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# Cuckoo Search Algorithm Application for Economic Dispatch with Wind Farm in Power Systems

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## Abstract

This paper introduces a new method to solve economic dispatch problem in power system operation with wind farm (WF) connecting. The method is cuckoo search algorithm (CSA) which can to solve effective ED problem. The subject of this paper is optimal solutions about total power output each generator and WF with minimum operation cost in power system. The research study CSA and develop this method which become new method more efficient than former methods. CSA apply to solve ED problem with WF which give the best results and programming time. For ED problem simulator, program applies 30 buses IEEE system and Matpower 4.1 Toolbox to run power system with WF connecting. The results of this method also are compared to other previous methods and assess its results.

**Keywords:** Economic dispatch; Cuckoo search; Wind turbine; Wind farm

**Abbreviations:** $N_p$: Number of Particles; $P_D$: Total Load System Demand; $A_i$. $B_i$. $C_i$: Cost Coefficients For Quadratic Cost Function of Generator *I*; $E_i$. $F_i$: Cost Coefficients of Generator *I* Reflecting Valve-Point Effects; $B_{ij}$. $B_{0i}$. $B_{00}$: B-Matrix Coefficients For Transmission; $N_g$: Number of Generators; $\delta_i$: Voltage Angle At Bus *I*; $\theta_{ij}$: Voltage Angle Difference Between Buses *I* And *J* In Rad; $G_{ij}$,$B_{ij}$: Inductor and Inductance of Line Between Buses *I* And *J*; $G_l$: Inductor of Branch *L*; $L_i$: Voltage Stability Index At Bus *I*; $N_b$: Total Buses; $N_d$: Number of Load Buses; $N_g$: Number of Generator Buses; $N_l$: Total Number of Transmission Lines; $N_T$: Number of Tap Changer; $P_{di}$. $Q_{di}$: Power and Reactive Power Demand at Bus *I*; $P_{gi}$.$Q_{gi}$: Power and Reactive Power Demand at Generator *I*; $Q_{ci}$: Reactvie Power Supplement at Bus I; $S_{li}$: Power on Transmission Line *I*; $T_k$: Tap Changer Level Position; $V_{gi}$: Voltage of Generator *I*; $V_{li}$: Voltage of Load Bus *I*; $V_i$.$\theta_i$: Voltage and Voltage Angle at Bus *I*

## Introduction

Economic dispatch (ED) optimization of power system is important problem in power generators system operation. Recently, power supply companies concentrate to ensure economic problem of power system because it can help the systems reduce operation costs and output the best power optimization of generators in system since practical numerical optimization methods applied to power system engineering and operation. The value contributed by the power system optimization is considerable in economics with hundreds of millions of dollars saved annually for large utilities from fuel cost, operational reliability, and security. On the other hand, power systems have been developed larger and more complicated due to the increase of load demand, leading to consuming more fossil fuel for thermal power plants and releasing more emission into the environment. Presently, hydro power plants become more important in power systems because the fuel sources for thermal plants will be exhausting in a not long future meanwhile thermal plants using fossil fuel cause environmental pollution. Moreover, alternative sources of energy such as wind power, solar energy, fuel cells, etc. are still being developed with a very limited capacity due to technical limitations and natural conditions. Nuclear power is not popular since it is facing public objection for the safety reason. Therefore, hydro and gas turbine power plants are considered as main contribution to power systems for the near future due to the advantages of cheap fuel cost and pollution free. However, scheduling of hydro plants depends on hydraulic constraint and gas supplied for gas turbine power plants can be restricted due limited reserve. For those reasons, wind farms builds in many countries on the world because wind farms have many advantages such as not pollution and fuel cost. However, there are some complicated calculations when wind farms connect to power system. ED is one of problems should solve to optimize system with wind farms operation.

There are many methods which solve ED problem such as Lagrange function, Newton's method, Particle Swarm Optimization (PSO) and POS Improvement (PSOI). However, it spends more time and gives not exact results [1-6]. Cuckoo search (CS) algorithm develops and effects more than PSO methods in optimization and ED problems with wind farm connecting. CS combines Levy flights were used in information technology and other science technical fields from 2009 up today [7-12]. However, there are very few CS applications for ED in power system operation.

