Solving Economic Dispatch Problems with Practical Constraints Utilizing Differential Search Algorithm

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Abstract—**This paper presents a recent swarm intelligence technique namely Differential Search (DS) algorithm in solving Economic Dispatch (ED) problems with considering the practical constraints in power system. DS simulates the *Brownian-like random-walk* movement used by organisms to migrate. In solving ED problem, DS will find the combination of power scheduling which fulfilling the demand so that the total generation cost can be minimized without violating any constraints. To demonstrate the feasibility of the proposed DS in solving ED problems, two well-known test cases have been used: 6-units and 15-units systems; and compared with various recently published methods in literature. The results of this study show that DS is able to obtain more economical solution than those determined by other methods.**

Keywords- Differential Search; Economic Dispatch; Prohibited zones; Ramp rate limits

I. INTRODUCTION

Power system is one of the most complex systems of human inventions. It must be operated in a reliable and economical ways especially in competition of deregulation systems. The most significant problem emerged in power system from the beginning until today is economic dispatch (ED) problem. ED is the fundamental problem which aims to determine the optimal power generated by individual power producer to match the load demand at minimum cost while fulfilling the system constraints. Moreover, by considering the practical and operational constraints, the ED problems become highly nonlinear and hard to solved, especially for the larger system. Small improvement in minimizing the cost can contribute significantly to the utility or Power Company. Thus, there are a lot of researches and methods have been studied and proposed in literature to solve ED problem.

Previous solution method have been applied in solving ED through various mathematical programming and conventional optimization techniques such as lambda-iteration method, the base point and participation factors method and gradient method [1]. This follows by evolutionary methods such as genetic algorithm (GA) [1, 2] and evolutionary programming (EP) [3]. Recently, quite new intelligence/ optimization techniques called swarm intelligence emerged as a popular choice in solving ED such as particle swarm optimization (PSO) [4-7], ant colony optimization (ACO) [8, 9], artificial bee colony (ABC) [10] and firefly algorithm [11, 12]. Other than that, there are some optimization techniques mimics to the nature also have been proposed to solve ED such as harmony search [13, 14], invasive weed optimization (IWO) [15], gravitational search algorithm (GSA) [16, 17] and many more. In order to improve the performance some of the methods, several hybrid methods have been proposed in solving ED [15, 18-23].

Although the said methodologies have been developed for ED, there is necessity to develop an efficient algorithm to accurately addressing the optimum solution of ED. That is why the researches of finding ED solutions are still continuous until today. In this paper, the recent developed algorithm, viz. differential search (DS) has been applied in solving ED problems. The results demonstrate that the proposed algorithm gives the significant solution in solving ED.

The rest of this paper is organized as follows: Section 2 and 3 give a brief review on ED and DS, followed by DS implementation in solving ED in Section 4. Section 5 presents the simulation results and discussion. Finally, Section 6 draws the conclusion of the research.

II. ECONOMIC DISPATCH

In the economic dispatch (ED) problem, the cost function takes the following form:

$$\min f = \sum_{i=1}^{n} F_i(P_i) \tag{1}$$

$$F_i(P_i) = \alpha_i P_i^2 + \beta_i P_i + \gamma_i \tag{2}$$

where n is the number of generator units, α_i, β_i, and γ_i are coefficients of generator i. The cost function in (2) is subject to the power balanced constraints and individual generation limits as follow:

$$\sum_{i=1}^{n} P_i = P_D + P_L \tag{3}$$

$$P_{i(\min)} \le P_i \le P_{i(\max)} \qquad i = 1, 2,\ldots, n \tag{4}$$

where P_D is the total load demand, P_L is the total loss and n is the total number of committed generator during the dispatched hour. Since the power loss is cannot avoided in interconnected power system, it must be taken into account to achieve as closed as practical economic dispatch by using the B-coefficient method, as follows:

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$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \quad (5)$$

