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An Ant Lion Algorithm for Multi-Fuel Power Dispatch with Emission Constraints

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ABSTRACT: The electrical power age from petroleum product discharges a few contaminants into air and this become excrescent if the creating unit is energized with Multiple Fuel Sources (MFS). Due to the ever stringent ecological guidelines, the power makers have been compelled to create power at the least expensive cost as well as at least degree of toxin discharges. Consideration of this issue in the operational undertaking is an invite point of view. By the by various distributed reports manage just the savvy activity, this work proposes an increasingly precise and handy operational model considering valve-point impacts, CO2 emanation and MFS. This operational issue can be perceived as a multi-objective compelled enhancement issue with clashing goals. The upsides of the latest nature motivated calculation called Ant Lion Algorithm (ALA) enthralled to use as an improvement apparatus. The fluffy supported ALA is proposed to decide the best undermined arrangement in multi-target structure. The standard 10-unit frameworks are utilized to approve the viability of ALA. Besides, the correlation and execution examination affirm that the present proposition is found outrival as far as arrangement quality. The financial benefit examination approves that the flow explore gives the promising operational model/device which is useful for electric utilities in the present fuel shortage situation.

KEYWORDS: Economic dispatch; Emission dispatch; Valve-point effects; Multiple fuel sources; Ant lion algorithm;

I. INTRODUCTION

1.1. Multi-fuel power generation dispatch

In practical conditions of power system operations, certain generating units are supplied with different Fuel Sources (FS) like coal, natural gas and oil. The cost function for each fuel type is derived and is segmented as piecewise quadratic cost function for a generating unit fed with Multiple Fuel Sources (MFS). These generating units face with the dilemma of determining the most economical fuel to burn. Further, the complexity is increased while considering the valve-point discontinuities. Now-a-days, emission control has also become an imperative objective, which must be considered along with fuel cost. The emission function can also be approximated like the fuel cost. Consequently, the process becomes trickier when the conflicting objectives (total operating cost and pollutant emission) are considered.

1.2. Existing solution methods

The multi-fuel power dispatch problem contains the discontinuity values at each boundary forming multiple local minima; hence it has been betided as a non-convex and complicated optimization problem. The solution approaches addressing this problem can be categorized into mathematical and heuristic methods. Table 1 summarizes the published reports for solving multi-fuel dispatch problem.

Mathematical and artificial intelligence methods

As the classical mathematical methods cannot solve this problem easily, the piecewise quadratic function is approximated as piecewise linear function and is solved by the traditional methods [1]. Lin and Viviani have approached the problem using Hierarchical based numerical Method (HM) [2]. The artificial neural network models such as Hopfield Neural Network (HNN), Adaptive HNN (AHNN) and Enhanced Lagrangian Neural Network (ELNN) models are also developed to address the economic operation problems [3-4]. The main drawback for these methods is the exponential growing time for large scale systems with non-convex constraints.

Soft computing techniques

The heuristic search techniques such as Genetic Algorithm (GA) [5], Evolutionary Programming (EP) [6], Particle Swarm Optimization (PSO) [7], Tauguchi Method (TM) [8], Artificial Immune System (AIS) [10], Differential Evolution (DE) [13], Artificial Bee Colony Algorithm (ABC) [17] and Biogeography Based Optimization (BBO) [18] have been reported for solving Economic Dispatch (ED) with piecewise cost functions.

A two phase hybrid GA method namely Hybrid Real Coded GA (HRCGA), in which real coded GA and non-linear programming method are employed for base level and local search respectively, is reported to fetch the desirable output settings [5]. The improved versions of EP such as Fast EP (FEP) and Improved FEP (IFEP) have been reported for cost effective solution [6]. The modified version of PSO (MPSO) is developed by incorporating a position adjustment method, has also been addressed for the feasible ED solution [7].