This paper introduces a new method, CS method is proposed for solving the ED with wind farms problem. The research propose minimizing the cost of system operation which include constraints such as real power losses, reactive power limits of generators and wind farm. The program has been tested on the IEEE 30-bus system with wind farms and the obtained results are compared to those from other variants and other methods in the literature. The paper includes six main parts: introduction, wind farm, ED with WF, CSA, results and comparison and conclusion.

## Wind Turbine and Wind Farm

Almost wind turbines work in a wind speed area which show on Figure 1 [13,14]. If wind speed under $V_{cut\text{-}in}$ or over $V_{cut\text{-}out}$ the wind

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turbine stop work because wind speeds are slow or too fast. Working wind speeds of wind turbine are from 5 m/s to 25 m/s. Following Figure 1, $V_{rate}$ = 5 m/s - 25 m/s.

Wind farm includes many wind turbines which connect together and output electricity to power sysetm. A wind farm can performances on Figure 2 below.

### Probability of wind speed and wind power

Wind speed was collected by 24 hours on a day in many years. From this data, wind speed can calculate about average value, standard deviation and wind speed probability.

The average value [15-17] of wind data calculate by below formula:

$$\mu = \frac{1}{k}\sum_{l=1}^{k} v_l \tag{1}$$

The standard deviation [15,16] of wind data can be as following:

$$\sigma = \sqrt{\frac{1}{k}\sum_{l=1}^{k}(v_l - \mu)^2} \tag{2}$$

From the average value and standard deviation, probability of wind speed of history data define by [15,16]:

$$PR_{vi} = \frac{1}{\sigma\sqrt{2\mu}}\exp\left[-\frac{(v_{li}-\mu)^2}{2\sigma^2}\right] \tag{3}$$

With:

$k$: A time measure wind speed (h).

$v_l$: Wind speed at k (m/s).

$S_{li}$: Wind speed history data.

$\mu$: Wind speed average value.

$\sigma$: Standard deviation.

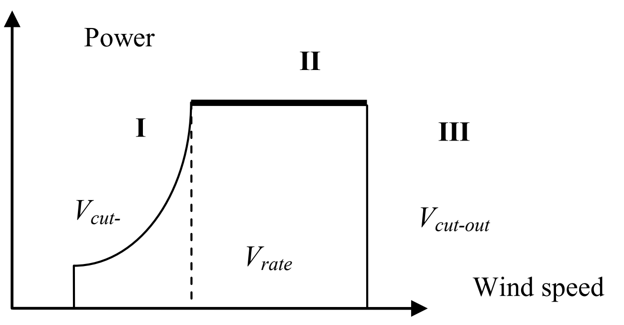


**Figure 1:** Working wind speed of wind turbine.

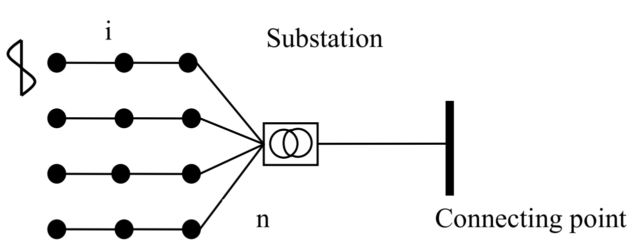


**Figure 2:** Wind farm performance.

$PR_{vi}$: Wind speed probability.

Wind turbine power is calculated by formula,

$$P_{wi} = \frac{1}{2}.\rho.A.C_p\int_{v_{l\min}}^{v_{l\max}} PR_v(v_l)^3\,dv_l = F_w\int_{v_{l\min}}^{v_{l\max}} PR_v(v_l)^3\,dv_l \tag{4}$$

Where:

$\rho$: Air density (kg/m³)

$A$: Total area wind though propeller of wind turbine (m²)

$C_p$: Rotor efficient

$v_{lmin}$: Wind speed minimum

$v_{lmax}$: Wind speed maximum

$v$: Wind speed (m/s)

$F_w$: wind power, $F_w$ = 1/2.ρ.A.$C_p$

The probability of wind speed is demonstrated by the chart in Figure 3.

### Wind power cost

Cost of wind power differs with other energy cost, wind power investment cost higher than operation and maintenance cost. Following [13] average wind power cost ($/kWh) include many elements below formula,

$$COE = \frac{ICC * FRC + LRC}{AEP_{NET}} + O\&M \tag{5}$$

With:

COE: Average wind power cost ($/kWh).

ICC: Install capacity cost ($).

