Optimal Placement of FACTS Devices using ABC Algorithm to Enhance System Performance

Y V Balarama Krishna Rao, R Srinivasa Rao. V V K Reddy

Abstract*: The interest of power is expanding everyday. Consequently, there is a stamped increment of booked power which streams in the transmission line and an abrupt power trades prompting complex power transmission issues.This can be overcome either by constructing new transmission lines or by extending range of existing loadability limit of transmission lines. The construction of new lines is cost effective, hence this problem is overcome by proper placement FACTS devices. This paper proposes a methodology for optimum location and sizing of Interline Power Flow Controller (IPFC), Thyristor Controlled Phase Shifting Transformer (TCPST) using artificial bee colony (ABC) algorithm. Power injection model of IPFC and TCPST is used to study the effects of parameters of IPFC, TCPST in power flow studies. In this work three objectives considered. They are improving system loadability, reduction of Installation cost, reduction of transmission loss. The adequacy of the proposed strategy is exhibited on 6 transport, IEEE 30 transport, IEEE 57 transport and IEEE118 transport frameworks. The proposed calculation is executed in MATLAB and results got are contrasted and existing writing. The outcomes plainly show that joining of FACTS gadgets in ideal area with suitable parameter setting increases the system loadability, reduced installation cost and reduction in transmission loss. From results it is observed that power flows are improved considerably and a better voltage is obtained.

Index Terms*: TCPST, IPFC, ABC algorithm, optimal placement, system loadability, voltage profile, power flow, transmission loss, installation cost.

I. INTRODUCTION

Electric power system is a network, in which the electrical components are deployed to transfer, store and supply the power. The overloaded lines are avoided by maximum capacity of power transmission lines. The power system is operated under loadability and stability margins on account of limitations of energy resources. The operational measures active power flow, reactive power flow control and reduction in transmission loss are to be done. The efficiency of existing networks can be improved through FACTS device installation which controls various parameters of the power system such as voltage, phase angle and line impedance in a rapid and effective manner.

Congestion management through optimal allocation and sizing of IPFC based on line utilization factor is presented [1]. Multi objective optimal power flow calculation to improve the execution of multi-smaller scale lattice is talked about [2]. Affectability examination strategy for ideal area of IPFC to diminish genuine power misfortune and genuine influence stream execution record is given [3]. Demonstrating, examination, impacts of IPFC working limitations, for example, infused arrangement voltages, line flows and traded powers among arrangement converters are researched [4-5]. Molecule swarm advancement and versatile gravitational pursuit calculation (GSA) strategies are proposed for improving the voltage soundness of the power transmission frameworks [6]. Economic load dispatch problem is solved by optimal location of IPFC based on line stability index using BAT algorithm [7]. Optimal location of IPFC for reducing installation cost and real power generation using LR method is presented [8]. Controlled power flow analysis of IPFC using its new steady state model by adjusting its parameters is presented [9]. Transient stability analysis by reducing rotor angle deviation during fault using IPFC is given [10].

Heuristic strategies SA, TS and GA are connected to the ideal area of TCPST in power framework to upgrade the security edge [11]. ICA utilized for explaining distribution of TCPST with the goal that low estimations of over-burdens and voltage deviations are come about both amid line possibilities and request development [12]. The ideal area and tuning of TCPST dependent on ideal power stream and cross entropy technique introduced [13]. The ideal area of TCPST utilizing computational knowledge calculation for improving the loadability of pool and cross breed models in rebuilt control framework [14]. Ideal area of TCPST to improve voltage steadiness edge and minimization of receptive power misfortune using Genetic algorithm is presented [15]. Optimal location and rating of FATCTS device TCPST using Graphical user interface for maximizing the system loadability and reduction of generation costs of active and reactive power using low discrepancy sequences are given [16]-[17]. Fault current is controlled by proper phase shift angle control of TCPST [18]. Optimal location and rating of TCPST using gravitational search algorithm for active power loss minimization of transmission line is presented 19].

This paper presents optimal location and sizing of Facts controllers IPFC, TCPST using artificial bee colony algorithm. The optimum placement is done, by satisfying IPFC and TCPST operating constraints. The optimal location is done to improve system loadability, reduce transmission loss, and reduce installation cost of FACTS devices IPFC and TCPST. The convergence characteristics of ABC algorithm is better in solving constrained optimization problem and improve active power flow, voltage profile.

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The cost function of IPFC, TCPST are taken from Siemens database [22]. The optimum location and sizing of IPFC, TCPST is determined using ABC. The MATLAB code is tested on 6 bus test system and standard IEEE-30 bus, IEEE-57 bus and IEEE-118 bus systems.

Rest of the paper is organized as follows: section II gives mathematical modeling of IPFC&TCPST, section III explains problem formulation, section IV highlights the implementation of proposed methodology, section V presents results and discussions, and section VI gives conclusions.

II. MATHEMATICAL MODELING OF IPFC AND TCPST

A. Interline Power Flow Controller (IPFC)

The interline control stream controller redresses or controls the power stream in various lines. The schematic portrayal of IPFC is appeared in Fig.1. IPFC comprises of no less than two air conditioning dc converters associated through a typical DC connect [20]. It has three transports I, j, k and two transmission lines I-j and I-k.

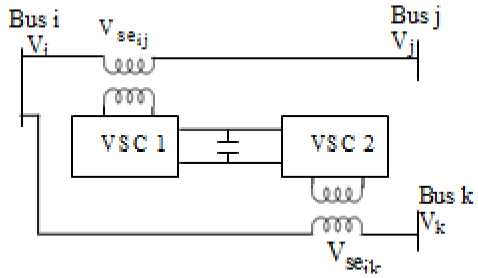

Fig.1. Schematic representation of IPFC

The power course through a line is constrained by controlling voltage greatness and stage point of IPFC. The converters have the capacity of engrossing or producing the responsive power freely. The unpredictable voltages at the transports I, j and k are $V_i\angle\delta_i$, $V_j\angle\delta_j$ and $V_k\angle\delta_k$ respectively. $V_{se_{in}}\angle\theta_{se_{in}}$, (n=j, k) are the infused voltages in lines I-j, I-k. The equal circuit of the IPFC alluded as power infusion demonstrate is appeared in Fig.2. The Voltage Source Converters might be spoken to as a synchronous voltage source [21] infusing sinusoidal voltage with controllable size and edge.

