

# Optimal Allocation of Facts Device for Voltage Profile Enhancement

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**Abstract:** Voltage profile on the load buses of a power system are very important parameter in maintaining the stability of the system and avoiding the voltage collapse, so the voltage profile (VP) are to be monitored and controlled on load buses. In this paper a new algorithm has been adopted to optimally allocate the FACTS devices at suitable places and optimize their parameters. The algorithm performance has been tested on IEEE standard 14, 30 and 57 bus systems and also the results are compared with PSO and GA algorithms. The results are fitting and highlighting the significance and features of the algorithm.

**Keywords:** FACTS Device, SVC, Cuckoo Search, Voltage Deviation, Voltage profile enhancement, loss minimization.

## 1. INTRODUCTION

In the developed and developing countries electrical energy is one among the important power/commodities that determine the growth of the country. The electrical energy has been used in a huge level in all engineering, agricultural, education, domestic and research fields/ areas. Power loss on both aspects (real, reactive power) is sternly occurring on the power line which is about 5 to 13 % of the total generated power that was given by the association of Asian Development Bank [1]. The VP of the load buses must be maintained within the limits of 0.95V to 1.05V per unit under the nonlinear load variation and misbehavior of the system components. Reactive power plays an important key role in maintaining the voltage stability and real power transfer in the system. The reactive power on the load buses can be maintained by adopting different techniques like connecting compensating components/ devices that would inject/observe the reactive power on the power system.

Earlier capacitor bank based compensating methods had been applied in view of maintaining the reactive power. Some of the technical problems of this type are large size which is not adoptable in the recent years. Power electronics is the emerging engineering field and its devices that can handle huge amount of voltage and current when used in the circuits. The converter based power electronic devices can work from 0 degree to 180 degree on converter mode and 180 to 360 degree on inverter mode that will provide real and reactive power flow. The branches of power electronic devices that can control huge amount of voltage and current on power system are known as FACTS devices used as the compensating devices for improving real power transfer capability. For the optimal placement of FACTS devices real and reactive power losses, congestion, contingency and voltage collapse will be reduced. SVC and STATCOM are the suitable devices for compensating the reactive power on the transmission lines for its connection on the load buses/end of the lines. Globally at many places FACTS devices have been installed on the transmission lines/buses to control and maintain the reactive power and the various parameters of the power system and hence to improve the system operation. The author has described the concept of FACTS placement in the power system for loss minimization and stability improvement [2] [3]. In general FACTS placement is the optimization problem in terms of placement and its parameter setting and that would be placed at suitable place with the help of optimization algorithm of mathematical approach/artificial intelligence techniques. The optimized placement of FACTS device will minimize the loss, reduce the voltage deviation on the load buses, adjust the reactive power flow, increase the real power transfer, decrease the fuel usage, maximize the voltage stability ; increase the transfer capability of the transmission line by relieving the congestion of the lines and also contingency of the system. So the FACTS placement is treated as non- linear and non- convex problem and thereby becoming challenging issue in the power system.

In this paper [4] congestion has been relieved by the low cost installation of FACTS devices in the deregulated power system to improve the stability and power quality. Loss reduction in power system is an important operation in view of improving the efficiency and maintaining the voltage stability. Particle swarm optimization (PSO) algorithm has been applied to minimize the voltage deviation and adjust the reactive power flow in [5]. The author [6] has distributed optimally

the DG sets using Harmony search algorithm and sensitivity analysis in the network towards minimization of loss. In the work [7] multifunctional FACTS device has been optimally placed to increase the transfer capability of the network. In this paper [8] security has been ensured by the placement of UPFC and controlling the over load and low voltage condition. Voltage Stability margin has been concentrated by the placement of UPFC in the system [9]. Bacterial foraging algorithm was applied to install the UPFC for controlling and maintaining the loss and voltage stability respectively [10]. Reactive power flow on the system is the major concern on maintaining the voltage level; the researcher optimized the reactive power flow by applying the Immune algorithm and improved the voltage stability of the system [11]. Analytical method was implemented in [12] to minimize the voltage deviation by compensating reactive power. Author had made a survey [13] on the methods used to improve voltage stability of the system for the installation of different FACTS devices and ensured the level of stability that would be developed for the location of the devices. In [14] the author had placed multiple SVCs optimally using PSO on the system to minimize the real power loss and maximize the voltage stability. Voltage collapse has been controlled by the strategy of reactive power flow control on the system in [15]. Congestion management has been followed to improve voltage stability of the system on the power market operation. [16]. OPF problem has been solved in [17] using Biogeography based optimization algorithm. In [18] author used multi type FACTS devices (SVC, TCSC and UPFC combination of the two devices) to enhance the voltage stability and the process had slightly increased the loss of the system. Voltage stability and loss of the system has been improved for the placement of multiple FACTS devices and BBO algorithm had been applied for the optimization in [19]. Multiple STATCOM had been placed on the power system using particle swarm optimization in [20]. Micro Genetic algorithm had been used to improve reactive power and voltage profile on Nigerian grid system [21]. Grey wolf optimization algorithm had been used for the optimal control of DC motor [22]. Bee swarm optimization had been applied for dynamic economic load dispatch [23]. BBO algorithm was used by the author to optimally place FACTS devices to improve reactive power reserve and hence voltage stability [24]. In [25] reactive reserve had been improved using PSO algorithm. The effectiveness of the cuckoo search algorithm has been proved by comparing the results with PSO, differential evolution and bee colony algorithms in [26]. The author had used the modified cuckoo search algorithm to solve unconstrained optimization problem [27]. Cuckoo search algorithm had been used for image compression and the results are compared with genetic algorithm in [28]. NR method given in [29] has been used in the simulation.

