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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Keywords: EC Dispatch; Combined Economic Emission Dispatch; Valve point effect.

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], Flower Pollination 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)

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.

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

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:

\[
Cost_{VPE} = \sum_{k=1}^{n} F_k(P_k) = \sum_{k=1}^{n} (a_k P_k^2 + b_k P_k + c_k + f_k \times \sin(e_k \times (P_{min} - P_k)))
\]

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:

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

where, Emission denotes the total emission. \( E_k \) represents the \( k^{th} \) generator emission. The coefficients of emission are indicated by \( k_k, l_k, g_k, m_k \) 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:

\[ F = \text{Cost} \_\text{VPE} + H \times \text{Emission} \]  

(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:

\[ H_k = \frac{f_k(p_k^{\text{max}})}{E_k(p_k^{\text{max}})} \]  

(5)

2. \( H_k \) is organized in ascending order.

3. Add the \( P_k^{\text{max}} \) of each unit at starting from the lowest \( H_k \) until

\[ P_k^{\text{max}} \geq P_D \]  

(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

\[ P_k^{\text{max}} \geq P_k \geq P_k^{\text{min}} \]  

(7)

where, \( P_k^{\text{max}} \) and \( P_k^{\text{min}} \) are indicates the maximum allowable output of generator \( k \) and its minimum limits, respectively.

2.3.2. Load balance constraint

\[ \sum_{k=1}^{n} P_k = P_D + P_{\text{Loss}} \]  

(8)

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

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

\[ P_{\text{Loss}} = \sum_{i=1}^{n} \sum_{j=1}^{n} (P_i B_{ij} P_j) + \sum_{i=1}^{d} B_{oi} P_i + B_{oo} \]  

(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]:

\[ \text{[17]} \]
\[ X(t + 1) = \begin{cases} X_b(t) + v_b \cdot (W \cdot X_A(t) - X_B(t)), & r < p \\ v_c \cdot X(t), & r \geq p \end{cases} \] 

(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:

\[ p = \tanh|S(i) - DF| \] 

(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:

\[ v_b = [-a, a] \] 

(19)

\[ a = \text{arctanh} \left( -\left( \frac{t}{t_{\text{max}}} \right) + 1 \right) \] 

(20)

The \( W \) is depicted using (21) as follows:

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

(21)

\[ \text{SmellIndex} = \text{sort}(S) \] 

(22)

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

3.2. Wrap food

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:

\[
X^* = \begin{cases} 
rand(UB - LB) + LB, & rand < z \\
X_b(t) + v_b \cdot (W \cdot X_A(t) - X_b(t)), & r < p \\
v_c \cdot X(t), & r \geq p 
\end{cases}
\]

(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 ≥ r, rand ≥ 0, respectively.

