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Optimal Power Flow using Cockroach Swarm Optimization

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ABSTRACT

Optimal Power Flow(OPF) faces challenges of convergence and local minima. This paper reviews nomenclature and literature of both OPF and metaphor-based heuristic optimization, emphasizing Cockroach Swarm Optimization (CSO). Then the paper investigates CSO as applied to OPF. The solution is tested on the benchmark systems such as IEEE 9 bus system using Matpower.

General Terms

Global optimization, Power Systems

Keywords

Optimal Power Flow,Cockroach Swarm Optimization

1. INTRODUCTION

Optimal Power Flow(OPF) is implicated in both security [49] and economy [13] of operation. Solving an OPF faces many challenges [50] such as convergence [29] and local minima [42] .

The rest of this paper presents OPF nomenclature and metaphor-based heuristic optimization, emphasizing *Cockroach Swarm Optimization (CSO)*, in the second section, before reviewing OPF literature in the third section. Then the paper investigates CSO as applied to OPF in the evaluation section where CSO is tested on benchmark systems, before concluding and showing future directions in the last sections.

2. BACKGROUND

2.1 OPF Formulation

Power flows can be calculated from voltage phase angle denoted as δ_i [53]. Hence, v_i, the voltage at node i, is

$$|v_i|\angle\delta_i \tag{1}$$

Admittance matrix Y of size $n_b \times n_b$ can perfectly describe a network of n_b buses [53, 23].

Now, p_f, the active power injected into bus f at time t, is

$$\sum_{t=1}^{n_b} |y_{ft} v_f v_t| \cos(\delta_f - \delta_t - \theta_{ft}) \tag{2}$$

and the reactive power, q_f, is

$$\sum_{t=1}^{n_b} |y_{ft} v_f v_t| \sin(\delta_f - \delta_t - \theta_{ft}) \tag{3}$$

where θ_{shift} is the phase shift angle.

OPF is a global minimization problem [32, §18], i.e.

$$\min_x f(x) \tag{4}$$

with constraints :

$$p_g^f - p_d^f = p^f \tag{5}$$

and

$$q_g^f - q_d^f = q^f, \tag{6}$$

where g is generation

$$g(x) = 0 \tag{7}$$

and d is demand

OPF operates near maximum loadability limit (MLL), formulated as [30]

$$\max_z \quad \alpha \tag{8a}$$

$$\text{subject to} \quad P_d = P_d^0 + \alpha d \tag{8b}$$

$$Q_d = \text{diag}(\tan\phi^0) P_d \tag{8c}$$

$$g(z) = 0 \tag{8d}$$

$$z_{\text{min}} \le z \le z_{\text{max}} \tag{8e}$$

where

$$z = [x^T \ \alpha]^T = \begin{bmatrix} \Theta \\ V_m \\ P_g \\ Q_g \\ \alpha \end{bmatrix}, \tag{9}$$

Differences among MLL and OPF regarding voltage constraints include [12]:

(1) Magnitudes at the reference buses are locked at their set point values.
(2) Magnitudes at all PV and PQ buses are not constrained from below.

(3) PQ magnitude upper bounds are relaxed.
(4) PV magnitude upper bounds are set to the voltage set point of correspondent generators.

2.2 Metaphor-based Heuristic optimization

Figure 1 depicts an arbitrary search space with many local minima/maxima. This nonlinear problem, and the like, requires global optimization [52, 7, 16].

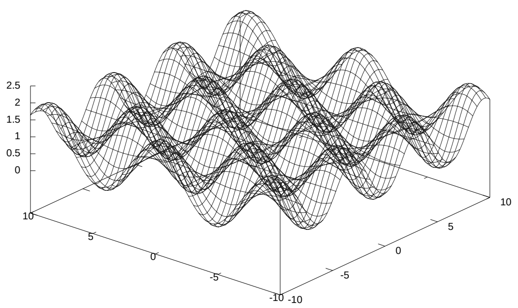

Fig. 1. an arbitrary search space with many local minima/maxima.

