DE Algorithm to solve CEED power system problem

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Abstract

Differential Evolution (DE) algorithm is a modern heuristic algorithm has ability to solve complex, non convex and non differential problems. In this paper DE is used to solve a complex power system problem, Combined Economic Emission Dispatch (CEED). CEED has two objectives, one is to minimize generation cost and another one is minimize emission level. Price penalty factor is used to convert these two objectives problem into single objective problem and subjected to equality and inequality constraints. Proposed DE result is compared with other heuristic algorithm in the literatures, to prove its capability to solve CEED problem. In addition to this one new constraint, reactive power limit is added to the problem for the practical application. For generation cost, quadratic cost equation with valve point effect is used and for emission calculation 5 coefficients quadratic emission function is considered. Standard IEEE 30 bus, power system having 6 thermal power plants, is considered to validate the simulation.

Keywords - differential evolution, economic load dispatch, emission dispatch, ceed, newton raphson power flow

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I. Introduction

Rainer Storn R and Kenneth Price proposed novel heuristic algorithm called Differential Evolution (DE) in1997 [16], to fulfill the requirement the optimization technique. DE algorithm is intended for minimization problem which may non-differential, non-linear and multimodal. DE is Easy to implement and it has good convergence for global optimization. Suganthan P. N explains different mutation and crossover methods in DE [8]. Yong Wang, and Zixing Cai describes multi objective DE to constraint optimization problem [15].

Abido M.A solves Environmental Economic Power Dispatch using Evolutionary Algorithms [1,2,3] to find best generating cost ($/hr), best emission (tons/hr) and optimal or compromise generating cost & emission output. He considers IEEE 30 bus data, quadratic cost function and total emission of sulpher oxides SO_x and nitrogen oxides NO_x to demonstrate his simulation. Spea S. R, Abou EL Ela A. A, and Abido M.A used DE algorithm for Pareto-optimal solutions for a quadratic cost function and 5 coefficients emission cost function [5]. Anurag Gupta, Swarnkar K.K, Dr. Wadhwani S, and Dr.A.K.Wadhwani used Particle Swarm Optimization (PSO) to find optimal solution for CEED, they used quadratic cost function and 3 coefficient emission function. In this paper [6] the bi-objective problem is converted into single objective function. Venkatesh P, Gnanadass R, and Narayana Prasad Padhy used Evolutionary Programming (EP) to solve CEED with transmission line flow constraint. A novel modified price penalty factor [9] for better optimum solution. Price penalty factor is used to convert bi-objective function into single objective function, to find line flow Newton Raphson (NR) is used. Mandal K. K, and Chakraborty N used DE to solve environmentally constrained economic dispatch (ECED) problem, which uses quadratic cost function and 3 coefficient emission function. Weight factor is used to importance either for minimizing generating cost or emission [11]. Gopalakrishnan R and Dr. Krishnan A used Modified Artificial Bee Colony Optimization to solve the CEED, which uses quadratic cost function with valve point loading and 5 coefficients emission function [13]. Hemamalini S, and Sishaj P Simon used PSO to solve ECED which consider quadratic cost function with valve point loading and 5 coefficient emission function [14]. This paper uses DE to solve CEED with power balance equality and real, reactive power generation and voltage limitation inequality constraints.

II Differential Evolution

The ability of DE is to optimize nonlinear, non-continuous and non-differential real world problem [18 – 20]. It mutate vector with a help of randomly selected a pair of vector in the same population. The mutation guides the vector towards the global optimum. The distribution of the difference between randomly sampled vectors is determined by the distribution of these vectors. This enables DE function robustly and more as a generic global optimizer. DE works on population of vectors, where vector is a group of decision variables [12]. Selection of decision variable is based on their impact on the problem to be optimized. These decision variables need to be encoded and set of initial values are chosen from the solution space. By mutation and recombination new vectors are created. The selection process selects the best vectors based on the selection criterion.

