Application of a new constraint handling method for economic dispatch considering electric market

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ABSTRACT

In this paper, optimal load dispatch problem under competitive electric market (OLDCEM) is solved by the combination of cuckoo search algorithm (CSA) and a new constraint handling approach, called modified cuckoo search algorithm (MCSA). In addition, we also employ the constraint handling method for salp swarm algorithm (SSA) and particle swarm optimization algorithm (PSO) to form modified SSA (MSSA) and modified PSO (MPSO). The three methods have been tested on 3-unit system and 10-unit system under the consideration of payment model for power reserve allocated, and constraints of system and generators. Result comparisons among MCSA and CSA indicate that the proposed constraint handling method is very useful for metaheuristic algorithms when solving OLDCEM problem. As compared to MSSA, MPSO as well as other previous methods, MCSA is more effective by finding higher total benefit for the two systems with faster manner and lower oscillations. Consequently, MCSA method is a very effective technique for OLDCEM problem in power systems.

Keywords: Constraint handling method, Cuckoo search algorithm, Economic load dispatch, Fitness function, Maximum profit

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1. INTRODUCTION

Power energy consumption demands are more and more ever-growing because of rapid population growth as well as a tremendous economic spurt of countries. This issue has become one of the most difficult problems for generation plants in operation and energy supply. An optimal solution to such problem is to determine the allocation of the most optimal active power output of thermal units with intent to reduce their fuel cost and meet all constraints. The solution is considered as an achievement of optimal load dispatch (OLD) problem with two main cases [1, 2]. In the first case, the fuel cost model with single fuel is usually presented as a quadratic function in which different fuels and loading effects are taken into consideration [2]. Optimization methodologies have been proposed to solve this problem [3-7]. In the second case, the OLD problem is divided into economic-emission dispatch (EED) problem and heat-power economic dispatch (HPED) problem. Some artificial intelligence-based methods have successfully solved EED problem [8, 9] and HPED problem [10, 11].

The fact that OLD problem has a huge contribution to power system operation but not considering competitive electric market. So, it is essential if the competitive electric market is added to such OLD problem in order to lift it a higher form with more complex and real characteristic [12, 13]. When considering OLD problem under the competitive market, there is a concept called a compromise price that is electric power providers and their customers are being considered as the most important factor. It affects the maximum profit of electric power supply company and the minimum benefit of consumers [14]. In this regard, the maximum profit can be obtained when the company determines reserved energy that will be supplied to users in next hours [15]. Besides, power loss on conductors is also an important element and effect on the profit of providers because they make the cost increase [16, 17]. Such profit can be dealt by different alternatives. In [16], authors have used the electricity flow tracing approach for suitably allocating the transmission losses to every thermal unit while authors in [17] have proposed the bidding price model dependent on the power transmission distance from the power plant to the loads.

In addition, solving OLD problem under the competitive electric market has been considered in unit commitment problem. A high number of methods have been applied for the problem such as augmented Lagrange Hopfield network (ALHN) [18], secant method and invasive weed method (SM-IWM) [19], memetic binary differential evolution (MBDE) [20], differential evolution (DE) [21], cuckoo search algorithm (CSA) [21] and Hopfield Lagrange network with different functions (HLNEF) [21]. In this paper, OLD problem under the competitive electric market (OLDCEM) is solved by three methods including MCSA, MSSA, and MPSO. The three methods are tested on 3-unit system and 10-unit system considering payment model for power reserve allocated, and constraints of system and generators. The main contributions in the paper can be expressed as follows:

1. Propose a new constraint handling approach for OLDCEM problem
2. Successfully apply the constraint handling approach for CSA, SSA and PSO
3. The new constraint handling approach supports MCSA reach much better results than CSA for all study cases
4. MCSA can reach higher profit and is faster than other compared methods

2. PROBLEM FORMULATION

OLD problem in competitive electric market aims to maximize total profit for the whole system meanwhile all constraints such as power demand, reserve demand, and generation limitations are required to be exactly satisfied. The objective and constraints are described as follows:

2.1. Objective function

The crucial objective of the OLDCEM problem is to find the maximum profit of all thermal generation units as showing the following equation:

$$\text{Maximize } PR = TRV - TFC$$

(1)

where TRV and TFC are the total revenue and the total cost of thermal units and obtained by:

$$TFC = (1 - \delta) \sum_{i=1}^{nC} FC_i (A_{P_i}) + \sum_{i=1}^{nC} FC_i (A_{P_i} + A_{R_i})$$

(2)

$$TRV = \sum_{i=1}^{nC} (A_{P_i}SP) + \sum_{i=1}^{nC} ((1 - \delta)RP + \delta SP_i)A_{R_i}$$

(3)
In (2), $FC_i(A_P)$ and $FC_i(A_P + AR_i)$ are defined by:

$FC_i(A_P) = e_i + f_i \times A_P + j_i \times A_P^2$  \hspace{1cm} (4)

