[Kanagasabai *, Vol.6 (Iss.10): October 2018] ISSN- 2350-0530(O), ISSN- 2394-3629(P)
(Received: September 24, 2018 - Accepted: October 27, 2018) DOI: 10.5281/zenodo.1476667

INTERNATIONAL JOURNAL OF RESEARCH – GRANTHAALAYAH
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Science

REDUCTION OF REAL POWER LOSS BY IMPROVED SHUFFLED FROG-LEAPING ALGORITHM

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Abstract

This paper presents Improved Shuffled Frog-Leaping (ISFL) algorithm for solving optimal reactive power problem. A new search-acceleration parameter has been introduced into the formulation of the original shuffled frog leaping (SFL) algorithm to create an adapted form of the shuffled frog algorithm for solving the reactive power problem. The shuffled frog-leaping algorithm draws its formulation from two other search techniques: the local search of the 'particle swarm optimization' technique; and the competitiveness mixing of information of the 'shuffled complex evolution' technique. Proposed Improved Shuffled Frog-Leaping (ISFL) algorithm has been tested in standard IEEE 30,57,118 & Practical 191 Utility (Indian) System bus test systems and simulation results show clearly about the better performance of the proposed algorithm in reducing the real power loss & control variables within the limits.

Keywords: Optimal Reactive Power; Transmission Loss; Evolutionary Algorithms; Shuffled Frog Leaping; Shuffled Complex Evolution.

Cite This Article: Dr. Lenin Kanagasabai. (2018). "REDUCTION OF REAL POWER LOSS BY IMPROVED SHUFFLED FROG-LEAPING ALGORITHM." *International Journal of Research - Granthaalayah*, 6(10), 146-157. https://doi.org/10.5281/zenodo.1476667.

1. Introduction

To till date various methodologies has been applied to solve the Optimal Reactive Power problem. Many types of mathematical methodologies like linear programming, gradient method [1-8] has been utilized to solve the reactive power problem, but those techniques found difficult in handling the constraints in the reactive power problem. After that various types of evolutionary algorithms [9-12] has been applied to solve the reactive power problem. But some algorithm good in exploration means, it lacks in exploitation and few algorithm's good in exploitation but lack in exploration. Speed of convergence is poor for some algorithms even though they got good trade-off between exploration and exploitation. This paper presents Improved Shuffled Frog-Leaping (ISFL) algorithm for solving optimal reactive power problem. A new search-acceleration parameter has been introduced into the formulation of the original shuffled frog leaping (SFL) algorithm [13-15] to create an adapted form of the shuffled frog algorithm for solving the reactive

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power problem. The shuffled frog-leaping algorithm draws its formulation from two other search techniques: the local search of the 'particle swarm optimization' technique; and the competitiveness mixing of information of the 'shuffled complex evolution' technique. Proposed Improved Shuffled Frog-Leaping (ISFL) algorithm has been tested in standard IEEE 30,57,118 & Practical 191 Utility (Indian) System bus test systems and simulation results show clearly about the better performance of the proposed algorithm in reducing the real power loss & control variables within the limits.

2. Objective Function

Active Power Loss

Main objective of the reactive power dispatch problem is to minimize the active power loss and mathematically written by,

$$F = P_L = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}\right) \tag{1}$$

Where F- objective function, P_L – power loss, g_k - conductance of branch, Vi and V_j are voltages at buses i,j, Nbr- total number of transmission lines in power systems.

Voltage Profile Improvement

Objective function (F) has be rewritten to minimize the voltage deviation in PQ buses as follows,

$$F = P_L + \omega_v \times VD \tag{2}$$

Where VD - voltage deviation, ω_v- is a weighting factor of voltage deviation.

And the Voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \tag{3}$$

Where Npq- number of load buses

Equality Constraint

the power balance equation with respect to the equality constraint of the problem is written as follows:

$$P_G = P_D + P_L \tag{4}$$

Where P_G- total power generation, P_D - total power demand.

