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Active and Reactive Load Ability Improvement using BBO Algorithm with FACTS Devices

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Abstract: ***Biogeography-based optimization (BBO) technique is used for the optimal positioning of FACTS devices under various loading cases in IEEE 14 bus system. In this paper, the effects of active and reactive loadings are studied and power flow analysis is performed for the proper placement of FACTS devices. The suggested method with active and reactive loading using FACTS devices is compared with Krill herd algorithm (KHA). It is found that the BBO algorithm improves real power loss, operating cost and system loadability significantly.***

Keywords : Real power loss (RPL), Active loading, Reactive loading, operating cost, Biogeography-based Algorithm

I. INTRODUCTION

In the existing Power system due to rapid change in the power demand and restriction on constructions of new lines transmission congestion increases due to change in the unscheduled power flow in the lines and because of that transmission loss also increases. For maintaining the voltage profile, power losses are controlled by effective control of reactive power compensation. It also improves the dynamics and steady state of the system. Basically, FACTS devices improve the load angle, impedance of the line and magnitude of the voltage profile. With proper coordination between FACTS devices the reactive and RPL can be controlled in an efficient manner. In 1988, FACTS concept was coined by Hingorani [1]. Power transfer capacity increased by the static phase shifters is described in [2]. Proper coordination and placement of FACTS devices are discussed in [3]. In [4] using FACTS devices improving power flow in the power network. In [5] by use of shunt and series FACTS devices switches are discussed for optimal reactive power dispatch. Available transfer capacity approach is used for optimal power flow are discussed in [6]. In [7] hybrid Genetic Algorithm for loadability enhancement with multi type FACTS devices is described.

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Active transmission congestion management approach by Lagrangian decomposition is discussed in [8]. The Optimal position of FACTS devices by using Genetic Algorithm (GA) is discussed in [9].

The preferred location and Static Var Compensator (SVC) size by using sensitivity analysis and linear programming techniques is discussed in [10]. Power system deregulated market is discussed in [11].Different optimal power flow solution techniques using multi-type FACTS devices are discussed in [12].In [13] use of multi-type FACTS devices to enhance the available transfer capacity and for loadability different optimization techniques are described in [15].. Allocation of FACTS device like TCSC for enhancing the loadability and reducing the RPL by GA is described in [14].Using Gravitational search Algorithm to reduce the active power loss and enhancing the bus voltage is presented in [16]. In this work, author has increased the load ability of power system by increasing loading on the system. Here we are using the BBO technique to locate the preferred position in order to decrease the RPL and operating cost (OC) [17].

II. MODELING OF FACTS DEVICES

The congested line is modeled by the multi-type FACTS devices. It can be shown by the injected power model. These models inject active and reactive power at weak node. By calibrating the reactance of the TCSC and SVC, power and voltage profile of weak buses can be maintained. In TCSC two types of reactance changing properties are present, capacitive and inductive, due to that it improves reactive power of the line and bus. TCSC and SVC are increases the transmission limit of the line, voltage profile improvement, stability margin and also decreases the loss. SVC's is also similar to TCSC in reactance. It improves bus voltage profile, reduces RPL and static voltage profile. TCSC and SVC power model are shown in figue-1, figure-2, and figure-3.

