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SOLVING COMBINED ECONOMIC AND EMISSION DISPATCH PROBLEM USING THE SLIME MOULD ALGORITHM

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Abstract

In this paper, a novel optimization method called Slime Mould Algorithm (SMA) for solving the ELD and CEED problem is presented. To investigate the effectiveness of the proposed algorithm, the 10 and 40 units considering the valve point loading effect test has been executed. The solving the Economic Load Dispatch (ELD) and Combined Economic and Emission Dispatch (CEED) are crucial task in modern power systems. The aim of ELD is assigning the best generation scheduling for minimum cost generation with satisfying the load demands while the CEED means assigning the best generation scheduling for cost and emission reduction simultaneously. The effectiveness of the proposed algorithm is compared with other algorithms.

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1. INTRODUCTION

Economic and emission load Dispatch (CEED) problem is a strenuous and important task for optimal planning and operation of electrical systems [1]. The ELD problem is determined optimal output powers of the thermal generation units to diminish the cost of electricity generation in order to satisfy the system demands [2]. It worth mentioning that the characteristics of generators' input-output in modern power are nonlinear due to the valve point effect, multi-fuel effects. In this context, the CEED and ELD are represented as a non-smooth and non-convex optimization problem. Several traditional methods have been implemented for solving ELD including linear programming [3], lambda iteration method [4, 5], the coordination methods [6]. The shortages of application these methods include the low accuracy this is due to using approximate approaching for solving this problem and these methods may be trapped in local optima. Therefore, different meta-heuristic methods have been utilized for solving this problem. Particle Swarm Optimization (PSO) [7, 8]. optimization utilizing Civilized Swarm (CS) [9]. Firefly Algorithm (FA) [10]. Among the hybrid algorithms, utilized in solving the EcD problem, we mentioned, hybrids which combine two metaheuristic algorithms (such as: PSO-GSA [11], DE-PSO [12]. Flower Pollination Algorithm (FPA) is utilized to solve Economic Load Dispatch (ELD) and Combined Economic Emission Dispatch (CEED) problems in large-scale power system with valve point effect [13]. A modified Symbiotic Organisms Search (MSOS) algorithm is utilized for largescale economic dispatch problem with valve-point effects, taking into consideration the transmission line losses [14].

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SMA is an efficient algorithm that simulates the behavior and morphological changes of a slime mold. Meanwhile, the use of weights in SMA is to simulate the positive and negative reactions produced by slime mold during foraging, thus forming three different types of morphs [15].

In this paper, SMA is utilized for solving the ELD and CEED problem. The Problem Formulation which illustrates the ELD and CEED problems and the system constraints is elucidated in Section 2. The proposed SMA technique is elucidated in Section 3. Simulation results are elucidated in Section 4. Finally, the conclusion is presented in Section 5.

2. PROBLEM FORMULATION

2.1. Economic Load Dispatch (ELD)

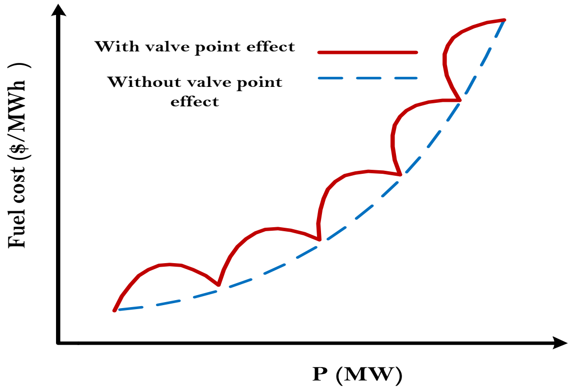

Fig.1. Representation of cost function with VPE.

