Novel Application of Whale-Optimization-Algorithm-Integrated with Local Search Deterministic Techniques to Solve Economic-Load-Dispatch-Problem with Valve-Point-Loading-Effect and Gaseous Emission

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Abstract— Amidst the prevailing energy crisis have thus pulled the thermal power plants to come into strike inorder to overcome the aforementioned issue seriously have invited ecological problem in parallel and is swelling day by day. Economic load dispatch (ELD) and economic emission dispatch (EED) are the Bi-objective opposite natured functions to each other which are brought into a single function with the aid of scaling factor (SF) and price penalty factor (PPF) to overcome the contradictory natures of fuel cost and emission levels at the same instant while keeping the alternators in their rated constraints of inequality in terms of maximum and minimum power levels and power balance constant as well as including/excluding the phenomena of valve point loading effects (VPLE). Thus both the functions are balanced at specific single point which not only cuts down the fossil fuel cost but also keeps in parallel the emission level of gaseous products at minimum. Hybridized optimization technique is proposed in this research that carries the capability to combine the nature inspired Whale optimization algorithm with the three specific local search techniques i-e interior point algorithm (IPA), sequential quadratic programming (SQP) and active set (AS) and have been applied on two test cases for cost effective solution.

Keywords— Thermal Power Plant, Economic Load Dispatch, Economic Emission Dispatch, Whale Optimization Algorithm, Local Search Techniques, Valve Point Loading Effect.

I. INTRODUCTION

Economic load dispatch is one of the major functions of electrical power management systems. In electric power industry efficient, high quality, reliable supply and optimum operation of electrical power generation is demanded by utilities so for this purpose the power production level of multiple coupled alternators in an interrelated power production system are scheduled in such a manner that the operating cost of the system is reduced and entire power demand is fulfilled subjected to satisfaction of all affiliated distinct constraints of power balance and generation capacity linked to electrical power generation units and plant are contented is called as problem of economic load dispatch [1]. The purpose of economic load dispatch is to find out the operating policy for “NG” number of generators that which generator will produce how much power. The following diagram clearly visualizes the scenario.

Figure 1: Policy of Economic Load Dispatch

With a rapid increase in population and commercialization, the electrical power demand raises day by day while fossil fuels are already high-priced so there should be an unavoidable need to cut down the operational cost of production in respect of fossil fuel cost. Fossil fuel are burnt in the furnace of thermal power plants emitting several toxic gases like carbon dioxide (CO2), silicon dioxide (SO2) and nitrogen dioxide (NO2) in the chimney promoting another serious issue called “global warming” when released into atmosphere. Due to the increased thermal power plants penetration, the level of gaseous emissions has been exponentially increased within no time [2]. So in order to challenge the reduction of the operational cost concurrently with the level of gaseous emissions into the air authors. 

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and afore said ecological effects, economic load dispatch concerned problem is reshaped into a latest expression and is labeled to be the problem of Combined Economic Emission Load Dispatch (CEELD). So this problem considering emissions not only reduces the level of gaseous emissions, but also have the ability to curtail the fuel cost magnificently.

Due to the involved natural complexities in traditional optimization techniques, a Hybridized optimization technique is developed that is capable to combine whale optimization algorithm with local search methods for cost effective solution.

II. SYSTEM MODE

A. Economic load dispatch Problem

The main objective of economic load dispatch problem is to schedule the generators power output at lower possible fuel cost. Characteristic equation of fuel cost as quadratic polynomial along with the valve point loading effect as sine term can be formulated as follows,

$$\text{Min } C_f(P) = \sum_{k=1}^{NG} C_k P_k = \sum_{k=1}^{NG} (a_k P_k^2 + b_k P_k + c_k + |d_k \times \sin(e_k \times (P_k^{\text{min}} - P_k^{\text{max}}))|)$$

(1)

Where ak, bk and ck are the related fuel cost coefficients of kth generator in $/MW, $/MW/h and $/h respectively while dk and ek are the related coefficients of valve point loading effect in $/h and rad. “P” is the variable power output assigned to each ganarator in MW, Pkmin and Pkmax denoting maximum and minimum power output limits while C(P) on the left hand side of the above equation gives the specified total fuel cost of power system in $/h for “NG” generators [3].

