Optimal Location of Facts Devices Considering Installation Cost, Transmission Loss And System Loadability Using Abc Algorithm

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Abstract **- The electricity demands and transactions in power markets increase frequently. Hence existing power networks must be enhanced for better utilization. In this work, Artificial Bee Colony Algorithm (ABC) is proposed for enhancing and controlling power flow using Flexible AC Transmission System (FACTS) controllers. The objectives considered are enhancement of system loadability, reduction of Installation cost of devices and reduction of transmission loss. Three types of FACTS devices such as Static VAR Compensator (SVC), Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC) are used. The optimal location and parameter setting of FACTS devices is achieved using ABC algorithm. In this paper two cases are considered: i) single type i.e. same type of FACTS device, and ii) multi type i.e. combination of SVC, TCSC, UPFC. The proposed algorithm is implemented on 6 bus, IEEE 30, IEEE 57 and IEEE 118 bus systems using MATLAB platform. The power flows are analyzed. The results obtained are compared with existing literature. The results indicate that the proposed algorithm gives better improvement in system loadability, reduction of transmission loss and installation cost. Hence the proposed algorithm will be useful in restructuring power networks.**

Keywords - Static var compensator, thyristor controlled series compensator, unified power flow controller, multi-type devices, optimal location, artificial bee colony algorithm.

I. INTRODUCTION

The Electric supply industry is undergoing a profound change worldwide, and the reason for the change is market forces, scare natural resources and an ever-increasing demand for electricity. In electric power industry restructuring has led to the more use of transmission grids. In a competitive market environment, transmission companies usually maximize the utilization of transmission systems as a construction of new transmission lines. Therefore in high demand periods, the system functions with a limit of transmission capacity with reduced security margin.

The advanced power electronics has introduced a new design namely flexible alternating current transmission system (FACTS) by Electrical Power Research Institute (EPRI)[1]. The power system oscillations taking place in the power systems due to contingencies such as the grid faults and sudden load changes, for a secure system operation the damping of these oscillations are necessary. If the controlled System's responses are quick against faults, the power system

power system stability will enhance significantly [2-4].In transmission systems there is a requirement of adequate transmission capacity for supporting transmission services. Flexible AC Transmission Systems (FACTS) devices are power electronic based devices with the ability to control network parameters such as current, voltage and impedance [5-6]. FACTS can provide assistances in increasing system transmission capacity and power flow control flexibility and speediness [7-9]. Transmission systems get improved due to FACTS in many ways which include congestion management and enhancing the loadability of the transmission lines [10].Due to the lack of synchronization between generation and transmission companies, Congestion or overload in one or more transmission lines occurs [11].

FACTS devices are revolutionary power transmission networks, leads increasing efficiency and stability of power systems [12].Control the reactive power flow for more efficient use of transmission lines using FACTS devices. [13].

FACTS devices can also significantly reduce voltage sags in the system and in modifying the effects of the remaining sags to minimize the high associated costs of equipment disoperation [14]. Voltage sag is defined as a short duration reduction of the root mean square value of AC voltage lasting between half a cycle and several cycles [15]. Voltage instability is considered as a primary concern in power systems mainly in planning and operation. Several power interruptions are related due to voltage instability [16-18]. Some of the factors for voltage instability are power system configuration, generation pattern and load pattern [19-21]. Proper location is a key to maximizing the benefits of the FACTS devices [22]. The location of FACTS devices is dependent on static or dynamic performances of the system. The sensitivity factor methods are used to find the best place to improve the static performance of the system [23].Meta heuristic Grey Wolf Optimizer (GWO) algorithm to solve OPF problems equipped with shunt connected FACTS device SVC[24].The TCSC location-allocation problem is formulated as a mixed integer nonlinear program, and proposes a novel decomposition procedure for determining the optimal location of TCSCs and their respective size for a network[25].An adaptive differential evolution algorithm to allocate TCSC incorporated with the reactive power management problem[26].For the restructuring power system (RPS), the self-adaptive differential evolutionary (SADE) algorithm is proposed for enhancing and controlling the power flow using UPFC under practical security constraints (SCs)[27].

This paper presents optimal location and sizing of FACTS devices SVC, TCSC and UPFC using ABC algorithm. In this work, TCSC has been modeled as a variable reactance inserted in the line and SVC is modeled as a reactive source added at both ends of the line. UPFC is modeled as combination of a SVC at a bus and a TCSC in the line connected to the same bus. The optimum placement is done, satisfying FACTS device operating constraints and power flow constraints. The optimal location is done to maximize system loadability, reduce transmission loss, and installation cost of FACTS devices. The cost function of SVC, TCSC and UPFC are taken from Siemens database [28]. The developed code is tested on 6 bus, IEEE-30 bus, IEEE-57 bus and IEEE-118 bus test systems in MATLAB platform.

Rest of the paper is organized as follows: section II gives static modeling of SVC, TCSC and UPFC, section III explains problem formulation, section IV explains the implementation of proposed methodology, section V presents results and discussions, and section VI gives conclusions.

II. STATIC MODELLING OF SVC,TCSC AND UPFC

A. Static Var Compensator (SVC) [29]

SVC is one of the shunt compensation devices. The variable reactance is shunt connected at both ends of transmission line and it can consume or produce the reactive power, in order to generate the voltage magnitude. The voltages at buses i and j are $V_i\angle\delta_i, V_j\angle\delta_j$ .The variable susceptance model of SVC is shown in Fig.1. It is an electrical device to compensate the reactive power on high voltages.

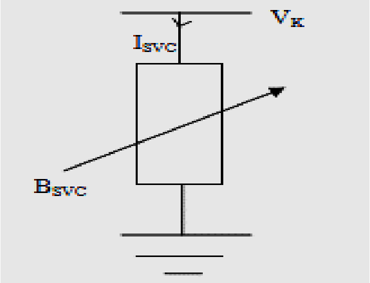


Fig.1. SVC model

Current drawn by SVC is:

$$I_{svc} = j\beta_{SVC} * V_K \tag{1}$$

Reactive power drawn by SVC is

$$q_{svc} = -V_K{}^2\beta_{SVC} \tag{2}$$

The equation (4) tells the reactive power is the square of voltage magnitude (V$_k$) and susceptance β_{SVC}. When the system voltage is low then it generates reactive power and when the system voltage is in high then the system can absorb the reactive power.

Load flow equations:

$$p_{Gi} - p_{Di} - p_i - \sum_{j=1}^{n} v_i v_j \left[G_{ij}\cos(\delta_{ij}) + \beta_{ij}\sin(\delta_{ij})\right] = 0 \tag{3}$$

$$q_{Gi} - q_{Di} - q_i - q_{svc} - \sum_{j=1}^{n} v_i v_j \left[G_{ij}\sin(\delta_{ij}) - \beta_{ij}\cos(\delta_{ij})\right] = 0 \tag{4}$$

B. Thyristor Controlled Series Compensator (TCSC) [30]

The TCSC is a capacitive reactance compensator. It is connected in series to the transmission lines to improve the power transfer capability and it is shown in Fig.2.

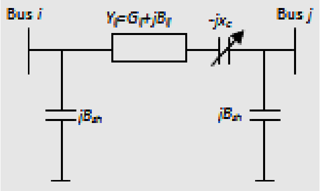


Fig. 2. Transmission line with TCSC

The total reactance of the line including TCSC is given by

$$x_{line}{}^{new} = x_{line}{}^{old} + x_{t\,\mathrm{csc}} \tag{5}$$

where $x_{line}{}^{old}$ is line reactance itself and $x_{t\,\mathrm{csc}}$ is the effective reactance of TCSC.

Load Flow Equations:

$$p_{Gi} - p_{Di} - p_i - \sum_{j=1}^{n} v_i v_j \left[G^1{}_{ij}\cos(\delta_{ij}) + \beta^1{}_{ij}\sin(\delta_{ij})\right] = 0 \tag{6}$$

$$q_{Gi} - q_{Di} - q_i - \sum_{j=1}^{n} v_i v_j \left[G^1{}_{ij}\sin(\delta_{ij}) - \beta^1{}_{ij}\cos(\delta_{ij})\right] = 0 \tag{7}$$

$G^1{}_{ij}, \beta^1{}_{ij}$ are modified line conductance and susceptance due to TCSC reactance.

$$x_{t\,\mathrm{csc}} = -k_{se} x_{line} \tag{8}$$

Where k_{se} is percentage of series compensation in reactance of transmission line (x$_{\mathrm{line}}$) [30].

C. Unified power flow controller (UPFC) [31]

UPFC controller consists of two inverters, one connected in shunt and other is coupled in series to transmission line. These inverters are operated from the common dc link provided by the dc storage capacitor. The shunt voltage source inverter provides reactive power, which in turn boosts voltage at buses. It maintains voltage of the DC capacitor at its reference value. Series converter controls power flow in transmission lines providing voltage with adjustable phase angle and magnitude. The equivalent circuit of UPFC is represented in Fig.3. This steady state model consists of ideal voltage sources $V_{cR}\angle\theta_{cR}$, $V_{vR}\angle\theta_{vR}$, Z_{sh}, Z_{se} are shunt and series coupling transformer impedances.

