OPTIMAL POWER FLOW WITH TCSC DEVICE USING CUCKOO OPTIMIZATION ALGORITHM

Duong Thanh Long[*], Cao Van Tuan

Department of Electrical Engineering, Industrial University of Hochiminh City,
12 Nguyen Van Bao Street, Ward 4, Go Vap District, Ho Chi Minh City

[*]Email: *duongthanhlong@iuh.edu.vn*

ABSTRACT

Optimal Power Flow (OPF) problem is an optimization tool through which secure and economic operating conditions of power system is obtained. In recent years, Flexible AC Transmission System (FACTS) devices, have led to the development of controllers that provide controllability and flexibility for power transmission. Series FACTS devices such as Thyristor controlled series compensators (TCSC), with its ability to directly control the power flow can be very effective to power system security. Thus, integration TCSC in the OPF is one of important current problems and is a suitable method for better utilization of the existing system. This paper is applied Cuckoo Optimization Algorithm (COA) for the solution of the OPF problem of power system equipped with TCSC. The proposed approach has been examined and tested on the IEEE 30-bus system. The results presented in this paper demonstrate the potential of COA algorithm and show its effectiveness for solving the OPF problem with TCSC devices over the other evolutionary optimization techniques.

Keywords: Cuckoo optimization algorithm, OPF, FACTS, TCSC.

1. INTRODUCTION

Power systems are becoming increasingly more complex due to the interconnection of regional system, deregulation of the overall electricity market and increased in power demand. Therefore, transmission networks require a substantial increase of power transfer which demands adequate available transfer capability to ensure all energy transactions. However, tight restrictions on the construction of new transmission lines due to increasingly difficult economic, environmental and social problems have led to a much more intensive shared use of the existing transmission systems facilities. In order to solve this problem, using of controllable flexible AC transmission system (FACTS) in improving transmission capacity to obtain minimal cost while satisfying specified transmission constraints and security constraints is one of main current issues. In which, incorporation the FACTS devices in OPF problem is a challenge for System Operator. Hsmmns and Lim [1] presented a review literature, which addresses the application of FACTS, concepts for the improvement of power system utilization and performance. Recent developments involving deregulation and restructuring of the power industry is feasible only if

the operation of AC transmission systems is made flexible by introducing FACTS devices [2]. Among FACTS controllers, TCSC is one of the effective FACTS devices that can control the load flow of the power system to reach the required goals.

Optimal Power Flow (OPF) aims to optimize a selected objective function via optimal adjustment of power system control variables while satisfying a set of equality and inequality constraints. Over the last three decades, many successful OPF techniques have been developed such as, the generalized reduced gradient method [3], linear programming solution, quadratic programming, the Newton method [4,5], the Interior Point Method (IPM). However the disadvantage of these techniques is that it is not possible to use these techniques in practical systems because of nonlinear characteristics such as valve point effects, prohibited operating zones, piecewise quadratic cost function and incorporation of FACTS devices to systems. Therefore it becomes necessary to improve the optimization methods that are capable of overcoming these disadvantages and handling such difficulties.

The conventional OPF problem is modified to incorporate the FACTS devices in the power system [6 – 11]. Various optimization algorithms such as hybrid tabu search and simulated annealing (TS/SA)[6], real coded GA (RCGA) [7], differential evolution (DE) [8], hybrid GA [9], Particle swarm optimization (PSO) [10] and novel oppositional krill herd [11] have been proposed in the literature for solving the OPF problem of power systems equipped with FACTS devices.

One of the recently proposed Meta heuristic algorithms is the cuckoo optimization algorithm (COA) [12]. COA is used to solve problems about optimization such as OPF [13], short-term hydrothermal scheduling [14] and combined heat and power economic dispatch [15]. It is based on the intelligent breeding behavior of cuckoo. In this algorithm, there are two main components including mature cuckoos and cuckoo's eggs. During the survival competition, the survived cuckoo societies immigrate to a better environment and restart the process. The cuckoo's survival effort hopefully converges to a state that there is only one cuckoo society with the same maximum profit values. This paper is applied COA for the solution of the OPF problem of power system equipped with TCSC which is formulated as a nonlinear optimization problem with equality and inequality constraints in a power system. Advantage of this algorithm is its simplicity. Therefore, it is very easy to implement. COA has a better convergence rate and probability of getting stuck in a local solution also gets minimized. The proposed approach has been examined and tested on the modified IEEE 30-bus system. Test results have indicated that the proposed method can obtain better optimal solution than GA, SA, TA and TS/SA algorithm.

