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VORTEX SEARCH ALGORITHM FOR SOLVING ECONOMIC LOAD DISPATCH PROBLEM INCLUDING RAMP RATE LIMITS IN POWER SYSTEMS

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Abstract- This paper presents an efficient optimization technique for solving economic load dispatch problem in power systems. This technique is vortex search algorithm (VSA). Vortex search algorithm was developed taking into account the shape of rotating fluids. Economic load dispatch problem (ELD) are very complex optimization problems due to inequality and equality constraints. Economic load dispatch has become more complicated with added ramp rate limits constraints to the problem. To illustrate the capable and applicable of vortex search algorithm, three, six and fifteen test systems were selected. Obtained results from the test systems were compared with particle swarm optimization (PSO) based techniques from the literature. These results were showed that VSA technique found better solution and gave lower cost value.

Keywords: Vortex Search Algorithm, Ramp Rate Limits Constraints, Economic Load Dispatch Problem, Optimization.

I. INTRODUCTION

The main aim of this study is solved the economic load dispatch problem including ramp rate limits via vortex search algorithm [1].

Thermal power plants are widely used around the world. Fuel cost has very big rate within the all cost for thermal power plants. The reason for this is these plants use fossil fuels. For this reason, economic load dispatch is very important. Economic load dispatch is defined as minimize the operating cost while satisfying some constraints and conditions. Primary objective of ELD is reduced the total fuel cost while meet the total demand power.

In the beginning, some traditionally methods were developed and used for solving economic load dispatch problem. Bundle Method [2], Dynamic Method [3], Quadratic Programming [4], Gradient Method [5] etc. can be given as some examples of traditional methods. Traditional methods may have bad convergence behavior because of mathematically complexity.

After decades, modern optimization techniques were developed and applied to economic load dispatch problem. Tabu Search [6], Ant Colony Algorithm [7], Genetic Algorithm [8], Enhanced Bee Swarm Optimization [9], Simulated Annealing [10] etc. can be given as some examples of heuristic techniques. These techniques have some user defined input data. For this reason, these techniques may not give global solution if not chosen functional input data.

The progress of this article organized as follows: Section II refers to economic load dispatch was defined as mathematically. Section III denotes to vortex search algorithm was defined and given its flow chart. Section IV describes test systems were defined and results were given. Section V includes the Conclusion.

II. DEFINITION OF ECONOMIC LOAD DISPATCH PROBLEM

Economic load dispatch is of the essence for power systems. Primary object of economic load dispatch problem is reduced the total fuel cost under equality and inequality constrained while satisfy the total demand power by the consumer.

A. Fuel Cost Function

Economic load dispatch can be defined as a second order quadratic function. Economic load dispatch formulation is given as follows:

$$F_i = a_i + b_i P_i + c_i P_i^2 \tag{1}$$

where, a_i, b_i and c_i are fuel cost coefficients of unit i and F is cost value. If there are N thermal generation unit in the system, total fuel cost is calculated as follows:

$$\sum_{i=1}^{N} F_i = a_i + b_i P_i + c_i P_i^2 \tag{2}$$

Figure 1 shows fuel cost-generated power curve.

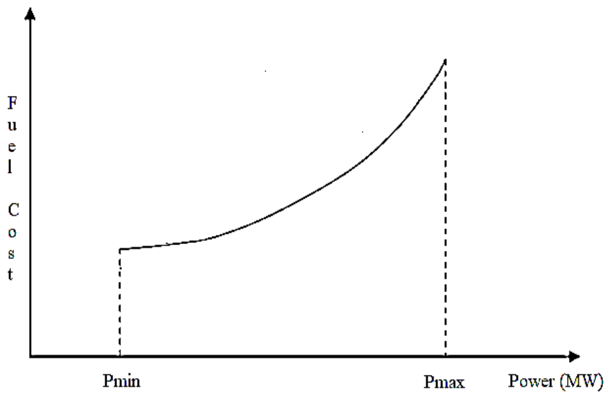

Figure 1. Incremental fuel cost and power curve

B. Real-Power Balance

For the power systems, generated power must be equal total demand power. This situation can be describing as follows:

$$P_1 + P_2 + P_3 + \ldots + P_N = P_d \quad (3)$$

$$\sum_{i=1}^{N} P_i = P_d \quad (4)$$

where, P_i is generated power of unit i and P_d is total demand power.