$FC_i(A_P + AR_i) = e_i + f_i \times (A_P + AR_i) + j_i \times (A_P + AR_i)^2$  \hspace{1cm} (5)

2.2. The set of constraints

Constraints considered in OLDCEM problem are presented as follows:
- Constrain of power demand and power reserve
  Load demand and total power generated by all units, and reserve demand and total reserved power of all units must meet the models below [18]:

$$\sum_{i} A_P \leq D_D$$  \hspace{1cm} (6)

$$\sum_{i} AR_i \leq R_D$$  \hspace{1cm} (7)

- Generation capacity restriction
  Active power output of each unit must be constrained by the following condition [22]:

$$AP_i^{\text{min}} \leq AP_i \leq AP_i^{\text{max}}$$  \hspace{1cm} (8)

- Reserved active power restriction
  Reserved active power of each unit is restricted by the condition below [23]:

$$0 \leq AR_i \leq AP_i^{\text{max}} - AP_i^{\text{min}}$$  \hspace{1cm} (9)

- Generated and reserved active power restriction
  The restriction of the generated active power and reserved active power of each unit is presented by:

$$AP_i + AR_i \leq AP_i^{\text{max}}$$  \hspace{1cm} (10)

3. METHOD

3.1. Cuckoo search optimization algorithm

Cuckoo search optimization algorithm (CSA) [24] is an efficient population-based methodology that was proposed by Yang and Deb in 2009. The method has successfully applied for many engineering problems [25-28]. The structure of CSA has two mechanisms corresponding two generations for producing solutions. The first mechanism employs Lévy flight random walk technique for creating the first generation. The second one uses the selective random walk technique for the second generation. The model of the first mechanism is formed as (11) below:

$$S_d = S_d + K \times (S_d - S_{\text{best}}) \oplus \text{Levy}(\phi)$$  \hspace{1cm} (11)

The model of the second mechanism is formulated by:

$$S_d = \begin{cases} S_d + \theta_2 (S_{\text{rand1}} - S_{\text{rand2}}) & \text{if } \theta_2 < \alpha \\ S_d & \text{otherwise} \end{cases}$$  \hspace{1cm} (12)

3.2. The proposed constraint handling approach

In [23], constraints of (8-10) are used to check the active power and reserved active power values of unit $i$. In some cases, solutions including the active power and reserved active power, only satisfy constraints (8) and (9) but they do not meet constraint (10), leading to low solution quality. To solve this issue, we propose a new constraint handling approach (CHA) by replacing the upper value of the inequality (9) with $(AP_i^{\text{max}} - AP_i^{\text{min}})$, and the process for checking solutions is implemented as algorithm 1:
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3.3. Fitness function

All solutions are evaluated by using the fitness function below:

\[
\text{Fitness} = (TRV - TFC) + K_1 \left( \frac{\sum_{i=1}^{N} (AP_i) - D_D}{\sum_{i=1}^{N} (AR_i) - D_D} \right)^2 + K_2 \left( \sum_{i=1}^{10} (AR_i') - R_D \right)^2 + K_3 \left( \sum_{i=1}^{10} (AP_i' + AR_i') - A_{P_{\text{max}}} \right)^2
\]

(13)

4. NUMERICAL RESULTS

In this section, the combination of CHA with CSA, PSO and SSA to form MCSA, MPSO, and MSSA has been applied to handle OLDCEM problem. Three methods have been executed on the two test systems with 3 units [18] and 10 units [21]. To evaluate robustness of the algorithms, 50 independent trials have been simulated for the first test system while 100 independent trials have been run for the second one. These algorithms are coded on a personal computer with processor Core i5-2.2 GHz, 4GB of RAM.

4.1. Testing the performance of the proposed constraint handling approach

In this portion, we implement the comparisons to optimal solutions gotten by CSA and MCSA. Figures 1 and 2 have been plotted to show results from CSA and MCSA for 3-unit system and 10-unit system. In Figure 1, MCSA and CSA reach the same maximum profit of 1102.4505 $/h but MCSA is more stable than CSA. In Figure 2, almost all runs of MCSA have the same fitness value, lie on a line and have tiny fluctuations. The maximum profit of MCSA is 13635.11 $/h meanwhile that of CSA is 13634.8366 $/h. In addition, the standard deviation of MCSA and CSA is also calculated via 100 trial runs. As result, that of MCSA is 0.2318 whilst that from CSA is 36.6832. From these comments, it can be given conclusion that the proposed constraint handling approach is useful for optimization tools.

