Simultaneous placement of FACTS devices using cuckoo search algorithm

Basanagouda Patil, S. B. Karajgi
Shri Dharmasthala Manjunatheshwara College of Engineering and Technology, India

Article Info	ABSTRACT
	The power system deregulation requires thechange in reactive power compensation in the power system. The optimal placement of FACTs (Flexi ble AC transmission system) devices is mandatory to recalculate the reactive power compensation in deregulation case. The FACTs devices generally used in series and shunt conections. Here the various facts devices connected in series & shunt combination simultaneously. The optimal placement and sizing of the devices are done in this paper by formulating the objective function with minimization of cost of the generation and minimizing the cost of Facts devices. MALAB is used for writing the code. IEEE 14 bus system is used to here for testing the system. Placing the FACTs separately and simultaneously are studied in case study. Cuckoo search algorithm is used to identify the solution to the optimization problem. *This is an open access article under the CC BY-SA license.*

Corresponding Author:

Basanagouda Patil,
Research Scholar,
Department of Electrical and Electronics Engineering,
Shri Dharmasthala Manjunatheshwara College of Engineering and Technology, Dharwad -580002,
Karnataka, India.
Email: patil.basanagowda@gmail.com

1. INTRODUCTION

The placement of FACTS devices is studied by many papers. The multiple number of different types like series and shunt facts devices are used together as shown in [1-4]. In the entire list of facts devices UPFC is one of that which provides both series and shunt combination [4, 5]. The papers [1-5] deals with the optimal placement and size of facts devices. Some literatures deal with the increasing the number of FACTS devices [6-9]. In many literatures the placement problem solution is given in [10-20]. This paper deals with the optimal placement of FACTS devices with cuckoo search algorithm [10, 20-25]. A matlab based code is developed for placing the FACTS devices. The dual FACTS devices are placed simulataneously using this algorithm. The FACTS devices used here are combination of series and shunt devices. The combination like SVC-TCSC, TCSC-UPFC and SVC-UPFC are used here are case studies. The objective fuction is used with cost function of the generation and cost function of FACTs devices. The IEEE 14 bus system is used here for testing.

2. PROBLEM FORMULATION

Bidding cost is considered as the thermal system cost curve so the biding cost can be represented as [9],

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

The incremental cost can be represented as below,

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

Deregulated power system optimal power flow equation is given below,

$$Minimize: \sum_{i=1}^{n} F_i(P_{gi}) \tag{3}$$
$$subjected\ to: \sum_{P_{gi}}^{N_g} P_{gi} = P_d \tag{4}$$
$$P_{i\,min} < P_{gi} < P_{i\,max}\ , i \in [1, N_g] \tag{5}$$

When $\sum_{i=1}^{N_g} P_{i\,min} > P_d\ or\ \sum_{i=1}^{N_g} P_{i\,max} = P_d$, -no feasible solution,

When $\sum_{i=1}^{N_g} P_{i\,min} = P_d$ -each seller is contracted amount is at its capacity lower limit.

When $\sum_{i=1}^{N_g} P_{i\,min} < P_d$ and $\sum_{i=1}^{N_g} P_{i\,min} > P_d$,--non-trivial case.

Here,
$F_i(P_{gi})$ $-\ cost\ of\ generator\ i$
P_{gi} $-\ Power\ in\ MW\ of\ i^{th}\ generator$
a_i, b_i, c_i $-\ constant\ co-ordinate$
$P_{i\,min}, P_{i\,max}$ $-\ minimum\ and\ maximum\ limits\ of\ i^{th}\ generator$
P_d $-\ Power\ demand\ in\ MW$
n, N_g $-\ Number\ of\ generators$

Facts devices costs
$$C_{TCSC} = 0.0015 S_{TCSC}^2 - 0.713 S_{TCSC} + 153.75 \tag{6}$$
$$C_{SVC} = 0.0003 S_{SVC}^2 - 0.3051 S_{SVC} + 127.38 \tag{7}$$
$$C_{UPFC} = 0.0003 S_{UPFC}^2 - 0.2691 S_{UPFC} + 188.2 \tag{8}$$

Here,
$IC_{devices} - investment\ cost\ of\ FACTS\ devices\ in\ \$$
$C_{TCSC} - TCSC\ cost\ per\ KVAR\ installed\ in\ \$$
$C_{SVC} - SVC\ cost\ per\ KVAR\ installed\ in\ \$$
$C_{UPFC} - UPFC\ cost\ per\ KVAR\ installed\ in\ \$$
$S_{TCSC} - TCSC\ capacity\ in\ MVAR$
$S_{SVC} - SVC\ capacity\ in\ MVAR$
$S_{UPFC} - TCSC\ capacity\ in\ MVAR$