2. OPF WITH TCSC DEVICES

2.1. Static model of TCSC

The effect of TCSC on the network can be seen as a series reactance with control parameter X_{TCSC} [6]. The model of the network with TCSC is shown in Fig. 1. TCSC is integrated in the OPF problem by modifying the line data. A new reactance (X_{New}) is given as follows

$$X_{New} = X_{ij} - X_{TCSC} \tag{1}$$

The power flow equations of the line can be derived as:

$$P_{ij} = V_i^2 G_{ij} - V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \tag{2}$$

$$Q_{ij} = -V_i^2 B_{ij} - V_i V_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}) \tag{3}$$

$$P_{ji} = V_j^2 G_{ij} - V_i V_j (G_{ij} \cos \delta_{ij} - B_{ij} \sin \delta_{ij}) \tag{4}$$

$$Q_{ji} = -V_j^2 B_{ij} + V_i V_j (G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}) \tag{5}$$

Where $\delta_{ij} = \delta_i - \delta_j$ is the voltage angle difference between bus i and bus j

$$G_{ij} = \frac{R_{ij}}{R_{ij}^2 + X_{New}^2} \quad \text{and} \quad B_{ij} = \frac{X_{New}}{R_{ij}^2 + X_{New}^2} \tag{6}$$
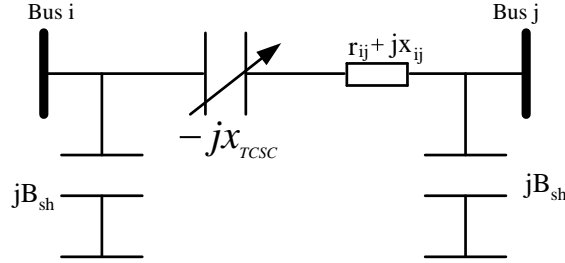

Figure 1. Model of transmission line with TCSC.

2.2. Problem formulation of OPF with TCSC

The objective of OPF is to minimize an objective function while satisfying all the equality and inequality constraints of the power system. The OPF problem with TCSC devices is expressed as follows:

$$Min\ F = \sum_{i=1}^{N} F_i(P_{Gi}) \tag{7}$$

where the fuel cost function $F_i(P_{Gi})$ of generating unit *i* can be expressed in one of the forms as follow:

Quadratic Function:
$$F_i(P_{Gi}) = a_i + b_i . P_{Gi} + c_i . P_{Gi}^2 \tag{8}$$

Valve Point Effect:
$$F_i(P_{Gi}) = a_i + b_i . P_{Gi} + c_i . P_{Gi}^2 + d_i |\sin(e_i(P_{Gi}^{min} - P_{Gi}))| \tag{9}$$

Multiple Fuels:
$$F_i(P_{Gi}) = \{a_{ik} + b_{ik} . P_{Gi} + c_{ik} . P_{Gi}^2, Fuels\ k,\ P_{Gi}^{k-1} \le P_{Gi} \le P_{Gi}^k \tag{10}$$

Subject to

Equality constraints
$$P_{Gi} - P_{di} - \sum_{j=1}^{Nb} |V_i||V_j||Y_{ij}(TCSC)| \cos(\theta_{ij}(TCSC) + \delta_{ij}) = 0 \tag{11}$$
$$Q_{Gi} - Q_{di} - \sum_{j=1}^{Nb} |V_i||V_j||Y_{ij}(TCSC)| \sin(\theta_{ij}(TCSC) + \delta_{ij}) = 0$$

Inequality constraints
$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad i = 1,2,\dots Ng$$
$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \qquad i = 1,2,\dots Ng$$
$$|V_i^{min}| \le |V_i| \le |V_i^{max}| \qquad i = 1,2,\dots Ng$$
$$X_{TCSCi}^{min} \le X_{TCSCi} \le X_{TCSCi}^{max} \qquad i = 1,2,\dots Ntcsc \tag{16}$$
$$T_i^{min} \le T_i \le T_i^{max} \qquad i = 1,2,\dots Nt \tag{17}$$
$$|V_{Li}^{min}| \le |V_{Li}| \le |V_{Li}^{max}| \qquad i = 1,2,\dots N_L$$
$$S_l \le S_l^{max} \qquad i = 1,2,\dots Nl \tag{19}$$

3. APPLICATION CUCKOO OPTIMIZATION ALGORITHM FOR SOLVING OPF WITH TCSC DEVICES

3.1. Introduction Cuckoo optimization algorithm

COA is insprired by a special life style of cuckoo bird, there is no cuckoo bird give birth to live young [12]. Mature cuckoos have to find a place to safely place their eggs and hatch the host bird nests. After that, the feed responsibility will belong to host bird. Some of chicks has come out or egg is laid in bad Habitat will be killed. There is only a number of cuckoo's eggs have chance to grow up and become mature cuckoo. All mature cuckoos will move forward to the best Habitat. After some iteration, the cuckoo poulations will converge in a Habitat with best profit values.