FRC: Interesting rate cost (%/year).

LRC: ($/year).

O&M: Operation and maintenance cost. ($/kWk, $/MWh).

AEP: Annual total wind power out put (kWh/year).

Following [14] operation and maintenance cost of wind power is from 0.005 to 0.007 $/kWh. Therefore, wind power cost can calculate by combination (4) and (5),

$$C_{wi} = 0.006.P_{wi} = 0.006.F_w\int_{v_{l\min}}^{v_{l\max}} PR_v(v_l)^3\,dv_l \tag{6}$$

## Economic Dispatch with Wind Farm

### Thermal turbine

Consider Power system with all thermal power generation, the total cost of power plants is sum of the cost of each generator can formulated as follows [5],

$$C_{TG} = \sum_{i=1}^{N_g}\left(a_i + b_iP_{gi} + c_iP_{gi}^2\right) \tag{7}$$

Where:

$C_{TG}$: Cost of thermal generator.

### Economic dispatch with wind farm

Economic dispatch is more different and complex when wind farm embark in to the system with many constraints about cost and power output. The target of economic dispatch system with wind

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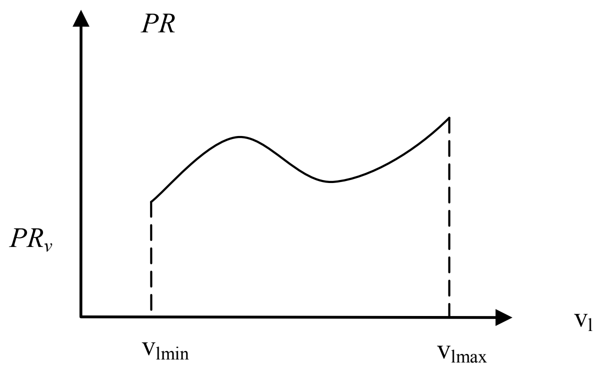


**Figure 3:** Probability of wind speed.

farms is minimum the cost of operation, total output power capacity of each generation and many system constraints. In this paper, some main constraints are interested such as power balance, power loss and generator limits.

Mathematically, the problem ED with WF is formulated as follows:

$$MinF_C = C_{TG} + C_W = \sum_{i=1}^{N_g}\left(a_i + b_i P_{gi} + c_i P_{gi}^2\right) + 0.006.F_w \int_{v_{l\min}}^{v_{l\max}} PR_v(v_l)^3 dv_l \quad (8)$$

**Power balance:** The total power generation from the online generating units must satisfy the load demand plus power loss,

$$\sum_{i=1}^{N_g} P_{gi} + \sum_{i=1}^{n} P_{wi} = P_D + P_L \quad (9)$$

The power loss $P_L$ can be approximately calculated using B-coefficients based on the power flow solution,

$$P_L = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{N_g} B_{0i} P_{gi} + B_{00} \quad (10)$$

**Generator limits:** The real power output $P_{gi}$ of unit i should be limited between its upper and lower bounds for safety operation represented by:

***Thermal generators limits:***

$$P_{gi,\min} \le P_{gi} \le P_{gi,\max} \quad (11)$$

***Wind farm power limits:***

$$P_{Wgen1} \le P_{wi} \le P_{Wgenn} \quad (12)$$

Productive power of a wind turbine normal is 1.5 MW to 2.5 MW [14], average installation and operation cost of a wind turbine give on Table 1.

## Cuckoo Search Algorithm (CSA)

Cuckoo search is a new meta-heuristic algorithm inspired from the nature for solving optimization problems. The basic idea of this algorithm is based on the obligate brood parasitic behavior of some cuckoo species in combination with the Lévy flight behavior of some birds and fruit flies. There are three idealized rules for the new cuckoo search algorithm (CSA) described as [15].

Each cuckoo lays one egg (a design solution) at a time and dumps its egg in a randomly chosen nest among the fixed number of available host nests;

The best nests with high a quality of egg (better solution) will be carried over to the next generation;

A host bird can discover an alien egg in its nest with a probability of pa∈[0,1]. In this case, it can simply either throw the egg away or abandon the nest and find a new location to build a completely new one.