Considering the above constraints entire cost function can be represented as below [6].
Case I:
$$minimize\ Total\ Cost = \sum_{i=1}^{n} F_i(P_{gi}) + IC_{SVC+TCSC} \tag{9}$$
Case II:
$$minimize\ Total\ Cost = \sum_{i=1}^{n} F_i(P_{gi}) + IC_{TCSC+UPFC} \tag{10}$$
Case III:
$$minimize\ Total\ Cost = \sum_{i=1}^{n} F_i(P_{gi}) + IC_{SVC+UPFC} \tag{11}$$
Here,
$$IC_{SVC+TCSC} = C_{svc} + C_{TCSC} \tag{12}$$
$$IC_{TCSC+UPFC} = C_{TCSC} + C_{UPFC} \tag{13}$$
$$IC_{SVC+UPFC} = C_{SVC} + C_{UPFC} \tag{14}$$

3. CUCKOO SEARCH ALGORITHM (CSA)

The cuckoo bird lays eggs in other bird nests. If the host bird recognizes it, it may drop the eggs or it may abandon the nest and form a new nest. The "cuckoo search algorithm" is built on this concept. To simplify, the hypothesis is replaced by the new nest (with new arbitrary solutions) of the number of nodes.

To simplify it, a depiction of the respective egg in the nest, and a crane egg represents a new solution, the goal is to use new and imaginative best answers (cuckoo) to replace the worst response in the nest. Here, it is assumed that there is only one egg in the respective nest.

Based on these guidelines, the basic steps of cuckoo search (CSOA) can be summarized as pseudo-code. When making new answers x(t+1) for, about, a cuckoo i, a Levy flight is performed

$$xx(t + 1) = xx(t) + \alpha \oplus Levy (\lambda) \tag{15}$$

Where α> 0 is the step size, which relates to the rulers of the problem. In most cases, it is used as α = 1. Typically, an arbitrary style is a Markovsync, the next rank / location is in the current location (the first word in the equation above) and the probability of the conversion (the second term). Product ⊕ means organ-wise multiplications. This element-wise product is similar to the PSO, but here the levee plane is more efficient at finding the search area because its step distance is too long.

The levy plane basically provides an arbitrary walk, while the arbitrary step length is derived from the levy distribution

$$Levy \sim u = t - \lambda, (1 < \lambda \le 3) \tag{16}$$

CSA can thus be prolonged to the type of meta-population algorithm. The algorithm is given below:

Step-1: Suppose that n host candidates are Xxi (i = 1, 2, .. n) and maximum iteration.

Step-2: Analyze the maximum number of epochs and select a hook arbitrarily using taxonomic planes to estimate fit or cost function (Fi).

Step-3: Select a nest between n and say arbitrarily (j).

Step-4: Test whether Fj is lower than replacing F with the new solution.

Step-5: (Pa) One of the worst candidates is abandoned and new ones are built. Have the best nest or solution

Step-6: Grade the answers and find out the current.

Step-7: Confirm this for all epochs and finish when you reach maximum epochs.

Step-8: Prove the results.

4. RESULTS AND DISCUSSION

The test system is 3-seller CSA is taken here. As shown in the results the fitness value of CSA in [28]. 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. 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, TCSC & UPFC and SVC & UPFC. SVC & UPFC models are taken as reactive power model and the TCSC is taken as reactance model.

The objective function discussed in eq (9/10/11) is taken as a fitness equation with voltage limit and power flow constraints. The well-known metaheuristic algorithm called CSA algorithms is used for testing the fitness function for without facts devices. The results obtained are discussed below.

The Figure 1 shows the convergence curve. It can be seen that SVC with UPFC gives lesser cost compared to SVC & TCSC and TCSC & UPFC. The loss is minimized drastically from the single FACTS devices to multiple facts devices. Table 1 shows the comparison of the loss cost and locations of the FACTS devices. The Figure 2 shows the voltage profile. Here series 1 is the SVC & TCSC, series 2 is the TCSC & UPFC and series 3 is SVC & UPFC. The voltage profiles are nearly equal. Figure 3 shows the power generated from the generator after placement of SVC & TCSC, TCSC & UPFC and SVC & UPFC. Here the slack bus power generation increases corresponding to the cases applied. From Table 1 it is evident that minimum cost is achieved when the UPFC alone is placed. But minimum loss is achieved when combining the TCSC with UPFC. But SVC & UPFC reduces loss as well as cost compared to other SVC & TCSC and TCSC & UPFC.
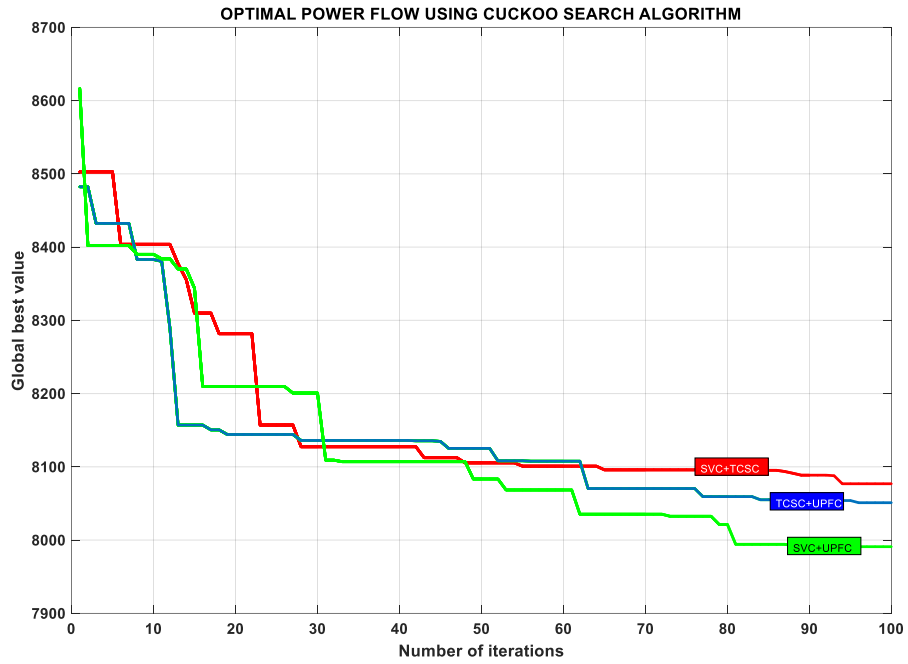
Figure 1. Convergence curve