A. Encoding

Encoding is the process of converting group of decision variables into vector and objective function into fitness function. Ability of DE is to operate on floating point and mixed integer makes ease of encoding decision variables into vectors. Number of decision variables is the size of the vector and each vector gives one solution from the solution space for the problem defined.

B. Mutation

The objective of mutation is to enable search diversity in the parameter space as well as to direct the existing vectors with suitable amount of parameter variation in a way that will lead to better results at a suitable time. It keeps the search robust and explores new areas in the search domain. There are 4 types of mutation [8].

DE/rand/1/ bin – $Y_i = X_{r1} + F^*(X_{r2} - X_{r3})$

DE/rand/2/bin – $Y_i = X_{r1} + F^*(X_{r2} - X_{r3}) + F^*(X_{r4} - X_{r5})$

DE/best/1/bin – $Y_i = X_{best} + F^*(X_{r1} - X_{r2})$

DE/best/2/ bin – $Y_i = X_{best} + F^*(X_{r1} - X_{r2}) + F^*(X_{r3} - X_{r4})$

r1“‘ r2“‘ r3“‘ r4“‘r5 are randomly selected

C. Crossover

It reinforces prior successes by generating child individuals out of existing individuals or vectors parameters. The cross over constant is used to determine if the newly generated individual is to be recombined. There are two types of cross over namely Binomial and Exponential [8]. To form trail vector in binomial method a random number is generated, if this value is less than the cross over constant then mutated vector variable is considered otherwise target vector variable is considered.

D. Selection

Fitness of the trail vector and the target vector is compared and the vector which has minimum objective value is selected for the next generation [10]. This keeps the population size constant for all the generation.

III. CEED Problem Formulation

Generation cost is a function of real power [21] and calculated in USD (United Sates Dollar) unit emission is also a function of real power [2] and is calculated in tons. For a single objective both should be measured in same units, so a price penalty factor is multiplied with emission which converts the unit tons into USD. Generating cost is the function of real power,

Minimize

$$C_t = \sum_{i=1}^{ng} \alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2 + \left|\zeta_i \sin\left[\lambda_i\left(P_{Gi}^{\min} - P_{Gi}\right)\right]\right| \text{ \$/hr} \quad (1)$$

Total ton/hour emission minimization [1] is the function of real power generation as given below,

$$\text{Min}\, E(P_G) = \sum_{i=1}^{ng} 10^{-2}(a_i + b_i P_{Gi} + c_i P_{Gi}^2) + d_i \exp(e_i P_{Gi}) \quad (2)$$

This two minimization objective is converted into single minimization objective function as follows,

Objective Function:

$$\text{Min } F(P_G) = C_t + h*E(P_G) \text{ \$/hour} \quad (3)$$

Where,
Ct = Total generation cost in \$/hour

$E(P_G)$ = Total emission in ton/hour

$F(P_G)$ = CEED cost in \$/hour

á, â, ã = Cost coefficients of the generator

a, b, c, d, e = Emission coefficients of the generator

P_{Gi}, Q_{Gi} = Active and Reactive power of i[th] generator

ng = Total number of generators

h = price penalty factor in \$/ton

Subject To:

Equality constraints

$$\sum_{i=1}^{ng} P_{Gi} = P_D + P_L \quad (4)$$

$$\sum_{i=1}^{ng} Q_{Gi} = Q_D + Q_L \quad (5)$$

Inequality constraints

$$V_{i(\min)} \le V_i \le V_{i(\max)} \text{ for i=1 to Nbus} \quad (6)$$

$$P_{Gi(\min)} \le P_{Gi} \le P_{Gi(\max)} \text{ for i=1 to ng} \quad (7)$$

$$Q_{Gi(\min)} \le Q_{Gi} \le Q_{Gi(\max)} \text{ for i=1 to ng} \quad (8)$$

Where,

P_{Gi}, Q_{Gi} = Active and Reactive generation of i[th] generator

P_D, Q_D = Active and Reactive demand

P_L, Q_L = Active and Reactive loss

V_i = Voltage at i[th] bus

Nbus = Number of buses

ng = Number of generators

Nbr = Number of branches or transmission lines.