Like other evolutionary algorithm, the proposed algorithm starts with an initial population of cuckoos. These initial cuckoos have some eggs to lay in some host bird's nests. Some of these eggs which are more similar to the host bird's eggs have the opportunity to grow up and become a mature cuckoo. Other eggs are detected by host birds and are killed. The grown eggs reveal the suitability of the nests in that area. The more eggs survive in an area, the more profit is gained in that erea. So the Habitat in which more eggs survive will be the term that COA is going to optimize.

3.2. Generating Initial Cuckoo Habitat

In order to solve an optimization problem, it's necessary that values of problem variablese formed as an array. In COA, it is called "Habitat". In an N_{var} dimensional optimization problem, a habitat is an array of $1 \times N_{var}$, representing current living Habitat of cuckoo. This array is defined as follows:

$$\text{Habitat} = [x1, x2, \ldots, x_{Nvar}] \tag{20}$$

Each of the variable values (x_1, x_2, ..., x_{Nvar}) is floating point number and a Habitat may represent for a vector of control variables in OPF problem. The profit of a habitat is obtained by evaluation of profit function f_P at a habitat of (x_1, x_2, ..., x_{Nvar}):

$$\text{Profit} = f_p(\text{habitat}) = f_p(x1, x2, \ldots, xNvar) \tag{21}$$

COA is an algorithm that maximizes a profit function. In order to use COA in cost minimization problem such as minimizing fitness function in OPF problem, equation (21) can be write as follow.

$$\text{Profit} = -\text{Cost (habitat)} = -f_c(x1, x2, \ldots, xNvar) \tag{22}$$

3.3. Cuckoo's Style for Eggs Laying

In the first iteration of this optimization algorithm, a candidate habitat matrix of size $N_{Pop} \times N_{Var}$ is generated. Then dedicated some random eggs to each cuckoo and calculate it ELR (Eggs Laying Radius). The ELR is defined as:

$$\text{ELR} = \alpha * \frac{\text{Number of current Cuckoo's eggs}}{\text{Total number of eggs}} * (var_{hi} - var_{low}) \tag{23}$$

Where α is a integer to handle the maximum value for ELR and Var_{hi} and Var_{low} is the up and down limits of optimal variables. This ELR has purposes to determine and limit the searching space in each iteration.

3.4. Eliminating Cuckoos in Worst Habitats.

Due to the equilibrium in bird's population, there is only a maximum number of cuckoos live in environment and it name is MaxNumofCuckoos. A priority list may be created by evaluate and sort the frofit valua of the habitat of each newly grown cuckoos. So, there are MaxNumofCuckoos cuckoos from the first of priority list alive, and other cuckoos will be killed. This work will decrease computational time because there are only a number of best solutions to be used in next iteration.

3.5. Immigration of Cuckoos

The habitat in which cuckoo has best condition to live and grow or having best profit value will be considered the goal point of other cuckoos. They will immigrate toward to the goal point to live but not exactly. After a period of time, cuckoos grow up to mature cuckoos and restart the process. It has mean that cuckoo's population will find the best place to live after many iterations. This work will help the OPF problem find the best solutions.

3.6. Application cuckoo optimization algorithm for solving OPF with TCSC

Step 1: Prepare a system data base:

- System topology
- Line and load specifications
- Generation limits
- Line flow limits
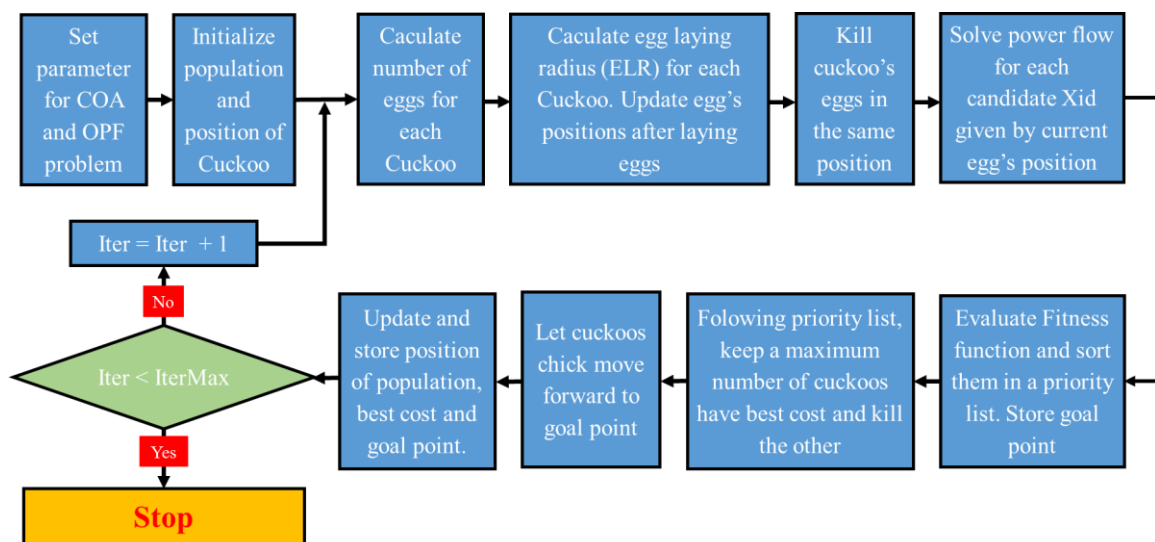- Cost coefficient parameters

Figuge 2. The flowchart of COA implementation for solving the OPF with TCSC.

Step 2: Set parameter for COA and OPF problem:

- NumCuckoos: the number of cuckoos in the first populations.
- MinEggs: the minimum number egg of each cuckoo.
- MaxEggs: the maximum number egg of each cuckoo.
- MaxIter: the maximum number of iterations.
- MotionCoceff : the variable to control the torwards to goal point process.
- MaxCuckoos: the maximum number of Cuckoos that can live at the same time in populations.
- RadiusCoceff: the control parameter of egg laying radius.
- N_{par} is number of optimal variables. It is set equal to number of variales incuded in vector X_{id}.
- K : the penalty factors.

Step 3: Create the initial population

- Each Habitat of cuckoos (X_{id}) are created as follow:

$$X_{id} = X_{id}^{min} + rand1 * (X_{id}^{max} - X_{id}^{min}) \qquad (24)$$

- Where: rand1 is random value in [0,1]

$$X_{id}^{max} = [P_{G2}^{max} \ldots P_{GNG}^{max}, V_{G1}^{max} \ldots V_{GNG}^{max}, T_1^{max} \ldots T_{NT}^{max}, Q_{c1}^{max} \ldots Q_{cNc}^{max}, X_{TCSC1}^{max} \ldots X_{TCSCn}^{max}] \quad (25)$$

$$X_{id}^{min} = \left[P_{G2}^{min} \ldots P_{GNG}^{min}, V_{G1}^{min} \ldots V_{GNG}^{min}, T_1^{min} \ldots T_{NT}^{min}, Q_{c1}^{min} \ldots Q_{cNc}^{min}, X_{TCSC1}^{min} \ldots X_{TCSCn}^{min} \right] \quad (26)$$

- A random goal point are created as follow:
-
$$GoalPoint = X_{id}^{min} + rand1 * (X_{id}^{max} - X_{id}^{min}) \qquad (27)$$

- Habitat is random matrix sized [1 x Npar], and it representing living environment of each cuckoo.

Step 4: Calculate the number of eggs for each cuckoo as follow:

$$NumberCuckoo's\ eggs = (MaxEggs - MinEggs) * rand2 + MinEggs \qquad (28)$$

- Where: rand2 is random value in [0,1].
- In this step, we will determine the amount of random control variable u (Xid). Their value will be determined in the next step.

Step 5: Caculate egg laying radius (ELR) for each Cuckoo. Update egg's positions after laying eggs.

$$ELR_i^{Max} = \frac{NumberCuckoo's\ eggs*(X_{id}^{max} - X_{id}^{min})*RadiusCoeff}{Total\ Number\ of\ Egg} \qquad (29)$$

- To lay eggs, we created some radius values less than maximum of egg laying radius.

$$ELR_i = ELR_i^{Max} * rand3 \qquad (30)$$

- Where rand3 is random matrix size [1 x Number of current eggs], so ELRi is a matrix has a number of eggs rows and Npar colums.

$$Add_i = ((-1)^{rand4} * ELR_i * Cosin(angles) + ELR_i * Sin(angles)) \qquad (31)$$

$$X_{id}^{(1)} = X_{id} + Add_i \qquad (32)$$

- Where rand4 is a random value, it can be set to 1 or 2, and angles is a random line space represent for the flying angles of cuckoo. Each row of matrix X_{id} is a candidate for vector habitat X_{id}, then check for limit for each X_{id} and the egg laying process is done.
- After this step, we have more control variables to be used as input variable for optimal power problem.