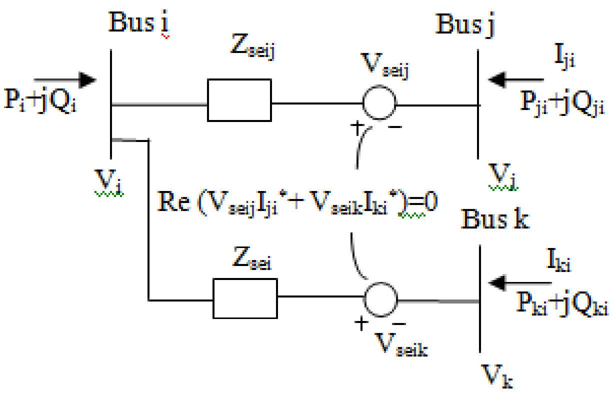

Fig.2.Equivalent circuit of IPFC

Zse_{ij}, Zse_{ik} are the series transformer impedances. The active and reactive powers injected by series converter connected between buses i, j are P_i, Q_i and P_{ji}, Q_{ji} respectively. I_{ji}, I_{ki} are the IPFC branch currents of lines j−i and k−i leaving bus j and k.

$$P_i = V_i^2 g_{ii} - \sum_{j=1, j\neq i}^{n} V_i V_j (g_{ij}\cos\delta_{ij} + b_{ij}\sin\delta_{ij}) - \sum_{j=1, j\neq i}^{n} V_i V_{seij}(g_{ij}\cos(\delta_i - \theta_{seij}) - b_{ij}\sin(\delta_i - \theta_{seij})) \quad (1)$$

$$Q_i = -V_i^2 b_{ii} - \sum_{j=1, j\neq i}^{n} V_i V_j (g_{ij}\sin\delta_{ij} - b_{ij}\cos\delta_{ij}) - \sum_{j=1, j\neq i}^{n} V_i V_{seij}(g_{ij}\sin(\delta_i - \theta_{seij}) - b_{ij}\cos(\delta_i - \theta_{seij})) \quad (2)$$

$$P_{ji} = V_j^2 g_{jj} - \sum_{j=1, j\neq i}^{n} V_i V_j (g_{ij}\cos\delta_{ji} + b_{ij}\sin\delta_{ji}) + \sum_{j=1, j\neq i}^{n} V_i V_{seij}(g_{ij}\cos(\delta_j - \theta_{seij}) - b_{ij}\sin(\delta_j - \theta_{seij})) \quad (3)$$

$$Q_{ji} = -V_j^2 b_{jj} - \sum_{j=1, j\neq i}^{n} V_i V_j (g_{ij}\cos\delta_{ji} - b_{ij}\sin\delta_{ji}) + \sum_{j=1, j\neq i}^{n} V_i V_{seij}(g_{ij}\cos(\delta_j - \theta_{seij}) - b_{ij}\sin(\delta_j - \theta_{seij})) \quad (4)$$

Where $g_{ij} + jb_{ij} = g_{jj} + jb_{jj} = \dfrac{1}{Z_{seij}} = Y_{seij}$ (5)

$$g_{ii} + jb_{ii} = (g_{ij} + g_{ik}) + j(b_{ij} + b_{ik}) \quad (6)$$

Similarly the equations for bus k also derived in the same manner.

Assuming a loss less converter, the active power supplied by one converter is equal to active demanded by another converter i.e. the active power exchange between converters via common dc link is

$$\mathrm{Re}\,(V_{seij}I_{ji}^{*} + V_{seik}I_{ki}^{*}) = 0 \quad (7)$$

B. Thyristor Controlled Phase Shifting Transformer (TCPST)

Thyristor Controlled Phase Shifting Transformer comprises of two converters specifically arrangement converter and shunt converter. The arrangement converter is coupled to the transmission line through arrangement transformer and the shunt converter is coupled through shunt transformer. The fundamental model of TCPST is appeared Fig.3

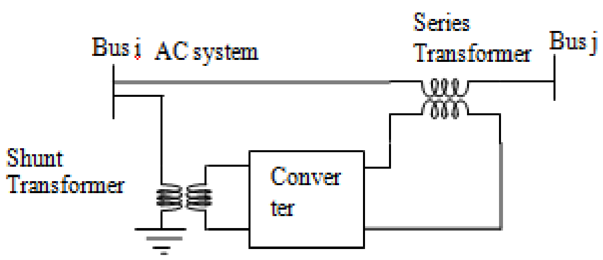

Fig.3. Basic model of TCPST

TCPST is modeled as a phase shifter to regulate the voltage angle (ø) between the sending end and receiving end of a transmission line and hence controls the power flow in lines.

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The equivalent circuit model of TCPST is shown in Fig.4.

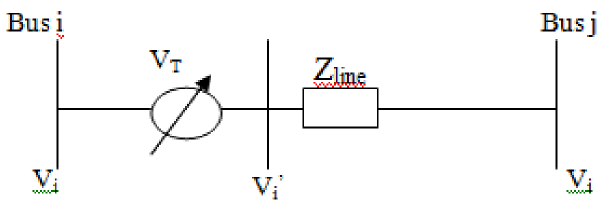

Fig.4.Equivalent model of TCPST

The shunt transformer draws power from the network and gives it to the series transformer to introduce voltage V_T at the series branch. The main purpose of TCPST is to control the power flow by shifting transmission angle (ø). The device losses are neglected. Here, V_i and V_j are complex voltages at bus i and j respectively.

Using circuit theory [23] the relationship between primary and secondary voltages is expressed as:

$$\bar{V}_i' = \bar{V}_i + \bar{V}_T \tag{8}$$

$$V_i' e^{j\theta_i} = V_i e^{j\theta_i} + V_T' e^{j(\theta_i - \pi/2)} \tag{9}$$

$$V_T = V_i \tan\delta \tag{10}$$

The real and reactive power flow equations in line i-j after placement of TCPST are given as:

$$P_{ij} = V_i^2 g_{ij} - V_i V_j \left[g_{ij} \cos(\delta_{ij} - \phi) + b_{ij} \sin(\delta_{ij} - \phi) \right] \tag{11}$$

$$Q_{ij} = -V_i^2 B_{ij} - V_i V_j \left[g_{ij} \sin(\delta_{ij} - \phi) - b_{ij} \cos(\delta_{ij} - \phi) \right] \tag{12}$$

$$P_{ji} = V_j^2 g_{ij} - V_j V_i \left[g_{ij} \cos(\delta_{ij} - \phi) - b_{ij} \sin(\delta_{ij} - \phi) \right] \tag{13}$$

$$Q_{ji} = -V_j^2 B_{ij} - V_i\ V_i \left[g_{ij} \sin(\delta_{ij} - \phi) + b_{ij} \cos(\delta_{ij} - \phi) \right] \tag{14}$$