IV. DE Algorithm for CEED

Standard test case IEEE 30 bus [1], [7] power system is considered. It has 6 steam generators and 41 transmission lines.

A. Encoding & Initialization

The test case has one slack generator and its real power generation (P_{G1}) is dependent variable based on system real power loss. So, the decision variables are 5 – real power generations (P_G) and 6 – generator bus voltages (V_G) are consider for a vector. 11 Number of decision variables (D) is taken and population size (NP) 66 is consider [11].

$$\text{Vector - j, } Y_j^{(G)} = [X_1^{(G)}, \ldots X_D^{(G)}] \quad (9)$$

$$\text{Population, } P = [Y_{1(G)}, \ldots \quad Y_{NP(G)}] \quad (10)$$

To incorporate the limits of equation (6) and (7) the following initialization for initial population is used, Y^{min} is the minimum limit and Y^{max} is the maximum limit of decision variables, η is random number between 0 and 1.

$$Y_j^{(0)} = Y_j^{min} + \eta_j \,(Y_j^{max} - Y_j^{min}) \text{ for } j = 1 \text{ to } D \qquad (11)$$

B. Mutation

The mutation process generate a mutate vector based on any one rule among earlier stated 4 rules [8]. In this paper 4th rule given below is consider for better divergent among the solutions

$$\text{DE/best/2/ bin} - Y_i = Y_{best} + F*(Y_{r1} - Y_{r2}) + F*(Y_{r3} - Y_{r4}) \qquad (12)$$

r1 ‘ “ r2 ‘ “ r3 ‘ “ r4 ‘ “best (13)

“best” is the global minimum in the current generation.

C. Crossover

Crossover process generate a trail vector form mutate and target vector in this case the target vector is a global minimum vector. For each decision variable a random number [0 to 1], is generated if this value is less than or equal to cross over constant (CR) than a decision variable from mutate vector is taken otherwise it is taken from target vector.

$$Y_{trail\_j}^{(G)} = \begin{cases} Y_{mutate\_j}^{(G)} \rightarrow if - \eta_j \le C_R \\ Y_{best\_j}^{(G)} \ldots\ldots\ldots otherwise \end{cases} \qquad (14)$$

D. Selection

The solution of trail vector from the crossover process and current generation best vector are compared, the vector which yield minimum value of the objective function is selected to the next generation

$$Y_i^{(G+1)} = \begin{cases} Y_{trail\_i}^{(G)} \rightarrow if \ldots f(Y_{trail\_i}^{(G)}) \le f(Y_{best\_i}^{(G)}) \\ Y_{best\_i}^{(G)} \ldots\ldots\ldots\ldots\ldots\ldots otherwise \end{cases} \qquad (15)$$

for i= 1 to NP

V. Implementation of DE Algorithm for CEED

This algorithm is implemented in MATLAB, R2010a – 32 bit version. Intel Core-2, CPU at 2.00 GHz processor is used for the installation and execution. Price penalty factor h is 1000, Number of decision variable (D) is 11, population size (NP) is 66, scaling factor value (F) is 0.9 and crossover constant (CR) value 0.3 is considered.

Developed DE algorithm for CEED uses the IEEE 30 bus data [1],[7], [14] and [17] for the validation, the values of maximum and minimum generation of generators and cost coefficient are given in Table I, Table II gives emission coefficient for the system. Minimum and maximum limit for all bus voltages is taken as 0.95pu and 1.05pu respectively. Real and reactive power demand for the system is 283.4 MW and 126.2 MVAR respectively.

