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Optimal Location of FACTS Devices in Order to Simultaneously Improving Transmission Losses and Stability Margin Using Artificial Bee Colony Algorithm

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ABSTRACT It is not possible to use the full capacity of the transmission lines due to voltage limitations and stability issues. Therefore, compensators must be used to improve the transmission line capacity. One of the suggested ways for this purpose is to use flexible alternating current transmission system (FACTS) devices in the power system. The various capabilities of the FACTS devices have made it possible to set different targets to determine their optimal location and position. Some of the most important placement targets include increasing voltage stability, improving voltage profiles, reducing losses, increasing line capacity limit and reducing fuel costs for power plants through optimal power distribution. In this paper, optimal locating of FACTS devices to improve power system stability and transmission line losses reduction. Also, artificial bee colony algorithm is proposed for solving optimization problem. The artificial bee colony algorithm with high accuracy and high convergence speed is suitable for conducting FACTS placement studies. Finally, a comparison was made between the artificial bee colony algorithm and genetic algorithm (GA) and particle swarm optimization (PSO) algorithm. The results indicate that the artificial bee colony algorithm works better than the other algorithms in minimizing the fitness function.

INDEX TERMS FACTS devices, line loading, loss reduction, voltage profile, artificial bee colony algorithm.

I. INTRODUCTION

Most of the world's electrical power systems have been extensively interconnected. The reason for the need for this interconnectivity, apart from providing the possibility of electricity delivery to the consumer, is to create concentration on the center of electricity production and consumption, in order to minimize production capacity and cost. The interconnected transmission network is able to supply the consumer with electrical energy at minimum cost and with the maximum reliability by utilizing the dispersion of loads, availability of supplies and fuel prices [1]. Lower reliability means that more production resources will be required. Nowadays, more than ever, it's important to design and operate power systems with high efficiency and reliability. Constructing new distribution lines is difficult and costly due to the lack of capacity and power transfer with the desired quality, especially if the construction of these lines is carried out at the city level and areas with no suitable space to construct these lines. This has resulted in to the full capacity usage of such lines instead of constructing new energy transmission lines. Flexible alternating current transmission system (FACTS) devices are active compensator or reactive compensator which can enhance the power system efficiency and reliability because of their fast response to turbulence and their flexibility in any power system operation conditions. FACTS devices present new chance

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for power system controlling and improving the operation limitation available for existing transmission lines [2]. The use of FACTS controllers controls the power control over the lines in the power system normal condition and also unpredictable situations. These chances are resulted from the FACTS controller's capability to control the parameters that guide the transmission system's performance. The parameters such as series and parallel impedance, voltage angle current, voltage and damping of resonances at various frequencies under the power system's nominal frequency [3]–[5]. Various ability of the FACTS instrument has made it possible to set several targets to decide their optimal placement. Improving voltage stability of the power system, enhancing transmission line loading capacity, modifying the voltage amplitude on buses, reducing losses and reducing the cost of power plants by providing optimal power distribution form the main placement targets among others. Three types of problems, operating point settings and installation location are considered simultaneously for optimizing the performance of these devices in the power system. As noted in the previous section, the installation location of FACTS devices in power systems has a significant effect on the performance of these equipment. This section review papers in which the placement of these devices has been conducted. Ref. [6] has studied the SVC placement with the aim of improving the voltage profile in the power system. The results indicate the correct SVC performance in retrieving the bus voltage in case of an error. In [7], the TCSC is used in the power system. This equipment improves the loading limit by changing the impedance of transmission line. Also, TCSC can improve the stability margin. Also, Ref. [8] has used the developed particle swarm algorithm for placement of TCSC in the power system. In this reference TCSC is considered as distributed. In [9], the placement and setting of the SVC and TCSC parameters was done with the aim of improving the stability of the small signal of the power system. The particle swarm algorithm has been used to solve the problem. Ref. [10] has investigated the placement of parallel compensators in the power system. The main purpose of using these compensators was to improve the voltage profile. It should be kept in mind that improving the voltage profile also reduces the losses in the power system. In [11], the placement of FACTS devices has been done using evolutionary planning. For this purpose, economic power flow has been used. Ref. [12] has used a genetic algorithm was used for placement of FACTS devices aimed at improving line loading limit. The main problem of genetic algorithm is to trap it at local optimal points. Unified power flow controller (UPFC) can have a significant impact on the reduction of line losses, as well as the voltage profile improvement, by controlling the load on the power system. Ref. [13] has studied the problem UPFC placement. For this purpose, a gravitational search algorithm was used. In this reference, the gravitational search algorithm is claimed to have a high convergence accuracy. But it should be considered that the main weakness of this algorithm is its low convergence rate. Also, in [14], UPFC's optimal placement has been based on probable events. So far, several methods are proposed to solve this issue, but the main drawback of these methods is trapping in local optimum [4]. The methods that find the global optimal results have very slow convergence rate. The main reason of this drawback is the random and linear action of the methods in finding the best solution [5]. In this paper the Artificial Bee colony (ABC) algorithm is used for optimal placement of the SVC, TCSC, STATCOM and SSSC to improve power system stability and transmission line losses reduction and compare the effectiveness of each FACTS devices on the objective functions.

