

Improvement of Power System Condition by Placement of Flexible Alternating Current Transmission Systems devices

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ABSTRACT

Flexible Alternating Current Transmission Systems (FACTS) devices have been used for several targets in power system, one of the main contributions of the devices is improving operation conditions. In this paper, two types of these devices have been placed to raise voltage profile, minimizing system loss and arising loadability. The suggested FACTS devices are: Unified Power Flow Controller (UPFC) and Static Var Compensator (SVC). This problem has been solved by a novel intelligent algorithms. Simulation has been performed on MATLAB software environment. Capability of the proposed model has been confirmed by testing on 30-bus IEEE test system.

Keywords

FACTS, UPFC, SVC, power system.

1. INTRODUCTION

Flexible AC Transmission Systems (FACTS) devices provide a means to improve on the utilization of existing infrastructure, with the capability of providing reactive power support, redirecting power flows, and improving utilization of available line ratings. Some common FACTS devices include the Static VAR Compensator (SVC), static synchronous compensator (STATCOM), Thyristor- Controlled Series Capacitor (TCSC), and the unified power flow controller (UPFC) [1-2].

Ref.[3] presents a generalized approach for determination of optimal locations for placement of FACTS devices in the power system with an objective of reducing real power loss and to reduce overloading of the lines. In [4], the new methodology for proper placement of FACTS devices in the restructured electricity market is proposed. An efficient and reliable evolutionary programming (EP) and differential evolution (DE) techniques based economic dispatch for pool electricity market is used to improve the social welfare.

In [5], applications of PSO for solving FACTS allocation problem are deeply reviewed from perspective of the

objectives, used basic PSO variant, parameter selection, multi-objective handling strategy, constraint handling strategy and discrete variable handling strategy. The planning problem in [6] is formulated as a single objective optimization problem where the real power loss and bus voltage deviations are minimized under different loading conditions. Gravitational Search Algorithm (GSA) based optimization algorithm and particle swarm optimization techniques (PSO) are applied on IEEE 30 bus system.

In [7], BSOA is employed to find optimal location and setting of FACTS devices. SVC's and thyristor controlled series compensators (TCSC's) are used as FACTS devices. Ref.[8] presents a comprehensive survey on application of various conventional, optimization and artificial intelligence (AI) based computational techniques for impact assessment of optimally placed and coordinated control of distributed generations (DGs) and FACTS controllers in power systems (PSs). In [9], a strategy for placement and sizing of shunt FACTS controller using Fuzzy logic and Real Coded Genetic Algorithm is proposed. A fuzzy performance index based on distance to saddle node bifurcation, voltage profile and capacity of shunt FACTS controller is proposed.

In [10], optimal placement of parallel and series FACTS devices is studied. The STATCOM is selected as a parallel FACTS device and SSSC as a series one. In order to find suitable FACTS locations more easily and with more flexibility, Ref.[11] presents a graphical user interface (GUI) based on a genetic algorithm (GA) which is shown able to find the optimal locations and sizing parameters of multi-type FACTS devices in large power systems. Ref. [12] presents a novel FACTS placement method based on mixed integer quadratically constrained programming (MIQCP). The method is capable of allocating both SVC and Thyristor-Controlled Series Capacitor (TCSC) either separately or simultaneously, to determine concurrently their numbers, locations as well as sizes.

In this paper, the cuckoo algorithm suggested for placement of UPFC and SVC in power system. This paper has been organized in five sections. Concept of objective

function and modeling of UPFC and SVC have been introduced in section 2. The proposed technique to solve the problem are discussed in third section. Simulation results are available in section 4. This work has been concluded in section 5.

2. FORMULATION

2.1 Objective function

In this paper, objective function has been formulated to improve dynamic behavior of power system. To do this, objective function of this study has been introduced as following:

$$OF = \sum \frac{VB}{N_{bus} + NFACTS} + \sum \frac{VA}{N_{bus} + NFACTS} + LA + PG \quad (1)$$

where, N_{bus} : the number of system buses, $NFACTS$: the number of FACTS devices, PG : loss system, VB : voltage magnitude deviation, VA : voltage angle deviation, LA : loadability margin which obtains as following:

$$LA = \sum \frac{SSL}{Nline + NFACTS} \quad (2)$$

where, $Nline$ and SSL are the number of lines and the transmitted power of line, respectively.