Chao- Lung Chiang has reported Improved GA with Multiplier Updating (IGA-MU) for solving economic operation considering valve-point discontinuities, in which IGA explores the search space and MU handles operational constraints [9]. A Modification is introduced in the cognitive behavior of traditional PSO (MPSO) and Local Random Search (LRS) is incorporated in the MPSO (MPSO-LRS) to explore non-convex search space [11]. The Penalty Parameter Less scheme is integrated with Evolutionary Algorithms (PPL-EA) such as PSO, DE and is applied for determining the feasible solution [12]. A hybrid approach combining Integer Coded DE and Dynamic Programming (ICDE-DP) [14] and sequential quadratic programming is combined with the Harmony Search (HS) method, so called Hybrid HS (HHS) method are also applied to solve multi-fuel power dispatch problem [15].

The arithmetic average bound crossover and hybrid mutation are introduced in the RCGA, called as New RCGA (NRCGA), is applied to obtain the cost effective schedules considering nonlinearities in the fuel cost [16]. The improved mutation strategy is integrated in the Adaptive PSO (APSO) namely New APSO (NAPSO) is reported to determine the feasible dispatches [19]. In recent years, the Augmented Lagrange HNN (ALHNN) and Enhanced ALHNN (EALHNN) have also been reported for obtaining cost effective schedules [20-21]. Recently, a distributed approach namely Auction based Algorithm (AA) and Dimensional Steepest Decline (DSD) method have been reported for solving economic operation considering valve-point effects [22-23]. Hopfield Lagrange Network (HLN) and Lambda Iteration Method (LIM) have also been reported to determine the feasible solution [24].

1.3. Research gap

The above mentioned approaches have addressed the economic operation considering a single objective (i.e. total operating cost). Since, the clean air amendments force the electric power utilities to maintain the pollutant level within the predefined limits; the environmental issues must be incorporated in the operational model to make it suitable for practical power system conditions. Thus, a multi-objective problem formulation has been contrived which includes optimizing the total fuel cost and emission in a single framework. Furthermore, the economic-environmental compromising operation is scarcely focused in the field of multi-fuel power generation dispatch.

1.4. Motivation

Recently, Nguyen Trung Thang has developed a model considering environmental issues with MFS [24]. In order to develop a practical model, the valve-point discontinuities must be incorporated in the Nguyen Trung Thang model. This motivates the authors to develop the most realistic model considering valve-point effects, environmental issues and MFS.

As the solution space has become highly non-linear, an appropriate optimization tool is desired. The reported heuristic methods have few drawbacks like algorithmic parameter settings, premature phenomena, trapping into infeasible solution and computationally expensive. Hence, it is of great significance to improve the existing optimization techniques or exploring new optimization techniques.

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1.5. Optimization tool

Recently, inspiring the hunting mechanism of ant lions in nature, a nature inspired optimization algorithm, the so called Ant Lion Algorithm (ALA), has been proposed [25]. This algorithm has few parameters and easy to implement, which makes it impressive than earlier ones. Moreover, the ALA has superior features than other heuristic techniques in terms of improved exploration, local optima avoidance, convergence and exploitation characteristics.

2. Multi-fuel power generation dispatch model

The mathematical model for cost effective–environmental compromising operation of thermal power plants is given in this section. In this formulation, the decision variables are real power outputs of on-line generators.

2.1. Problem objectives

2.1.1. Objective 1: Minimization of total fuel cost

The total fuel cost of thermal power plant is the sum of fuel costs of online generating units and is expressed as,

$$FC = \text{Min} \sum_{i=1}^{N} F_i(P_i) \tag{1}$$

The fuel cost of a generating unit considering valve-point loadings and MFS is expressed as a piecewise segment function and is stated as,

$$F_i(P_i) = \begin{cases} a_{i1} + b_{i1}P_i + c_{i1}P_i^2 + \left|e_{i1} \times \sin(f_{i1} \times (P_{i1}^{\min} - P_i))\right|, & fuel\,1, P_i^{\min} \le P_i \le P_{i1} \\ a_{i2} + b_{i2}P_i + c_{i2}P_i^2 + \left|e_{i2} \times \sin(f_{i2} \times (P_{i2}^{\min} - P_i))\right|, & fuel\,2, P_{i1} \le P_i \le P_{i2} \\ . & . \\ . & . \\ . & . \\ a_{ik} + b_{ik}P_i + c_{ik}P_i^2 + \left|e_{ik} \times \sin(f_{ik} \times (P_{ik}^{\min} - P_i))\right|, & fuel\,k, P_{ik-1} \le Pi \le P_i^{\max} \end{cases} \tag{2}$$

