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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.

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NOMENCLATURE

α	Mutation factor
θ_1 , θ_2	Random number in range [0,1]
δ	Probability of called reserve power
AP_i, AR_i	Generated power and reserved power of unit *i*
AP_i^{min}, AP_i^{max}	The minimum and maximum active power of unit *i*
D_D, R_D	Forecasted demand and forecasted reserve
e_i , f_i , j_i	Coefficients of cost function of unit *i*
FC_i	Cost function of unit *i*
K	Scale factor for Levy flight technique
K_1,K_2,K_3	Penalty factors
PR	Total profit
SP, RP	Forecasted spot price and forecasted reserve price
S_d , S_{best}	The *dth* solution and the best solution of a population
S_{rand1}, S_{rand2}	Two randomly selected solutions
TG	Number of thermal units
c_1, c_2	Acceleration factors

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 met 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 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:

- Propose a new constraint handling approach for OLDCEM problem
- Successfully apply the constraint handling approach for CSA, SSA and PSO
- The new constraint handling approach supports MCSA reach much better results than CSA for all study cases
- 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:

$$\text{Maximize } PR = TRV - TFC \tag{1}$$

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

$$TFC = (1-\delta)\sum_{i=1}^{TG} FC_i(AP_i) + \sum_{i=1}^{TG} FC_i(AP_i + AR_i) \tag{2}$$

$$TRV = \sum_{i=1}^{TG}(AP_i.SP) + \sum_{i=1}^{TG}((1-\delta).RP + \delta.SP).AR_i \tag{3}$$

In (2), FC_i (AP_i) and FC_i (AP_i+AR_i) are defined by:

$$FC_i(AP_i) = e_i + f_i \times AP_i + j_i \times AP_i^2 \quad (4)$$

$$FC_i(AP_i + AR_i) = e_i + f_i \times (AP_i + AR_i) + j_i \times (AP_i + AR_i)^2 \quad (5)$$

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]:

$$\sum_{i=1}^{TG} AP_i \le D_D \quad (6)$$

$$\sum_{i=1}^{TG} AR_i \le R_D \quad (7)$$

- Generation capacity restriction

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

$$AP_i^{\min} \le AP_i \le AP_i^{\max} \quad (8)$$

- Reserved active power restriction

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

$$0 \le AR_i \le AP_i^{\max} - AP_i^{\min} \quad (9)$$

- Generated and reserved active power restriction

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

$$AP_i + AR_i \le AP_i^{\max} \quad (10)$$

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:

$$S_d = S_d + K \times \left(S_d - S_{best}\right) \oplus Levy(\phi) \quad (11)$$

The model of the second mechanism is formulated by:

$$S_d = \begin{cases} S_d + \theta_1.(\mathrm{S}_{rand1} - S_{rand2}) & \text{if } \theta_2 < \alpha \\ S_d & \text{otherwise} \end{cases} \quad (12)$$

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 $\left(AP_i^{\max} - AP_i\right)$, and the process for checking solutions is implemented as algorithm 1:

Algorithm 1. The proposed constraint handling approach for checking solutions

i) $S_d^{new} = [AP_i; AR_i]$

ii) If $AP_i < AP_i^{\min}$

$AP_i = AP_i^{\min}$

Else if $AP_i > AP_i^{\max}$

$AP_i = AP_i^{\max}$

End

iii) $AR_i^{\min} = 0$

iv) $AR_i^{\max} = AP_i^{\max} - AP_i$

v) If $AR_i < AR_i^{\min}$

$AR_i = AR_i^{\min}$

Else If $AR_i > AR_i^{\max}$

$AR_i = AR_i^{\max}$

End

3.3. Fitness function

All solutions are evaluated by using the fitness function below:

$$Fitness = (TRV - TFC) + K_1\left[\sum_{i=1}^{TG}(AP_k) - D_D\right]^2 + K_2\left[\sum_{i=1}^{TG}(AR_k) - R_D\right]^2 + K_3\left[\sum_{i=1}^{TG}(AP_k + AR_k) - AP_k^{\max}\right]^2 \quad (13)$$

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.