The injected power flows of a TCPST at bus i and j are given as:

$$P_{is} = -V_i^2 K^2 G_{ij} - V_i V_j K \left[G_{ij} \sin\delta_{ij} - B_{ij} \cos\delta_{ij} \right] \tag{15}$$

$$P_{js} = -V_i V_j K \left[G_{ij} \sin\delta_{ij} + B_{ij} \cos\delta_{ij} \right] \tag{16}$$

$$Q_{is} = V_i^2 K^2 B_{ij} + V_i V_j K \left[G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij} \right] \tag{17}$$

$$Q_{js} = -V_i V_j K \left[G_{ij} \cos\delta_{ij} - B_{ij} \sin\delta_{ij} \right] \tag{18}$$

Where, $K = \tan(\phi)$

III. PROBLEM FORMULATION

The ABC algorithm is implemented on 6 bus, standard IEEE30, IEEE 57 and IEEE 118 test systems to determine the optimal placement and parameter setting of IPFC and TCPST in transmission network. In this work the multi objective function is formulated in terms of device parameters (V_{se}, θ_{se}, ø). Here three objectives and two devices IPFC and TCPST are considered to enhance the system loadability, minimize the transmission loss and reduce installation cost.

Multi objective optimization problem with constraints is formulated as:

$$\text{Max } \lambda = \frac{p_d^1}{p_d^0}$$

Subject to F (λ, V, δ, P, Q, V_{se}, θ_{se}, ø)=0 (19)

With equality and inequality constraints and also devices constrains presented in equations (30)-(39).

Where F = λ+ TL+ VD + LFD + IC_{cost} and F (V, δ, P, Q)=0 are power flow equations given by (1)-(4) and (11)-(14) .

A. *Maximization of System loadability (λ):*

The Maximum System Loadability (MSL) is calculated by using the equation given as:

$$P_d^1 = \lambda P_d^0 \tag{20}$$

Where λ is the loading parameter, P_d^0 and P_d^1 are initial system load and system load after placement of devices.

(i) Voltage Deviation (VD):

In power systems, the voltage deviation can be maintained within the desirable limits of ±5%, the Voltage Deviation is calculated using equation (21).

$$VD = \sum_{i=1}^{n} \left(\left| V_i^{ref} \right| - \left| V_i \right| \right)^2 \tag{21}$$

V_i –Voltage at i'th bus

V_i^{ref}–Reference Voltage at 'i th bus

(ii) Line flow deviation (LFD):

The line flow limits of the power system network must be maintained within specified limits. The line flow deviation is calculated using equation (22).

$$LFD = \sum_{ij-lines} \left(\left| LF_{ij}^{ref} \right| - \left| LF_{ij} \right| \right)^2 \tag{22}$$

LF_{ij} –Line flow of line 'i-j

LF_{ij}^{ref}– Line flow limit of line 'i-j

B. *Reduction of Transmission loss (TL):*

The reduction of total real power loss is responsible for redistribution of reactive power in the network. The proposed algorithm also considers the minimization of these losses for optimally locating FACTS devices. The transmission loss is calculated using equation (23).

$$TL = \sum_{i=1}^{gen} p_{Gi} - \sum_{i=1}^{n} p_{Di} \tag{23}$$

Where n is number of buses.

C. *Reduction of Installation Cost (IC_{cost}):*

The installation cost is the sum IPFC and TCPST cost. The cost functions of IPFC, TCPST are taken from Siemens database [22].

$$IC_{COST} = IC_{IPFC} + IC_{TCPST} \tag{24}$$

(i)IPFC installation cost (IC_{IPF}):

The cost function of IPFC is given as:

$$c_{IPFC} 0.00015 r^2 - 0.01345 r + 94.11 U\$/kVAR \tag{25}$$

$$IC_{IPFC} = c_{IPFC} \times r \times 1000 US\$ \tag{26}$$

(ii) *TCPST installation cost (IC_{TCPST}):*

The cost function of TCPST is given as:

$$c_{TCPST} = 0.0003 r^2 - 0.3051 r + 12 U\$/kVAR \tag{27}$$

$$IC_{TCPST} = c_{TCPST} \times r \times 1000 US\$ \tag{28}$$

In the equations (25) and (27) the value of r is the operating range of FACTS device given as:

$$r = \left| Q_2 - Q_1 \right| \tag{29}$$

Where Q_2 and Q_1 are the reactive power flow in the line after and before installing the FACTS devices in MVAR respectively.

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The cost depends on the operating range of the facts device.

D. Constraints:

The optimal placement of FACTS devices is a constrained optimization problem which includes equality and inequality constraints.

(i). Equality constraints:

The equality constraints are given as:

$$P_{gi}+P_i-P_{di}=\sum_{j=1}^{n}V_iV_jY_{ij}\cos(\theta_{ij}+\delta_j-\delta_i) \quad (30)$$

$$Q_{gi}+Q_i-Q_{di}=\sum_{j=1}^{n}V_iV_jY_{ij}\sin(\theta_{ij}+\delta_j-\delta_i) \quad (31)$$

Where P_{gi}, Q_{gi} are real and reactive power generations, Pi, Qi are real and reactive power injections, P_{di}, Q_{di} are real and reactive power demands at the i^{th} bus. $Y_{ij}\angle\theta_{ij}$ is ij^{th} element of admittance matrix.

(ii). Inequality constraints:

The inequality constraints are given as:

$$P_G^{\min}\le P_G\le P_G^{\max} \quad (32)$$

$$Q_G^{\min}\le Q_G\le Q_G^{\max} \quad (33)$$

$$V^{\min}\le V\le V^{\max} \quad (34)$$

$$\delta^{\min}\le\delta\le\delta^{\max} \quad (35)$$

$$\lambda\le\lambda^{\max} \quad (36)$$

Where P_G, Q_G are real and reactive power generations at generator busses, V and δ are bus voltage magnitude and phase angle.

(iii)IPFC Constraints:

$$V_{se}{}^{\min}\le V_{se}\le V_{se}{}^{\max} \quad (37)$$

$$\theta_{se}{}^{\min}\le\theta_{se}\le\theta_{se}{}^{\max} \quad (38)$$

Where V_{se}, θ_{se} are voltage magnitude and phase angle of series voltage source.

(iv)TCPST constraints:

$$\phi_i{}^{\min}\le\phi_i\le\phi_i{}^{\max} \quad (39)$$

$\phi_i{}^{\min},\phi_i{}^{\max}$ minimum and maximum limits of phase shifting transformer.

