International Journal on Emerging Technologies 11(1): 245-256(2020)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Optimal Location of Static VAR Compensator using Evolutionary Optimization Techniques

***Rahul Agrawal*[1], *S.K. Bharadwaj*[2] *and Kishor C. Muley*[3]**

[1]*Associate Professor, Department of Electrical Engineering, Sandip University, Nashik (Maharashtra), India.*
[2]*Professor, Department of Electrical Engineering,*
Maulana Azad National Institute of Technology, Bhopal (Madhya Pradesh), India.
[3]*Assistant Professor, Department of Electrical Engineering, Sandip University Nashik (Maharashtra), India.*

(Corresponding author: Rahul Agrawal)
(Received 09 October 2019, Revised 05 December 2019, Accepted 13 December 2019)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: The location and size of the Flexible AC Transmission System (FACTS) and its potential play a vital role in the accomplishment of any utility which in turn results inexpensive power at the consumer end. This paper introduces the evolutionary optimization technique, Artificial Bee Colony (ABC) algorithm to get the optimal location and size of Static VAR compensator (SVC) to explore the active and reactive power transmission losses and establishment cost of SVC. The proposed algorithm has been tested on the IEEE 14, IEEE 30 and UPSEB 75 bus systems, to exemplify the relevance of the algorithm. The outcomes assimilated from ABC are analogized with the Particle Swarm Optimization (PSO) and Teaching Learning Based Optimization (TLBO) to show the predominance and capability of the ABC over TLBO and PSO.

Keywords: ABC, Installation cost, SVC, TLBO and Transmission Losses.

I. INTRODUCTION

With the improvement of mankind the power system turns out to be increasingly complex. The complexity and dimension of present day power system are multiplying step by step. The vital thought based on diurnal activity of current power system is stability and reliability alongside specific limitations, for example, least transmission loss. Through in power system the transmission loss are inborn, causing financial losses. From the utility viewpoint the loss minimization is a significant tool for planning, operation and design and thereby minimizes the expense of distribution and transmission systems. FACTS devices give the empowering arrangement of this issue.

The idea of FACTS first comes in the literature in 1986 [1]. The use of FACTS devices in a power system context is first proposed in Hingorani (1988) [2]. The related terms and portrayal of different sorts of FACTS controller is proposed by Edris (1997) [3]. FACTS controllers operate continuously and increase the safe operating limits of the power system without compromising stability. The rating and location of the FACTS devices assume an imperative trade in the power market for the utilities to estimation future speculation plan and power network extension [4-5]. Based on the power electronics switch FACTS devices can be classified as thyristor based and VSC based FACTS controller [6]. SVC, Thyristor- Controlled Series Capacitor (TCSC) and Thyristor-Controlled Phase Angle Regulator (TCPAR) are classified as thyristor based FACTS controller, whereas STATic *synchronous Compensator* (STATCOM), Unified Power Flow Controller (UPFC), *Static Synchronous Series Compensator* (SSSC), and Interline Power Flow Controller (IPFC) are classified as VSC based FACTS controller [6].

SVC is most generally utilized FACTS device and more than 850 SVCs are as of now in application worldwide by industry and utilities. In industry SVC is utilized especially in arc furnace and rolling mills application [7]. ABB and Siemens is a pioneer in the innovative work of SVC.

The optimal rating and position of FACTS devices are useful to minimize the transmission loss, investment cost, generation cost, voltage variation, sub synchronous resonance and reactive power compensation. The location and size of FACTS devices are also helpful to enhance power transfer capability, load sharing capability, power quality, loading capacity, transient stability and security of the modern transmission system. The disbursement of FACTS devices is expensive, so one should select their positions and optimal value judiciously. To overcome the limitation of conventional optimization techniques such as slow speed and large computation burden, numerous heuristic optimization techniques such as Harmony Search Algorithm (HSA), Bacteria Swarm Optimization, Teaching learning Based Optimization, and Artificial Bee Colony, Multi-Objective Differential Evolution, etc. has been presented in the literature during recent years to determine the location, size, type and control of FACTS devices.

In Dragonfly algorithm is presented for the optimal cost and optimal value of the SVC to enhance the voltage deviation [8]. The algorithm is tested on the IEEE 14 and 30 bus frameworks and result of Dragonfly algorithm compares with other methods of optimization. Alvarez-Alvarado (2018) discussed the optimal size, location and scheduling of Dispersed Static Var Compensators (D-SVC) using multi state PSO with linear and non-linear loads [9]. Singh & Agrawal (2010) presented the optimal location and the size of the SVC to improve the voltage profile of the system using Newton Raphson power flow algorithms [10]. MATPOWER and MATLAB Simulations were performed on IEEE 14 and IEEE 30 bus test systems under different reactive power condition. Nguyen *et al.,* (2016) examines the effectiveness of Cuckoo search algorithm to minimize the voltage deviation and investment cost of Static VAR Compensator [11].

The result obtained from the Cuckoo search algorithm was found better as compared to PSO and Harmony search algorithm. Balachennaiah *et al.,* (2015) describes the application of ABC for optimal power flow with SVC has multi-objective function, namely, power loss minimization and voltage stability enhancement [12]. The optimal location and sizing is used as a control variable and simulation is performed on standard IEEE 14 bus test system using MATLAB. The optimal location and size of SVC using a Galaxy based search algorithm with voltage deviation and real power losses as an objective function is presented in [13]. The optimal location and size of SVC to enhance voltage and minimize the transmission loss of the IEEE 14, IEEE 30 and IEEE 57 bus systems using a Self Adaptive Firefly Algorithm (SAFA) were examined by [14]. The result obtained from Self adaptive Firefly algorithm was found better as compared to Bacterial Foraging algorithm. Hemachandra *et al.,* (2019) proposed a hybrid Kinetic Gas Molecule Optimization-PSO for optimal sizing of PSO to minimize the cost of SVC for the standard IEEE-30 bus system [25]. Sahu and Saxena, (2013) proposed a method to enhance the dynamic performance of the power system stabilizer with SVC. Simulation results are carried with MATLAB software [26].

Going through the literature we observed that many papers appeared for improving voltage profile, sizing of the FACTS device, optimization of the location and minimization of the active power loss for various standard IEEE bus systems and do not take reactive power loss in account to optimize the location and size of SVC. In this paper, an Artificial Bee Colony algorithm is presented for solution of multi-objective problems. The Newton Raphson power flow algorithm is implemented with and without SVC using evolutionary optimization techniques for optimizing the objective function. The objective function consists of real power transmission loss, reactive power transmission loss and installation cost of the SVC. In order to show the effectiveness of the proposed simulation the IEEE 14, IEEE 30 and Indian 75 bus test systems are taken as examples. The results obtained are reasonable and comparison of ABC with PSO and TLBO are presented.

This research work presented the optimal location and rating of SVC in power system using the ABC. The ABC Algorithm is a heuristic optimization technique developed by Karaboga (2005) [15]. It is a population based swarm intelligence method [17]. It is based on the foraging behavior of the honey bees [15, 17]. The colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts. An employed bee searches the available food sources, after collecting bring it to their origin and as per the food availability they do waggle dance. An onlooker bee selects the food source, depending upon the probability of food [16]. The scout bee searches the new food source when the food source of any employed bee is abandoned.

