

Optimal Allocation of FACTS Devices in Deregulated Electricity Market Using Bees Algorithm

R.MOHAMAD IDRIS, A.KHAIRUDDIN, M.W.MUSTAFA

Department of Electrical Power Engineering

Universiti Teknologi Malaysia

Skudai, 83100, Johor

MALAYSIA

rasyidah@fke.utm.my, azhar@fke.utm.my, wazir@fke.utm.my

Abstract: - In this paper, a novel method using Bees Algorithm is proposed to determine the optimal allocation of FACTS devices for maximizing the Available Transfer Capability (ATC) of power transactions between source and sink areas in the deregulated power system. The optimizations are made on three parameters: the location of the devices, their types and their sizes. The FACTS devices are located in order to enhance the available transfer capability (ATC) between source and sink area. Four types of emerging FACTS controllers are used and modeled for steady state studies, namely; TCSC, SVC, UPFC and TCPST. The IEEE9 bus test system and IEEE118 Bus test system are used to illustrate the applicability of the proposed algorithm to enhance ATC effectively. The installation costs of FACTS devices are also included. A Genetic Algorithm (GA) configured to the same purpose is used for validation. Results show the difference of efficiency of the devices used in this situation. They also show that simultaneous use of several kinds of controllers is the most efficient solution to increase the ATC. The obtained results indicate that both techniques can successfully find the optimal solution and parameter setting of FACTS devices, but BA is better in term of value of objective function and speed of convergence compared to GA.

Key-Words: - Bees Algorithm, GA, ATC, FACTS, SVC, UPFC, TCPST, TCSC

1 Introduction

The electric trade around the world is enduring a radical paradigm move towards deregulation. Due to competition among utilities and contracts between producers and consumers in modern network, unplanned power exchanges increases. Transmission congestion may occur if these exchanges are not controlled and well planned. In a deregulated environment, this sort of control is subject to ancillary services market. Thus, it is in the attention of the Transmission System Operator (TSO) to acquire another way of controlling power in order to permit a more efficient and secure use of transmission lines.

The FACTS devices (Flexible AC Transmission Systems) allows the system operator to control the power flows as desired and has the potential to improve line transfer capability up to its thermal limits. These devices may be used for power flow control, as well as the voltage control with their ability to change the apparent impedance of a transmission line. Because of this, these devices are believed to be one of key solution to congestion problems. However, in economical point of view, careful planning is required before it is installed in the system because the benefit also comes with high financial cost. With this reason, the optimal placement is one of the most popular and main researches on these

devices. With the aim to obtain the highest benefit from them.

The above quoted benefits can only be achieved efficiently by some of a given kind of FACTS devices. Hence, in order to reach the required goals, it is important to choose the suitable type of FACTS devices. In this paper, optimal location of different kind of FACTS devices will be analyzed with specific characteristics. They are modeled for steady state analysis, and located in order to maximize the available transfer capability between the source and sink area. Thus, attention is paid in this current work to study a technique to optimally allocate the devices to enhance ATC.

The task of calculating ATC is one of main concerns in power system operation and planning. ATC is determined as a function of increase in power transfers between different systems through prescribed interfaces. In this research, the ATC is calculated using Repetitive Power Flow (RPF) and the effectiveness of the devices to enhance ATC is investigated using IEEE9 bus system and IEEE118 bus test systems.

The problem formulation in this research is a nonlinear mixed integer which requires a complex optimization tool to solve the allocation problem. For this purpose, a new algorithm called Bees algorithm is proposed to optimally allocate the devices in the system effectively

in order to achieve the objective function.

This paper is divided into several sections. Section II explains on definition of ATC. Section III describes in general about FACTS devices and some of its benefits while Section IV details out the problem formulation. In section V, the proposed methodology for optimal allocation of FACTS is described in detail. The simulation results are presented and discussed briefly in Section VI. Section VII concludes the paper.

2 Available Transfer Capability

According to NERC definition [1]; ATC is defined as a measure of the transfer capability, or available room in the physical transmission network, for transfers of power for further commercial activity, over and above already committed uses.

Practically, ATC is determined as a function of increase in power transfers between different systems through prescribed interfaces. The flows in transmission line increase as the transfers increase. The calculation of ATC involves three major components which are Total Transfer Capability (*TTC*) and transmission margin; Transmission Reliability Margin (*TRM*) and Capacity Benefit Margin (*CBM*). The TRM is the amount of transmission capacity necessary to ensure that the interconnected system is secure under a reasonable range of uncertainty. While the CBM is the transmission capacity reserved by load serving entities to ensure access to generation from interconnected systems to meet the generation reliability requirement.

Obviously, the *TTC* minus the base flow and appropriate transmission margin is the ATC for the selected interfaces. Therefore, mathematically, ATC can be expressed as [1];

$$ATC = TTC - ETC - TRM - CBM \quad (1)$$

The *ETC* is the sum of the existing transmission commitment between two areas or known as base case flow. The effects of contingencies are taken into account in ATC determination. Generally, the information of base case is from a contingency case, a real time state estimate or a future postulated system condition. Information on the base cases for future hours are obtained from the Current Operating Plan which includes: (i) hourly company system bus load predictions, (ii) commitment of generating units in the system, and their incremental costs, (iii) amount and duration of all contractual agreements on an hourly basis and (iv) schedule of transmission and generation outages. The listed information is used in the ATC computation to build power flow base cases to calculate the base transmission flows.

The Determination of *TTC* is very important. It is the key component in ATC calculation. It is not easy to

calculate *TTC* accurately because *TTC* changes with time and location, related to parameters of power system components, operating conditions and constraints. In addition, the determination of *TTC* not only takes normal operation mode but also takes into account contingency conditions.

Increasing the power transfer increases the loading in the network and at some stage, further increases is prevented when it reaches the operational or physical limits. Therefore, the largest flow of power between the selected source-sink that transfers without any constraints such as thermal overloads, voltage limit violations and voltage collapse and or any other system security problems such as transient stability etc is defined as *TTC*.