2.1.2. Objective 2: Minimization of pollutant emissions

This objective is realized by summing up the release of pollutants from online generating units into the atmosphere and is expressed as,

$$EC = \text{Min} \sum_{i=1}^{N} E_i(P_i) \tag{3}$$

The emission characteristics of a generating unit with multiple fuel options is also expressed as a piecewise segment function and is stated as,

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$$E_i(P_i)=\begin{cases}\alpha_{i1}+\beta_{i1}P_i+\gamma_{i1}P_i^2, & fuel\,1, P_i^{\min}\le P_i\le P_{i1}\\ \alpha_{i2}+\beta_{i2}P_i+\gamma_{i2}P_i^2, & fuel\,2, P_{i1}\le P_i\le P_{i2}\\ . & .\\ . & .\\ . & .\\ \alpha_{ik}+\beta_{ik}P_i+\gamma_{ik}P_i^2, & fuel\,k, P_{ik-1}\le P_i\le P_i^{\max}\end{cases} \quad (4)$$

2.1.3. Development of multi-objective model

The most realistic operational model can be formulated by unifying the design objectives *FC and EC* detailed as (1) and (2) in a single composition. Thus the model is proposed as in (5) to optimize the conflicting objectives concurrently subject to variety of constraints.

$$\text{minimize} \quad F_i(x)=(FC,EC) \quad (5)$$

2.2. Constraints

2.2.1. Power balance

The total generation by all the generators must be equal to the total power demand (P_d)

$$\sum_{i=1}^{N}P_i=P_d \quad (6)$$

2.2.2. Generation limits

The real power generation of each generator is to be controlled inside its upper (P_i^{max}) and lower (P_i^{min}) operating limits.

$$P_i^{\min}\le P_i\le P_i^{\max},\quad i=1.....N \quad (7)$$

III. ANT LION ALGORITHM

The ant lions are a class of net-winged insects in nature. The lifecycle of ant lions include: larvae and adult. A larva is the longest period in their lifecycle and ant lions mostly hunt during this period. An ant lion larvae digs a cone shaped pit in sand by moving along a circular path, then the larvae hides underneath the bottom of the cone and waits for the prey to be trapped in the pit. Once the ant lion realizes a prey in the trap, it tries to catch it by intelligently throw sands towards the edge of the pit to slide the prey into the bottom of the pit. After consuming the prey, ant lions throw leftovers outside the pit and amend the pit for next hunt.

The ALO mimics the interactions between the ant lions and ants in the trap. The ants are allowed to move over the search space and ant lions hunt those using traps to become fitter. These activities are mathematically modeled and are detailed in the literature [25]. The main steps involved in the ALO are random walk of ants, building traps, entrapment of ants in preys, catching in preys and rebuilding of traps.

IV. FUZZY SUPPORTED ANT LION ALGORITHM

In multi-objective optimization problems, two or more conflicting objectives are optimized simultaneously subject to variety of equality and inequality constraints. Many feasible solutions are obtained rather than a single solution and these solutions are contradictory. In population based algorithms, an initial population is randomly generated for a chosen problem domain variables. The objective function for each candidate is evaluated and non-

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dominated sorting procedure is applied on the candidate solutions to obtain a Pareto-front set. The fuzzy decision making tool is applied to select the Best Compromised Solution (BCS) as per the requirement.