A fuel cost diminishing is a single objective function, which is the important consideration during Economic Load Dispatch solution, whilst CEED solution refers to diminishing a two fitness functions, fuel cost and emission, respectively. The mathematic presentation of fuel cost can be formulated as follows.

$$Cost = \sum_{k=1}^{n} F_k(P_k) = \sum_{i=1}^{n} a_k P_k^2 + b_k P_k + c_k \tag{1}$$

where, Cost indicate the fuel cost. Whilst the generator cost coefficients are indicated by a_k, b_k and c_k respectively, as well the number of generation units are indicated by n. practically, turbine have intromission valves which utilized to regulate the amount of fuel according to variations of the required energy, it leads to rippling impact in the quadratic cost function which known as valve point effect (VPE) as shown in Fig. 1 [16]. The fuel cost considering the VPE can be formulated as follows:

$$\text{Cost\_VPE} = \sum_{k=1}^{n} F_k(P_k) = \sum_{k=1}^{n}(a_k P_k^2 + b_k P_k + c_k + f_k \times sin(e_k \times (P_{min} - P_k))\,) \tag{2}$$

where e_k and f_k indicates the unit coefficients for the VPE.

2.2. Economic and emission load Dispatch (CEED)

A summation of quadratic and exponential terms is utilized to fulfill the emission of each generator as follows:

$$Emission = \sum_{k=1}^{n} E_k(P_k) = \sum_{k=1}^{n}(k_k P_k^2 + l_k P_k + g_k + m_k \times exp\ (h_k \times P_k)) \tag{3}$$

where, Emission denotes the total emission. E_k represents the k^{th} generator emission. The coefficients of emission are indicated byk_k, l_k, g_k, m_k and h_k.

The fuel cost along with emission can be diminished by obtain the optimal output powers of the connected generation units from CEED problem solution. The multi-objective function is converted to a single objective function by utilizing the price penalty factor method as follows:

$$F = Cost\_VPE + H \times Emission \tag{4}$$

where H denotes the price penalty factor (PPF). The steps for finding the PPF can be stated as follows:

1. Assign the PPF for each unit as following:

$$H_k = \frac{F_k(P_k^{max})}{E_k(P_k^{max})} \tag{5}$$

2. H_k is organized in ascending order.
3. Add the P_k^{max} of each unit at starting from the lowest H_k until

$$P_k^{max} \geq P_D \tag{6}$$

4. The PPF is fulfill by determining the lowest limit of H_k which fulfil the upper condition.

2.3. Constraints

2.3.1. The constraint of generator

$$P_k^{max} \geq P_k \geq P_k^{min} \tag{7}$$

where, P_k^{max} and $\mathrm{P_i^{min}}$ are indicates the maximum allowable output of generator *k and its* minimum limits, respectively.

2.3.2. Load balance constraint

$$\sum_{k=1}^{n} P_k = P_D + P_{Loss} \tag{8}$$

where P_D , P_{Loss} are the power of load demand and power loss, respectively.

The power loss can be found by Kron's loss formula as follows.

$$P_{\mathrm{Loss}} = \sum_{i=1}^{n}\sum_{j=1}^{n}\left(P_i B_{ij} P_j\right) + \sum_{i=1}^{d} B_{oi} P_i + B_{oo} \tag{9}$$

where B_{ij}, B_{oi} and B_{oo} denote the loss coefficients.

3. SLIME MOULD ALGORITHM (SMA)

This algorithm simulates a method for finding multiple heads in a vesarium that inhabits cold and wet places. In this technique, weights approach to negative and positive feedbacks created by sticky mold during the foraging process. During this stage, the slurry can determine the best food-gathering path in a superior way. The organic matter in the slime mold searches for food. Then it encircles it and releases enzymes for its consumption. In the migration stage, the anterior end expands into a fan shape along with a venous network that allows the cytoplasm to slide inward. An intravenous network consists of using multiple food sources simultaneously to form to connect them. In this mechanism, a reproductive wave is formed when a vein approaches a food source. The mathematical representation of MSA is formulated as follows:

3.1. *Approach food.*

The shrinkage mode of a slime mold can be represented as follows [17]:

$$X(t+1) = \begin{cases} X_b(t) + v_b \cdot \left(W \cdot X_A(t) - X_B(t)\right), r < p \\ v_c \cdot X(t), \qquad\qquad\qquad\qquad r \geq p \end{cases} \tag{17}$$

where v_b denotes a parameter with a range of $[-a, a]$, v_c is reduced from one to zero. t denotes the current iteration,X_b is the location of slime mould with the highest odor concentration currently assigned, X denotes the location of slime mould, X_A and X_B are two individuals randomly selected from the swarm, W represents the weight of slime mould. The p is a parameter which can be obtained as follows:

$$p = tanh|S(i) - \mathrm{DF}| \tag{18}$$

where $i \in 1,2,\ldots,n$, $S(i)$ denotes the objective function of X, DF is the best objective function obtained in all iterations. v_b is calculated as follows:

$$v_b = [-a, a] \tag{19}$$

$$a = \operatorname{arctanh}\left(-\left(\frac{t}{\max\_t}\right) + 1\right) \tag{20}$$

The W is depicted using (21) as follows:

$$W = \begin{cases} 1 + r \cdot log\left(\frac{bF - S(i)}{bF - wF} + 1\right), & condition \\ 1 - r \cdot log\left(\frac{bF - S(i)}{bF - wF} + 1\right), & others \end{cases} \tag{21}$$

$$\mathrm{SmellIndex} = \mathrm{sort}(S) \tag{22}$$

where condition indicates that $S(i)$ classifies the first half of the population, r represents a random parameter in rang $[0,1]$, bF represents the optimal objective function, wF represents the worst objective function.

3.2. Wrap food

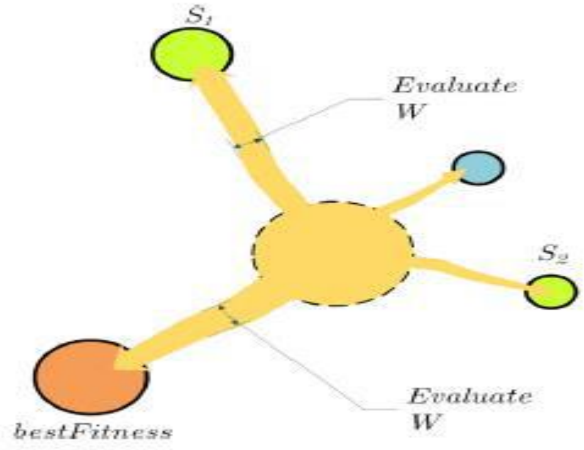

Fig. 2. Evaluation of fitness.

The case simulates a slime mold to control research patterns related to food quality. If the food concentration is contained, the weight near the area is greater; when the concentration of food is low, the weight of the area will decrease, and thus it will turn to explore other areas. Fig. 2 illustrates the process of evaluating the fit values of a slime mold. Based on the principle above, the mathematical formula for updating a slime mold site is as follows:

$$X^* = \begin{cases} rand(UB - LB) + LB, & rand < z \\ X_b(t) + v_b \cdot \left(W \cdot X_A(t) - X_B(t)\right), & r < p \\ v_c \cdot X(t), & r \geq p \end{cases} \tag{23}$$

where LB is the lower bound of control variable while UB is its maximum, rand and r are random variables which equal to $1 \geq r,$ rand ≥ 0, respectively.

3.3. Grabble food

The v_b varied randomly within rang $[-a, a]$ and gradually go to zero with as increasing the iterations number. The value of v_c varied between [-1, 1] and reached to zero eventually.

Algorithm 1 Pseudo-code of SMA

```
Define the parameters of SMA the maximum number of iterations.
Generate initial locations of slime mould $X_i (i = 1,2, \dots, n)$;
While ($t \leq$ Max_iteraition)
evaluate the objective function for each slime mould;
    $Update\ bestFitness,\ X_b$
Obtain the $W$ using Eq. (21);
For $each\ search\ portion$
  $Update\ p, v_b, v_c$;
  $Update\ locations\ by$ Eq. (23);
End For
$t = t + 1$;
End While
Return $bestFitness,\ X_b$;
```