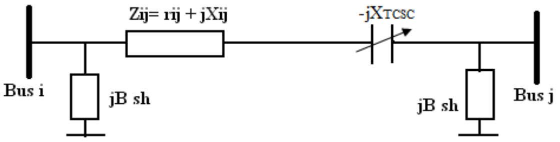

Fig.1. TCSC Model

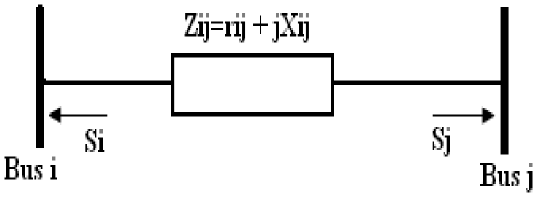

Fig.2. TCSC injection Model

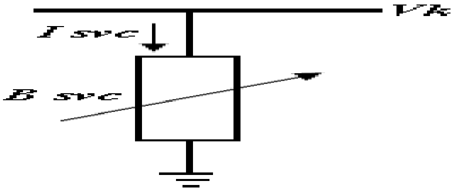

Fig.3. SVC Model

III. COST FUNCTION AND PROBLEM FORMULATION

The emphasis of this work is find best location and control variable size (tap changing transformer, TCSC etc.). It also decreases the RPL and the total OC. Energy loss and shunt capacitor cost situated at weak buses are also taken in account. RPL can be minimized by the following objective function:

$$F_1 = P_l \sum_{b=1}^{n} G_{ij} \left[U_i^{\,2} + U_j^{\,2} - 2U_i U_j \cos(\delta_i - \delta_j) \right] \tag{1}$$

where,

n = no. of lines

G_{ij} = conductance between bus 'i' and 'j'

U_i = ith bus voltage

U_j = jth bus voltage

δ_i = ith bus angle

δ_j = jth bus angle

P_l = line RPL

Using different control variable optimal value we can reduce the real power loss.it is denoted by vector D

The transmission line RPL can be minimised by using best value of control variables depicted by vector V

$$D = \left[U_c^i, \ldots\ldots U_c^b, Q_c^i, \ldots\ldots Q_c^q, t_n^1, \ldots\ldots t_n^t \right] \tag{2}$$

In the above equation 2 ,

U_c^i is voltage controlled bus and U_g^i is it's voltage ,where i=1, 2, ……,b, and Q_c^i is value of parallel capacitor at the ith weak bus, where i=1, 2, ...,q. The total count of shunt capacitors or weak nodes is given by q and number of on load tap changing transformers (OLTC) is given by t. Based on the optimal variables related with the function, M_1 is constituted by vector E.

$$E = \left[P_g^1, V_l^1, \ldots\ldots V_l^n, Q_g^1, \ldots\ldots Q_g^k \right] \tag{3}$$

Where, P_g^1 is slack bus power, V_l^i is load bus i voltage and i = 1, 2, 3. . . n, n is load bus count in the system. Q_g^i is ith generator reactive power output and i = 1, 2. . . k, and k is no. of generator buses. The principle emphasis is to decrease the line RPL by suitable control of variables in equation (2). Hence, a function can be expressed as,

$$M_1' = C_1 + C_2 \tag{4}$$

Where $C_1 = f(M_1)$

C_1 is cost inferred because of energy loss. C_2 is shunt variable expense. Shunt capacitor expense =1000 US$. Energy consumption (EC) expense =6 ×10^{-2} US$ per kWh. Capacitor expense per KVar = 3dollars,

Where,

$$C_1 = P_1 \times \text{Energy consumption rate (ECR)} \tag{5}$$

ECR = 6 ×10^{-2} × 10^5 × 8760. Minimising M_1 also minimises total operating expense. All datas are referred from [16].

It's troublesome to maintain the good voltage profile throughout for various reactive loads. It's very tedious for generation companies. The detached function mentioned below is for voltage profile:

$$M_2 = \sum_{i=1}^{n} \left| U_i - U_{specified} \right| \tag{6}$$

where, $U_{specified}$ is the bus voltage and n is total bus in the system.

