Optimized placement of multiple FACTS devices using PSO and CSA algorithms

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ABSTRACT

This paper is an attempt to develop a multi-facts device placementin deregulated power system using optimization algorithms. The deregulated power system is the recent need in the power distribution as it has many independent sellers and buyers of electricity. The problem of deregulation is the quality of the power distribution as many sellers are involved. The placement of FACTS devices provides the solution for the above problem. There are researches available for multiple FACTS devices. The optimization algorithms like Particle Swarm Optimization (PSO) and Cuckoo Search Algorithm (CSA) are implemented to place the multiple FACTS devices in a power system. MATLAB based implementation is carried out for applying Optimal Power Flow (OPF) with variation in the bus power and the line reactance parameters. The cost function is used as the objective function. The cost reduction of FACTS as well as generation by placement of different compensators like, Static Var Compensator (SVC), Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC). The cost calculation is done on the 3-seller scenario. The IEEE 14 bus is taken here as 3-seller system.

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1. INTRODUCTION

The world's electric power is heavily interconnected for economic reason. And when the power transfer increases the connection grows due to that security problems takes place. The security of the system is affected when the large power transfer is done through the transmission line without considering its limits. The deregulation of power system is one of the important methods in power system to reduce these problems. But deregulation leads to power quality problems. For improving power transfer, FACTS devices do very important role [1]. Series capacitors which is variable, unified power flow controllers (UPFC) and phase shifters can be utilized [2]. FACTS devices provide better control in steady state and in dynamic state [3, 4]. The cost-effective devices are series capacitors which is variable and helps in minimizing losses [5, 6]. The FACTS devices are costly according to the size of it. If the size is less the cost would reduce. So, the optimal location and sizing becomes important [7-9].

There are researches articles available on optimal location based on sensitivity analysis [10], solving economic load dispatch [11], congestion management using FACTs devices [12-14], real power performance index [15], in [16] open power market analysis, electric system energy [17], the automatic contingency selection [18], Electric energy systems analysis and operation [19], Investigation of the load low problem [20] and reducing the losses when congestion is not present [21-24]. The paper [25, 26] shows the economic dispatch solution method for deregulated environment. The solution techniques shown in [27, 28] are used here for multi-facts device placement. This paper is done for minimizing the total cost of the generation and FACTS devices (like SVC, TCSC & UPFC). The optimal location and size are identified. Section 2 consists Problem Formulation for optimal location of multiple FACTS are described. Section 3 consist of Problem solution methods; Section 4 consists of simulation results. Finally, a conclusion about the results of simulation is deduced in Section 5.

2. PROBLEM FORMULATION

The generation cost and the cost of FACTS devices are the major economic sources. Here in the optimal power flow the cost of generation minimization and the FACTs device placement with minimum possible or optimal cost has to be identified. Bidding cost is considered as the thermal system cost curve so the bidding cost can be represented as [25],

$$F_i(P_{gi}) = a_i + b_i P_{gi} + c_i P_{gi}^2 \quad (1)$$

the incremental cost can be represented as below,

$$IC_i(P_{gi}) = b_i + 2c_i P_{gi} \quad (2)$$

deregulated power system optimal power flow equation is given below,

$$Minimize: \sum_{i=1}^{n} F_i(P_{gi}) \quad (3)$$

$$subjectedto: \sum_{P_{gi}}^{N_g} P_{gi} = P_d \quad (4)$$

$$P_{imin} < P_{gi} < P_{imax}, i \epsilon [1, N_g] \quad (5)$$

when $\sum_{i=1}^{N_g} P_{imin} > P_d or \sum_{i=1}^{N_g} P_{imax} = P_d$, -no feasible solution,
when $\sum_{i=1}^{N_g} P_{imin} = P_d$, -each seller is contracted amount is at its capacity lower limit,
when $\sum_{i=1}^{N_g} P_{imin} < P_d$ and $\sum_{i=1}^{N_g} P_{imin} > P_d$-non-trivial case.
Here,

