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ARTICLE

SOLVING ECONOMIC POWER DISPATCH PROBLEM WITH TRANSMISSION LOSS AND VALVE POINTS USING WHALE OPTIMIZATION ALGORITHM

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ABSTRACT

Economic Power Dispatch (EPD) is a non-linear and non-convex optimization problem in the field of power system for operational planning. EPD is the sharing of power demand among generator units by minimizing cost while satisfying constraints. This work presents an investigation on meta-heuristic approach Whale Optimization algorithm (WOA) to solve EPD problem. To demonstrate the efficacy of the proposed algorithm two benchmark test problems having ten-unit system and thirteen-unit system are evaluated. The simulation results are compared with other nature inspired algorithms and Whale optimization algorithm proves its superior performance in terms of convergence rate and accuracy.

KEY WORDS
Evolutionary algorithm, economic power dispatch problem, power system, Whale optimization algorithm, Transmission Loss.

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INTRODUCTION

ED problem is allocating power to the generating units for minimized cost with constraints. The generators are coordinated so that lowest cost generator is used as much as possible rather than costlier generator. Costlier generators are used when the demand is increased. Traditional ED problem are solved using conventional methods such as Lamba iteration method, gradient method, Lagrangian multiplier method, base point participation factors method and branch and bound method. In these numerical methods, incremental fuel cost curves of generating units are required which in turn monotonically increase piece-wise linear cost function approximation. The input-output characteristic of non-linear ED includes ramp-rate, valve point, prohibited zones and fuel cost functions which are non-convex in nature. Thus it get trapped in multiple local minimum points and for larger-scale generating units conventional method results in longer computational time due to oscillatory problem. Dynamic programming [1] is used to solve non-linear economic dispatch problem with valve point. However this method had dimensional problem for large-scale generating units and results in local optimality.

In past decades, the researcher found alternative solution to conventional methods for solving ED problem is meta-heuristic optimization algorithms like evolutionary programming [2], genetic algorithm [3], simulated annealing [4], tabu search [5], particle swarm optimization [6]. This method does not require large memory and their iterative search strategy helps to find optimal solution by eliminating local optima. The selection of control parameters for evolutionary algorithms helps to attain optimal solution. The other stochastic search algorithms uses artificial intelligent techniques like Hopfield neural network [7], Adaptive Hopfield neural network [8]. These methods have sigmoidal functions which results in huge numerical calculations and iterations.

Hybrid algorithm started to emerge due to the quality of the solution. Hybridization of conventional PSO with generator constraints is used to solve ED problem. The diversification process in PSO was improved with the use of differential evolution based mutation operator. This algorithm takes the advantage of both method and provides robust result [9]. Dipankar Santra et al [10] proposed hybrid PSO-ACO algorithm to solve Economic Load Dispatch (ELD) problem by considering transmission loss. They provided solution for both convex and non-convex ELD problems using 3-generator 5-bus system. They considered ramp rate, valve value, prohibited zone, transmission loss and capacity of the generator. Their hybrid approach handles smooth and non-smooth, convex and non-convex problems. Boubakeur Hadji et al [11] proposed a variant of dance bee colony algorithm with dynamic step size adjustment to solve economic emission dispatch problem with valve effects. The performance of the proposed variant is tested on IEEE 30-Bus and 40 unit generators.

D.B. Prakash, C. Lakshminarayana [12] proposes a Whale Optimization Algorithm to increase the reliability and stability of the power system. The proposed approach reduce the operational cost with inequality constraints. SeyedaliMirjalili and Andrew Lewis [13] proposed nature-inspired meta-heuristic optimization algorithm called Whale Optimization Algorithm (WOA). It mimics the natural behavior of hunting of preys in humpback whales. The technique used to carry out the hunting process is called bubble-net. It is shown that the algorithm is compared with other meta-heuristic algorithms as well as conventional algorithms.