II. FACTS DEVICES MODELING

The FACTS devices are devices which have power electronic-based controllers. The existing transmission lines structure is used in a power system of FACTS devices, in order to increase the system's controllability, the power transmission capacity, ease of exchange of power, and to overcome the constraints. FACTS technology is an important tool that makes it possible to operate the equipment in an emergency to a thermal level, without reducing safety. Their most interesting features are the ability to directly control the transmission power of lines by changing the network parameters and the use of high gain controllers based on fast switching. These equipment can be used in series, parallel or parallel series states in the power system. FACTS devices are classified according to the technology used in both the first generation and the second generation. This section introduces two FACTS devices used in this paper.

A. STATIC VAR COMPENSATOR (SVC)

A reactive VAR generator or actuator coupled in parallel whose output is set for inductive or capacitive flow exchange to retain or control certain parameters in the power system. The SVC performance is based on non-interrupted thyristors and includes separate equipment for the priority or delay in phase of reactive power. Figure (1) shows the building of an SVC and I-V characteristic.

This equipment can operate in two self or capacitance reactive modes. For capacitor current larger than i_{cmax}, the SVC is converted into a capacitor and its reactive power varies as a function of the network voltage. The most important uses of the SVC are:

- Voltage stabilization in weak networks
- Reducing transmission losses and increasing power transfer capacity
- Increased the small disturbance damping
- Improved voltage stability
- Removed power fluctuations

B. THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

The original design of the thyristor-controlled series capacitor was proposed by Vitayatil *et al.* in 1986 as a "fast network impedance setting" method. This design includes a series compensator capacitor which is parallel to a thyristor-controlled reactor. In the practical implementation of the

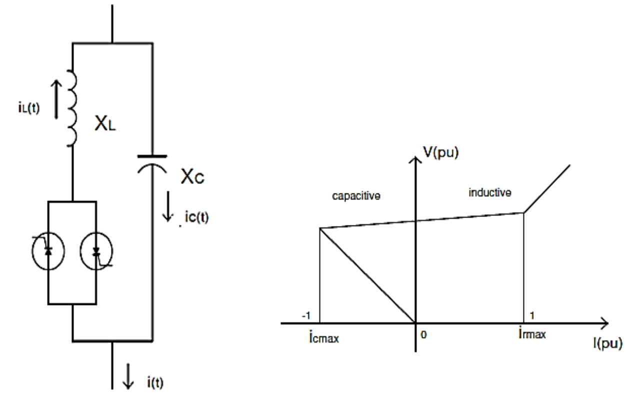

FIGURE 1. SVC building and its I-V characteristic based on [7].

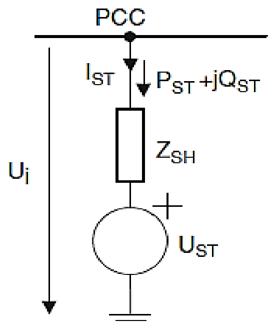

FIGURE 2. The building of a STATCOM based on [5].

