Squirrel Search Algorithm for Solving Optimal Reactive Power Dispatch Problem with FACTS Device

M. Balasubbareddy, Divyanshi Dwivedi

Abstract: ***In this paper, a novel algorithm which is being inspired by the natural foraging phenomenon of squirrel, called as Squirrel SSA for solving optimal reactive power dispatch (ORPD) problem of power system, in which FACTS device namely, UPFC is incorporated. Power Injection Modeling (PIM) and Current Injection Modeling (CIM) of UPFC are considered, both are compared for determining the best modeling technique of UPFC which can be incorporated in power system. The performance and possibility of the proposed algorithm are validated on IEEE 30-bus power system. Results obtained are compared with the other recent algorithms to show the superiority of SSA.***

Keywords **:** ***Squirrel Search Algorithm (SSA), ORPD problem, UPFC, generation fuel cost, transmission line losses.***

I. INTRODUCTION

In the recent years, power system's development, mainly transmission network has been increased because of higher requirement in industries and deregulation. Thus, new ways to maximize the power transfer and effectively using existing transmission network has become an important aspect which is to be considered with balancing the acceptable levels of the stability. One of the ways is to incorporate the latest emerging power electronics devices i.e., FACTS (flexible AC Transmission system) controllers including TCSC, SSSC and UPFC which can vary the system parameters effectively, the detailed explanation regarding these devices are referred from [1].

On the other hand, solution of OPRD problem lead to improvise the planning and operation in the power system. Usually, OPRD is considered as a complex, nonlinear problem that can minimize the general objectives including generation fuel cost and transmission line losses. This can be achieved by identifying optimal values of control parameters which includes generator's voltage, tap-changing transformers, and shunt capacitors. Whenever power system is operating, the changes in demand exhibit to vary the generation of reactive power and then load voltages also suffer fluctuations. The voltages may be adjusted by suitable reactive power controlling devices. For solving the OPRD problems, a number of classical and metaheuristics optimization techniques have been developed by researchers in past decades. Classical techniques include gradient methods, linear programming, nonlinear programming, quadratic programming, interior point and Newton formulation [2-5], but these techniques cannot be used to solve problem of large-scale power systems and sometimes it led the solution to be stuck in local minima. On the other hand, the metaheuristic optimization techniques such as genetic algorithm [6], GSA [7], simulated annealing (SA) [8], grey wolf optimizer [9], PSO [10], ABC algorithm [11] and many more algorithms had been developed which are considered as intelligent algorithms which help to overcome the problem faced in classical approaches.

Similarly in this paper, a novel squirrel search algorithm [12] is used for solving OPRD problems with incorporation of FACTS device i.e. UPFC. This paper deals to identify the most suitable way of modeling UPFC among PIM and CIM [13]-[14] of UPFC and furthermore optimal values for considered objectives is compared with existing algorithms for IEEE 30-bus standard test system.

II. STEADY STATE MODEL OF UPFC

A. Power Injection Modeling of UPFC

PI model of UPFC is referred from [13] is shown in Fig. 1. This modeling helps to understand the effect of the UPFC on the system in the steady state condition. Furthermore, it can be incorporated in the power flow model easily. The modeling of UPFC is expressed as

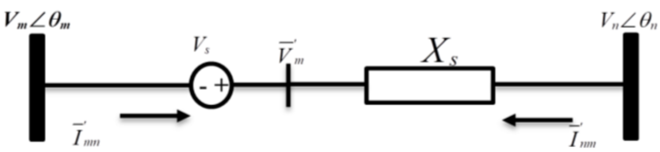

Fig. 1. Representation of VSC of UPFC

where, $\overline{V}'_m = V_s + V_m$ and $V_s = rV_m e^{j\gamma}$, directs the limits for the operation of UPFC which are: $0 \le r \le r_{max}$ and $0 \le \gamma \le 2\pi$. Final elements of equivalent power injections are:

$$P_m^{UPFC} = rB_sV_m^2 \sin\gamma - rB_sV_mV_n \sin(\delta_{mn} + \gamma) \quad (1)$$

$$Q_m^{UPFC} = rB_sV_m^2 \cos\gamma \quad (2)$$

$$P_n^{UPFC} = -rB_sV_mV_n \sin(\delta_{mn} + \gamma) \quad (3)$$

$$Q_n^{UPFC} = rB_sV_mV_n \cos(\delta_{mn} + \gamma) \quad (4)$$

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B. Current Injection modeling of UPFC