IV. PROPOSED METHODOLOGY

Artificial bee colony (ABC) calculation is one of the ongoing populace based hunt calculation used to take care of advancement issues [24]-[25]. This calculation is gotten from the scrounging conduct of bumble bees and its look for sustenance source around multidimensional space. The settlement of fake honey bees comprises of three gatherings: utilized honey bees, spectators and scouts. The utilized honey bees discover nourishment source and offer the data among alternate honey bees through waggle move. This move is corresponding to the nature of nourishment source. Spectator honey bees pick the best sustenance source dependent on the data. The utilized honey bee of a deserted sustenance source turns into a scout honey bee and when it finds another nourishment source it winds up utilized honey bee. On the off chance that the sustenance source is dismissed because of low quality, the utilized honey bee will change into scout honey bee to scan haphazardly for new sources.

In the ABC calculation, each cycle of the pursuit comprises of the accompanying method: the utilized honey bees goes onto the sustenance sources and measures nectar sums; choosing the nourishment sources by the spectator honey bees in the wake of sharing the data of utilized honey bees and finding the nectar measure of the nourishments; deciding the scout honey bees and after that sending them onto conceivable sustenance sources. In this calculation the situation of a nourishment source speaks to a conceivable arrangement of the enhancement issue and the nectar measure of a sustenance source relates to the quality (wellness) of the related arrangement. The control parameters of ABC are province size and greatest cycle number (MCN). The procedure of proposed method is described as follows:

1. Specify the lint data, bus data, generation limits, control parameters of ABC and FACTS device type and its parameters.

2. Generate the initial random population $K=[x_1, x_2, x_3\ldots x_n]^T$, of n solutions(food positions) where n represents the size of population. Each solution $x_i=[p_{i1}, p_{i2},\ldots p_{ij\ldots} p_{id}]$, i = 1, 2, 3, …n and j = 1, 2, 3 … d, here d is the number of parameters to be optimized which includes the real power generations, voltages and the FACTS device parameters. The real power generations are distributed uniformly between minimum and maximum values, given by

$$p_{ij}=p_{j\min}+rand(0,1)*(p_{j\max}-p_{j\min}) \quad (40)$$

The fitness for each food source corresponding to the employed bees in the colony is calculated using (26) and (28). Choose the best fitness value, the corresponding cost and the parameters responsible for the minimum cost. Repeat the following steps by setting a cycle count of one until the maximum cycle number is reached.

4. The employed bees move towards the food source from its original position to new position. The new food source position is given by

$$x_{ij}=x_j{}^{\min}+rand(0,1)*(x_j{}^{\max}-x_j{}^{\min}) \quad (41)$$

$x_j{}^{\max},x_j{}^{\min}$ are upper and lower limits of the food source position in dimension j. The new food source position is checked for all the constraints given by (30)-(39). If any one of the limitation is disregarded, at that point max limit is set. Presently the wellness work for the new nourishment position is determined, and contrasted with the wellness esteem comparing with the old sustenance position in Step 3. In the event that the wellness estimation of the new sustenance position is superior to old one, at that point the old position is supplanted with the upgraded one. In the event that the wellness estimation of the new position isn't superior to the former one, at that point the old position is held. 5. On the off chance that every single utilized honey bee complete the pursuit procedure, at that point the utilized honey bees share the data about the sustenance sources and positions to the passerby honey bee. At that point the spectator honey bee discovers sustenance position dependent on the likelihood condition given by

$$p_i=\frac{fit_i}{\sum_{k=1}^{n}fit_k} \quad (42)$$

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Where fit_i is the fitness value of the food source i, where i = 1, 2, 3 …n. Onlooker bees are placed onto the food source sites by using a fitness-based selection technique called roulette wheel selection process.

6. As discussed in step 4, the onlooker modifies the position in its memory using (41), and checks the nectar amount of source. If the new food source has equal or better nectar amount than the old source, it is replaced with the old one in the memory Otherwise, the old one is retained in the memory. Greedy selection mechanism is employed to select a position between the new and the old one.

7. If the solution for food source is not improved after a number of trials, the food source is abandoned and the scout bee finds a new food source with x_i. Memorize the best solution achieved so far and increment the cycle count.

8. The process is terminated when MCN is reached. The best fitness and the corresponding food position is memorized at the end of the termination .The installation cost of FACTS device, system loadability, transmission loss and FACTS device parameters are calculated.

Flow chart for the proposed methodology is shown in Fig. 5.

V. RESULTS AND DISCUSSIONS

The ABC algorithm is tested in 6 bus test system, IEEE 30, IEEE 57 and IEEE 118 bus systems [26]. The parameter settings for ABC algorithm are based on trial and error method and the parameters for various test systems are given in appropriate sections. The effectiveness of IPFC and TCPST to improve power flow for all cases is discussed. The cost of IPFC and TCPST is calculated in all the cases using (25) and (26) respectively, which depends on the reactive power flow in the line. The complexity in deriving the Jacobian matrix is eliminated by the proposed ABC algorithm.

A. 6 Bus test system

In the 6 bus [26] test system consists of three generators and three loads with 7 transmission lines. Bus 1 is considered as slack bus and base MVA is 100. The optimal placement and sizing of considered devices is obtained using ABC Algorithm. The colony size and MCN for ABC are taken as 10 and 100.IPFC and TCPST are placed in various locations in sample 6 bus system and its effectiveness to improve power flow is given in TABLE I. For IPFC the minimum and maximum amplitude of converter voltages are chosen as 0.95 p.u and 1.05 p.u. The minimum and maximum phase angle of the two converters is taken as -15^0 and 15^0 respectively. In the case of TCPST minimum and maximum phase angle of the two converters are taken as -15^0 and 15^0.

In the case of IPFC placement power flow has improved considerably after placement in line 1-4-5. The IPFC setting in line 1-4 is 0.921p.u.Voltage magnitude at an angle of -3.83^0 and in 4-5, 0.997 at angle of -8.73^0. The maximum system loadability is 30% more than before placement of IPFC. The installation cost is 21,568.3 US$.