The major contribution of this research work includes the following

(i) The proposed mathematical model of transmission line includes a half line charging susceptance and tap changing transformer to determine the complex transmission losses of the system.

(ii) Apart from the determination of the overall active and reactive power losses, reactive power flow of the transmission line is also present in the present research work.

(iii) The solution is converging to optimal value in all the three techniques, but the variation occurs merely in the last converged values.

The paper is organized as follows. Section II presents the modelling of SVC. In section III formulations of the objective function are described. Section IV describes the implementation of ABC for optimal placement of SVC. Section V discusses the results. The suitability of the artificial bee colony algorithms using flexible AC transmission system devices is presented by comparing the results. Finally, section VI presents the conclusion.

II. MODELING OF SVC

The Fig. 1 shows the variable susceptance model of SVC. This model of SVC is considered in power flow equation with ABC to determine the optimal location and sizing. By varying the susceptance, reactive power varies to maintain the bus voltage. The current through the SVC and reactive power capacity of the SVC at bus 'k' is formulated as

$$I_{svc} = j\,B_{svc} \times V_k \quad (1)$$

$$Q_{svc} = -\,j\,B_{svc} \times V_k^2 \quad (2)$$

where, V_k is the voltage, B_{SVC} is the susceptance of SVC, I_{SVC} is the injected current of SVC and Q_{SVC} is the injected reactive power of SVC at the k^{th} bus respectively.

The lower and upper bound of susceptance is given by the Eqn. (3)

$$B_{svc}^{min} \le B_{svc} \le B_{svc}^{max} \quad (3)$$

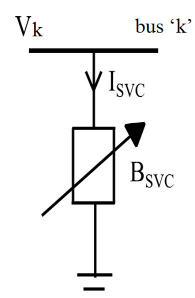

Fig. 1. The Variable susceptance model of SVC.

III. OBJECTIVE FUNCTIONS

The objective functions described are as follows:

A. Minimization of the Active Power and Reactive Power Loss

Consider the equivalent π model of a transmission line with admittance Y_{ik} between the *earth* and *quiet* bus as shown in Fig. 2. Let the current enters at i^{th} and k^{th} bus are I_i and I_k and bus voltage at i^{th} and k^{th} bus are V_i and V_k respectively.

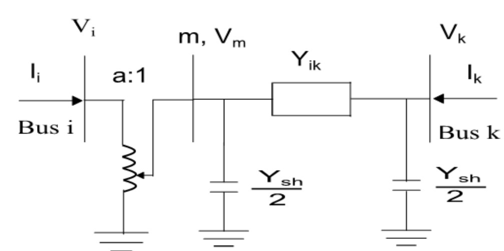

Fig. 2. Equivalent pi model of transmission line.

Here Y_{sh} is the line charging admittance and '*a*' is the tap ratio of the tap setting transformer.

The current flowing from the i^{th} bus to k^{th} bus is given by I_{ik}

$$I_{ik} = \left(\frac{V_i}{a^2} - \frac{V_k}{a}\right) Y_{ik} + \frac{V_i}{a^2} \times \frac{Y_{sh}}{2} \quad (4)$$

Similarly the current flowing from the k^{th} bus to i^{th} bus is given by I_{ki}

$$I_{ki} = \left(V_k - \frac{V_i}{a}\right) Y_{ik} + V_k \times \frac{Y_{sh}}{2} \quad (5)$$

The complex power S_{ik} and S_{ki} measured at the buses i and k respectively, and both defined positive into the line are expressed as

$$S_{ik} = P_{ik} + jQ_{ik} = V_i I_{ik}^* = V_i \left(\frac{V_i^*}{a^2} - \frac{V_k^*}{a}\right) Y_{ik}^* + \frac{|V_i|^2}{a^2} \times \frac{Y_{sh}^*}{2} \quad (6)$$

$$S_{ki} = P_{ki} + jQ_{ki} = V_k I_{ki}^* = V_k \left(V_k^* - \frac{V_i^*}{a}\right) Y_{ki}^* + |V_k|^2 \times \frac{Y_{sh}^*}{2} \quad (7)$$

The algebraic sum of Eqns. (6) and (7) determine the complex losses in the transmission line.

$$S = S_{ik} + S_{ki} \quad (8)$$

The first objective is defined by the real part of the Eqn. (8) and expressed mathematically as

$$P_{loss} = \text{real } (S) \quad (9)$$

After the normalization first objective function is given by

$$\min f_1 = \frac{P_{loss}}{P_{loss_o}} \quad (10)$$

where, P_{loss} is the active power transmission loss with SVC and optimization methods and P_{loss_o} is the active power transmission loss without SVC and optimization method.

The second objective is defined by the imaginary part of the Eqn. (8) and expressed mathematically as

$$Q_{loss} = \text{Img } (S) \quad (11)$$

The normalization form of second objective function can be expressed as

$$\min f_2 = \frac{Q_{loss}}{Q_{loss_o}} \quad (12)$$

where, Q_{loss} is the reactive power transmission loss with SVC and optimization methods and Q_{loss_o} is the reactive power transmission loss without SVC and optimization method.

A. Minimization of the Installation Costs

The minimization of the installation cost of the SVC device is selected as the third objective and written by (13)

$$IC_{SVC} = C_{SVC} \times S_{SVC} \times 1000 \quad (13)$$

where, IC_{SVC} is the installation cost of SVC [in US$], C_{SVC} is the cost of SVC devices [in US$/ kVAR] and S_{SVC} is the Operating range of SVC [in MVAR].

The total SVC cost in US$/ kVAR is given as

$$C_{svc} = 0.0003S^2 - 0.3051S + 127.38 \text{ [US\$/kVAR]} \quad (14)$$

The normalization form of installation cost is given by the Eqn. (15)

$$\min f_3 = \frac{IC_{SVC}}{IC_{SVCo}} \quad (15)$$

where, IC_{SVCo} installation cost of SVC without optimization method.

The multi objective optimization problem consisting Eqns. (10), (12) and (15) and network constraints is converted into a single objective optimization problem with the fitness function expressed as

$$F = \alpha_1 \times f_1 + \alpha_2 \times f_2 + \alpha_3 \times f_3 \quad (16)$$

where, α_2, α_2 and α_3 are the weighting factors. The weighting factors are defined as the [19]

$$\alpha_1 = w_1 \times w_2 \quad (17)$$

$$\alpha_2 = (1 - w_1) \times w_2 \quad (18)$$

$$\alpha_3 = (1 - w_2) \quad (19)$$

$$\alpha_1 + \alpha_2 + \alpha_3 = 1 \quad (20)$$

The factor w_1 and w_2 are selected between 0 and 1. In present research the value of the factor w_1 = 0.7120, w_2 = 0.6850, α_1 = 0.4877, α_2 = 0.1973 and α_3 = 0.3150 are chosen based upon the weightage given to the objective function.