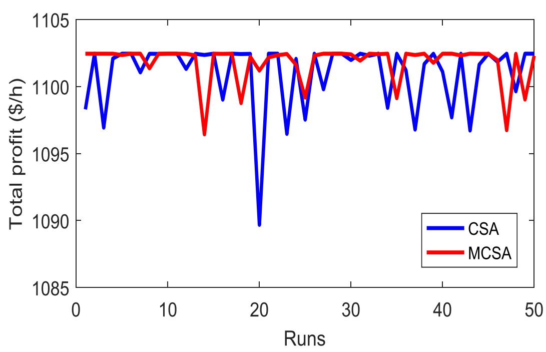

Figure 1. 50 trial runs obtained by CSA and MCSA methods for system 1

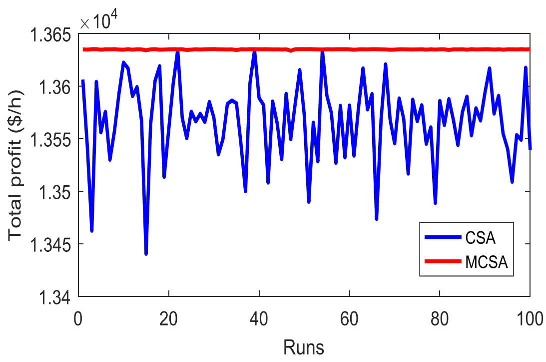

Figure 2. 100 trial runs obtained by CSA and MCSA methods for system 2

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 (N_p) and the maximum number of iterations (Max_L) together with parameters of MSSA, MPSO and MCSA are set by:

- MPSO: c_1=2.05, c_2=2.05, N_p=10, and Max_L=50
- MSSA: N_p=10 and Max_L=50
- MCSA: P_a=0.9, N_p=10 and Max_L=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.

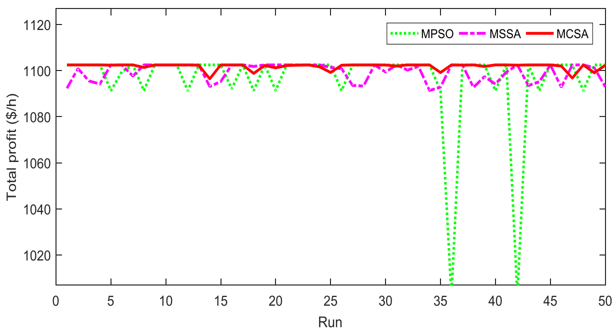

Figure 3. The maximum profit values given by three methods over 50 trial runs

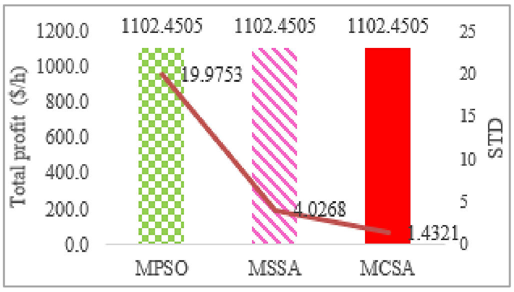

Figure 4. The maximum profit and standard deviation values given by three methods over 50 trial runs

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.

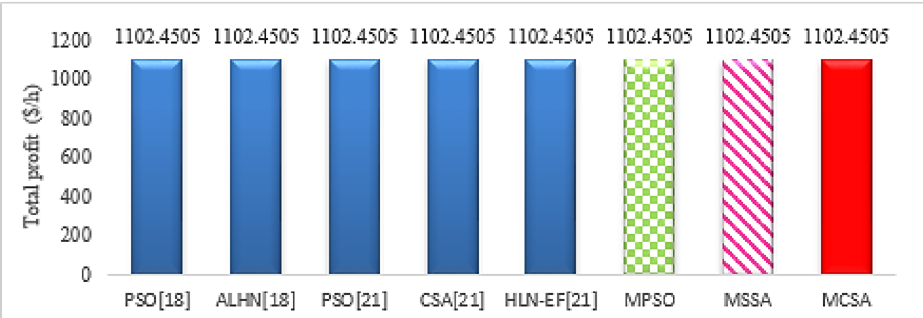

Figure 5. Fitness values for comparison obtained by eight methods for system 1

Table 1. Optimal solution for the three-unit system obtained by three methods

Unit	MPSO		MSSA		MCSA	
	AP_k (MW)	AR_k (MW)	AP_k (MW)	AR_k (MW)	AP_k (MW)	AR_k (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

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.

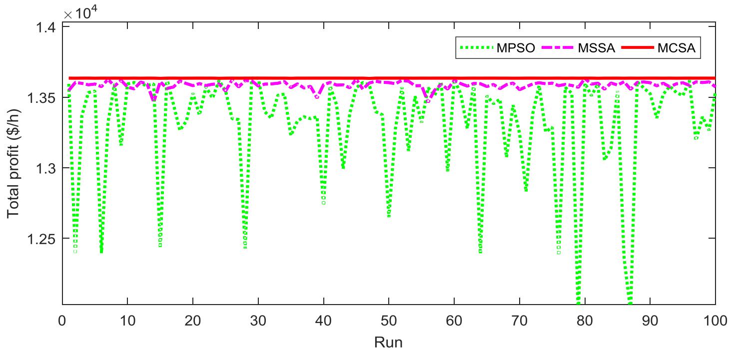

Figure 6. Fitness values given by these implemented methods for system 2 over 100 trial runs

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 13635.11 $/h meanwhile that of MPSO and MSSA is 13634.63 $/h and 13632.87 $/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.