Table 1. Conventional method

	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

Table 2. Conventional method

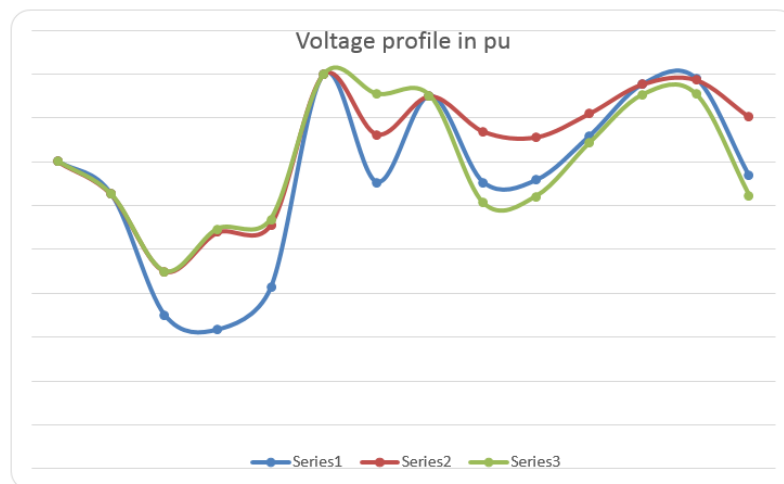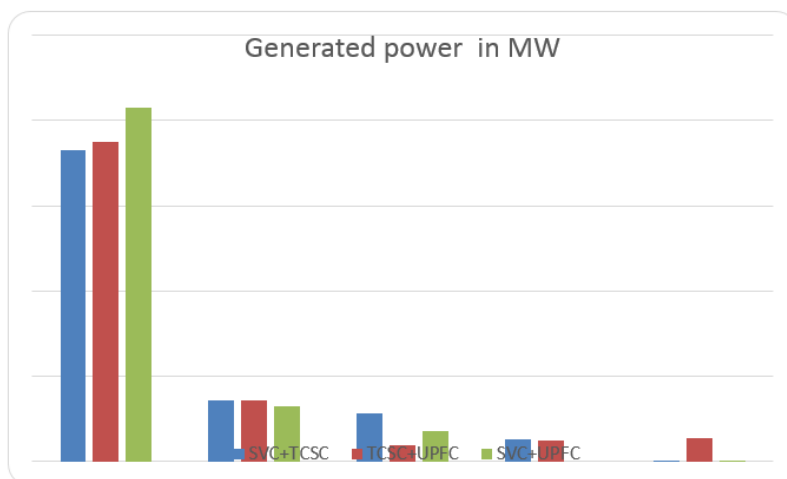|	Location	Size	Total Cost in $	Loss in MW
NO FACTS	-	-	8054.4	7.6699
SVC&TCSC	13+(13to14)	28.9790,0.3973	8076.9	1.2658
TCSC&UPFC	13, 7 to 9	20.1577, 0.3139	8051	**0.2941**
SVC&UPFC	10,13	**22.14,18.4MVAR**	**7991**	0.3662

Figure 2. Voltage profile

Figure 3. Generated power in MW

5.   CONCLUSION

The combination of SVC & TCSC, TCSC & UPFC and SVC & UPFC are placed by minimizing the cost of investment and the cost of generation at a time. The cuckoo search algorithm is used here as the solution technique. And the IEEE 14 bus which is also known as 3-seller deregulated system is considered here for testing the performances. The comparison is provided in the results and discussion section.

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BIOGRAPHIES OF AUTHORS

MrBasanagouda Patil Received the M. Tech in PES from BEC Bagalkot Karnatakain year 2010.At Present He is Pursuing Ph. D (Power System) fromSDMCET Dharwad & Life Member of Indian Society for Technical Education (ISTE), His Research Interest in Power system.

Dr S. B. Karajgi Received the M.E in REC Warangal 1987, & Ph. D from NITK Surathkal in 2014. Presently He is Working asva Professor in Department of EEE SDMCET Dharwad Karnataka. HIS Research Area interests in Power System Operation & Distribution Generation, Life Member of Indian Society Technical Education (ISTE).