3 FACTS Devices

3.1 Generalities

According to IEEE, Flexible Ac Transmission System (FACTS) and Facts Controllers are defined as follows respectively: [2]

FACTS: Alternating current transmission system incorporating power electronic based and other static controller to enhance controllability and increase power transfer capability.

In general, FACTS facts controller can be divided into four categories [2];

- Series controller
- Shunt controller
- Combined series-series controller
- Combined series-series controller

Each category has different types of FACTS devices and may be used for specific contexts. The choice of appropriate devices is important since it depends on the targets to be accomplished. In a deregulated power system, facts is becoming an essential component to manage power flow in transmission lines nearer to their thermal limits. The ability to transmit at higher transfer limits will necessitate greater coordination to balance reliability and economy of operation of the power system [3, 4]. The role of FACTS devices in economic and reliable system operation and management are summarized as follows;

(i) Access to lower production cost

Transmission owners always look forward to utilize the lowest cost generation. Using facts, the utilization of transmission system can be improved. The inclusion of facts devices can increase the power flow through the lines and allow greater use of utilities generation capacity. The degree of success to transfer more active power depends on the choice of the transmission line in which the device is installed. The greatest effect occurs when the device

can reduce reactive flow on a key line, thus allowing more active power flow or when the devices protects that line from overloading while allowing the remaining lines to be more heavily utilized. This allows lowering the generation cost.

(ii) **Stability enhancement**

Facts technologies enable to increase the system security. It raised the transient stability limit, damping electromechanical oscillations of power systems and limiting short circuit current and overloads. In power system operation, the damping of electromechanical oscillations has been recognized as an important issue among the stability issues.

The applications of power system stabilizer (PSS) might help to enhance the damping of power swings. However, in some cases where the transmission line is too long, the use of PSS might not be sufficient to damp the oscillation. Therefore, facts devices were found as an effective solution for this purpose. The device provides fast control of active power through transmission line. The ability of controlling the transmittable power implies the potential application of these devices for damping power system oscillation.

(iii) **Voltage support benefits**

Voltage sag is one of the problems faced by the industrial suppliers nowadays. It is ranged from several milliseconds to a few seconds. Even a momentary drop in the voltage supply may cause the failure of many manufacturing systems. As one of the solution, facts device is installed at the distribution level to solve the voltage sag problem and to supply a continuous of high quality power.

(iv) **Increasing power transfer capability**

Facts device such as Thyristor Controlled Series Compensator can help to increase power transfer capacity in heavily loaded network because of its capability to control power flow flexibly. This means the device can increase further the existing loading capability of lines up to their thermal limits [5]. Normally, the thermal capability of lines varies by a very large margin based on the environmental conditions and loading history.

(v) **Electronic fence**

The concept of electronic fence is an attempt by utility to protect its property rights by preventing another utility from using its transmission system. Facts device can provide secure tie line connections to neighboring utilities and regions and thereby decreasing overall generation reserve requirements on both sides.

(vi) **Prevention of loop flows**

The placement of FACTS controllers in the power system to prevent loop flows depend on the location

of loop flows. The device should be placed in one of the transmission lines on which the loop flow occurs. The power flow in the lines is being forced to zero or sent in the opposite direction of the loop flow.

4 Optimal FACTS Allocation

4.1 Problem Formulation

The RPF with FACTS devices is used to evaluate the feasible ATC value of power transactions. The objective function is to maximize the power that can be transferred from a specific set of generators in a source area to loads in a sink area subject to voltage limits, line flow limits and FACTS devices operation limits.

Four types of FACTS devices are included; Thyristor Controlled Series Compensator (TCSC), Thyristor Controlled Phase Shift Transformer (TCPST), Static Var Compensator (SVC) and Unified Power Flow Controller (UPFC). The mathematical models of the FACTS Devices are used to perform the steady state studies. Hence, TCSC is modeled to modify the reactance of the transmission lines directly. The TCPST varies the phase angle between the two terminal voltages, The SVC can be used to control the reactive compensation of a system at nominal voltage of 1 pu while the UPFC is the most versatile and powerful FACTS devices. The line impedance, voltages angle and the terminal voltages can controlled by it as well. The objective function is formulated as [6];

$$\text{Max } F(x) = P_{Di} \quad (2)$$

Subject to:

$$P_{Gi} - P_{Di} + \sum_{k=1}^{m(i)} P_{Fi}(\alpha_{Pk}) + \sum_{k=1}^{n(i)} P_{Ui}(V_{Uk}, \alpha_{Uk}) - \sum_{j=1}^N V_i V_j Y_{ij}(X_S) \cos(\theta_{ij}(X_S) - \delta_i + \delta_j) = 0 \quad (3)$$

$$Q_{Gi} - Q_{Di} + \sum_{k=1}^{m(i)} Q_{Fi}(\alpha_{Pk}) + \sum_{k=1}^{n(i)} Q_{Ui}(V_{Uk}, \alpha_{Uk}) + Q_{Vi} + \sum_{j=1}^N V_i V_j Y_{ij}(X_S) \sin(\theta_{ij}(X_S) - \delta_i + \delta_j) = 0 \quad (4)$$

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad (5)$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \quad (6)$$

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (7)$$

$$S_j \leq S_j^{max} \quad (8)$$

$$X_{Si}^{min} \leq X_{Si} \leq X_{Si}^{max} \quad (9)$$

$$Q_{Vi}^{min} \leq Q_{Vi} \leq Q_{Vi}^{max} \quad (10)$$

$$\alpha_{Pi}^{min} \leq \alpha_{Pi} \leq \alpha_{Pi}^{max} \quad (11)$$

$$0 \leq V_{Ui} \leq V_{Ui}^{max} \quad (12)$$

$$-\pi \leq \alpha_{Ui} \leq \pi \quad (13)$$

where,

F : total load in sink area

P_{Gi}, Q_{Gi} : real and reactive power generation at bus i

P_{Di}, Q_{Di} : real and reactive loads at bus i

$P_{Fi}(\alpha_{PK}), Q_{Fi}(\alpha_{PK})$: injected real and reactive powers of TCPST at bus i .

