International Journal of Engineering Works
ISSN-p: 2521-2419
ISSN-e: 2409-2770
Vol. 7, Issue 09, PP. 312-317, September 2020
https://www.ijew.io/
https://doi.org/10.34259/ijew.20.709312317

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

Hafeez ullah Khan
Department of Electrical Energy System Engineering, US-Pakistan Center for Advanced Studies in Energy (USPCAS-E), UET, Peshawar, Pakistan
hafeezullahkhan273@gmail.com
Received: 13 September, Revised: 20 September, Accepted: 26 September

***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 constarint 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.

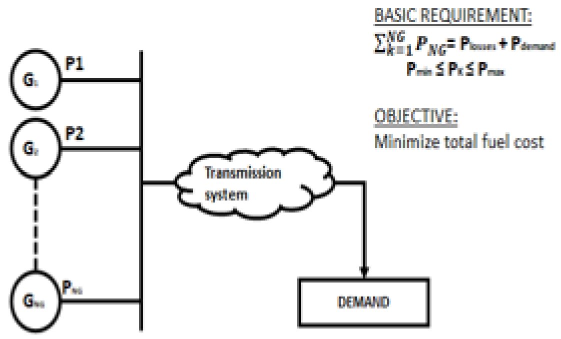


Figure 1: Policy of Economic Load Dispatch

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 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 follws,

$$\boldsymbol{Min\ C_V(P) = \sum_{K}^{NG} C_K P_K = \sum_{k=1}^{NG} (a_k P_k^2 + b_k P_k + c_k + |d_k \times \sin(e_k \times (P_k^{min} - P_k))|)} \tag{1}$$

Where ak, bk and ck are the related fuel cost coefficients of kth generator in \$/MW2h, \$/MW/h and \$/h respectively while dk and ek are the related coefficients of valve point loading effect in \$/h and rad. "Pk" 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,

$$\mathbf{Min\ E_V(P) = \sum_{k=1}^{NG} E_k(P_k) = \sum_{k=1}^{NG} (ae_k P_k^2 + be_k P_k + ce_k + de_k \times \exp(fe_k \times P_k))} \tag{2}$$

aek, bek, cek, dek 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

$$\boldsymbol{Min\ (F_{C.E.E.L.D}) = W * C_v(P) + (1 - W)(P.P.F)_k * E_V(P)} \tag{3}$$

Where

$$\boldsymbol{(P.P.F)_k = \frac{C_V(P_k^{max})}{E_V(P_k^{max})}} \tag{4}$$

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 manevours [4].

A. Shrinking Surrounding Mechanism

This mechanism employs the following equation in which the value of "$\vec{a}$" is dropped down from 2 to 0 in iterations which in turn effects the value of arbitrary "$\vec{A}$" in interval [-a,a] decreased too. Thus mentioning the value of "$\vec{A}$" 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.

$$\boldsymbol{\vec{D} = |\vec{C}.\overrightarrow{X_{arb}} - \vec{X}|} \tag{4}$$

$$\boldsymbol{\vec{X}(t+1) = \overrightarrow{X_{arb}} - \vec{A}.\vec{D}} \tag{5}$$

Vector $\vec{A}\ and\ \vec{C}$ can be find out with the help of equations given below.

$$\boldsymbol{\vec{A} = 2\vec{a}.\vec{r} - \vec{a}} \tag{6}$$

$$\boldsymbol{\vec{C} = 2.\vec{r}} \tag{7}$$

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,

$$\vec{X}(t+1) = \vec{F}.e^{cl}.\cos ine(2.\pi.l) + \overrightarrow{X*}(t) \quad (8)$$

"I" in [-1,1] denotes arbitrary number, "c" is a scalar identifying logarithmic spiral shape while $\vec{F} = |\overrightarrow{X*}(t) - \vec{X}(t)|$ 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

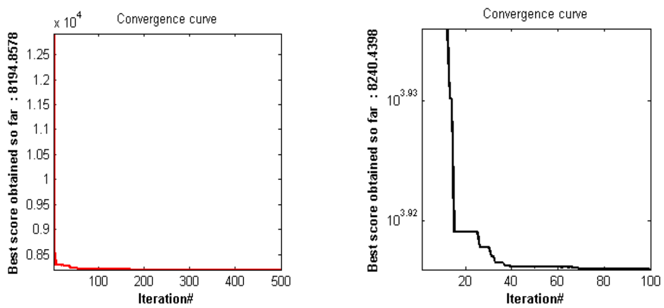
$$\vec{X}(t+1) = \begin{cases} \overrightarrow{X*}(t) - \vec{A}.\vec{D} & when\ q < 0.5 \\ \vec{F}.e^{cl}.\cos(2\pi l) + \overrightarrow{X*}(t) & when\ q \geq 0.5 \end{cases} \quad (9)$$

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.



