

Optimal Power Flow by Cuckoo Search Via Lévy Flight Algorithm

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Abstract - The approach is based on used of meta-heuristic optimization for solving an Optimal Power Flow problem. The meta-heuristic methods aim to find a global minimum, all gradient methods trend to fail because of the existences of the local's minimum, the solutions are often very dependent on the initials start values. The methodology is to use a modified power flow solver (MatPower) as an objective function with constraints, the meta-heuristic solver (cuckoo-search) will pilot and control all parameters to find the best parameters values. The approach was tested on a standard IEEE 30-bus, with different objectives function as fuel costs minimization, voltage profiles. The results are similar, the study was compared with others meta-heuristic (Particle Swarm Optimization and Differential Evolution) study of OPF and show the efficiency of this approach. The respect of all constrains is one big advantage of this method in solving nonlinear problems.

Keywords: *Metaheuristic, Power flow, MatPower, cuckoo-search, nonlinear optimization*

I. INTRODUCTION

Recently, optimization of nonlinear problem is a real challenge for cost optimization and energy saving. The metaheuristic solution is often used in many fields of electrical engineering, for strategies in power management and storage [1], for off-grid design [2]. For power flow problems, there are two main fields, the optimal scheduling or optimal planning [3] and the optimal power flows problems. OPF is a huge challenge in grid management. Some studies were already made in this field. It is at the same time an optimization and combinatory problem. The optimal power flow problem is to minimize the fuel cost without violating the system's constraints. Those constraints are the limits of the operating limits of each system elements, like the voltage at each node or the generated power

II. LITERATURE REVIEW

A. OPF problem

The OPF solution is a well-known problem, the deterministic approach is based on the Newton-Raphson solver [4]. The disadvantage of those kind of method is those are method of gradients, for power flow problems, it needs some pre-processing to reach convergence.

The OPF is a discrete problem as combinatory problems [5] and maybe a continuous time-domain problem [6]. The OPF problem is a complex problem due to the huge number of parameters and constraints. The optimal power flow problem is static studies of the optimal dispatch of active and reactive power within the limits and the constraints of the system.

The optimal power flow plan to optimize an objective function under cost minimization and system limits constraints. The OPF problems aim to satisfy various equations and inequations; The equality equations are the power flow equations; the inequalities are the constraints.

B. Metaheuristic approach

During evolution, nature finds an ingenious way to solve problems. Recently the nature inspired algorithm [7] has become popular. The study of natures' behavior leads to a new way of thinking. A new family algorithm [8] for solving nonlinear problems have emerged. Those kinds of solutions imitate some nature's compartment, Evolutionary Algorithm (EA), Particle Swarm optimization (PSO), Ant (ACO), Bee colony algorithm (BCO) or bacteria foraging optimization (BFO). When we look at bee, they can manage to do some huge complex teamwork; it can give a clue in complex resolution of the system.

A lot of study was being made for solving nonlinear problems [9–11] in deterministic way. All of them is based on gradient or Hessian methods. The biggest problem in derivative method is the existence of some local minima or maxima. The local extremum can be easily found with this kind of method. But the solution is extremely dependent on the start point [12] of the search. Unlike the gradient's method for solving OPF, metaheuristic solvers like cuckoo-search developed by Yang [13] is able to handle a global solution for nonlinear problems. Metaheuristic algorithm doesn't fail in local extremum trap but trend to find the global solution even if it finds the local minima. It uses some stochastic process to find a way or to choose the start point. We have some random process with convergence. Those are very powerful tools to find extrema. The majority of metaheuristic process lack of mathematical foundation but are empirically validated and are more efficient than deterministic in such way.

In the family of metaheuristic algorithm, cuckoo-search is one of the latest algorithm [14].