$F_i(P_{gi}) - costofgeneratori$

$P_{gi} - PowerinMWofi^{th}generator$

$a_i, b_i, c_i - constantco - ordinate$

$P_{imin}, P_{imax} - minimumandmaximumlimitsofi^{th}generator$

$P_d - PowerdemandinMW$

$n, N_g - Numberofgenerators$

facts devices costs;

$$C_{TCSC} = 0.0015S_{TCSC}^2 - 0.713S_{TCSC} + 153.75 \quad (6)$$

$$C_{SVC} = 0.0003S_{SVC}^2 - 0.3051S_{SVC} + 127.38 \quad (7)$$

$$C_{UPFC} = 0.0003S_{UPFC}^2 - 0.2691S_{UPFC} + 188.2 \quad (8)$$

here;

$IC_{devices} - investmentcostofFACTSdevicesin$ $

$C_{TCSC} - TCSCcostperKVARinstalled$ in $

$C_{SVC} - SVCcostperKVARinstalledin$ \$

$C_{UPFC} - UPFCcostperKVARinstalledin$ \$

$S_{TCSC} - TCSCcapacityinMVAR$

$S_{SVC} - SVCcapacityinMVAR$

$S_{UPFC} - UPFCcapacityinMVAR$

Considering the above constraints entire cost function can be represented as below [6].

$$minimizeTotalCost = \sum_{i=1}^{n} F_i(P_{gi}) + IC_{device} \quad (9)$$

3. SOLUTION METHODS

For the problem shown in (9) is the objective function to solve that many techniques can be used. Here PSO algorithm which is the faster algorithm and the CSA algorithm which gives guaranteed results are considered for the solution. The algorithm explanation is given below.

3.1. Particle swarm optimization (PSO)

The algorithm is formed with the behavior of insects/fish on its behavior of food searching. Steps of algorithm described given below.

- The Nsize of the swarm, X-control variable (generated power Pg) are initialized.
- Initial population of Pg is given as within the power limit. And initial velocity of the swarm particles (Vj) is taken as zero.
- For each population calculate fuel cost (F) and find velocitieswith given formula (10).and increment the iteration.
- Eachparticle is personal best (Pbest) of its own Pgvalue. Then the X value which is responsible for the lower cost value is taken as global best (Gbest). Then velocity function is calculated using the following equation,

$$V_j(i) = V_j(i-1) + c_1 r_1 \left[P_{bestj} - X_j(i-1)\right] + c_2 r_2 \left[G_{best} - X_j(i-1)\right] \quad (10)$$

where $j = 1,2, \ldots, N$
here,

$c1, c2$ $arecognitiveandsociallearningratestaken$ 2

$r1, r2$ $areuniformydistributedrandomsinrange$ 0 and 1

- Then the X value is updated with the following equation

$$X_j(i) = X_j(i-1) + V_j(i) \quad (11)$$

- Then go to step (c), do it till the stop criteria.

3.2. Cuckoo search algorithm (CSA)

The Cuckoo search algorithm is based on the cuckoo bird on behavior of its breeding. The cuckoo bird can’t build the nest. It depends on the host bird nest for laying eggs and hatching it. But host bird nest not allows to do so. It may abandon the nest or pushes the birds’ eggs down. But cuckoo lays eggs similar to the host bird and if it hatches the cuckoo chicks mimics the sound of the host bird. So, finding the best nest to make survive the cuckoo birds makes a fine search that is represented as the mathematical equation steps are following.

- The initial population of X variable in n host nests is randomly generated.
- A cuckoo is selected by levy random distribution and evaluated the objective function for all the host nests.
- Randomly selected nest iscompared with the objective which is randomly selected and calculated. If the new cuckoo fits then replace the old cuckoo.
- Remaining nests are abandoned with the fraction of Pa and best ones are saved.