$P_{Ui}(V_{UK}, \alpha_{UP}), Q_{Ui}(V_{UK}, \alpha_{UP})$: injected real and reactive power of UPFC at bus i

$V_i^{\min}, V_i^{\max}$: lower and upper limit of voltage magnitude at bus i

$S_i^{\min}, S_i^{\max}$: thermal limit of line i

Q_{Vi} : reactive power injected by SVC

V_i, V_j : voltage magnitude at bus i and bus j

$Y_{ij}(X_S), \theta_{ij}(X_S)$: magnitude and angle of the ij^{th} element in bus admittance matrix with TCSC.

δ_i, δ_j : voltage angle of bus i and bus j

α_{Fi} : phase shift angle of TCPST at bus i

V_{Ui} : voltage magnitude of UPFC at bus i

α_{Ui} : voltage angle of UPFC at bus i

N : total number of buses

For calculating Total Transfer Capability (TTC) and ATC, the injected P_{Gi} at source area, and P_{Di} and Q_{Di} at sink area are increased in function of λ in which;

$$P_{Gi} = P_{Gi}^0(1 + \lambda K_{Gi}) \quad (14)$$

$$P_{Di} = P_{Di}^0(1 + \lambda K_{Di}) \quad (15)$$

$$Q_{Di} = Q_{Di}^0(1 + \lambda K_{Di}) \quad (16)$$

where $P_{Gi}^0, P_{Di}^0, Q_{Di}^0$ are the base case injection at bus i and K_{Gi}, K_{Di} are the constant used to specify the rate of changes in load as λ varies. In order to maintain a zero balance, the incremental power losses resulting from increases in transfer power are allocated by a given formula. At PV buses, the reactive power is maintain at the base case value. However, in sink area, the reactive power demand (Q_{Di}) is incremented accordingly to real power in order to keep a constant value of power factor.

The rate of λ change from $\lambda=0$ corresponds to no transfer (base case) to $\lambda=\lambda_{\max}$ corresponds to the largest value of transfer power that causes no limit violations. $P_{Di}(\lambda_{\max})$ is the sum of load in sink area when $\lambda=\lambda_{\max}$ while P_{Di}^0 refers to the sum of load when $\lambda=0$. Therefore the sum of real power loads in sink area at the maximum power transaction in (normal or contingency case) represents the TTC value and ATC equals to TTC -base case value.

$$TTC = \sum_{i=1}^{ND_SNK} P_{Di}(\lambda_{\max}) - \sum_{i=1}^{ND_SNK} P_{Di}^0 \quad (17)$$

4.2 Steady State Model of FACTS Devices

Different types of FACTS have been used in this study namely; TCSC, SVC, TCPST and UPFC. The line reactance can be changed by TCSC. SVC can be used to control the reactive compensation while TCPST varies the phase angle between the two terminal voltages. The UPFC is the most powerful and versatile FACTS. It may change the line impedance, terminal voltages and the

voltage angle simultaneously.

In this paper the steady state model of FACTS devices are developed for power flow studies. The models are implemented using Matpower 3.2 [7]. The TCSC is a series connected device. It is modeled simply to modify the reactance of transmission line. It may be inductive or capacitive, respectively to decrease or increase the reactance of the transmission line. The reactance of TCSC is adjusted directly based on the reactance of the transmission line. The working range of TCSC is between $-0.7X_L$ and $0.2X_L$ where X_L is the line reactance.

The SVC is a shunt connected static var generator or absorber. The SVC can be used to control the reactive compensation of a system at nominal voltage of 1 pu. In this study, it is modeled as an ideal reactive power injection at bus i , at where it is connected. The working range of SVC is between -100Mvar and 100Mvar.

TCPST is a shunt-series connected device. The voltage angle between the sending and receiving end of transmission line can be regulated by TCPST. The working range of TCPST is between -5° and 5° . The steady state of UPFC in this paper is modeled with combination of TCSC and SVC.

4.3 Dependant and Control Variables

The objective function in the problem formulation dependent on the vector dependant variables which represent the typical load flow equations and a set of the control variables represents the operating limit of FACTS devices and security limits. The particular limit for each FACTS type is mentioned in the previous section. Besides, the considered two security limits are; the line thermal limits and bus voltage limits

5 Proposed Methodology

5.1 Approaches Inspired By Bees

In the literature, numerous algorithms which are inspired from intelligent behaviors of honey bees have been developed and applied to different engineering fields [8]-[14]. However, a few algorithms based on this idea were presented for numerical optimization such as *Bees Algorithm (BA)* [8], *Artificial Bees Algorithm (ABC)* [9], *Bees System (BS)* [14], *Virtual Bees Algorithm (VBA)* [15] and *Honey Bee Colony Algorithm (HBCA)* [16].

The two most inspiring bees algorithms for the development of the new method to solve numerical optimization were *ABC* and *BA*.

In *BA* approach by PHAM [8], only one employed bee per solution is allowed. A number of best solutions (m) are taken to form the initial population P of employed bees, based on the randomly created solutions. The selection of dances by the follower bees is done deterministically. The e best employed bees of P each

recruit a fixed number of follower bees. The other ($m-e$) employed bees also recruit a fixed number of bees per iteration. The best solution per food source is selected after the solution construction of the follower bees. Finally, the remaining scout bees randomly create additional solutions. From this set of existing solutions, again the best m ones are selected and taken over into the new population P' .