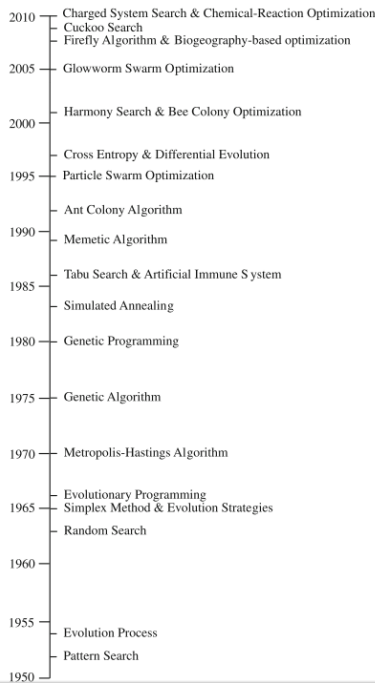


Fig. 1. Timeline of the main Metaheuristic algorithm [14]

III. TOOLS

A. MatPower

MatPower [15] is a MatLab package for solving power flow problems. It is a simulation tool for researchers and educators. It is a modifiable code and initially a part of the PowerWeb project. MatPower gives a lot of tools for power flow problems [16]. Because it was implemented in Matlab, it can be easily modified.

B. Cuckoo-search

- Overview

The cuckoo breeding behavior is a reproduction's strategy of brood parasitism. Some species engage the brood parasitism by lying their eggs in others host bird's nest. Some species remove host eggs to improve the chance of his eggs to not be found by the host, if it is found, the host may leave the nest or eject the cuckoo eggs. Like the cuckoo for finding the best host nest to place his eggs, cuckoo-search find global minima [17].

Cuckoo search was developed on cuckoo behaviors. It was used in structural optimization [14] like truss optimization or mass structure optimization [18]. Some comparisons [19] with other metaheuristics algorithm show that cuckoo-search is a promising algorithm for non linear problem solving.

- Levy flights:

To improve cuckoo search efficiency, it was enhanced by Levy flights rather than a simple random walk which follow normal look-like law. The Levi flight is a class of random walk with non-constant step, those steps are chosen from a distribution with a power-law tail. Viswanathan et al. [20] show that albatrosses wandering can be classified in Levy flights. Also, Levy flights can be used in fluid's mechanics for turbulence studies [21]. The introduction of Levy flights aims to give a certain balance for optimal search [22] between diffusion and dispersion. The levy flights generate a random walk with random step length based on Levy's distribution.

$$Levy\ u = t^{-\lambda}, (1 < \lambda < 2) \quad (1)$$

C. Algorithm

- Cuckoo brooding

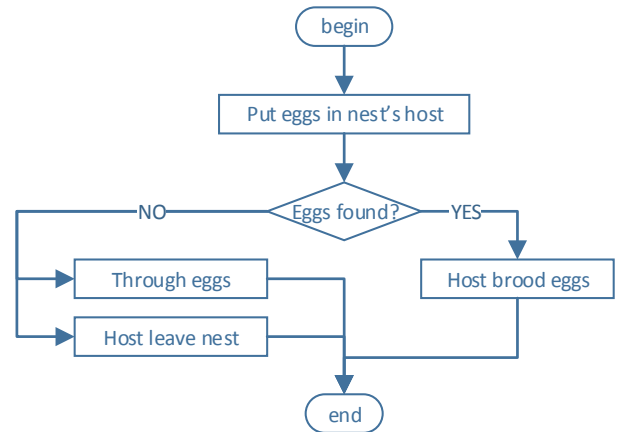


Fig. 2. Cuckoo brooding chart flow

- Cuckoo Search Algorithm [14]

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begin
Objective function f(x), x=(x 1 ,..., x d )T;
Initial a population of n host nests x i (i=1,2,...,n);
while (t < Maximum Generation) or (stop criterion);
    Get a cuckoo (say i) randomly and generate a new solution by Lévy flights;
    Evaluate its quality/fitness; Fi;
    Choose a nest among n (say j) randomly;
    if (Fi > Fj),
        Replace j by the new solution;
    end
    Abandon a fraction (Pa) of worse nests [and build new ones at new locations via Lévy flights];
    Keep the best solutions (or nests with quality solutions);
    Rank the solutions and find the current best;
end while
Post process results and visualization;
End
    