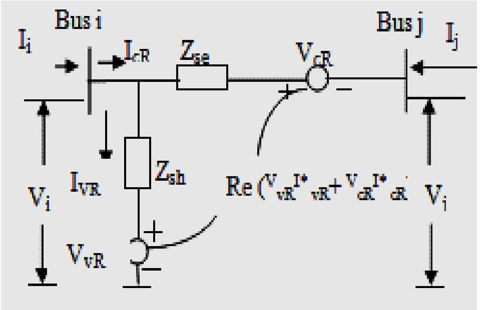


Fig.3.UPFC Equivalent Circuit

The active and reactive power flows of the shunt and series converters are expressed by the equations (9) -(12).

Shunt Inverter:

$$P_{sh} = V_i^2 g_{sh} - V_i V_{vR}(g_{sh}\cos(\delta_i - \theta_{vR}) + b_{sh}\sin(\delta_i - \theta_{vR})) \quad (9)$$

$$Q_{sh} = -V_i^2 b_{sh} - V_i V_{vR}(g_{sh}\sin(\theta_i - \theta_{vR}) - b_{sh}\cos(\theta_i - \theta_{vR})) \quad (10)$$

Series Inverter:

$$\begin{aligned} P_{ij} &= V_i^2 g_{ij} - V_i V_j (g_{ij}\cos\delta_{ij} + b_{ij}\sin\delta_{ij}) \\ &- V_i V_{cR}(g_{ij}\cos(\delta_i - \theta_{cR}) + b_{ij}\sin(\delta_i - \theta_{cR})) \end{aligned} \quad (11)$$

$$\begin{aligned} Q_{ij} &= -V_i^2 b_{ij} - V_i V_j (g_{ij}\sin\delta_{ij} - b_{ij}\cos\delta_{ij}) \\ &- V_i V_{cR}(g_{ij}\sin(\delta_i - \theta_{cR}) - b_{ij}\cos(\delta_i - \theta_{cR})) \end{aligned} \quad (12)$$

Where $g_{sh} + b_{sh} = \frac{1}{z_{sh}}, g_{ij} + b_{ij} = \frac{1}{z_{se}}$

The power injection model of UPFC is given in Fig.4.

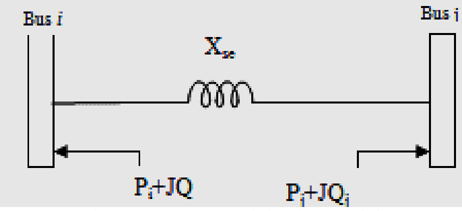


Fig.5. UPFC Power injection model

The cost of FACTS device depends on the complexity of model used. UPFC has the highest cost among FACTS devices [32]. According to [33], the cost of UPFC is estimated as 0.33 million$ where as cost of SVC is approximately 0.19 million$ and that of TCSC is 0.22 million$ for 1MVAR generated power. UPFC acts on three parameters: phase angle, line impedance, and bus voltage either simultaneously or separately. Hence, our idea is to model an equivalent of UPFC by joining the action of TCSC, as a series device to that of SVC which acts for the shunt compensation. Hence, in this work UPFC is modeled [37] as the combination of SVC at a bus and TCSC in the line connecting the same bus and the limits are given by combination of both.

III. PROBLEM FORMULATION

The FACTS devices are integrated into transmission system to maximize system loadability, reduce transmission losses and Installation cost of devices. The optimal placement and parameter setting of FACTS device is done using artificial bee colony algorithm.

The Multi objective optimization problem is formulated as:

Maximize $\lambda = P_d^l/P_d^0$

Subject to $F(\lambda, V, \delta, P, Q, Q_{svc}, X_{tcsc}) = 0$ (13)

with constraints given by (26)-(36)

Where $F = \lambda + TL + VD + LFD + IC_{cost}$

And $F(V,\delta,P,Q)$ is the power flow equations described by (3),(4),(6),(7),(9)-(12).

A. Maximization of System loadaility (λ):

The Maximum System Loadability, MSL is calculated by

$$P_d^l = \lambda P_d^0 \quad (14)$$

Where λ, is loading parameter, P_d^0 and P_d^1 are system load before and after FACTS device placement.

(i) Voltage Deviation (VD):

The desirable limits of voltage in power system are within ± 5%. The Voltage Deviation is calculated using equation (15).

$$VD = \sum_{i=1}^{n}\left(\left|V_i^{ref}\right| - \left|V_i\right|\right)^2 \quad (15)$$

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 transmission network must be maintained within specified limits. The line flow deviation is calculated using equation (16).

$$LFD = \sum_{ij-lines}\left(\left|LF_{ij}^{ref}\right| - \left|LF_{ij}\right|\right)^2 \quad (16)$$

LF_{ij} –Line flow of line 'ij'

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

C. Reduction of Transmission Loss (TL):

The proposed algorithm considers the minimization of transmission losses by optimal placement of FACTS devices. The transmission loss is calculated using equation (17).

$$TL = \sum_{i=1}^{gen} p_{Gi} - \sum_{i=1}^{n} p_{Di} \tag{17}$$

Where n is number of buses.

D. Reduction Of Installation Cost (IC_{cost}):

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

$$IC_{COST} = IC_{SVC} + IC_{TCST} + IC_{UPFC} \tag{18}$$

(i)SVC installation cost (IC_{SVC}):

The cost function of SVC is given as:

$$c_{svc} = 0.0003r^2 - 0.3051r + 127.38 \tag{19}$$

$$IC_{svc} = c_{svc} \times r \times 1000US\$ \tag{20}$$

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

The cost function of TCSC is given as:

$$c_{t\,\mathrm{csc}} = 0.015r^2 - 0.7130r + 153.75 \tag{21}$$

$$IC_{t\,\mathrm{csc}} = c_{t\,\mathrm{csc}} \times r \times 1000US\$ \tag{22}$$

(iii) UPFC installation cost(IC_{UPFC})

The cost function of UPFC is given by

$$c_{upfc} = 0.0003r^2 - 0.2691r + 188.22 \tag{23}$$

$$IC_{upfc} = c_{upfc} \times r \times 1000US\$ \tag{24}$$

In the equations (19),(21) and (23) the value of r is the operating range of FACTS device given as:

$$r = |Q_2 - Q_1| \tag{25}$$

Where Q_2 and Q_1 are the reactive power flow in the line after and before installing the FACTS devices in MVAR respectively. The cost depends on the operating range of the facts device.

E. 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:

$$P_{gi} + P_i - P_{di} = \sum_{j=1}^{n} V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) \tag{26}$$

$$Q_{gi} + Q_i - Q_{di} = \sum_{j=1}^{n} V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \tag{27}$$

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 ith bus. $Y_{ij}\angle\theta_{ij}$ is ijth element of admittance matrix.

(ii). Inequality constraints:

The inequality constraints are given as:

$$P_G^{\min} \le P_G \le P_G^{\max} \tag{28}$$

$$Q_G^{\min} \le Q_G \le Q_G^{\max} \tag{29}$$

$$V^{\min} \le V \le V^{\mathrm{ma}} \tag{30}$$

$$\delta^{\min} \le \delta \le \delta^{\max} \tag{31}$$

$$\lambda \le \lambda^{\max} \tag{32}$$

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

(iii) SVC Constraints:

$$q_{SVC}{}^{\min} \le q_{SVC} \le q_{SVC}{}^{\max} \tag{33}$$

$$\beta_{svc}{}^{\min} \le \beta_{svc} \le \beta_{svc}{}^{\max} \tag{34}$$

$$-100MVAR \le q_{svc} \le 100MVAR \tag{35}$$

(iv)TCSC constraints:

$$x_{t\,\mathrm{csc}}{}^{\min} \le x_{t\,\mathrm{csc}} \le x_{t\,\mathrm{csc}}{}^{\max} \tag{35}$$

$$-0.8 \le x_{t\,\mathrm{csc}} \le 0.2p.u \tag{36}$$

(v) UPFC constraints:

The constraints of UPFC are given by (33) - (36).

IV. PROPOSED METHODOLOGY

The electric power is transmitted from one end to anther end over the transmission line in accordance to the consumer requirements incurring minimum amount of losses. The consumer power is varied on the basis of load variation or disturbances in the transmission line. The flexible alternating current transmission systems devices are introduced to change the voltage, phase angle and impedance in power systems. During the operation of these devices the active and reactive power is maintained in the balanced manner. The FACTS device can control the power flow and increase the transmission capacity. The various electrical parameters in the transmission circuits are controlled by the solid state converters of the FACTS devices and the installation cost of these devices are reduced when the location of these device are optimal while satisfying the constraints. In this case single type FACTS devices like SVC, TCSC, and UPFC and multi type devices are used.

The Meta heuristic technique of artificial bee colony algorithm [34] is defined by Karaboga in 2005. This algorithm is derived from the foraging behaviour of honey bee and it searches the food source around multidimensional search space. The bees are classified into three based on its experience and without experience as employee, onlooker and scout bees. In which each employed bees find out the food source and share the information among the other bees through specialized dance. The waggle dance is proportional to the quality of food source. The other bees are waiting in the dancing area to choose the best food source. The scout bees search the food source without any guidance.

The employed bees move towards the food source from its original location (a_{ij}1) to new location (z_{ij}) and it may be written by (37),

$$z_{ij} = a_{ij} + \pi_{ij}\left(a_{ij} - a_{kj}\right) \tag{37}$$

π_{ij} is the number of food sources and uniform random umber between -1 to 1. If the new location of the food source is better than that of the current position then the new location is dated.