The *ABC* approach was proposed by KARABOGA [9] is based on a population of bees, of which one half are employed bees and the other half are follower bees. Besides this, from time to time, an employed bee can become a scout bee. The employer bees find food sources and advertise them through waggle dance while the follower bees follow their interesting employer. The scout bee, on the other hand, flies spontaneously to find better food sources.

In *ABC*, each food source (solution to the problem) is assigned with one employed bee. The algorithm starts with an initial population P of employed bees. The probabilistic selection of the dances by the follower bees take place based on their solution quality. After that, a follower bee constructs its *preferred path* according to the information from the dance. Only the best solution of each food source (either the one of the follower bees or one of the employed bees) is carried over to the new population P' . If a solution cannot be improved for a certain number of iterations, it is removed from the population and replaced by the solution of a scout bee. An age-based strategy in *ABC* ensures this to happen.

Lučić [14] applies completely different approach for *BS*. The bees forms their solutions stepwise and also communicate about the partial solutions. Hence, the employed bee recruits follower bees for its particular partial solutions. A recruited follower bee follows the preferred path exactly and adds additional solution components to the partial solution afterwards.

In 2005, Yang proposed *VBA* [15] with aim to optimize the numerical function in 2 dimensions using a swarm of virtual bees which move randomly in the phase space and interact by finding food sources corresponding to the encoded values of the function. The strength of interactions between these bees results the solution for the optimization problem.

The *HBCA* [16] is an approach developed by Chong that is strongly influenced by ant algorithms. In *HBCA*, the follower bees decide for a preferred path randomly with a certain probability. An age-based replacement strategy is used to diversify the neighborhood search.

5.2 Overview of the Bees Algorithm

Bees Algorithm is a novel optimization method developed by D.T.Pharm in 2006 [8] It is a kind of Swarm-based optimisation algorithms (SOAs) that

mimic nature's methods to drive the search towards the optimal solution. This algorithm is inspired by honey bees' foraging behavior. In nature, bees are well known as social insects with well organized colonies. Their behaviors such as foraging, mating and nest site location have been used by researchers to solve many difficult combinatorial optimization and functional optimization problems. The Bees Algorithm has proved to give a more robust performance than other intelligent optimization methods for a range of complex problems.

5.3 Natural World of Bees

A colony of honey bees can fly on itself in multiple directions simultaneously to exploit a large number of food sources. In principle, flower patches with plentiful amounts of nectar or pollen that can be collected with less effort should be visited by more bees, whereas patches with less nectar or pollen should receive fewer bees [8].

In a colony, the foraging process starts by sending out scout bees to search for potential flower patches. The scout bees move from one patch to another randomly. During the harvesting season, a colony continues its exploration, keeping a percentage of the population as scout bees [8]. Those scout bees that found a patch deposit their nectar or pollen when they return to the hive and go to the "dance floor" to perform a dance called as the "waggle dance" [8]. Figure 1 shows waggle dance model of bee.

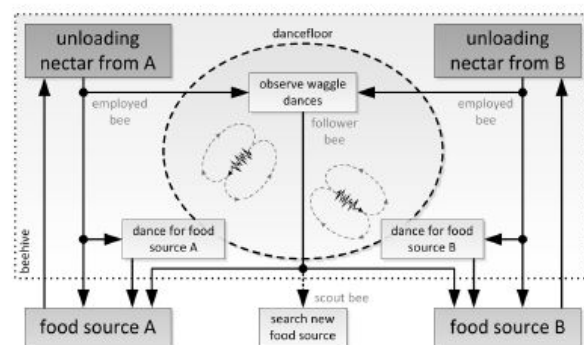


Figure 1: *Waggle dance* model of Bee [17]

This dance contains three pieces of information regarding a flower patch: its distance from the hive, the direction in which it will be found, and its quality rating (or fitness) [8]. This dance is necessary for colony communication, and the information helps the colony to send its bees to flower patches precisely, without using guides or maps.

The information provides from the dance enables the colony to evaluate the relative merit of different patches according to both the quality of the food they provide

and the amount of energy needed to harvest it.

The dancer (scout bees) goes back to the flower patch with follower bees that were waiting inside the hive, after the waggle dance. More follower bees are sent to more promising patches. This allows the colony to gather food in fast and efficiently. The bees monitor its food level during harvesting from a patch to decide upon the next waggle dance when they return to the hive. More bees will be recruited to that source if the patch is still good enough as a food source. This information will be advertised in the waggle dance.

5.4 Description of Optimal allocation of FACTS Devices using Bees Algorithm

This section summarizes the main steps in BA to optimally allocate the FACTS devices to enhance ATC. The flowchart of the algorithm is shown in its simplest form in Figure 2. This flowchart represents the foraging behavior of honey bee for food.

This algorithm requires a number of parameters to be set, namely, number of scout bees (n), number of sites selected for neighbourhood search (out of n visited sites) (m), number of top-rated (elite) sites among m selected sites (e), number of bees recruited for the best e sites (nep), number of bees recruited for the other ($m-e$) selected sites (nsp), and the stopping criterion.

Step 1: The algorithm start with initial population of n scout bees. The initial population is generated from the following parameters [18];

- n_{FACTS} : the number of FACTS devices to be simulated
- n_{type} : FACTS types
- $n_{Location}$: the possible location for FACTS devices
- $n_{individual}$: the number of individual in a population.

The number of individual in a population is calculated using the following equations, where:

$$n_{individual} = 3 \times n_{FACTS} \times n_{Location}$$

Step 2: the fitness computation process is carried out for each site visited by a bee by calculating the ATC.

Step 3: repeat (*step 4-8*) until stopping criteria is not met. Else terminate.

Step 4: bees that have the highest fitnesses are chosen as “selected bees” (m sites) and sites visited by them are chosen for neighbourhood search.

Step 5: It is required to determine the size of neighborhood search done by the bees in the “selected sites”.