The equation mentioned above as detached functions are to be reduced using equality and inequality limits. If M_2 is attached with M_1' the whole function will be,

$$M_3 = M_1' + M_2 \tag{7}$$

Equality limits: Active power equation.

$$P_{ga} - P_{da} - U_a \sum_{a=1}^{n} U_b \left[G_{ab} \cos(\delta_a - \delta_b) + B_{ab} \sin(\delta_a - \delta_b) \right] = 0$$

i=1,2, 3…...n (8)

Reactive power equation

$$Q_{ga} - Q_{da} - U_a \sum_{b=1}^{n} U_b \left[G_{ab} \sin(\delta_a - \delta_b) + B_{ab} \cos(\delta_a - \delta_b) \right] = 0$$

i=1, 2, 3……n (9)

where,

n = total bus in the system

P_{ga} = ath bus generation of active power

Q_{ga} = ath bus generation of reactive power

P_{da} = demand of active power at ath bus

Q_{da} = demand of reactive power ath bus

G_{ab} =transfer conductance adjoining ath bus and bth bus

B_{ab} =transfer susceptance adjoining ath bus and bth bus

Inequality limits: The generator voltage magnitude and reactive power outputs must be limited within max and min limits:

$P_{gk,min} \le P_{gk} \le P_{gk,max}$ k=1, 2, 3….….B_{pv} (10)

Generator bus voltage & Reactive power limits are given below:

$Q_{gk,min} \le Q_{gk} \le Q_{gk,max}$ k=1,2,3….….B_{pv} (11)

$U_{gk,min} \le U_{gk} \le U_{gk,max}$ k=1, 2, 3….….B (12)

Transformer taps limits: Upper and lower limit values are limited to:

$t_{k,min} \le t_k \le t_{k,max}$ k=1, 2, 3….….B (13) where,

B_{pv} = place of PV buses
B = place of buses

SVC reactive power limits:

$$Q_{svc}^{min} \le Q_{svc} \le Q_{svc}^{max} \qquad (14)$$

TCSC reactive power constraints:

$$Q_{tcsc}^{min} \le Q_{tcsc} \le Q_{tcsc}^{max} \qquad (15)$$

IV. BIOGEOGRAPHY-BASED OPTIMIZATION

BBO is the Meta heuristic technique for locating the ideal place of FACTS devices in the system. Using this method we are connecting the FACTS devices at the ideal locations in the power system network. Here TCSC is connected in the line and SVC at the node of bus voltage. TCSC changes the reactance of the line and hence changing the reactive power of the line and SVC injects reactive power in the bus. Generator control is affected by the tap changer. In 2008 basic concept of BBO was proposed by Dan Simon. It solves a different type of optimization problem [19]. It is basically based on the habitat behavior of species as like rainfall, soil, temperature and diversity of vegetation. For the standard of living decided by the no of species lies in the habitat. If no of species is more than it is the more favorable area for living and vice-versa. A large number of species showed a high suitability index (HIS). Control variables are associated with the suitability index (SIVs). Here low HSI showed high immigration rate. In immigration to emigration process low HSI is good feature rather than high HSI. Using the immigration and emigration process is to a strong node.
The immigration rate (IR) and the emigration rate(ER) can be calculated as follows:

$$\lambda_{Ir} = I_r\left(1 - \frac{K_s}{K_{s\,max}}\right) \qquad (16)$$

$$\mu_{Er} = E_r\left(\frac{K_s}{K_{s\,max}}\right) \qquad (17)$$

where,

I_r= max. possible IR

E_r = max. possible ER

K_s = no of individual species in the ordered population
$K_{s\,max}$ = largest number of species

A probabilistic model represents emigration and immigration mathematical operation. If K_s species are in a habitat then P_{ks} is the probability of the habitat.
If P_{ks} change from time t to t+Δt then:

$$P_{ks}(t + \Delta t) = P_{ks}(1 - \lambda_{Ir}\Delta t - \mu_{Er}\Delta t) + P_{k(s-1)}\ \lambda_{Ir(s-1)}\Delta t + kP_{(s+1)}\ \lambda_{Ir(s+1)}\Delta t \qquad (18)$$

where,

$\lambda_{Ir(s-1)}, \lambda_{Ir(s+1)}$=IR when there are K_{s+1} and K_{s-1} species in the habitat. $\mu_{Er(s+1)}, \mu_{Er(s-1)}$= ER when there are K_{s+1}, K_{s-1} species in the habitat.