- Rank the solution; find the best cuckoo.
- Increase the iteration and go to step second step.
- Do it till termination

The proposed solution algorithm is described:

Step 1: Initialize line and bus data of the power system, contingency data, all constraints, and PSO/CSA parameters.

Step 2: Initialize population of particles with random numbers and velocities/new nest representing FACTS devices location & size.

Step 3: Set iteration index iteration = 0.

Step 4: The particle carries the location and size of FACTS devices updates the line-data at the reactance column and in bus-data power injection column. Determine the load level and output power. Conduct OPF incorporating FACTS devices, for normal and contingency states. Compute the operating cost and required devices capacities for each state.

Step 5: Calculate cost with FACTS using operating costs of all states and their associated probabilities to occur. Calculate devices investment cost using (8).

Step 6: Evaluate the value of the objective function (9) subject to all the constraints (4 & 5). If any of the constraint violation penalty is added in cost. The calculated value of the fitness function is served as a fitness value of a particle/cuckoo.

Step 7: Each particle objective is calculated with the personal best, local best. If the fitness value is lower than local best, set this value as the current local best, and save the particle position corresponding to this local best value.

Step 8: Select the minimum value of local best from all particles to be the current global best, Global best, and record the particle position corresponding to this Global best value.

Step 9: Update each particle velocity and also position.

Step 10: If the maximum number of iterations is reached, the particle/cuckoo associated with the current Global best is the optimal solution. Otherwise, set iteration = iteration + 1 and goto Step 4. And repeat till termination

4. RESULTS AND DISCUSSION

Test system is 3-seller system and two solution algorithms are used.Here the no FACTs devices results are the conventional methods. ThePSO and CSA are taken here. As shown in the results the fitness value of PSO and CSA in [28], it varies from $8340 to 8190. As it is economic load dispatch the loss consideration also based on the loss matrix. When the same 3-seller system is used in the optimal power flow the cost of the generation reduces to $ 8034.4. we use the same 3-seller system as the test system and we implement the facts devices with inclusion of investment cost.

The FACTS devices considered here are SVC, TCSC and UPFC. SVC and UPFC models are taken as reactive power model and the TCSC is taken as reactance model. The objective function discussed in (1) is taken as fitness equation with voltage limit and power flow constraints. The well-known metaheuristic algorithm called PSO and CSA algorithms are used for testing the fitness function for without facts devices. Then the (9) is used for testing with FACTS devices. ICdevices variable can be replaced with each facts device cost equation respectively. The results obtained are discuss below.

4.1. PSO algorithm

PSO algorithm as explained in the solution technology section the MATLAB code is implemeted to solve both (1) and (2). The Figure 1 shows the convergence graph of the PSO algorithm for without and with placement of SVC, TCSC and UPFC. From that it can be seen that the UPFC gives reduced cost including the cost of UPFC. Figure 2 shows the voltage profile of NO facts device condition, SVC placed, TCSC placed and UPFC placed. The performance of votlage profile is better and TCSC is not performing well, as the cost increases. Figure 3 shows the power generated at generator number 1, 2, 3, 6 and 8. It can be seen from Figure 3 that G3, G6 and G8 has significant reduction in generated total power when the FACTS devices are placed. Table 1 shows the generated power in IEEE-14 bus system. Table 2 shows the location, size, cost and loss of the 3-seller system with PSO algorithm. It can be seen from [28] the cost from $ 8100 (approx.) to $ 7910.4 when using UPFC including the investment cost of UPFC.

4.2. CSA algorithm

Figures 4-6 shows the results taken from CSA for FACTS device placement and Tables 3 and 4 shows the numerical results. Using CSA cost is still reduced to $ 7907.5 with UPFC.