The new position can be updated by,

$$z_{ij} = a_{ij} + w\pi_{ij}\left(a_{ij} - a_{kj}\right) \tag{38}$$

The weight coefficient of employed bee information is mentioned as w. The probability of food source can be calculated by,

$$P = \frac{fit}{\sum_{j=1}^{sn} fit_j} \tag{39}$$

The employed bees fitness values is find out by,

$$fit_j = \begin{Bmatrix} \dfrac{1}{1+f(x)} & f(x) \geq 0 \\ 1+\left|f(x)\right| & f(x) < 0 \end{Bmatrix} \tag{40}$$

Where $f(x)$ represents the amount of objective function to be used in optimization.

$$fit_j = IC + pf * \left\| j-1 \right\| \tag{41}$$

Where IC denotes the installation cost of FACTS devices, pf is the penalty factor. The flowchart of proposed algorithm is given in Fig.5.

V. RESULTS AND DISCUSSION

The optimal placement of FACTS devices are done under the platform MATLAB. The optimal location and sizing of FACTS devices is carried out using ABC algorithm with a colony size of 20 and MCN 100. To prove the Effectiveness of locating FACTS devices, following five cases are considered.

- Base case without FACTS device

Single type

- With SVC
- With TCSC
- With UPFC
- Multi type devices.

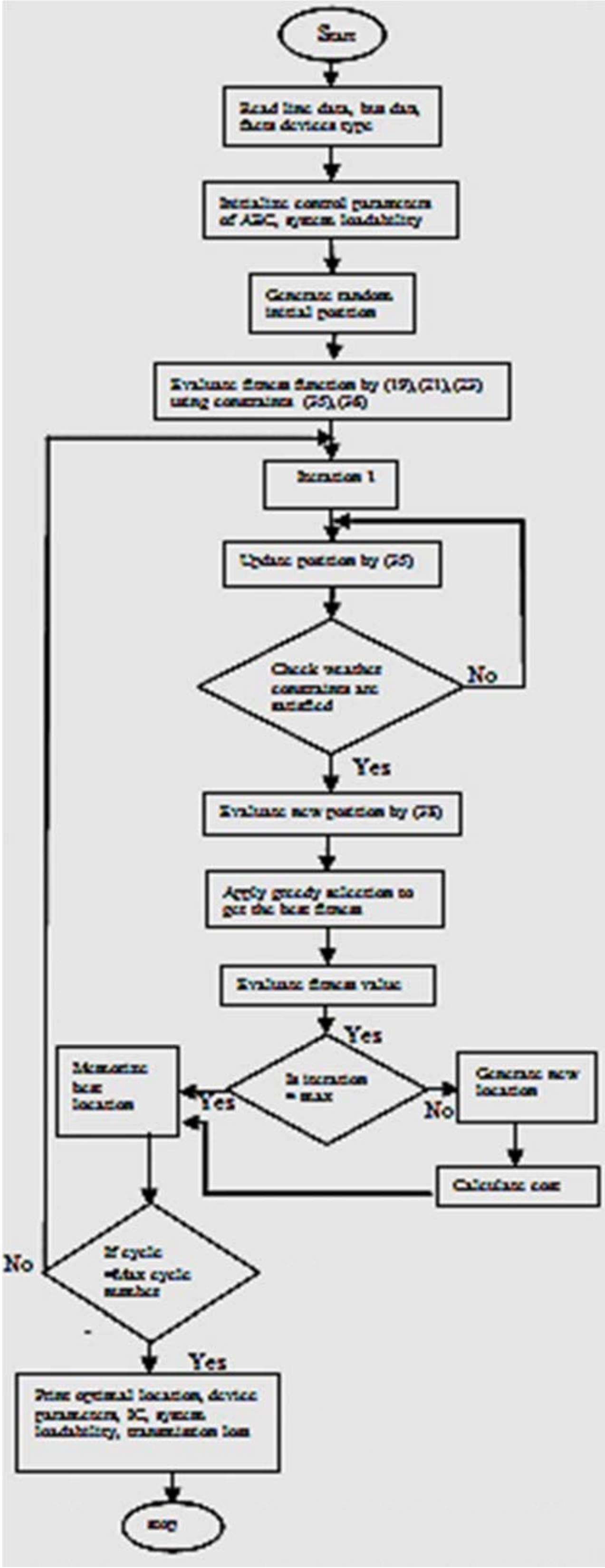


Fig.5. Flow chart of proposed methodology

A. 6-Bus System

The line data and bus data of 6 bus system are taken from [38] and the system contains 1 slack bus, 2 PV buses, 3 PQ buses and 7 lines. Here the FACTS devices SVC, TCSC, UPFC single and multi type are integrated. Here the optimal placement, FACTS device parameter setting is obtained using ABC Algorithm. Pb, Qb and Pa, Qa are real and reactive power flows in lines before and after placement of FACTS device respectively.

TABLE I. LINE FLOWS IN 6 BUS

Type	Device	From Bus	To Bus	P_b	Q_b	P_a	Q_a	Device setting	IC(US$)	MSL (%)
Singles	SVC	1	4	44.427	28.736	44.737	15.648	19.8Mvar	23,029.6	1.43
		2	3	31.202	150.54	32.14	150.57	29.5Mvar		
		5	2	13.317	-1.219	12.586	-19.413	26.3Mvar		
	TCSC	1	4	42.389	16.854	40.344	15.267	0.0515pu	3994.63	1.95
		5	2	-16.68	1.136	-13.097	-12.216	0.05151pu		
	UPFC	2	3	31.202	-128.3	32.064	12.878	0.00639pu 63.2Mvar	40,030.3	1.56
		2	5	18.898	0.942	18.076	-3.068	0.00639pu 63.2Mvar		
		4	3	19.976	9.996	18.557	-0.519	0.00639pu 56.7Mvar		
Multi	SVC	2	3	31.202	150.54	32.486	150.55	50.3Mvar	48565.5	1.95
	TCSC	1	4	-13.317	1.806	-12.923	0.000	0.015pu		
	UPFC	2	5	18.989	0.942	17.614	-3.834	0.00596pu 33.2Mvar		

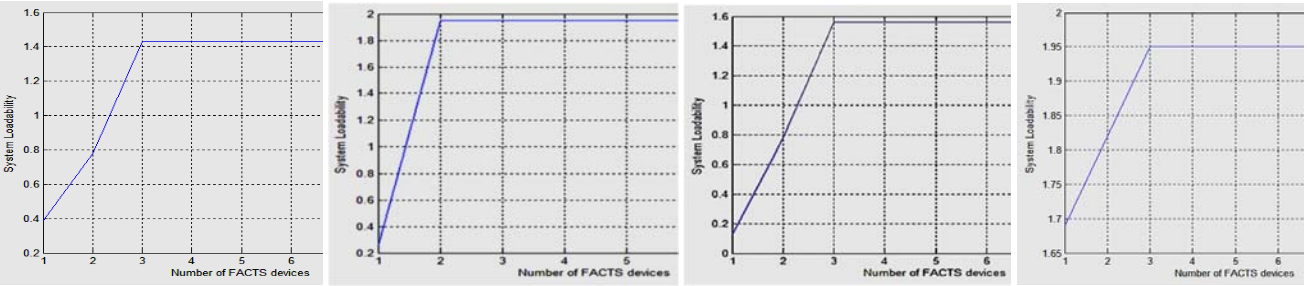
Table I, shows power flow before (column 5,6) and after (column 7,8) placement of FACTS devices in lines, parameter setting of FACTS device(column 9), installation cost (column 10), maximum system loadability(column 11), in IEEE6 bus system. The FACTS device locations are given in column 3,4 for each device.

In the case of SVC the system loadability obtained is 1.43% and installation cost is 23029.6 US$ and device is located in lines 1-4, 2-3, 5-2. In lines 1-4, 2-3 active power flow is improved and reactive power is reduced in lines 1-4, 2-3, 5-2. The parameter setting of SVC in lines 1-4,2-3,5-2 is 19.8,29.5,26.3Mvar respectively.

By locating TCSC in lines (1-4, 5-2) gives the installation cost of 3994.63US$, and system loadability of 1.95%.Among the two locations of TCSC the power flow is improved and reactive power is compensated. The TCSC device setting is 0.0515pu.

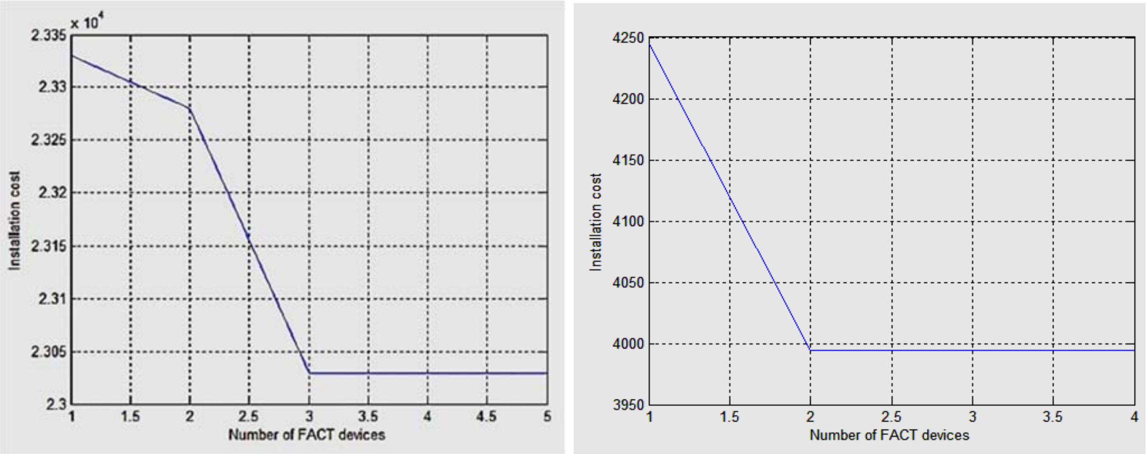
In case of UPFC installation cost and loadability are 40030.3US$ and 1.56% is obtained by placing UPFC in three locations (2-3, 2-5, 4-3 power flow is improved and reactive power is reduced.

