Enhancing system loadability with multiple FACTS devices using Artificial Bee Colony Algorithm

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***Abstract*—With the vulnerability of load curve and exchange of power between various utilities the upper limit of the power capability of the system is crossing. So there is need of finding the solution to limit the usage of existing system and to give satisfactory voltage support. In these situations Flexible AC Transmission system (FACTS) devices assume significant job in increasing system performance and loadability. These FACTS devices whenever put ideally can be viable in giving voltage support, controlling power flows and thusly coming about in to bring down the system losses. Here FACTS devices SVC, STATCOM, TCSC have been considered for optimal placement. The Artificial Bee Colony algorithm (ABC) has been developed for simultaneous placement of above said FACTS devices. The effect of these devices for lowering losses, increasing the loadability has been observed by placing at optimal locations dictated by ABC algorithm. The results have been validated on IEEE 14 and 30-bus systems.**

Keywords—FACTS; Artificial Bee Colony algorithm; SVC; STATCOM; TCSC;

I. INTRODUCTION

The FACTS gadgets which are created with the overhauls in semiconductor development are beneficial to smoother the issues of electromechanical switching devices. So these FACTS devices are utilized for expanding the usable limit of existing transmission lines and power control [1, 2, 7].
Studies and researches have demonstrated the proficiency of power control of FACTS devices in dynamic and transient stabilities. The FACTS gadgets have the ability to shift the impedance (Z) of a transmission line. Additionally, these FACTS devices have the limit with respect to power control, and voltage control [11, 12]. The power flow control is the fundamental task for an interconnected system in order to improve system performance. So FACTS devices accept a basic part in interconnected networks. These FACTS devices are very complex devices and also not economical to place in all sensitive places. Choosing and perfect placing of FACTS devices are significant things for the stability of the network [13, 15, 22].

II. MODELLING OF FACTS DEVICES

A. *Model of SVC*

The model of SVC used here is a changing susceptance (*B)* of SVC which represents the fundamental frequency equivalent of all shunt modules making up the SVC. This model is an improved variant of SVC models. This is giving the shunt compensation for the system. It is appeared in the fig. 1.

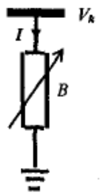

Fig. 1. Variable susceptance model of SVC [6]

B. *Model of STATCOM*

STATCOM is a shunt-associated reactive power compensation devices that is equipped for creating or potentially retaining reactive power and in which the yield can be changed to control the particular parameters of an electric power network [3]. Exact power flow estimation ought to consider the losses of STATCOM. The losses of the converter incorporate principally three sections: the power loss in the dc capacitor, the losses due to switching, and losses due to conduction. The level of every loss componenet identifies with the control method of STATCOM and the steady state working point. The equivalent circuit of STATCOM is appeared in fig. 2. In this circuit, the inductance xs speaks to the leakage inductance of the transformer, rs speaks to the shunt resistance, rp speaks to the power loss in the dc capacitor. From figure it very well may be seen that the VSC goes about as an AC voltage source behind equivalent impedance, where both magnitude and Phase angle of the source are controllable.

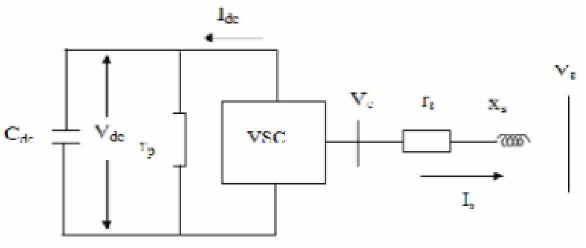

Fig. 2. Model of STATCOM

C. Model of TCSC

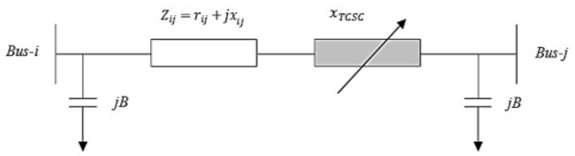

Figure 3. Model of TCSC

The above figure shows the TCSC associated between buses as shown in the figure. The adjustment in the power flows happens because of arrangement of series impedance set in the line. The genuine power infusion at buses i and j are ($P_{i\,inj}^{TCSC}$) and ($P_{j\,inj}^{TCSC}$).

III. OBJECTIVE FUNCTION

The objective is to find the steady-state operation point of a system, which limits pre-specified functions (real power losses, generation cost, minimizing voltage deviations, cost of FACTS devices).

