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SOLVING ECONOMIC LOAD DISPATCH PROBLEM WITH VALVE POINT LOADINF EFFECT USING WHALE OPTIMIZATION ALGORITHM INTEGRAT-ED WITH LOACAL SEARCH DETERMINISTIC TECHNIQUES

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KeyWords

Active Set, Economic Load Dispatch, Evolutionary Programming, Improved Tabu search Algorithm, Interior Point Algorithm, Modified Ant Colony Optimization Algorithm, Sequential Quadratic Programing, Valve Point Loading Effect, Whale Optimization Algorithm.

ABSTRACT

In Modern era with the swelling demand electrical power ELD has turn out to be the principal problem in electrical networks. Use of orthodox petroleum for the production of electricity consequences in diminution of assets for yet to come generations. One possible solution to the aforesaid problem is operating generators optimally i.e. assigning optimal power to generators. Whale optimization algorithm (WOA) is a novel solution for the reduction of the fuel cost. The hunting method of Humpback whales is inspired from bubble-net feeding method. The algorithm has been tested on IEEE 3-generator test system and a standard 13-generator test system for both with and without valve point loading effects for effective solutions. For rapid local convergence a hybrid computing framework is utilized for the solution of ELD problem using WOA supported with Sequential Quadratic Programming, Active Set and Interior Point Algorithm. Performance of the given scheme is analysed in terms of superlative, middling and poorest cost as well as on the basis of total function evaluations and constraints violation.

1. Overview

To resolve the complicated problems of ELD a lot of work has been done in this area. Researchers utilized diverse intelligence algorithms & tried to decipher these complications around the globe. The exploration work by the researchers which they did in the area of Economic Load Dispatch is presented as follow.

Whale Optimization Algorithm has been applied to solve the complex problem of Economic Load Dispatch for reducing the price of fuel for electrical power generation.[1]. The deterministic methods such as lambda iteration, Gauss Jacobi etc. often fails to give global optimum results for Economic Load Dispatch problems. Different optimization problems are used for optimization in recent researches. An optimization problem may perform well in one optimization problem but may not perform well in the other one. This statement is based on No Free Lunch theorem [2]. Considering the effects of valve point of modern generators another algorithm named Improved Tabu Search Algorithm for (iii), (vi) and (xiii) generators system is employed [3]. The problem of economic dispatch is associated with some major problems. If we try to decrease the cost of fuel, we get an increase in emission of gases into our atmosphere and if we try to decrease the level of emission of gases into our surrounding atmosphere that results in very high prices of fuel and these problems cannot be solved simultaneously. With emission constrained this study is thus itemised mainly to lessen total fuel cost. Six generator system is analysed through Modified Ant Colony Optimization algorithm [4]. The inspiration of this algorithm are ants. Ants search for their food randomly. While searching for their food they leave traces for their fellow ants to follow them by dropping pheromone in their exploration track for their food. In this way other ants trail pheromone which clues them to their fellow ants and consequently to their food. Another algorithm is suggested called Modified Ant Colony Optimization algorithm for further refining of the obtained results. As compared to some other optimization problems seen or recorded in literature like the most common genetic algorithm and particle swarm optimization etc. this new modified Ant Colony Optimization algorithm technique resulted in much competitive results in economic dispatch problems. Another method for solving the conventional problems of economic dispatch is the Evolutionary Programming which is an effective optimization tool [5]. Slight amendments are done to elementary approaches that caused amplified convergence speed and consequently resulted in reduced calculating duration. The amendments done are divided in two fragments. For the amendment of first fragment scale cost has been adopted while for the amendment of second fragment Empirical learning rate is amendment technique in use. Gravitational Search Algorithm which is a new investigative method of optimization problems is brought into use for analysing CEELD [6]. Four test systems are analysed using the proposed technique. Economic Load Dispatch problem is resolved by means of PSO [7]. But one problem with PSO is that it sticks in local optima and consequently resulting in premature convergence which is a problem of serious concern. For this reason, PSO is integrated with time variable acceleration coefficients. By the aforesaid integration the premature convergence is avoided results in global optimum.