C. Generator Limits

Thermal generators are operated in a certain operating power range. This can be write as follows:

$$P_{i,\max} \geq P_i \geq P_{i,\min} \quad (5)$$

where, $P_{i,\max}$ represents maximum operating power and $P_{i,\min}$ represents minimum operating power of unit i.

D. Ramp Rate Limits

Sometimes it may be desirable to change the generator power without going below a certain ratio and without going beyond a certain ratio. These situations can be defined as follows:

$$\max(P_i^{\min}, P_0^i - DR_i) \leq P_i \quad (6)$$

$$P_i \leq \min(P_i^{\max}, P_0^i + UR_i) \quad (7)$$

where, UR_i is up-ramp rate limit, DR_i is down-ramp rate limit and P_0^i is previous output power of unit i.

III. MODELLING OF VORTEX SEARCH ALGORITHM

Vortex search algorithm is new optimization method and it is metaheuristic technique [11]. Vortex search algorithm developed considering the shape of rotating liquids. VSA has controllable step range so it has good equilibrium between the explorative and exploitative behavior of the search [12].

When considering the two dimensional space, vortex patterns are like as nested circuits. The biggest of these nested circuits is beginning circuit and it can be defined first search space. The center for this circuit is calculated as follows:

$$\mu_0 = \left(upperlimit + lowerlimit\right)/2 \quad (8)$$

where, *upperlimit* represents maximum limit vector and *lowerlimit* represents minimum limit vector. These are d×1 vectors and defined border of the problem.

Using Gaussian distribution, possible solutions are generated in the first and the biggest circuit. After this, the standard deviation of the distribution is found. It is calculated as follows:

$$\sigma_0 = \left(\max\left(upperlimit\right) - \min\left(lowerlimit\right)\right)/2 \quad (9)$$

where, σ_0 represent standard deviation and it is considered the radius of biggest circuit at the same time.

Possible solutions must be within the search space. Some possible solutions are not into the search space. If there is such a situation, these possible solutions are taken to the search space by using below equation:

$$s_i^k = lowerlimit^i + (upperlimit^i - lowerlimit^i) \times \text{rand} \quad (10)$$

where, i is related to border of the problem (i= 1, 2, 3, 4, 5, …, d) and k is the total generated possible solutions number (k= 1, 2, 3, 4, 5, … n).

After this stage, the best possible solution (s') is found and saved. This solution appointed as a new center. New possible solutions are generated from now on. New best possible solution is found and memorized as s_{best}. s' and s_{best} are compared. If s_{best} is better results than s', s_{best} is appointed as a new center.

Every iteration radius of the circuit must be decreased by using below equation:

$$r_t = \sigma_0 \times \left(1/x\right) \times gammaincinv\left(x, a_t\right) \quad (11)$$

where, a_t is coefficient for *gammaincinv* function. Its value changes every iteration and calculated by using below equation:

$$a_t = a_0 - \left(t/\text{MaxItr}\right) \quad (12)$$

where, a_0 is generally chosen as 1. Thus, all search space is covered. Figure 2 shows flow diagram of VSA.

IV. POWER SYSTEMS AND RESULTS

In this paper three different power systems were selected and used for solving economic load dispatch problem and for evaluate the efficiency of vortex search algorithm. Only ramp rate limits constraints are considered for these power systems. Results of the VSA compared with the different techniques from [13]. Cost coefficients, generator operating limits and ramp rate limits were taking from [13].