2.2 Constraints

To solve the objective function, four constraints should be observed. Equations (3) and (4) show active and reactive power flow constraints, respectively.

$$P_{gi} - P_{di} - V_i \sum_{j=1}^N Y_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (3)$$

$$Q_{gi} - Q_{di} - V_i \sum_{j=1}^N Y_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (4)$$

where, i and j are the number of receiving and sending buses determined based on the size of the used distribution network. P_{gi} and P_{di} are generated and consumed active power in bus i , respectively. Q_{gi} and Q_{di} are the generated and consumed reactive power in bus i , respectively. V and δ are system bus voltages magnitudes and phase angles, respectively. Y_{ij} and θ_{ij} are bus admittance matrix elements magnitudes and phase angles, respectively.

Bus voltage and active power flowed through buses should be limited in reasonable ranges; this fact has been illustrated in Equations (5) and (6),

$$V_i^{\min} \leq V_i \leq V_i^{\max}, i = 1, \dots, N \quad (5)$$

$$P_j^{\min} \leq P_j \leq P_j^{\max}, i = 1, \dots, N \quad (6)$$

where, V_i^{\min} and V_i^{\max} are the minimum and maximum voltages of bus i , respectively. P_i^{\min} and P_i^{\max} are the minimum and maximum voltages of bus i , respectively. N is the number of buses of network.

2.3 Modeling FACTS devices

2.3.1 SVC model

Based on equations of power flow of power system, the injected active and reactive powers to bus i are:

$$P_i = \sum_{j=1}^n V_i V_j (G_j \cos \theta_j + B_j \sin \theta_j) \quad (7)$$

$$Q_i = \sum_{j=1}^n V_i V_j (G_j \sin \theta_j - B_j \cos \theta_j) \quad (8)$$

where, B_{ij} , G_{ij} and θ_{ij} obtain as:

$$\theta_j = \theta_i - \theta_j \quad (9)$$

$$G_j = \mathbf{R}^{-1} (Y_j) \quad (10)$$

$$B_j = \mathbf{Im} \mathbf{g} (Y_j) \quad (11)$$

where, Y_{ij} is system admittance matrix. SVC can be easily fixed to the reactive power into the equation (8) add busbar and the power injected in accordance with the following formula obtained.

$$Q_i = \sum_{j=1}^n V_i V_j (G_j \sin \theta_j - B_j \cos \theta_j) + Q_{sh,i} \quad (12)$$

where, $Q_{sh,i}$ is reactive power capacitor and reactor shunt is installed in the busbar i . It should be noted that in the case of a negative capacitance value is Q_{sh} .

2.3.2 UPFC model

UPFC consists of a series voltage source and a parallel current source (see Figure 1). With the proviso that the sum of active power injected by the series voltage source and current source in parallel active power injected into the grid is zero [11].

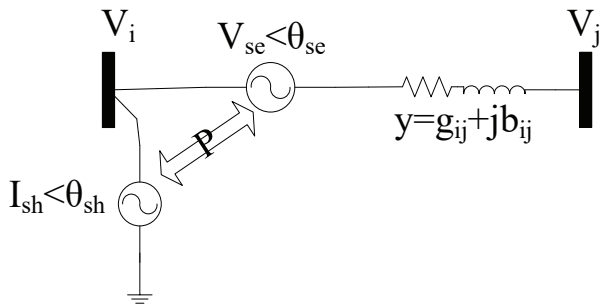


Figure 1. Electrical model of UPFC

$$P_{j,UPFC} = P_{j,SSSC} \quad (13)$$

$$Q_{j,UPFC} = Q_{j,SSSC} \quad (14)$$

$$P_{j,UPFC} = P_{j,SSSC} \quad (15)$$

$$Q_{j,UPFC} = Q_{j,SSSC} \quad (16)$$

$$P_j^{new} = P_j + P_{j,UPFC} \quad (17)$$

$$Q_j^{new} = Q_j + Q_{j,UPFC} \quad (18)$$

$$P_j^{new} = P_j + P_{j,UPFC} \quad (19)$$

$$Q_j^{new} = Q_j + Q_{j,UPFC} \quad (20)$$

Shunt current source changes the injected power at ith busbar.