The remainder of this work is organized as follows: Section 2 presents the formulation of the economic power dispatch problem. Section 3 provides the overview and algorithm framework to solve EPD. The simulation results of a ten-unit problem and a thirteen-unit problem are shown in Section 4. Finally Section 5 concludes the work with summary.

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ECONOMIC POWER DISPATCH PROBLEM

Economic dispatch problem may be of static or dynamic. The static economic dispatch problem allows constant power supply for the given time with minimized generation cost. In the static method, the generation load of the power system is to be determined for the scheduled period and it may vary based on the customer demand. The nature of the static ED problem the load should be scheduled according to the customer demand. The dynamic economic dispatch, dynamic constraints are used to retain the life of the generator with the help of ramp rate units to minimize the cost of generation unit. The ramp rate unit is to maintain the life of the power generator by avoiding shortening of the generator and thermal stress. Solving dynamic ED problem is diffiult due to large dimensional but provides the accurate formulation.
The objective function of the dynamic ED problem is to minimize the cost of generation unit of the output power system. The generation cost (C_G) of the power system is the summation of the cost of each generating unit N and the mathematical formulation is given as follows.

$$Minimize\ C_G = \sum_{i=1}^{N} C_i(P_i) \tag{1}$$

where N is the number of generators, C_i and P_i is the cost function and power of the ith generator in the power systems.
The fuel cost of generating unit is represented in the quadratic polynomial function of output power as follows.

$$C_i(P_i) = x_i P_i^2 + y_i P_i + z_i \tag{2}$$

where x_i, y_i and z_i are the cost coefficient of the ith generator.
The quadratic polynomial function represented is smooth function in practical which cannot determine the input or output of the power generators. Value point effects consists of higher-order nonlinearity sinusoidal function are added with generation cost function to obtain an accurate result.

$$C_i(P_i) = x_i P_i^2 + y_i P_i + z_i + V_i \tag{3}$$

where V_i is the higher-order nonlinearity sinusoidal function caused by value point effects and it can be defined as

$$V_i = \left| u_i \sin(v_i(P_i^{min} - P_i)) \right| \tag{4}$$

where u_i, v_i are value point coefficients of generator i and P_i^{min} is the minimum generation limit.
The objective function of the ED problem is represented as

$$Minimize\ C_G = \sum_{i=1}^{N} x_i P_i^2 + y_i P_i + z_i + V_i + \left| u_i \sin(v_i(P_i^{min} - P_i)) \right| \tag{5}$$

Constraints
The equality and inequality constraints to be satisfied in economic dispatch problem in terms of generating capacity and power balance are described.
Power balance
The total generated power is the summation of the total power demand and transmission loss in the power system. The constraint is mathematically formulated as.

$$\sum_{i=1}^{N} P_i = P_D + P_{TL} \tag{6}$$

where P_D is the total power demand in the system, P_{TL} is the total transmission loss in the system.
The total transmission loss is calculated using B coefficient and the formulated is represented as follows.

$$P_{TL} = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \tag{7}$$

where B_{ij}, B_{00} and B_{0i} are the ijth loss coefficient of the matrix B, loss coefficient constant and ith element of loss coefficient vector respectively.
Generating capacity constraint
The power output of the each generation must satisfy generating capacity constraints and it is represented as.

$$P_i^{min} \le P \le P_i^{max} \tag{8}$$

where P_i^{min} and P_i^{max} are the minimum limit and maximum limit of the power system output of generator i.

PROPOSED SYSTEM

Whale optimization algorithm mimics the social behavior of bubble-net hunting in humpback whales. This algorithm describes the special hunting behavior called bubble-net feeding method. During hunting the whales follow 9-shaped path or creation of circulation movement. During hunting, humpback whale moves down to the water at 15meter depth. It knows the position of the prey and produce bubbles in spiral shape which encircles the prey. Whale hunting can be defined in three different ways namely, Encircling the prey, Bubble-net feeding and search for a prey.