In single type of devices system loadability and low installation cost is achieved with TCSC placement in two locations. Cost wise TCSC is best option. In multi type devices the installation cost of placing SVC in one location, TCSC in one location and UPFC in one location is 48565.5 US$ and system loadability obtained is 1.95%. The variation of system loadability and installation cost for different cases are given in Fig.6. and Fig. 7.

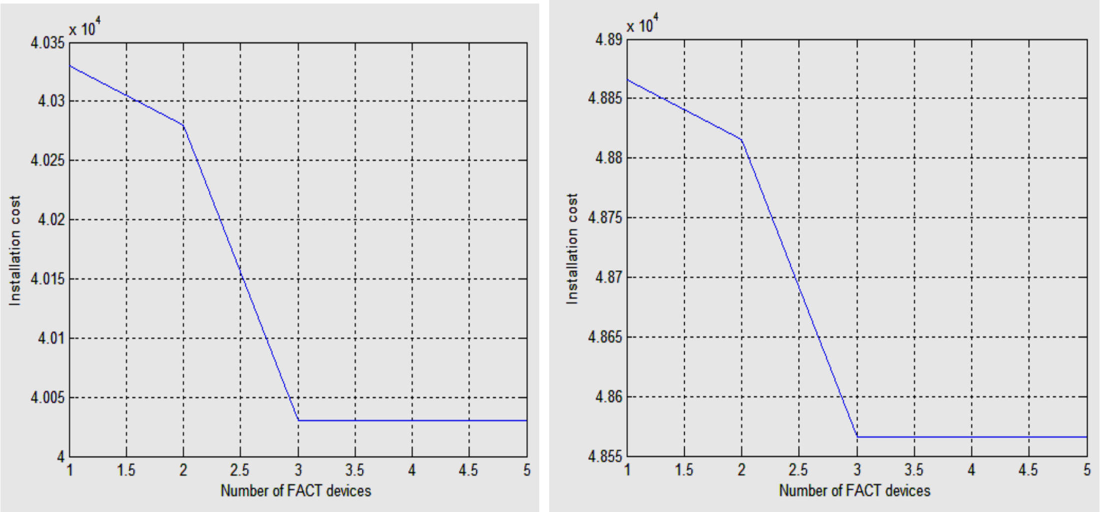


(a).SVC (b).TCSC (c).UPFC (d).Multi

Fig.6. system loadability in IEEE 6 bus system.



(a).SVC (b).TCSC



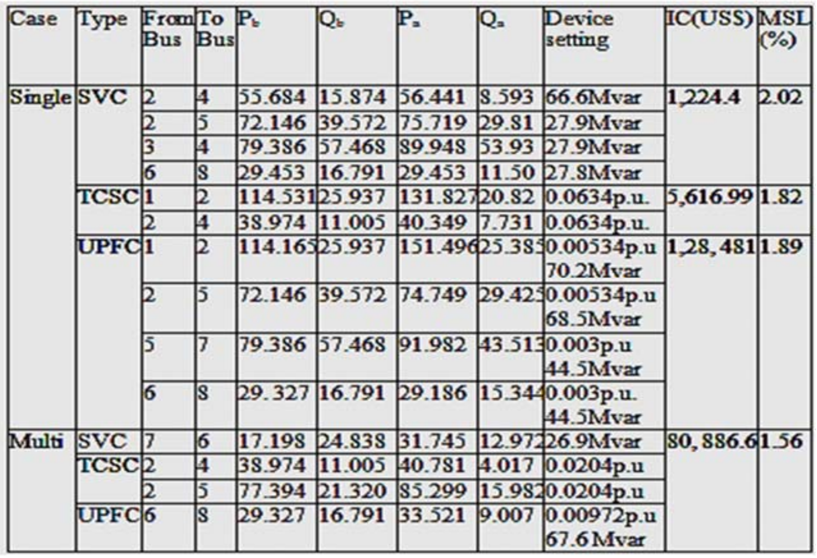
(c).UPFC (d). Multi

Fig.7. Installation cost in IEEE 6 bus system

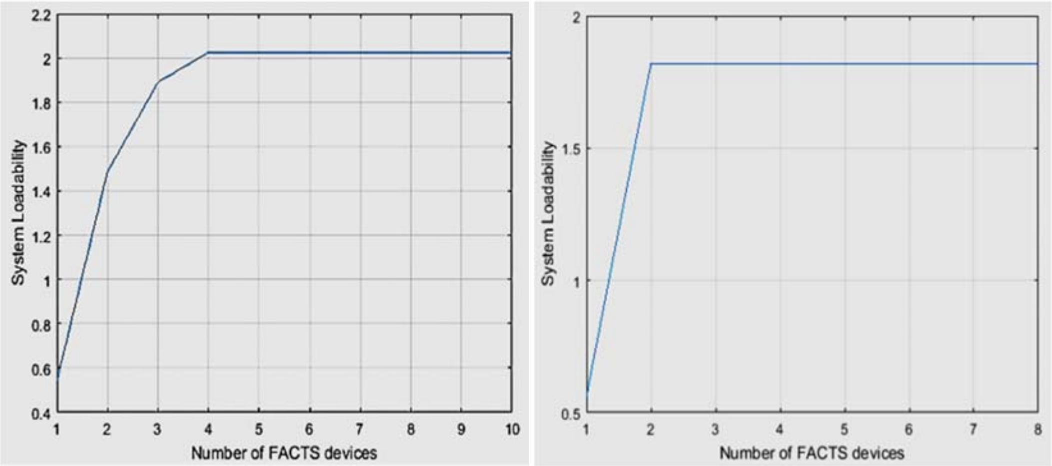
B. IEEE 30-bus system

The data for IEEE 30 bus system is taken from [38] and system contains 1 slack bus, 5 PV buses, 24 PQ buses and 41 lines. In this case single type SVC, TCSC, UPFC and multi type devices are considered. The optimal placement and parameter setting of device are obtained using ABC algorithm. Table 2 shows that the line flows in IEEE 30 bus system. The FACTS device locations are given in the Table2.In single type, the locations of SVC are 2-4, 2-5, 3-4, 6-8. In the case of TCSC, the locations are 1-2, 2-4. For UPFC the locations are 1-2, 2-5, 5-7, 6-8. In Multi type the location of FACTS devices are 7-6, 2-4, 2-5, 6-8.The installation cost of SVC, TCSC and UPFC are 1224.4US$, 5616.99US$, 128481US$ respectively. The system loadability in single type SVC, TCSC, UPFC are 2.02%, 1.82%, and 1.89% respectively. In multi type the installation cost and loadability are 80,886.6US$, and 1.56%. The system loadability is improved in single type SVC at low installation cost. The installation cost of UPFC location is more. The variation of system loadability and installation cost with number of FACTS devices is given in Fig. 8. and Fig. 9. In single type system loadability is saturated after four locations in SVC, UPFC and for two locations in TCSC. In multi type system loadability is saturated after locating SVC in one location, TCSC in two locations and UPFC in one location. The variations of system loadability and installation cost are shown in Fig.8. and Fig.9.