Step 6 and 7: the algorithm conducts searches around the selected sites based on size determined in the step 4. More bees are assigned to search in the vicinity of the best e sites. Selection of the best sites can be made directly according to the fitnesses related to them. In

other word, the fitness values are used to determine the probability of the sites being selected. Searches in the neighbourhood of the best e sites which represent the most promising solutions are made more detailed by recruiting more bees for the best e sites than for the other selected sites [8]. Together with scouting, this differential recruitment is a key operation of the Bees Algorithm [8].

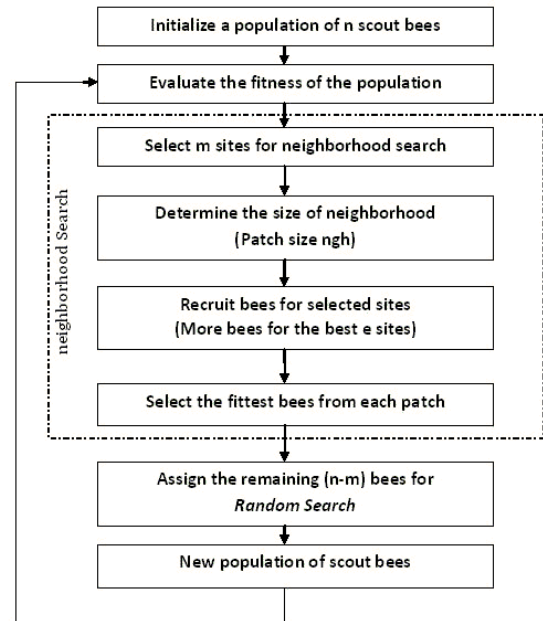


Figure 2: Flowchart of Bees Algorithm

Step 8: The remaining bees ($n-m$) are sent for *random search* to find other potential sites.

Step 9: Randomly initialized a new population.

Step 10: Find the global best point.

5.5 Genetic Algorithm

A Genetic Algorithm (GA) is based on the mechanism of natural selection. It is a powerful numerical optimization algorithm to reach an approximate global maximum of a complex multivariable function over a wide search space. It always produces high quality solution because it is independent of the choice of initial configuration of population.

In GA, the solution to a problem is called a chromosome. A chromosome is made up of a collection of genes which are simply the parameters to be optimized. A genetic algorithm creates an initial population (a collection of chromosomes), evaluates this population, then evolves the population through multiple generations using the genetic operators such as selection, crossover and mutation in the search for a good solution for the problem at hand.

6 Case Studies and Results

6.1 IEEE9 Bus Test System

The IEEE 9-bus system has been used in this paper to show the effectiveness of the proposed technique to calculate ATC. The diagram of the test system is shown in Figure 3. The system is divided into two areas. The system data are in per unit system where base MVA value assumed to be 100MVA. Only two inequality constraints are considered in this studies; voltage limit and line thermal limits. The voltage magnitude limit of each bus is assumed to be within 0.9 pu and 1.1 pu. The flow limits in all transmission lines assumed to be 275MVA. The simulations studies were carried out on Intel Quad Core Q6600 running at 2.4GHz system in Matlab 7 environment

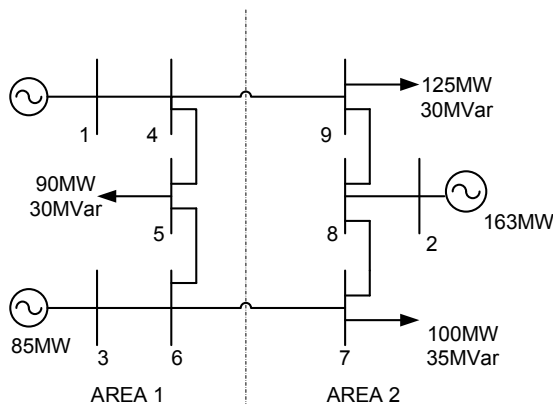


Figure 3 : IEEE9 bus system

The system has 3 generators and 3 load buses. Bus 1 is the slack bus, Bus 2 and 3 are the PV buses, while Bus 5, 7 and 9 are load buses. In order to perform the ATC studies, the system is divided into two areas. Area 1 is a source while area 2 is a sink. The active and reactive power of source area is increased as well as the loads in sink area, so that the power is transferred from source to sink via the tie-line. The active powers of all the generators are keeping constant except for the slack bus, so that the power increase in load are drawn from the slack bus.

The system is simulated under normal operating condition when $\lambda=0$, to gives the base case value. The RPF is used to make a step increase in transfer of power. The TTC is calculated for normal and contingency cases. The ATC is calculated accordingly using: $ATC = TTC - \text{base case value}$. Table I shows the GA and BA parameters used for simulation purposes. The system was tested under two FACTS devices installation scenarios: single type and multi-type of FACTS devices.

The system is simulated under two cases: normal operating (without any contingency) and with contingency case, taking into account line outage. The results for this system are tabulated in Table II.

Comparing both techniques, BA and GA, it can be observed from the table that BA always outperformed the GA in term of value of objective function and speed of convergence for both normal and contingency cases.

The ATC between Area 1 and Area 2 at normal operating conditions without any contingency is 151.2MW. It is shown that Bus 9 is violated first. The value of ATC performed by BA always higher compared to GA. Furthermore, BA converges in 25 iterations while GA takes 250 generations to converge.

TABLE I
PARAMETERS SET FOR GA AND BA FOR
IEEE9 BUS SYSTEM

G A	Population size	9
	Crossover rate, μ_c	0.8
	Mutation rate, μ_m	0.01
	Number of generation	250
B A	Number of scout bees, n	9
	Number of sites selected for neighbourhood search, m	4
	Number of best "elite" sites out of m selected sites, e	2
	Number of bees recruited for best e sites, n_{ep}	12
	Number of bees recruited for the other ($m-e$) selected sites, n_{sp}	6
	Number of iterations, R	25

In term of FACTS type, it is shown that TCSC, SVC and UPFC can be used for ATC enhancement in the system while TCPST does not show any increment in the transfer capability between the areas. Therefore the result for TCPST is not included in the Table. It also proved that SVC is the best choice of FACTS type for ATC enhancement in the system at normal condition. For the case of multi-type, SVC is also the best choice of FACTS type for ATC enhancement at normal condition.