### The Lévy flight distribution

In nature, animals can search for food in a random or quasi-random manner. Generally, the foraging path of an animal is effectively a random walk since the next move is based on the current location state and the transition probability to the next location. The chosen direction depends implicitly on a probability which can be mathematically modeled. Recent various studies have shown that the flight behavior of many animals and insects has demonstrated the typical characteristics of Lévy flights following formula:

$$L\acute{e}vy \sim u = t^{-\lambda}, \ \left(1 < \lambda \le 3\right) \quad (13)$$

### CSA application for ED problem with WF

The fitness function of ED problem is,

$$F_{fitness} = MinF_C = \sum_{i=1}^{N_g}\left(a_i + b_i P_{gi} + c_i P_{gi}^2\right) + 0.006.F_w \int_{v_{l\min}}^{v_{l\max}} PR_v(v_l)^3 dv_l \quad (14)$$

Overall procedure of CSA for ED problem following as steps:

***Step 1***: Choose bird nests $N_p$, parameters of CSA: $U_b$, $L_b$, $p_a$, $IT_{max}$, total generators N include cost function parameters $a_i$, $b_i$, $c_i$, $e_i$, $f_i$. Set up initial variables $X_{id}$ such as power output of thermal and wind generation corresponding number of cuckoo eggs in a nest.

***Step 2***: Choose $X_{id}$ random. Use Matpower 4.1 Toolbox to calculate:

Value objective function *FC*.

Value of fitness function $FF_{inf}$.

***Step 3***: Apply Lévy flights distribution to choose the eggs of cuckoo corresponding with $X_{id}$. Calculate $FF_{inf}$ following (14). From these results, calculate new value of fitness function $FF_{new}$ following (14).

***Step 4***: Assess the quality of initialized cuckoo eggs.

If $FF_{new} > FF_{inf}$ reject initialized eggs.

If $FF_{new} < FF_{inf}$ continue to run iterations and reject number of eggs with $p_a$ probability.

***Step 5***: From $p_a$ rejected eggs, calculate fitness function $FF_{dis}$.

***Step 6***: Continue program to maximum iteration $IT_{max}$, compare and assess value of $FF_{new}$ and $FF_{dis}$, choose the eggs with the best quality corresponding power output of generators with minimum *FF*value.

***Step 7***: Diagram characteristic of FF with each iteration.

***Step 8***: Show result of problem: $P_{gi}$, $P_{wgi}$, iterations, programming time of computer.

| IEEE 30 buses system data | Total | Bus No. |
|---|---|---|
| Generators | 7 | 1, 2, 5, 8, 11, 13,22 |
| Transformers | 4 | 6-9, 6-10, 4-12, 27-28 |
| Capacitor banks | 9 | 10, 12, 15, 17, 20, 21, 23, 24, 29 |
| Tap changers | 4 | 4, 6, 10, 28 |
| Branches | 41 | From 1 to 30 |
| Loads | 24 | 3, 4, 6, 7, 9, 10, 12, 14 to 30 |

**Table 1:** IEEE 30 bus system data.

## Numerical Results

### Testing system data

The CSA for ED problem is tested on IEEE 30 buses system and Matpower 4.1 toolbox [18,19]. Target of problem is minimum operation cost with the best power out of thermal and wind generation. Total load demand is 289.3 MW and 189.3 MW. The data of IEEE 30 buses follow on Table 1.

History wind data vary following different areas and defence many conditions such as weather, location, terrain and high level. Almost wind farms, the history wind data will be supplied by proficient meteorological companies. Therefore, the research computes programming with wind speed scenarios which help to calculate wind turbine power output. Moreover, wind turbine capacity is produced from 1 MVA to 2.5 MVA, the research chooses each wind turbine capacity 2.5 MVA, wind farm include 50 wind turbines. The WF connects as 22[nd] bus and its total power capacity is 125 MVA. Normally, wind speed from 5 m/s to 25 m/s at wind farm location which is equivalent output power from 12.5 MVA to 112.5 MVA. Following previous researches [20-22], the research select two scenarios suitable with wind turbine power production and parameters of previous research.

***Scenario 1*****:** Load demand is 289.3 MW and WF power is 100 MVA.

***Scenario 2*****:** Load demand is 189.3 MW and WF power is 16 MVA.

Program used computer with processor 2.70 GHz, memory RAM at 8GB and Matlab software 2012b. The program also used Power Toolbox 4.1 to run ED problem with WF connecting by CSA method.

Following standard functions testing, CSA parameters set at $N_p$ =15, $P_a$ = 0.25, $K$=1e6 and $IT_{max}$= 100, the program run twenty times and get the best value after program closing. The program also calculates standard deviation of the best results after twenty times running for CSA assessment with ED problem and best results selection.