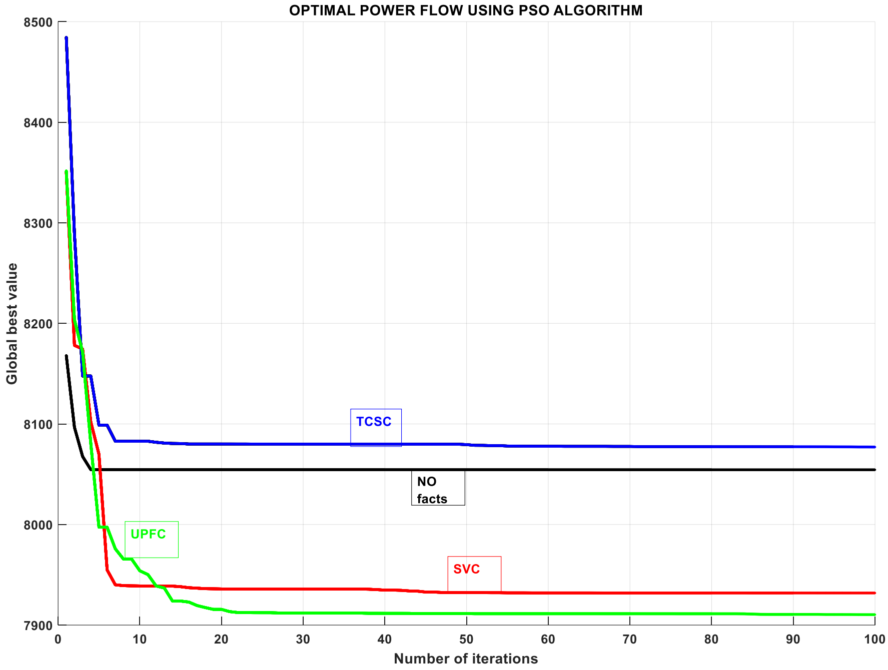

Figure 1. Convergence graph of PSO algorithm with and without SVC, TCSC and UPFC

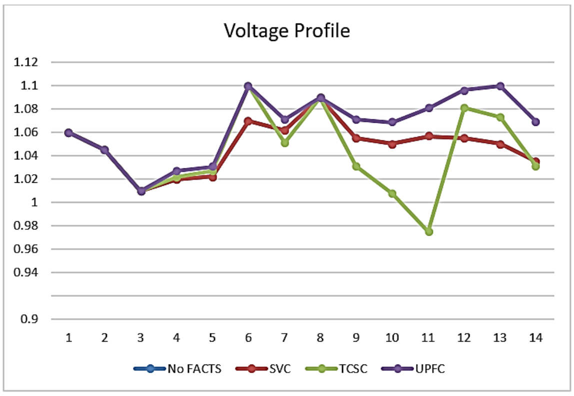

Figure 2. Voltage profile with and without SVC, TCSC and UPFC

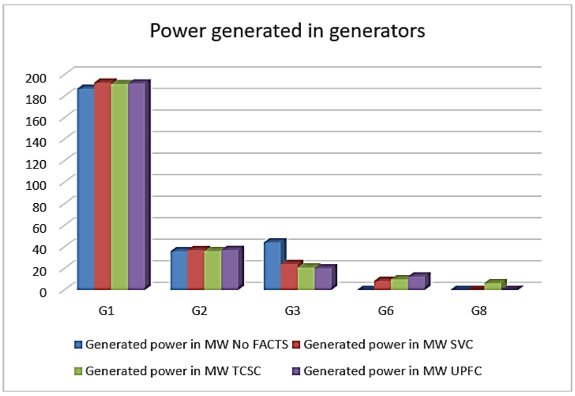

Figure 3. Generated power with and without SVC, TCSC and UPFC

Table 1. Generated power in MW

Gen. nos	Generated power in MW			
	No FACTS	SVC	TCSC	UPFC
G1	186.75149	192.454	191.048	191.687
G2	35.820405	36.9311	36.112	37.0097
G3	44.052839	23.9131	20.7523	19.8806
G6	0	8.20814	9.92287	12.39808
G8	0	0	6.29444	0