Step 6: Solve power flow for each candidate X_{id}:

- Updates values of X_{id} given by step 5 and run Newton-Raphson load flow. The fitness function is calculated by:
$$F\text{T} = f(x, u) + K(P_{G1} - P_{G1}^{\lim})^2 + K\sum_{i=1}^{NG}(Q_{Gi} - Q_{GNG}^{\lim})^2 + K\sum_{i=1}^{NL}(V_{Gi} - V_{Gi}^{\lim})^2 + K\sum_{i=1}^{nl}(S_{li} - S_{li}^{\max})^2 \quad (33)$$
- Where K are penalty factors for real power black bus generation, reactive power generations, load bus vlotages, and power flow in transmission lines, respectively.

$$x^{\lim} = \begin{cases} x_{\max} & if & x > x_{\max} \\ x_{\min} & if & x < x_{\min} \\ x & otherwise \end{cases} \quad (34)$$

- Where $x_{\max}$ and $x_{\min}$ are limits of P_{gi}, Q_{gi}, V_{li} and S_{li}.

Step 7: Evaluate fitness funtion for each X_{id} in step 6. Sorting value of all fitness funtion as a priority list and store the relevant X_{id}.

Step 8: Base on the priority list, keep a number of MaxNumofCuckoos X_{id} and kill the others at the bottom of list.

Step 9: The X_{id} at the first of list is best solution for X_{id} in this interator. It become the best cost and will be the new goal point for others going forward to it's habitat. Their new Habitat is determined as:

$$X_{id}^{(2)} = \left(\text{GoalPoint} - X_{id}^{(1)}\right) * \text{rand5} * \text{MotionCoeff} + X_{id}^{(1)} \quad (35)$$

where rand5 is random number in [0,1]. Then check for X_{id} limits.

Step 10: Updates new values to X_{id} and save best cost, goal point.

Step 11: Check the condition to stop the program. If Iter < IterMax, Iter = Iter + 1 and return to step 3. Otherwise , stop.

- The above steps will help the problem OPF find better solutions.

4. SIMULATIONS RESULTS

In the present work, COA is applied to system IEEE 30-bus [13, 16]. Generator data, load data, line data and minimum and maximum limits for active power sources, bus voltages, tap settings and reactive power sources are also given in [6]. This test system has six generators (at buses 1, 2, 5, 8, 11 and 13), four transformers with off-nominal tap ratios (at lines 6–9, 6–10, 4–

12 and 28–27) and nine shunt VAR compensation devices (at buses 10, 12, 15, 17, 20, 21, 23, 24 and 29). The total system demand is 2.834 p.u. at 100 MVA base. The software is written in MATLAB 2008a computing environment and applied on a 2.63 GHz Pentium IV personal computer with 3 GB RAM. Penalty factors are set to 10^6. The number of cuckoo is set to 10, the maximum and minimum number of eggs is set to 8 and 6, respectively. The *radiusCoeff, motionCoeff* factors and maximum number of cuckoos can live at the same time are 10. Simulation results is tested on three case below.

- **Case 1**: *Comparison COA algorithm with* **TS/SA algorithm and other**
  In this work, line 4 (lines 3-4) is installed with TCSC;
- **Case 2:** *COA algorithm with TCSC is installed at different locations*
  Scenario 1: The OPF problem with TCSC at line 1-3 and line 3-4.
  Scenario 2: The OPF problem with TCSC at line 1-3, line 3-4, line 6-8 and line 28-27
- *Case 3: COA algorithm with different fuel cost functions*
  In this work, scenario 2 in case 2 is considered and the quadratic cost function, valve point effect cost function and multiple fuels cost function are used for OPF problem.

Case 1: Comparison COA algorithm with **TS/SA algorithm and other.**

Table 1. Comparison COA with other algorithms.