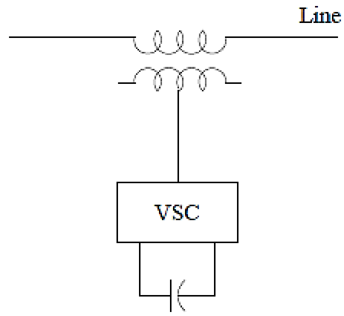

FIGURE 3. Building of static series synchronous compensator based on [5].

TCSC, several compensators of this type can be connected in series to obtain the nominal voltage and desired performance characteristics.

This arrangement is similar in structure to the TSSC, and if the reactor impedance is smaller than the capacitor impedance, it can act as a TSSC as a disconnect. However, the main thesis behind the TCSC design is the creation of a capacitor with uniform changes, by eliminating a part of the effective capacitance by TCR.

C. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The STATCOM is a parallel reactive power device and its output is controllable independently of the power system parameters [6]. The STATCOM are based on a voltage or current source converter. In the voltage source convertors, the AC voltage output is controlled to be sufficient for the control of the current flow of the reactive power. For each AC bus voltage, the voltage of the DC capacitor is automatically set to the required value, for acting as the voltage source of the converter. STATCOM can be designed in such a way as to capture the harmonics of the system as an active filter [5]. The main element in STATCOM is a voltage source converter (VSC) that converts the DC input voltage to the AC voltage at the base frequency. Figure 2 shows the building of a STATCOM.

According to the above figure, the voltage source converter (VSC) generates a voltage at the base frequency (U^{st}) with a controllable amplitude and phase. The VSC is connected to a network by a self-impedance, which is represented by Z_{SH}. P_{ST} and Q_{ST} are the power exchanged with the network.

D. STATIC SERIES SYNCHRONOUS COMPENSATOR (SSSC)

The SSSC is a series device with an output voltage with a 90-degree phase difference with the line current. The SSSC is controllable independently of the line current is used to increase or reduce the reactive voltage total loss across the line and hence to control the transmitted electric power.

The SSSC compensator can include energy savings of up to a transient amount with devices consuming energy to increase the dynamic performance of the power system by compensating for additional excessive power temporarily and increase or decrease the actual voltage drop across the line instantaneously. This compensator is similar to the STATCOM, with the difference that the output AC voltage is in series with the line. Figure 3 shows the SSSC building.

III. ARTIFICIAL BEE COLONY ALGORITHM

Various methods have been suggested to the model of intelligent swarm behavior of the bee and have been used to solve compound-type problems. This algorithm was also presented by Karaboga in 2005, entitled the Artificial Bee Colony Algorithm (ABC). In this paper the modified version of the ABC algorithm is used. Like the population of bees, the population in this algorithm includes three categories of employed bees, onlooker bees and scout bees. The half of the population with the best results are employed bees and the half other are onlooker bees. For each food a employed bee for is considered. Also, the employed bees polpulation is equal to the same of food sources around the hive. The employed bee whose food supply is finished is turning into a scout bee. The algorithm is initialized randomly in the first part. In this part, the foods positions are chosen randomly and their nectar is selected. After that, these bees come to hive and the nectar data of each resource is shared by the bees waiting in the dance place inside the hive.

$$x_{ij} = x_{\min,j} + rand[0, 1] \times (x_{\max,j} - x_{\min,j}) \tag{1}$$

In equation (1), X_{ij} is the j-th optimization variable from the i-th possible optimization solution, $X_{\min j}$ is the lower band of j-th variable, $X_{\max j}$ is the upper band of j-th variable. Equation (1) states, random numbers are generated in the permitted range of variations for each optimization variable.

Equation (2) is used initializing the ABC algorithm to determine the objective function of the possible results.

$$fit_i = \begin{cases} \frac{1}{1+f_i} \Rightarrow & if \rightarrow f_i \geq 0 \\ 1+|f_i| \Rightarrow & if \rightarrow f_i \langle 0 \end{cases} \tag{2}$$

where fi is the possible solution cost of xi and fit_i represents the fitness of this solution. Any onlooker bees or employed bees can make changes to the existing food source (feasible solution) in its memory and calculate its objective function. If the new result is greater than the its previous version, the new result will be chosen and the old result will be dismissing; otherwise, the previous result will be held in its memory. In the algorithm, the production of a new solution from the previous solution is based on Equation (3):