The paper has been organized with six sections. Section 1 introduction, 2 cuckoo search algorithms, 3 FACTS devices, 4 proposed method 5 Simulation and 6 conclusions.

## 2. CUCKOO SEARCH ALGORITHM

Cuckoo birds are different in nature and some of the verities are having peculiar character in egg laying. They involve in brood parasitism during giving birth to young ones. A particular verity of cuckoo uses the nest of other types to lay eggs and to etch. CS algorithm is population based meta heuristic algorithm. It uses two basic strategies of exploration and exploitation to search the global optimum solution within the search space. CS algorithm is adopting the general random walk technique to search the random location for laying their eggs. In this algorithm the artificial cuckoo lays one egg at a time. Elitist is the process through which the good solutions among the numerous is kept aside from the repeated iteration. Host bird of a nest discovers the egg of the other cuckoo with the probability  $P_d$  of (0, 0.1). If the egg of the other cuckoo is disclosed by the host then it may be thrown away or it may be abandoned to the cuckoo intruder by its owner. The host cuckoo will build new nest and it is of probability of  $n$  nests that are replaced by the new nests with random solution. The quality of a solution can simply proportional to the value of its objective function. One egg in a nest represents a solution and a cuckoo egg represents a new solution to replace worse solution that is in the nests. A new solution  $x^{(t+1)}$  for cuckoo 'i' is generated using levy flight according to the following equation:

$$x^{(t+1)} = x_i^{(t)} + \alpha \wedge Levy(\lambda) \quad (1)$$

Where  $\alpha$  ( $\alpha > 0$ ) represents a step scaling size. This parameter should be related to the scales of problem that the algorithm is trying to solve. In most cases  $\alpha$  can be set to the value of 1 or some other constants.

The random step length is drawn from a levy distribution which has an infinite variance with an infinite mean:

$$Levy \sim u = t^{-\lambda} \quad (2)$$

Where  $\lambda \in [0, 3]$

Taking into account basic three rules described

**Start**

Objective function  $f(x)$ ,  $x = (x_1, x_2, x_3, \dots, x_u)^T$

Generating initial population of  $n$  host nests  $x_i$  ( $i=1, 2, \dots, n$ )

**While** ( $t < \text{max generations}$ ) and (terminal count)

Move a cuckoo randomly via levy flights

Evaluate its fitness  $F_i$

Randomly choose nest among  $n$  variable nests (for example  $j$ )

**IF** ( $F_i > F_j$ ) replace  $j$  by the new solution;

Fraction  $P_d$  of worse nests are abandoned and new nests are being built;

Keep the best solutions or nests with quality solutions;

Rank the solutions and find the current best

**End While**

Post process and visualize results

**End**

Step size is calculated using the code expression;

$$R * \text{nests}[\text{permute1}[i][j]] - \text{nests}[\text{permute2}[i][j]] \quad (3)$$

Where  $r$  is random number  $[0, 1]$  range, nests is matrix which contains candidate solutions along with their variables, permute1 and permute2 are different rows permutation functions applied on nests matrix.

CS algorithm detects best solution  $X_{best}$  at the beginning of each iterative step. Also at this point step scale factor is being calculated using the following equation

$$\sigma_u = \left\{ \frac{\gamma(1+\beta)\sin(\pi\beta/2)}{\gamma\left[\frac{1+\beta}{2}\right]\beta 2^{(\beta-1)/2}} \right\} 1/\beta, \quad \sigma_v=1 \quad (4)$$

where  $\beta$  denotes levy distribution parameter and  $\gamma$  denotes gamma function.