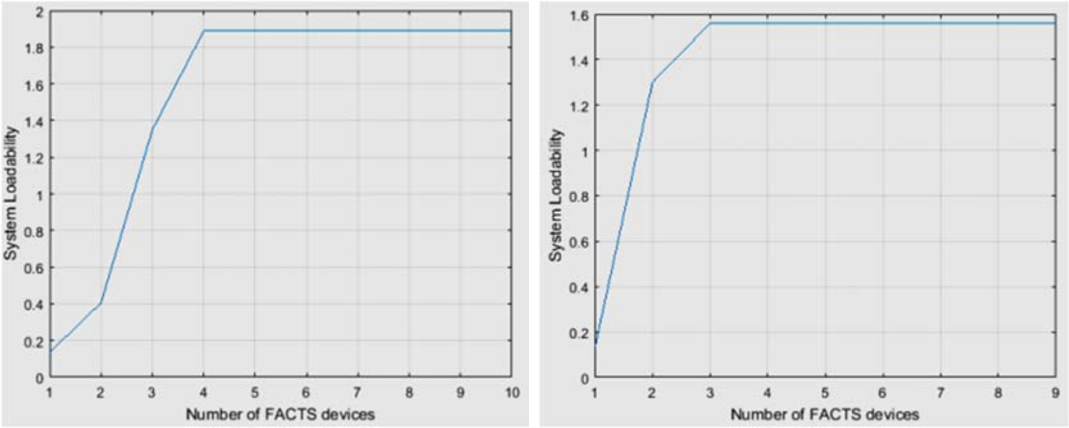
TABLE. II. LINE FLOWS IN IEEE 30BUS SYSTEM



Case	Type	From Bus	To Bus	P_b	Q_b	P_a	Q_a	Device setting	IC(USS)	MSL (%)
Single	SVC	2	4	55.684	15.874	56.441	8.593	66.6Mvar	1,224.4	2.02
		2	5	72.146	39.572	75.719	29.81	27.9Mvar		
		3	4	79.386	57.468	89.948	53.93	27.9Mvar		
		6	8	29.453	16.791	29.453	11.50	27.8Mvar		
	TCSC	1	2	114.531	25.937	131.827	20.82	0.0634p.u.	5,616.99	1.82
		2	4	38.974	11.005	40.349	7.731	0.0634p.u.		
	UPFC	1	2	114.165	25.937	151.496	25.385	0.00534p.u 70.2Mvar	1,28, 481	1.89
		2	5	72.146	39.572	74.749	29.425	0.00534p.u 68.5Mvar		
		5	7	79.386	57.468	91.982	43.513	0.003p.u 44.5Mvar		
		6	8	29. 327	16.791	29.186	15.344	0.003p.u. 44.5Mvar		
Multi	SVC	7	6	17.198	24.838	31.745	12.972	26.9Mvar	80, 886.6	1.56
	TCSC	2	4	38.974	11.005	40.781	4.017	0.0204p.u		
		2	5	77.394	21.320	85.299	15.982	0.0204p.u		
	UPFC	6	8	29.327	16.791	33.521	9.007	0.00972p.u 67.6 Mvar		