$$v_{ij} = x_{ij} + \Phi_{ij}(x_{ij} - x_{kj}) \tag{3}$$

In above equation, Φ_{ij} is a random which controls the production of food sources beside *xij*, denoting an eye comparison of the sources. According to equation (3), as the difference between *xij* and *xkj* reduces, the deviation from the *xij* position will also reduce. Hence, as the search procedure approaches the optimal result in search area, the deviation from the optimal result reduces. In equation (3), it is tried to select a dimension from one of the food sources and, considering Φ, motion is dined in the direction or the reverse way. If the parameters produced by equation (3) violates its bound, its amount is changed by an acceptable amount in a way that if it violates the upper bound, the upper bound will be used and if it violates the lower bound, the lower bound will be used. By exchanging data between employed bees and onlooker bees, onlookers select the food source with a possibility that meets the amount of the nectar in the source of food. This possibility can be calculated by several methods, which are presented in equation (4) and equation (5).

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \tag{4}$$

$$p_i = \frac{A \times fit_i}{\max(fit) + B} \tag{5}$$

In equation (5), *max(fit)* is the highest objective function value in the possible results. Also, the parameter A and the parameter B are constant.

By the explanation of this section, it may be said that the number of food sources (SN) is equal to the number of employed and onlooker bees. Bee colony algorithm for the placement of compensators in the power system is in the form of Fig. 4. The persecute for optimal placement of the FACTS devices in the power system is as Table 1.

To increase the accuracy of the ABC algorithm, its parameters have been determined by repeated simulations and trial and error methods.

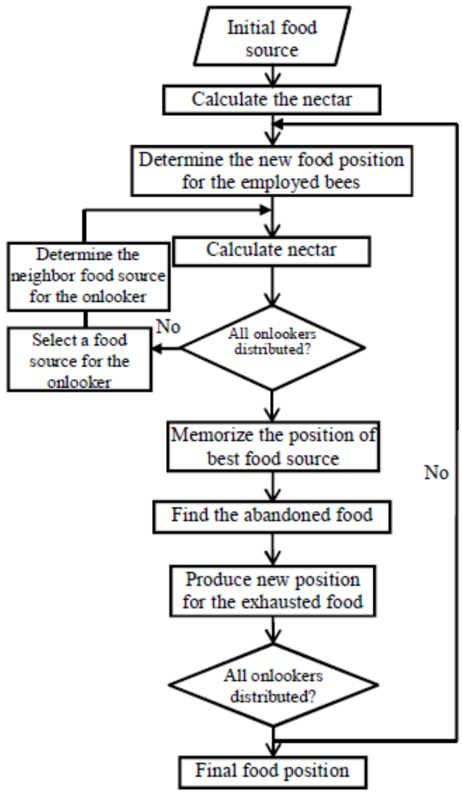

FIGURE 4. Flowchart of artificial bee colony algorithm based on [15].

IV. OBJECTIVE FUNCTIONS

The FACTS devices placement in the power system has high importance. In order to precisely determine the location of the equipment in the lines, solution (1) is used as the objective function. In this dissertation, two objectives have been considered simultaneously: reducing system losses and improving the stability margin of the system. This criterion is chosen in such a way to improve and minimize the load capacity of the line by minimizing it.

$$f = \alpha_1 f_1 + \alpha_2 f_2 \tag{6}$$

where, the objective function is the approach to improving the loading limit and the margin of stability of the system and the relationship shows the losses in the transmission lines calculated by relationships (7) and (8).

$$f_1 = \int_0^{t_{sim}} t\,\{|\Delta\omega_1 + \Delta\omega_2 + \Delta\omega_3 + \Delta\omega_4|\} \tag{7}$$

where t in (7) represents time, $\Delta\omega_1 + \Delta\omega_2 + \Delta\omega_3 + \Delta\omega_4$ represents the velocity variation of each of the generators.

$$f_2 = \sum_{x=1}^{n} g_x(v_i^2 + v_j^2 - 2v_i v_j \cos\theta_{ij}) \tag{8}$$

In equation (8), *gx* denotes the conductance of the line, v_i, v_j are respectively, the bus voltages *i, j*. Also θ_{ij} is phase difference is also between the two nodes *i, j*.

TABLE 1. The pseudo-code of the ABC.