```

Fig. 3. Pseudo-code of the Cuckoo Search method

D. Cuckoo-Search implementation

Like MatPower, the cuckoo-search algorithm was written and implemented in MatLab. To validate the Cuckoo-Search code, Michaelwicz function [17] was used as validation function.

$$f(x, y) = -\sin(x) \cdot \sin^{2m}\left(\frac{x^2}{\pi}\right) - \sin(y) \cdot \sin^{2m}\left(\frac{2y^2}{\pi}\right) \quad (2)$$

Where $m = 10$ and $(x, y) \in [0,5] \times [0,5]$

The minimal global in the domain is

$$f \approx -1.8013at(2.20319, 1.57049)$$

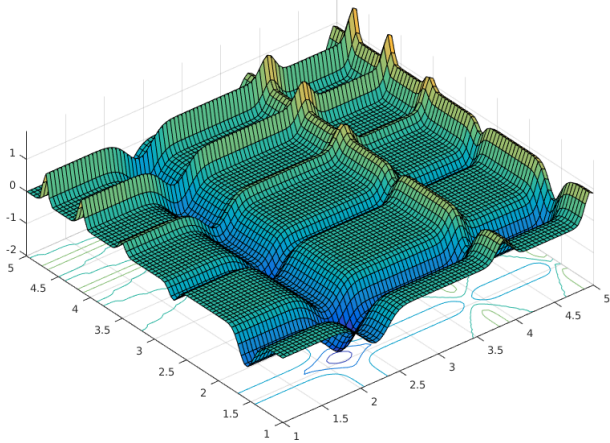


Fig. 4. 3D view of Michaelwicz function

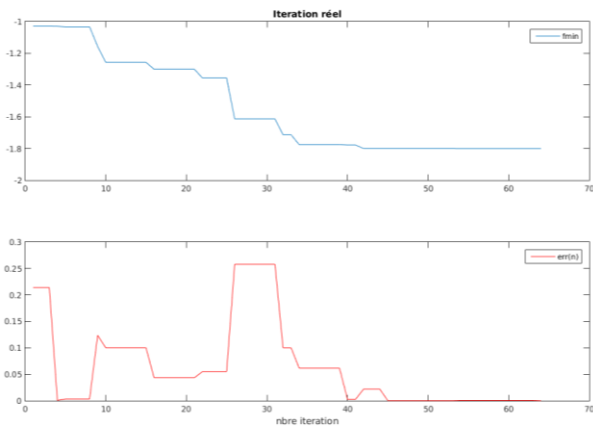


Fig. 5. Cuckoo-Search iteration

The implementation finds the solution after 65 iterations, it's a trend to an asymptotic constant with precision of 10^{-3} . Conclusion, the code can be used for solving nonlinear problems.

E. Optimal Power-flow via Cuckoo-Search

For solving OPF problems, we need to satisfy the constraints with varying the parameters.

TABLE I. CONSTRAINT—PARAMETERS

Parameters	Constraints
Tap ratio transformer	Generator limits
Shunt capacity	Transformer
	Cost limits

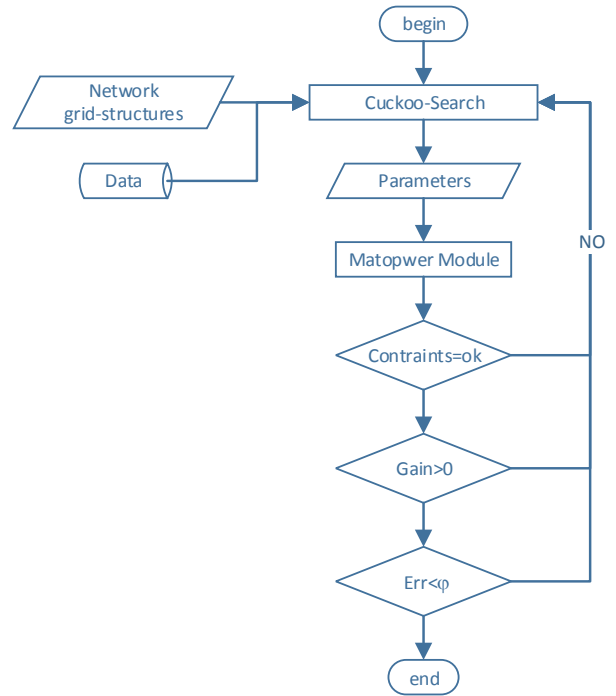


Fig. 6. OPF via Cuckoo-search

IV. NUMERICAL RESULT

A. System overview

For the test of the method, the system test is the IEEE 30 bus, it has six generators at buses 1, 2, 5, 8, 11 and 13; Four transformers with off-nominal tap ration at lines 6-9, 6-10, 4-12 and 28-27; like in OPF via Differential Evolution [23], shunt VAR capacitors were placed on buses 10, 12, 15, 17, 20, 21, 23, 24 and 29.

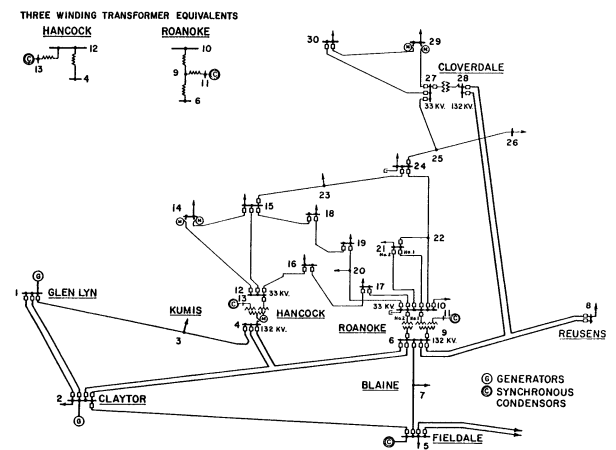


Fig. 7. Single line diagram of IEEE 30 Bus test

B. Objective function

There are 3 objective function in this study.