In term of location, it is also observed that ATC is increased more significantly by TCSC when it is installed in the lines connected to the bus (Bus 9) where voltage limit is violated. At the same time when SVC is used, it can be seen that the selected location for the installation of SVC for ATC enhancement is at the bus where voltage limit is violated. The effect is also same for UPFC. It is also connected at the line closer to the overloaded bus. However, SVC shows the best performance of ATC enhancement compared to the other type of FACTS devices. Therefore, it is obviously shows that the location and types of FACTS devices depend on the violations of the system.

For a contingency case, the outage of branch line between bus 6 and 7 implies the power transferred between area 1 and area2 is only between branch line bus 4 and 9. At this stage the ATC without the installation of any FACTS devices is 89.37MW and it

TABLE II
RESULTS FOR IEEE9 BUS SYSTEM

Case	ATC without FACTS		Type	FACTS Type	ATC with FACTS Devices					
	ATC(MW)	Limit condition			Allocation Technique	Size (rated value)	Location	ATC (MW)	Percentage of Increment	Cost of Installations (US\$Million/yr)
NORMAL	151.2	$V_{Bus\ 9}$	Single Type	TCSC	GA	$-69.6\ \%X_{line}$	Line 8-9	164.65	8.90	74.8
					BA	$70.0\ \%X_{line}$	Line 8-9	164.67	8.91	75.1
				SVC	GA	-97.9MVAR	Bus 9	175.99	16.40	2.56
					BA	-98.0MVAR	Bus 9	176.01	16.41	2.57
				UPFC	GA		Line 9-4	175.55	16.10	68.2
					BA		Line 9- 4	175.77	16.25	69.1
			Multi-type	SVC	GA	-99.2MVAR	Bus 9	175.99	16.40	0.25
					BA	-98.0MVAR	Bus 9	175.99	16.40	0.25
CONTINGENCY	89.37	$V_{Bus\ 7}$	Single Type	TCSC	GA	$-69.6\ \%X_{line}$	Line 8-2	142.98	60.11	63.8
					BA	$-70.0\ \%X_{line}$	Line 8-2	143.17	60.32	64.4
				SVC	GA	100MVAR	Bus 7	157.39	76.25	0.30
					BA	-99.9MVAR	Bus 7	157.42	76.28	0.30
				UPFC	GA		Line 8-9	157.96	76.89	15.60
					BA		Line 8-9	158.39	77.37	15.78
				TCPST	GA	-2.845^0	Line 8-9	94.59	5.92	0.678
					BA	-1.720^0	Line 8-9	94.59	5.92	0.678
			Multi-type	SVC	GA	100MVAR	Bus 7	157.39	76.25	0.30
				UPFC	BA		Line 8-9	157.99	76.92	15.5

shows that Bus 7 violates first. The effects of FACTS devices on ATC enhancement are best shown during the contingency case. Using both techniques, BA and GA, all type of FACTS devices, TCSC, SVC, TCPST and UPFC can be used for ATC enhancement. Furthermore the percentage of ATC increment in contingency case is completely higher compared to the normal condition. This shows that at the case of line breakdown, FACTS devices can be effectively used to increase the transfer capabilities of the available lines.

However, it is shown that at contingency case, UPFC is the best choice of FACTS type for ATC enhancement and it is connected to the lines closer to bus where violation occur. The corresponding costs of installations of FACTS devices are also included in Table II.

6.2 IEEE118 Bus Test System

In order to show the applicability of the proposed algorithm in large scale system, an IEEE118 bus test system is used. The solutions for optimal location of FACTS devices to maximize the ATC that can be transferred from a specific set of generators in a source area (Bus 69) to loads in a sink area (Bus 23) subject to voltage limits, line flow limits and FACTS devices operation limits for IEEE118 bus test system was obtained and discussed below.

TABLE II
PARAMETERS SET FOR GA AND BA FOR
IEEE118 BUS SYSTEM

G	Population size	2805
A	Crossover rate, μ_c	0.6
	Mutation rate, μ_m	0.01
	Number of generation	100
	Number of scout bees, n	2805
B	Number of sites selected for neighbourhood search, m	1964
	Number of best "elite" sites out of m selected sites, e	982
	Number of bees recruited for best e sites, nep	30
	Number of bees recruited for the other ($m-e$) selected sites, nsp	15
	Number of iterations, R	100

Referring to Figure 2, the system consists of 55 generators with 187 branches. The bus and line data can be found in reference [19]. Table III shows the GA and BA parameters used for simulation purposes. The system was tested under two FACTS devices installation scenarios: single type and multi-type of FACTS devices. For each case, a total of five FACTS devices were installed in order to enhance the transferred power from source area to sink area. The location, setting and type of FACTS devices are obtained using GA and BA