Start

- Select the parameters of the algorithm (Bee population size (nPop), maximum number of iterations (Max_Ite), Upper bound (ub) and Lower band (lb) of variables and so on.
- Select the positions of Bees randomly in the lb and ub limits.
- Install FACTS device and run power system simulation.
- Calculate objective function (Power loss and load limit factor) for each Bees.
- Selection of Elite Sites and Non-Elite Sites according to the values of the objective functions obtained in the previous step.
- **While** Ite<Max_Ite
- Update the position of the Elite Sites Bees.
- Select the positions of Non-Elite Sites randomly in the lb and ub limits.
- Chang FACTS device place and run power system simulation.
- Calculate objective function (Power loss and load limit factor) for each Bees.
- Selection of Elite Sites and Non-Elite Sites.
- Ite=Ite+1;
- **end while**
- Chose the best results.

End

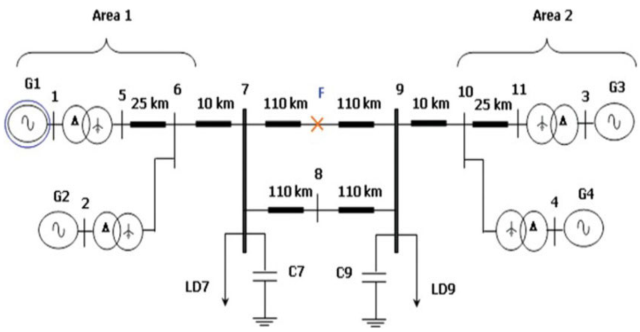

FIGURE 5. Multi-machine power system based on [16].

V. THE STUDY SYSTEM

The block of single-line diagram of the four-machine system in two regions has been illustrated in Figure 5. This system is used to study and analyze the low-frequency resonance problem. The system includes two similar areas connected with a weak link. Each region consists of two generator units together with the nominal 900MVA values of 20 kv. For each unit, a 900 MVA transformer and 20/230 KV conversion ratio have been used. Detailed information on buses, lines, generators and loads is given in [12]. Parameters of generators except H are the same in two regions. The first-region generators have H = 5.6s, and in the second region, H = 6.175 has been considered for generators. Loads have been modeled as a constant impedance.

The output values of reactive power and reactive power for each of the generators of the stabilizer parameters of the power system as well as the loads have been given in Table 2.

The Wash factor for stabilizers is 10. In order to improve the line loading limit and increase the stability margin of the system, first and second-generation FACTS devices have been used in simulations. For this purpose, the SVC and TCSC are two parallel and series-first-generation components, and STATCOM and SCCC have been used as second-generation devices. The values of the parameters of each FACTS devices have been given in Table 3.

TABLE 2. System loading conditions (p.u.).

	P	Q	K	T1	T2	T3	T4
Generator							
G1	0.78	0.15	18.32	0.42	0.36	0.76	0.39
G2	0.77	0.26	28.4	0.21	0.86	0.51	0.63
G3	0.78	0.14	20.36	0.32	0.17	0.47	0.63
G4	0.77	0.22	23.71	0.89	0.76	0.39	0.94
Load							
LD7	0.7	0.35					
LD9	0.6	0.3					

TABLE 3. Parameters of FACTS devices.

SVC			
nominal voltage	230e3	Voltage Reg(Kp)	1
Pbase	200e6	Voltage Reg (Ki)	300
Qc	200e6		
Ql	-200e6		
TCSC			
nominal voltage	230e3		
Capacitance	21.97e2		
Reactance	0.043		
STATCOM			
nominal voltage	230e3	Vac Regulator Gains (Kp)	5
Converter rating (VA)	100e6	Vac Regulator Gains (Ki)	1000
DC link nominal voltage	40000	Vdc Regulator Gains (Kp)	1e-3
DC capacitance	350e-6	Vdc Regulator Gains (Ki)	20e-3
SSSC			
nominal voltage	230e3	Injected voltage regulator (Kp)	0.03
Converter rating (VA)	100e6	Injected voltage regulator (Kp	1.5
DC link nominal voltage	40000	Vdc Regulator Gains (Kp)	1e-3
DC capacitance	375e-6	Vdc Regulator Gains (Ki)	20e-3

TABLE 4. Parameters of the ABC algorithm.