B. Economic Emission Dispatch problem

Similarly economic emission dispatch is the function to curtail the level of gaseous emissions as minimum possible while satisfying the demanded load. EED problem can be expressed mathematically as follows,

$$\text{Min } E_v(P) = \sum_{k=1}^{NG} E_k(P_k) = \sum_{k=1}^{NG} (a_{ek} P_k^2 + b_{ek} P_k + c_{ek} + d_{ek} \times \exp(f_{ek} \times P_k))$$

(2)

ak, bk, cek, d ek and fek are the coefficients of gaseous emissions expressed in ton/MW2h, ton/MWh, ton/h respectively while Ev(P) on the left hand side is expressed as the total level of emission in tons/h.

C. Combined Economic Emission Load Dispatch problem

In need to reduce the fossil fuel cost and degree of gaseous discharge simultaneously while keeping in mind both the equality and inequality constraints, both the objective functions of ELD and EED are combined together by introduction of price penalty factor (PPF), whereas for their contradictory nature, scaling factor (SF) is inserted, the so called as problem of (CEELD), which is a real-world many-objective optimization problem shown below

$$\text{Min } (F_{CEELD}) = W \times C_f(P) + (1 - W) (P.P.F)_k$$

(3)

Where

$$ (P.P.F)_k = \frac{C_v(P_{\text{max}})}{E_v(P_{\text{max}})}$$

(4)

III. HYBRIDIZED WOA TECHIQUE

Whales are considered to be the largest and longest amongst all the mammals and thus has been categorized into seven distinct species of blue, Minke, killer, finback, humpback, sei and right. These fancy gigantic mammals are assumed to be an intelligent and smart like a human being due to the presence of spindle cells in their brain twice in count than a human adult. They are responsible to develop their emotions, judgment and social behavior like a human being. Whales can live in a family or live alone depending upon the specie. Adult humpback whale is found to be a school bus Equivalent in length and are being grazed on krill and small fish herds present on the surface of water. The unique mechanism of Bubble Net Feeding has been detected uniquely in humpback specie in which they start to dive about 12m deep inside the water when prey is sighted. Humpback then travel upward towards the targeted prey following two types of manoeuvres [4].

A. Shrinking Surrounding Mechanism

This mechanism employs the following equation in which the value of “a” is dropped down from 2 to 0 in iterations which in turn effects the value of arbitrary “A” in interval [-a,a] decreased too. Thus mentioning the value of “A” in [-1,1] any location can be achieved from the location of search agent towards the best agent location. The equations below shows the achievable position of search agent towards the best agent location in 2D between 0≤A≤1.

$$\vec{D} = |\vec{C.X_{arb}} - \vec{X}|$$

(4)

$$\vec{X}(t + 1) = \vec{X}_{arb} - \vec{A.D}$$

(5)

Vector A and C can be find out with the help of equations given below.

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a}$$

(6)

$$\vec{C} = 2.\vec{r}$$

(7)
B. Spiral Updating Mechanism

A coil shaped path between the original position of whale and targeted position of prey is followed in this spiral updating mechanism with the help of a spiral equation subjected below,

$$\mathbf{X}(t + 1) = \overline{\mathbf{F}} \cdot e^{ct} \cdot \cos(2 \pi l) + \mathbf{X}^*(t) \quad (8)$$

“l” in [-1,1] denotes arbitrary number, “c” is a scalar identifying logarithmic spiral shape while $\overline{\mathbf{F}} = |\mathbf{X}^*(t) - \mathbf{X}(t)|$ describes gap between the targeted prey and the kth humpback.

Humpback whale while on its journey towards its targeted prey follow together their spiral shaped and shrinking encircling paths assumed to have 50% chances of selection each at the same time while designing their hunting technique mathematically expressed as follows

$$\mathbf{X}(t + 1) =\begin{cases} \frac{1}{2} |\mathbf{X}^*(t) - \mathbf{X}(t)| & \text{when } q < 0.5 \\ \frac{1}{2} \overline{\mathbf{F}} \cdot e^{ct} \cdot \cos(2\pi l) + \mathbf{X}^*(t) & \text{when } q \geq 0.5 \end{cases} \quad (9)$$

IV. SIMULATION RESULTS AND DISCUSSION

This section illustrates the detailed results of simulation tested upon 2 cases discussed below.

A. Case 1: System of 3 Generators

In this case, 3 generator units for ELD problem subjected with and without valve point loading effect with load demand of 850 MW is examined. For the 2-test case systems i-e 3 and 6 units, their corresponding generation power limits and scalar coefficients of fuel cost and emission level have been obtained from [5]. Both the cases including and excluding the phenomena of valve point loading effect compiled for 100 independent runs limited to 500 iterations maximum per run where the search agents are kept to 15000 with VPLE phenomena whereas 7500 for without VPLE phenomena.