2. Characteristic Functions

2.1. Economic Load Dispatch

Economic Load Dispatch schedules power generation of different power generators connected in an interconnected power system and gives an optimized cost of generation i.e. fuel cost and also fulfils the constraints that are associated with power systems. The expression of fuel cost in mathematical form can be written as.

$$F_{WOV}(P) = \sum_{i=1}^{NG} \left(z_i P_i^2 + y_i P_i + x_i \right)$$
(1)

Looking into above written equation NG shows total generating units. The coefficients for the fuel cost are represented by z_i , y_i , x_i , the electrical power generated by each generator is shown by P_i and at the last $F_{WOV}(P)$ shows total fuel cost of electrical power generators in dollars per hour or can also pe shown in rupees per hour. Recent advancement in technologies in the field of valves opening and closing according to power demend can be shown by adding a sinusoidal term in equation (1) and is shown below in equation (2). This sinusoidal term is called valve point loading effect.

$$F_{m\nu}(P) = \sum_{i=1}^{NG} \left(z_i P_i^2 + y_i P_i + x_i + \left| w_i \times \sin(v_i \times (P_i^{\min} - P_i)) \right| \right)$$
(2)

The coefficients related to valve point loading effect in above equation (2) are denoted by w_i and v_i . Minimum electrical power generated by i^{th} unit is represented by P_i^{min} is the whereas $F_{wv}(P)$ represents fuel cost in dollars per hour or rupees per hour.

2.2. ELD Constraints

a. Equality Constraint Of ELD

The electrical power generated by generators in a power generation station should meet the load demand of consumers and the transmission losses associated with power system. Another term which is often used for equality constraint is power balance constraint. The expression for this constraint can m_{NG} written in mathematical form as.

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

In the above expression PD shows the power requirement of consumers while PL represents the line losses. PL in above expression is considered zero in this research work.

b. Inequality Constraint Of ELD

One more constraint associated with power system is the inequality constraint which states that each generator unit should generate with in its lower and upper bounds. It is often also called generation capacity constraint.

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{4}$$

 P_{\min} and P_{\max} are the generation limits defined for each generator.

3. ELD problem solution through WOA

Different real world problems are solved through optimization techniques. One such real world problem is the Economic Load Dispatch. In this research work Whale Optimization Algorithm is used to solve the problem of Economic Load Dispatch [1]. Further WOA is hybridized with Sequential Quadratic Programing, Active Set and Interior Point Algorithm in order to further optimize results. Whales are very beautiful and intelligent creatures. The main cause of their intelligence is the spindle cells. Whales have much more spindle cells in brain than a full grown human. Whales have got a very unique way of hunting. Their hunting method is known as Bubble net hunting method. Humpback whales feed on pray that are mostly near the surface of water i.e. krill & small fish. Humpback whales dive around 12 meters in water and then starts to move towards the surface of water i.e. prey in an upward spiral of shape 9 and also creates bubbles while moving in this trajectory.

The following equations describes the positions changed by whales once the best agent or target prey is identified and All the remaining whales will update their position according to best search agent once defined.

$$\overrightarrow{\mathsf{D}} = |\mathsf{C}.X^*(t) - X(t)| \tag{5}$$

$$X(t+1) = X^*(t) - A.$$
 D (6)

Looking into above equation 't' is used for existing iteration, the coefficients vectors are represented by A and C. The situation vector of the best result is represented by X*, X symbolises the situation vector. In each iteration X* is updated if there is a better solution present. The expressions for vectors A & C are written as.

$$A = 2a. r - a \tag{7}$$

$$C = 2. r \tag{8}$$

'r' in above equations is a capricious vector in [0,1] and 'a' is shrunk linearly from 2 to 0 respectively in subsequent repetitions. It means that with the the help of capricious vector 'r' any position or location can be reached while searching for prey. For mathematical modelling of the approach used by humpback whales i.e. bubble net feeding methods two methods are discussed and are presented as follow.

3.1. Shrinking Surrounding:

This approach is achieved by reducing 'a' in equation 7. The decrease in 'a' also effects the value of A causing it to reduce its range. Fresh locality can be established anyplace among the prevailing finest agent locality and original locality of the search agent by describing capricious values of A in [-1, 1].

3.2. Spiral Updating:

In this approach amid the locality of target and whale a spiral equation is created to reproduce the helix formed motion of whales.

$$X(t+1) = \overrightarrow{F'} \cdot e^{cl} \cdot \cos 2\pi l + \overrightarrow{X^*}(t)$$
(9)

 $\vec{F}' = |\vec{X}^*(t) - \vec{X}(t)|$ postulates the distance amid ith whale and the prey, the profile of logarithmic spiral is defined by 'c' which is a constant, 'l' is a capricious figure in [-1, 1].

Humpback whales updates their localities towards the prey in spiral fashioned path and in shrinking approach at the same time. So we take chance that there is fifty percent possibility of either approach and is shown below in mathematical form.

$$\vec{X}(t=1) = \begin{cases} \vec{X*}(t) - A.D & \text{if } h < 0.5 \\ \vec{F'}.e^{cl}.\cos 2\pi l + \vec{X*}(t), \text{ if } h \ge 0.5 \end{cases}$$
(10)

'h' designates a capricious figure in [0, 1].