	NSc outB ee	Iteratio ns	nSelect edSite	nEliteS ite	nSelected SiteBee	nElite SiteB ee
ABC	100	50	50	20	50	100

VI. SIMULATION RESULTS

In order to improve the line loading limit and increase the stability margin of the system, FACTS devices of the first and second generation have been used in simulations. For this purpose, the SVC and TCSC are two parallel and series-first-generation components, and also STATCOM and SCCC have been used as second-generation devices. But the problem which is important is the installation location of the equipment in the power system which depends on the system and network topology conditions. To determine the proper location of these equipment, the Artificial Bee Colony (ABC) Optimization Algorithm was used in the communication line of the system, and its parameters are accumulated in Table 4.

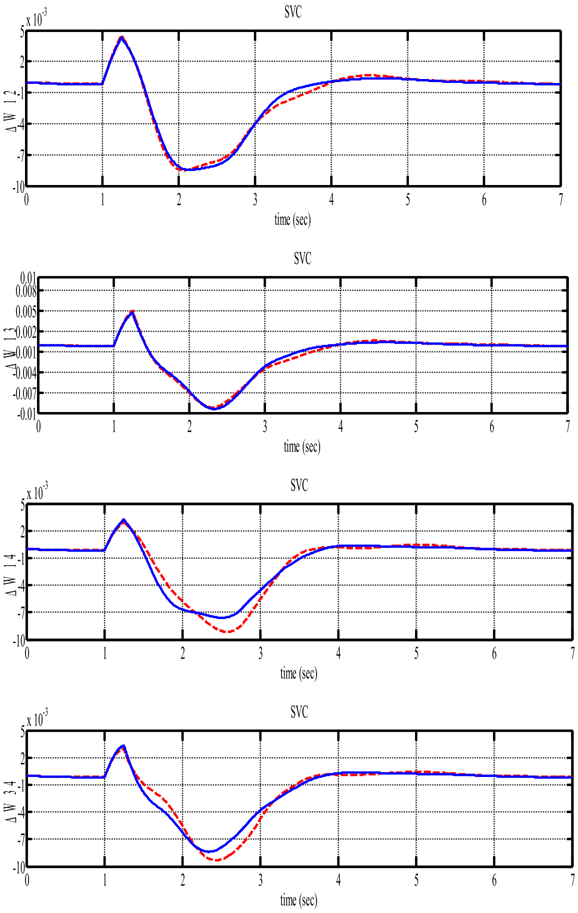

FIGURE 6. **Angular velocity changes of generators in the case of using SVC.**

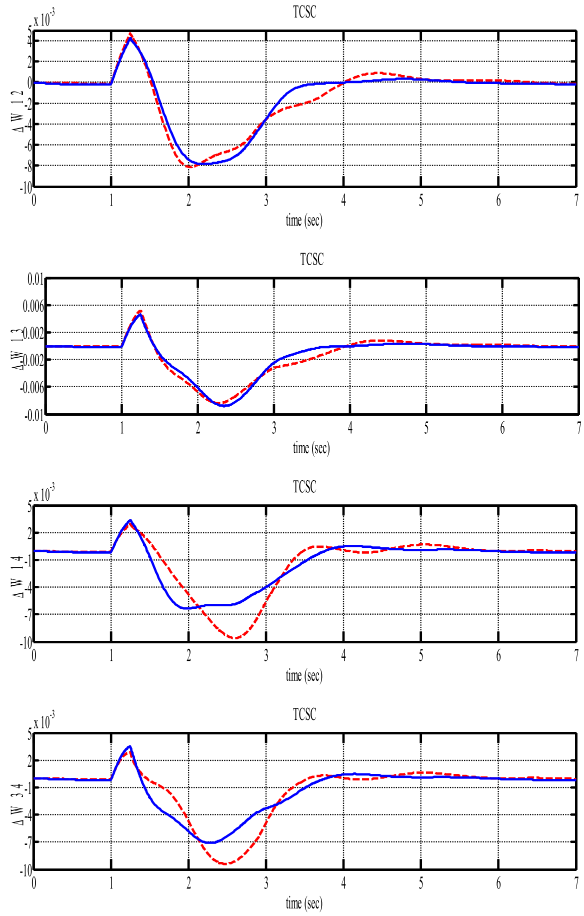

FIGURE 7. **The angular velocity changes of generators using TCSC.**

The performance of each FACTS device has been evaluated by applying three-phase error with 250 ms of durability. Initially, it is assumed that locating has not been made and the FACTS devices are installed in the middle of the communication line, namely, in bus 8. The distance from the two buses is 110 kilometers. The location of the FACTS devices is then determined by the bee colony algorithm to minimize the objective function.