- Case 1 Minimization of fuel costs

The fuel cost minimization is based on the function of total [24] fuel of the cost of generators.

$$J = \sum_{i=1}^{NG} f_i(\$/h) \tag{3}$$

With f_i is the fuel cost of i^{th} generator the generator curves are given by

$$f_i = a_i + b_i P_{Gi} + c_i P_{Gi}^2 (\$/h) \tag{4}$$

TABLE II. GENERATOR COST COEFFICIENTS

	G1	G2	G5	G8	G11	G13
a	0	0	0	0	0	0
b	200	175	100	325	300	300
c	37.5	175	625	83.5	250	250

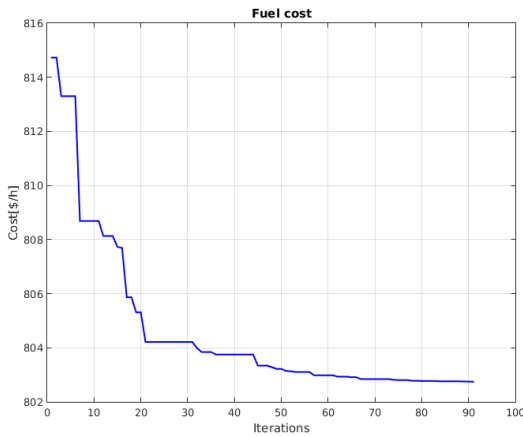


Fig. 8. Case 1 fuel costs minimization

- Case 2: voltage profile improvement

The voltage profile management objective function is auditioned to minimization of fuel costs. The objective is to have the same value of voltage magnitude in each node. The voltage must be near to the unity as possible.

$$J = \sum_{i=1}^{NG} f_i(\$/h) + w \sum_{i \in NL} |V_i - 1.0| \tag{5}$$

w is a weight factor.

Here like in D.E. [23], the weight factor is set to 100.

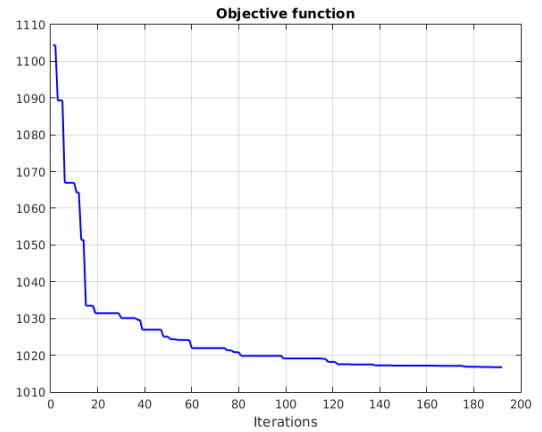


Fig. 9. Objective function evolution

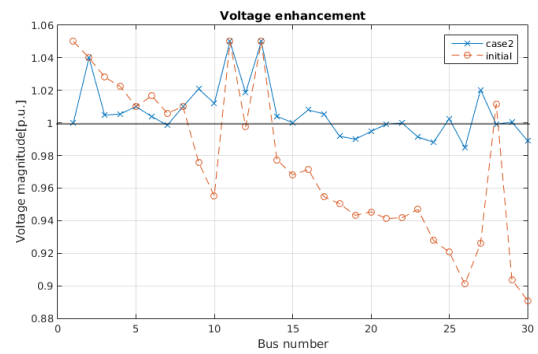


Fig. 10. Voltage magnitude for the 30 Bus

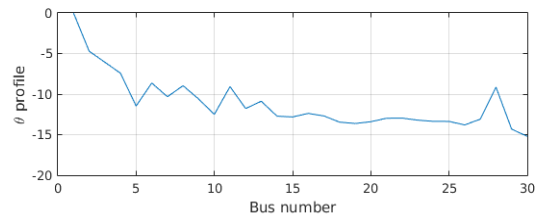
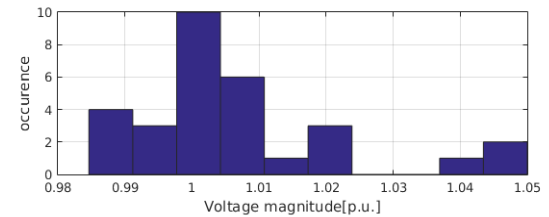


Fig. 11. Magnitude voltage distribution and phase angle

- Case 3: piece-wise quadratic cost curve

This case is to establish a cross-references validation between Cuckoo-Search OPF and others [23], [24] metaheuristic OPF approach. The upper limit of voltage magnitude at bus 1 is 1.05 PU and all the VAR compensation are removed.

The same objective function at case 1 is considered. The variation of the coefficient for generator costs is shown in the next table. The coefficient of the price depends on some inequalities.