Below mentioned conditions should be satisfied for equation 18.

(1)No immigration or emigration happens between t to t+Δt if number of species is K_s.
(2)For K_{s-1} species one species immigrates at time t and
(3)For K_{s+1} one species emigrates at time t.

For small Δt taking the limit of Eq.(18) . Such that $\Delta t \rightarrow 0$.

$$P_{ks} = -(\lambda_{Ir} + \mu_{Er})P_{ks} + \mu_{Er(s+1)}P_{k(s+1)}$$

$$K_s = 0 \qquad (19)$$

$$P_{ks} = -(\lambda_{Ir} + \mu_{Er})P_{ks} + \lambda_{Ir(s-1)} + \mu_{Er(s+1)}P_{k(s+1)}$$

$$1 \le K_s \le K_{s\,max} \qquad (20)$$

$$P_{ks} = -(\lambda_{Ir} + \mu_{Er})P_{ks} + \lambda_{Ir(s-1)}P_{k(s-1))}$$

$$K_s = K_{s\,max} \qquad (21)$$

Migration and mutation are two main operators of BBO. A vector with p SIVs is spoken to by every competitor arrangement (i.e., every living space). Here four control factors are tap changer, SVC, shunt capacitor and TCSC's. On the off chance that there are accessible (p) self-standing factors than jth single natural surroundings characterized as follows:

$$H^j = [SIV^{j1}, SIV^{j2}, \dots\dots\dots\dots, SIV^{jp}] \qquad (22)$$

j=1,2,3………n
Where,
p= count of independent variable
n= habitat number
Dimension of the population is (n×m)
H^j= the jth habitat holds (p) independent variable (SIVs) for above detached function

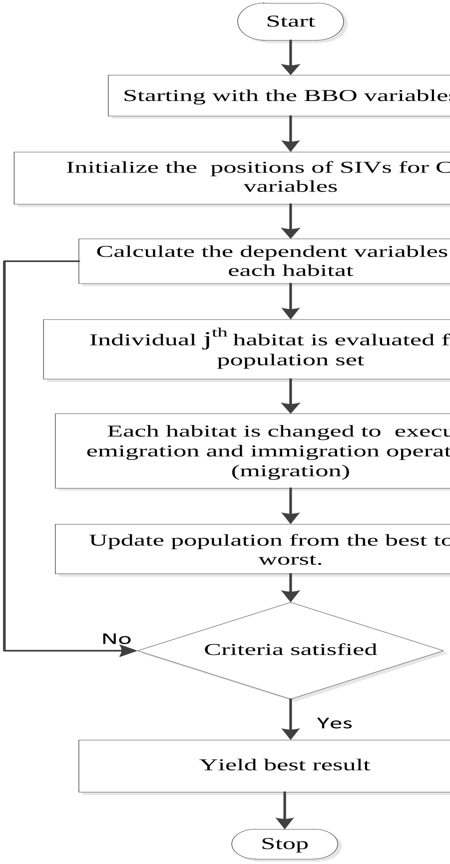

Fig.4. Flow diagram of the BBO algorithm

V. RESULTS AND DISCUSSIONS

Here we are using two types of FACTS devices, TCSC and SVC. Proper positioning of FACTS devices decreases the RPL .TCSC is placed in 8, 9, and 11. SVC is connected at bus 10, 13, 14. Variation of RPL to minimum cost for different loading condition is described in figure-5, figure-6, and figure-7. Operating Cost fluctuation with generation for various loading using BBO is described in figure 8, figure 9, and figure 10. FACTS devices are installed at the proper place as defined by the proposed approach and system output is observed in presence and absence of FACTS devices. Table 1 shows the optimal positions of multi-type FACTS devices in the lines.