4. SIMULATION RESULTS AND DISCUSSIONS

The SMA is utilized for optimal solution the ELD and CEED problems on two test systems (10 and 40 units) and a comparison with other techniques has been reported to verify the SMA technique validation. The program code of the SMA for ELD and CEED was written and carried out on MATLAB software on Core I5 PC with 4 GB RAM. The selected parameters of SMA are set to be 50, 500 and 1000 for number of the search agents, number of iterations for Case 1 (40 units) and Case 2 (10 units), respectively. Two case study are listed as follows:

4.1. Test case 1

In this test, a large-scale plant, which includes a 40-thermal units' system, are studied. The system constraints and cost coefficients are given in [16]. Neglecting the transmission loss, the ELD problem is solved for cost minimization with the valve loading effects in this case. The best-yielded powers of generation units, which obtained by the proposed SMA technique and other algorithms are, listed in Table 1. The total cost that obtained by SMA technique is 121,413.0 \$. Judging from Table I, the yields fuel cost by SMA technique is a lower cost than APPSO [18], MPSO[19], CDE_SQP [20] and SOMA[21] and the system constraints have been satisfied. The trend of the objective function with iterations utilizing SMA is shown in Fig. 3. Simulation results confirm that the SMA technique presented the preferable stable convergence characteristics.

TABLE 1. THE OPTIMAL SCHEDULING OF THE GENERATORS AND COMPARISON OF ELD OF 40-UNITS.

Outputs in $\boldsymbol{MW}$	APPSO [18]	MPSO [19]	CDE_SQP [20]	SOMA [21]	Proposed SMA
$\boldsymbol{P1}$	112.579	113.9971	111.7576	112.8544	110.8583
$\boldsymbol{P2}$	111.553	112.6517	111.55584	111.7795	111.5738
$\boldsymbol{P3}$	98.751	119.4255	97.3999	97.4059	97.4005
$\boldsymbol{P4}$	180.384	189.0000	179.7300	179.7274	179.7332
$\boldsymbol{P5}$	94.389	96.8711	91.656	87.9306	88.9196
$\boldsymbol{P6}$	139.943	139.2798	140.0000	139.988	139.7189
$\boldsymbol{P7}$	298.937	223.5924	300.0000	259.7736	259.9878
$\boldsymbol{P8}$	285.827	284.5803	300.0000	284.628	284.6308
$\boldsymbol{P9}$	298.381	216.4333	284.5997	284.7539	284.6812
$\boldsymbol{P10}$	130.212	239.3357	130.0000	130.0291	130.0232
$\boldsymbol{P11}$	94.385	314.8734	168.7900	168.7908	94.0734
$\boldsymbol{P12}$	169.583	305.0565	94.0000	168.8084	94.0182
$\boldsymbol{P13}$	214.617	365.5429	214.7600	214.7191	214.8024
$\boldsymbol{P14}$	304.886	493.3729	394.2800	394.2888	394.2854
$\boldsymbol{P15}$	304.547	280.4326	304.5200	304.5196	394.2858
$\boldsymbol{P16}$	304.584	432.0717	304.5200	394.2952	394
$\boldsymbol{P71}$	498.452	435.2428	489.2800	489.2905	489.2885
$\boldsymbol{P18}$	497.472	417.6958	489.2800	489.2779	489.2961
$\boldsymbol{P19}$	512.816	532.1877	511.2800	511.2861	511.2783
$\boldsymbol{P20}$	548.992	409.2053	511.2800	511.2792	511.3655
$\boldsymbol{P21}$	524.652	534.0629	523.2800	523.2858	523.2984
$\boldsymbol{P22}$	523.399	457.0962	523.2900	523.2899	523.5002
$\boldsymbol{P23}$	548.895	441.3634	523.2800	523.2783	523.8690
$\boldsymbol{P24}$	525.871	397.3617	523.2800	523.3199	524.1585
$\boldsymbol{P25}$	523.814	446.4181	523.2800	523.2791	523.2903
$\boldsymbol{P26}$	523.565	442.1164	523.2800	523.3076	523.3877
$\boldsymbol{P27}$	10.575	74.8622	10.0000	10.0021	10.0008
$\boldsymbol{P28}$	11.177	27.5430	10.0000	10.0054	10.0091
$\boldsymbol{P29}$	11.210	76.8314	10.0000	10.0061	10.0974
$\boldsymbol{P30}$	96.178	97.0000	90.3329	88.8932	87.9300
$\boldsymbol{P31}$	189.999	118.3775	190.0000	189.9975	189.9935
$\boldsymbol{P32}$	189.924	188.7517	190.0000	189.9919	189.5022
$\boldsymbol{P33}$	189.714	190.0000	190.0000	189.9825	190.0000
$\boldsymbol{P34}$	199.284	120.7029	200.0000	164.9291	164.8326
$\boldsymbol{P35}$	199.599	170.2403	200.0000	164.8031	191.2286
$\boldsymbol{P36}$	199.751	198.9897	200.0000	164.9387	199.8973
$\boldsymbol{P37}$	109.973	110.0000	110.0000	109.9974	109.4106
$\boldsymbol{P38}$	109.506	109.3405	110.0000	109.9856	110
$\boldsymbol{P39}$	109.363	109.9243	110.0000	109.9995	109.9998
$\boldsymbol{P40}$	511.261	468.1694	511.2794	511.2813	511.3730
Cost×105 ($)	1.220446	1.216492	1.21741979	1.214187	1.214130