The suitable locations for placement of TCPST are in lines 1-6, 4-6 and optimal location for placement of IPFC is obtained in line 1-4(master line), 4-5 is considered as slave

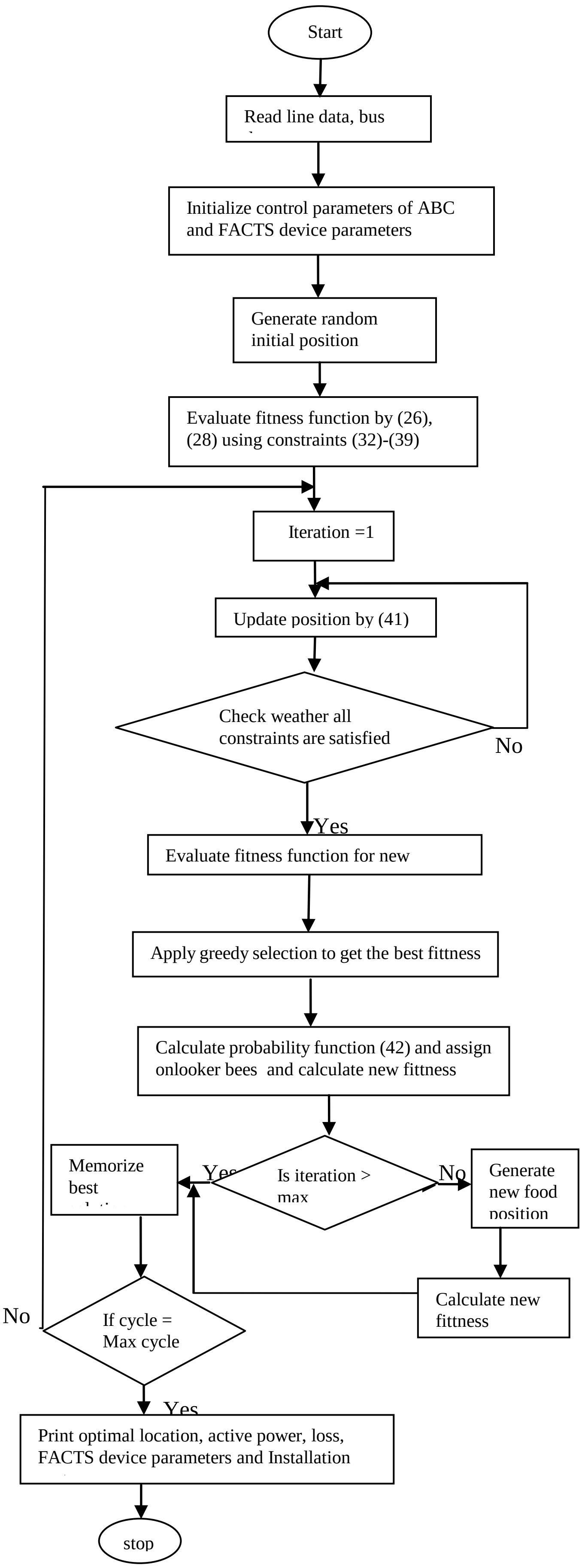

Fig.5. Flowchart for proposed methodology

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line. Here P_b, Q_b (TABLE I, column 4, 5) and P_a, Q_a (TABLE I , column 6,7) are real, reactive power flows in lines before and after placement of FACTS device respectively. The device parameter setting (column 8), installation cost (column 9) and maximum system loadability (column 10) are given in TABLE I.

The power flow has improved considerably after placement of TCPST (TABLE I, column 6). The parameter setting of TCPST in line 1-6 is $-0.993^0$and -12.7^0 in line 4-5.The Installation cost obtained with TCPST placement is 85,664 US$. The maximum system loadability is 1.95% i.e.95% more loading is achieved with TCPST placement.

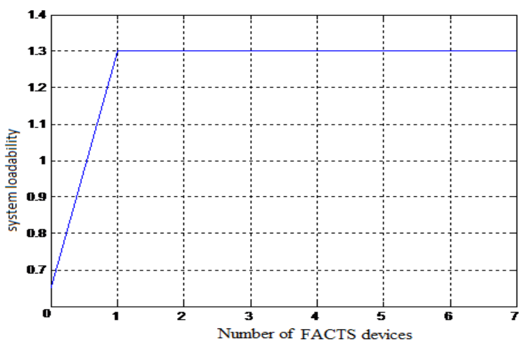
In 6 bus system, considerable increase in system loadability with minimum installation cost is achieved with IPFC and maximum system loadability is obtained at higher installation cost with TCPST.

From the results it is observed that system loadability is improved considerably, the installation cost is reduced. These are presented pictorially in Fig.6, fig.7. The voltage profile has improved at all buses.

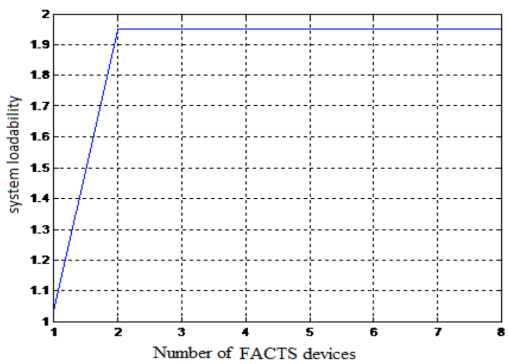
However, the system loadability and installation cost is saturated after placement of IPFC in line 1-4-6 and TCPST in lines 1-6, 4-6.

TABLE I. Line flow in 6 Bus system

FACTS device	From bus	To bus	P_b	Q_b	P_a	Q_a	Device setting	IC(US$)	MSL (%)
IPFC	1	4	44.793	8.634	45.416	8.634	0.921 pu -3.83^0	21,568.3	1.3
	4	6	12.376	-3.45	12.999	-3.458	0.997 pu -8.73^0		
TCPST	1	6	41.266	23.657	41.889	23.657	-0.993^0	85664.8	1.95
	4	6	9.157	-1.552	9.780	-1.552	-12.7^0		

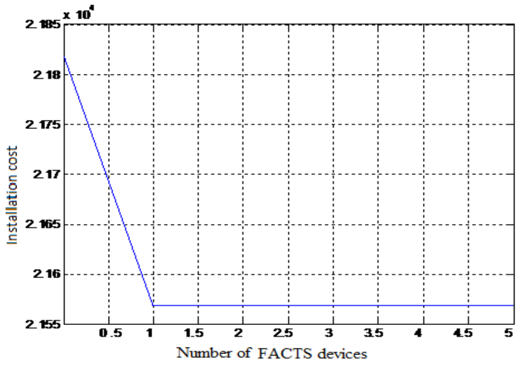


a. IPFC

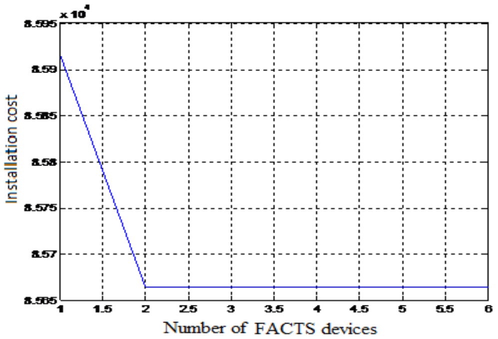


b. TCPST

Fig.6. System loadability 6 Bus system



a. IPFC



b. TCPST

Fig.7. Installation cost in 6 Bus system

B. IEEE 30 Bus system.

The one line diagram, bus data and line data are taken from [26]. This system consists of 1 slack bus, 5 PV buses, 24 PQ buses and 41 lines. The simulation code is developed using ABC algorithm and is tested for IEEE 30 bus system. The ABC parameters are colony size of 10 MCN is considered as 100. The results are given in TABLE II.