A. Minimization of real power loss

In order to minimize the real power losses the FACTS devices (SVC, STATCOM, TCSC) have to place in ideal locations. The following objective function is selected:

$$\min f_1(x) = \sum_{k=1}^{ntl} PL_{tl}$$

Here

f_1-is the function to decrease power loss

PL_{tl} - is the real power loss of the tlth line

ntl - total number of lines in the system

B. Minimization of the total generation cost

The quadratic cost model of generation units are normally,

$$C_{P_{Gi}} = a_i P_{Gi}^2 + b_i P_{Gi} + C_i \quad \$/hr$$

Where ai, bi and ci are the cost coefficients and P_{Gi} is the real power generation in MW of the generator i. The objective function f_2 for the entire power system can then be written as the summation of the quadratic cost model of each generator.

$$f_2(x) = \sum_i (a_i P_{Gi}^2 + b_i P_{Gi} + C_i) \quad \$/hr$$

C. Minimization of voltage Deviations

The voltage deviation is a sum of voltage deviations at all the buses in the power system from reference values. The below formula define the voltage deviation objective

$$f_3(x) = \Delta V = \sum_{i=1}^{nb} \left[\frac{V_i^{ref} - V_i}{V_i^{ref}}\right]^2$$

D. Cost of the FACTS devices

We know that by placing FACTS devices at selective buses in the power system, it is possible to accomplish the desired voltage security. If more FACTS devices located at various sensitive buses in the system, then it leads uneconomical operation. So the cost of installing the FACTS devices is also considered for minimizing objective function.

$$f_4(x) = K_v * (X)$$

$K_v = \sum_{j=1}^{n} C_{FACTSj}$ = Installing Cost of the FACTS devices/MVAr

$X=[x_1\ x_2\ x_3 \ldots.\ x_n]$, is the capacity of the FACTS devices determined from the selection strategy.

E. Multi-Objective function

In Multi-objective optimization all the central variables, such as transmission losses and the system generation cost, voltage deviations, installation cost of FACTS are minimized simultaneously. In the proposed study, the objective function is defined as the summation of all the objectives with different weights

$$F(x) = w_1 f_1(x) + w_2 f_2(x) + w_3 f_3(x) + w_4 f_4(x)$$

Where w_1, w_2, w_3, w_4 are weight factors. Above objective function can be solved by assighing different weights to $w_1, w_2 w_3$ and w_4 such that $w_1 + w_2 + w_3 + w_4 = 1$

IV. ARTIFICIAL BEE COLONY ALGORITHM

Artificial Bee Colony algorithm is a algorithm which is influenced by honey bee swarm foraging technique. In the model of honey bee there are three kinds of bees; those are employed honey bees, onlooker honey bees and scout honey bees. Employed honey bees are the one which finds the nectar sources and offering information to the onlooker honey bees in the hive about the idea of the sustenance source destinations. Onlooker honey bees find out the best sustenance source considering the information given by the employed honey bees. Scouts erratically exploit nectar sources, remembering the ultimate objective to find another sustenance source in a social event of missed sustenance sources.

In ABC algorithm, the situation of a sustenance source suggests a response for the issue which must be optimized. Here the nectar proportion of a sustenance source suggests the profitability or fitness of the solution. The utilized employed bee can pick only a solitary sustenance source which infers the amount of utilized employed bees is proportional to the amount of sustenance sources existing around the hive. So along these lines the amount of solutions can be found in the population. The utilized employed bee whose sustenance source has been done transforms into a scout bumble bee.

V. PROCEDURE FOR OPTIMAL PLACEMENT OF FACTS DEVICES USING ARTIFICIAL BEE COLONY ALGORITHM

Here first sensitive buses and lines are found using Newton's load flow algorithm. The objective function has been defined and this objective function has been minimized by Artificial Bee Colony algorithm to optimize the parameters explained in section III. Following flow chart explains the procedure of optimal placement of FACTS devices.