A. Test System 1: 3-Unit Power System

For the first case three-unit power system was used. Fuel cost coefficients and maximum-minimum limits of generator are given in Table 1. Ramp rate limits values are given in Table 2. For this system total demand power is 850 MW.

VSA method compared with PSO based methods from [13]. It can be clearly seen that from the Table 3, other methods are supported by VSA so VSA is feasible technique for solving ELD with ramp rate limits.

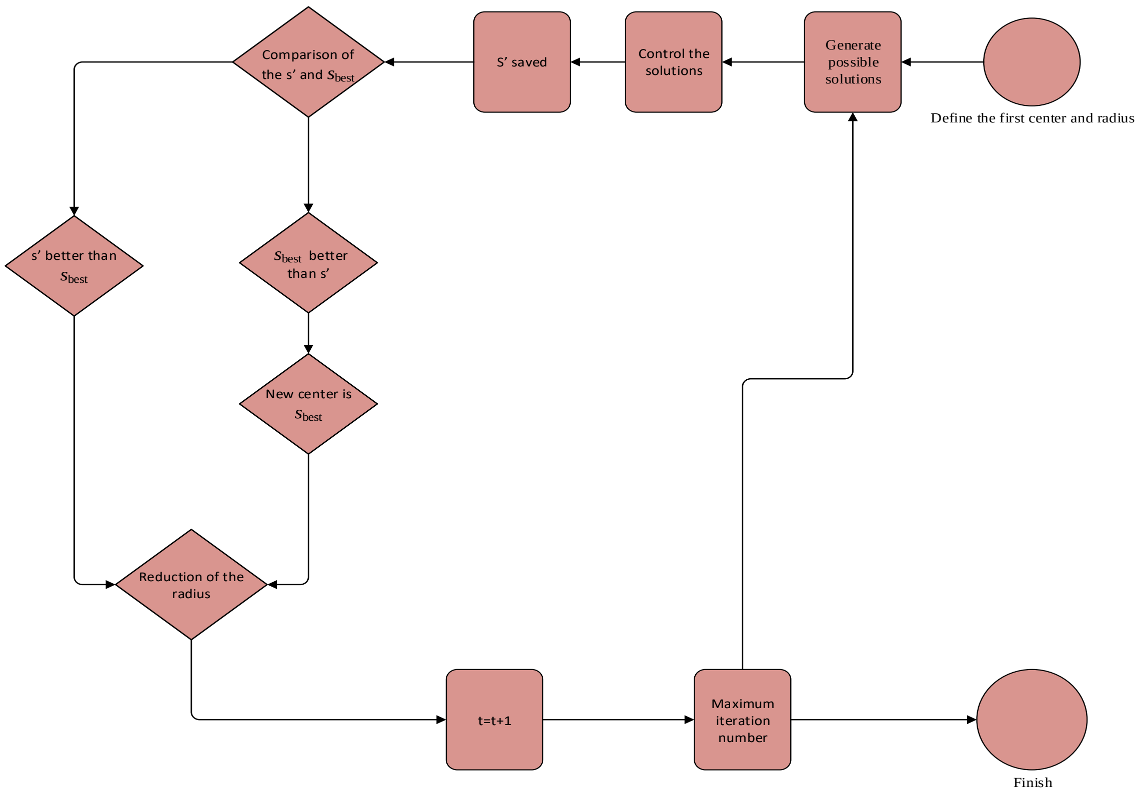

Figure 2. Flow diagram of vortex search algorithm

Table 1. Data for three-unit system

Unit	*a*	*b*	*c*	P_{min}	P_{max}
1	0.004820	7.97	78	50	200
2	0.001940	7.85	310	100	400
3	0.001562	7.92	562	100	600