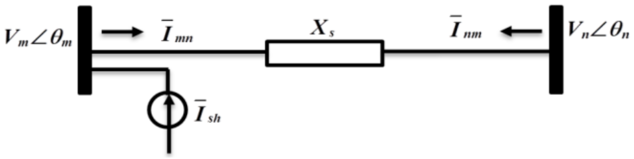

Fig. 2. CI model of UPFC

The current injection model of UPFC is shown in Fig. 2 referred from [14]. Final elements of equivalent power injections are:

$$P_m^{UPFC} = -B_s V_m V_n \sin\theta_{mn} - rB_s V_m V_n \sin(\theta_{mn}+\gamma) \quad (5)$$

$$Q_m^{UPFC} = -B_s r V_m^2 \cos\gamma - B_s V_m V_n \cos\theta_{mn} - V_m^2 B_s \quad (6)$$

$$P_n^{UPFC} = B_s V_m V_n \sin\theta_{mn} + rB_s V_m V_n \sin(\theta_{mn}+\gamma) \quad (7)$$

$$Q_n^{UPFC} = -B_s r V_m V_n \cos(\theta_{mn}+\gamma) - B_s V_m V_n \cos\theta_{mn} + V_n^2 B_s \quad (8)$$

III. PROBLEM FORMULATION

The objective functions can be expressed

Min $F_l(x,y)$ $\qquad \forall l = 1,2,.......N$

Subject to: $\quad g(x,y)=0,$

$\qquad h(x,y)\le 0$

A. Objective Functions

i). Minimization of total real power loss
It can be expressed as

$$F_1 = \min(TP_{LOSS}) = \sum_{m=1}^{N_{line}} P_{LOSS,m} MW \quad (9)$$

ii). Minimization of Generation Cost
It can be expressed as

$$F_2 = \min(F_m(P_{G_m})) = \sum_{m=1}^{N_G} a_m P_{G_m}^2 + b_m P_{G_m} + c_m \$/hr \quad (10)$$

B. Constraints

i) Equality Constraints:

$$\sum_{m=1}^{N_G} P_{G_m} - P_D - P_L = 0; \sum_{m=1}^{N_G} Q_{G_m} - Q_D - Q_L = 0; \quad (11)$$

where, P_D, Q_D are the total active and reactive power demands.

ii) In equality Constraints

- Generator

  $V_{G_m}^{\min} \le V_{G_m} \le V_{G_m}^{\max}$

  $Q_{G_m}^{\min} \le Q_{G_m} \le Q_{G_m}^{\max}$, $\qquad \forall m \in N_G$

- Voltage and transformer tap settings

  $V_m^{\min} \le V_m \le V_m^{\max}$, $\qquad$ m=1,2,… N_B ;

  $T_m^{\min} \le T_m \le T_m^{\max}$, $\qquad$ m=1,2,… N_T

- Power generation limits

  $P_{G_m}^{\min} \le P_{G_m} \le P_{G_m}^{\max}$, $\qquad \forall m \in N_G$

- Reactive power

  $Q_{C_m}^{\min} \le Q_{C_m} \le Q_{C_m}^{\max}$, $\qquad$ m=1, 2, …. N_C

- Line loadings

  $S_{l_m} \le S_{l_m}^{\max}$, $\qquad$ m=1,2,… N_{line}

iii).UPFC constraints

$0 \le r \le 0.1$; $0 \le \gamma \le 360^\circ$; $0 \le X_s \le 0.1$

IV. SQUIRREL SEARCH ALGORITHM

SSA is based on the dynamic foraging technique and gliding locomotive mechanism of flying squirrels. Basically squirrel used to have two types of nuts; one is hickory nuts which are rarely available and can be stored for longer duration and second is acron nuts which are available in abundance but can be consumed at same instance.

Squirrels are considered to active during summer so they rigorously searches for the food, and after finding acron nuts they consume them immediately and fulfill their daily needs then they start searching for hickory nuts so that they can store them for winters and can increase their lifespan. Squirrel with hickory nut is shown in Fig. 3.

Fig. 3. Squirrel with hickory nut

Here in this algorithm, we considered s number of squirrels locating at s number of trees and among which only one is hickory nut tree, three is acron tree and remaining are the general trees. So squirrels on general tree tries to reach at acron trees or at hickory nut tree and squirrels on acron trees tries to move towards the hickory nut tree.

A. Steps to implement Squirrel Search Algorithm (SSA)

1. Initialize the parameters of SSA i.e., number of squirrels, dimension and maximum number of iterations.

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2. Initially generates the random location for the **s** squirrels by following equation:

$$S_i = S_l + U(0,1) \times (S_u - S_l)$$

where, S_l and S_u are lower and upper bounds respectively of i[th] squirrel in j[th] dimension and U(0,1) random number in the range of [0,1].