$$\hat{S}_{i,k} = V_i I_k^* = V_i I_k [\cos \theta_{i,k} + j \sin \theta_{i,k}] \quad (21)$$

$$P_{i,k} = V_i I_k \cos \theta_{i,k} \quad (22)$$

$$Q_{i,k} = V_i I_k \sin \theta_{i,k} \quad (23)$$

Based on these equation, $P_{i,sh}$ is equal to $P_{ij,UPFC}$ thus the injected active power of ith busbar is same $P_{i,sh}$ and the injected reactive power at ith busbar and the injected active and reactive powers at jth busbar change as following;

$$P_i^{new} = P_i + P_{i,k} \quad (24)$$

$$Q_i^{new} = Q_i + Q_{j,UPFC} + Q_{i,k} \quad (25)$$

$$P_j^{new} = P_j + P_{j,UPFC} \quad (26)$$

$$Q_j^{new} = Q_j + Q_{j,UPFC} \quad (27)$$

3. OPTIMIZATION

3.1 Cuckoo optimization algorithm

Based on Figure2 in order to solve an optimization problem, it's necessary that the values of problem variables be formed as an array. In GA and PSO terminologies this array is called "Chromosome" and "Particle Position", respectively. But here in Cuckoo Optimization Algorithm (COA) it is called "habitat". In a N_{var} -dimensional optimization problem, a habitat is an array of $1 \times N_{var}$, representing current living position of cuckoo. This array is defined as follows:

$$habitat = [x_1, x_2, \dots, x_{N_{var}}] \quad (28)$$

Each of the variable values ($x_1, x_2, \dots, x_{N_{var}}$) is floating point number. The profit of a habitat is obtained by evaluation of profit function at a habitat of ($x_1, x_2, \dots, x_{N_{var}}$). So

$$Profit = f_p(habitat) = f_p(x_1, x_2, \dots, x_{N_{var}}) \quad (29)$$

To start the optimization algorithm, a candidate habitat matrix of size $N_{pop} \times N_{var}$ is generated. Then some randomly produced number of eggs is supposed for each of these initial cuckoo habitats. In nature, each cuckoo lays from 5 to 20 eggs. These values are used as the upper and lower limits of egg dedication to each cuckoo at different iterations. Another habit of real cuckoos is that they lay eggs within a maximum distance from their habitat. From now on, this maximum range will be called "Egg Laying Radius (ELR)". In an optimization problem with upper limit of var_{hi} and lower limit of var_{low} for variables, each cuckoo has an egg laying radius (ELR) which is proportional to the total number of eggs, number of current cuckoo's eggs and also variable limits of var_{hi} and var_{low} . So ELR is defined as:

$$ELR = \alpha \times \left(\frac{N_{CE}}{N_{tot}} \right) \times (var_{hi} - var_{low}) \quad (30)$$

where, α is an integer, supposed to handle the maximum value of ELR. N_{CE} and N_{tot} are the total number of eggs available and the total number of eggs, respectively. Another interesting point about laid cuckoo eggs is that

only one egg in a nest has the chance to grow. This is because when cuckoo egg hatches and the chicks come out, she throws the host bird's own eggs out of the nest. In case that host bird's eggs hatch earlier and cuckoo egg hatches later, cuckoo's chick eats most of the food host bird brings to the nest (because of her 3 times bigger body, she pushes other chicks and eats more). After couple of days the host bird's own chicks die from hunger and only cuckoo chick remains in the nest.

$$X_{NextHabitat} = X_{CurrentHabitat} + F (X_{GlobalPoint} + X_{CurrentHabitat}) \quad (31)$$

When young cuckoos grow and become mature, they live in their own area and society for sometime. But when the time for egg laying approaches they immigrate to new and better habitats with more similarity of eggs to host birds and also with more food for new youngsters. After the cuckoo groups are formed in different areas, the society with best profit value is selected as the goal point for other cuckoos to immigrate. When mature cuckoos live in all over the environment it's difficult to recognize which cuckoo belongs to which group. To solve this problem, the grouping of cuckoos is done with K-means clustering method (a k of 3–5 seems to be sufficient in simulations). Now that the cuckoo groups are constituted their mean profit value is calculated. Then the maximum value of these mean profits determines the goal group and consequently that group's best habitat is the new destination habitat for immigrant cuckoos.