The Eqn. (16) is subjected to the following equality and inequality constraints

Equality constraints:

The real and reactive power balance equations for n-bus power system is

$$P_i^{spc} - \sum_{j=1}^{n} |V_i||V_j| \{G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)\} = 0 \quad (21)$$

$$Q_i^{spc} - \sum_{j=1}^{n} |V_i||V_j| \{G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j)\} = 0 \quad (22)$$

P_i^{spc} and Q_i^{spc} are the specified real and reactive power at the bus 'i' and expressed in terms of total power generated and total load demand as per the Eqn. (23) and (24)

$$P_i^{Spc} = P_i^G - P_i^D \quad (23)$$

$$Q_i^{Spc} = Q_i^G - Q_i^D \quad (24)$$

where P_i^G and P_i^D are the real power generation and real power demand at the i^{th} bus, Q_i^G and Q_i^D are the reactive power generation and reactive power demand at the i^{th} bus, B_{ij} the susceptance between the ith i^{th} and j^{th} bus, G_{ij} the conductance between the i^{th} and j^{th} bus, V_i and V_j is the voltage of the i^{th} and j^{th} bus, δ_i and δ_j is the phase angles of the i^{th} and j^{th} bus respectively.

Inequality constraints: Real power generation constraint

$$|P_{Gi}| \leq \varepsilon \quad \text{for } i=1, 2...NG \quad (25)$$

Reactive power generation constraint

$$|Q_{Gi}| \leq \varepsilon \quad \text{for } i=1, 2...NG \quad (26)$$

Bus voltage constraint

$$|V_i^{min}| \leq |V_i| \leq |V_i^{max}| \quad \text{For } i=1, 2...N \quad (27)$$

Tap setting Transformer constraint

$$tap_i^{min} \leq tap_i \leq tap_i^{max} \quad \text{For } i=1, 2...N \quad (28)$$

SVC reactive power constraint

$$-100 \text{ MVAR} \leq Q_{SVC} \leq 100 \text{ MVAR} \quad (29)$$

where, NG is the set of PV buses, N is the set of buses and ε is the tolerance. Here ε it is 0.0001 pu.

IV. IMPLEMENTATION OF ABC FOR THE OPTIMAL PLACEMENT OF SVC

ABC algorithm is the effective and powerful algorithm for determining the location and size of the FACTS devices. In the ABC algorithm, first half of the colony consists of employed artificial bees and the second half constitutes the onlookers. In the ABC algorithm, each cycle of the search consists of three steps: sending the employed bees onto the food sources and then measuring their nectar amounts; selecting of the food sources by the onlookers after sharing the information of employed bees and determining the nectar amount of the foods; determining the scout bees and then sending them on to possible food sources [15-17].

Step by step procedure of ABC is explained in the subsection below:

Step1: Set the location and size of SVC as a decision variable of ABC.

Step II: Initialize the ABC parameter namely

D = Number of parameter or decision variable

CS = Colony size, it represents the number of ants in the colony

Max cycle = Maximum number of iterations

Cycle = Current iteration

EB = CS/2 = Number of employed bee

Step III: Initialize the employed bee position randomly in the search space bounded by D and EB. The j^{th} parameter of i^{th} employed bee is given by the following equation

$$x_i = x_j^{min} + (x_j^{max} - x_j^{min}) \times rand(EB, D) \quad (30)$$

where

x_j^{min} = minimum value of decision variable

x_j^{max} = maximum value of decision variable

$rand$ = uniformly distributed random number between (0, 1)

Step IV: Read the line data, generator data, transformer data and bus data. Run the Newton Raphson (NR) load flow for each employed bee as generated above. Calculate the objective function f_i for each employed bees. The objective function value in ABC, represent the amount of nectar in the food source.

Step V: Calculate fitness function using the following equation

$$fit_i = \begin{cases} \dfrac{1}{(1+f_i)} & \text{if } f_i \geq 0 \\ 1+abs(f_i) & \text{if } f_i < 0 \end{cases} \quad (31)$$

Fitness function corresponds to the quality of the food source.

Step VI: Employed bee phase

(a) Set cycle =1.

(b) Update the employed bee position using the equation

$$V_{ij} = x_{ij} + R_{ij}(x_{ij} - x_{kj}) \quad (32)$$

where V_{ij} = new position of employed bee

x_{ij} = current position of employed bee

j = parameter to change (1, 2…………, D)

k = neighbour bee parameter generates randomly between 1, 2………, EB ≠ i

R_{ij} = random no. in the interval [–1, 1]

(c) Update the bus data, and run the load flow using the NR method for each decision variable of employed bee. Update the objective function f_i^{new} corresponding to V_{ij}. Update the fitness function fit_i^{new} corresponding to V_{ij}.

(d) Apply greedy selection for employed bee phase. Compare the new food source V_{ij} to x_{ij}, to decide the good food source. If the new food source is better than the old food source, bee remembers it and corresponding value of f_i^{new} and fit_i^{new}.

Step VII: Onlooker bee phase

(a) Select onlooker bee based on the probability value p_i of the food source using the fitness function f_i^{new} as per the formula

$$p_i = \frac{f_i^{new}}{\sum_{n=1}^{EB} f_i^{new}} \quad (33)$$

(b) Update onlooker bee position by using (30). Update the bus data, and run the load flow using the NR method for each decision variable of onlooker bee. Evaluate objective function f_i^{new1} and fit_i^{new1}.

(c) Apply greedy selection for onlooker bee phase. If the new solution f_i^{new1} is better than the previous solution f_i^{new}, replace the previous solution with the new one, and corresponding position.

Step VIII: Scout bee phase-If the position of employed bee cannot be improved from pre-determined number of cycle than that food source is called abundant food source. That employed bee becomes a scout bee and randomly produced a new solution x_i as per the Eqn. (34).

$$x_i = x_j^{min} + rand(1, D) \times (x_j^{max} - x_j^{min}) \quad (34)$$

Where $rand$ (1, D) is the uniformly distributed random number between (0, 1).

Step IX: Remember the best food so far.

Step X: Cycle = Cycle + 1

Step XI: If cycle ≤ max cycle, go to step VI otherwise go to step XII.

Step XII: Stop

The pseudo code of the proposed ABC algorithm with an optimal location of SVC is given in Table 1.

Table 1: The Pseudo code for ABC algorithm with SVC.