Table 2. Location, size, cost and loss of the 3- seller system with PSO algorithm

	Location	Size	Total Cost in $	Loss in MW
NO FACTS	-	-	8054.4	7.6247
SVC	4	84.27 MVAR	7931.9	2.5061
TCSC	6 to 11	0.75 ohms	8977	5.1297
UPFC	13	**27.953 MVAR**	**7910.4**	**1.9754**

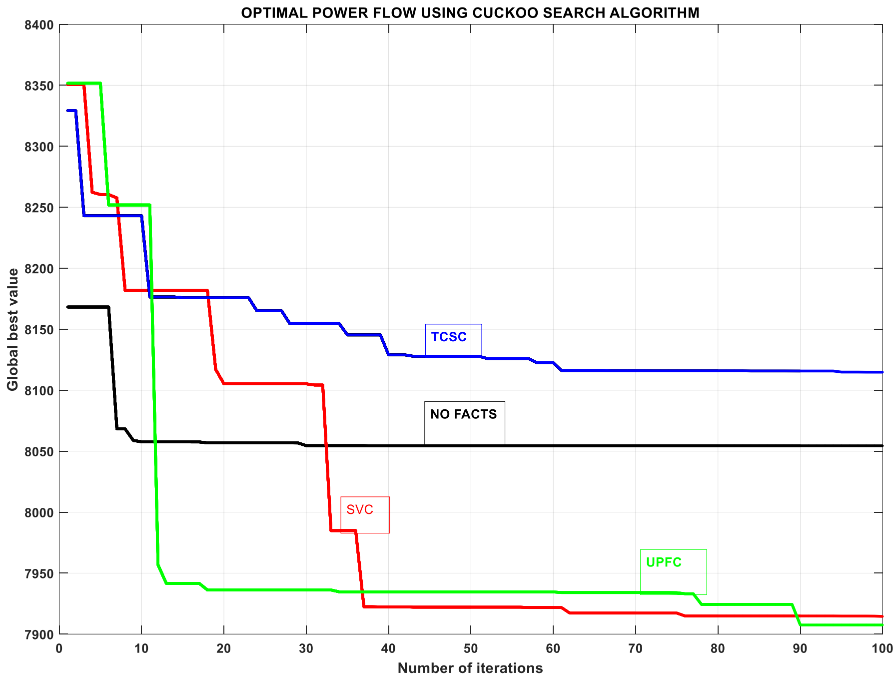

Figure 4. Convergence graph of CSA algorithm with and without SVC, TCSC and UPFC

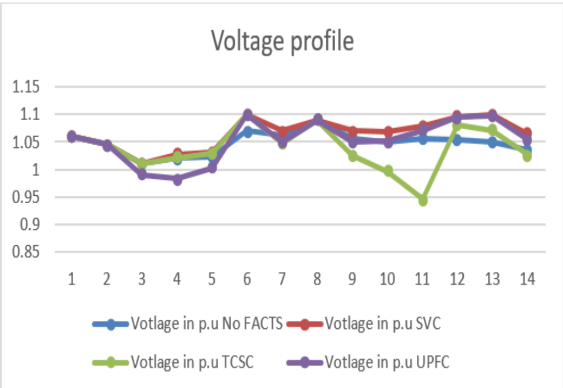

Figure 5. Voltage profile with and without SVC, TCSC and UPFC

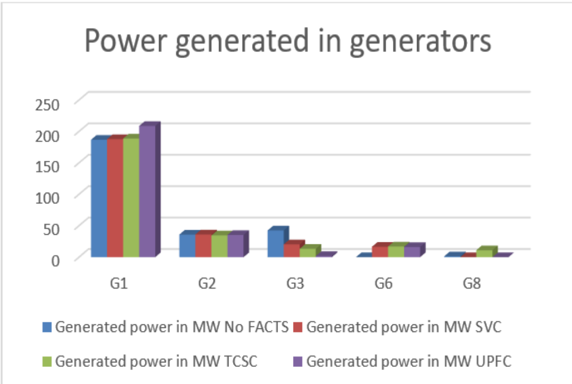

Figure 6. Generated power with and without SVC, TCSC and UPFC

Table 3. Generated power in MW

Gen. nos	Generated power in MW			
	No FACTS	SVC	TCSC	UPFC
G1	186.8083133	187.7138	188.8311	208.7254
G2	35.97583531	36.09213	34.69885	35.30854
G3	42.57066531	20.33008	13.26914	1.799593
G6	0	16.49721	16.97138	16.22596
G8	1.315076167	0	11.00931	0

Table 4. Location, size, cost and loss of the 3- seller system with CSA algorithm

	Location	Size	Total Cost in $	Loss in MW
NO FACTS	-	-	8054.4	7.6699
SVC	13	26.7432 MVAR	7914.5	1.6333
TCSC	6 to 11	1 pu	8114.8	5.7798
UPFC	13	**28.2819 MVAR**	**7907.5**	3.0595

5. CONCLUSION

The MATLAB implementation of the placement of multiple FACTS devices on the IEEE 14 bus system and the results were inferred. The optimization algorithm that was used for the placement of the multiple FACTS devices included PSO and CSA algorithm. The results obtained from the CSA implementation outperformed PSO algorithm and the cost function reduced value while optimizing using the CSA algorithm. So, compared to before placement and after placement of multi-facts devices the total cost of generation reduces even including the FACTS device cost.

REFERENCES

[1] S. N. Singh and A. K. David, "Congestion Management by Optimizing FACTS Device Location," *DRPT2000. International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*. *Proceedings (Cat. No.00EX382)*, London, UK, pp. 23-28, 2000.