Inequality Constraints

The inequality constraint with upper and lower bounds on the active power of slack bus (P_g), and reactive power of generators (Q_g) are written as follows:

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \tag{5}$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}, i \in N_g \quad (6)$$

Upper and lower bounds on the bus voltage magnitudes (V_i) is given by:

$$V_i^{min} \leq V_i \leq V_i^{max}, i \in N \quad (7)$$

Upper and lower bounds on the transformers tap ratios (T_i) is given by:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in N_T \quad (8)$$

Upper and lower bounds on the compensators (Q_c) is given by:

$$Q_c^{min} \leq Q_c \leq Q_C^{max}, i \in N_C \quad (9)$$

Where N is the total number of buses, Ng is the total number of generators, N_T is the total number of Transformers, N_c is the total number of shunt reactive compensators.

3. Shuffled Frog-Leaping Algorithm

The shuffled frog-leaping algorithm (SFL) is a memetic metaheuristic that is designed to seek a global optimal solution by performing a heuristic search. It is based on the evolution of memes carried by individuals and a global exchange of information among the population. In essence, it combines the benefits of the local search tool of the particle swarm optimization and the idea of mixing information from parallel local searches to move toward a global solution. The SFL algorithm has been tested on several combinatorial problems and found to be efficient in finding global solutions. The SFL algorithm involves a population of possible solutions defined by a set of frogs (i.e. solutions) that is partitioned into subsets referred to as memeplexes. The different memeplexes are considered as different cultures of frogs, each performing a local search. Within each memeplex, the individual frogs hold ideas, that can be influenced by the ideas of other frogs, and evolve through a process of memetic evolution. After a number of memetic evolution steps, ideas are passed among memeplexes in a shuffling process. The local search and the shuffling processes continue until convergence criteria are satisfied.

First, an initial population of ‘P’ frogs is created randomly. For S-dimensional problems, each frog i is represented by S variables as Xi=(xi1, xi2, ... , xiS). The frogs are sorted in a descending order according to their fitness. Then, the entire population is divided into m memeplexes, each containing n frogs (i.e. P=m6n). In this process, the first frog goes to the first memeplex, the second frog goes to the second memeplex, frog m goes to the mth memeplex, and frog m+1 goes to the first memeplex, and so on. Within each memeplex (figure 1b), the frogs with the best and the worst fitness are identified as Xb and Xw, respectively. Also, the frog with the global best fitness is identified as Xg. Then, an evolution process is applied to improve only the frog with the worst fitness (i.e. not all frogs) in each cycle. Accordingly, the position of the frog with the worst fitness is adjusted as follows:

$$change\ in\ frog\ position\ (D_i) = rand\ ( ).(X_b - X_w) \quad (10)$$

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$$new\ position\ X_w = current\ position\ X_w + D_i\ ;\ (D_{max} \geq D_i \geq -D_{max}) \quad (11)$$

Where rand () is a random number between 0 and 1; and Dmax is the maximum allowed change in a frog's position. If this process produces a better frog (solution), it replaces the worst frog. Otherwise, the calculations in equations (10) and (11) are repeated with respect to the global best frog (i.e. Xg replaces Xb). If no improvement becomes possible in this latter case, then a new solution is randomly generated to replace the worst frog with another frog having any arbitrary fitness. The calculations then continue for a specific number of evolutionary iterations within each memeplex. The main parameters of the SFL algorithm are: number of frogs P, number of memeplexes, and number of evolutionary iterations for each memeplex before shuffling.

Begin;
Generate random population of P solutions (individuals);
For each individual i E P: calculate fitness (i);
Sort the whole population P in descending order of their fitness;
Divide the population P into m memeplexes;
For each memeplex;
Determine the best and worst individuals;
Improve the worst individual position using Equations- (10) & (11);
Repeat for a specific number of iterations;
End;
Combine the evolved memeplexes;
Sort the population P in descending order of their fitness;
Check if termination=true;
End;

4. Improved Shuffled Frog-Leaping (ISFL) Algorithm

In the SFL algorithm, each memeplex is allowed to evolve independently to locally search at different regions of the solution space. In addition, shuffling all the memeplexes and re-dividing them again into a new set of memeplexes results in a global search through changing the information between memeplexes. As such, the SFL algorithm attempts to balance between a wide search of the solution space and a deep search of promising locations that are close to a local optimum.