Begin Read system data, line data and bus data Run the Newton Raphson load flow algorithm and determine the bus voltage, active power and reactive power for all the buses. Initialize the position and rating of the SVC as an optimization parameter of ABC. Initialize D, CS, EB and termination criterion Generate an initial population of employed bee $x_i = x_j^{min} + (x_j^{max} - x_j^{min}) \times rand(EB, D)$ Evaluate the objective function f(x) for all employed bee Calculate the fitness function fit(x) as per eq. (31) trial=zeros(1, EB) **For cycle= 1: maximum cycle {termination criterion}** { Employed bee phase} Update the initial population of employed bee $V_{ij} = x_{ij} + R_{ij}(x_{ij} - x_{kj})$ Update system data, line data and bus data Run the Newton Raphson load flow algorithm for each employed bee V_{ij} Update the objective function f^{new}

```
            Update the fitness function fit^new
            Calculate the minimum value of the objective function
             Apply greedy selection for employee bee phase
                for i=1:EB
                       If f(i) <= f^new(i)    (if previous value less then new value)
                       V_ij (i)=x_ij (i)
                       f^new(i)= f(i)
                       fit^new(i)= fit(i)
                        trial(i)=trial(i)+1  (trial counter increase by one, if new value not better than previous value)
                       end
                end of employed bee phase
{ Onlooker bee phase}
      Select onlooker bee based on the probability value p_i of the food source using the fitness function f^new as per the Eqn. (33)
           Update onlooker bee position V_ij1 = x_ij + R_ij (x_ij - x_kj)
            Update system data, line data and bus data
            Run the Newton Raphson load flow algorithm for each onlooker bee V_ij1
            Update the objective function f^new1
            Update the fitness function fit^new1
             Calculate minimum value of the objective function
              Apply greedy selection for onlooker bee phase
                 for i=1:EB
                        If f^new (i) <= f^new1(i)    (if previous value less then new value)
                        V_ij1 (i)=V_ij (i)
                        f^new1(i)= f^new (i)
                        fit^new1(i)= fit^new (i)
                         trial(i)=trial(i)+1  (trial counter increase by one, if new value not better than previous value)
                        end
                 end of onlooker bee phase
Scout bee phase
Memorize  the best food so far
End of termination criterion
Display optimal value of result
```

V. TEST RESULTS AND DISCUSSION

The three optimization algorithms are coded using MATLAB programming language with Newton Raphson power flow and applied on a 4 GHz, i5 personal laptop with 4 GB RAM. Simulation is performed on the following test systems

(a) Test system 1- IEEE 14 bus system,
(b) Test system 2- IEEE 30 bus system and
(c) Test system 3- UPSEB 75 bus system.

The line data, bus data, shunt data and generator data (at 100 MVA base) are taken from [20, 21]. The location and rating of SVC are considered as the optimized variable in the objective function. SVC is placed on the load buses only, where the generator and condenser are not connected. The parameter values of the ABC, PSO and TLBO optimization methods are listed in Table 2. The minimum and maximum limits of voltage magnitude are here considered to be 0.95 p.u. to 1.05 p.u. The number of generators, condenser, load buses, transmission lines and transformer taps for the test systems is presented in Table 3.

A. Result for IEEE 14 bus System

The real and reactive power transmission loss, location, rating and installation cost of SVC of the IEEE 14 bus system obtained from ABC are compared with those obtained from PSO and TLBO is presented in Table 4. Table 4 indicates that the optimal location of SVC for test system 1 is at bus number 7. From the Table 4 it is evident that if SVC is placed on the bus number 7, the real power transmission loss is reduced from 11.165 MW to 10.7878 with ABC, though with PSO and TLBO it is discovered 10.7878 MW and 10.7999 MW individually. Similarly the reactive power transmission loss without SVC is 29.2705 MVAR while with SVC using ABC, TLBO and PSO; it is found 26.333MVAR, 26.976 MVAR and 26.429 MVAR respectively.

Table 2: Parameter values for ABC, PSO and TLBO.

ABC parameter		PSO Parameter		TLBO parameter	
Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
Maximum number of iterations	35	Number of iterations	35	Termination criterion	35
Number of decision variable	2	Number of design variable	2	Number of subjects	2
Colony Size (CS)	40	Population size	20	Number of students	20
Limit	40	Inertial Weight, w	0.88 to 0.38	Rand	0 to 1
Number of employed bees (EB)	20	Constant, C1	2		
Rand	0 to 1	Constant, C2	2		
		rand1	0 to 1		
		rand2	0 to 1		

Table 3: System data for the standard test systems.

System Data	IEEE 14 Bus System	IEEE 30 Bus System	UPSEB 75 Bus System
Number of generators	2 (bus no. 1 and 2)	3 (bus no. 1 to 6)	15 (bus no. 1 to 15)
Number of condenser	3 (bus no. 3, 4 and 5)	3 (bus no. 3, 4 and 5)	
Number of load buses	9 (bus no. 6 to 14)	24 (bus no. 7 to 30)	60 (bus no. 16 to 75)
Number of transmission lines	20	41	98
Number of Transformer taps	3 (between buses 8-3, 9-6, 9-7)	4 (between buses 11-9, 13-7, 13-8 and 28-10)	24 buses (between buses 16-2, 17-1, 17-16, 18-3, 19-20, 22-25, 23-24, 24-10, 26-27, 28-4, 29-30, 31-5, 32-6, 33-7, 34-8, 35-9, 36-37, 38-39, 40-11, 41-12, 42-13, 43-14, 44-15 and 45-44).

It is shown in Table 4 that after placing SVC, both real and reactive power transmission losses of the test system 1 is reduced. The installation cost of the SVC with PSO is 48551 US$, with TLBO it is 54016 US$ whereas with ABC it is found 31651 US$. The installation cost of the SVC with PSO is less against those obtained from TLBO. For the test system 1 the bus voltage without SVC at bus number 7 is 0.9938 per unit (pu), whereas with PSO, it is 0.9985 pu, with TLBO it is 0.9972 pu and with ABC it is found 0.9991 pu. Table 4 indicates the improvement in the bus voltage with SVC. The graphical representation of the bus voltage for the test system 1 is also shown in Fig. 3. The real power transmission loss for the IEEE 14 bus system with iterations is shown in Fig. 4. The results converge faster with ABC as compared to TLBO and PSO is also depicted in the Fig. 4. The results of SVC using ABC are superior as compared to those obtained from PSO and TLBO for all the control variables.

Table 4: Transmission loss and installation cost analysis without and with SVC using ABC, PSO and TLBO of IEEE 14 bus system.

Control Variable	Without SVC	With SVC using PSO	With SVC using TLBO	With SVC using ABC
Real power Transmission loss (MW)	11.165	10.7878	10.7999	10.7878
Reactive power Transmission loss (MVAR)	29.2705	26.429	26.976	26.333
SVC size (MVAR)		38.1743	42.4749	24.8779
Installation Cost (US$)		48551	54016	31651
Bus Number		7	7	7
Voltage in pu at bus 7 (pu)	0.9938	0.9985	0.9972	0.9991

Table 5: Reactive power flow (MVAR) without and with SVC using ABC, PSO and TLBO of IEEE 14 bus system.