By considering the practical constraints, the operating range of all online units is restricted by their ramp rate limits [1]. Thus, the inequality constraints due to ramp rate limits are expressed as:

$$P_i - P_i^o \le UR_i \text{ if generation is increases} \quad (6)$$

$$P_i^o - P_i \le DR_i \text{ if generation is decreases} \quad (7)$$

where P_i^o is the previous power generation of unit *i*. UR_i and DR_i are the up-ramp and down-ramp limits in MW/h of the *i*-th generator, respectively. The generator operation constraints with the ramp rate limit now becomes as:

$$\max(P_i^{\max}, UR_i - P_i^o) \le P_i \le \min(P_i^{\max}, P_i^o - DR_i) \quad (8)$$

The other practical constraint that will be considered in this paper is the prohibited operation zones for the generators. Since the shape of the input-output curve in the neighborhood of the prohibited zone is difficult to determined, the best economical approach is achieved by avoiding the operation in these areas. The feasible operating zones of a unit can be expressed as follow [24]:

$$\begin{cases} P_i^{\min} \le P_i \le P_{i,1}^{lower} \\ P_{i,j-1}^{upper} \le P_i \le P_{i,j}^{lower}, \ j = 2,3,...,PZ_i \\ P_{i,PZ_i}^{upper} \le P_i \le P_i^{\max} \end{cases} \quad (9)$$

III. DIFFERENTIAL SEARCH ALGORITHM

DS algorithm is inspired by migration of living beings which constitute superorganisms during climate change of the year. Migration behavior allows them to move from one habitat to more efficient habitat. They start to change their position by moving toward more fruitful areas. The movement of superorganism can be described by a *Brownian-like random-walk* model [25].

It is assumed that random solution of population is corresponding to the artificial-superorganism migration to global optimum solution of the problem. During the migration, the artificial-superorganism tests whether some randomly selected position are suitable for temporarily basis. If the position tested is suitable to stop over for a temporary during the migration, the members of the artificial-superorganism that made the discovery immediately settle at the discovered position and continue their migration from this position. DS search strategy may simultaneously use more than one individual and no inclination to correctly go towards the *best* solution of the problem which makes it has a successful search strategy for finding the solution of multimodal functions. Pseudo-code of DS algorithm is shown in Fig.1.

IV. DS IMPLEMENTATION ON ECONOMIC DISPATCH PROBLEMS

In solving ED using DS, a member of an artificial-organism firstly will be initialized. This comprises of the number of generations of the system that will be optimized which resulted a minimum cost by fulfilling all the constraints. The mechanism of finding stopover site at the areas is using a random searching process. Various random processes are utilized in DS until the optimal results are found by the migration of artificial-organisms.

Equations (1)-(2) were applied in the evaluation process of the ED problem. In order to deal with the inequality constraint, i.e. upper and lower limits of each generator, normally when the solutions obtained out of these boundaries, the algorithm will choose the boundary values. For equality constraint on the other hand, viz. power balance constraint, the penalty method was used. The penalty value is reflected to the power balance mismatch and embedded in the cost function (1) as follows:

$$F = (F) + PF * abs[(\sum_{i=1}^{n} P_i) - P_D - P_L] \quad (10)$$

where *PF* is the penalty factor.

The advantage of DS is it has only two control parameter i.e. p_1 and p_2 which is normally are set to 0.3 [25] which provides the best solution. DS also is very simple. Nevertheless, to obtain good results, large number of iterations needs to be set in this algorithm.

V. SIMULATIONS AND DISCUSSION

All simulations for solving ED problem using DS are implemented using MATLAB. The proposed DS algorithm has been tested on two test system: 6-units and 15-units systems which are normally used when testing the practical ED problems.

A. 6-units system

The system comprises 26 buses including 6 thermal units and 46 transmission lines. For this study, the load demand is set to 1263 MW and the characteristics of this system can be seen in [4]. Ramp rate limits and prohibited zones of generating units data is tabulated in Table I.