3. Calculate the fitness for each location of flying squirrels and then sort them in accordance to its fitness values.

4. Fittest value will be of that flying squirrel, located at hickory nut tree, then next three fit values will be of flying squirrel which is on acron trees and then remaining will be on normal trees.

5. Select any of the flying squirrel located at normal trees and target them to directs toward hickory nut tree and remaining to the acron trees.

***while* (threshold value not achieved)**

6. for i=1 to n1(n1=number of squirrels present on acorn trees and directed towards hickory nut tree)

if $R1 \geq 0.1$

else

S_{at}^{t+1} =Random position will be allocated

end

7. for i=1 to n2

if $R2 \geq 0.1$

$$S_{nt}^{t+1} = S_{nt}^{t} + R_2 \times (S_{at}^{t} - S_{nt}^{t})$$

else

S_{nt}^{t+1} =Random position will be allocated

end

8. for i=1 to n3

if $R3 \geq 0.1$

$$S_{nt}^{t+1} = S_{nt}^{t} + R_3 \times (S_{ht}^{t} - S_{nt}^{t})$$

else

S_{nt}^{t+1} =Random position will be allocated

end

9. Calculate the seasonal constant by using following equation:

$$S_c^t = \sqrt{\sum_{k=1}^{d} (S_{at,k}^{t} - S_{ht,k}^{t})^2}$$

10. Verify the seasonal monitoring condition i.e. $S_c^t < S_{min}$, if it found valid then find levy flight operator using equation:

$$Levy(x) = 0.01 \times \frac{r_1}{|r_2|^{1/\alpha}} \times \gamma,$$

Where, r_1 and r_2 are random numbers in the range of (0,1) and

$$\gamma = \left(\frac{\Gamma(1+\alpha) \times \sin(0.5\pi\alpha)}{\Gamma(\frac{1+\alpha}{2}) \times \alpha \times 2^{0.5(\alpha-1)}} \right)^{\frac{1}{\alpha}},$$

where, α is a constant having value equal to 1.5. Then, randomly relocate the flying squirrel by following equation:

$$S_{nt}^{new} = S_l + Levy(n) \times (S_u - S_l)$$

11. Minimum value of seasonal constant, S_{min} can be computed as:

$$S_{min} = \frac{10e^{-06}}{(365)^{t/(t_m/2.5)}},$$. Go to step 6.

end

12. The squirrel present on hickory nut tree will be considered as optimal value of objective.

end

V. RESULTS AND ANALYSIS

The proposed SSA has been verified on IEEE-30 bus system by solving the OPF problems. The details are given in[15].

A. Single Objective Optimization

Hereby, single objectives functions are considered for solving OPRD. Initially, the generation fuel cost is being considered and solved to obtain an optimal value, thus it validates the proposed SSA method and then the results are being compared with other existing algorithms. The optimal values of control variables for generation fuel cost are shown in Table 1 and we can say that we can say that the generation fuel cost is minimized to a better value by implementation of SSA in comparison to other existing algorithms. In Fig. 4, convergence characteristics is shown in comparison with other existing algorithms and it is clearly analyzed that the proposed method initiates with better function value and converges in lesser number of iterations.

Table- I: Solution for generation fuel cost minimization

Variables	PSO [16]	HSCA [16]	SSA
PG1, MW	178.556	176.87	173.4146
PG2, MW	48.6032	49.8862	48.78894
PG5, MW	21.6697	21.6135	20.9484
PG8, MW	20.7414	20.8796	24.0219
PG11, MW	11.7702	11.6168	12.92311
PG13, MW	12	12	12.37984
V1, p.u.	1.1	1.057	1.1
V2, p.u.	0.9	1.0456	0.983134
V5, p.u.	0.9642	1.0184	1.028617
V8, p.u.	0.9887	1.0265	1.032742
V11, p.u.	0.9403	1.057	0.912917
V13, p.u.	0.9284	1.057	1.074455
T 6-9, p.u.	0.9848	1.0254	0.972776
T 6-10, p.u.	1.0299	0.9726	1.024313
T 4-12, p.u.	0.9794	1.006	1.072996
Tap 28-27, p.u.	1.0406	0.9644	1.028331
Qc 10, p.u.	9.0931	25.3591	19.7065
Qc 24, p.u.	21.665	10.6424	7.346241
Generation fuel cost $/h	**803.454**	**802.034**	**801.8134**