Line Number	From Bus	To Bus	Without SVC	With SVC using TLBO	With SVC using PSO	With SVC using ABC
3	9	7	9.313	3.915	0.760	0.087
12	6	7	27.064	18.278	12.077	10.054
13	7	10	7.370	7.223	6.331	4.473
17	7	14	6. 269	5.622	5.050	3.866

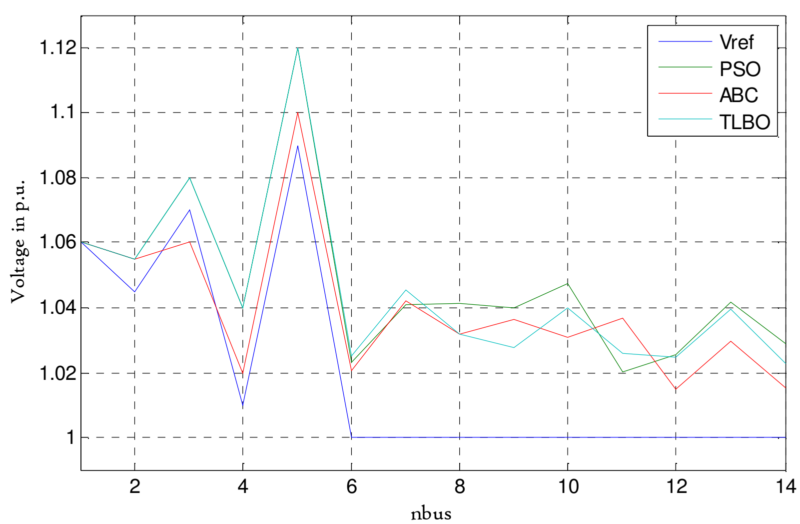

Fig. 3. Bus voltage (pu) of IEEE 14 bus system with SVC using ABC, PSO and TLBO.

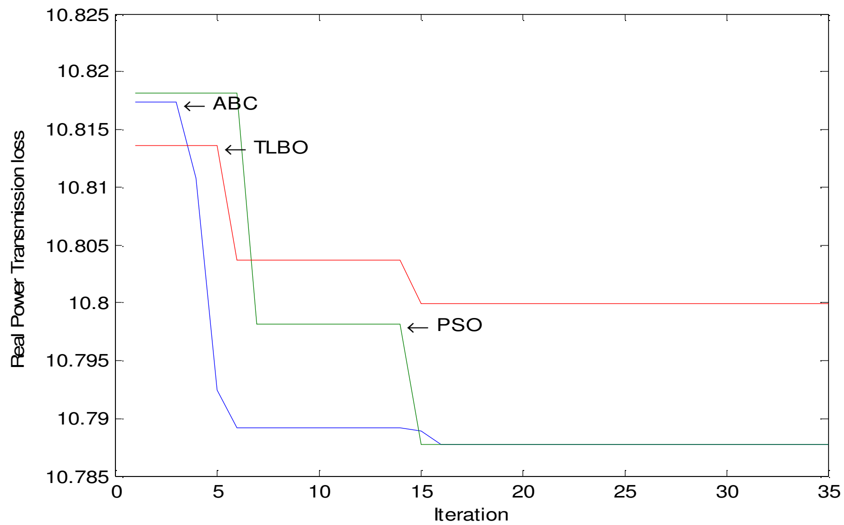

Fig. 4. Real power transmission loss (MW) of IEEE 14 bus system with optimization methods.

From the Table 4 it is clear that SVC is placed on the bus number 7, which is connected to bus number 9, 6, 10 and 14 through the line number 3, 12, 13 and 17 respectively. The reactive power flow without SVC and with SVC for the line number 3, 12, 13 and 17 are presented in Table 5. From the Table 5 it is visible that before the placement of SVC the reactive power is heavily flow in the lines, and after placement of SVC the reactive power flow of the lines is reduced.

For the IEEE 14 bus system with the identical system constraints, the results obtained using the ABC, PSO and TLBO technique presented in this paper are compared to some other optimization techniques reported in the literature as shown in Table 6. From the Table 6 it is evident that, the techniques presented in present paper perform better as comparable to those obtained using other techniques for minimizing the transmission losses. This highlights their capacity to give a superior quality solution.

B. Result for IEEE 30 bus System

The single line diagram of the IEEE 30 bus system is illustrated in Fig. 5. The system data for the IEEE 30 bus system is shown in Table 3.

The real and reactive power transmission loss, location, size and installation cost of SVC for the IEEE 30 bus system is given in Table 7. The real power transmission loss without SVC for IEEE 30 bus system is 6.8212 MW and with SVC it is found 6.5124 MW, 6.5169 MW and 6.5108 MW are respectively using PSO, TLBO and ABC. This outcome demonstrates that power transfer capacity of the considered test system has made strides.

From the Table 7 it is clear that if SVC is placed on the bus number 7, the reactive power transmission loss is reduced from 20.309 MVAR to 18.375 MVAR with ABC, though with PSO and TLBO it is discovered 19.178 MVAR and 19.215 MVAR respectively. From the result, it is evident that both real and reactive power transmission losses of the IEEE 30 bus system are decreased. The installation cost of the SVC with PSO is 69803 US$, with TLBO it is 80181 US$ whereas with ABC it is found 68581 US$ respectively. It is also seen from the Table 7 that SVC is placed on the bus number 7 with a value 54.906 MVAR, 63.081 MVAR and 53.942 MVAR using PSO, TLBO and ABC respectively. The results of SVC using ABC are superior as compared to those obtained from PSO and TLBO for all control variables.

The graphical representation of the real power transmission loss for the IEEE 30 bus system with iterations is shown in Fig. 6. It is observed from the Fig. 6 that during the first iteration, the real power transmission loss is lowest with PSO while highest with TLBO. With the iterations the results of all the three optimization methods are improved and after 20 iterations they give the best results. It is also depicted in the Fig. 6 that the result converges faster with ABC as compared to TLBO and PSO.

The reactive power flow without and with SVC using ABC, PSO and TLBO of IEEE 30 bus system is presented in Table 8. The reactive power flow in the line number 8 without SVC is -19.893 MVAR while with SVC using TLBO, PSO and ABC it is found -4.583 MVAR, -4.537 MVAR and -3.256 MVAR respectively. From the Table 8 it is clear that after the placement of SVC the reactive power flow of all the lines connected to bus number 7 is reduced.

Table 6: Comparative study of transmission loss of IEEE 14 bus system with SVC and optimization techniques.

S. No.	Optimization Technique	Active Power Transmission Loss in MW
1.	Firefly Algorithm [14]	13.2451
2.	Bacterial Foraging [14]	13.2616
3.	Bacterial Foraging [23]	17.1690
4.	Biogeography Based optimization (BBO) [24]	12.9306
5.	Chemical Reaction Optimization (CRO) [24]	12.8246
6.	Quasi-Oppositional Chemical Reaction Optimization QOCRO [24]	12.7843