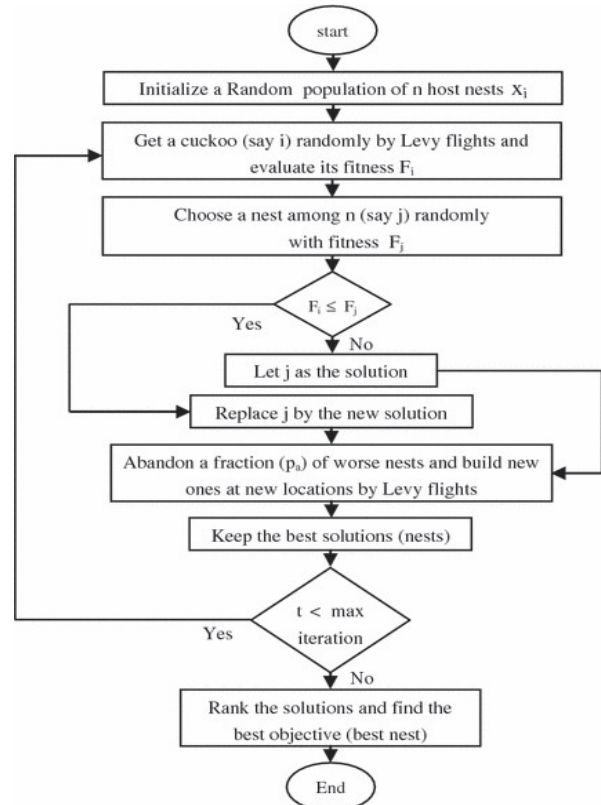


Figure 2. Flowchart of cuckoo algorithm

3.2 Solving problem

After the introduction of the objective function parameters and algorithm, how to encode this issue must be expressed in the MATLAB environment. Hence, the 9-step problem solving presented in the following location FACTS devices placed Tuesday.

Step 1. Login Information: In the first step should, be provided information needed to run the program. In general, three categories of information required, including equipment information, network and algorithms.

- Information Equipment.
- Information Network (resistance and reactance line, the coefficient of tap changer, number of nodes, bus active power, reactive power and the bass line)
- All algorithms (most frequently, the number of repetitions, number and rate Cuckoo)

Step 2. Create a matrix sections: the first column matrix has two columns and column number two and number of sections along the sections where the last number is supposed FACTS system installed in the first column sections to Section been installed.

Step 3. Creating random matrix: at this stage, to implement a genetic algorithm random matrix with the size of the initial population size and number of parameters is generated.

Step 4. Running load flow program: load flow program

to determine parameters such as flow and can be implemented.

Step 5. Running the algorithm Cuckoo: Cuckoo operators algorithm is applied on the existing generations to be better solutions.

Step 6. Check the devices: at this stage, by creating a matrix to identify sub power as well as power plants and the recognition of them, according to the available information the selection of equipment is done.

Step 7. Check the values of the objective function parameters: value parameters in compliance with the provisions aide come to be evaluated.

Step 8. Check satisfy the number of repeat and return to step 4 in case of non-fulfillment.

Step 9. Derive optimal output.