![Learning curve for test case 1](image)

**Table 1:** Inequality constraints, fuel cost and VPLE coefficients for system of 3-generators test

| G.N | Generator Bound limits | a x10^{-3} | b x10^{-3} | c x10^{-2} | d | e x10^{-3} |
|-----|------------------------|------------|------------|------------|---|------------|
| G1  | 100-600                | 1.56       | 7.92       | 5.61       | 300 | 31.5       |
| G2  | 100-400                | 1.94       | 7.85       | 3.10       | 200 | 42         |
| G3  | 50-200                 | 4.82       | 7.97       | 0.78       | 150 | 63         |

**Table 2:** Combined refined results of test case 1 without VPLE

| Power (MW) | WOA | WOA Hybridized with | IPA | SQP | AS |
|------------|-----|---------------------|-----|-----|----|
| P1         | 393 | 400.00              | 600.00 | 393.5 | 393.00 |
|            | 7667| 0000                | 0000  | 1698.00 | 1698.00 |
| P2         | 344 | 400.00              | 100.00 | 334.00 | 334.00 |
|            | 1687| 0000                | 0000  | 6038.00 | 6038.00 |
| P3         | 114 | 50.00               | 150.00 | 122.00 | 122.00 |
|            | 0646| 0000                | 0000  | 2264.00 | 2264.00 |
| Total power| 850 | 850.00              | 850.00 | 850.00 | 850.00 |
|            | 0000| 0000                | 0000  | 0000.00 | 0000.00 |
| Cost S/h   | 8194.00 | 8227.00 | 8371.00 | 8194.00 | 8194.00 |
|            | 8578.00 | 8700.00 | 6700.00 | 3561.00 | 3561.00 |
| T (sec)    | 0.7046 | 0.7400 | 0.7011 | 0.100 | 0.0593 | 0.0357 |

Simulation results for whale optimization algorithm alone interms of best, mean and worst, and in hybridized form with three local search techniques are tabulated in table 2&3 along with levels of power assigned to each and every generator and execution time for the load demand of 850MW with and without considering the phenomena of valve point loading effect. Learning curve for test case 1 is shown in figure 2 whereas results for 100 independent runs for both the cases including/excluding VPLE Phenomena are showing in figure 3&4.
Table 3: Combined Refined Results of Test Case 1 with VPLE.

| Power (MW) | WOA | WOA Hybridized with |
|------------|-----|---------------------|
|            | Best| Medium | worst | IPA | SQP | AS |
| P1         | 300 | 392    | 423   | 300 | 300 | 300 |
|            | 6138| 3836   | 5195  | 2668| 2668| 1957|
| P2         | 400 | 257    | 226   | 400 | 400 | 400 |
|            | 0000| 6164   | 4805  | 0000| 0000| 0000|
| P3         | 149 | 200    | 200   | 149 | 149 | 149 |
|            | 3862| 0000   | 0000  | 7332| 7332| 8043|
| Total Power| 850 | 850    | 850   | 850 | 850 | 850 |
| cost       | 8240| 8368   | 8624  | 8234| 8234| 8234 |

Learning curve for test case 2 is shown in figure 5 while the Simulation results relating the proposed Algorithm for the cost of fuel and gaseous emissions are mentioned in table 5.

B. Case 2: System of 6 Generators

This test case consists of 6 generator units for combined economic emission dispatch (CEEELD) problem without valve point loading effect (VPLE) having the required power demand of 1000 MW. The required data has been tabulated below in table 4. At scaling factor SF=1, CEEELD problem becomes economic load dispatch (ELD) problem which cuts down fuel cost to 5039.6315 $/h but increases emission levels to 978,8066 ton/h. Conversely at scaling factor SF=0, it becomes economic emission dispatch (EED) problem decreasing down emission level to 800.1264 ton/h but increases fuel cost to 5211.1423 $/h.