First, SVC has been located in the studied system. After optimization, the appropriate location for the SVC installation is 14 kilometers away from the bus 7 so the objective function after optimization is 4.23. While the value of the objective function has been calculated to be 4.73 when the SVC is used in the middle of the communication line between the two regions. To illustrate the stability margin of the system, it is possible to show inter-regional and intra-regional modes. The changes in the angular velocity of the generators relative to the reference generator (generator G1) have been shown in Fig. 6.

In this figure, the charts of $\Delta\omega_{12}$, $\Delta\omega_{13}$, $\Delta\omega_{14}$ and $\Delta\omega_{34}$ are optimally located for the two systems with SVC, and are shown before placement. The red dashed diagrams are associated with the power system, where the SVC is located in the middle of the communication line, and the blue line for the SVC has been located. As shown in Fig. 6, with the placement of the SVC in the study system, angular velocity variations for all generators after the error elimination have lower amplitude and damping times than the non-placement system. Whatever the extent of these fluctuations is lower, the stability margin of the system is greater and there is the possibility of higher power transfer than the communication line between the two regions.

In the following, the series type TCSC have been selected from first-generation FACTS devices to assess its impact of placement on the improvement of the loading limit and the margin of stability of the system. For this purpose, using the artificial bee algorithm and with the goal of reducing the objective functions, the optimal placement of this element has been performed on the communication line between the two buses 7 and 9. After optimizing the location for the installation of this element, the distance of 33.8 km is obtained for Bus No. 7.

The value of the fitness function in term of use of the TCSC before the optimum placement was 4.12, which reached the value of 3.78 after the placement. This means improving the stability of the system. Figure 7 has shown the angular velocity curve of the generators.

After placement of the first generation FACTS in the study system, the effect of the optimal placement of the series and parallel second-generation (converter) FACTS has been

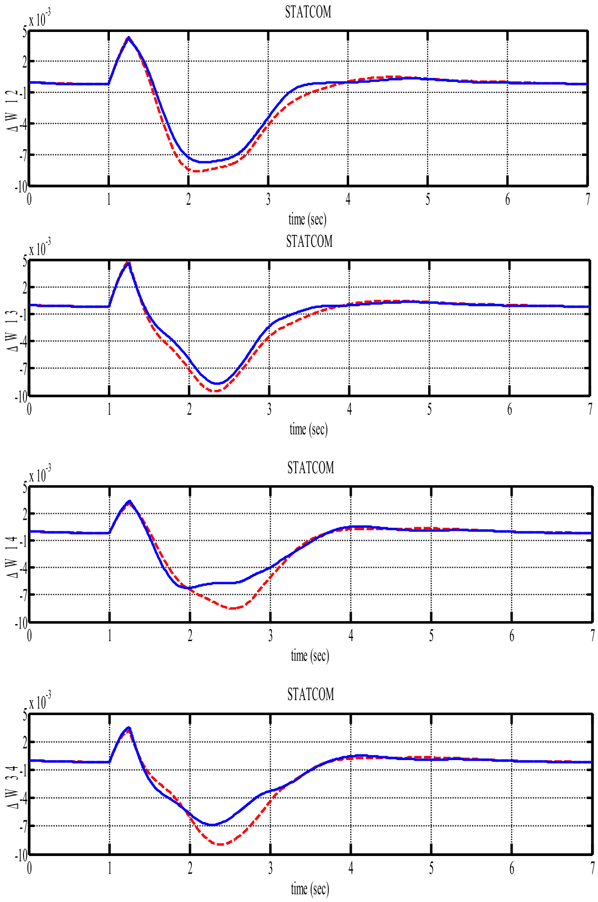

FIGURE 8. The speed changes of generators angles using STATCOM.