### Program results

Following the system data, the program has results each scenario with different load demand and total power of wind farm. Figures 4 and 5 show the best slope down of graph after twenty times running, it proves that CAS can solve ED & WF problem with the best result and good converging roots. Moreover, the result also has short time programming and small standard deviation value.

The scenario 1 and scenario 2 results of CSA for ED problem with WF are showed on Table 2, Figures 4-7 below.

### Results comparison

Table 2 and Figures 4-7 shows that CSA can calculate power output of thermal generators and wind farm in the system with minimum operation cost. The power output of power plants ensure to supply for loads and balance for system. Root converging of optimization ED problem is good slope after several iterations that mean CSA can be the best method for optimization problem solution.

From results by 5.2, CAS can solve ED problem with WF, CAS and Matlab software combination can run the program effective, give accurate results and fast time. From Table 2 and previous research [20-22], result comparison perform on Table 3 which give detail power output value of thermal generations and wind farm.

From Table 3, the CSA has advance points more than other methods MBO and LP because CSA give minimum cost of system operation with WF. Two methods MBO and LP have not the time programming and standard deviation. The cost of CSA are 494.03 $/h and 439.91 $/h

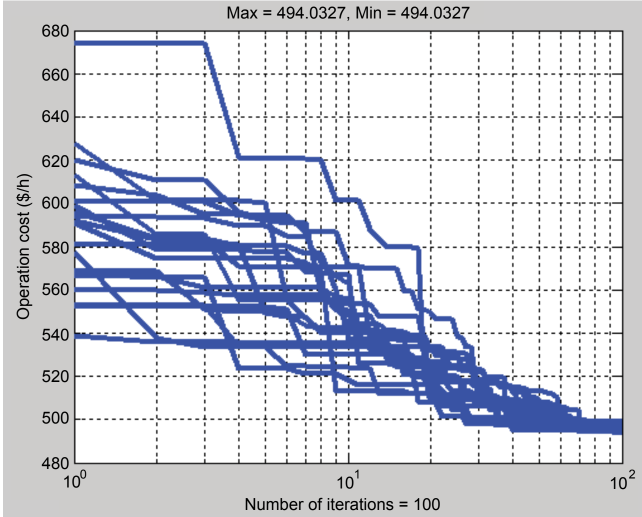


**Figure 4:** Characteristic scenario 1 of ED with WF by CS.

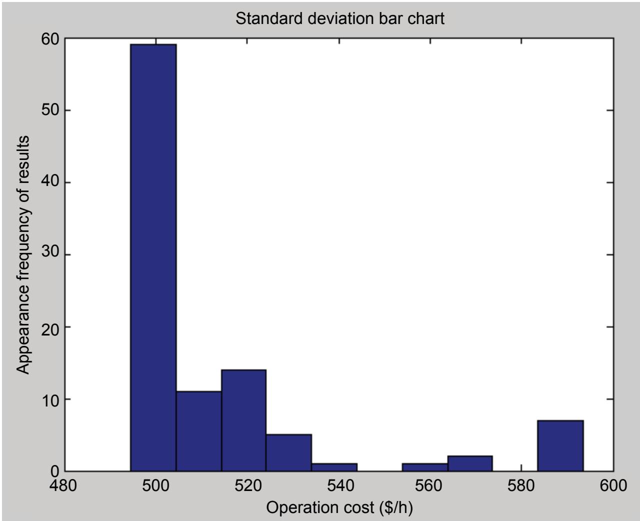


**Figure 5:** Standard deviation scenario No. 1 by CS with 20 programming.

| | Scenario 1 | Scenario 2 |
|---|---|---|
| $P_{g1}$ (MW) | 115.7674 | 94.7986 |
| $P_{g2}$ (MW) | 33.3536 | 35.0555 |
| $P_{g3}$ (MW) | 15.0000 | 15.0169 |
| $P_{g4}$ (MW) | 10.0098 | 10.0000 |
| $P_{g5}$ (MW) | 10.0000 | 10.0000 |
| $P_{g6}$ (MW) | 12.0010 | 12.0076 |
| $P_{wind}$ (MW) | 100.0000 | 15.9674 |
| *PD* (MW) | 289.3 | 189.3 |
| Cost ($/h) | 494.0327 | 439.9149 |
| Std | 1.1175 | 0.8580 |
| Iterations | 100 | 100 |
| Pro-time (s) | 45.482 | 19.385 |