TABLE III. CASE 3 GENERATOR COST

	From MW	To MW	Cost coefficients		
			<i>a</i>	<i>b</i>	<i>c</i>
Gen1	50	140	55.0	10	50
	140	200	82.5	105	75
Gen2	20	55	40.0	30	100
	55	80	80.0	60	200

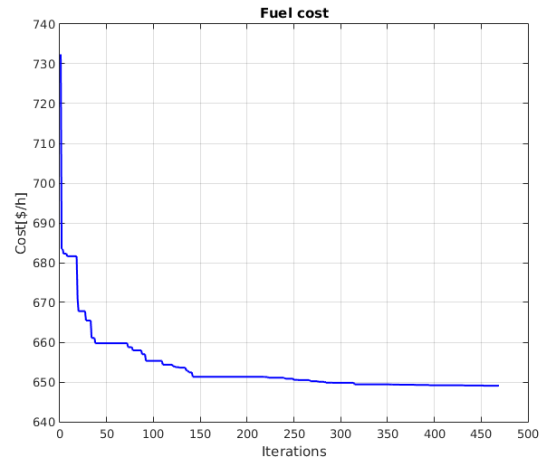


Fig. 12. Quadratic fuel costs

- Comparison with Differential Evolution and Particle swarm optimization:

TABLE IV. COMPARISON

Parameters			case 1: Fuel costs minimization			Case 2: Voltage enhancement			Case 3: Piecewise quadratic cost curve		
	<i>Min</i>	<i>Max</i>	<i>DE</i>	<i>PSO</i>	<i>Cuckoo-Search</i>	<i>DE</i>	<i>PSO</i>	<i>Cuckoo-Search</i>	<i>DE</i>	<i>PSO</i>	<i>Cuckoo-Search</i>
P1	50,00	200,00	176,2592	176,9600	176,0940	183,1277	173,6800	174,6846	139,9830	140,0000	139,9962
P2	20,00	80,00	48,5602	48,9800	49,4134	47,4435	49,1000	49,9958	54,8249	55,0000	54,9794
P5	15,00	50,00	21,3402	21,3000	21,5000	18,7281	21,8100	21,1803	25,7889	24,1500	24,9997
P 8	10,00	35,00	22,0553	21,1900	21,3390	16,1515	23,3000	23,9187	34,8331	35,0000	34,7023
P 11	10,00	30,00	11,7785	11,9700	12,4266	11,8855	13,8800	13,8054	17,2469	18,5100	18,6979
P 13	12,00	40,00	12,0217	12,0000	12,2193	16,5050	12,0000	12,0000	18,3565	17,7900	17,3602
V 1	0,95	1,10	1,0999	1,0855	1,0630	1,0490	1,0142	0,9999	1,0421	1,0500	1,0576
V 2	0,95	1,10	1,0890	1,0653	1,0400	1,0335	1,0022	1,0400	1,0364	1,0412	1,0400
V 5	0,95	1,10	1,0659	1,0333	1,0100	1,0117	1,0170	1,0100	1,0080	1,0170	1,0100
V 8	0,95	1,10	1,0697	1,0386	1,0100	1,0043	1,0100	1,0100	1,0070	1,0282	1,0100
V 11	0,95	1,10	1,0965	1,0848	1,0500	1,0432	1,0506	1,0500	1,0402	1,0910	1,0500
V 13	0,95	1,10	1,0996	1,0512	1,0500	0,9931	1,0175	1,0500	1,0204	1,0876	1,0500
T 11	0,90	1,10	1,0429	1,0233	1,0006	1,0439	1,0702	0,9935	0,9984	1,0192	0,9820