Table 2. Ramp rate limits for three-unit system

UR	*DR*	P_0
50	90	170
80	120	350
80	120	440

Table 3. Results of three-unit system

Unit Power	VSA	PSO	PSOCFA	PSOIWA	PSOCFIWA
P_1	126.22	122.22	122.22	122.22	122.22
P_2	332.73	334.60	334.60	334.60	334.60
P_3	391.03	393.16	393.16	393.16	393.16
Cost ($)	8195.4	8195.4	8195.4	8195.4	8195.4

B. Test System 2: 6-Unit Power System

For the second case six-unit power system was used. Fuel cost coefficients and maximum-minimum limits of generator are given in Table 4. Ramp rate limits values are given in Table 5. Table 6 gives results of VSA and results of PSO based methods from [13]. For this system total demand power is 1263 MW. When compared other techniques in Table 6, VSA gave lower fuel cost value.

Table 4. Data for six-unit system

Unit	*a*	*b*	*c*	P_{min}	P_{max}
1	0.0070	7	240	100	500
2	0.0095	10	200	50	200
3	0.0090	8.5	220	80	300
4	0.0090	11	200	50	150
5	0.0080	10.5	200	50	200
6	0.0075	12	190	50	120

Table 5. Ramp rate limits for six-unit system

UR	*DR*	P_0
80	120	440
50	90	170
65	100	200
50	90	150
50	90	190
50	90	110

Table 6. Results of six-unit system

Unit Power	VSA	PSO	PSOCFA	PSOIWA	PSOCFIWA
P_1	453.06	446.70	446.50	446.70	446.66
P_2	168.43	171.25	171.10	171.25	171.66
P_3	260.53	264.10	265.00	264.10	263.77
P_4	121.19	125.21	125.05	125.21	125.44
P_5	169.10	172.11	171.93	172.11	171.58
P_6	90.55	83.59	83.40	83.59	83.86
Cost ($)	15275.55	15276	15276	15276	15276

C. Test System 3: 15-Unit Power System

For the third case fifteen-unit power system was used. Fuel cost coefficients and maximum-minimum limits of generator are given in Table 7. Ramp rate limits values are given in Table 8. Table 9 gives results of VSA and results of PSOCFIWA from [13]. For this system total demand power is 2630 MW.

Results from Table 9 show that VSA has better cost value when compared with PSOCFIWA.

D. Convergence Characteristics of Power Systems

Figures 3, 4 and 5 show convergence characteristic of Test Systems 1, 2 and 3, respectively.

Table 7. Data for fifteen-unit system

Unit	*a*	*b*	*c*	P_{min}	P_{max}
1	0.0003	10.1	671	150	455
2	0.0002	10.2	574	150	455
3	0.0011	8.8	374	20	130
4	0.0011	8.8	374	20	130
5	0.0002	10.4	461	150	470
6	0.0003	10.1	630	135	460
7	0.0004	9.8	548	135	465
8	0.0003	11.2	227	60	300
9	0.0008	11.2	173	25	162
10	0.0012	10.7	175	25	160
11	0.0036	10.2	186	20	80
12	0.0055	9.9	230	20	80
13	0.0004	13.1	225	25	85
14	0.0019	12.1	309	15	55
15	0.0044	12.4	323	15	55

Table 8. Ramp rate limits for fifteen-unit system

UR	*DR*	P_0
80	120	400
80	120	300
130	130	105
130	130	100
80	120	90
80	120	400
80	120	350
65	100	95
60	100	105
60	100	110
80	80	60
80	80	40
80	80	30
55	55	20
55	55	20

Table 9. Results of fifteen-unit system

Unit Power	VSA	PSOCFIWA
P_1	435.9834	432.2206
P_2	372.2342	380.0000
P_3	115.1300	129.9956
P_4	123.2024	125.4094
P_5	162.1438	160.3348
P_6	452.6253	451.4987
P_7	401.5986	430.0000
P_8	145.8286	98.4596
P_9	81.8640	116.1367
P_{10}	120.6917	124.0749
P_{11}	67.6675	53.4100
P_{12}	71.4642	71.1366
P_{13}	36.6424	26.5963
P_{14}	25.2157	15.7267
P_{15}	17.7206	15.0000
Cost ($)	32432.9	32441

