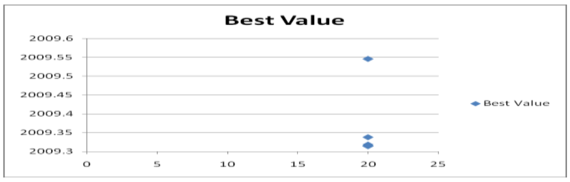


Figure. 5 Best value using DE

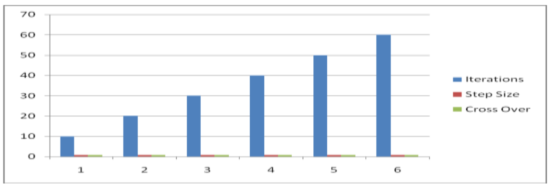


Figure. 6 Iterations, step size and cross over using DE

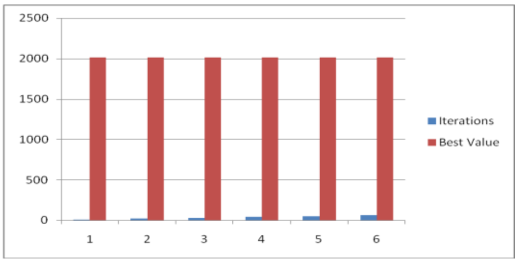


Figure. 7 Iterations and best value using DE

VI. Conclusion

An application of evolutionary techniques in economic load dispatch planning optimization has been inherently evolving for last few decades. Different evolutionary methods whether stand alone or hybrid in nature have been developed and successfully applied to economic load dispatch area. In the current research, an application of DE algorithm has been applied successfully for economic load dispatch problem. Proposed technique is tested on IEEE 25 bus system. Test results reveal the minimum operating cost, optimum power generation and high speed convergence of solution. A comparison has been made other techniques presented in literature. It out-performs other techniques presented in literature. Hence, DE algorithm is more robust and lead to optimal solution in economic dispatch problem.

VII. Future Scope

Future studies involve the extension of DE leads to the formulation of hybrid algorithm to polish the search capacity of the proposed technique as well as fast convergence for optimal solution with incorporation of more constraints.

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NOMENCLATURE

N Number of units
P_D Power Demand
P_{Gmax} Maximum limit of Unit
P_{Gmin} Minimum Limit of Unit
P_G Power Generation
C Total Cost
P_L Power Losses
a,b,c Cost Coefficients
B Loss Coefficients

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