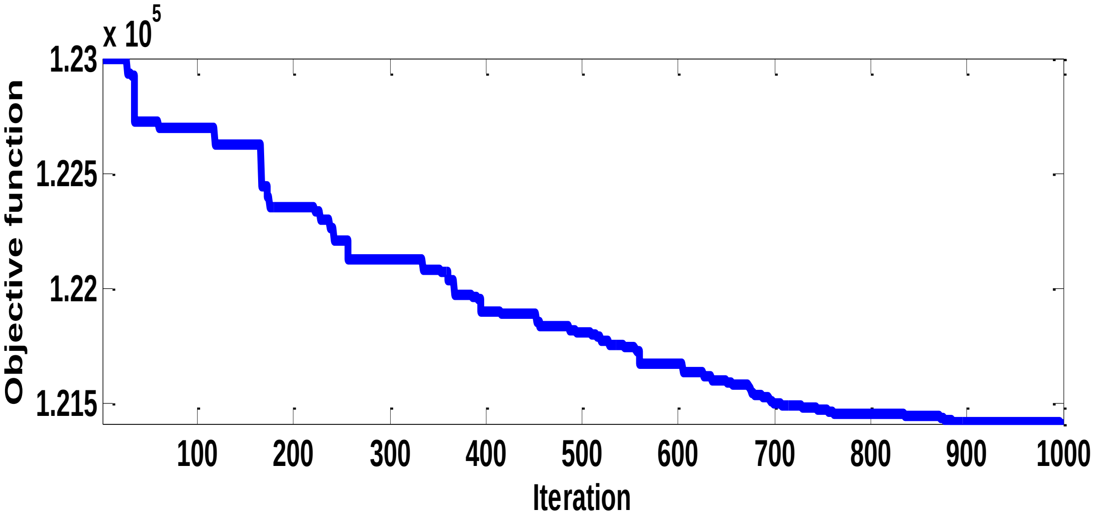

Fig. 3. The convergence characteristics of MSA for ELD in 40-unit system.

4.2. Test case 2

TABLE 2 THE OPTIMAL SCHEDULING OF THE GENERATORS AND THE COMPARISON OF THE CEED FOR 10-UNIT.

