Application of Cuckoo Search Algorithm for Optimal Power Flow in Power System

Le Anh Dung and Vo Ngoc Dieu

Abstract— *The cuckoo search algorithm is applied in many scientific fields such as computer, mechanic and power system. Especially, the cuckoo search can solve and give results in optimization problems with many variables and constraints. A advance of cuckoo search algorithm is solving time which can solve the problems with short time and many iterations. This paper research and apply the algorithm for optimization power flow in power system operation. The research also tests this algorithm by IEEE 30 bus system and use Matlab software to launch optimization program. The results of progress show that the cuckoo search algorithm has many advantages more than former particle swarm optimization methods.*

Keywords— **Cuckoo search algorithm, particle swarm optimization, optimal power flow.**

1. INTRODUCTION

Power flow optimization is important problem in power system operation. Especial, it become difficult and complicated when power system has many power plants, many loads, transmission substations, transformer tap changers and more capacitors. The main target of optimal power flow problem is power on transmission lines, capacity of capacitor banks, and tap changer level with minimum cost of generation in system.

There are many methods to solve optimal problem, classical methods are Lagrange algorithm and Newton method, artificial intelligence methods such as GA (Genetic Algorithm), DE (Differential Evolution), Particle swarm optimization (PSO) and PSO improvement [1][2][3]. Artificial intelligence methods have some advantages more than classical methods, it can solve optimal problem with quadratic functions and sum functions which are available in fuel function of thermal generation in power system. From 2004, PSO and PSO improvement methods such as PSO with Time-Varying Acceleration Coefficients (PSO-TVAC), Pseudo Gradient PSO (PG-PSO), Pseudo Gradient PSO Constriction Factor (PG-PSOCF) [4][5][6] were researched for economic dispatch optimal operation in power system.

Cuckoo Search Algorithm (CAS) is new algorithm in optimization field nearly years. Furthermore, CS combine Levy flights were used in information technology and other science technical fields from 2009 up today [7][8][9][10][11][12]. However, there are very little CS application for optimal power flow (OPF) in power system operation.

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This paper introduces new method to solve OPF problem which is CS algorithm. CSA can be method bester than classical methods or PSO and PSO improvement because CS method has quick convergence, so CS method can save time and give good results. From these advantages, so CSA can be applied in large scale power system with many constraints and other requirements of power system operation.

In this paper, Section 2 shows OPF formulas and constraints equations in power system operation. Section 3 build CSA and Lévy flights distribution. Section 4 applies CAS for OPF problem. Section 5 gives results of OPF problem with data IEEE 30 bus system which are solved by CSA. The results also compare to some previous methods the same OPF problem.

2. PROBLEM FORMULATION

Target of OPF problem in powers system operation is voltage, current, power load, reactive power and capacitor values of each bus in system with minimum generator cost [13][14][15][16]. In addition, OPF problem is very important because it should calculate about balance power between generators and load demands, quality of voltage, current and power which supply to customers.

Objective function

The objective function of OPF problem is:

$$MinF = \sum_{i=1}^{N_g} F_i(P_{gi}) \tag{1}$$

Cost function of thermal generators is:

$$\text{Min } F = \sum_{i=1}^{NG} \left(a_i + b_i P_{Gi} + c_i P_{Gi}^2 \right) \tag{2}$$

Cost function of thermal generator with vale point effect:

$$\text{Min } F = \sum_{i=1}^{N_g} \begin{pmatrix} a_i + b_i P_{gi} + c_i P_{gi}^2 + \\ \left| e_i \sin(f_i (P_{gi,\min} - P_{gi})) \right| \end{pmatrix} \quad (3)$$

Constraint factors

Balance of power and reactive power

$$P_{gi} - P_{di} = V_i \sum_{j=1}^{N_b} V_j \left[G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j) \right] \quad (4)$$

$i = 1, ..., N_i$

$$Q_{gi} + Q_{ci} - Q_{di} = V_i \sum_{j=1}^{N_b} V_j \begin{bmatrix} G_{ij} \sin(\delta_i - \delta_j) + \\ B_{ij} \cos(\delta_i - \delta_j) \end{bmatrix} \quad (5)$$