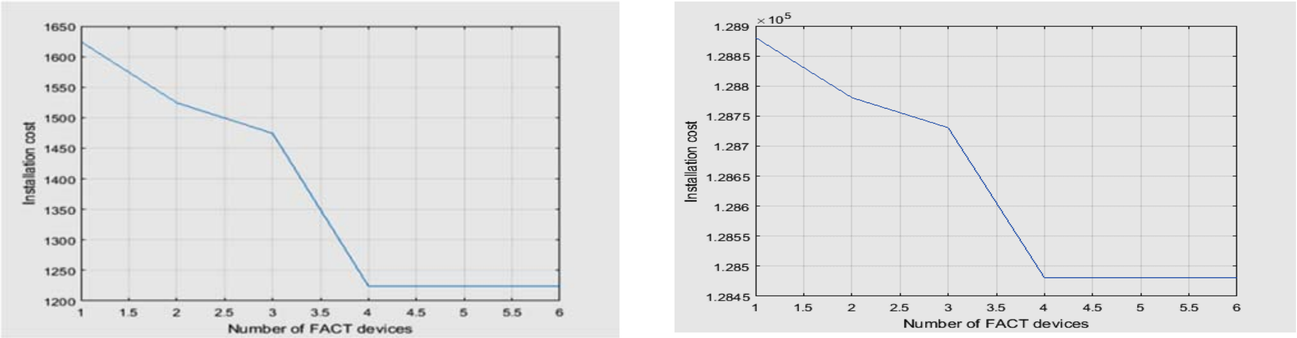


(a).SVC (b).TCSC

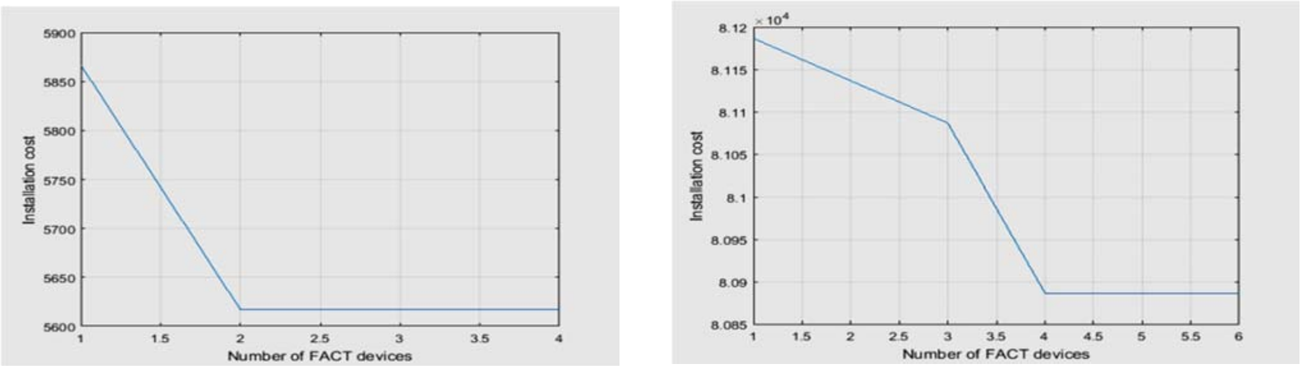


(c).UPFC (d).Multi

Fig.8. system loadability in IEEE 30 bus system



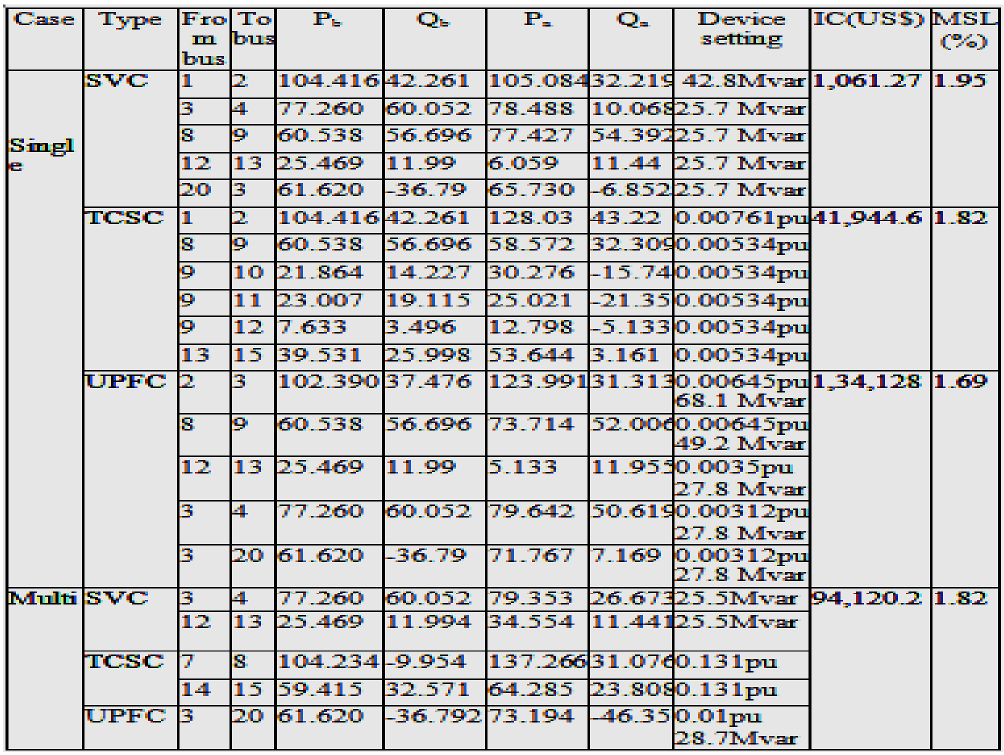
(a).SVC (c).UPFC



(b).TCSC (d).Multi

Fig.9. Installation cost in IEEE 30 bus system

TABLE III. LINE FLOW IN IEEE 57 BUS SYSTEM

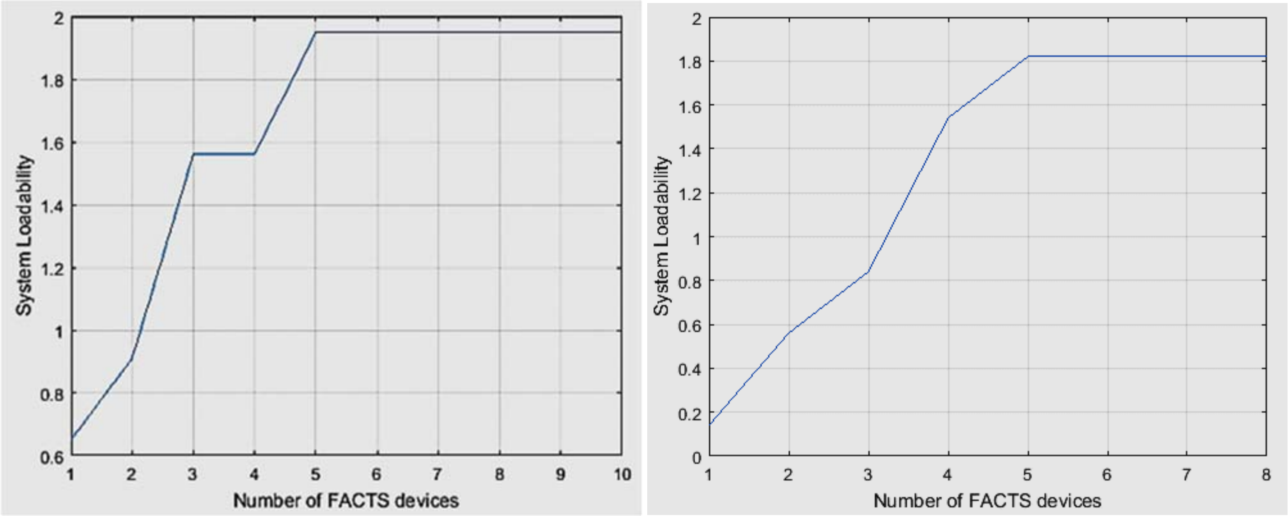


Case	Type	From bus	To bus	P_b	Q_b	P_a	Q_a	Device setting	IC(US$)	MSL (%)
Single	SVC	1	2	104.416	42.261	105.084	32.219	42.8Mvar	1,061.27	1.95
		3	4	77.260	60.052	78.488	10.068	25.7 Mvar		
		8	9	60.538	56.696	77.427	54.392	25.7 Mvar		
		12	13	25.469	11.99	6.059	11.44	25.7 Mvar		
		20	3	61.620	-36.79	65.730	-6.852	25.7 Mvar		
	TCSC	1	2	104.416	42.261	128.03	43.22	0.00761pu	41,944.6	1.82
		8	9	60.538	56.696	58.572	32.309	0.00534pu		
		9	10	21.864	14.227	30.276	-15.74	0.00534pu		
		9	11	23.007	19.115	25.021	-21.35	0.00534pu		
		9	12	7.633	3.496	12.798	-5.133	0.00534pu		
		13	15	39.531	25.998	53.644	3.161	0.00534pu		
	UPFC	2	3	102.390	37.476	123.991	31.313	0.00645pu 68.1 Mvar	1,34,128	1.69
		8	9	60.538	56.696	73.714	52.006	0.00645pu 49.2 Mvar		
		12	13	25.469	11.99	5.133	11.955	0.0035pu 27.8 Mvar		
		3	4	77.260	60.052	79.642	50.619	0.00312pu 27.8 Mvar		
		3	20	61.620	-36.79	71.767	7.169	0.00312pu 27.8 Mvar		
Multi	SVC	3	4	77.260	60.052	79.353	26.673	25.5Mvar	94,120.2	1.82
		12	13	25.469	11.994	34.554	11.441	25.5Mvar		
	TCSC	7	8	104.234	-9.954	137.266	31.076	0.131pu		
		14	15	59.415	32.571	64.285	23.808	0.131pu		
	UPFC	3	20	61.620	-36.792	73.194	-46.35	0.01pu 28.7Mvar		

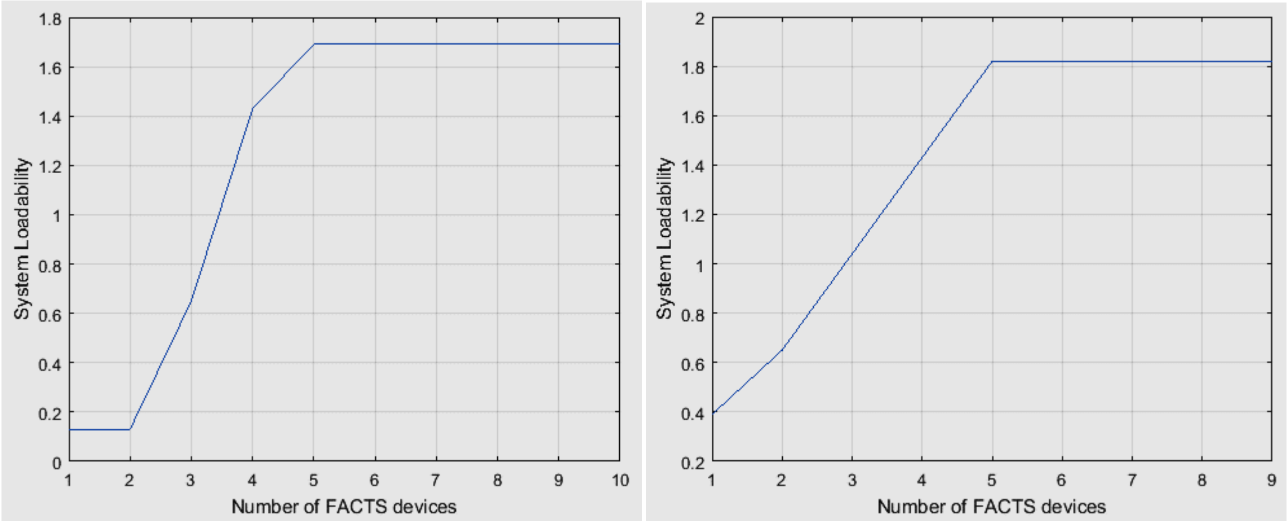
C. IEEE 57 Bus System

The data for IEEE 57 bus system is taken from matpower 3.0. and this system contains 1 slack bus, 6 PV buses, 50PQ buses and 80 transmission lines.

The simulations are performed in MATLAB and the results are obtained using ABC algorithm. Table.3. shows line flows in IEEE 57 bus system. The FACTS device locations are given in the table for single and multi type. In single type, SVC is located in lines 1-2, 3-4, 8-9, 12-13, 20-3. TCSC locations are 1-2, 8-9, 9-10, 9-11, 9-12, and 13-15. UPFC is located in lines 1-2, 2-3, 8-9, 9-12, and 19-20. In multi type, SVC is located at 3-4, 12-13, TCSC in 8-9, 14-15, UPFC in line 19-20. The installation cost of single type SVC, TCSC, UPFC, Multi type are 1,061.27US$, 41,944.6US$, 134,128US$, 94,120.2US$, respectively. The system loadability with single type SVC, TCSC, UPFC, Multi type are 1.82%, 1.95%, 1.69%, and 1.82% respectively. From IEEE 57 bus system we concluded that highest system loadability is achieved with low installation cost with SVC. Highest installation cost at moderate system loadability is obtained with UPFC. System loadability and installation cost variations are shown in Fig.10. and Fig.11.

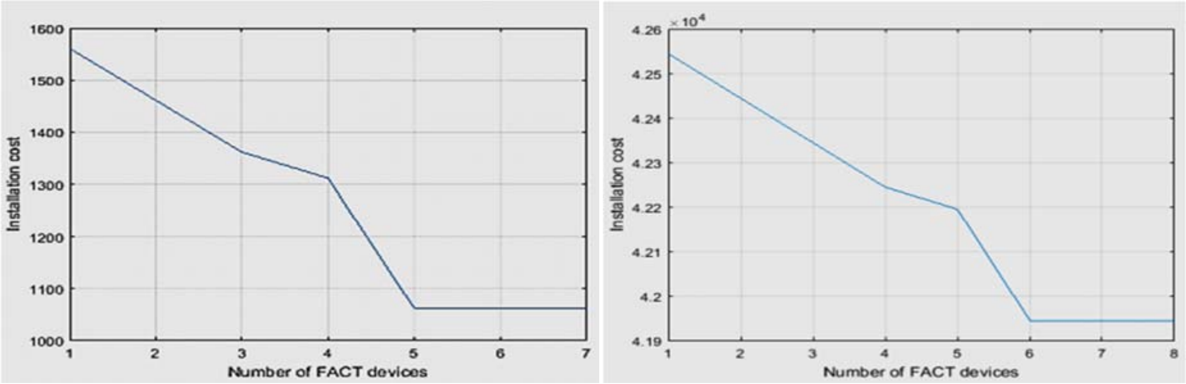


(a). SVC (b)TCSC

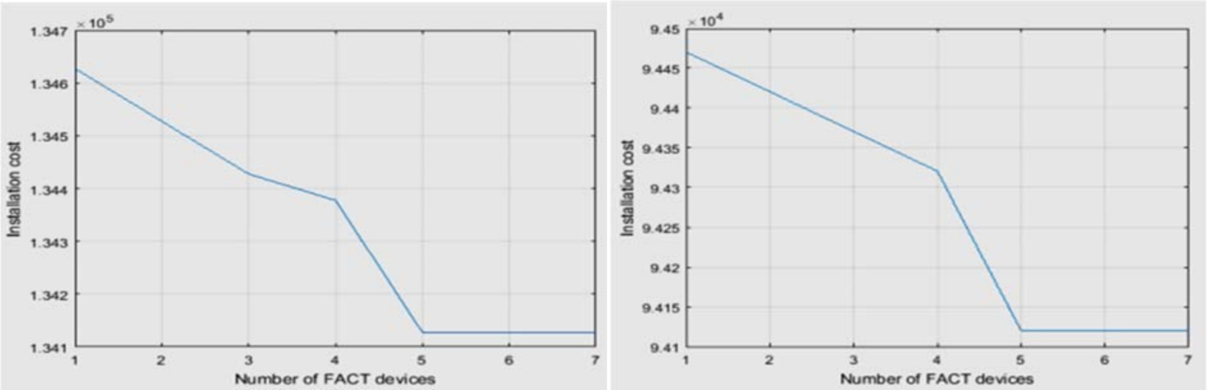


(c).UPFC (d).Multi

Fig. 10. System loadability in IEEE 57 bus system.