TABLE I. Generator Limits & Cost Coefficients

Gen. No	P Limit (MW)		Q Limit (Mvar)		Cost Coefficients				
	Min	*Max*	*Min*	*Max*	α	β	γ	ζ	λ
1	5	50	-40	50	10	200	100	15	6.283
2	5	60	-40	50	10	150	120	10	8.976
3	5	100	-40	40	20	180	40	10	14.784
4	5	120	-10	40	10	100	60	5	20.944
5	5	100	-6	24	20	180	40	5	25.133
6	5	60	-6	24	10	150	100	5	18.480

TABLE II. Generator Emission Coefficients

Gen. No	Emission Coefficients				
	a	b	c	d	e
1	4.091	-5.554	6.490	2e-4	2.857
2	2.543	-6.047	5.638	5e-4	3.333
3	4.258	-5.094	4.586	le-6	8.000
4	5.426	-3.550	3.380	2e-3	2.000
5	4.258	-5.094	4.586	le-6	8.000
6	6.131	-5.555	5.151	le-5	6.667

VI. SIMULATION RESULTS AND DISCUSSION

Newton Raphson (NR) power flow solution is used to find real and reactive power losses and to satisfy equation (4) and (5). From NR method calculated real, reactive power losses are 1.088 MW and 5.718 Mvar respectively. Generation is 285.57 MW and 131.918 Mvar. In addition to this NR solution also satisfies other inequality constraints.

Proposed DE algorithms results for without valve point loading is compared with Strength Pareto Evolutionary Algorithm (SPEA) and PSO. PSO is compared for with valve point loading. For with and without valve point loading DE provide best solution as given in Table III.

TABLE III. Combined Economic and Emission Minimization

Gen. (MW)	Without valve point loading			With Valve point loading	
	SPEA[1]	PSO[14]	DE	PSO[14]	DE
P_{G1}	29.96	17.613	18.7185	14.089	5.48251
P_{G2}	44.74	28.188	38.785	34.415	39.9074
P_{G3}	73.27	54.079	54.0016	67.558	67.5466
P_{G4}	72.84	76.963	75.8716	83.971	66.3525
P_{G5}	11.97	65.019	55.4841	49.043	67.3228
P_{G6}	53.64	44.569	43.1681	39.797	38.9585
Fuel Cost $/hr	629.394	612.35	**612.02**	639.6507	**619.731**
Emission ton/hr	0.21043	0.20742	**0.20545**	0.21205	**0.209816**

DE algorithm convergence curve for generating cost, emission and combined emission and economic dispatch is given in figure 1. As stop criterion for convergence is taken 200, simulation is run till 200 iterations. CEED is combination of generation fuel cost and emission, is settling to low value in 150th iteration.

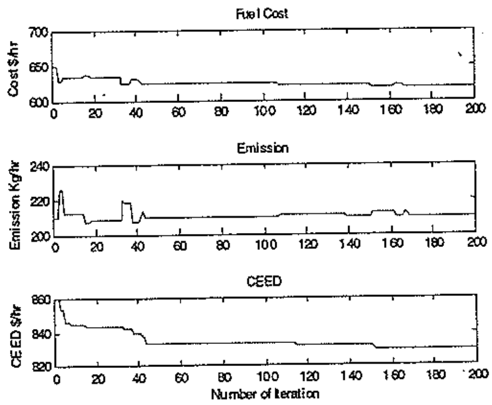

Figure 1. Convergence curve for Combined Economic Emission Dispatch

VII. Conclusion

Combined Economic Emission Dispatch (CEED) problem has bi-objective, one is to minimize generation cost and another one is to minimize emission. Intended to minimize generation cost increase emission and vice-versa. To optimize these two objectives, CEED is converted into single objective problem using price penalty factor. Differential Evolution (DE) is the efficient algorithm used to solve this CEED. To get best result fourth mutation rule of DE is implemented. The result of proposed algorithm is compared with earlier literatures and it is evident, the best result. The novel work in the paper is considered reactive power limits, actual value of real and reactive power loss are calculation.

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