T 12	0,90	1,10	0,9179	0,9557	0,9465	0,9230	0,9000	0,9001	0,9880	0,9573	0,9392
T 15	0,90	1,10	1,0190	0,9724	1,0554	0,9345	0,9954	0,9966	1,0674	1,0120	0,9901
T 36	0,90	1,10	0,9896	0,9728	0,9834	0,9616	0,9703	0,9441	0,9307	0,9505	0,9980
Q c10	-	0,05	0,0455	0,0335	0,0187	0,0365	0,0403	0,0152	-	-	-
Q c12	-	0,05	0,0442	0,0220	0,0337	0,0038	0,0369	0,0357	-	-	-
Q c15	-	0,05	0,0417	0,0198	0,0138	0,0409	0,0500	0,0027	-	-	-
Q c17	-	0,05	0,0252	0,0315	0,0208	0,0294	-	0,0008	-	-	-
Q c20	-	0,05	0,0209	0,0454	0,0078	0,0480	0,0500	0,0337	-	-	-
Q c21	-	0,05	0,0420	0,0381	0,0346	0,0447	0,0500	0,0500	-	-	-
Q c23	-	0,05	0,0255	0,0398	0,0200	0,0382	0,0500	0,0500	-	-	-
Q c24	-	0,05	0,0438	0,0500	0,0381	0,0420	0,0500	0,0001	-	-	-
Q c29	-	0,05	0,0275	0,0251	0,0213	0,0126	0,0259	0,0300	-	-	-
Fuel cost (\$/h)			799,2891	800,4100	802,7462	805,2619	806,3800	812,5412	650,8224	647,6900	649,0496
Power losses (MW)			8,6150		9,5923	10,4412		12,1849	7,6333	0,7722	7,3358
Voltage deviations			1,5306	0,8765	0,6708	0,1357	0,0891	0,3403	0,5733	0,1417	0,5976
Iteration					91	0,1316		192			469

V. DISCUSSION AND CONCLUSION

The convergence's criterion is an asymptotic trending with an error of 0,01. For the fuel cost optimization, the 3 methods give some similar results. The Cuckoo-Search (CS) fail for the voltage profile improvement, the voltage deviation of the CS is too big (0,3403 >> 0,0891). With the convergence reaching criteria, for the same problem with different objective function, the iteration of the CS has a huge variance, between 90 and 469.

The main point for the CS is the start point, no need for calibration or pre-processing, it is a promising tool for solving electrical engineering problems.

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