$i = 1, ..., N_i$

Limit of power and reactive power each generator bus

$$P_{gi,\min} \le P_{gi} \le P_{gi,\max}; \;\; i = 1, ..., N_g \quad (6)$$

$$Q_{gi,\min} \le Q_{gi} \le Q_{gi,\max}; \;\; i = 1, ..., N_g \quad (7)$$

$$V_{gi,\min} \le V_{gi} \le V_{gi,\max}; \;\; i = 1, ..., N_g \quad (8)$$

Transformer tap setting constraints

$$T_{k,\min} \le T_k \le T_{k,\max}; \;\; k = 1, ..., N_i \quad (9)$$

Voltage and power flow constrains at load buses and transmission line

$$V_{li,\min} \le V_{li} \le V_{li,\max}; \;\; i = 1, ..., N_d \quad (10)$$

$$S_l \le S_{l,\max}; \;\; i = 1, ..., N_i \quad (11)$$

3. CUCKOO SEARCH ALGORITHM

Cuckoo search algorithm (CSA) is a new meta-heuristic algorithm inspired from the nature for solving optimal 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. In nature, cuckoo birds usually lay their eggs in nests of the other bird species (host nests). There are some cases which can happen. First, the birds of host nests know the eggs of cuckoo birds (alien eggs) and they can reject it throw out their nests or they release their nests and build new nests. Second, the birds of host nests do not know alien eggs and it will become cuckoo birds. Following cuckoo behavior, CSA described as three main steps [17]

- 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 $p_a \in$ [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 step [18]:

$$Lévy \sim u = t^{-\lambda}, (1 < \lambda \le 3) \quad (12)$$

4. CSA APPLICATION FOR OPF PROBLEM

Fitness function of OPF problem is:

$$F_{fitness} = F(x,u) + K_P \sum_{i=1}^{N_g} \left(P_{gi} - P_{gi}^{\lim} \right)^2 + K_q \sum_{i=1}^{N_g} (Q_{gi} - Q_{gi}^{\lim})^2 + K_v \sum_{i=1}^{N_d} (V_{li} - V_{li}^{\lim})^2 + K_s \sum_{l=1}^{N_l} (S_l - S_{l\max})^2 \quad (13)$$

Overall procedure of CSA for OPF problem following as steps:

Step 1: Choose bird nests N_p, parameters of CSA: p_a, IT_{max}, total generators N includes cost function parameters a_i, b_i, c_i, e_i, f_i. Power of generators P_{gi} correspond number of cuckoo eggs in nest N.

Step 2: Slack power P_s calculation and choose initial output power of generators. Use Matpower 4.1 Toolbox to calculate:

- Value objective function FC.
- Reactive power of generators Q_g.
- Bus voltage of generators V_g, and voltage of load bus V_l.
- Power on transmission lines S_l.
- Voltage output of tap changer V_T, capacity of capacitors Q_C.
- Value of fitness function FF_{inf}.

Step 3: Apply Lévy flights distribution to choose the eggs of cuckoo corresponding with initial power output of generators. Calculate FC, Q_g, V_g, V_{load}, S_l, V_T, Q_c. From these results, calculate new value of fitness function FF_{new}.

Step 4: Assess 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 cost FF.

Step 7: Diagram characteristic of FF with each iteration.

Step 8: Show result of problem: P_{gi}, FC, P_{loss}, Q_g, V_g, V_{load}, S_l, V_T, Q_c, iterations, programming time of computer.

5. NUMERICAL RESULTS

The CSA for OPF problem is tested on IEEE 30 bus system. Target of problem is minimum operation cost with the best parameters about voltage at generator and load buses, power output of generators, power loss, power on transmission lines, reactive power of generators, capacity of capacitors, and voltage of tap changers. The data of IEEE 30 bus give on Table 1

Table 1. IEEE 30 bus system data

IEEE 30 buses	Total	Bus No.
Generators	6	1, 2, 5, 8, 11, 13
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

The program has been developed in Matlab software and Power Toolbox 4.1 [19] to solve OPF problem with CSA. The parameters of the CSA are selected as follows: the number of nest N_p = 15, probability for an alien egg to be discovered p_a = 0.25, maximum number of iterations It_{max} = 100, penalty factor for fitness function $K = 10^6$. For obtaining the optimal solution, the algorithm is performed 20 independent runs.