**Table 2:** Results of ED problem with WF by CSA.

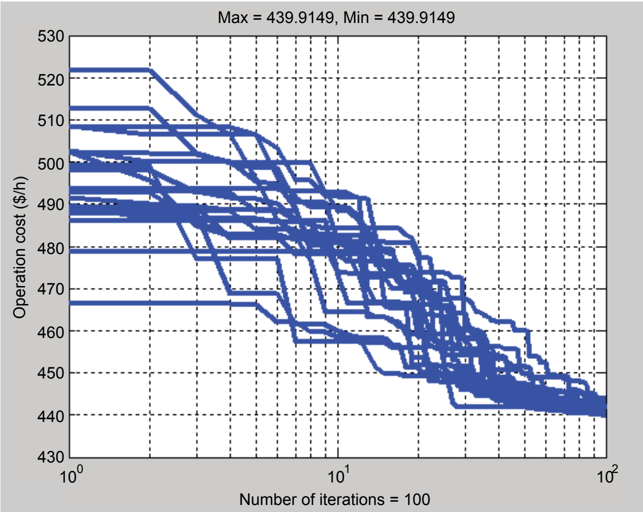


**Figure 6:** Characteristic scenario 2 of ED with WF by CS.

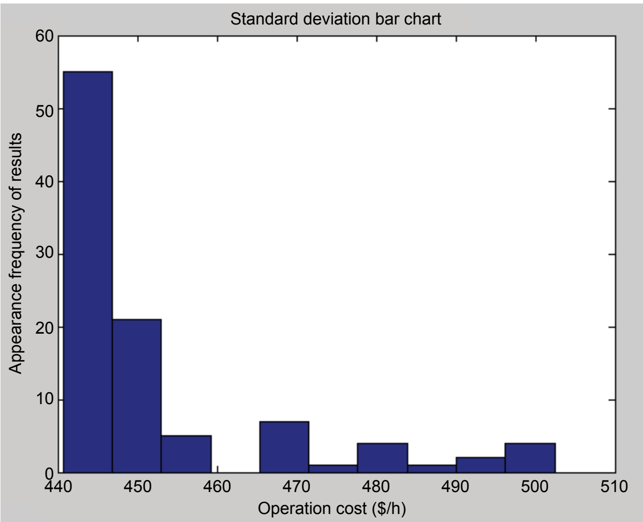


**Figure 7:** Standard deviation scenario No. 2 by CS with 20 programming.

| | MBO [20] | CS Scenario 1 | LP [21] | CS Scenario 2 |
|---|---|---|---|---|
| $P_{g1}$ (MW) | 48.45 | 115.7674 | 45 | 94.7986 |
| $P_{g2}$ (MW) | 34.44 | 33.3536 | 60.9 | 35.0555 |
| $P_{g3}$ (MW) | 30.43 | 15.0000 | 15 | 15.0169 |
| $P_{g4}$ (MW) | 29.07 | 10.0098 | 21 | 10.0000 |
| $P_{g5}$ (MW) | 16.12 | 10.0000 | 16 | 10.0000 |
| $P_{g6}$ (MW) | 28.61 | 12.0010 | 39.89 | 12.0076 |
| $P_{wind}$ (MW) | 99.73 | 100.0000 | 16 | 15.9674 |
| *PD* (MW) | 289.3 | 289.3 | 189.3 | 189.3 |
| Cost ($/h) | 514 | 494.0327 | 450 | 439.9149 |
| Std | - | 1.1175 | - | 0.8580 |
| No. of iterations | - | 100 | - | 100 |
| Pro-time (s) | - | 45.482 | - | 19.385 |

**Table 3:** Results comparison between the methods.

which under two cost values of MBO and LP methods. Standard deviation of scenario No.2 is 0.8585 that show small deviation between many runs. The cost values and small deviation of CSA prove CSA is the best method to solve ED problem with WF. It can apply in larger power system with WF connecting in future.

## Conclusion

From above results, CSA can solve ED problem with WF connecting by shortest CPU time and give the best result. Although other method improvement has new solution, their value results is higher and long CPU time.