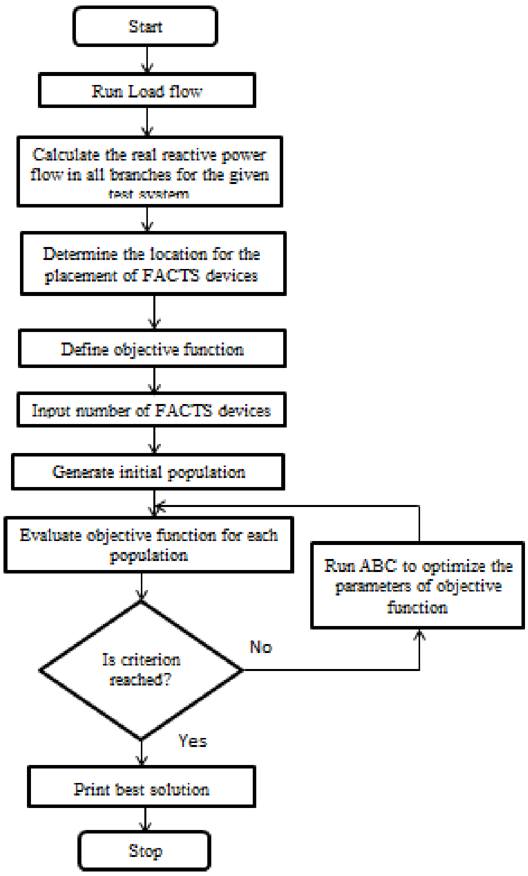

Fig.4. Flow chart of placement of FACTS using ABC algorithm

VI. RESULTS AND DISCUSSIONS

The proposed technique has been approved on IEEE 14-transport framework and IEEE 30-transport frameworks. The outcomes got have been arranged and compared with the system with no FACTS device.

Following parameters are used for ABC algorithm:

Reference MVA= 100
Accuracy = 0.0001
Population size =100
Maximum number of Iterations= 100

A. IEEE 14-bus system [20]

Here the IEEE 14-bus system has been used to test the effectiveness of the proposed model. The system consists of 5 generator buses, 9 load buses and 20 transmission lines.

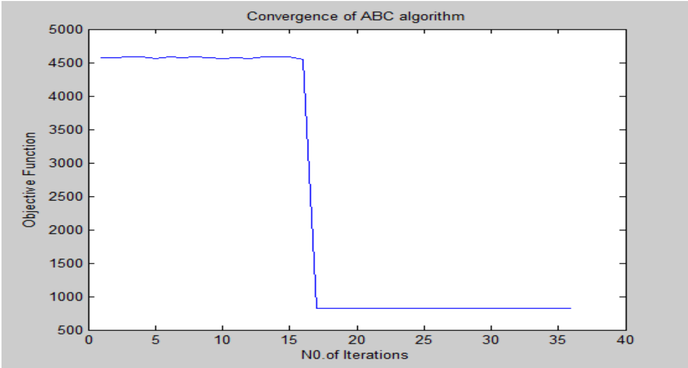

Fig.5. Convergence criteria of ABC algorithm

The multi objective optimal power flow solution using ABC algorithm converges in 36 iterations. As shown in the curve the objective function becomes minimum value after 15 iterations. The elapsed time for convergence is 190.17 seconds.

In this case two different conditions are considered

1. Base case OPF solution without FACTS devices (i.e. OPF by ABC algorithm)
2. Base case OPF with multi FACTS devices (i.e. OPF with multi FACTS by ABC algorithm)

First optimal power flow using ABC algorithm has been performed for multi objective optimized solution (i.e. to minimize total generation cost and total transmission loss) without considering any FACTS devices for IEEE 14-bus system. After running this ABC algorithm for placement of multi FACTS devices, the 7^{th} bus is identified as the optimal location for SVC, 9^{th} bus is identified as the optimal location for STATCOM and the line 17 i.e between buses 13 - 14 is identified as the optimal location for TCSC.
The following table gives the losses, fuel cost, size and location of multi FACTS devices using the ABC algorithm.

TABLE I: OPF RESULTS WITH AND WITHOUT FACTS DEVICES IN 14-BUS SYSTEM.

		Without FACTS devices (ABC)	with multi FACTS (ABC)
V(p.u.)	V_2	1.03	1.06
	V_5	1.01	1.029
	V_9	1.00	1.039
	V_{11}	1.03	1.058
	V_{14}	1.01	1.048
P_G(MW)	P_{G1}	232.39	201.35
	P_{G2}	40	52.21
$\sum P_G$(MW)		272.9	252.35
$\sum P_{loss}$ (MW)		14	7.463
Cost of generation (US$/hr)		766	759
Device type	**SVC**	**STATCOM**	**TCSC**
Location(Bus or Line)	7[th] bus	9[th] bus	(13 – 14)

The figure shows about the voltage profiles of the system with multi type FACTS devices in 14-bus system. This figure also consists of the voltage profiles without FACTS devices. It is evident from the figure that voltage profile has been improved by the placing of multi type FACTS devices in 14-bus system.