Outputs in ***MW***	PDE [22]	ABC_PSO [23]	MODE [22]	NSGAII [22]	GSA [24]	SPEA-2 [22]	proposed SMA
***P*1**	54.9853	55	54.9487	51.9515	54.9992	52.9761	55.0000
***P*2**	79.3803	80	74.5821	67.2584	79.9586	72.813	79.9998
***P*3**	83.9842	81.14	79.4294	73.6879	79.4341	78.1128	84.8929
***P*4**	86.5942	84.216	80.6875	91.3554	85.0000	83.6088	81.9638
***P*5**	144.4386	138.3377	136.8551	134.0522	142.1063	137.2432	138.8652
***P*6**	165.7756	167.5086	172.6393	174.9504	166.5670	172.9188	169.2749
***P*7**	283.2122	296.8338	283.8233	289.4350	292.8749	287.2023	297.9312
***P*8**	312.7709	311.5824	316.3407	314.0556	313.2387	326.4023	314.5669
***P*9**	440.1135	420.3363	448.5923	455.6978	441.1775	448.8814	425.0811
***P*10**	432.6783	449.1598	436.4287	431.8054	428.6306	423.9025	436.3166
Losses (MW)	83.9	84.1736	84.33	84.25	83.9869	84.1	83.89
Cost×105($)	1.1351	1.1342	1.13484	1.13539	1.1349	1.1352	1.13490
Emission (ton/h)	4111.4	4120.1	4124.9	4130.2	4111.4	4109.1	4108.6

In this test, the MSA is employed for solving CEED for the 10 units system. The coefficients of the generation units and the system constraints are depicted in [16]. In this case, the *CEED* is the solved for the fuel cost and the emission reduction. The optimal scheduling of generators that obtained by using the MSA and other optimizers are presented in Table II. The total cost and emission that obtained by SMA technique are 1.13490 $\times 10^5$ $ and 4108.6 ton/h. Judging from Table 2, the yields fuel cost by SAM technique is a lower cost than the other techniques such as,

APPSO[18], MPSO[19], CDE_SQP [20] and SOMA[21]. Fig.4 depicts the convergence of the fitness function by SMA. Simulation results confirm that the SMA technique presented the preferable stable convergence characteristics.

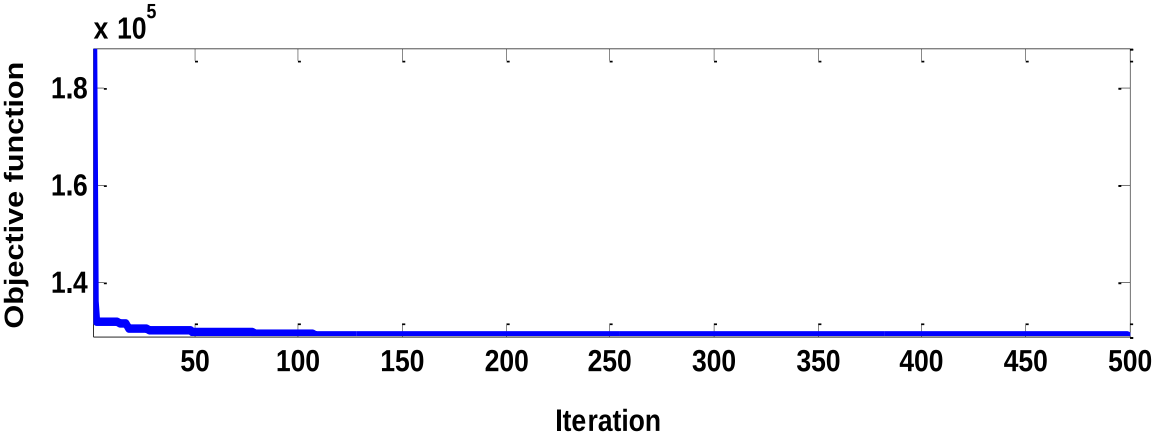

Fig. 4. The convergence characteristics of MSA for CEED solution for 10-unit system.

5. CONCLUSION

This paper presented application of novel optimizer called SMA to solve the ELD and the CEED problems. A two test systems (10 and 40 units) have been carried out utilizing SMA optimization technique. The obtained results from SMA have been compared with other report algorithms. Simulation results proof that the SMA presented the best one compared with other technique, in additions the simulation results verified superiority of the SMA for ELD and CEED problem solutions compared to other optimizers.

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