There are some artificial algorithms which solve ED problem in power system operation. However, CSA is best method because it can quickly give exact results. Especially, when power system has WF jointing that change many important results such as operation cost and power output of generations. Although WF has operation and maintenance cost but operation cost of system reduces when the system has WF connecting [2,22,23].

In the future, the power system becomes more complicated when the system connects with WFs or other renewable energy such as solar, tide and wave power. ED problem in power system should be concern more about cost optimization that need mathematical methods help to solve ED problem with big power system.

From the research result of this paper, CSA can solve ED problem with WF connecting in power system for the best results about time programming and minimum operation cost. So CSA can be very useful and perfect method in power system calculations and CSA can apply to calculate large power system more generators, loads and other constraints of other power system in future.

### References

1. Kennedy J, Eberhart R (1995) Particle swarm optimization. In: Proceedings IEEE Conference. Neural Networks. Perth, Australia.
2. Mahor A, Prasad V, Rangnekar S (2009) Economic dispatch using particle swarm optimization: A review. Renewable and Sustainable Energy Reviews. 13: 2134-2141.
3. Ratnaweera A, Halgamuge SK, Watson HC (2004) Self-organizing hierarchical particle swarm optimizer with time-varying acceleration coefficients. IEEE Trans. Power Systems 8: 240-255.
4. Pham DT, Jin G (1995) Genetic algorithm using gradient-like reproduction operator. Electronic Letter 22: 1558-1559.
5. Wu Z, Tommy W, Chow S (2012) A local multi-objective optimization algorithm using neighborhood field. Struct Multidisc Optim 46: 853-870.
6. Lee TY (2008) Short term hydroelectric power system scheduling with wind turbine generators using the multi-pass iteration particle swarm optimization approach. Energy Conversion and Management 49: 751-760.
7. Clerc M, Kennedy J (2002) The particle swarm–explosion: stability and convergence in a multidimensional complex space. IEEE Trans. Evolutionary Computation 6: 58-73.
8. Vasant P, Vo DN, Schegner P (2013) Meta-heuristics optimization algorithm in engineering. Business. Economics and Finance. Malaysia.
9. Yang X, Deb S (2009) Cuckoo search via Lévy flights. In: Proceedings of the World Congress on Nature & Biologically Inspired Computing (NaBIC), India.
10. Yang X, Deb S (2010) Engineering optimization by cuckoo search. Int J Mathematical Modeling and Numerical Optimization.
11. Vo DN, Schegner P, Ongsakul W (2013) Cuckoo search algorithm for non-convex economic dispatch. Generation. Transmission & Distribution. IET Journals & Magazines 7: 645-654.
12. Vo DN, Schegner P, Ongsakul W (2011) A newly improved particle swarm

optimization for economic dispatch with valve point loading effects. In: Proc. IEEE Power & Energy Society General Meeting, USA.

13. Brini S, Abdallah H, Ouali A (2009) Economic dispatch for power system included wind and solar thermal energy. Leonardo Journal of Sciences 14: 204-220.

14. Thomas A (2005) Wind power in power systems. British Library Cataloguing in Publication Data Royal. Institute of Technology. John Wiley & Sons Inc. NJ, USA.

15. Mathew S, Philip GS (2011) Advances in wind energy conversion technology. Springer -Verlag Berlin Heidelberg.

16. Wikipedia contributors (2015) Version ID: 676642395). Normal distribution.

17. Wikipedia contributors (2015) The Free Encyclopedia, Correlation and dependence.

18. Wikipedia contributors (2015) The Free Encyclopedia, Artificial neural network.

19. Zimmerman RD, Murillo-Sánchez CE, Thomas RJ (2011) Matpower steady-state operations. Planning and analysis tools for power systems research and education. IEEE Transactions 26: 12-19.

20. Martin TH, Howard BD, Mark HB (1996) MATLAB and Simulink Based Neural Network Software.

21. Prakornchai P (2011) Optimal placement of wind farm on power system using multiobjective Bee Algorithm . WCE 2011, Vol II, Proceedings of the World Congress on Engineering , London UK.

22. Elsaiah S, Benidris M, Mitra J, Cai N (2014) Optimal economic power dispatch in the presence of intermittent renewable energy sources. PES General Meeting. Conference & Exposition.

23. Mishra C, Singh SP, Rokadia J (2015) Optimal power flow in the presence of wind power using modified cuckoo search. IETGeneration, Transmission & Distribution 9: 615-626.