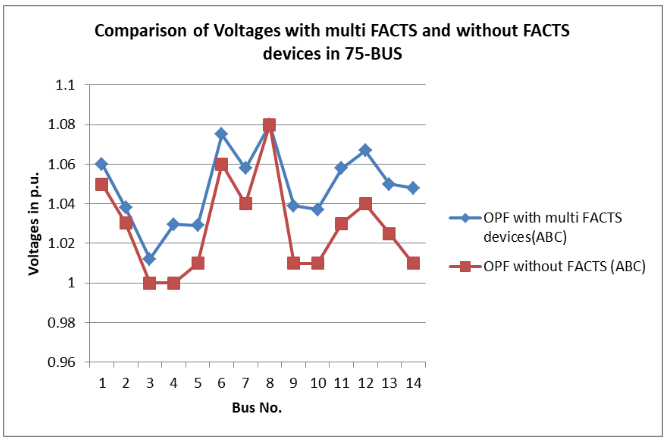

Fig.6. Comparison of voltage profiles in 14-bus system with placing of different FACTS devices

B. IEEE 30-bus system [20]

The system consists of 6 generator buses, 24 load buses and 41 transmission lines. In this section multi FACTS devices which are SVC, STATCOM and TCSC are taken for multi objective optimization of optimal power flow solution.

After running this ABC algorithm for placement of multi FACTS devices, the 30[th] bus is identified as the optimal location for SVC, 29[th] bus is identified as the optimal location for STATCOM and the line 2 i.e between buses 1 - 3 is identified as the optimal location for TCSC.

The following table gives the losses, fuel cost, size and location of multi FACTS devices using the ABC algorithm.

TABLE II: OPF RESULTS WITH AND WITHOUT FACTS DEVICES IN 30-BUS SYSTEM.

		Without FACTS devices using ABC algorithm	with multi FACTS devices using ABC algorithm
V(p.u.)	V_1	1.05	1.06
	V_3	1.02	1.03
	V_6	1.01	1.025
	V_{11}	1.082	1.094
	V_{18}	1.026	1.043
	V_{26}	1.00	1.02
	V_{29}	1.005	1.03
	V_{30}	0.9935	1.028
P_G(MW)	P_{G1}	146.02	150
	P_{G2}	49.78	49
	P_{G5}	25.51	23.1
	P_{G8}	35	34.1
	P_{G11}	18.5	17.3
	P_{G13}	15.62	14.9
Size of TCSC p.u.		-	0.4401
Location(Between bus-bus)		-	10 - 21
$\sum P_G$(MW)		290.64	288.4
$\sum P_{loss}$ (MW)		17.869	8.298
Cost of generation (US$/hr)		802.4918	800.51
Device type	**SVC**	**STATCOM**	**TCSC**
Location(Bus or Line)	30[th] bus	29[th] bus	Line 2 (1 – 3)

Following fig. 7 gives the comparison of voltage profiles between OPF multiple FACTS devices and OPF without any FACTS devices. The placement in all these cases has been found using ABC algorithm. It is evident from the figure that the voltage profile has been improved by using multi FACTS devices with ABC algorithm compared to voltage profile when no FACTS were present in 30 –bus system.

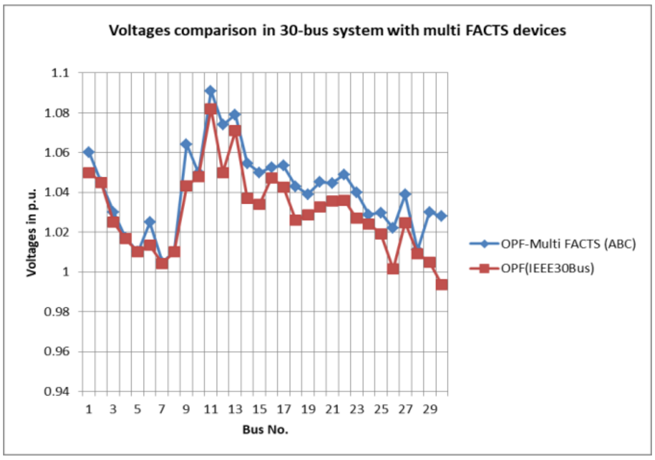

Fig.7. Comparison of voltage profile in 30-bus system placing multi FACTS devices

VII. CONCLUSIONS

The ABC algorithmic based OPF (Optimal Power Flow Solution) has been created to find the ideal place for SVC, STATCOM, TCSC to upgrade the voltage profile and minimize the losses in the power system. The perfect place for FACTS controllers has been endeavored using the ABC calculation. The method has been approved on IEEE 14-transport, IEEE 30 bus and systems.

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