Global heuristic optimization, a.k.a metaheuristics [22], scrutinize search spaces using a dichotomy of intensification and diversification [21, 10] .
Metaphor-based optimization [1] usually mimic nature [54] such as Genetic Algorithms (GAs)[24], Cuckoo Search (CS) [55], Hoopoe Heuristic(HH) [19], or swarms [34] of particles(PSO) [35], bees (BCO) [33], or ants (ACO) [18].

2.3 Cockroach Swarm Optimization (CSO)

Many algorithms mimic cockroaches [57, 27]. CSO uses:

(1) *Swarming* of a quorum of cockroaches, excreting a fecal matter trail in the way for the others to follow [5].
(2) *Dispersion* in presence of danger or resource sparsity [5].
(3) *Eliminating* each other in resource shortage [57].

Blattodea insects, comprising cockroaches, have an affinity with Hymenoptera,comprising ants and bees, showing gregarious behaviour [40]. Ants are eusocial with distinguishable behavioral specializations [28]. Otherwise, the nocturnal cockroaches swarm in aggregations [9] for collective decision-making [39].
As depicted in figure 2, cockroaches quorum is initialized randomly, as shown in figure3. Then, they are evaluated, the best individual being associated with a given position in their field of vision. Hence, forming a cluster based on that, as shown in figure4.CSO converses rapidly as shown in figure5.

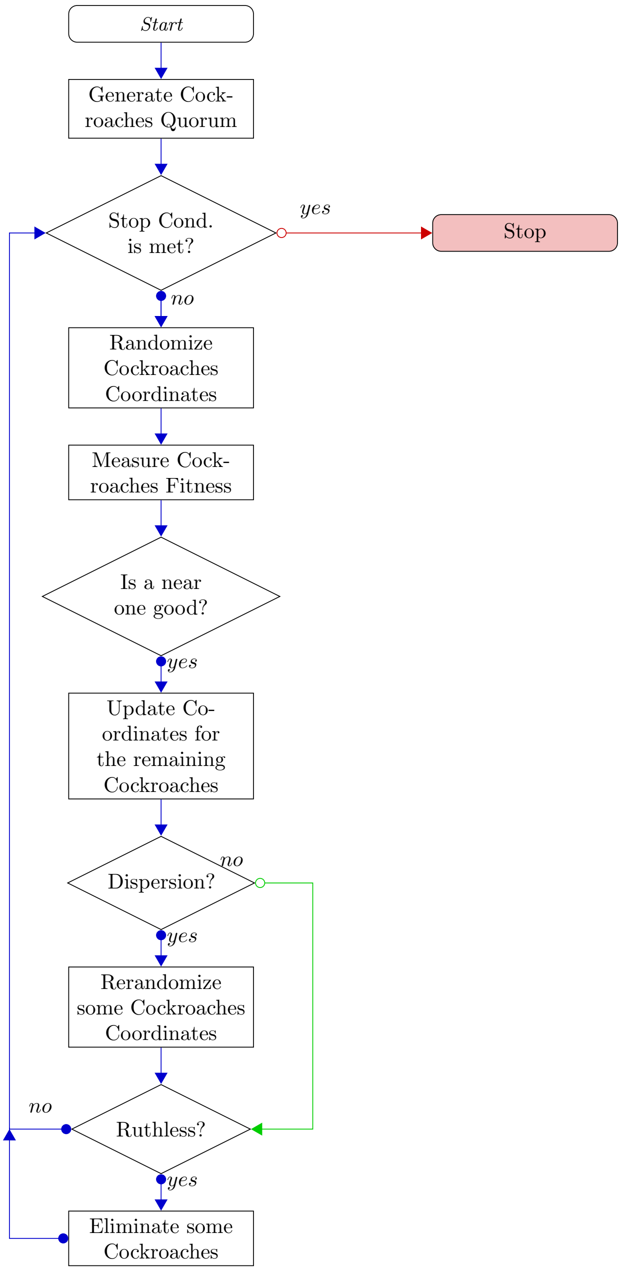

Fig. 2. CSO Flowchart.