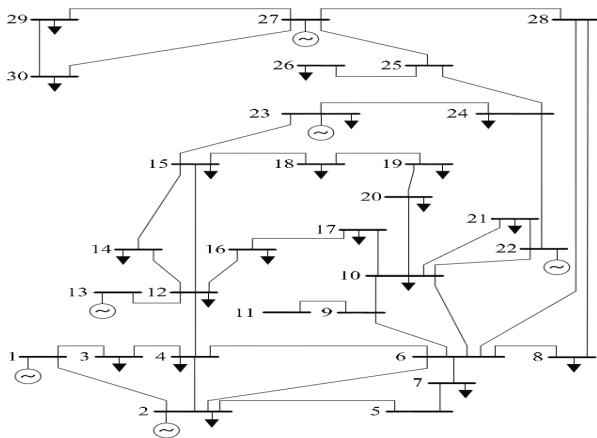


Figure 3. 30-bus test system Single line diagram

4. CASE STUDY

In this section, simulation is done on 30-bus network. Single-line diagram of this test network is provided in Figure 3. Several cases have been suggested based on the number of equipment. The maximum number of equipment is six. Each placement case by a two-digit number shown. The first number on the left side of UPFC and the number of SVC is second from left.

4.1 Voltage deviation

The first studied parameter is voltage deviation in the network. Figure 4 shows voltage deviation in the network.

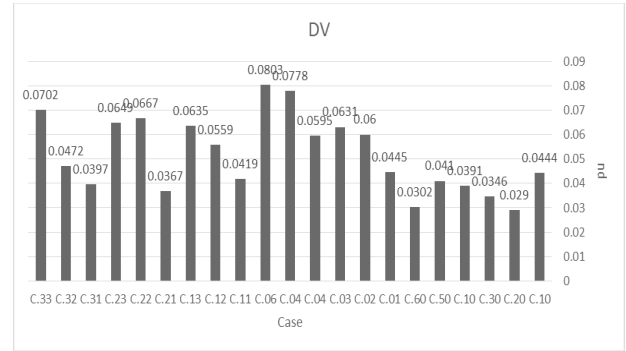


Figure 4. Voltage deviation of system

According to Figure 4, the presence of two UPFC in the placement of just UPFC give the best possible answer. While the placement of SVC, the presence of only a single SVC offer lowest voltage deviation. In simultaneous placement of two UPFCs and one SVC has the most ideal possible answers.

4.2 Voltage angle

The voltage angle is the second parameter which examined and presented in Figure (5).

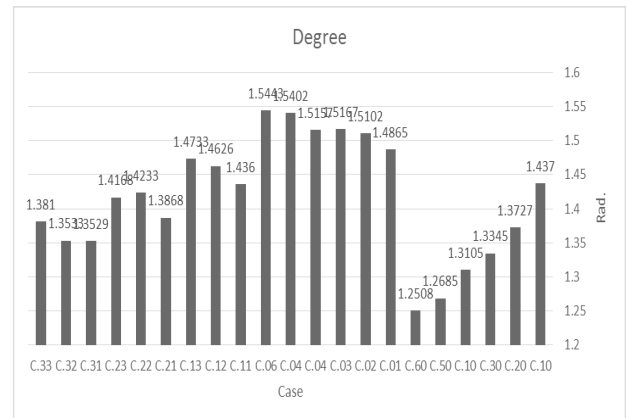


Figure 5. Voltage angle of system

Based on the figure (5), in placement just UPFC, voltage angle value by increasing the number of UPFC has taken a downward turn and the best response in the presence of six UPFC sure the screw. But the SVCs placement with, this trend is reversed and increasing the number of SVC has opposite effect on voltage impact angle and destroys it. This contradictory behavior in the placement of SVC and UPFC is remarkable but the presence of three UPFCs and one SVC has offer better solution respect other cases.

4.3 Loadability margin

In figure (6), loadability margin of system is visible in all cases.