Encircling prey

Humpback whales can identify the exact location of the prey i.e small fishes and it update its current position towards optimal solution for each iteration. Thus for unknown result in search space, the current best solution is prey for each iteration. Once the optimal solution is obtained it is updated in position table and it can be used by other search agents. To update the position according to the current best solution can be found using

$$\vec{D} = |\vec{C}.\vec{X}^{*}(t) - \vec{X}(t)| \qquad (9)$$

where $\vec{D}$ represents distance vector between current position ($\vec{X}$) and best position $\vec{X}^{*}$ for each iteration t. $\vec{C}$ represents the coefficient vector and provides direction towards current best solution. The solution for next iteration can be found using

$$\vec{X}(t+1) = \vec{X}^{*}(t) - \vec{A}.\vec{D} \qquad (10)$$

where $\vec{A}$ represents coefficient vector. The coefficient vectors are calculated using

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a} \qquad (11)$$

$$\vec{C} = 2.\vec{r} \qquad (12)$$

where $\vec{a}$ is the linearly decreased in range [2,0] with respect to increase in iteration and $\vec{r}$ is random vector range [0,1].

Bubble-Net Feeding

Bubble-net behavior of whale can be in two ways as follows, shrinking encircling and spiral updating position.

Shrinking Encircling

The value of a is decreased from 2 to 0 for the iteration. In this method, whales does not exhibit discontinued circle motion between its current and predecessor position. It exhibits continuous spiral path to hunt prey.

Spiral updating position

The spiral updating position between whale and prey forms helix-shape movement as

$$\vec{X}(t+1) = \vec{D}'.e^{bl}.\cos(2\pi l) + \vec{X}^{*}(t) \qquad (13)$$

where $\vec{D} = |\vec{X}^{*}(t) - \vec{X}(t)|$ shows the distance of whale to prey, b is defined as constant value to define the shape of the logarithmic spiral and l is the random number range from [-1,1].

SeyedaliMirjalili, et al. [18] shows the probability of 50-50% which follows either shrinking encircling or spiral model using

$$\vec{X}(t+1) = \begin{cases} \vec{X}^{*}(t) - \vec{A}.\vec{D} & if\ p < 0.5 \\ \vec{D}'.e^{bl}.\cos(2\pi l) + \vec{X}^{*}(t) & if\ P \geq 0.5 \end{cases} \qquad (14)$$

where p is the random number [0,1].

Search for prey

Humpback whales to search for prey randomly according to the position of each other search agents. The exploration of search space to find best solution for each iteration can be calculated using

$$\vec{D} = |\vec{C}.\overrightarrow{X_{rand}} - \vec{X}| \qquad (15)$$

$$\vec{X}(t+1) = \overrightarrow{X_{rand}} - \vec{A}.\vec{D} \qquad (16)$$

EXPERIMENTAL DESIGN AND ANALYSIS

Experimental environment setup

In order to prove the performance of the proposed algorithm on solving EPD problem, two different benchmark test systems: ten-unit system [14] and thirteen-unit system [15] are considered. The experiments are conducted on different nature inspired algorithms under similar environment conditions in order to evaluate the performance of WOA. The proposed algorithm is coded using MATLAB 2015 platform is used to solve small and medium scale EDP problem by WOA under Windows on an Intel 2 GHz Core 2 quad processor with 2GB RAM. [Table 1] describes the instances considered by WOA to solve EDP. The empirical evaluations will set the parameters of the proposed system. Appropriate parameter values are determined based on the preliminary experiments.

Table 1: Parameter settings for Experimental Evaluation

Type	Method
Number of Bees	100
Maximum Iterations	1000
Heuristic Used	Modified Nelder-Mead Method
Termination Condition	Maximum Iterations
Run	20
$\vec{a}$	Range =(2,0)
l	Range =(-1,1)

Case Study

Test case 1

In this case study the benchmark [25- 27] system of ten-unit with total demand of 300MW is tested. Along with power balance and generating capacity constraints valve point effect and transmission loss are considered. The cost coefficient and B-loss coefficient matrix are given in [14]. The efficiency of the WOA to solve test case 1 are compared with the other optimization algorithm like ACO [16], ABC [17], GSA [18], and HAS [19] along with traditional approach Gradient search and PSO [6]. From the [Table 2], it is evident that our proposed algorithm WOA outperforms with respect to fuel cost.