	GA [6]	SA [6]	TS [6]	TS/SA [6]	COA
P_{G1} (MW)	192.5105	192.5105	192.5105	192.5105	177.6318
P_{G2} (MW)	48.3951	48.3951	48.3951	48.3951	49.2279
P_{G5} (MW)	19.5506	19.5506	19.5506	19.5506	21.8312
P_{G8} (MW)	11.6204	11.6204	11.6204	11.6204	14.0136
P_{G11} (MW)	10	10	10	10	16.0120
P_{G13} (MW)	12	12	12	12	13.5002
Total P_G (MW)	294.0766	294.0766	294.0766	294.0766	292.2165
P_{loss} (MW)	10.6766	10.6766	10.6766	10.6766	8.8165
Total cost ($/h)	**804.1072**	**804.1072**	**804.1072**	**804.1072**	**799.9561**
TCSC (pu)	0.02	0.02	0.02	0.02	0.021

Table 2. Comparison of various methods from 20 runs.

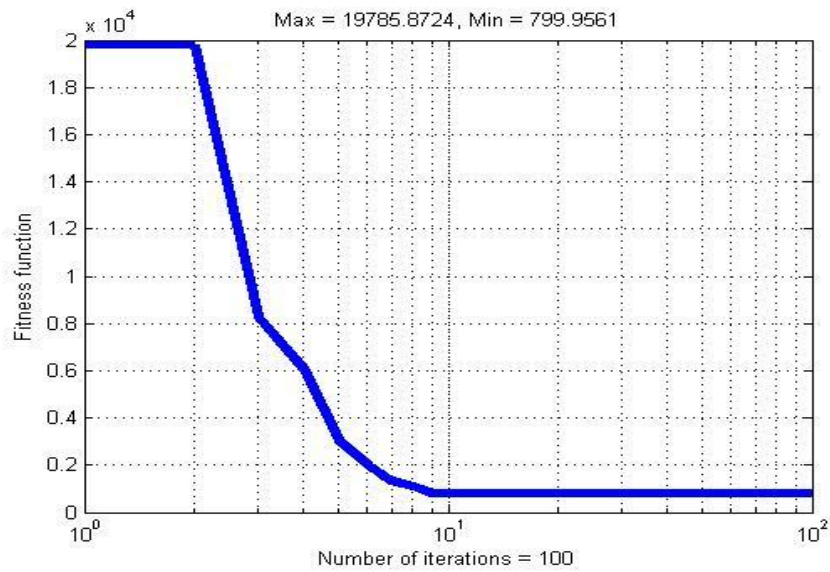|	GA	SA	TA	TS/SA	COA
Max cost	804.3255	804.1082	804.1078	804.1074	803.9582
Average cost	804.2142	804.1075	804.1074	804.1073	801.5984
Min cost	804.1072	804.1072	804.1072	804.1072	799.9561

Figure 3. Convergence characteristic with valve point effect.

It can be seen from Table 1, the obtained minimum fuel cost by the proposed approach is **799.9561** $/h. This value obtained by COA is less than compared to GA, TS, SA and TS/SA. In addition, from Table 2, it can be also seen that, results obtained by COA is better than GA, SA, TA and TS/SA after 20 runs.

Case 2: *COA algorithm with TCSC is installed at different locations*

Table 3. The simulation results of COA in other cases.

	Scenario 1	Scenario 2
P_{G1} (MW)	179.1553	177.5963
P_{G2} (MW)	47.8153	47.4095
P_{G5} (MW)	21.0198	21.0775
P_{G8} (MW)	18.7795	20.4210
P_{G11} (MW)	13.4071	13.3149
P_{G13} (MW)	12.0752	12.2835
Total P_G (MW)	292.2521	292.1028
Total cost ($/h)	**799.0763**	**798.9857**

Case 3: COA algorithm with different fuel cost functions

60

Table 4. The results of COA with different fuel cost functions.

	Quadratic fuel cost function	Valve point effect	Multiple Fuels cost function
P_{G1} (MW)	177.5963	199.6008	139.9865
P_{G2} (MW)	47.4095	20.0000	54.9571
P_{G5} (MW)	21.0775	23.5567	27.8188
P_{G8} (MW)	20.4210	18.5873	20.5987
P_{G11} (MW)	13.3149	15.2091	21.7638
P_{G13} (MW)	12.2835	15.9524	25.3760
Total P_G (MW)	292.1028	292.9062	290.5008
Total cost ($/h)	798.9857	919.1082	641.6920