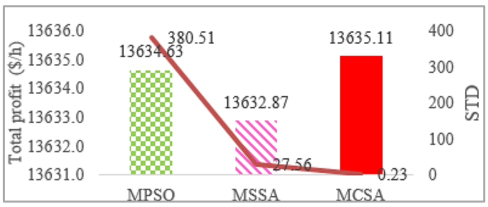

Figure 7. Maximum total profit and STD values obtained by these methods for system 2 over 100 trial runs

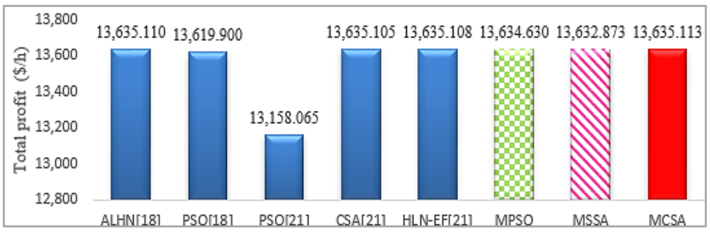

Figure 8. Fitness values for comparison obtained by eight methods for system 2

Table 2. Optimal solution for the ten-unit system obtained by three methods

Unit	MPSO		MSSA		MCSA	
	AP_k (MW)	AR_k (MW)	AP_k (MW)	AR_k (MW)	AP_k (MW)	AR_k (MW)
1	455.000	0.000	455.000	0.000	455.000	0.000
2	455.000	0.000	455.000	0.000	455.000	0.000
3	130.000	0.000	130.000	0.000	130.000	0.000
4	130.000	0.000	130.000	0.000	130.000	0.000
5	162.000	0.000	162.000	0.000	162.000	0.000
6	80.000	0.000	80.000	0.000	79.999	0.000
7	25.000	60.000	25.000	59.240	25.000	60.000
8	42.974	12.026	42.992	12.008	43.000	12.000
9	10.000	32.028	10.008	44.141	10.000	44.943
10	10.000	45.000	10.000	27.919	10.000	33.057

5. CONCLUSION

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.

REFERENCES

[1] L. H. Pham, T. T. Nguyen, L. D. Pham, and N. H. Nguyen, "Stochastic fractal search-based method for economic load dispatch," *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 17, no. 5, pp. 2535-2546, 2019.

[2] T. T. Nguyen and D. N. Vo, "The application of one rank cuckoo search algorithm for solving economic load dispatch problems, " *Applied Soft Computing*, vol. 37, pp. 763-773, 2015

[3] T. Dey, "Economic Load dispatch for multi-generator systems with units having nonlinear and discontinuous cost curves using gravity search algorithm," *Int. Journal of Applied Power Engineering*, vol. 3, no. 3, pp. 166-174, 2014.

[4] W. Khamsen, C. Takeang, and P. Aunban, "Hybrid method for solving the non smooth cost function economic dispatch problem," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 1, pp. 609-661, 2020.

[5] T. P. Van, V. Snasel, and T. T. Nguyen, "Antlion optimization algorithm for optimal non-smooth economic load dispatch," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 2, pp. 1187-1119, 2020.

[6] A. Azmi1, S. M. Zali, M. N. Abdullah, M. F. N. Tajuddin, and S. R. A. Rahim, "The performance of COR optimization using different constraint handling strategies to solve ELD," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 2, pp. 680-688, 2020.

[7] S. K. Gachhayat, S. K. Dash, and P. Ray, "Multi objective directed bee colony optimization for economic load dispatch with enhanced power demand and valve point loading," *International Journal of Electrical & Computer Engineering* vol. 7, no. 5, pp. 2088-8708, 2017.

[8] M. N Abdullah, N. A Abdullah, N. F Aswan, S. A. Jumaat, and N. H. Radzi, A. F. M. Nor, "Combined economic-emission load dispatch solution using firefly algorithm and fuzzy approach," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 16, no. 1, pp. 127-135, 2019.

[9] F. P. Mahdi, P. Vasant, M. Abdullah-Al-Wadud, V. Kallimani, and J. Watada, "Quantum-behaved bat algorithm for many-objective combined economic emission dispatch problem using cubic criterion function," *Neural Computing and Applications*, pp. 1-13, 2018.