Furthermore, the generation fuel cost and transmission line losses are considerd with PIM and CIM of UPFC. Significantly, UPFC is placed between buses 10-17. The results obtained for both the objectives in Table 2. It can be observed that without any FACTS device generation fuel cost obtained is 801.8134$/h which is further minimized by using UPFC but it can also be seen that generation fuel cost obtained with CIM of UPFC is 799.8826$/h while with PIM of UPFC is 800.736$/h, thus we can say that CIM is best technique for modeling UPFC. Similarly, transmission line losses obtained with CIM of UPFC is 3.103MW which is better value obtained in comparison to the PIM of GIPFC.

Table- II: Single objective OPF results of generation fuel cost and transmission line losses with PIM and CIM of UPFC

	Generation fuel cost, $/h			Transmission line losses, MW		
Variables	***Without FACTS devices***	***PIM of UPFC***	***CIM of UPFC***	***Without FACTS devices***	***PIM of UPFC***	**CIM of UPFC**
PG1, MW	173.4146	177.817	177.7548	64.926	60.81635	51.50466
PG2, MW	48.78894	49.6322	48.82273	67.781	80	80
PG5, MW	20.9484	20.7973	21.488	50	50	50
PG8, MW	24.0219	19.8118	21.01923	35	33.50448	35
PG11, MW	12.92311	12.2234	11.21453	30	30	30
PG13, MW	12.37984	12.2959	12	40	32.77332	40
V1, p.u.	1.1	1.1	1.1	1.0998	1.082045	1.1
V2, p.u.	0.983134	1.0868	1.043946	1.02653	1.026591	1.03651
V5, p.u.	1.028617	1.0658	1.06612	1.06537	1.055954	1.081808
V8, p.u.	1.032742	1.07204	1.071553	1.07114	1.056863	1.077256
V11, p.u.	0.912917	1.08935	1.1	1.0289	0.968815	1.01721
V13, p.u.	1.074455	0.99026	1.1	1.02694	1.026339	1.099327
T 6-9, p.u.	0.972776	0.93913	1.00552	1.1	1.004835	0.964174
T 6-10, p.u.	1.024313	1.078	1.005329	1.08777	0.972508	0.989744
T 4-12, p.u.	1.072996	0.94419	1.025489	1.1	0.999987	0.941364
T 28-27, p.u.	1.028331	0.97005	0.982578	1.0721	0.945153	0.962597
Qc 10, p.u.	19.7065	8.03898	12.92405	25	6.031126	23.32114
Qc 24, p.u.	7.346241	28.0015	12.00949	21.985	16.02577	10.38963
r	NA	0.08629	0.034822	NA	0.0344954	0.02387
γ	NA	96.5632	109.541	NA	170.5344	181.3545
X_s	NA	0.04563	0.00546	NA	0.08932	0.04212
Generation fuel cost $/h	**801.8134**	**800.736**	**799.8826**	**899.664**	**895.3662**	**890.455**

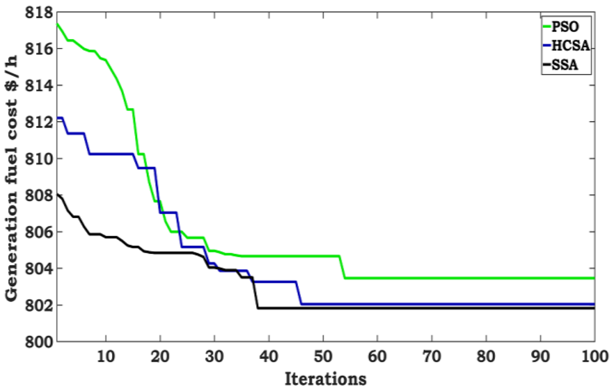

Fig. 4. Convergence curve of generation fuel cost

VI. CONCLUSION

In this research work, a novel squirrel search algorithm (SSA) was effectively used to solve the OPRD problem for IEEE-30 bus system satisfying equality and in-equality constraints. Cost of generation and transmission line losses are minimized more optimally as compared to other existing algorithms. The result analyzed proves that the proposed method yields to good convergence curve in comparison to other existing methods. Furthermore, incorporation of UPFC in power system results the better solution for the objectives in comparison with the system with FACTS controller. It is also being observed that among both the considered modeling technique, CIM of UPFC is more reliable as compared to PIM of UPFC.

Hence, we can say that solution of OPRD using SSA with incorporation of CIM of UPFC is a better alternative and more feasible method.

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