From results in case 2 (Table 3) and case 3 (Table 4, Fig 4 – Fig 6) it can be seen that, with many TCSC is installed at different locations, COA has still the ability to converge to a better quality solution and possesses good convergence characteristics for OPF problem having multiple fuel cost function and valve point effect function. The convergence characteristic show that COA quickly move to the goal point. Thus, proposed COA can be used for solving large-scale OPF problem.
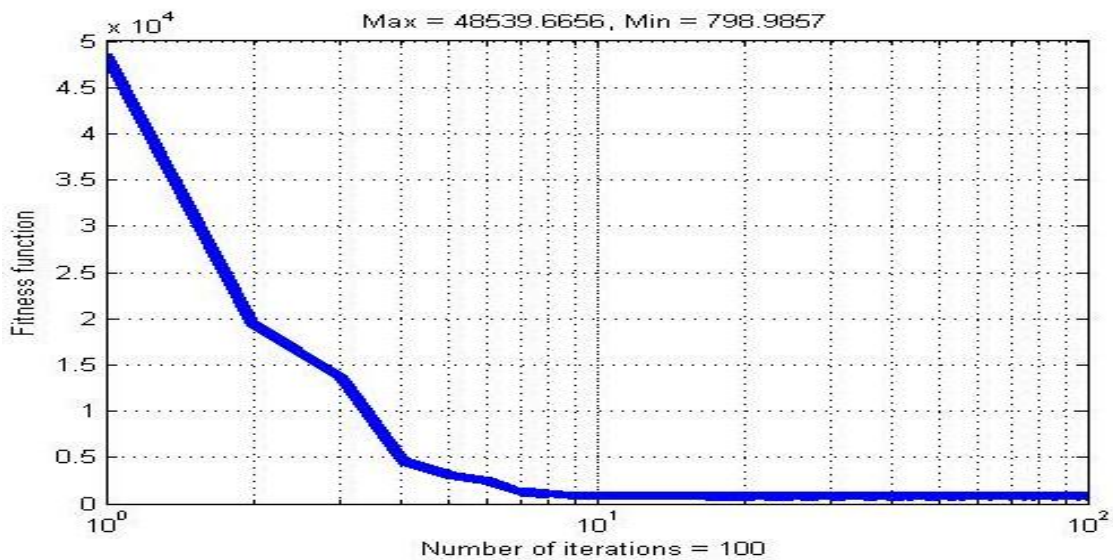

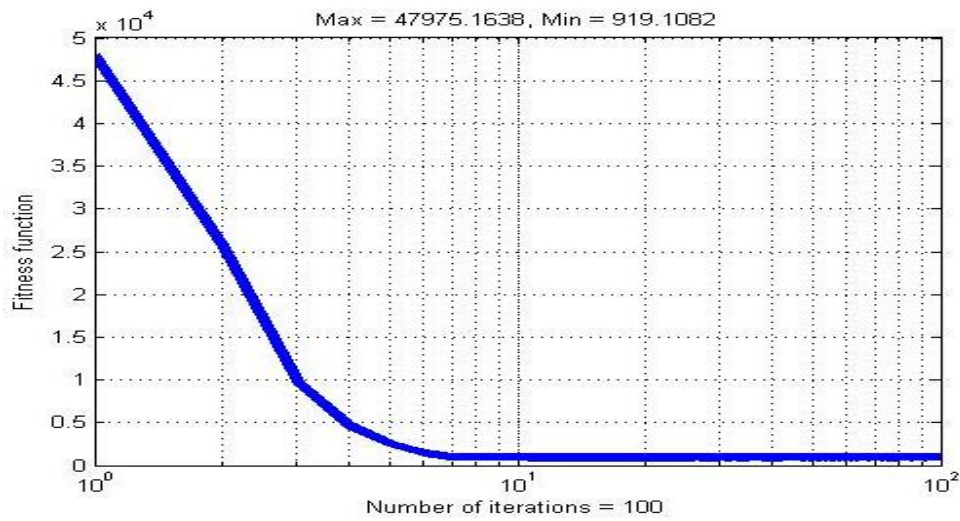*Figure* 4. Convergence characteristics with quadratic function.