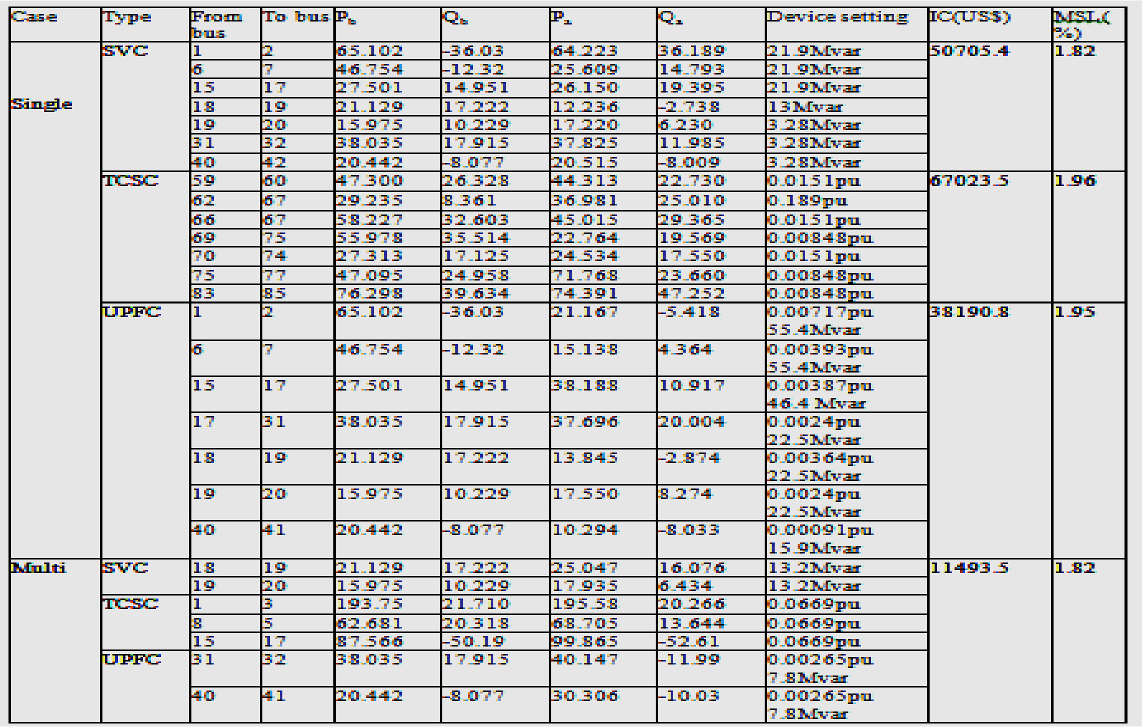
(a).SVC (b). TCSC



(c).UPFC (d).Multi

FIG.11. Installation cost in IEEE 57 bus system.

TABLE IV. LINE FLOWS IN IEEE 118BUS SYSTEM

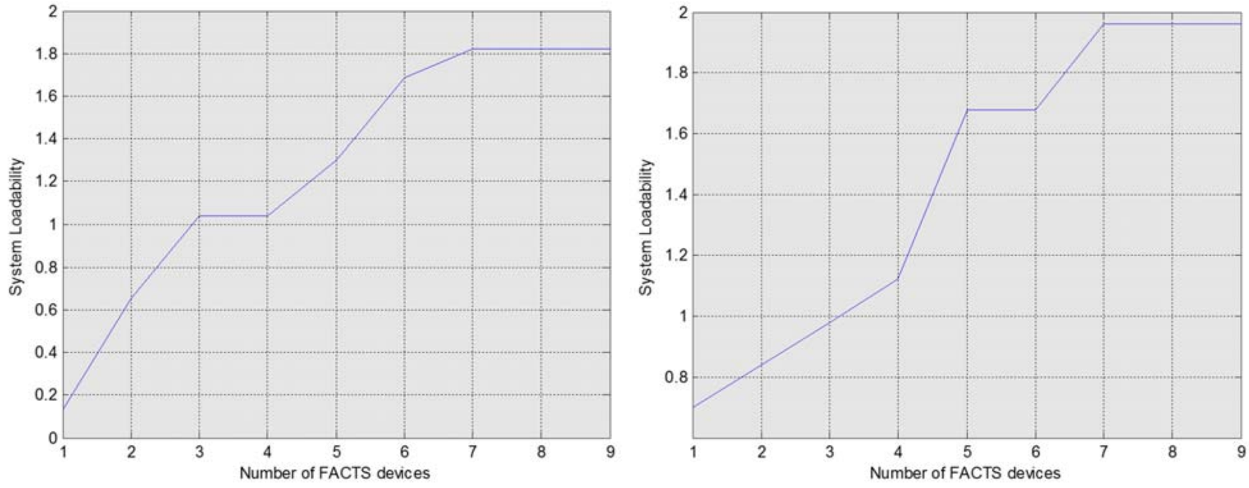


Case	Type	From bus	To bus	P_s	Q_s	P_r	Q_r	Device setting	IC(US$)	MSL(%)
Single	SVC	1	2	65.102	-36.03	64.223	36.189	21.9Mvar	50705.4	1.82
		6	7	46.754	-12.32	25.609	14.793	21.9Mvar		
		15	17	27.501	14.951	26.150	19.395	21.9Mvar		
		18	19	21.129	17.222	12.236	-2.738	13Mvar		
		19	20	15.975	10.229	17.220	6.230	3.28Mvar		
		31	32	38.035	17.915	37.825	11.985	3.28Mvar		
		40	42	20.442	-8.077	20.515	-8.009	3.28Mvar		
	TCSC	59	60	47.300	26.328	44.313	22.730	0.0151pu	67023.5	1.96
		62	67	29.235	8.361	36.981	25.010	0.189pu		
		66	67	58.227	32.603	45.015	29.365	0.0151pu		
		69	75	55.978	35.514	22.764	19.569	0.00848pu		
		70	74	27.313	17.125	24.534	17.550	0.0151pu		
		75	77	47.095	24.958	71.768	23.660	0.00848pu		
		83	85	76.298	39.634	74.391	47.252	0.00848pu		
	UPFC	1	2	65.102	-36.03	21.167	-5.418	0.00717pu 55.4Mvar	38190.8	1.95
		6	7	46.754	-12.32	15.138	4.364	0.00393pu 55.4Mvar		
		15	17	27.501	14.951	38.188	10.917	0.00387pu 46.4 Mvar		
		17	31	38.035	17.915	37.696	20.004	0.0024pu 22.5Mvar		
		18	19	21.129	17.222	13.845	-2.874	0.00364pu 22.5Mvar		
		19	20	15.975	10.229	17.550	8.274	0.0024pu 22.5Mvar		
		40	41	20.442	-8.077	10.294	-8.033	0.00091pu 15.9Mvar		
Multi	SVC	18	19	21.129	17.222	25.047	16.076	13.2Mvar	11493.5	1.82
		19	20	15.975	10.229	17.935	6.434	13.2Mvar		
	TCSC	1	3	193.75	21.710	195.58	20.266	0.0669pu		
		8	5	62.681	20.318	68.705	13.644	0.0669pu		
		15	17	87.566	-50.19	99.865	-52.61	0.0669pu		
	UPFC	31	32	38.035	17.915	40.147	-11.99	0.00265pu 7.8Mvar		
		40	41	20.442	-8.077	30.306	-10.03	0.00265pu 7.8Mvar		

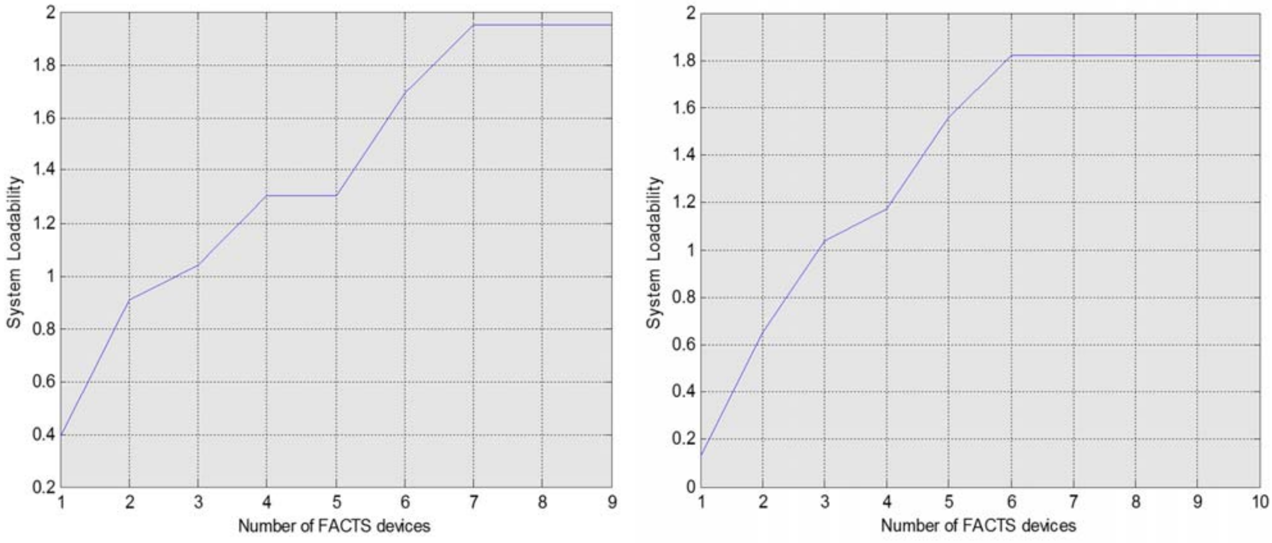
D. IEEE 118 Bus System

The line data and bus data of 118 bus system are taken from [38]. The system contains 1 slack bus 53PV buses, 64PQ buses and 186 lines.