The evolution of cuckoo  $i$  starts with the donor vector  $v$  where  $v = x_i^{(t)}$  step size is being calculated according to the below given equation

$$\text{stepsize}^{(t+1)} = 0.01 \frac{u^{(t+1)}}{|v^{(t+1)}|^{\frac{1}{\beta}}} (V - X_{best}) \quad (5)$$

Where  $u \sim N(0, \sigma_u^2)$   $V \sim N(0, \sigma_v^2)$  are samples from corresponding normal distributions the step size according to Levi distribution  $\beta = 1.5$ .

### 3. FACTS DEVICES

FACTS devices are the power electronics based solid state converters that can be integrated in power system as shunt and series connected devices. The series controllers builds up voltage in series with the line and the shunt controllers injects current into the system. The combined series and shunt controllers inject both voltage and current into the system SVC, STATCOM, TCSC, SSSC, UPFC, and IPFC are some of the FACTS devices.

#### A. MODELING OF SVC

Each and every type of FACTS device is having their own merits and demerits on controlling the power system parameters. The choice of the appropriate device depends on the problem and the solution that can be produced by the device in order to reach the desired goal. Hence the Steady state model of SVC is developed as shunt compensating devices as shown in figure.

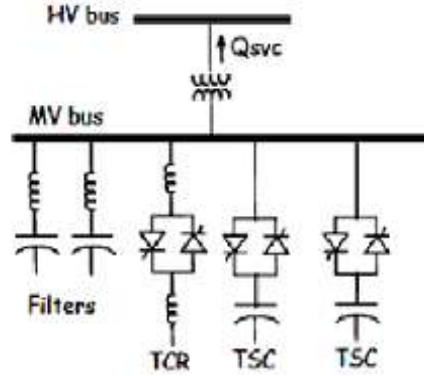


Figure.1: SVC model

The active and reactive power flow from bus  $i$  to  $j$  through transmission line- $m$  may be approximated by the following equations

$$P_{ij} = \frac{V_i V_j}{x_{ij}} \sin \delta_{ij} \quad (6)$$

$$Q_{ij} = \frac{1}{x_{ij}} (V_i^2 - V_i V_j \cos \delta_{ij}) \quad (7)$$

On high voltage transmission systems under normal operating conditions, the voltage on both buses are approximately equal and the voltage angle difference between two buses are very small, which decouples the active and reactive power flow through any line. Active and reactive power flow depends only on the voltage angle difference and voltage magnitude difference respectively. However, both of them can be controlled by varying the line reactance. The SVC is shunt connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of electrical power system, typically a bus voltage. The change in reactive power at bus- $i$  with SVC can be represented as

#### 4. PROPOSED METHOD

Exact FACTS device should be installed at the best likely locations with optimal parameter settings in order to minimize the load voltage deviations. The FCATS placement problem is formulated as an optimization problem involving voltage deviations as:

$$\text{Minimize} \quad \Psi = \sum_{i=1}^{n_{load}} V_{di} \quad (8)$$

Subject to FACTS device constraints

$$-200 \text{ MVAR} \leq Q_{Fi} \leq +200 \text{ MVAR for SVC} \quad (9)$$

Power Flow Constraints

$$P(V, \delta) - P^{sp} = 0 \text{ for PV and PQ buses} \quad (10)$$

$$Q(V, \delta) - Q^{sp} = 0 \text{ for PQ buses} \quad (11)$$

Where

$$V_{di} = \max_{k \in N_{bus}} |V_K - V_{refk}| \quad (12)$$

$N_{bus}$  is the total load buses and  $V_K$  is the voltage magnitude of  $k$ -th bus.  $V_{refk}$  is the reference or nominal voltage of  $k^{th}$  bus.

The FACTS placement problem, represented through Equation 9-13 offers a solution that enhances the VP through placing FACTS device at appropriate transmission line end or bus. This is achieved by altering the network parameters and injecting or absorbing reactive power at appropriate bus, which may increase the transmission losses. The increase in power loss can however be controlled by modifying the objective of Eq. (8) by blending both the net voltage deviations and the network losses as a bi-objective function of Eq. (13).

$$\text{Minimize } \Psi = w_1 \sum_{i=1}^{nload} V_{di} + w_2 P_L \quad (13)$$

Where,

$w_1$  and  $w_2$  are the weight constants

$$P_L = \sum_{m=1}^{nl} g_k (V_i^2 + V_j^2 - 2 V_i V_j \cos \delta_{ij}): \text{ network loss} \quad (14)$$

## B. FITNESS FUNCTION

The CS searches for optimal solution by maximizing a fitness function, denoted by ‘ $\varphi$ ’, which is formulated from the objective function Eq. (13), involving net voltage deviations and/or minimizing system loss as

$$\text{Maximize } \varphi = \frac{1}{1 + \Psi} \quad (15)$$

## C. PROCEDURE TO CONTROL PLACEMENT OF DEVICE ON THE SAME BUS

An initial population of nests is obtained by generating random values within the limits to every individual from the search space.