To obtain the BCS, the objective functions values of each candidate solution are normalized. In this work, a linear membership function (μ_i) has been followed for each objective function. The membership function describes numerically the level of acceptance. The decision maker is fully satisfied with the objective value if μ_i = 1 and not satisfied at all if μ_i =0. The membership function μ_i is defined as,

$$\mu_i = \begin{cases} 1, & if\ F_i \le F_i^{\min} \\ \dfrac{F_i^{\max} - F_i}{F_i^{\max} - F_i^{\min}}, & if\ F_i^{\min} < F_i < F_i^{\max} \\ 0, & if\ F_i \ge F_i^{\max} \end{cases} \tag{8}$$

For each non-dominated solution q, the normalized membership value is calculated using,

$$\mu^q = \frac{\left(\sum_{i=1}^{N_{obj}} \mu_i^q\right)}{\left(\sum_{q=1}^{N_{nds}} \sum_{i=1}^{N_{obj}} \mu_i^q\right)} \tag{9}$$

The fuzzy mechanism has been incorporated in the ALA tool, to develop a Fuzzy Supported ALA (FSALA). The pseudo code for FSALA is defined as follows. The inclusion of multi-objective strategy in the ALA is highlighted.

```
Initialize the first population of ants and ant lions randomly
Normalize the objective function values by fuzzy based decision making mechanism
Evaluate the normalized membership value for each non-dominated solution
Find the best compromised solution and treat it as the elite
While the stopping criterion is not satisfied
        for every ant
                Select an ant lion using Roulette wheel
                Update the x_lb and x_ub
                Create a random walk and normalize it
                Update the positions of ant
        end for
        Normalize the objective function values and check for non-domination
        Find the best compromise solution
        Replace an ant lion with its corresponding ant if it becomes fitter
        Update elite if an ant lion becomes fitter than elite
end while
Return elite
```

V. TEST CASE STUDIES AND DISCUSSIONS

The ALA is chosen as the main optimization tool to address the multi-fuel power generation dispatch problem and the implementation steps are detailed in the previous section. The optimization procedure is coded in Matlab 7 and is executed in a personal computer with the hardware configuration of Intel Core i3 2.4 GHz processor and 4 GB RAM.

The potential of the intended method is verified by the implementation on the standard 10-unit system. Moreover, the following operation cases are considered in order to validate the applicability of the projected algorithm.

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Case 1: Cost Effective (CE) operation
Case 2: Environmental Responsive (ER) operation
Case 3: CE-ER operation

5.1 Standard 10-unit system

This system has three subsystems and 10 generating units, is considered as the benchmark test system for economic operation with MFS studies. Lin and Viviani have proposed this test system and the system particulars are available in the literature [2]. The generating units are fuelled with two or three fuels. Each generator has two or three fuel options and the piecewise quadratic cost functions represents different fuel types. The generating unit 9 is a special case where fuel 2 is not always economical to burn but it may be substituted immediately in the solution algorithm if fuel 1 or 3 is exhausted or not available. The total system demand is gradually varied in steps of 100 MW from 2400 MW to 2700 MW neglecting transmission loss.

Case 1: The intended algorithm is used for the economic operation, considering the valve-point effects along with the quadratic fuel cost functions are considered. The test system particulars are available in the literature [9]. As detailed in the previous case, the simulations are performed for various load demands. The obtained best feasible dispatches using ALA are presented in Table 1. The total fuel costs attained by the ALA are to be $482. 4127, $526.8142, $575.0544 and $623.8278 for load demands of 2400 MW, 2500 MW, 2600 MW and 2700 MW respectively. For the sake of comparison, the total fuel cost for load demand of 2700 MW is compared against the published reports and is presented in Table 2. The reports by using ABC [17], BBO [18] and NAPSO [19] cannot be taken for direct comparison as the results contains errors due to erroneous test data. It is also seen from Table 2, the ALA affords the exact dispatch schedule that leads to a nominal savings in the fuel cost.