Humpback whales also hunt haphazardly. Consequently, by varying value of \vec{A} chase for target is completed. In order to make humpback whales move away from a whale capricious values greater than one or less than '-1' are to be used.

$$\vec{D} = |\vec{C}.\vec{X_{arb}} - \vec{X}| \tag{11}$$

$$\vec{X}(t+1) = \overrightarrow{X_{arb}} - \vec{A}.\vec{D}$$
(12)

WOA starts with a set of capricious results. In each repetition humpback whales update their localities w.r.t either a capricious whale or the prevailing finest result depending upon the value of $abs\vec{A} > 1$ or $abs\vec{A} < 1$. Similarly, reliant upon the value of 'h' WOA change between spiral or circular approach. Lastly, WOA is ended after meeting a termination criteria.

4. Model Results

4.1. Three Generators System

In this test system for the power requirement of 850 MW the required coefficients for fuel cost and the minimum and maximum generation limits of generators are obtained from [6]. The losses associated with power transmission are overlooked for the three generators test system situation. The test system is analysed for the effects of VPL as well as without the effects of VPLE. The WOA is executed for 500 iterations in each independent run. The number of independent were kept 20. While executing the algorithm for without the effects of valve point loading the search agents were kept 7500 while for including the effects of valve point loading the search agents were kept 15000 respectively. The results obtained using WOA for the aforesaid parameters are presented in Table 1 in the form as superlative, middling and poorest and fuel charge. The superlative results of WOA for the above stated parameters defined for three generators system are also shown with convergence characteristics curve shown in Fig. 1 for both with the effects of valve point loading and without the effects of loading.

Units (MW)		NO VPLE VPLE				
	Superlative	Middling	Poorest	Superlative	Middling	Poorest
Unit i	398.991169	482.379308	325.792619	299.597265	403.329790	600.000000
Unit ii	335.534286	260.432851	324.207381	400.000000	246.670210	100.000151
Unit iii	115.474545	107.187841	200.000000	150.402735	200.000000	149.999849
P _D	850	850	850	850	850	850
Fuel Charge	8194.630467	8218.549683	8230.811687	8234.445424	8305.924172	8386.799056





Fig. 1. WOA Convergence curves (a) No VPLE (b) VPLE.

The results obtained were fed to local search methods like sequential quadratic programing, active set and interior point algorithm. The hybridization was performed for both with the effects of valve point loading and without the effects of valve point loading. The results are presented in below Table 2 for three generators system in terms of fuel charge. As can be seen in Table 2 hybridization resulted in almost same results i.e. **8194.35612127020** for the case of neglecting the effects of valve point loading while in case of with the effects of valve point loading WOA when combined with Sequential Quadratic programing presented improved result i.e. **8234.071857**. The graphs of convergence for the hybridized results are shown below in Figures.

Table 2. Outcomes of Hybridized schemes of WOA with Some	e Deterministic techniques for three generators system.
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Unit (MW) —		NO VPLE			VPLE		
	WOA-SQP	WOA-Active Set	WOA-IPA	WOA-SQP	WOA-Active Set	WOA-IPA	
Unit i	393.169839	393.169838	393.169825	300.266672	300.2661646	300.2663837	
Unit ii	334.603756	334.603755	334.603765	400	400	399.9998498	
Unit iii	122.226405	122.226407	122.226410	149.733328	149.7338354	149.7337665	
P _D	850	850	850	850	850	850	
Fuel Charge	8194.35612127020	8194.35612127020	8194.35612127020	8234.071857	8234.072141	8234.0721783	



Fig. 2(a). WOA-IPA Convergence curves of hybridized scheme rejecting VPLE.



Fig. 2(b). WOA-SQP Convergence curves of hybridized scheme rejecting VPLE.

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Fig. 2(c). WOA-SQP Convergence curves of hybridized scheme rejecting VPLE.



Fig. 3. WOA-SQP Convergence curves of hybridized scheme comprising VPLE.

4.3. Thirteen Generators Systems

In this test system for the power requirement of 1800 MW the required coefficients for fuel cost and the minimum and maximum generation limits of generators are obtained from [6]. The losses associated with power transmission are overlooked for the three generators test system situation. The test system is analysed for the effects of VPL as well as without the effects of VPLE. The WOA is executed for 500 iterations in each independent run. The number of independent were kept 20. While executing the algorithm for without the effects of VPL the search agents were kept 13500 while for including the effects of VPL the search agents were kept 27000 respectively. The results obtained using WOA for the aforesaid parameters are presented in Table 3 in the form as superlative, middling and poorest and fuel charge. The superlative results of WOA for the above stated parameters defined for thirteen generators system are also shown with convergence characteristics curve shown in Fig. 4 for both with the effects of valve point loading and without the effects of loading.