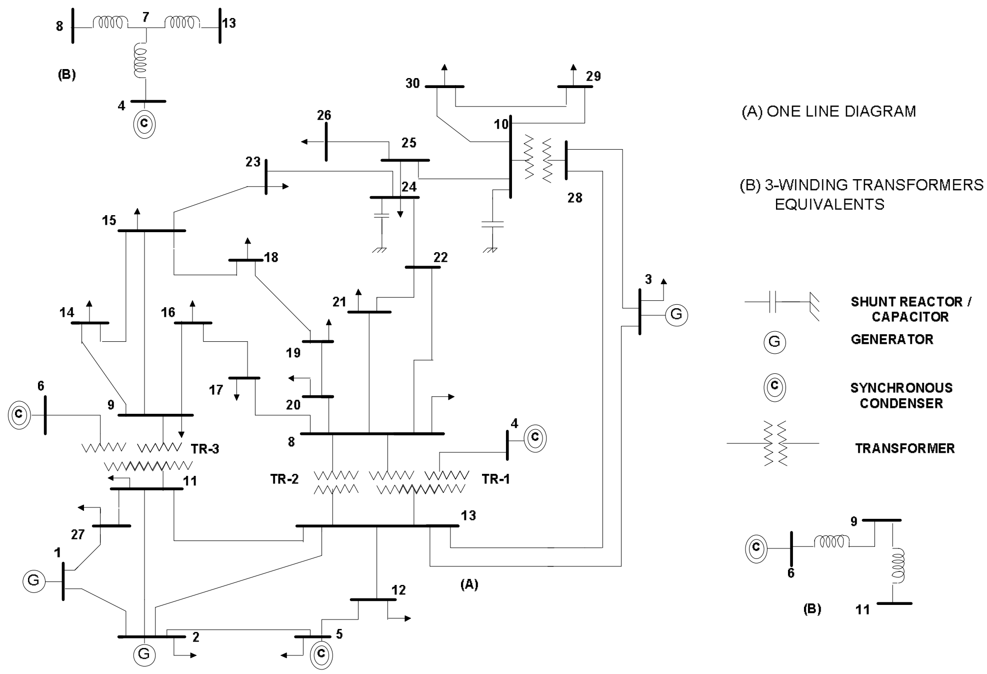

Fig. 5. Single line diagram of the IEEE 30 bus system.

Table 7: Transmission loss and installation cost analysis without and with SVC using ABC, PSO and TLBO of IEEE 30 bus system.

Control Variable	Without SVC	With SVC using PSO	With SVC using TLBO	With SVC using ABC
Real power Transmission loss in MW	6.8212	6.5124	6.5169	6.5108
Reactive power Transmission loss in MVAR	20.309	19.178	19.215	18.375
SVC size (MVAR)		54.906	63.081	53.942
Installation Cost (US$)		69803	80181	68581
Bus Number		7	7	7

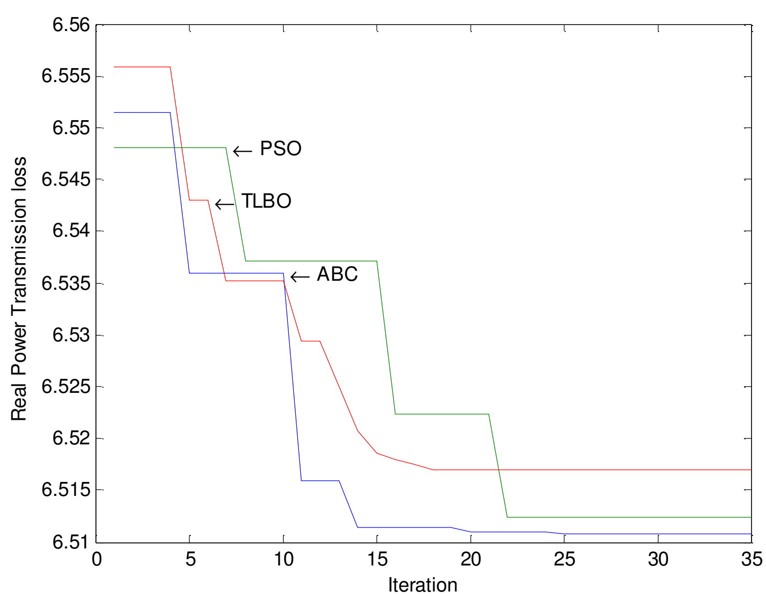

Fig. 6. Real power transmission loss of IEEE 30 bus system with optimization methods.

The bus voltage with SVC using optimization techniques is indicated in Table 9. From the Table 9 it is clear that, voltage of all the load buses is improved with optimization methods. The outcome obtained from ABC is better as compared to those obtained from TLBO and PSO. The pictorial representation of the bus voltage for the test system 2 is also shown in Fig. 7.

Table 8: Reactive power flow (MVAR) without and with SVC using ABC, PSO and TLBO of IEEE 30 bus system.

Line Number	From Bus	To Bus	Without SVC	With SVC using TLBO	With SVC using PSO	With SVC using ABC
8	7	4	-19.893	-4.583	-4.537	-3.256
9	7	8	-14.566	-7.169	-7.111	-5.268
23	13	7	1.628	1.574	1.573	1.56

Table 9: Bus voltage of the IEEE 30 bus system in pu with SVC.

Bus Number	Specified Voltage Magnitude Vsp in p.u.	Voltage With SVC in p.u.			Bus Number	Specified Voltage Magnitude Vsp in p.u.	Voltage With SVC in p.u.		
		PSO	ABC	TLBO			PSO	ABC	TLBO
1	1.0600	1.0600	1.0600	1.0600	16	1.0000	1.0180	1.0018	1.0172
2	1.0450	1.0550	1.0550	1.0550	17	1.0000	1.0104	1.0009	1.0027
3	1.0100	1.0300	1.0200	1.0300	18	1.0000	1.0101	1.0068	1.0045
4	1.0820	1.0812	1.0800	1.0820	19	1.0000	1.0141	1.0125	1.0120
5	1.0100	1.0210	1.0100	1.0200	20	1.0000	1.0251	1.0125	1.0263
6	1.0710	1.0410	1.0381	1.0391	21	1.0000	1.0191	1.0109	1.0128
7	1.0000	1.0042	1.0022	1.0031	22	1.0000	1.0108	1.0102	1.0104
8	1.0000	1.0176	1.0101	1.0125	23	1.0000	1.0153	1.0105	1.0148
9	1.0000	1.0158	1.0111	1.0155	24	1.0000	1.0155	1.0138	1.0142
10	1.0000	1.0111	1.0101	1.0108	25	1.0000	1.0127	1.0103	1.0105
11	1.0000	1.0113	1.0106	1.0106	26	1.0000	1.0106	1.0111	1.0102
12	1.0000	1.0196	1.0192	1.0198	27	1.0000	1.0142	1.0021	1.0140
13	1.0000	1.0109	1.0025	1.0046	28	1.0000	1.0123	1.0046	1.0120
14	1.0000	1.0140	1.0132	1.0135	29	1.0000	1.0145	1.0139	1.0140
15	1.0000	1.0142	1.0095	1.0112	30	1.0000	1.0163	1.0115	1.0137

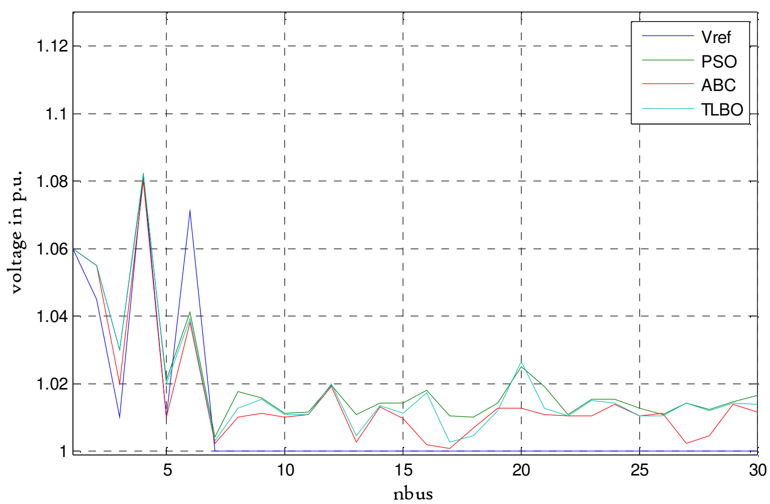

Fig. 7. Bus Voltage (pu) of IEEE-30 Bus system with SVC using ABC, PSO and TLBO.