TABLE I. RAMP RATE LIMITS AND PROHIBITED ZONES OF GENERATING UNITS FOR 6-UNITS TEST SYSTEM

Unit	P_i^0	UR_i (MW/h)	DR_i (MW/h)	Prohibited zones (MW)
1	440	80	120	[210 240] [350 380]
2	170	50	100	[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]

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Algorithm : Differential Search Algorithm
Require:
N: The size of the population, where i = {1,2,3,...,N}.
D: The dimension of the problem.
G: Number of maximum generation.
    Superorganism =initialize(), where Superorganism=[ArtificialOrganism_i]
    y_i = Evaluate(ArtificialOrganism_i)
    for cycle=1: G do
        donor = Superorganism_Random_Shuffling(i)
        Scale = randg[2·rand_1]·(rand_2 − rand_3)
        StopoverSite = Superorganism + Scale·(donor − Superorganism)
        p_1 = 0.3·rand_4 and p_2 = 0.3·rand_5
        if rand_6 < rand_7 then
            if rand_8 < p_1 then
            r = rand(N,D)
                for Counter1=1:N do
                    r(Counter1,:)=r(Counter1,:)< rand_9
                endfor
            else
            r = ones(N,D)
                for Counter2=1:N do
                    r(Counter2,randi(D))=r(Counter2,randi(D))< rand_10
                endfor
            endif
        else
            r=ones(N,D)
            for Counter3=1:N do
                d = randi(D,1,⌈p_2·rand·D⌉)
                for Counter4=1:size(d) do
                    r(Counter3,d(Counter4)) = 0
                endfor
            endfor
        endif
        individuals_I,J ← r_I,J > 0 | I ∈ i, J ∈ [1 D]
        StopoverSite(individuals_I,J) := Superorganism(individuals_I,J)
        if StopoverSite_i,j < low_i,j or StopoverSite_i,j > up_i,j then
            StopoverSite_i,j := rand·(up_j − low_j) + low_j
        endif
        y_StopoverSite;i = evaluate(StopoverSite_i)
        y_Superorganism;i := { y_StopoverSite;i      If y_StopoverSite;i < y_Superorganism;i
                             { y_Superorganism;i     else
        ArtificialOrganism_i := { StopoverSite_i         If y_StopoverSite;i < y_Superorganism;i
                                { ArtificialOrganism_i   else
    endfor
```

Figure 1. Pseudo code of DS algorithm [25].

The best result of DS together with other recently published methods [2, 4, 5, 24, 26] is shown in Table II. It can be noted that the result obtained operating in the non-prohibited zones and fulfill the ramp rate limits constraints shown in Table I. The proposed DS has a better solution quality in term of cost generated compared to other methods except modified firefly algorithm (MFA). It also can be seen that the result is quite similar with MFA. Fig. 2 shows the result of cost function versus iteration of DS for this test case.

B. 15-units system

In this test system, all the mentioned practical constraints and nonlinear characteristics of the ED problem are included. The load demand is set to 2630 MW. The characteristic of this system can be obtained in [4]. Table III shows the ramp rate limits and prohibited operating zones for this system. It can be seen that the prohibited operating zones embedded in the 4 units, viz. units 2, 5, 6 and 12.