Table 2: Unit output of different methods for test case 1

Unit	WOA	ABC	ABC	GSA	HSA	PSO	Gradient search
P1	49.77446	27.74896	94.33846	97.52896	36.48311	0	0
P2	13	13	13	13.00106	13	0	0
P3	10.00713	10	10	10	10	20.4046	18.56
P4	15	15.03227	15.09696	15	15.00042	15	15
P5	21.56978	21.48645	21.43165	21.41054	21.3972	65.2755	125
P6	14	14.00178	14.00092	14.00387	14.03365	44.0719	34.9027
P7	20	20.00383	20.04302	20	20	20	68.7361
P8	25	25	25	25.02442	25	29.7851	0
P9	150	150	150	150	150	17.5	0
P10	20.00144	20.05393	20.00574	20.13838	20.14682	96.1525	44.9138
Total Loss	38.35282	16.32722	82.91674	86.10724	25.06118	0.849413	0.730886
Total Cost	7367.335	7367.794	7367.854	7368.862	7368.607	12343.774	11274.296

Test case 2

The system comprises of thirteen-unit benchmark test case with valve units and transmission loss is taken as test case 2. The overall load demand of the test case is 2520MW. The data for cost coefficient and B-loss coefficient matrix have been extracted from [14]. The performance of the WOA to solve test case 2 are compared with variants of Grey wolf OGWO [20], GWO [21] and other nature inspired meta-heuristic algorithms OIWO [22], SDE [23], ORCCRO [24]. On comparing with existing algorithms, our proposed WOA outperforms with respect to fuel cost are shown in [Table 3].

Table 3: Unit output of different methods for test case 2

Unit	WOA	OGWO	GWO	OIWO	SDE	ORCCRO
P1	454.5374	628.2940	628.1678	628.3185	628.32	628.32
P2	344.3787	299.1803	298.9229	299.1989	299.20	299.20
P3	358.8063	297.5041	298.2269	299.1991	299.20	299.20
P4	179.2704	159.7284	159.7232	159.7331	159.73	159.73
P5	173.2179	159.7325	159.7210	159.7331	159.73	159.73
P6	174.4962	159.7295	159.7270	159.7331	159.73	159.73
P7	178.5798	159.7334	159.7173	159.7330	159.73	159.73
P8	145.1762	159.7323	159.6793	159.7331	159.73	159.73
P9	143.607	159.7327	159.6673	159.7330	77.40	77.40
P10	96.9857	77.3963	77.3971	77.3953	113.12	112.14
P11	107.2662	114.7487	114.6051	113.1079	92.40	92.40
P12	74.82939	92.3974	92.3886	92.3594	92.40	92.40
P13	91	92.3780	92.3550	92.3911	92.40	92.40
Total Loss	22.151	40.2874	40.2983	40.3686	40.43	39.43
Total Cost	24324.03	24512.7250	24514.4774	24514.83	24514.88	24513.91

CONCLUSION

This work solves economic power dispatch problem for power units by considering transmission loss and valve points using WOA. WOA is implemented to solve small and medium sized benchmark unit systems such as ten-unit system and thirteen unit system. To solve EPD, the social behavior of humpback whales and the hunting of prey by the whales are mapped to obtain optimal solution. To evaluate the performance of the WOA, the obtained results are compared with other existing algorithms and the performance are tabulated in Table 2 and 3. From the simulation result, it is evident WOA outperforms in succeeding minimal cost for the power generation unit for various test cases.

CONFLICT OF INTEREST

There is no conflict of interest

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None

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