Table 1 Best Economic dispatch obtained by ALA for 10-unit system

Unit	Cost Effective Operation							
	P_d = 2400 MW		P_d = 2500 MW		P_d = 2600 MW		P_d = 2700 MW	
	FS	P_i (MW)	FS	P_i (MW)	FS	P_i (MW)	FS	P_i (MW)
P_1	1	189.283	2	206.283	2	218	2	218.593
P_2	1	200.21	1	206	1	210	1	211.216
P_3	1	254.4623	1	266.2502	1	278.1012	1	280.656
P_4	3	234.0337	3	235.6046	3	237	3	239.3707
P_5	1	241.3677	1	258.3708	1	275	1	279.934
P_6	3	233.0557	3	235.3683	3	239.912	3	239.3707
P_7	1	253.6068	1	268.6968	1	286	1	287.7275
P_8	3	233.4948	3	235.9671	3	239	3	239.5051
P_9	1	320.6885	1	331.6617	1	343	3	427.7583
P_{10}	1	239.7971	1	255.7971	1	274	1	275.865
FC ($/h)	**482.4127**		**526.8142**		**575.0544**		**623.8278**	

Table 2 Comparison of total fuel costs ($/h) obtained by ALO and other reports for 10-unit system

Methods	P_d = 2400 MW	P_d = 2500 MW	P_d = 2600 MW	P_d = 2700 MW
IGA-MU [9]	NA	NA	NA	624.5178
CGA-MU [9]	NA	NA	NA	624.7193
NPSO [11]	NA	NA	NA	624.1624
NPSO-LRS[11]	NA	NA	NA	624.1273

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PSO-LRS [11]	NA	NA	NA	624.2297
RGA [12]	482.5114	527.0189	575.1610	624.5081
DE[12]	482.5275	527.0360	575.1753	624.5146
PS0[12]	482.5088	527.0185	575.1606	624.5074
RCGA[16]	NA	NA	NA	623.8281
ABC [17]	NA	NA	NA	609.2250*
BBO [18]	NA	NA	NA	605.6387*
NAPSO [19]	NA	NA	NA	623.6217*
AA[22]	NA	NA	NA	623.9524
DSD[23]	NA	NA	NA	623.8325
ALA	**482.4127**	**526.8142**	**575.0544**	**623.8278**

*-Not feasible NA- Not Applicable

Case 2: The ALA algorithm is applied to optimize the real power outputs of generating units for the environmental friendly operation. The CO_2 emission is considered and its characteristics are taken from the literature [24]. The obtained feasible dispatch schedules for load demands varying from 2400 MW to 2700 MW are presented in Table 3. It is noted that the optimal fuels are selected to achieve minimum emission operation. The total fuel costs for load demand of 2400MW, 2500 MW, 2600 MW and 2700 MW are $501.0115, $547.9708, $598.6458 and $651.0349 respectively. Considering the non-linear cost function, the total fuel cost is increased to $501.36, $548.2843, $599.2157 and $651.4051 of the similar dispatch.

Table 3 Best feasible dispatches for environmentally responsible operation of 10 unit system

Unit	**P_d = 2400 MW**		**P_d = 2500 MW**		**P_d = 2600 MW**		**P_d = 2700 MW**	
	FS	**P_i (MW)**	**FS**	**P_i (MW)**	**FS**	**P_i (MW)**	**FS**	**P_i (MW)**
P_1	1	169.8432	2	196.0725	2	196.0924	2	196.6752
P_2	1	199.9977	1	209.734	1	209.615	1	211.4194
P_3	1	270	1	281.0024	1	298.2023	1	301.2775
P_4	3	248.7711	3	254.0253	3	255.0274	3	257.0464
P_5	1	260.9987	1	297.1178	1	300.0157	1	288.5928
P_6	1	165.9886	1	157.9894	1	158.4795	1	167.92
P_7	1	291.5958	1	271.4834	1	291.9906	2	365.299
P_8	3	245.2193	3	243.5108	3	250.4337	3	258
P_9	1	347.5856	3	388.8667	3	439.9585	3	439.7546
P_{10}	1	200	1	200.1975	1	200.1856	1	214.0187
EC (kg/h)	**4692.544**		**5137.025**		**5572.284**		**6042.812**	

Case 3: The FSALA algorithm is applied for close practical operation that aims for the cost effective and environmental response operation in the multi-objective framework. The extreme points in the search space are identified by the ALA algorithm through the single objective optimization procedure which is detailed in the previous sub-sections. As detailed in the section 5, the FSALA algorithm is applied to solve in the multi-objective frame in which the fuzzy mechanism is adopted for coordinating the conflicting objectives. The obtained best feasible dispatches for various load demands are presented in Table 4. The projected algorithm attains the total fuel costs and emissions corresponding to the best feasible dispatches as $499.0612 and 4693.51 kg for 2400 MW; $546.3413 and 5142.899 kg for 2500 MW; $595.1461 and 5572.487 kg for 2600 MW and $649.8673 and 6043.63 kg for 2700 MW. Table 5 details

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the comparison of the BCS for all load demands that indicates the FSALA attains the best dispatches for all load demands against the comparing methods like HLN[24], LIM [24], ABC, TLBO and GWO.