[2] S. N. Singh, "Location of FACTS devices for enhancing power systems' security," *LESCOPE 01. 2001 Large Engineering Systems Conference on Power Engineering. Conference Proceedings. Theme: Powering Beyond 2001 (Cat. No.01ex490)*, Halifax, NS, Canada, pp. 162-166, 2001.

[3] N. G. Hingorani, "Flexible AC transmission," in *IEEE Spectrum*, vol. 30, no. 4, pp. 40-45, April 1993.

[4] L. Gyugyi, "A unified power flow control concept for flexible AC transmission systems," in *IEE Proceedings C - Generation, Transmission and Distribution*, vol. 139, no. 4, pp. 323-331, July 1992.

[5] E. Larsen, N. Miller, S. Nilsson and S. Lindgren, "Benefits of GTO Based compensation systems for electric utility applications," in *IEEE Transactions on Power Delivery*, vol. 7, no. 4, pp. 2056-2064, Oct. 1992.

[6] M. Noroozian and G. Anderson, "Power flow control by use of controllable series components," in *IEEE Transactions on Power Delivery*, vol. 8, no. 3, pp. 1420-1429, July 1993.

[7] S. Gerbex, R. Cherkaoui, and A. Germond, "Optimal location of multitype FACTS devices in a power system by means of genetic algorithms," in *IEEE Transactions on Power Systems*, vol. 16, no. 3, pp. 537-544, Aug. 2001.

[8] N. K. Sharma, A. Ghosh, and R. Varma, "in *IEEE Transactions on Power Delivery*, vol. 18, no. 3, pp. 982-987, July 2003.

[9] J. G. Singh, S. N. Singh, and S. C. Srivastava, "Placement of FACTS controllers for enhancing power system loadability," *2006 IEEE Power India Conference*, New Delhi, pp. 7, 2006.

[10] P. Preedavichit and S.C. Srivastava, "Optimal reactive power dispatch considering FACTS devices," *1997 Fourth International Conference on Advances in Power System Control, Operation and Management, APSCOM-97. (Conf. Publ. No. 450)*, Hong Kong, vol. 2, pp. 620-625, 1997.