Table 2 and Table 3 depict RPL and bus voltage of the test system. Table 4 shows optimal control variables values at different loading conditions and table 5 shows the operating expense of the FACTS devices at different loading condition by using the BBO techniques.

Table-1: Positions of FACTS devices

TCSC in Lines	SVC in Buses
8, 9, 11	10, 13,14

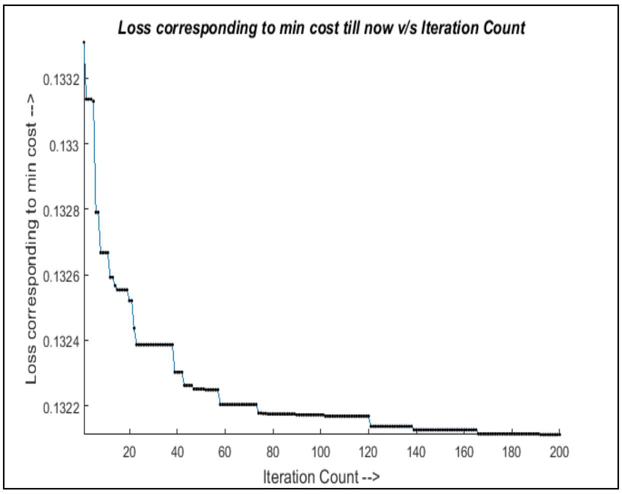

Fig.5 RPL variation w.r.t. iteration for base loading using BBO

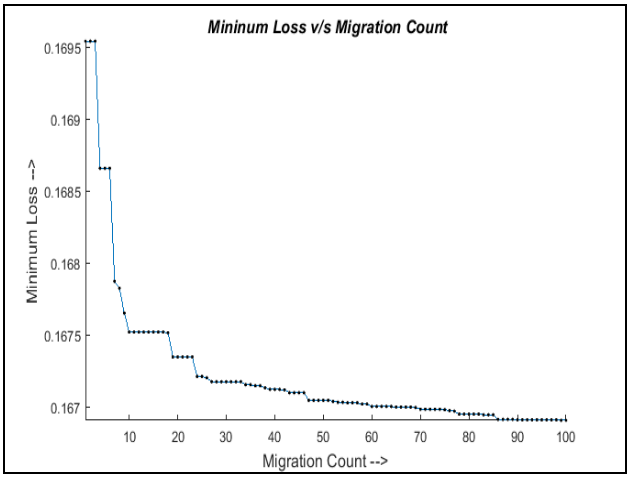

Fig.6 RPL variation for (1.10Pd, 1.10Qd) loading using BBO w.r.t. iteration

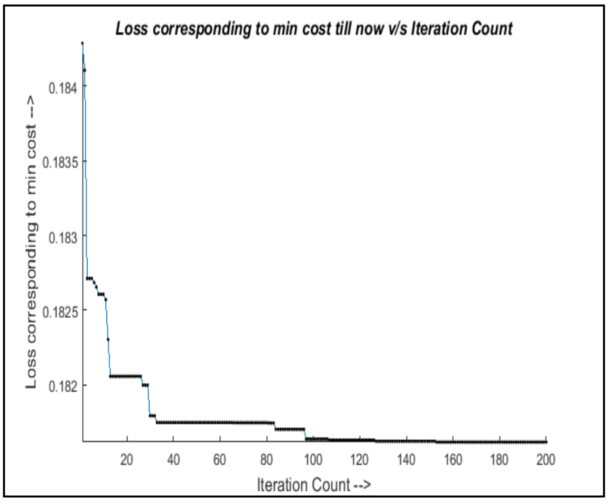

Fig.7 RPL variation for (1.20Pd, 1.20Qd) loading w.r.t. iteration