Figure 1. 50 trial runs obtained by CSA and MCSA methods for system 1

Figure 2. 100 trial runs obtained by CSA and MCSA methods for system 2
4.2. Discussion of results on 3-unit system

In this section, 3-unit system is employed to test the performance of MCSA. In addition to the implementation of MCSA, MSSA and MPSO are also run. The setting of the population (Np) and the maximum number of iterations (MaxL) together with parameters of MSSA, MPSO and MCSA are set by:
- MPSO: c1=2.05, c2=2.05, Np=10, and MaxL=50
- MSSA: Np=10 and MaxL=50
- MCSA: Pα=0.9, Np=10 and MaxL=25

The results obtained by three methods have been presented in Figure 3. In the figure, it is easy to see that the fluctuation of MCSA is the smallest while that of MPSO is the highest. For more information about performance of three methods, Figure 4 indicates that these methods can achieve the same maximum profit but their standard deviations are different. Specifically, that of MCSA is 1.4321 while that of MPSO and MSSA is 19.9753 and 4.0268, respectively. From mentioned discussions, it could give conclusion that MCSA is more potential and stable than MPSO and MSSA.

![Figure 3. The maximum profit values given by three methods over 50 trial runs](image)

![Figure 4. The maximum profit and standard deviation values given by three methods over 50 trial runs](image)

For comparing to other methods, the results obtained by MCSA, MSSA, MPSO and five other considered methods such as PSO [18], ALHN [18], PSO [21], CSA [21], and HLN-EF [21] in term of the maximum profit are displayed in Figure 5. As seen from the figure, all methods attain the same highest profit. This proves that eight methods also solve the first test system. The solutions obtained by three methods are shown in Table 1.

![Figure 5. Fitness values for comparison obtained by eight methods for system 1](image)

| Unit | MPSO APk (MW) | MPSO ARk (MW) | MSSA APk (MW) | MSSA ARk (MW) | MCSA APk (MW) | MCSA ARk (MW) |
|------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1    | 324.5058      | 100.0000      | 324.5000      | 100.0000      | 324.4988      | 100.0000      |
| 2    | 400.0000      | 0             | 400.0000      | 0             | 400.0000      | 0             |
| 3    | 200.0000      | 0             | 200.0000      | 0             | 200.0000      | 0             |

Table 1. Optimal values for comparison obtained by eight methods for system 1
4.3. Discussion of results on 10-unit system

In this system, the setting of the population is 30 for MPSO, MSSA and MCSA and the setting of the maximum number of iterations is 600, 600, and 300 for implementing MPSO, MSSA, and MCSA, respectively whilst the parameter selection of these methods keeps constant as section 4.2. For comparing MCSA to MSSA and MPSO, total profit achieved by MPSO, MSSA, and MCSA have been allocated on curves in Figure 6. As shown in such figure, there are blue points of MCSA, yellow points of MSSA and green points of MPSO distributed in such curves. In which, most of points of MCSA approximately lied on a line. Those of MSSA and MPSO are randomly distributed and fluctuations of MPSO are higher than those of MSSA.

![Figure 6. Fitness values given by these implemented methods for system 2 over 100 trial runs](image)

For better comparison, we plot Figure 7 to show the highest profit and standard deviation value achieved by MPSO, MSSA and MCSA. In such figure, the highest profit of MCSA is better than that of MPSO and MSSA while the standard deviation of MCSA is the smallest. Namely, the highest profit of MCSA is 13,635.11 $/h meanwhile that of MPSO and MSSA is 13,634.63 $/h and 13,632.87 $/h, respectively. The standard deviation of MCSA is 0.23 whilst that from MPSO and MSSA is 380.51 and 27.56, respectively. To compare with other compared methods, Figure 8 is concerned. As observing columns, the red column is one of the highest columns. In fact, MCSA is the best method among nine methods with the highest profit of 13,635.113 $/h whereas the second-best method and the worst method, which are ALHN [18] and PSO [21], have to suffer lower profit with 13,635.110 $/h and 13,158.065 $/h. The exact calculation shows that the proposed MCSA can reach higher profit than the worst and the second-best method by $477.048 and $0.003. The difference indicates that the proposed method can improve result better other ones up to 3.63%. From this view, it can lead to a conclusion that MCSA is the powerful tool for this test system. The solutions obtained by three methods are presented in Table 2.

![Figure 7. Maximum total profit and STD values obtained by these methods for system 2 over 100 trial runs](image)

![Figure 8. Fitness values for comparison obtained by eight methods for system 2](image)
In this paper, the constraint handling approach (CHA) has been proposed, and then the proposed method has been employed to the traditional methods, such as CSA, SSA and PSO for dealing with OLDCEM problem. The combination of CHA and CSA, SSA and PSO is used to test on two systems with payment model for allocated reserve. Result comparisons between MCSA and CSA indicate that MCSA always finds better optimal solutions than CSA. As results, it is proven that the proposed constraint handling approach is considered as suitable tool for integrating with optimization methods. In comparison to MSSA and MPSo, results from three methods via two test systems are proven that MCSA is more stable and effective. In comparison to other reported methods in term of the highest profit, all methods reach the same results for system 1 but for system 2, that from MCSA is the highest than that from other methods. For all comments, it can give a conclusion that MCSA method is a very effective technique for handling OLDCEM problem.

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