Table 4 Best feasible economic and environmental dispatches of 10 unit system

Unit	P_d = 2400 MW		P_d = 2500 MW		P_d = 2600 MW		P_d = 2700 MW	
	FS	**P_i (MW)**	**FS**	**P_i (MW)**	**FS**	**P_i (MW)**	**FS**	**P_i (MW)**
P_1	1	166.5633	2	196.0623	2	196.0832	2	196.6752
P_2	1	199.3945	1	205.4360	1	208.1230	1	211.4194
P_3	1	259.5376	1	285.0330	1	296.4113	1	302.2775
P_4	3	245.6166	3	254.0144	3	247.1356	3	256.0464
P_5	1	251.7806	1	297.1287	1	298.1175	1	288.5928
P_6	1	156.1777	1	164.9885	1	167.5686	1	170.42
P_7	1	283.8588	1	271.4525	1	297.8834	2	365.299
P_8	3	244.4792	3	236.6117	3	249.4328	3	255.5
P_9	3	392.6513	3	388.9856	3	438.8587	3	439.7546
P_{10}	1	200.0003	1	200.2887	1	200.3876	1	214.0187
FC ($/h)	**499.0612**		**546.3413**		**595.1461**		**649.8673**	
EC (kg/h)	**4693.517**		**5142.899**		**5572.487**		**6043.63**	

Table 5 BCS Comparison for CE-ER operation

Methods	P_d = 2400 MW		P_d = 2500 MW		P_d = 2600 MW		P_d = 2700 MW	
	FC ($/h)	**EC (kg/h)**	**FC ($/h)**	**EC (kg/h)**	**FC ($/h)**	**EC (kg/h)**	**FC ($/h)**	**EC (kg/h)**
HLN[24]	498.202	4694.992	547.0897	5143.397	596.5429	5574.018	649.7493	6050.6
LIM[24]	499.0613	4693.518	547.0907	5143.407	596.7164	5573.464	650.0047	6044.31
ABC	501.4721	4702.458	546.5634	5143.059	595.9169	5587.210	649.9823	6044.83
TLBO	501.3097	4701.675	546.5096	5143.041	595.7641	5586.527	649.9541	6044.65
GWO	500.5019	4701.964	546.3560	5143.029	595.6833	5585.685	649.8996	6043.64
FSALA	**499.0612**	**4693.517**	**546.3413**	**5142.899**	**595.1461**	**5572.487**	**649.8673**	**6043.63**

VI. CONCLUSIONS

In this paper, the most realistic operational model including valve-point effects, environmental issues and MFS is proposed. These operational constraints increase further the complexity in the non-linear solution space. The modern swarm intelligence algorithm known as ALA is applied for solving the operational problem and fuzzy decision making mechanism is used to extract the BCS in the multi-objective framework. Various kinds of power system operational problems considering MFS are demonstrated on the standard 10-unit test system. The obtained numerical results for all test cases are compared with the earlier reports. The comparison clearly indicates that new best feasible dispatches have been attained for the problem under study. The salient features of FSALA for solving CE-ER problems are: it can consistently find good dispatch schedule within a reasonable execution time; simple, easy implementation and has the ability to handle the operational constraints. The proposed operational model brings together the major operational issues. The economical deviation indices also validates the appropriate model is proposed. The developed model is useful to enhance the effective usage of fuels which is desirable in the present

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operational scenario. In future, the ALA would be likely to be applied for solving optimal operation of hybrid power system which has multiple renewable energy sources.

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