[11] T. T. Lie and W. Deng, "Optimal flexible AC transmission systems (FACTS) devices allocation," *International Journal of Electrical Power and Energy systems*, vol. 19, no. 2, pp. 125-134, Febuary 1997.

[12] Fang, R., S., David, A., K., "Transmission Congestion Management in an Electricity Market," in *IEEE Transactions on Power Systems*, vol. 14, no. 3, pp. 877-883, Aug. 1999.

[13] Acharya, N., Mithulanathan, N., "Locating Series FACTS devices for Congestion Management in Deregulated Electricity Markets," *Electric Power Systems Research*, vol. 77, no. 3-4, pp. 352-360, March 2007.

[14] Brosda, J., Handschin. E, "Congestion management methods with a special consideration of FACTS-devices," *2001 IEEE Porto Power Tech Proceedings (Cat. No.01EX502)*, Porto, Portugal, vol. 1, pp. 6, 2001.

[15] A. A. Athamneh, W. J. Lee, "Benefits of FACTS devices for power exchange among Jordanian Interconnection with other Countries," *2006 IEEE Power Engineering Society General Meeting, Montreal*, Que., pp. 7, 2006.

[16] S. N. Singh, A. K. David, "A new approach for placement of FACTS devices in open power markets," *in IEEE Power Engineering Review*, vol. 21, no. 9, pp. 58-60, Sept. 2001.

[17] I. O. Elgerd and H. J. Happ, "Electric Energy System Theory - An Introduction," in *IEEE Transactions on Systems, Man, and Cybernetics*, vol. SMC-2, no. 2, pp. 296-297, April 1972.

[18] G. C. Ejebe and B. F. Wollenberg, "Automatic contingency selection," in *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-98, no. 1, pp. 97-109, Jan. 1979.

[19] Antonio Gomez-Exposito, Antonio J. Conejo, and Claudio Canizares, "Electric Energy Systems Analysis and Operation," CRC Press, New York, 2009.

[20] L. L. Freris and A. M. Sasson, "Investigation of the Load Flow Problem," in *Proceedings of the Institution of Electrical Engineers*, vol. 115, no. 10, pp. 1459-1470, October 1968.

[21] S. N. Singh and S. C. Srivastava, "Corrective action planning to achieve a feasible optimum power flow solution," in *IEE Proceedings - Generation, Transmission and Distribution*, vol. 142, no. 6, pp. 576-582, Nov. 1995.

[22] G. D. Galiana et al, "Assessment and control of the impact of FACTS devices on power system performance," in *IEEE Transactions on Power Systems*, vol. 11, no. 4, pp. 1931-1936, Nov. 1996.

[23] R. Rajaraman, F. Alvarado, A. Maniaci, R. Camfield and S.Jalali, "Determination of location and amount of series compensation to increase power transfer capability," in *IEEE Transactions on Power Systems*, vol. 13, no. 2, pp. 294-300, May 1998.

[24] E. J. de Oliveira and J. W. M. Lima, "Allocation of FACTS devices in a competitive environment," 13th PSCC, pp. 1184-1190, 1999.

[25] R. K. Swain, P. K. Hota, R. Chakrabarty, "An Auction Based Dispatch Algorithm for Deregulated Power Systems using Differential Evolution Technique," *Fifteenth National Power Systems Conference (NPSC)*, IIT Bombay, pp. 201-207, December 2008.

[26] M. C. Bhuvaneswari and J. Saxena (eds.), "Intelligent and Efficient Electrical Systems," Lecture Notes in Electrical Engineering 446, Springer nature Singapore Pvt Ltd, pp.167-174, 2018.
[27] X. Yang and Suash Deb, "Cuckoo Search via Lévy flights," *2009 World Congress on Nature & Biologically Inspired Computing (NaBIC)*, Coimbatore, pp. 210-214, 2009.
[28] Singiresu S. Rao, "Engineering optimization: Theory and Practice, Fourth Edition," John Willey & Sons, Inc., 2009.

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