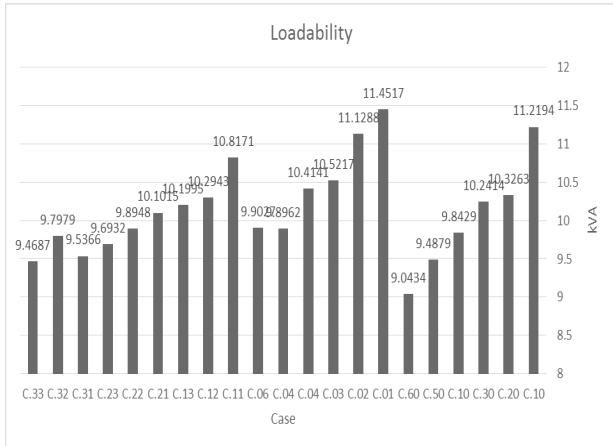


Figure 6. Loadability margin of system

According to Figure (6) we can say that reduction of three placements of just UPFC, just SVC and simultaneous SVC-UPFC are Almost similar and declining. According to this placement of six UPFCs and five SVCs (with minor difference respect to six SVCs), the best solution are present for placements of just UPFC and just SVC, respectively. Placement of simultaneous three UPFCs and three SVCs are the most acceptable answer among cases of simultaneous placement.

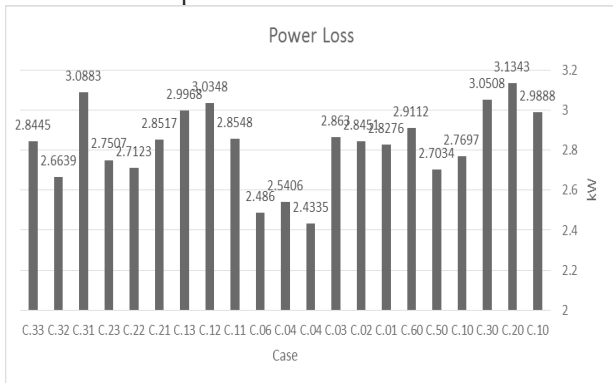


Figure 7. Power loss of system

4.4 Power loss

Power loss is other parameter which has been analyzed in this study and their results illustrated in figure (7). Based on figure (7), the presence of five UPFCs in UPFC placement has best answer respect to other cases. The presence of four SVCs present lower power loss in placement of just SVCs. Finally in simultaneous placement of UPFC and SVC, the presence of three UPFCs and two SVCs have the best solution.

4.5 Objective function

Discussion about of the objective function of this study is the last case. Figure 8 shows objective function of this paper.

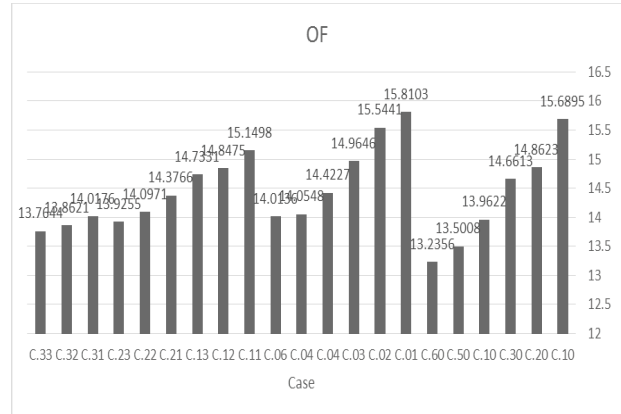


Figure 8. Objective function of system

Value of objective function has a direct and significant correlation with the number of equipment. The most of the equipment means the best answer. Therefore the presence of six UPFCs and six SVCs as well as three SVCs-three UPFCs generate the best solutions for placements of just UPFC, just SVC and simultaneous, respectively.

4.6 Size and location

4.6.1 UPFC

The location of UPFC and its injected voltage have been listed in Table 1.

Based on Table 1, lines 6-8 and 3-4 have the maximum number of UPFC. Table (2), shows values of the injected reactive power of UPFC.

Based on Table 2, 0.58 pu is the maximum value for reactive power and 0.01 pu is the minimum value for the injected reactive power by UPFC.

4.6.2 SVC

As you can see, the Table (3) the location and capacity of the SVC and the amount of reactive power have been listed.