As expressed by equation (10), each individual frog (solution) in a memeplex is trying to change its position towards the best frog within the memeplex or the overall best frog. As shown in this equation, when the difference in position between the worst frog Xw (i.e. the frog under evolution) and the best frogs (Xb or Xg) becomes small, the change in frog Xw's position will be very small, and thus it might stagnate at a local optimum and lead to premature convergence. To overcome such an occurrence, this Improved Shuffled Frog-Leaping (ISFL) algorithm proposes that the right-hand side of equation (10) be multiplied by a factor C called the 'search – acceleration factor', as follows:

$$change\ in\ frog\ position\ (D_i) = rand\ ().C.(X_b - X_w) \quad (12)$$

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Assigning a large value to the factor C at the beginning of the evolution process will accelerate the global search by allowing for a bigger change in the frog's position and accordingly will widen the global search area. Then, as the evolution process continues and a promising location is identified, the search – acceleration factor, C, will focus the process on a deeper local search as it will allow the frogs to change its positions. The search – acceleration factor, which can be a positive constant value, linear, or nonlinear function of time, provides the means to balance between global and local search.

Start
Determine Population size (p), Number of memeplexes (m) Iterations within each memeplex
Generate population (p) randomly
Evaluate the fitness of (p)
Sort (p) in descending order
Partition p into m memeplexes
Shuffle the memeplexes
Is Convergence criteria satisfied?
If yes determine the best solution
If no go back to step e
End

In order to intensify the search, the algorithm has been modified as follows,
When m=m+1, it=it+1 then determine
x_b, x_w , x_g.
Apply equations (10,11)
Is new frog is better than worst?
If no- apply equations (10, 11) with replacing x_b by x_g.
If yes -go to step 5.
Is new frog better than worst?
If no generate new frog randomly.
If yes go to step 5.
Replace worst frog
End
Else go back to determine m and it again
Where m = no of memeplexes
It = no of iterations

5. Simulation Results

In standard IEEE 30-bus, 41 branch system validity of proposed Improved Shuffled Frog-Leaping (ISFL) algorithm has been verified and the system has 6 generator-bus voltage magnitudes, 4 transformer-tap settings, and 2 bus shunt reactive compensators. 2, 5, 8, 11 and 13 are considered as PV generator buses, Bus 1 is taken as slack bus and others are PQ load buses. Primary variables limits are given in Table 1.

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Table 1: Primary Variable Limits (Pu)

List of Variables	Minimum	Maximum	group
Generator Bus	0.95	1.1	Continuous
Load Bus	0.95	1.05	Continuous
Transformer-Tap	0.9	1.1	Discrete
Shunt Reactive Compensator	-0.11	0.31	Discrete

In Table 2 the power limits of generators buses are listed.

Table 2: Generators Power Limits

Bus	Pg	Pgminimum	Pgmaximum	Qgminimum	Qmaximum
1	96.00	49	200	0	10
2	79.00	18	79	-40	50
5	49.00	14	49	-40	40
8	21.00	11	31	-10	40
11	21.00	11	28	-6	24
13	21.00	11	39	-6	24

Table 3 shows the proposed Improved Shuffled Frog-Leaping (ISFL) algorithm successfully kept the control variables within limits.Table 4 narrates about the performance of the proposed Improved Shuffled Frog-Leaping (ISFL) algorithm. Table 5 list out the overall comparison of the results of optimal solution obtained by various methods.

Table 3: After optimization values of control variables

List of Control Variables	ISFL
V1	1.0379
V2	1.0286
V5	1.0198
V8	1.0232
V11	1.0542
V13	1.0346
T4,12	0.00
T6,9	0.00
T6,10	0.90
T28,27	0.90
Q10	0.10
Q24	0.10
Real power loss	4.2586
Voltage deviation	0.9098