Under the identical network conditions, the results obtained using the ABC, PSO and TLBO techniques reported in this work are compared with other optimization techniques as shown in Table 10. From the Table 10 it is evident that, the proposed techniques outperform many techniques used to minimize the real power transmission loss because the results obtained using the ABC is 6.5108 MW, which are better as comparable to those obtained using other techniques.

C. Utter Pradesh State Electricity Board (UPSEB) 75 bus Indian power system

The single line diagram of Utter Pradesh State Electricity Board (UPSEB) 75 bus Indian power system is shown in Fig. 8. The generator data, load bus data, transformer data and line data are given in the appendix with Tables A1 A2, A3 and A4 respectively.

Table 10: Comparative study of transmission loss of IEEE 14 bus system with other optimization techniques.

S. No.	Optimization Technique	Active Power Transmission Loss in MW	IEEE Bus System	FACTS Device
1.	Bacterial Foraging [14]	17.1906	30	SVC
2.	Differential Evolution [18]	9.3200	30	TCSC
3.	Evolutionary Programming [18]	10.4200	30	TCSC
4.	Genetic Algorithms [18]	10.1700	30	TCSC
5.	Bacterial Foraging [22]	10.1900	30	TCSC
6.	Firefly algorithm [14]	17.1601	30	SVC

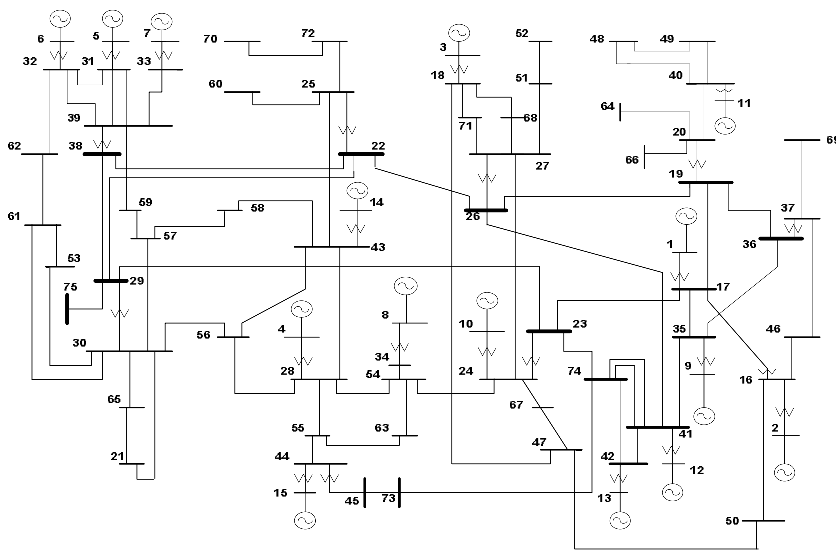

Fig. 8. Single line diagram of the UPSEB 75 bus system.

The real power transmission loss and reactive power transmission loss, location, size and installation cost of SVC for the UPSEB 75 bus system is presented in Table 11. It is evident from the results that after placement of SVC, the real power transmission loss and reactive power transmission loss of the test system 3 are reduced, with all the three optimization techniques. The installation cost of the SVC with PSO is 117730 US$, with TLBO it is 126020 US$ whereas with ABC it is found 101940 US$ respectively. From the Table 11 it is clear that installation cost and size of SVC with ABC is better as compared to PSO and TLBO.

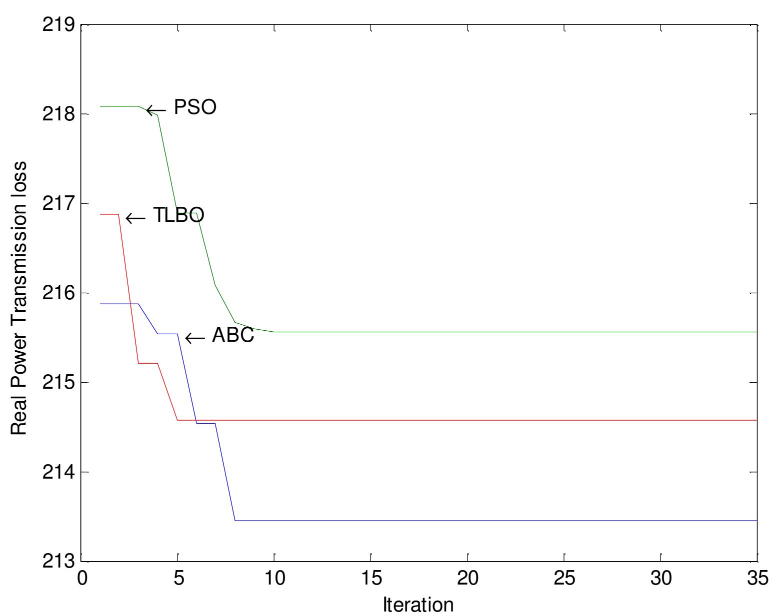

Fig. 9. Real power transmission loss (MW) of UPSEB-75 bus system with optimization methods.

Table 11: Transmission loss and installation cost analysis without and with SVC using ABC, PSO and TLBO of UPSEB 75 bus system.

Control Variable	Without SVC	With SVC using PSO	With SVC using TLBO	With SVC using ABC
Real power Transmission loss in MW	224.3341	215.5505	214.5742	213.4502
Reactive power Transmission loss in MVAR	319.519	289.165	291.2512	288.056
SVC size (MVAR)		92.6846	99.2294	80.2366
Installation Cost (US$)		117730	126020	101940
Bus Number		53	26	38

For the test system 3 the optimal location of the SVC is at bus number 38, 53 and 26 for the ABC, PSO and TLBO respectively. The bus voltage without SVC at bus number 38, 53 and 26 is 0.9752, 0.9534 and 0.9341 pu respectively. The bus voltage including SVC at bus number 38, 53 and 26 with ABC, PSO and TLBO is 0.9999, 1.0149 and 0.9873 pu respectively. From the Table 11 it is clear that the result of ABC is superior as compared to those obtained from PSO and TLBO.

Real power transmission loss for the UPSEB 75 bus system with iterations is illustrated in Fig. 9. It is seen from the Fig. 9 that the real power transmission loss obtained from ABC, in the first iteration is minimum for the test system 3. It is observed from the Fig. 9 that the reduction in real power transmission loss with iteration is better using ABC as compared to TLBO and PSO.