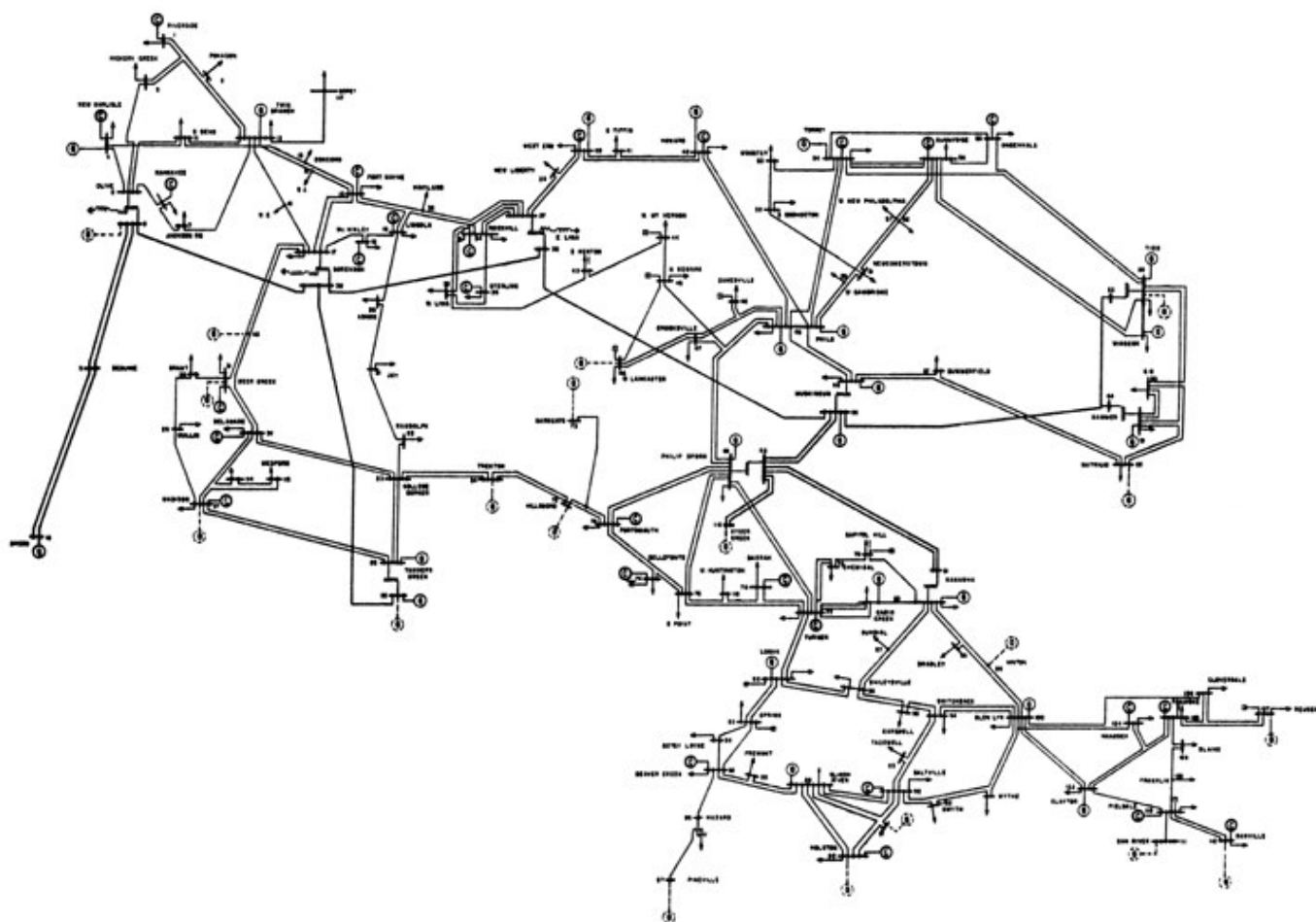


Figure 2: IEEE118 Bus test system

techniques and it is given in Table IV. The comparison shown in the Table has proved that BA can be competently used with fast convergence compared to GA for FACTS devices allocation problem in large scale system.

The ATC before installation of any FACTS devices is 534.91MW with the limit condition of bus 23 voltage. In the case of single type of devices, it has shown that TCSC, SVC, UPFC and TCPST can be used for ATC enhancement. However, compared to the percentage of ATC increment, UPFC shows the best performance using both techniques with 93.39% and 97.04% using GA and BA respectively. Next to UPFC, SVC gives ATC of 93.29% and 95.45% using GA and BA respectively. TCSC increases 57% and 57.29% using GA and BA respectively, while TCPST gives the lowest percentage of ATC increment. In this system, the bus voltage violation limit dominates and therefore FACTS devices are employed for reactive power and voltage control. In that case SVC and UPFC is the best choice of FACTS type. TCSC and TCPST are mainly used for active power control. Hence, in this system TCSC and

TCPST are not the best selection of FACTS devices for ATC enhancement. Comparing the cost, SVC is best option. Even though UPFC shows good performance in improving ATC, it is very much costlier than SVC.

In the case of multi-type devices, both techniques have chosen the same combination of FACTS devices for ATC enhancement: SVC, UPFC and TCPST. However, the setting and the location of FACTS devices found by BA technique has higher value of ATC compared to that found by GA. Instead, the allocation using GA has lower FACTS devices installation cost compared to BA. This is mainly due to the objective function of the allocation is to find the best allocation of FACTS devices in order to enhance ATC. Therefore, the allocation technique can only find the best allocation according to its objective function.

In all cases, it is observed that FACTS devices improve the power flow of the lines near to its thermal limits and at the same time improve the bus voltage profiles. It is concluded that for an IEEE118 bus system for single type scenarios, UPFC is the best choice of FACTS devices for ATC enhancement, but SVC is cost