(a) Without VPLE (b) With VPLE

Figure 2: Learning curve for test case 1

Table 1: Inequality constraints, fuel cost and VPLE coefficients for System of 3-Generators test

G.N	Generator Bound limits	a x10^{-3}	b	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		
	Best	Mean	worst	IPA	SQP	AS
P1	391. 7667	400. 0000	600. 0000	393. 1698	393. 1698	393. 1698
P2	344. 1687	400. 0000	100. 0000	334. 6038	334. 6038	334. 6038
P3	114. 0646	50. 0000	150. 0000	122. 2264	122. 2264	122. 2264
Total power	850. 0000	850. 0000	850. 0000	850. 0000	850. 0000	850. 0000
Cost $/h	8194. 8578	8227. 8700	8371. 6700	8194. 3561	8194. 3561	8194. 3561
T (sec)	0.7046	0.7400	0.7011	0.100 5	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.

$/h	4398	7836	4998	0718	0718	1115
T(sec)	0.2770	0.2800	0.277 3	0.0838	0.0841	0.0490

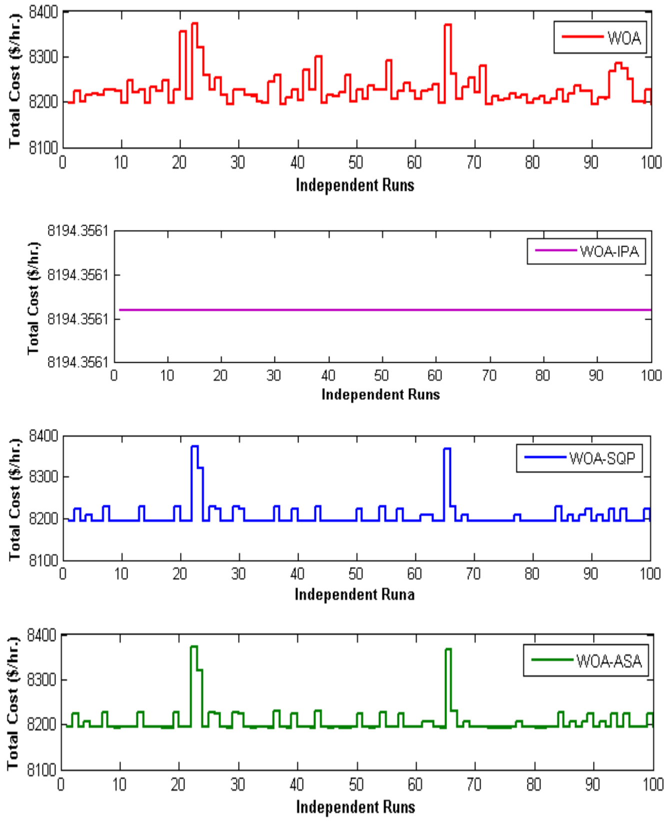


Figure 3:100 independent runs for test case 1 without VPLE.

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. 6138	392. 3836	423. 5195	300. 2668	300. 2668	300. 1957
P2	400. 0000	257. 6164	226. 4805	400. 0000	400. 0000	400. 0000
P3	149. 3862	200. 0000	200. 0000	149. 7332	149. 7332	149. 8043
Total Power	850	850	850	850	850	850
cost	8240.	8368.	8624.	8234.	8234.	8234.