Figure 5. Convergence characteristic with valve point effect.
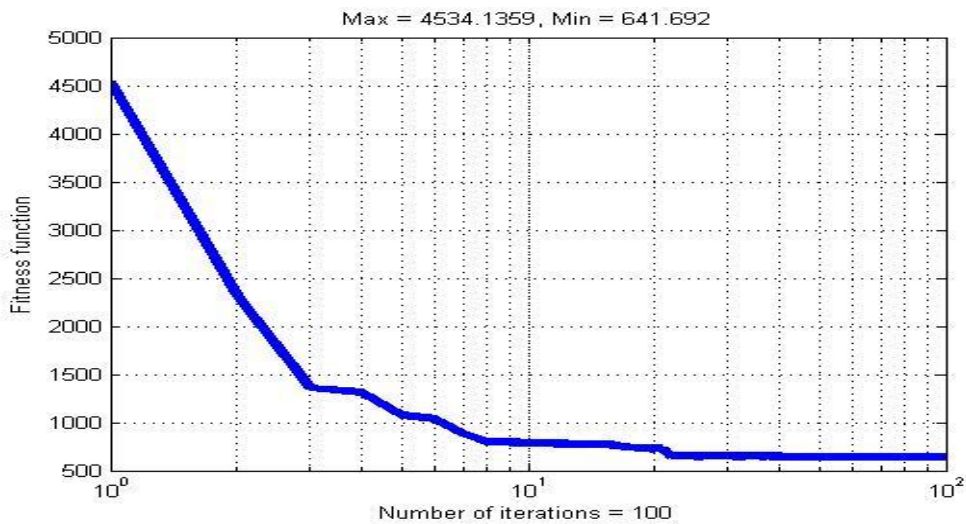

Figure 6. Convergence characteristic with multiple Fuels cost function.

5. CONCLUSIONS

In this paper, COA has been, successfully, implemented to solve OPF problem of power system equipped with TCSC devices. This algorithm has been tested for the solution of OPF problem with TCSC devices having different types of objective functions on IEEE 30-bus test power system. This network is equipped with TCSC devices at fixed locations. The results obtained from the proposed COA approach are compared with other techniques recently reported in the literature. It has been observed that the COA has the ability to converge to a better quality solution and possesses good convergence characteristics compared with GA, SA, TA and TS/SA techniques

REFERENCES

1. Hsmmns., Lim S.K. - Flexible AC transmission system (FACTS). Electric Mach Power Syst. **25** (5) (1997) 73–85.

2. Zhang X., Rehtanz C., Pal B. - Flexible AC transmission systems: modelling and control. Berlin Springer (2006) 380.

3. Stagg G.W., El-Abid A.H. - Computer methods in power system analysis. McGraw-Hill (1968) 288.

4. Carpentier J. - Optimal power flows. Electric Power Energy Syst **1** (8) (1979) 959–972.

5. Sun D.I., Ashley B., Brewer B., Hughes A., Tinney W.F. - Optimal power flow by newton approach. IEEE Trans Power Apparat Syst **103** (10) (1984) 2864–2880.

6. Ongsakul W., Bhasaputra P. - Optimal power flow with FACTS devices by hybrid TS/SA approach. Int. J. Electr. Power Energy Syst. **24** (10) (2002) 851–857.

7. Basu M. - Multi-objective optimal power flow with FACTS devices. Energy Convers Manage **52** (2) (2011) 903–910.

8. Basu M. - Optimal power flow with FACTS devices using differential evolution. Int J Electr Power Energy Syst. **30** (2) (2008) 150–156.

9. Chung T.S., Li Y.K. - A hybrid GA approach for OPF with consideration of FACTS devices. IEEE Power Eng. Rev. **20** (8) (2000) 54–57.

10. Rudra Pratap Singh., Mukherjee V., Ghoshal S.P. - Particle swarm optimization with an aging leader and challengers algorithm for optimal power flow problem with FACTS devices. Electrical Power and Energy Systems **64** (3) (2015) 1185–1196.

11. Aparajita Mukherjee., Mukherjee V. - Solution of optimal power flow with FACTS devices using a novel oppositional krill herd algorithm. Electrical Power and Energy Systems **78** (5) (2016) 700–714.

12. Rajabioun R. - Cuckoo optimization algorithm. Applied Soft Computing **11** (7) (2011) 5508 – 5518.

13. Nguyen Tu Le Anh., Dieu Ngoc Vo, Weerakorn Ongsakul, Pandin Vasant and Timothy Ganesan - Cuckoo optimization algorithm for optimal power flow. Proceeding in Adaptation, Learning and Optimization **1** (37) (2015) 479-493.

14. Thang Trung Nguyen., Dieu Ngoc Vo. - Modified cuckoo search algorithm for short-term hydrothermal scheduling. Electrical Power and Energy Systems **65** (4) (2015) 271–281.

15. Thang Trung Nguyen., Dieu Ngoc Vo., Bach Hoang Dinh - Cuckoo search algorithm for combined heat and power economic dispatch. Electrical Power and Energy Systems **81** (4) (2016) 204–214.

16. Zimerman R. D., Murillo Sanchez C. E. and Gam D. - MATPOWER A MATLAB power system simulation package", Version 4, available at:

    http://www.pserc.cornell.edu/matpower. 15-02-2016.