TABLE III
RESULTS FOR IEEE 118BUS SYSTEM

ATC without FACTS		Type	Allocation Technique	ATC with FACTS Devices					
ATC(MW)	Limit condition			Facts Type	Size (rated value)	Location	ATC (MW)	Percentage of Increment	Cost of Installations (US\$Million/yr)
534.91	V_{23}	Single Type	GA	TCSC	-0.69% X_{line} -0.69% X_{line} -0.69% X_{line} -0.69% X_{line} -0.69% X_{line}	Line 23-25 Line 24-70 Line 19-20 Line 25-27 Line 20-21	839.83	57.00%	1,332
			BA	TCSC	-0.70% X_{line} -0.70% X_{line} -0.70% X_{line} -0.70% X_{line} -0.70% X_{line}	Line 23-25 Line 30-17 Line 24-70 Line 19-20 Line 25-27	841.41	57.29%	1,414
			GA	SVC	-99.98MVAR -90.86MVAR -97.86MVAR -63.76MVAR -95.08MVAR	Bus 96 Bus 30 Bus 38 Bus 37 Bus 23	1033.97	93.29%	1,241
			BA	SVC	-100MVAR -100MVAR -99.64MVAR -67.52MVAR -98.32MVAR	Bus 23 Bus 37 Bus 38 Bus 45 Bus 30	1045.52	95.45%	1,338
			GA	TCPST	-4.9 4.1 4.9 4.9 -4.9	Line 15-17 Line 69-70 Line 32-114 Line 26-25 Line 27-32	541.77	1.28%	1,487
			BA	TCPST	-4.4° 4.9° -4.9° 4.7° 4.9°	Line 31-32 Line 26-25 Line 27-32 Line 114-115 Line 32-114	541.93	1.31%	1,124
			GA	UPFC		Line 23-25 Line 38-65 Line 21-22 Line 22-23 Line 71-73	1034.48	93.39%	12,31
			BA	UPFC		Line 23-25 Line 38-65 Line 21-22 Line 22-23 Line 20-21	1054.02	97.04%	14,16
		Multi-type	GA	SVC UPFC	-99.9MVAR	Bus 23 Line 30-38 Line 24-70 Line 22-23 Line 75-77	1245.42	132.82%	11,147
			BA	SVC UPFC TCPST	-98.7MVAR -4.9°	Bus 23 Line 30-38 Line 24-70 Line 21-22 Line 15-17	1247.75	133.26%	15,933

wise cheaper while considering better improvement in system loadability. For multi-type cases, increment of ATC is much better than single type case. However, compared to its installation cost and increment of ATC, single type case is much better. For all of the cases, BA always outperformed GA in term of objective function

(ATC) and speed of convergence. Figure 3 shows the improvement of bus voltage profile on selected bus when FACTS devices are installed in the system for ATC enhancement. It is observed that the voltage profile on buses which are connected to the bus where FACTS devices are installed has improved while BA is always

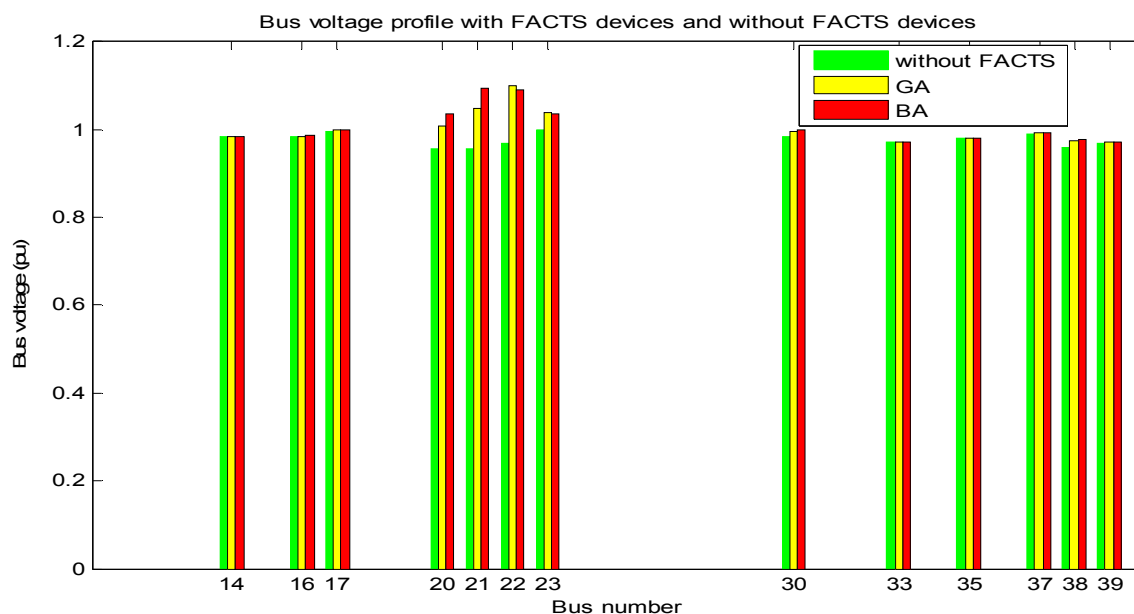


Figure 3: Voltage Profile

shows better improvement on the voltage profile compared to GA.

7 Conclusion

This paper introduces a novel method to find the optimal location and parameter setting of FACTS devices for ATC enhancement for single type and multi-type FACTS devices using BA. Simulations were performed on simple IEEE9 bus system and large scale system: an IEEE118 bus test system. The results show the effectiveness of the new approach in simultaneously optimized the FACTS location, rated values and FACTS types. In the case of multi-type of FACTS devices, the type of devices to be placed is also considered as a parameter in the optimization. They also show that simultaneous use of several kinds of controllers is the most efficient solution to increase the ATC.

The selection of types and location of FACTS devices for ATC enhancement depends on the violation of the system. For the case of bus voltage violation, it is understood that SVC is always the best choice and it is installed at the bus where violation occur. Besides, FACTS technology can also improve the voltage profile at the buses which near to where it is installed.

The proposed algorithm generally outperformed the GA techniques that were compared in terms of speed of optimization and accuracy of the results obtained. The Bees algorithm converged to the maximum without becoming trapped at local optima. The main advantage of BA is that it does not require external parameters such as cross over rate and mutation rate etc, as in case of genetic algorithms these are hard to determine in prior. The other advantage is that the global search ability in

the algorithm is implemented by introducing neighborhood source production mechanism which is a similar to mutation process. As far as the authors are concerned, this is the first application of bees algorithm in power system application regarding FACTS devices. Ideas presented in this paper can be applied to many other power system problems also.

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