3. PREVIOUS WORK

Since the original formulation of OPF [13], the Newton-Raphson was the de facto solving method [51, 45] even for ill-conditioned systems[31].
OPF is periodically surveyed [26, 29, 11]. A honorable mention is use of linear programming (LP)[4].
Metaphor-based heuristic optimizations [14, 37] are used such as

—PSO [47, 2] and fuzzy version [8]

—GAs [36, 56]

—ACO [38]

—BCO [48]

—CS [46]

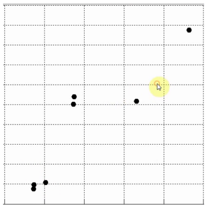

Fig. 3. Initial settings.

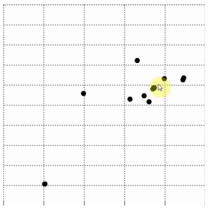

Fig. 4. Cockroach Clustering.

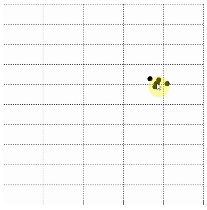

Fig. 5. Pre-Convergence.

4. EVALUATION

CSO applied to OPF is tested on the IEEE 9 bus system [6] implemented in MATPOWER.V.6[58] as CASE09.m as shown in figure6 . CASE09 has 1 area, 9 buses, 9 branches, 3 generators and 3 loads. Consider continuation flow, `runcpf` in MATPOWER.V.6, with no reactive power limits.

Bus	Volt.magnitude	Volt.angle
1	1	0
2	1	-50.45
3	1	-55.24
4	0.84	-19.34
5	0.77	-37.63
6	0.82	-58.71
7	0.61	-79.87
8	0.78	-57.92
9	0.74	-38.42

The results are:

Bus	P	Q
1	482	362
2	163	355.5
3	85	305.5
Total:	730	1023

Compare This with MLL as shown below.

Bus	MLL Load	Voltage
1	0	1
2	0	1
3	0	1
4	0	0.87
5	90	0.81
6	0	0.85
7	439.53	0.66
8	0	0.82
9	125	0.78

%

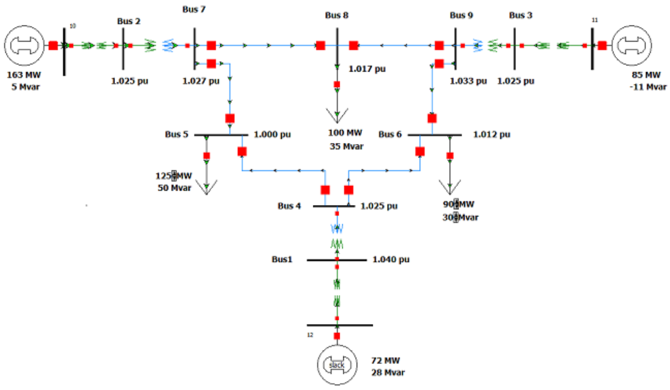

Fig. 6. IEEE 9 bus system [6].

All busses have direction 0, except the 7th has direction 1.
The Reactive power production and generators voltages are :

Bus	Qgen	Qmax
1	305.15	9999
2	300	300
3	255.64	300

All with Qmin=-300, Vm=Vref=1.
CSO converges in 4 iterations, approx.0.29 seconds, giving

Bus	Volt.magnitude	Volt.angle
1	1	0
2	1	9.67
3	1	4.77
4	0.99	-2.41
5	0.98	-4.02
6	1	1.92
7	0.99	0.62
8	0.99	3.8
9	0.96	-4.35

The generations are

Bus	P	Q
1	71.95	24.07
2	163	14.46
3	85	-3.65
Total:	319.95	34.88

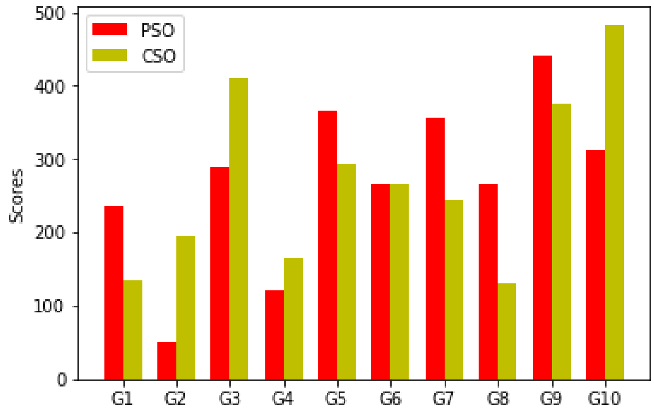

Fig. 7. PSO vs CSO on Systems with 10 groups [15].