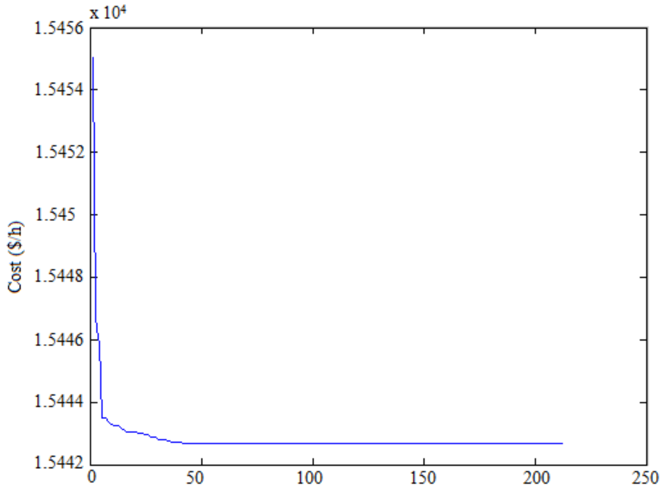

Figure 2. Cost versus iteration for 6-units system

TABLE II. RAMP RATE LIMITS AND PROHIBITED ZONES OF GENERATING UNITS FOR 15-UNITS TEST SYSTEM

Unit	P_i^0	UR_i (*MW/h*)	DR_i (*MW/h*)	***Prohibited zones (MW)***
1	400	80	120	-
2	300	80	120	[185 225] [305 335] [420 450]
3	105	130	130	-
4	100	130	130	-
5	90	80	120	[180 200] [305 335] [390 420]
6	400	80	120	[230 255] [365 395] [430 455]
7	350	80	120	-
8	95	65	100	-
9	105	60	100	-
10	110	60	100	-
11	60	80	80	-
12	40	80	80	[30 40] [55 65]
13	30	80	80	-
14	20	55	55	-
15	20	55	55	-

Table IV shows the results of best, average and worst of the proposed DS together with the most recently reported in literature. From this table, it was clearly seen that proposed DS offers the best solution so far in term of generation cost among the other methods. It also can be seen that all constraints were satisfied and not violated in order to obtain a significant result. This is proved in Table V where the performance of DS is compared with modified FA and FA where the power generated for each unit meet the generation limit and operated in the non-prohibited zones. The performance of cost versus iteration for this system is shown in Fig. 3.

TABLE III. BEST, AVERAGE AND WORST SOLUTIONS OF 15-UNITS SYSTEM

Methods	Generation Cost ($/h)		
	Best	Average	Worst
PSO [4]	32,858	33,039	33,331
SOH_PSO[5]	32,751	32,878	32,945
GA [24]	33,113	33,228	33,337
CPSO1 [11]	32,835	33,021	33,318
CPSO2 [11]	32,834	33,021	33,318
BF [23]	32,784.50	32,796.80	NA
FA [11]	32,704.50	32,856.10	33,175
MFA [26]	32,697	32,703	32,713
DS	32,688	32,690	32,696

TABLE IV. BEST SOLUTIONS RESULTOF 15-UNITS SYSTEM

Unit	DS	MFA [26]	FA [11]
	Power (MW)	Power (MW)	Power (MW)
1	454.9672	454.9737	455
2	380	379.9481	380
3	130	130	130
4	130	129.9541	130
5	169.784	170	170
6	460	460	460
7	430	429.995	430
8	86.8948	115.3589	71.745
9	47.255	43.6778	58.9164
10	155.145	126.6485	160
11	79.8704	79.9884	80
12	79.9331	79.8974	80
13	25.0001	25	25
14	15.0487	15.0288	15
15	15.2179	18.456	15
Losses (MW)	29.9796	29.5101	30.6614
Generation cost ($/h)	32,688	32,697	32,704.4501

VI. CONCLUSION

This paper proposed a new developed method, Differential Search (DS) algorithm to solve ED problems with considering the practical constraints. The effectiveness of DS was demonstrated and tested on two-well known test systems. From the simulations that have been conducted and presented, it can be seen that DS algorithm gave the best results of total cost minimization so far compared to the other methods. The proposed DS can be utilized to solve ED problems with valve-point effects which is in progress to be published in the near future.

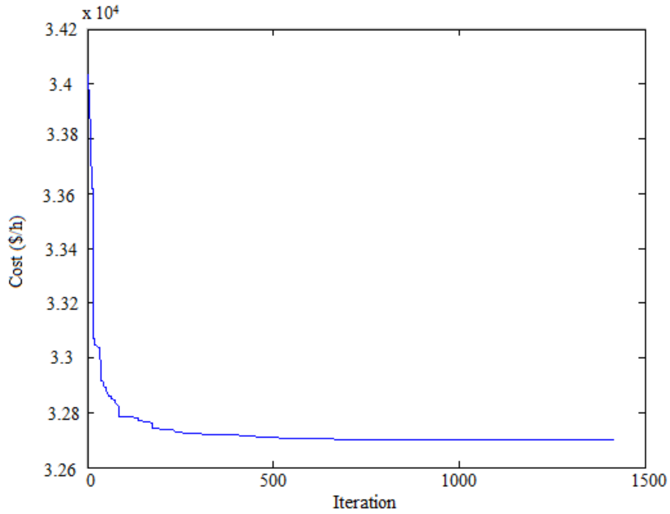

Figure 3. Cost versus iteration for 15-units system

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