The optimal location for IPFC is obtained as line 12-14-15. The voltage and angle in master line 12-14 is 1.06pu and -12.9^0 respectively. In line 14-15 the IPFC settings are 1.02p.u and -9.57^0.The maximum system loadability obtained with IPFC is 82% more compared to before placement of device.

The installation cost of IPFC is 15691.1 US$.

The possible locations of TCPST is obtained as lines 5-7,10-21.The device parameter settings in two lines 5-7,10-21 are -10.4^0,-11.4^0 respectively. The power flow has improved considerably and is within limits. The system loadability obtained with TCPST is 43% more compared to before placement .The Installation cost of TCPST is 44937.3 US$.

In IEEE 30 bus system, maximum system loadability at minimum installation is obtained with IPFC compared to TCPST.

The graphs showing the variation of system loadability and installation cost, with respect to number of FACTS devices lines is given in Fig.8, Fig.9 respectively. Voltage profile is improved at all buses.

However installation cost and system loadability is saturated after placement of TCPST in lines 5-7, 10-21 and in the case of IPFC after placement in line 12-14-15.

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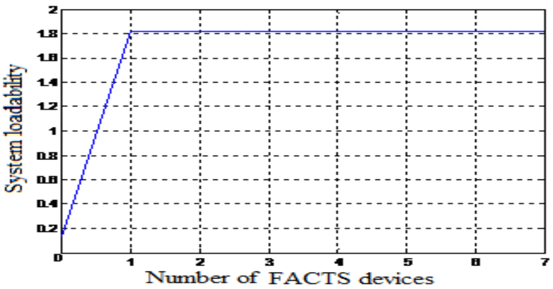
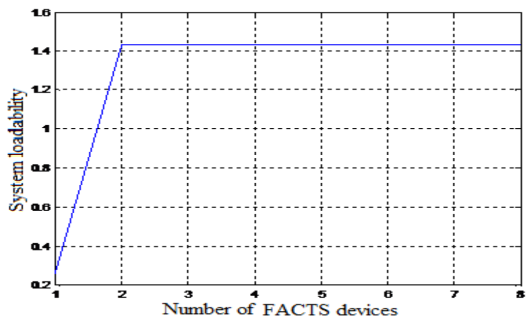
TABLE II. Line flow of IEEE 30 Bus system

FACTS device	From bus	To bus	P_b	Q_b	P_a	Q_a	Device setting	IC(US$)	MSL (%)
IPFC	12	14	7.746	2.314	8.599	2.314	1.05 pu -12.9^0	15691.1	1.82
	14	15	1.474	0.565	2.327	0.565	1.02 pu -9.57^0		
TCPST	5	7	-17.05	6.211	62.359	-22.342	-10.4^0	44937.3	1.43
	10	21	18.329	11.928	19.182	11.928	-11.4^0		

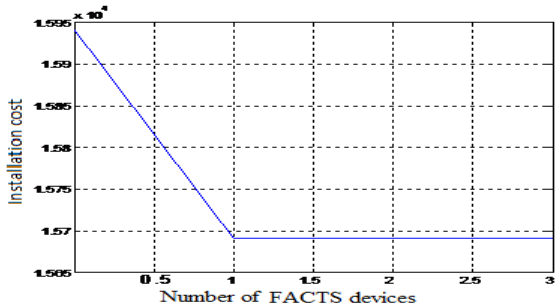


a. IPFC

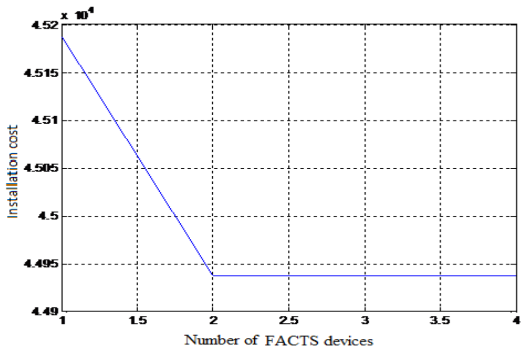


b. TCPST

Fig.8. System loadability in IEEE 30 bus system



a. IPFC



b.TCPST

Fig. 9. Installation cost in IEEE 30 bus system

C. IEEE 57 Bus system

The data for IEEE 57 bus system is taken from [26]. This system consists of 1 slack bus, 6 PV buses, 50 PQ buses and 80 lines. The number of buses, lines is increased, compared to IEEE 6 and IEEE 30 bus systems. The FACTS devices IPFC and TCPST are placed in all possible locations. The optimal location and parameter setting of TCPST and IPFC are obtained using ABC algorithm. The control parameters of ABC are colony size of 20 and MCN 150. Results are given in TABLE III.

From TABLE III it is clear that active power flow has improved considerably with placement of IPFC, TCPST in various possible locations.

In the case of IPFC the possible locations are 36-37-38 and 53-54-55.The parameters for location 36-37-38, in master line 36-37 is 1.02p.u, 8.19^0 and in line 37-38 is 1.03p.u, 9.99^0. For the location 53-54-55 parameters in line 53-54 is 1.02p.u, 8.19^0 and in line 54-55 is 1.05p.u, 8.47^0 .The loadability is 43% higher compared to before placement of IPFC. The Installation cost obtained is 55404.3 US$.

The suitable locations for TCPST are 3-15, 14-15 and 38-44.The system loadability is 95% more than before placement of TCPST. The installation cost with TCPST is 1818.84. US$. The TCPST setting in lines 3-15, 14-15, 38-44 are 8.58^0, 9.99^0, and 9.170 respectively.

In IEEE 57 bus system, system loadability is less with IPFC compared to TCPST. The installation cost with IPFC is more than that with TCPST. The system loadability is saturated after placement in three locations for TCPST and two locations for IPFC. The voltage profile is improved with IPFC and TCPST placemen

The variation of system loadability and installation cost, with respect to number of FACTS devices is given in Fig.10, Fig.11.The voltage profile is considerably improved at all buses.