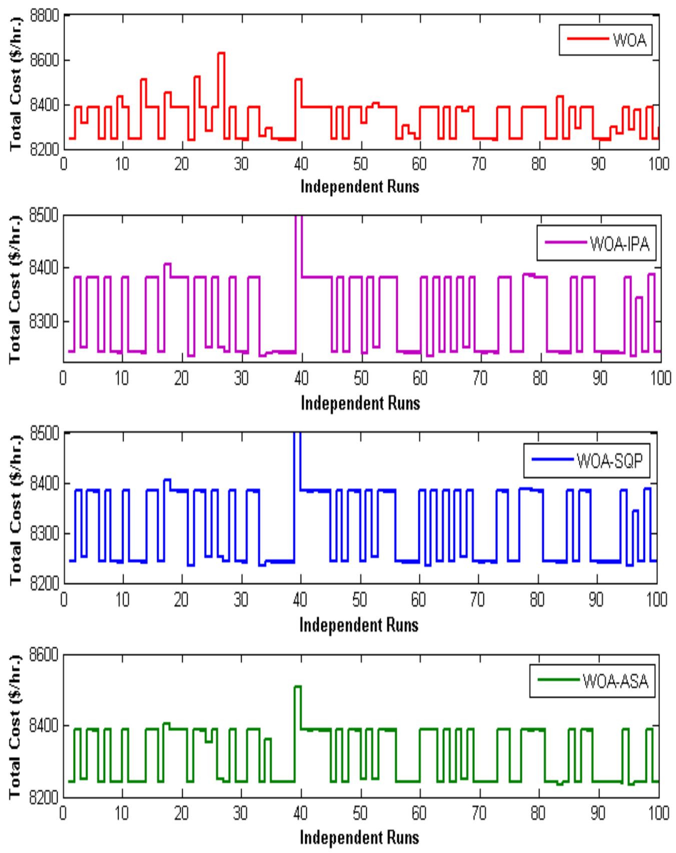


Figure 4: 100 independent runs for test case 1 with VPLE

B. Case 2: System of 6 Generators

This test case consists of 6 generator units for combined economic emission dispatch (CEELD) 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, CEELD 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	b	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 P_D=1000MW						Cost $/h	EmissionTons/h
	G1	G2	G3	G4	G5	G6		
0	100.7180	104.5094	166.7849	166.9590	228.8116	232.2171	5211.1423	800.1264
.1	82.7954	95.7914	160.4211	146.5920	253.7708	260.6293	5150.5907	819.7198
.2	61.4815	92.3611	197.1234	148.0541	274.0373	226.9426	5128.4269	847.7854
.3	57.7113	120.0979	157.8813	165.8447	242.9844	255.4804	5175.4062	824.2638
.4	94.3480	73.5812	165.1936	159.1398	272.5470	235.1904	5138.9258	827.0479
.5	79.5469	73.4171	152.2838	164.0147	255.3650	275.3725	5111.7421	839.3119
.6	61.5374	59.9085	151.9599	172.4086	274.8620	279.3236	5073.9744	870.4544
.7	55.9275	88.6383	178.7685	151.6686	280.5957	244.4014	5110.9701	849.9554
.8	76.5679	59.3863	160.3021	177.2455	228.8013	297.6969	5099.6485	861.9298
.9	61.0173	31.5855	162.5899	169.4998	284.7081	290.5994	5052.2486	905.6545
1	30.7412	23.4987	173.4407	142.8450	319.6550	309.8194	5039.6315	978.8066

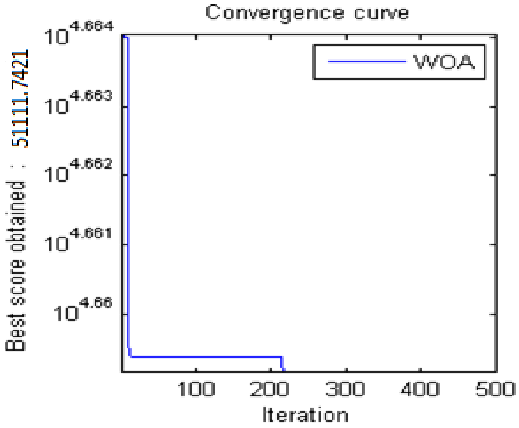


Figure 5: Learning curve for test case 2

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 wholy 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.

REFERENCES

[1] S. Basak and S. Banerjee, "Adaptive Jaya Optimization Technique for Economic Load Dispatch Considering Valve Point Effect," in 2019 Devices for Integrated Circuit (DevIC), 2019, pp. 104-107.

[2] F. P. Mahdi, P. Vasant, M. Abdullah-Al-Wadud, V. Kallimani, and J. Watada, "Quantum-behaved bat algorithm for many-objective combined economic emission dispatch problem using cubic criterion function," Neural Computing and Applications, pp. 1-13, 2018.

[3] L. T. Al-Bahrani, J. C. Patra, and A. Stojcevski, "Solving economic dispatch problem under valve-point loading effects and generation constrains using a multi-gradient PSO algorithm," in 2018 International Joint Conference on Neural Networks (IJCNN), 2018, pp. 1-8.

[4] S. Mirjalili and A. Lewis, "The whale optimization algorithm," Advances in engineering software, vol. 95, pp. 51-67, 2016.

[5] T. M. Subhani, C. S. Babu, and A. S. Reddy, "Particle swarm optimization with time varying acceleration coefficents for economic

Hafeez ullah khan was born on September the 16th 1994 in district swabi Khyber pukhtoonkhwa Pakistan. He has received his BSc degree in electrical engineering (Power) back in 2016 from university of engineering and technology (UET) Peshawar Pakistan. He is a post graduate researcher in united states Pakistan centers for advanced studies in energy (US.-PCASE) university of engineering and technology peshawar and has completed his MS in Electrical Energy Systems Engineering from the same university in 2019. His major interest is to design algorithms for fuel cost optimization and emission reductions.