Table 1. Location and injected voltage by UPFC

The number	Location (voltage)
10	8-6(-0.6000- i 0.0361)
20	4-3(i0.0548+0.0435), 2-1(i 0.0540-0.0590-)
30	-6(i 0.0177+0.0573), 6-2(i 0.0095+0.0032-), 16-12(i 0.0173+0.0101-)
40	8-6(i 0.0075+0.0067-), 25-24(i 0.0361-0.0600-), 3-1(i 0.0268+0.0754-), 2-6(i 0.0455+0.0208-)
50	8-6(i 0.0081--0.0059), 25-24(i 0.0342+-0.0723), 9-11(i 0.0818-0.0375-), 1-3(i 0.0100-0.0003-), 28-8(i 0.0379+0.0129-)
60	1-3(i 0.0117+ 0.0276), 9-11(i 0.0117+ 0.0276), 24-25(i 0.0030- 0.0299), 10-6(i 0.0783- 0.0622), 12-4(i 0.0691- -0.0404), 11-9(i 0.0671+ -0.0600)
11	1-2(i 0.0167+0.0680-)
12	7-5(i 0.0268+0.0754-)
13	7-5(i 0.0081+0.0059-)
21	4-3(i 0.0097+0.0023-), 1-2(i 0.0397+0.0052-)
22	6-2(i 0.0198+0.0026-), 17-16(i 0.0072-0.0291-)
23	6-2(i 0.0713-0.0363), 10-6(i 0.0568+0.0194-)
31	1-3(i 0.0144+0.0263), 15-14(i 0.0289+0.0080), 6-2(i 0.0198+0.0026-)
32	1-2(i 0.0056-0.0396-), 19-18(i 0.0384-0.0702), 4-3(i 0.0637+0.0291-)
33	12-4(i 0.0694-0.0090-), 2-6(i 0.0284-0.0097-), 10-6(i 0.0412+0.0686-)

Table 2. Location and injected reactive power by UPFC

The number	Location (voltage)
10	8-6(0.50)
20	4-3(0.23), 2-1(0.33)
30	8-6(0.17), 6-2(0.24), 16-12(0.01)
40	8-6(0.32), 25-24(0.05), 3-1(0.03), 2-6(0.26)
50	8-6(0.26), 25-24(0.04), 9-11(0.08), 1-3(0.45), 28-8(0.11)
60	1-3(0.25), 9-11(0.06), 24-25(0.11), 10-6(0.28), 12-4(0.28), 11-9(0.18)
11	1-2(0.58)
12	7-5(0.47)
13	7-5(0.45)
21	4-3(0.09), 1-2(0.12)
22	6-2(0.14), 17-16(0.10)
23	6-2(0.48), 10-6(0.47)
31	1-3(0.44), 15-14(0.20), 6-2(0.37)
32	1-2(0.38), 19-18(0.06), 4-3(0.46)
33	12-4(0.17), 2-6(0.45), 10-6(0.11)

5. CONCLUSION

The capability and highlights of this paper are:

- Problem formulation: Objective function of each work determines vision and direction. In problem formulation, all main challenges of power system have been considered; i.e. power loss, voltage profile and loadability margin.
- Solution technique: The cuckoo algorithm is one of the newest intelligent algorithms which used to solve power system problems. This context, in addition to system study, capability of the algorithm has analyzed.
- Case study: Simulation has been performed in IEEE standard test system. In the system, power loss, deviation and angle of voltage, the installed capacity, loadability and objective function have been presented in curves and tables. The number of parameters, it can lead to a comprehensive view of the location of the FACTS devices.

Table 3. Location and injected reactive power by SVC

The number	Location (reactive power)
01	8(0.56)
02	8(0.63)• 13(0.38)
03	2(0.59)• 13(0.43)• 8(0.61)
04	5(0.59)• 2(0.65)• 4(0.21)• 8(0.54)
05	12(0.29)• 5(0.66)• 8(0.69)• 13(0.11)• 2(0.59)
06	8(0.59)• 5(0.45)• 19(0.06)• 12(0.36)• 2(0.46)• 5(0.17)
11	8(0.58)
12	8(0.63)• 12(0.21)
13	8(0.62)• 13(0.63)• 17(0.09)
21	8(0.51)
22	8(0.62)• 24(0.11)
23	16(0.11)• 13(0.60)• 21(0.10)
31	8(0.48)
32	5(0.54)• 8(0.61)
33	8(0.44)• 13(0.40)• 5(0.55)

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