1. Read power system data
2. Choose CK parameters such as nest,  $P_d, \beta, \sigma_u, \sigma_v$  and step size.
3. Carryout NR load flow and obtain bus voltages
4. Randomly generate nest to represent reactive power  $Q_F^k$  values to form nest matrix and set iteration counter  $i = 0$
5.  $i = i + 1$
6. For each nest, alter the system parameters, carryout load flow, compute loss and voltage deviations and evaluate fitness using Eq. (16)
7. Identify elite nests having highest suitability and retain them as it is without making any modifications
8. Abolish the useless nest.
9. Check for convergence. If converged, go to next step; else go to step (5).
10. Optimum is reached. Carry out NR load flow after placing the SVC device corresponding to the best nest and compute real power loss and voltage deviations
- 11.

## 5. SIMULATIONS

The proposed CS based strategy is tested on IEEE 14, 30 and 57 bus test systems. NR program in [29] is used to carry out the load flow during the optimization process. The results of the CS are compared with that of GA and PSO based approaches for all the three test systems with a view to demonstrate the effectiveness. The location and their parameters of FACTS device SVC are given in Table-1 for 14, 30 and 57 bus systems respectively, which endeavors to minimize the net voltage deviation. The lowest and highest voltage magnitude ( $V^{\min}$  and  $V^{\max}$ ) at the load buses for the CS, PSO and GA are compared and is given in table-2. The system loss  $P_L$  before and after SVC placement for all the three test systems are given in Table-3. It is clear from Table -2 and 3 that the CS provides better voltage profile and loss respectively than that of GA and PSO based methods. It is to be noted that the FACTS placement slightly increases the system loss for all the three test systems which can be minimized by blending the loss reduction objective with voltage deviation minimization.

Table 4 presents the CS parameters involved in this narration.

**Table 5.1: Location and parameters of FACTS device (SVC)**

Parameter	14 Bus system			30 Bus system			57 Bus system		
	CS	PSO	GA	CS	PSO	GA	CS	PSO	GA
$L_k$	13	12	4	14	12	27	37	19	10
$Q_{Fi}$	0.030	0.065	0.188	0.064	0.183	0.260	0.074	0.159	0.188

**Table 5.2: Comparison of Results (voltage profile) before and after placement of FACTS device**

System/ Algorithm	$V^{\min} / V^{\max}$		
	IEEE 14 bus System	IEEE 30 Bus System	IEEE 57 Bus System
	Before		
	1.0100/1.0103	0.9978/1.0200	0.8304/1.0172
	After		
CS	1.0161/ 1.0230	0.9979/1.0595	0.9818/1.0235
PSO	0.9994 / 1.0144	0.9864/1.0190	0.9800/1.0272
GA	0.9973/1.0064	0.9859/1.0153	0.9678/1.0175

**Table 5.3: Comparison of Results (loss) before and after FACTS placement**

System/ Algorithm	$P_L$		
	14	30	57
	Before		
	0.4151	0.4315	1.4295
	after		
CS	0.4058	0.4217	1.4184
PSO	0.4122	0.4282	1.4386
GA	0.4188	0.4397	1.4465

**Table 5.4: Cuckoo Search Parameters**

Parameters	Chosen Value
n	50
$\beta$	1.5
$P_d$	[0,10]
$\alpha$	1
$\sigma_v$	1
$\lambda$	[0,3]

It is very clear from the discussions that the CS reduces system losses and offers better voltage profile and makes it suitable for practical implementations.

## 6. CONCLUSION

Cuckoo search optimization algorithm is the population based Meta heuristic recently developed optimization tool useful in optimizing the constrained and non-constrained problems. In this work it is applied to minimize the voltage deviation on the load buses of IEEE 14, 30 and 57 bus standards for the suitable allocation of SVC and thereby the voltage profile of the system has been enhanced reducing the real power losses as well. The results of the CS are compared with the outputs of PSO and GA techniques. The simulation results have clearly illustrated that the CS algorithm minimizes net voltage deviations, and reduces system losses in an appreciable level thus makes it suitable for practical implementations.



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