TABLE III. Line flow in IEEE 57 bus system

FACTS device	From bus	To bus	P_b	Q_b	P_a	Q_a	Device setting	IC(US$)	MSL (%)
IPFC	36	37	15.918	1.349	16.674	1.349	1.02pu 8.19^0	55404.3	1.43
	37	38	19.032	0.425	19.788	0.425	1.03pu 9.99^0		
	53	54	12.290	2.04	13.046	2.048	1.02pu 8.19^0		
	54	55	16.390	3.157	17.146	3.157	1.05pu 8.47^0		
TCPST	3	15	-26.46	-14.82	61.244	-0.244	8.58^0	1818.84	1.95
	14	15	61.402	0.718	62.158	0.718	9.99^0		
	38	44	27.816	27.66	28.572	27.66	9.17^0		

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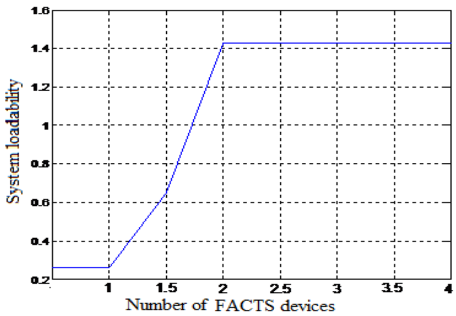
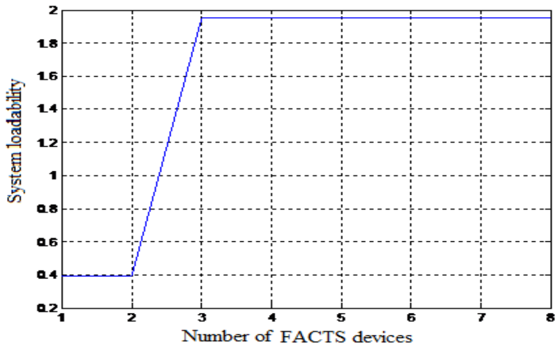


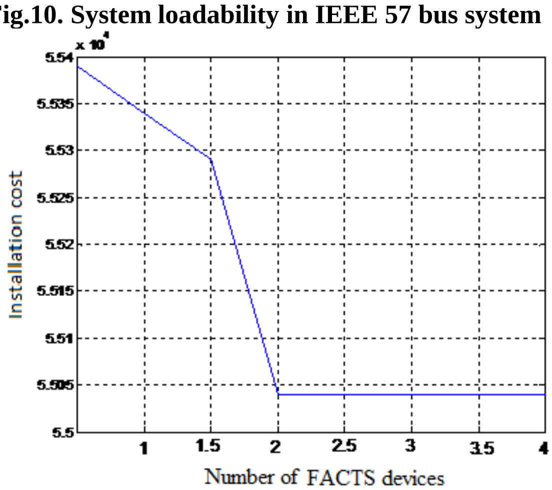
a. IPFC



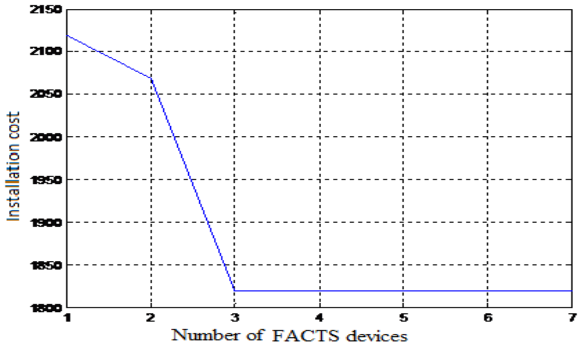
FACTS device	From line	To line	P_b	Q_b	P_a	Q_a	Device setting	IC(US$)	MSL (%)
IPFC	1	3	192.213	-24.17	193.139	-24.17	0.989pu -13.1^0	48850.1	1.95
	3	5	85.093	-33.22	81.359	-38.01	1.0pu 5.55^0		
	26	25	59.985	0.653	60.911	0.653	0.968pu -10.5^0		
	25	27	138.226	38.317	158.482	19.046	0.985pu -12.2^0		
TCPST	3	5	85.093	-33.22	99.208	-32.82	5.55^0	69541.5	1.56
	8	5	64.236	17.531	21.69	18.99	-9.61		
	25	27	138.226	38.317	164.264	44.734	-11.6^0		

b. TCPST

Fig.10. System loadability in IEEE 57 bus system



a. IPFC



b. TCPST

Fig.11. Installation cost in IEEE 57 bus system

D. IEEE 118 Bus system

IEEE 118 bus system is the largest network with 186 lines. It has 1 slack bus, 53 PV buses and 64 PQ buses. The IEEE 118 bus system data is taken from [26]. TCPST and IPFC are located in various lines using ABC algorithm for optimal solution. The control parameters of ABC algorithm are colony size of 50 and MCN is 300. The optimal location and parameter setting of IPFC and TCPST in IEEE 118 bus system are obtained with ABC algorithm. Simulations are performed on standard IEEE 118 bus system and results are given in TABLE IV.

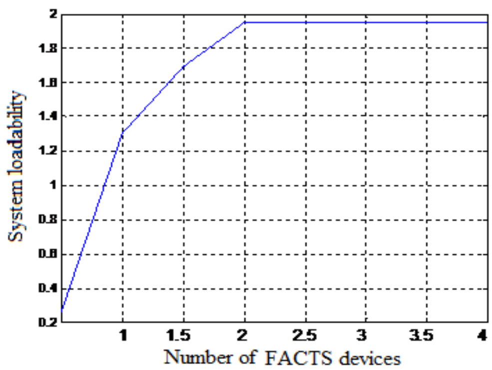
The suitable locations for IPFC are lines 1-3-5, 26-25-27. The parameters for IPFC location 1-3-5, in line 1-3 is 0.989p.u, -13.1^0 and in line 3-5 is 1p.u, -10.5^0. For location of line 26-25-27, in line 26-25, 0.968p.u, -10.5^0 and in line 25-27 0.985p.u, -12.2^0. The system loadability is 95% more with IPFC placement. The installation cost is 48850 US$.

The various possible locations of TCPST(TABLE IV, column 2,3) is obtained as lines 3-5, 8-5, 25-27 with sizing of 5.55^0, -9.61^0, and 11.60 respectively. The loadability is 56% more before placement of device and the installation cost is 69541.5 US$.

The system loadability obtained is more at reduced installation cost for IPFC placement compared to TCPST placement.

The variation of system loadability, installation cost with respect to number of FACTS devices is given in Fig.12, Fif.13. The voltage at all buses is within limits.