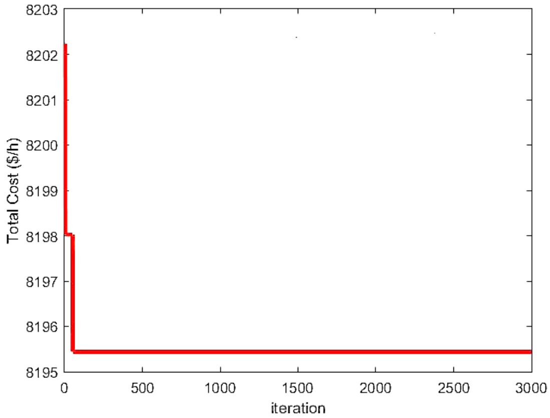

Figure 3. Convergence characteristic of VSA for test system 1

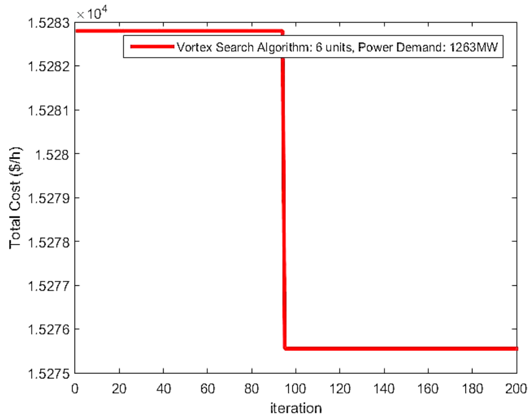

Figure 4. Convergence characteristic of VSA for test system 2

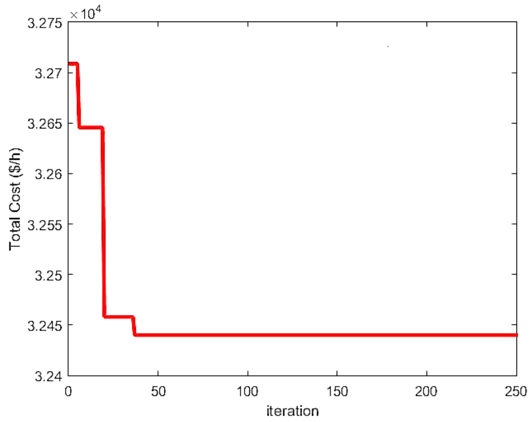

Figure 5. Convergence characteristic of VSA for test system 3

V. CONCLUSIONS

In this paper vortex search algorithm is proposed for solving economic load dispatch problem with ramp rate limit constraints. Obtained results from Table 3, Table 6 and Table 9, show the proposed vortex search algorithm is applicable, influential, advantageous technique for solving ELD with ramp rate limits at the power system.

NOMENCLATURES

A. Acronyms

ELD Economic Load Dispatch
VSA Vortex Search Algorithm
PSO Particle Swarm Optimization
PSOCFA Particle Swarm Optimization with Constriction Factor Approach
PSOIWA Particle Swarm Optimization with Inertia Weight Factor Approach
PSOCFIWA Particle Swarm Optimization with Constriction Factor and Inertia Weight Factor Approach

B. Symbols / Parameters

a, *b*, *c*: Cost coefficients of unit *i*
DR: Down-Ramp Rate Limit Value
F_i : Cost value of unit *i*
N : Number of generator
P_d : Total demand power
P_i : Generated power of unit *i*
P_{max}: Maximum Power Value
P_{min}: Minimum Power Value
UR: Up-Ramp Rate Limit Value

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BIOGRAPHIES

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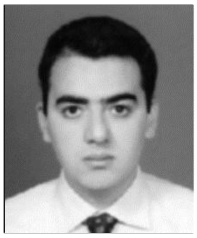

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