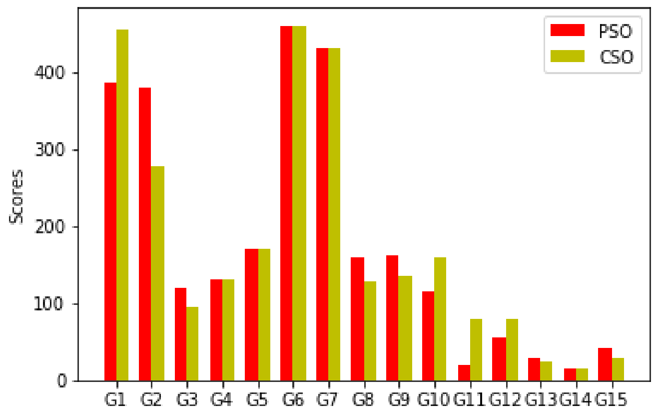

Fig. 8. PSO vs CSO on Systems with 15 groups [20].

As PSO is widely applied in power systems[17, 3], let us compare it with CSO on benchmark systems such as [15] in figure7 and [20]in figure8.

5. CONCLUSION

CSO shows a fast convergence as compared to PSO.

6. FUTURE WORK

An enunciated future work may be applying CSO in other cases such as IEEE Reliability Test test [25] in figure9 to investigate the invariants among systems of varying sizes.
Another direction may be considering improved versions of CSO [43, 44], or parameter optimization [41].

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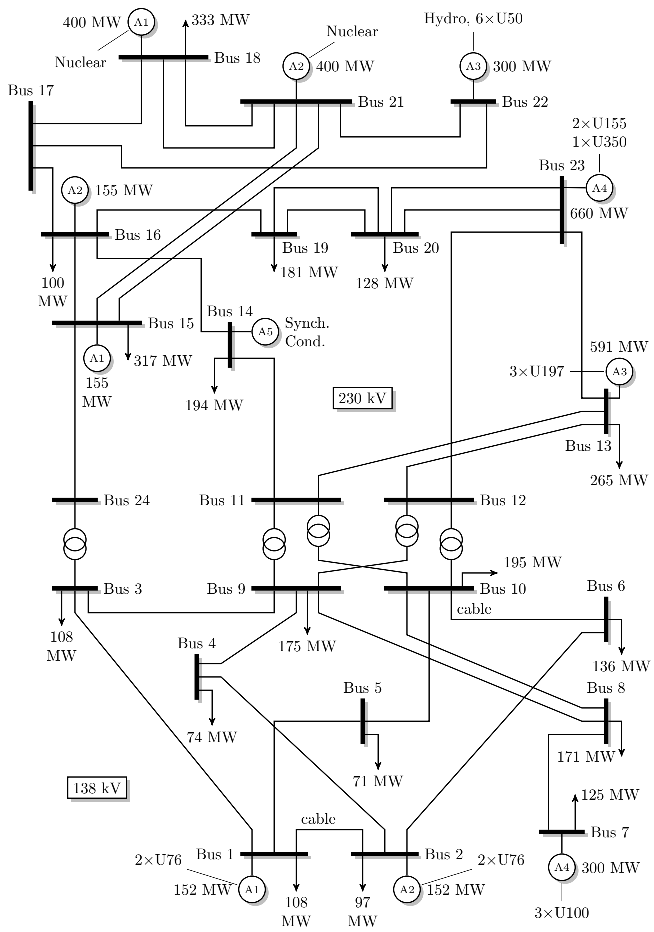

Fig. 9. IEEE Reliability Test test [25].

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