Power flows in IEEE 118 bus system are shown in Table.4. In single type, SVC is located in lines 1-2, 6-7, 15-17, 18-19, 19-20, 31-32, 40-42. TCSC is located in lines 59-60, 62-67, 66-67, 69-75, 70-74, 75-77, 83-85. UPFC locations are 1-2, 6-7, 15-17, 17-31, 18-19, 19-20, 40-41. In multi type, SVC located in line 18-19, 19-20, TCSC is located in 1-3, 8-5, 15-17, UPFC is located in lines 31-32, 40-41.In single type, installation cost of SVC,TCSC,UPFC is 50705.4US$, 67023.5US$, 38190.8US$ and in multi type installation cost is 11493.5US$.The system loadability in single type of SVC, TCSC, UPFC is 1.82%, 1.96%, 1.95% and in multi type it is 1.82%. Highest system loadability is achieved in the case of TCSC and the installation cost is high. Installation cost is minimum with UPFC at moderate system loadability.The system loadability is saturated after seven locations of FACTS device in both single and multi type. The variations of system loadability and installation cost in IEEE 118 bus system are shown in Fig.12. and Fig.13

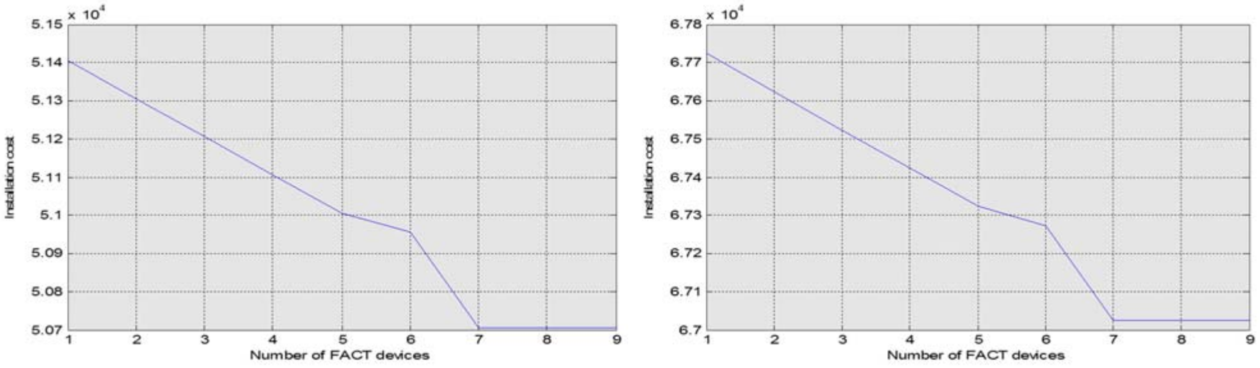


(a).SVC (b).TCSC

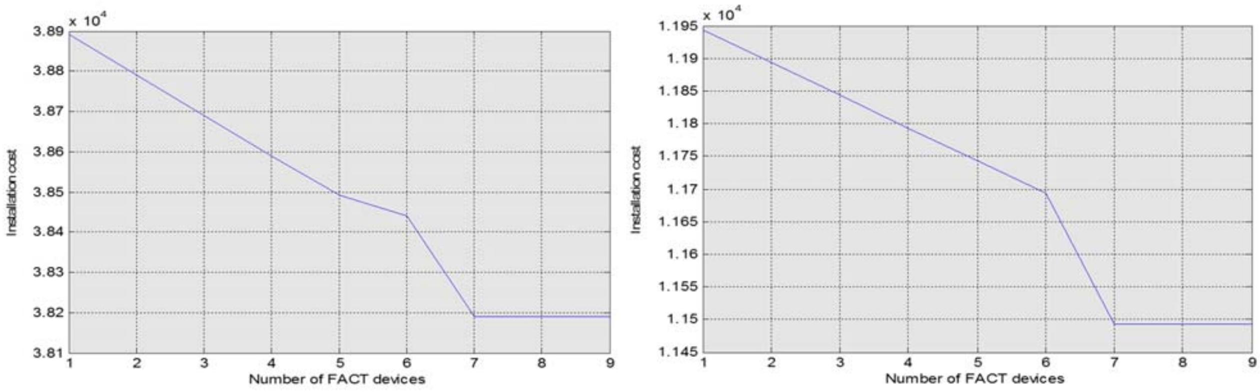


(c).UPFC (d).Multi

Fig.12. System loadability in IEEE 118 bus system



(a).SVC (b).TCSC



(c).UPFC (d).Multi

Fig.13 : Installation cost in IEEE 118 bus system

The transmission losses of different FACTS devices location in 6 bus, IEEE 30, IEEE 57, and IEEE 118 bus systems is shown in Table V.

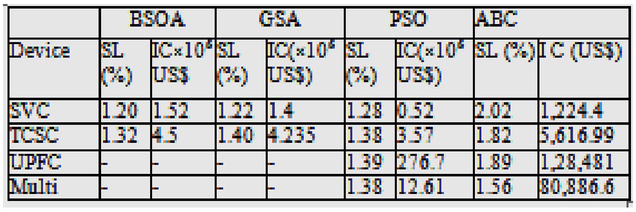
TABLE V. TRANSMISSION LOSS OF FACTS DEVICE

Transmission Loss				
Case	6 bus	IEEE 30	IEEE 57	IEEE 118
Basic	4.916	2.978	5.999	16.051
SVC	1.882	2.901	5.225	16.254
TCSC	1.235	2.621	5.007	15.205
UPFC	1.886	2.920	5.082	16.589
Multi	1.114	2.510	6.338	18.476

From Table V it is clear that, the basic loss i.e. the loss before location of FACTS device is high, the FACTS device placement is basically used here to reduce the loss produced in the system.

The comparison of system loadability, installation cost of proposed method with the existing methods in IEEE 30 bus system is shown in Table VI. The obtained results are compared with the various algorithms such as brainstorm optimization algorithm [35], Gravitational search algorithm [36], Particle Swarm Optimization [37].

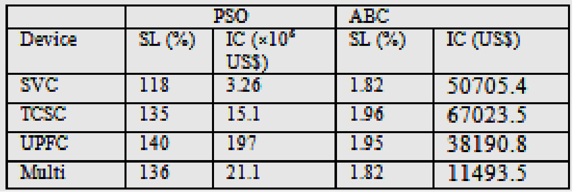
TABLE.VI. COMPARISON OF PROPOSED WITH EXISTING SYSTEM IN IEEE 30 BUS



	BSOA		GSA		PSO		ABC	
Device	SL (%)	IC×10^6 US$	SL (%)	IC(×10^6 US$)	SL (%)	IC(×10^6 US$)	SL (%)	I C (US$)
SVC	1.20	1.52	1.22	1.4	1.28	0.52	2.02	1,224.4
TCSC	1.32	4.5	1.40	4.235	1.38	3.57	1.82	5,616.99
UPFC	-	-	-	-	1.39	276.7	1.89	1,28,481
Multi	-	-	-	-	1.38	12.61	1.56	80,886.6

Table VI shows that system loadability is improved and installation cost is reduced with ABC algorithm in IEEE 30 bus system. The comparision of system loadability and installation cost in IEEE 118 bus system is given in Table VII.

TABLEVII. COMPARISON OF PROPOSED WITH EXISTING SYSTEM IN IEEE 118 BUS



	PSO		ABC	
Device	SL (%)	IC (×10^6 US$)	SL (%)	IC (US$)
SVC	118	3.26	1.82	50705.4
TCSC	135	15.1	1.96	67023.5
UPFC	140	197	1.95	38190.8
Multi	136	21.1	1.82	11493.5

The system loadability is improved and installation cost is reduced with ABC algorithm in IEEE 118 bus syem. Hence, Existing algorithms such as brainstorm, gravitational search and particle swarm optimization are compared with the proposed artificial bee colony algorithm. From comparison tables, it is concluded that, proposed system gives better system loadability at reduced installation cost and transmission loss.

V. CONCLUSION

In this work, optimal placement and parameter setting of FACTS devices is determined for reducing transmission losses, installation cost of devices and improvement of system loadability using ABC algorithm. Simulations are performed on 6 bus, IEEE 30, IEEE 57 and IEEE 118 bus systems. Single type FACTS devices SVC, TCSC, UPFC and multi type devices are placed. In the case of multi type FACTS device the type of device is taken as variable in optimization. In both single and multi type system loadability cannot be improved further after placing certain number of devices. Voltage deviation and line flow deviation are within limits. Voltage profile is improved. Power flow is improved with reduction of reactive power. Hence voltage instability problems are solved. The total loss in the system is reduced compared to existing literature. Thus proposed system enhances the power flow better than existing methods and reactive power is maintained in balanced condition. In 6 bus test system, TCSC gives better improvement in system loadability at low cost of installation. In IEEE 30, IEEE 57 and 118 systems SVC gives lowest cost of installation with maximum system loadability. Hence proposed algorithm gives reduction in Transmission loss and installation cost of FACTS device, system loadabiliyty is improved.

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