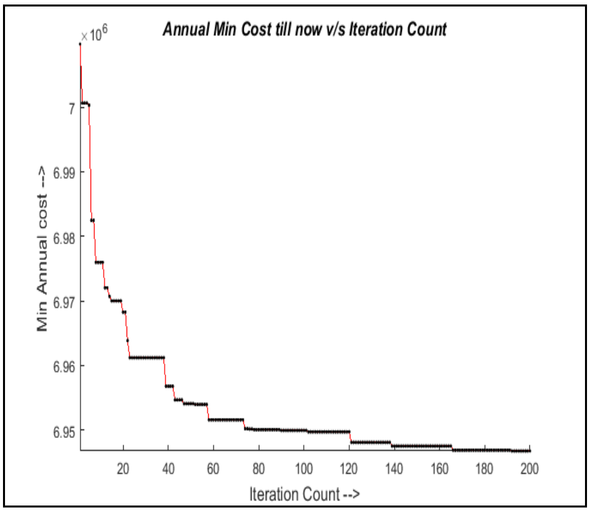

Fig.8 OC variation w.r.t. iteration for base loading using BBO

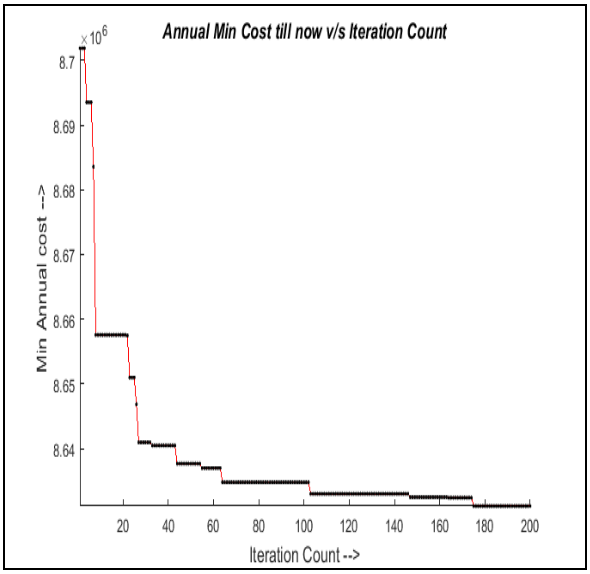

Fig.9 OC variation w.r.t. iteration for (1.10Pd, 1.10Qd) loading using BBO

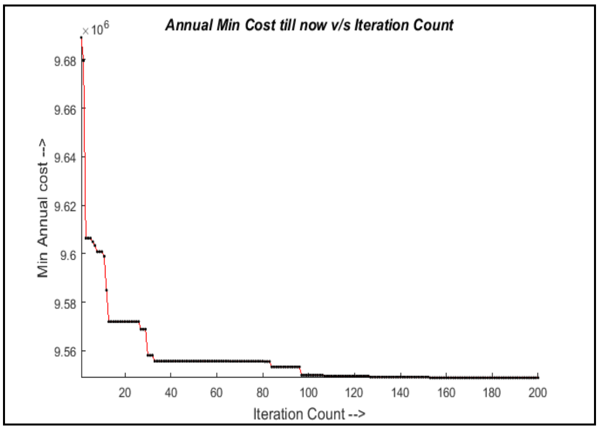

Fig.10 OC variation w.r.t. iteration for (1.20Pd, 1.20Qd) loading using BBO

Table 2 Transmission loss (RPL) without and with FACTS devices

Pd and Qd loading (%)	Transmission loss without FACTS devices in (per unit)	Transmission loss with FACTS devices using BBO technique (per unit)	Transmission loss with FACTS devices using KHA technique (per unit)
100	0.1555	0.1321	0.1324
110	0.1974	0.1641	0.1646
120	0.2294	0.1816	0.1821