VI. CONCLUSION

This paper shows a multi-criterion-based optimization utilizing an evolutionary technique ABC so as to decide the optimal location and rating of an SVC device for a given power network. The simulation outcomes of the Artificial Bee Colony (ABC) are distinguished with the Particle Swarm Optimization (PSO) and Teaching Learning Based Optimization (TLBO) to demonstrate the adequacy of the ABC and its predominance over PSO and TLBO. The exhibited ABC algorithm gives promising and preferable outcomes over the PSO and TLBO for minimization of the establishment cost, real and reactive transmission power losses and improves the performance of the system under consideration. The attended results demonstrate that the real power transmission loss of the test system 1 with ABC and PSO is same though for the test system 2 and 3 the consequence of ABC is better when contrasted with PSO and TLBO. All the three optimization strategies performed well and can also be applied to the different kinds of FACTS devices for the previously mentioned goal work in conjunction with wind generation or DG unit.

REFERENCES

[1]. Electric Power Research Institute Journal, Vol. 11, Number 3, April-May 1986

[2]. Hingorani, N. G. (1988). Power electronics in electric utilities: role of power electronics in future power systems. *Proceedings of the IEEE*, *76*(4), 481-482.

[3]. Edris, A. A. (1997). Proposed terms and definitions for flexible AC transmission system (FACTS). *IEEE Transactions on Power Delivery*, *12*(4), 1420-1429.

[4]. Song, Y. H., & Johns, A. (Eds.). (1999). *Flexible ac transmission systems (FACTS)* (No. 30). IET.

[5]. Gupta, M., Kumar, V., Banerjee, G. K., & Sharma, N. K. (2017). Mitigating congestion in a power system and role of FACTS devices. *Advances in Electrical Engineering*, 1-7.

[6]. Narain, G.. Hingorani, & Gyugyi, L. (2000). *Understanding FACTS: concepts and technology of flexible AC transmission systems*. IEEE press. (Page No.)

[7]. Kashani, M. G., Babaei, S., & Bhattacharya, S. (2013). SVC and STATCOM application in Electric Arc Furnace efficiency improvement. In *2013 4th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG)* (pp. 1-7). IEEE.

[8]. Vanishree, J., & Ramesh, V. (2018). Optimization of size and cost of static var compensator using dragonfly algorithm for voltage profile improvement in power transmission systems. *International Journal of Renewable Energy Research (IJRER)*, *8*(1), 56-66.

[9]. Alvarez-Alvarado, M. S., Rodríguez-Gallegos, C. D., & Jayaweera, D. (2018). Optimal planning and operation of static VAR compensators in a distribution system with non-linear loads. *IET Generation, Transmission & Distribution*, *12*(15), 3726-3735.

[10]. Singh, B., & Agrawal, G. (2018). Enhancement of voltage profile by incorporation of SVC in power system networks by using optimal load flow method in MATLAB/Simulink environments. *Energy Reports*, *4*, 418-434.

[11]. Nguyen, K. P., Fujita, G., & Dieu, V. N. (2016). Cuckoo search algorithm for optimal placement and sizing of static var compensator in large-scale power systems. *Journal of Artificial Intelligence and Soft Computing Research*, *6*(2), 59-68.

[12]. Balachennaiah, P., Reddy, P. H., & Raju, U. N. K. (2015). A novel algorithm for voltage stability augmentation through optimal placement and sizing of SVC. In *2015 IEEE international conference on signal processing, informatics, communication and energy systems (SPICES)* (pp. 1-5). IEEE.

[13]. Kumara, B. S., Suryakalavathib, M., & Kumara, G. N. (2016). Optimal Power Flow with Static VAR Compensator Using Galaxy Based Search Algorithm to Minimize Real Power Losses. *Procedia Computer Science*, *92*, 42-47.

[14]. Selvarasu, R., Kalavathi, M. S., & Rajan, C. C. A. (2013). SVC placement for voltage constrained loss minimization using self-adaptive Firefly algorithm. *Archives of Electrical Engineering*, *62*(4), 649-661.

[15]. Karaboga, D. (2005). *An idea based on honey bee swarm for numerical optimization*, *200*, 1-10. Technical report-tr06, Erciyes university, engineering faculty, computer engineering department.

[16]. Karaboga, D., & Basturk, B. (2007). Artificial bee colony (ABC) optimization algorithm for solving constrained optimization problems. In *International fuzzy systems association world congress* (pp. 789-798). Springer, Berlin, Heidelberg.

[17]. Karaboga, D., & Basturk, B. (2007). A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm. *Journal of global optimization*, *39*(3), 459-471.
[18]. Basu, M. (2008). Optimal power flow with FACTS devices using differential evolution. *International Journal of Electrical Power & Energy Systems*, *30*(2), 150-156.
[19]. Kim, I. Y., & De Weck, O. L. (2006). Adaptive weighted sum method for multiobjective optimization: a new method for Pareto front generation. *Structural and multidisciplinary optimization*, *31*(2), 105-116.
[20]. Joshi, S. K. (1995). *Voltage stability and contingency selection studies in Electric Power systems* (Doctoral dissertation, Ph. D. thesis, Department of Electrical Engineering, IIT Kanpur, India).
[21]. Verma, M.K. (2005). Voltage Stability Considered Power System Security Assessment and its Enhancement Using FACTS Controllers, Ph. D. Thesis, IIT Kanpur,
[22]. Kumar, M. S., & Renuga, P. (2010). Bacterial foraging algorithm based enhancement of voltage profile and minimization of losses using Thyristor Controlled Series Capacitor (TCSC). *International Journal of Computer Applications*, *7*(2), 21-27.
[23]. Prabaakaran, K., Jaisiva, S., Selvakumar, A., Kumar, K. S. (2013). Implementation of Bacterial Foraging Algorithm for Enhancing Voltage Profile and Loss Minimization using Static Var Compensator. *International Journal for Research and Development in Engineering*, *1*(3), 43-50.
[24]. Dutta, S., Paul, S., & Roy, P. K. (2018). Optimal allocation of SVC and TCSC using quasi-oppositional chemical reaction optimization for solving multi-objective ORPD problem. *Journal of Electrical Systems and Information Technology*, *5*(1), 83-98.
[25]. Reddy, H. K., Reddy, P. R. K. K. and Ganesh, V. (2019). Optimal Allocation of Multiple Facts Devices with Hybrid Techniques for Improving Voltage Stability. *International Journal on Emerging Technologies*, *10*(4): 76–84.
[26]. Sahu, Ravi Kumar and Saxena, Nitin (2013). Dynamic Performance of Power Transmission system improvement using Static Var Compensator, *International Journal of Electrical, Electronics and Computer Engineering, 2*(2): 134-137.

How to cite this article: Agrawal, Rahul, Bharadwaj, S. K. and Muley, Kishor C. (2020). Optimal Location of of Static VAR Compensator Using Evolutionary Optimization Techniques. *International Journal on Emerging Technologies*, *11*(1): 245–256.