TABLE IV. line flow in IEEE 118 bus system



a. IPFC

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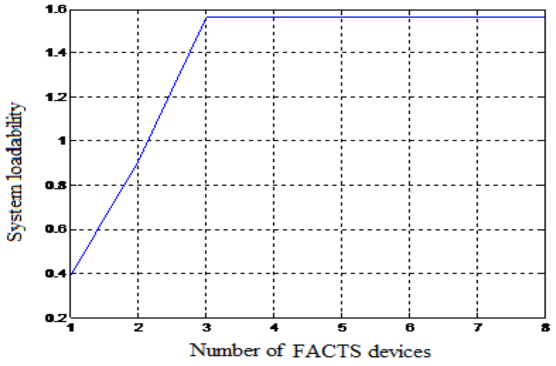
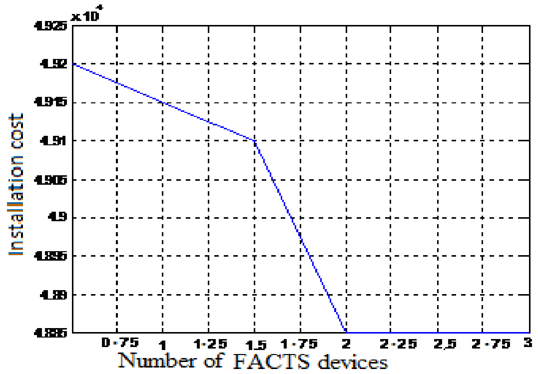
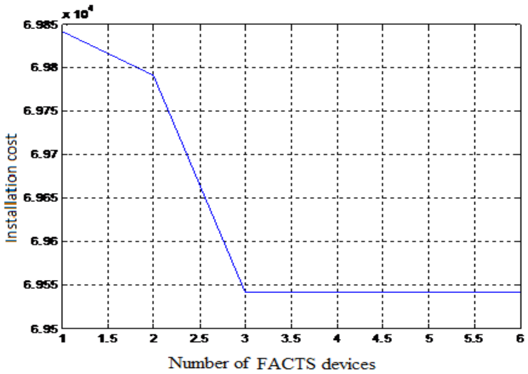


b. TCPST

Fig .12. System loadability in IEEE 118 bus system



a. IPFC



b. TCPST

Fig. 13. Installation cost in IEEE 118 bus system

The system loadability is saturated after three TCPST locations and two IPFC locations individually. The voltage profile is improved.

The transmission loss, voltage deviation and line flow deviations obtained in 6 bus, IEEE30, IEEE 57, IEEE 188 bus systems with IPFC and TCPST is given in TABLE V and TABLE VI respectively.

The transmission loss obtained is less compared with before placement. The line flow deviation and voltage deviation obtained with IPFC are within limits. Hence the location and parameter setting obtained with ABC algorithm gives the best solution.

TABLE V. The loss, voltage and line flow deviation of IPFC

FACTS device	Bus system	Loss(MW)		Voltage deviation (p.u)	Line flow deviation
		Before	After		
IPFC	6	4.048	3.916	0.00124	0.00424
	IEEE 30	5.072	4.19	0.0109	0.0057
	IEEE 57	6.503	5.773	0.0014	0.0032
	IEEE 118	16.481	16.396	0.0455	0.0083

Transmission loss obtained with test system 6, IEEE30, IEEE 57, and IEEE 188 is less compared with before and after TCPST placement. The voltage deviation and line flow deviation are within the limits. The transmission loss obtained after placement of TCPST is less compared to before placement. The voltage deviation and line flow deviation are within limits.

TABLE VI. The loss, voltage and line flow deviation of TCPST

FACTS device	Bus system	Loss(MW)		Voltage deviation	Line flow deviation
		Before	After		
TCPST	6	3.909	3.07	0.0388	0.0648
	IEEE 30	5.072	4.283	0.0216	0.0727
	IEEE 57	6.503	4.54	0.0451	0.0075
	IEEE 118	16.39	15.939	0.0730	0.0038

TABLE VII shows, IPFC and system loadability and installation cost. The system loadability with ABC algorithm in 6, IEEE 30, 57 and 118 bus systems is about 1.3%, 1.82%, 1.43%, and 1.95% The installation cost of 6, IEEE 30, 57 and 118 bus systems are 21568.3US$, 15961.1US$, 55040.3US$, and 48850.1US$ respectively. In existing literature the system loadability is poor when comparing with the proposed method. Thus the comparison results clearly demonstrate that the proposed method artificial bee colony algorithm gives better solution.

TABLE VII. Comparison of proposed system loadability and Installation cost with existing methods in IPFC

FACTS device	Bus system	LR [8]		Proposed (ABC)	
		SL (%)	IC (M$)	SL (%)	IC (US$)
IPFC	IEEE 6	-	-	1.3	21568.3
	IEEE 30	1.65	11.86	1.82	15691.1
	IEEE 57	-	-	1.43	55040.3
	IEEE 118	1.72	28.84	1.95	48850.1

The system loadability and installation cost have been compared with the existing GA and CIA algorithms for 6 bus, standard IEEE 30, 57 and 118 systems. The system loadability of IEEE 30 and 118 bus systems are 1.43%, 1.56% respectively. When we are comparing with the existing values, which is about 0.82% and 1.4% in genetic algorithm. In case of computational intelligence, the system loadability of IEEE 118 bus system is about 1.05%. Hence, we can clearly say that the proposed artificial bee colony algorithm gives better solution compared to existing literature in the case of TCPST placement given in TABLE VIII.

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TABLE VIII. Comparison of proposed system loadability and Installation cost with existing literature in TCPST

FACTS device	Bus system	CIA [14]		GA [15]		Proposed (ABC)	
		SL (%)	IC (US$)	SL (%)	IC (US$)	SL (%)	IC (US$)
TCPST	6	-	-	-	-	1.85	85664.8
	IEEE 30	-	-	0.82	20,34,500	1.43	44937.3
	IEEE 57	-	-	-	-	1.95	1818.84
	IEEE 118	1.05	1,15,000	1.4	1,00,000	1.56	69541.5

VI. CONCLUSION

In this work, suitable locations and optimal parameter setting of TCPST and IPFC are obtained in a power transmission network using artificial bee colony algorithm. Three objectives used are improvement in system loadability, minimization in installation cost, reduction in Transmission losses. The proposed method is applied to four standard test systems. They are 6 bus, IEEE 30 bus, IEEE 57 bus and IEEE 118 bus systems. From the results it is observed that the system loadability is improved, installation cost is reduced and there is a considerable reduction in transmission loss in all the considered test systems. In addition to above results the FACTS devices helps to maintain the uniform voltage profile at all the buses and significant improvement of power flow in a transmission network. The simulation results clearly indicate that the proposed ABC algorithm is found to be effective compared with existing literature.

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