The results of CSA for OPF problem show on figures and tables, appendixes. Table 2 shows voltage of tap changers, table 3 give results of capacitor banks, table 4 shows power, reactive power and voltage of generators, table 5 compare efficient between CS and different artificial intelligence methods. Appendix 1 is voltage results of load buses. Appendix 2 shows power flow on transmission lines.

The final results were compared with other methods such as DE, Weight Inertia-PSO (WIPSO), GA, Sequential Quadratic Programming (SQP), Simulated Annealing (SA), Newton-based Optimal Power Flow (NOFP), Extended Dommel-Tinny OPF (ED-OPF), and Improved Evolutionary Programming (IEP) [20][21][22].

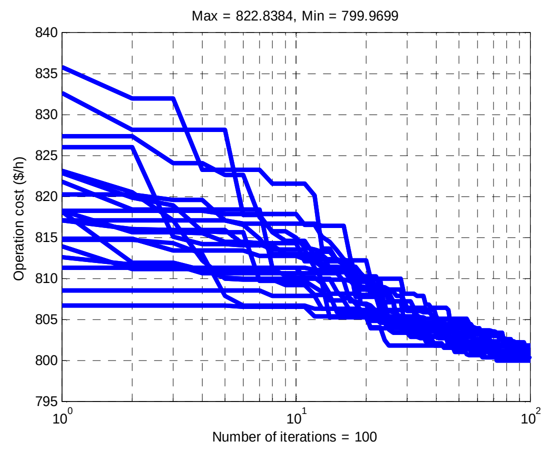

Fig. 1. The convergence characteristics of CSA for cost OPF problem with 20 running.

Table 2. Voltage at Tap changer buses

Bus No.	4	6	10	28
V_T (p.u)	1.07	0.98	1.10	1.02

Table 3. Capacity of capacitor banks

Bus No.	10	12	15	17	20
Q_c	4.65	2.20	0.77	0.00	5.00
Bus No.	21	23	24	29	
Q_c	5.00	5.00	0.66	0.82	

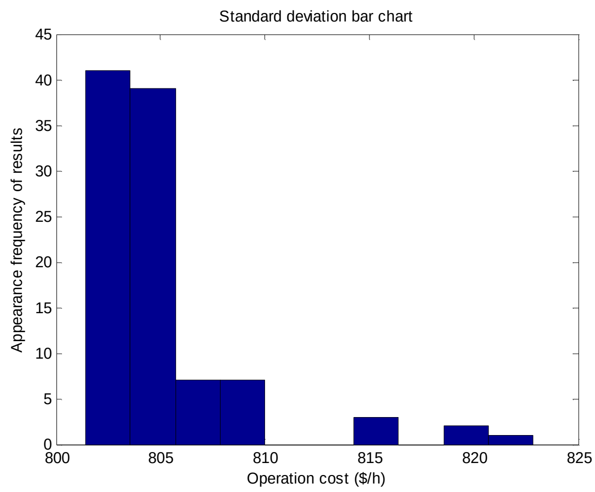

Fig. 2. The statistic chart of CSA for cost of OPF problem after 20 running.

Table 4. Power and voltage generator buses resultes

Bus No.	Power generation P_{gi} (MW)	Voltage generator buses V_{gi} (p.u)	Reactive power generation Q_{gi} (MVAr)
1	174,4256	1.10	-7.27
2	47,8077	1.08	6.33
5	19,5673	1.05	20.99
8	23,9503	1.06	18.12
11	10,0000	1.07	22.01
13	16,4716	1.10	44.57