Learning curve for test case 2 is shown in figure 5 while the Simulation results relating the proposed Algorithm for the cost of fuel and gaseous emissions are mentioned in table 5.
### Table 4: Inequality Constraints, Fuel Cost Coefficients and Emission Coefficients for System of 6-Generators Test

| G.N | Generator Bound limits | a x10^3 | b x10^3 | c x10^3 | ae | Be x10^-3 | ce x10^-3 |
|-----|------------------------|---------|---------|---------|----|-----------|-----------|
| G1  | 10-125                 | 756.8   | 38.540  | 152.5   | 13.860 | 330       | 4.2       |
| G2  | 10-150                 | 451.325 | 46.160  | 106     | 13.860 | 330       | 4.2       |
| G3  | 35-225                 | 1050.0  | 40.400  | 28      | 40.267 | 545.5     | 6.8       |
| G4  | 35-210                 | 1243.53 | 38.310  | 35.5    | 40.267 | 545.5     | 6.8       |
| G5  | 130-325                | 1658.57 | 36.328  | 21.1    | 42.900 | 511.2     | 4.6       |
| G6  | 125-315                | 1356.66 | 38.270  | 18      | 42.900 | 511.2     | 4.6       |

### Table 5: Combined Refined Results of Test Case 2 Without VPLE

| S.F | Megawatts allocated to each and every generator for Pd=1000MW | Cost $/h | Emission Tons/h |
|-----|-------------------------------------------------------------|---------|-----------------|
| 0   | 100. 104. 166. 228. 232.                                   | 5211.   | 800.            |
|     | 7180 5094 7849 9590 8116 2171                               | 1423    | 1264            |
| .1  | 82. 95. 160. 253. 260.                                     | 5150.   | 819.            |
|     | 7954 7914 4211 5920 7708 6293                               | 5907    | 7198            |
| .2  | 61. 92. 197. 274. 226.                                     | 5128.   | 847.            |
|     | 4815 3611 1234 0541 0373 9426                               | 4269    | 7854            |
| .3  | 57. 120. 157. 242. 255.                                     | 5175.   | 824.            |
|     | 7113 0979 8813 8447 9844 4804                               | 4062    | 2638            |
| .4  | 94. 73. 165. 272. 235.                                     | 5138.   | 827.            |
|     | 3480 5812 1936 1398 5470 1904                               | 9258    | 0479            |
| .5  | 79. 73. 152. 255. 275.                                     | 5111.   | 839.            |
|     | 5469 4171 2838 0147 3650 3725                               | 7421    | 3119            |
| .6  | 61. 59. 151. 274. 279.                                     | 5073.   | 870.            |
|     | 5374 9085 9599 4086 8620 3236                               | 9744    | 4544            |
| .7  | 55. 88. 178. 280. 244.                                     | 5110.   | 849.            |
|     | 9275 6383 7685 6686 5957 4014                               | 9701    | 9554            |
| .8  | 76. 59. 160. 228. 297.                                     | 5099.   | 861.            |
|     | 5679 3863 3021 2455 8013 6969                               | 6485    | 9298            |
| .9  | 61. 31. 162. 284. 290.                                     | 5052.   | 905.            |
|     | 0173 5855 5899 4998 7081 5994                               | 2486    | 6545            |
| 1   | 30. 23. 173. 319. 309.                                     | 5039.   | 978.            |
|     | 7412 4987 4407 8450 6550 8194                               | 6315    | 8066            |
CONCLUSION

This paper analyzes two test case systems for economic load dispatch and combined economic emission load dispatch problems having distinct power load demands. Test case 1 contains the proposed algorithm alone and in hybridized form both for the cases with and without VPLE Phenomena. Without considering the Valve point loading effect, above table 2 shows best, mean and worst fuel cost results for whale optimization algorithm and hybridized whale optimization algorithm showing that the best score achieved for W.O.A alone is $8194.8578/h. “S.Q.P”, “A.S” and “I.P.A” are known as local search techniques which have the capability to reduce down the cost more when hybridized with Whale algorithm of optimization. All the three local search techniques integrated with W.O.A tabulated the same fuel cost results of $8194.3561/h and thus showed their optimality. On the other hand, Taking into account the phenomena of valve point loading effect, the simulation results are listed above in table 3. The best score achieved for W.O.A is $8240.4398/h executed in 0.2770 seconds. Whale optimization algorithm admits $8234.0718/h hybridized with local search techniques I.P.A & S.Q.P while A.S hybridization admitted $8234.1115/h. Thus it is clear from the table that W.O.A-I.P.A & S.Q.P proved to be more cost effective and optimum compared to W.O.A by tailoring the fuel cost from $8240.4398/h to $8234.0718/h. Similarly in test case 2, at scaling factor 1 and 0, the established function converts wholly to ELD and EED problems respectively due to their contradictory natures thus to overcome the unbalanced phenomena between fuel cost and emission level SF=0.5 is selected that makes the functions mutually stable to cut down the fuel cost and emissions volume at the same time.

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