Table 4: Performance of ISFL algorithm

Iterations	34
Time taken (secs)	10.92
Real power loss	4.2586

Table 5: Comparison of results

List of Techniques	**Real power loss (MW)**
SGA (Wu et al., 1998) [16]	4.98
PSO (Zhao et al., 2005) [17]	4.9262
LP (Mahadevan et al., 2010) [18]	5.988
EP (Mahadevan et al., 2010) [18]	4.963
CGA (Mahadevan et al., 2010) [18]	4.980
AGA (Mahadevan et al., 2010) [18]	4.926
CLPSO (Mahadevan et al., 2010) [18]	4.7208
HSA (Khazali et al., 2011) [19]	4.7624
BB-BC (Sakthivel et al., 2013) [20]	4.690
MCS (Tejaswini sharma et al.,2016) [21]	4.87231
Proposed ISFL	4.2586

At that Improved Shuffled Frog-Leaping (ISFL) algorithm has been tested in standard IEEE-57 bus power system. The reactive power compensation buses are 18, 25 and 53. Bus 2, 3, 6, 8, 9 and 12 are PV buses and bus 1 is selected as slack-bus. The system variable limits are given in Table 6.

The preliminary conditions for the IEEE-57 bus power system are given as follows:
Pload = 12.108 p.u. Qload = 3.012 p.u.
The total initial generations and power losses are obtained as follows:
$\sum P_G = 12.148$ p.u. $\sum Q_G = 3.3123$ p.u.
Ploss = 0.25832 p.u. Qloss = -1.2041 p.u.
Table 7 shows the various system control variables i.e. generator bus voltages, shunt capacitances and transformer tap settings obtained after optimization which are within the acceptable limits. In Table 8, shows the comparison of optimum results obtained from proposed methods with other optimization techniques. These results indicate the robustness of proposed approaches for providing better optimal solution in case of IEEE-57 bus system.

Table 6: Variable Limits

Reactive Power Generation Limits							
Bus no	1	2	3	6	8	9	12
Qgmin	-1.4	-.015	-.02	-0.04	-1.3	-0.03	-0.4
Qgmax	1	0.3	0.4	0.21	1	0.04	1.50
Voltage And Tap Setting Limits							
vgmin	Vgmax	vpqmin	Vpqmax	tkmin	tkmax		
0.9	1.0	0.91	1.05	0.9	1.0		
Shunt Capacitor Limits							
Bus no	18	25	53				
Qcmin	0	0	0				
Qcmax	10	5.2	6.1				

Table 7: Control variables obtained after optimization

Control Variables	ISFL
V1	1.10
V2	1.022
V3	1.028
V6	1.020
V8	1.021
V9	1.000
V12	1.000
Qc18	0.0600
Qc25	0.200
Qc53	0.0401
T4-18	1.000
T21-20	1.023
T24-25	0.802
T24-26	0.801
T7-29	1.002
T34-32	0.804
T11-41	1.010
T15-45	1.029
T14-46	0.910
T10-51	1.020
T13-49	1.060
T11-43	0.910
T40-56	0.900
T39-57	0.950
T9-55	0.950

Table 8: Comparison results

S.No.	Optimization Algorithm	Finest Solution	Poorest Solution	Normal Solution
1	NLP [22]	0.25902	0.30854	0.27858
2	CGA [22]	0.25244	0.27507	0.26293
3	AGA [22]	0.24564	0.26671	0.25127
4	PSO-w [22]	0.24270	0.26152	0.24725
5	PSO-cf [22]	0.24280	0.26032	0.24698
6	CLPSO [22]	0.24515	0.24780	0.24673
7	SPSO-07 [22]	0.24430	0.25457	0.24752
8	L-DE [22]	0.27812	0.41909	0.33177
9	L-SACP-DE [22]	0.27915	0.36978	0.31032
10	L-SaDE [22]	0.24267	0.24391	0.24311
11	SOA [22]	0.24265	0.24280	0.24270
12	LM [23]	0.2484	0.2922	0.2641
13	MBEP1 [23]	0.2474	0.2848	0.2643

14	MBEP2 [23]	0.2482	0.283	0.2592
15	BES100 [23]	0.2438	0.263	0.2541
16	BES200 [23]	0.3417	0.2486	0.2443
17	Proposed ISFL	0.22052	0.23048	0.22234

Then Improved Shuffled Frog-Leaping (ISFL) algorithm has been tested in standard IEEE 118-bus test system [24]. The system has 54 generator buses, 64 load buses, 186 branches and 9 of them are with the tap setting transformers. The limits of voltage on generator buses are 0.95 -1.1 per-unit., and on load buses are 0.95 -1.05 per-unit. The limit of transformer rate is 0.9 -1.1, with the changes step of 0.025. The limitations of reactive power source are listed in Table 9, with the change in step of 0.01.