Table 5. Compareation of the best results between methods

Method	**Min. cost ($/h)**	**Standard deviation**	IT_{max}	**Time running (s)**
DE [20]	801,23	-	100	30,945
WI-PSO [21]	799,1665	-	200	15,4
GA [21]	801,24	-	-	-
SQP [21]	802,23	-	200	20
SA [22]	803,97	2.6317	150	28,29
NOFP [22]	805.45	-	-	-
EDOPF [22]	813,74	-	-	-
IEP [22]	802,58	-	-	99,013
PSO TVAC	798,9687	0,3640	100	8,84
PG PSO	799,5107	1,9276	100	4,59
PG PSO CF	798,9997	2,5343	100	4,48
CS	**799,9699**	**0,5493**	**100**	**8,97**

6. CONCLUSION

Although particle swarm optimization algorithms such as PSO, DE, GA have advances in optimal power system operation. However, CS algorithm is new method and has fortes more than former methods. In OPF problem, CS algorithm can solve and give accurate results with short progress CPU time. CSA also has quick convergence after some iterations.

The results on table 5 and appendix 1, 2 show effecient of CS method which can solve more complicated or bigger problems in power system. Especialy, when renewable energy become popular in power generation, OPF problem calculation need exact and fast progress. The CS algorithm is new method which can help to solve OPF problem in future.

NOMENCLATURE

N_p	Number of particles.
P_D	Total system load 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 power loss.
N_g	Number of generators.
P_{gi}	Power output of generator *i*.
$P_{gi,min}$, $P_{gi,max}$	Minimum and maximum power outputs of generator *i*, respectively.
Q_{gi}	Reactive power output of generator *i*.
$Q_{gi,min}$, $Q_{gi,max}$	Minimum and maximum reactive power outputs of generator *i*.
P_L	Total transmission loss.
V_{gi}	Voltage of generator *i*.
V_{li}	Voltage of line number *i*.
S_{li}	Power on transmission line *i*.
T_k	Tap changer level position.
FF_{inf}	Initial value of fitness function.
FF_{new}	Value of fitness function applied Lévy flights distribution.
FF_{dis}	Value of fitness function calculated from reject eggs with p_a probability.

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APPENDIX

Table A1. Load buses voltage result

Bus	V_{max}	V_{min}	V
3	1.06	0.94	1.07
4	1.06	0.94	1.07
6	1.06	0.94	1.06
7	1.06	0.94	1.06
9	1.06	0.94	1.09
10	1.06	0.94	1.08
12	1.06	0.94	1.05
14	1.06	0.94	1.04
15	1.06	0.94	1.04
16	1.06	0.94	1.05
17	1.06	0.94	1.07
18	1.06	0.94	1.05
19	1.06	0.94	1.04
20	1.06	0.94	1.04
21	1.06	0.94	1.02
22	1.06	0.94	1.00
23	1.06	0.94	1.02
24	1.06	0.94	1.06
25	1.06	0.94	1.00
26	1.06	0.94	0.99
27	1.06	0.94	1.04
28	1.06	0.94	1.04
29	1.06	0.94	1.02
30	1.06	0.94	1.00

Table A2. Transmision lines power result

Bus	From bus	To bus	S_{max} (MVA)	S_l
1	1	2	130	114.67
2	1	3	130	63.61
3	2	4	65	34.79
4	3	4	130	59.85
5	2	5	130	62.56
6	2	6	65	46.28
7	4	6	90	55.58
8	5	7	70	11.29
9	6	7	130	33.62
10	6	8	32	20.27
11	6	9	65	25.91
12	6	10	32	16.90
13	9	11	65	26.45
14	9	10	65	31.85
15	4	12	65	41.62
16	12	13	65	46.15
17	12	14	32	7.73
18	12	15	32	17.71
19	12	16	16	7.41
20	14	15	16	1.31
21	16	17	16	3.39
22	15	18	16	5.57
23	18	19	16	2.28
24	19	20	16	8.08
25	10	20	32	9.56

26	10	17	32	7.37
27	10	21	32	17.17
28	10	22	32	8.27
29	21	22	32	1.51
30	15	23	16	4.78
31	22	24	16	6.71
32	23	24	16	4.27
33	24	25	16	0.99
34	25	26	16	4.26
35	25	27	16	5.04
36	28	27	65	18.79
37	27	29	16	6.28
38	27	30	16	7.23
39	29	30	26	3.80
40	8	28	32	3.30
41	6	28	32	17.23