[10] T. T. Nguyen, T. T. Nguyen, and D. N. Vo, "An effective cuckoo search algorithm for large-scale combined heat and power economic dispatch problem," *Neural Computing and Applications*, vol. 30, no. 11, pp. 3545-3564, 2018.

[11] L. Branchini, A. De Pascale, F. Melino, and N. Torricelli, "Optimum organic rankine cycle design for the application in a CHP unit feeding a district heating network," *Energies*, vol. 13, no. 6, pp. 1-22, 2020.

[12] X. Y. Kong, T. S. Chung, D. Z. Fang, and C. Y. Chung, "An power market economic dispatch approach in considering network losses," *IEEE Power Engineering Society General Meeting*, pp. 208-214, 2005.

[13] C. W. Richter and G. B. Sheble, "A profit-based unit commitment GA for the competitive environment," *IEEE Transactions on Power systems*, vol. 15, no. 2, pp. 715-721, 2000.

[14] M. Hermans, K. Bruninx, S. Vitiello, A. Spisto, and E. Delarue, "Analysis on the interaction between short-term operating reserves and adequacy, " *Energy Policy*, vol. 121, pp. 112-123, 2018.

[15] E. H. Allen and M. D. Ilic, "Reserve markets for power systems reliability," *IEEE Transactions on Power Systems*, vol. 15, no. 1, pp. 228-233, 2000.

[16] B. Rampriya, K. Mahadevan, and S. Kannan, "Application of differential evolution to dynamic economic dispatch problem with transmission losses under various bidding strategies in electricity markets," *Journal of Electrical Engineering and Technolog*y, vol. 7, no. 5, pp. 681-688, 2012.
[17] A. M. L. da Silva, J. G. de Carvalho Costa, and L. H. L. Lima, "A new methodology for cost allocation of transmission systems in interconnected energy markets, " *IEEE Transactions on Power Systems*, vol. 28, no. 2, pp. 740-748, 2012.
[18] D. N. Vo, W. Ongsakul, and K. P. Nguyen, "Augmented Lagrange Hopfield network for solving economic dispatch problem in competitive environment," *In AIP Conference Proceedings*, vol. 1499, no. 1, pp. 46-53, 2012.
[19] A. V. V. Sudhakar, C. Karri, and A. J. Laxmi, "A hybrid LR-secant method-invasive weed optimisation for profit-based unit commitment," *International Journal of Power and Energy Conversion*, vol. 9, no. 1, pp. 1-24, 2018.
[20] J. S. Dhaliwal and J. S. Dhillon, "Profit based unit commitment using memetic binary differential evolution algorithm," *Applied Soft Computing*, vol. 81, pp. 105502, 2019.
[21] T. L. Duong, P. D. Nguyen, V. D. Phan, D. N. Vo, and T. T. Nguyen, "Optimal load dispatch in competitive electricity market by using different models of hopfield lagrange network," *Energies*, vol. 12, no. 15, pp. 2932, 2019.
[22] Y. V. K. Reddy and M. D. Reddy, "Flower pollination algorithm to solve dynamic economic loading of units with piecewise fuel options, " *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 16, no. 1, pp. 9-16, 2019.
[23] P. Attaviriyanupap, H. Kita, E. Tanaka, and J. Hasegawa, "A hybrid LR-EP for solving new profit-based UC problem under competitive environment," *IEEE Trans. Power Syst*., vol. 18, no. 1, pp. 229-237, 2003.
[24] X. S. Yang and S. Deb, "Cuckoo search via Lévy flights," *In Proc. World Congress on Nature & Biologically Inspired Computing*, pp. 210-214, 2009.
[25] J. García, F. Altimiras, A. Peña, G. Astorga, and O. Peredo, "A binary cuckoo search big data algorithm applied to large-scale crew scheduling problems," *Complexity*, vol. 2018, pp.1-15, 2018.
[26] D. Niu, W. Zhao, S. Li, and R. Chen, "Cost forecasting of substation projects based on cuckoo search algorithm and support vector machines," *Sustainability*, vol. 10, no. 1, pp. 1-11, 2018.
[27] W. Zhao and D. Niu, "Prediction of CO_2 emission in China's power generation industry with gauss optimized cuckoo search algorithm and wavelet neural network based on STIRPAT model with ridge regression," *Sustainability*, vol. 9, no. 12, pp. 1-15, 2017.
[28] R. Hou, Y. Yang, Q. Yuan, and Y. Chen, "Research and application of hybrid wind-energy forecasting models based on cuckoo search optimization," *Energies*, vol. 12, no. 19, pp. 1-17, 2019.