Table 9: Limitation of reactive power sources

BUS	5	34	37	44	45	46	48
QCMAX	0	14	0	10	10	10	15
QCMIN	-40	0	-25	0	0	0	0
BUS	74	79	82	83	105	107	110
QCMAX	12	20	20	10	20	6	6
QCMIN	0	0	0	0	0	0	0

The statistical comparison results have been listed in Table 10 and the results clearly show the better performance of proposed Improved Shuffled Frog-Leaping (ISFL) algorithm in reducing the real power loss.

Table 10: Comparison results

Active power loss (MW)	**BBO [25]**	**ILSBBO/ strategy1 [25]**	**ILSBBO/ strategy1 [25]**	**Proposed ISFL**
Min	128.77	126.98	124.78	110.28
Max	132.64	137.34	132.39	116.34
Average	130.21	130.37	129.22	112.62

Finally Improved Shuffled Frog-Leaping (ISFL) algorithm has been tested in practical 191 test system and the following results have been obtained. In Practical 191 test bus system – Number of Generators = 20, Number of lines = 200, Number of buses = 191 Number of transmission lines = 55. Table 16 shows the optimal control values of practical 191 test system obtained by ISFL. And table 17 shows the results about the value of the real power loss by obtained by proposed Algorithm.

Table 11: Optimal Control Values of Practical 191 Utility (Indian) System by ISFL

VG1	1.1000		VG 11	0.9000
VG 2	0.7600		VG 12	1.0000
VG 3	1.0100		VG 13	1.0000
VG 4	1.0100		VG 14	0.9000
VG 5	1.1000		VG 15	1.0000
VG 6	1.1000		VG 16	1.0000

VG 7	1.1000		VG 17	0.9000
VG 8	1.0100		VG 18	1.0000
VG 9	1.1000		VG 19	1.1000
VG 10	1.0100		VG 20	1.1000

T1	1.0000		T21	0.9000		T41	0.9000
T2	1.0000		T22	0.9000		T42	0.9000
T3	1.0000		T23	0.9000		T43	0.9100
T4	1.1000		T24	0.9000		T44	0.9100
T5	1.0000		T25	0.9000		T45	0.9100
T6	1.0000		T26	1.0000		T46	0.9000
T7	1.0000		T27	0.9000		T47	0.9100
T8	1.0100		T28	0.9000		T48	1.0000
T9	1.0000		T29	1.0100		T49	0.9000
T10	1.0000		T30	0.9000		T50	0.9000
T11	0.9000		T31	0.9000		T51	0.9000
T12	1.0000		T32	0.9000		T52	0.9000
T13	1.0100		T33	1.0100		T53	1.0000
T14	1.0100		T34	0.9000		T54	0.9000
T15	1.0100		T35	0.9000		T55	0.9000

Table 17: Optimum Real Power Loss Values Obtained For Practical 191 Utility (Indian) System by ISFL.

Real power Loss (MW)	**ISFL**
Min	146.4140
Max	149.4651
Average	147.0040

6. Conclusion

In this paper Improved Shuffled Frog-Leaping (ISFL) algorithm successfully solved the optimal reactive power problem. The shuffled frog-leaping algorithm draws its formulation from two other search techniques: the local search of the ‘particle swarm optimization’ technique; and the competitiveness mixing of information of the ‘shuffled complex evolution’ technique. Proposed Improved Shuffled Frog-Leaping (ISFL) algorithm has been tested in standard IEEE 30,57,118 & Practical 191 Utility (Indian) System bus test systems and simulation results show clearly about the better performance of the proposed algorithm in reducing the real power loss & control variables within the limits.

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(Received: September 24, 2018 - Accepted: October 27, 2018) DOI: 10.5281/zenodo.1476667

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