Units (MW)		No VPLE			VPLE		
	Superlative	Middling	Poorest	Superlative	Middling	Poorest	
Unit i	495.031526	274.504158	514.265018	537.645229	338.095317	170.079805	
Unit ii	321.299266	335.067366	40.482843	360.000000	148.921768	230.381119	
Unit iii	352.805927	179.082276	156.206740	338.955595	307.843709	208.209907	
Unit iv	71.360422	153.682948	125.521066	60.000000	114.116783	93.274510	
Unit v	60.000000	99.236706	76.528101	60.000000	144.679216	158.005817	
Unit vi	93.853760	70.008972	117.675601	60.000000	60.000000	167.709494	
Unit vii	60.000000	124.702991	99.369639	73.399176	162.451518	164.953441	
Unit viii	88.852994	159.887434	170.414277	60.000000	120.534559	105.927198	
Unit ix	60.000000	132.783152	170.092201	60.000000	152.917295	147.946222	
Unit x	45.086675	74.309195	83.815452	40.000000	100.439836	94.757979	
Unit xi	40.000000	46.955987	57.605743	40.000000	40.000000	58.008233	
Unit xii	56.709430	65.214953	100.241990	55.000000	55.000000	97.823727	
Unit xiii	55.000000	84.563862	87.781327	55.000000	55.000000	102.922548	
P _D	1800	1800	1800	1800	1800	1800	
Fuel Charge	17961.916087	18029.922786	18084.408553	18402.129838	18735.270028	19113.530411	

Table 3. Outcomes of WOA for Thirteen Generators System (Total Power =1800 MW)



Fig. 4. WOA Convergence curves (a) No VPLE (b) VPLE.

The results obtained were fed to local search methods like sequential quadratic programing, active set and interior point algorithm. The hybridization was performed for both with the effects of valve point loading and without the effects of valve point loading. The results are presented in below Table 4 for thirteen generators system in terms of fuel charge. As can be seen in Table 4 hybridization with IPA resulted in improved result i.e. **17932.474059** for the case of neglecting the effects of valve point loading while in case of with the effects of valve point loading WOA when combined with Sequential Quadratic programing presented improved result i.e. **18247.926005**. The graphs of convergence for the hybridized results are shown below in Figures.

		No VPLE			VPLE			
	MFO-SQP	MFO-Active Set	MFO-IPA	MFO-SQP	MFO-Active Set	MFO-IPA		
Unit i	559.180329	495.702378	506.911748	538.558739	538.546363	538.558099		
Unit ii	279.590151	299.029095	253.455877	360.000000	360.000000	359.999999		
Unit iii	279.590167	320.833892	253.455892	351.441261	351.453637	351.441892		
Unit iv	103.879786	112.610774	99.362770	60.000000	60.000000	60.000001		
Unit v	60.000000	60.000000	99.362752	60.000000	60.000000	60.000001		
Unit vi	103.879790	99.448800	99.362730	60.000000	60.000000	60.000001		
Unit vii	60.000000	60.000000	99.362748	60.000000	60.000000	60.000001		
Unit viii	103.879777	102.375061	99.362747	60.000000	60.000000	60.000001		
Unit ix	60.000000	60.000000	99.362736	60.000000	60.000000	60.000001		
Unit x	40.000000	40.000000	40.000000	40.000000	40.000000	40.000001		
Unit xi	40.000000	40.000000	40.000000	40.000000	40.000000	40.000001		
Unit xii	55.000000	55.000000	55.000000	55.000000	55.000000	55.000001		
Unit xiii	55.000000	55.000000	55.000000	55.000000	55.000000	55.000001		
PD	1800	1800	1800	1800	1800	1800		
Fuel Charge	17949.262721	17951.873096	17932.474059	18247.926005	18247.996385	18247.929785		

Table 4. Outcomes of Hybridized schemes of WOA with Deterministic techniques for thirteen generators system.



Fig 5 WOA-IPA Convergence curves of hybridized scheme rejecting VPLE.



Fig 6 WOA-SQP Convergence curves of hybridized scheme comprising VPLE.

5. Conclusion

Whale Optimization Algorithm is inspired from the unique hunting method of humpback whales observed only in humpback whales. In this research work Whale Optimization Algorithm was tested on different test systems with different parameters and also hybridized schemes with some local search techniques were used. Problems with Constraints such as power expectation, the reactive power flow etc. can be solved with the proposed algorithm in future works and in many other optimization fields.

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