3.3. Grabble food

The \(v_b\) varied randomly within range \([-a, a]\) 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 \(X_i (i = 1, 2, \ldots, n)\); |
| While \((t \leq \text{Max\_iteration})\) |
| evaluate the objective function for each slime mould; |
| \(\text{Update bestFitness, } X_b\) |
| Obtain the \(W\) using Eq. (21); |
| For each search portion |
| \(\text{Update } p, v_b, v_c;\) |
| \(\text{Update locations by Eq. (23)};\) |
| 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 1, 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.
| Outputs in MW | APPSO [18] | MPSO [19] | CDE_SQP [20] | SOMA [21] | Proposed SMA |
|--------------|------------|-----------|--------------|------------|--------------|
| P1           | 112.579    | 113.9971  | 111.7576     | 112.8544   | 110.8583     |
| P2           | 111.553    | 112.6517  | 111.5584     | 111.7795   | 111.5738     |
| P3           | 98.751     | 119.4255  | 97.3999      | 97.4059    | 97.4005      |
| P4           | 180.384    | 189.0000  | 179.7300     | 179.7274   | 179.7332     |
| P5           | 94.389     | 96.8711   | 91.656       | 87.9306    | 88.9196      |
| P6           | 139.943    | 139.2798  | 140.0000     | 139.988    | 139.7189     |
| P7           | 298.937    | 223.5924  | 300.0000     | 259.7736   | 259.9878     |
| P8           | 285.827    | 284.5803  | 300.0000     | 284.628    | 284.6308     |
| P9           | 298.381    | 216.4333  | 284.5997     | 284.7539   | 284.6812     |
| P10          | 130.212    | 239.3357  | 130.0000     | 130.0291   | 130.0232     |
| P11          | 94.385     | 314.8734  | 168.7900     | 168.7908   | 94.0734      |
| P12          | 169.583    | 305.0565  | 94.0000      | 168.8084   | 94.0182      |
| P13          | 214.617    | 365.5429  | 214.7600     | 214.7191   | 214.8024     |
| P14          | 304.886    | 493.3729  | 394.2800     | 394.2888   | 394.2854     |
| P15          | 304.547    | 280.4326  | 304.5200     | 304.5196   | 394.2858     |
| P16          | 304.584    | 432.0717  | 304.5200     | 394.2952   | 394           |
| P17          | 498.452    | 435.2428  | 489.2800     | 489.2905   | 489.2885     |
| P18          | 497.472    | 417.6958  | 489.2800     | 489.2779   | 489.2961     |
| P19          | 512.816    | 532.1877  | 511.2800     | 511.2861   | 511.2783     |
| P20          | 548.992    | 409.2053  | 511.2800     | 511.2792   | 511.3655     |
| P21          | 524.652    | 534.0629  | 523.2800     | 523.2858   | 523.2984     |
| P22          | 523.399    | 457.0962  | 523.2900     | 523.2899   | 523.5002     |
| P23          | 548.895    | 441.3634  | 523.2800     | 523.2783   | 523.8690     |
| P24          | 525.871    | 397.3617  | 523.2800     | 523.3199   | 524.1585     |
| P25          | 523.814    | 446.4181  | 523.2800     | 523.2791   | 523.2903     |
| P26          | 523.565    | 442.1164  | 523.2800     | 523.3076   | 523.3877     |
| P27          | 10.575     | 74.8622   | 10.0000      | 10.0021    | 10.0008      |
| P28          | 11.177     | 27.5430   | 10.0000      | 10.0054    | 10.0091      |
| P29          | 11.210     | 76.8314   | 10.0000      | 10.0061    | 10.0974      |
| P30          | 96.178     | 97.0000   | 90.3329      | 88.8932    | 87.9300      |
| P31          | 189.999    | 118.3775  | 190.0000     | 189.9975   | 189.9935     |
| P32          | 189.924    | 188.7517  | 190.0000     | 189.9919   | 189.5022     |
| P33          | 189.714    | 190.0000  | 190.0000     | 189.9825   | 190.0000     |
| P34          | 199.284    | 120.7029  | 200.0000     | 164.9291   | 164.8326     |
| P35          | 199.599    | 170.2403  | 200.0000     | 164.8031   | 191.2286     |
| P36          | 199.751    | 198.9897  | 200.0000     | 164.9387   | 199.8973     |
| P37          | 109.973    | 110.0000  | 110.0000     | 109.9974   | 109.4106     |
| P38          | 109.506    | 109.3405  | 110.0000     | 109.9856   | 110           |
| P39          | 109.363    | 109.9243  | 110.0000     | 109.9995   | 109.9998     |
| 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 |
|-----------------|----------|--------------|-----------|-------------|---------|------------|-------------|
| $P1$            | 54.9853  | 55           | 54.9487   | 51.9515     | 54.9992 | 52.9761    | 55.0000     |
| $P2$            | 79.3803  | 80           | 74.5821   | 67.2584     | 79.9586 | 72.813     | 79.9998     |
| $P3$            | 83.9842  | 81.14        | 79.4294   | 73.6879     | 79.4341 | 78.1128    | 84.8929     |
| $P4$            | 86.5942  | 84.216       | 80.6875   | 91.3554     | 85.0000 | 83.6088    | 81.9638     |
| $P5$            | 144.4386 | 138.3377     | 136.8551  | 134.0522    | 142.1063| 137.2432   | 138.8652    |
| $P6$            | 165.7756 | 167.5086     | 172.6393  | 174.9504    | 166.5670| 172.9188   | 169.2749    |
| $P7$            | 283.2122 | 296.8338     | 283.8233  | 289.4350    | 292.8749| 287.2023   | 297.9312    |
| $P8$            | 312.7709 | 311.5824     | 316.3407  | 314.0556    | 313.2387| 326.4023   | 314.5669    |
| $P9$            | 440.1135 | 420.3363     | 448.5923  | 455.6978    | 441.1775| 448.8814   | 425.0811    |
| $P10$           | 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×10^5($)    | 1.1351   | 1.1342      | 1.13484   | 1.13539     | 1.1349  | 1.1352     | 1.1349      |
| 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.
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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