Table 3 Bus Voltage value (p.u.) with and without FACTs devices using BBO

Bus No.	Voltage obtained without FACTs in (p. u.)	Voltage obtained with FACTs by using the Optimization technique in (p. u.)					
		Base (Pd, Qd)		*110 % (Pd, Qd)*		*120 % (Pd, Qd)*	
		Using BBO	Using KHA	Using BBO	Using KHA	Using BBO	Using KHA
1	1.0000	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600
2	0.9747	1.0471	1.0471	1.0445	1.0460	1.0461	1.0461
3	0.9305	1.0177	1.0173	1.0132	1.0139	1.0144	1.0144
4	0.9371	1.0266	1.0261	1.0211	1.0222	1.0233	1.0201
5	0.9419	1.0322	1.0331	1.0274	1.0318	1.0286	1.0318
6	0.9816	1.0993	1.0941	1.0939	1.0827	1.0905	1.1000
7	0.9748	1.0890	1.0758	1.0851	1.0772	1.0759	1.0859
8	1.0053	1.0974	1.0999	1.0999	1.1000	1.0995	1.1000
9	0.9660	1.0895	1.0840	1.0827	1.0737	1.0808	1.0882
10	0.9606	1.0904	1.0786	1.0823	1.0673	1.0823	1.0820
11	0.9672	1.0914	1.0829	1.0843	1.0712	1.0825	1.0871
12	0.9653	1.0897	1.0827	1.0841	1.0698	1.0796	1.0864
13	0.9600	1.0892	1.0778	1.0843	1.0646	1.0792	1.0809
14	0.9436	1.0811	1.0658	1.0743	1.0522	1.0700	1.0669

Table 4 Optimal Value of Control parameters by using BBO technique in the transmission network

Control parameters	Optimal Value of Control parameters by using Optimization technique					
	Base (Pd, Qd)		*110 % (Pd, Qd)*		*120 % (Pd, Qd)*	
	Using BBO	Using KHA	Using BBO	Using KHA	Using BBO	Using KHA
$Q_g(2)$	0.3401	0.3396	0.3985	0.4140	0.4639	0.4619
$Q_g(3)$	0.2589	0.2574	0.3149	0.3069	0.3349	0.3541
$Q_g(6)$	0.2079	0.1555	0.2296	0.1527	0.2339	0.1631
$Q_g(8)$	0.0524	0.1508	0.0924	0.1421	0.1477	0.0883
svc(10)	0.0828	0.0120	0.0738	0.0120	0.1077	0.0120
svc(13)	0.0635	0.0120	0.0873	0.0120	0.0785	0.0120
svc(14)	0.0545	0.0120	0.0620	0.0120	0.0614	0.0120
tap(8)	0.9588	0.9736	0.9633	1.0062	0.9668	1.0050
tap(9)	0.9504	0.9928	0.9501	0.9647	0.9828	0.9557
tap(11)	0.9819	0.9000	0.9828	0.9374	0.9559	0.9003

Table 5 OC without and with FACTS devices

Pd and Qd loading (%)	OC in absence of FACTS devices $\times 10^6$ in (($) (A)	OC in presence of FACTS devices with BBO technique $\times 10^6$ in ($) (B)	OC in presence of FACTS devices with KHA technique $\times 10^6$ in ($) (C)	Net saving with BBO technique $\times 10^6$ in ($) (A-B)	Net saving with KHA technique $\times 10^6$ in ($) (A-C)
100	8.173	6.946	6.965	1.227	1.208
110	10.375	8.631	8.656	1.744	1.719
120	12.057	9.548	9.571	2.509	2.486

VI. CONCLUSION

The BBO algorithm is used for the effective reactive power planning with FACTS devices under different active and reactive loads. By varying active and reactive loads we find RPL and OC in absence of FACTS. Using the BBO algorithm we find the proper location of FACTS devices. Here we observe that reactive power flow improves. RPL and OC reduce for all loading conditions. Hence it is easily noted that system load ability is increased with allocation of FACTS devices using the BBO algorithm. Hence it can be observed that BBO is an effective method for load ability enhancement and RPL minimization.

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