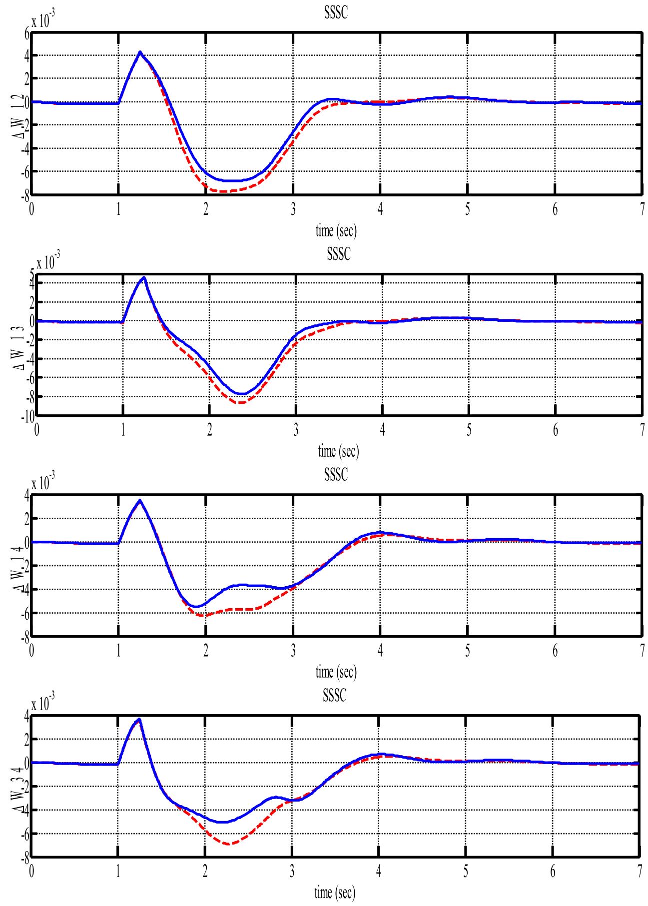

FIGURE 9. The angular velocity changes of generators using SSSC.

studied. For this purpose, STATCOM has been used in the network. This equipment improves the ability of it in a variety of stable margin loading. Prior to the placement of STATCOM, the value of the objective function is equal to 4.21, which is reached the value of 85.3 after the optimal placement. By comparing the simulation results, STATCOM has had a better performance than SVC, which is a parallel element of the first generation and has been able to further increase the system's loading limit. Figure 8 has shown angular velocity changes of generators in the case of using STATCOM.

In the final step, the SSSC as a series element of the second generation of FACTS devices, has been used in the communication line. The SSSC capacity is selected in such a way that it compensates up to 30% of the line impedance. The reason for this choice is to prevent the occurrence of the phenomenon of sub-synchronous resonance (SSRs). By installing this compensator in the communication line between two areas, the impedance of the line is reduced and it's possible to flow more electrical power through the line. The result of the application of the ABC algorithm to locate this element in the communication line was obtained in the case of installing SSSC at a distance of 56 km from bus. As a result, the objective function in these conditions is equal to 3.26. Figure 9 has shown the curves of angular velocity changes in the presence of SSSCs.

A. NUMERICAL ANALYSIS OF SIMULATION RESULTS

This section has analyzed and evaluated the results of simulation for first and second generation FACTS devices. The value of the objective function before and after placement has been obtained in the presence of different compensators, as shown in Fig. 10. As shown in the figure, series compensators have shown better performance than parallel compensators, and have been able to decrease the objective function. Also, the value of the objective function for a power system with a compensator placed for all compensators is less than the non-placed system. This reflects the effect of placement on system capabilities.

In the following, values 11 and 12 as he loading limit and system losses in the objective function, have been compared with each other. These values have been represented as bar graphs in Fig. 11.

The minimum amount of the fitness function is associate with the power system with the SSSC compensator, which is equal to 3.26. This means a higher sustainability margin and fewer losses. On the other hand, the largest amount of the fitness function is related to the system with the SVC, in which the value of the objective function is calculated as 4.23.

According to the results, it can be concluded that the power system with conveyor compensators (second generation) has

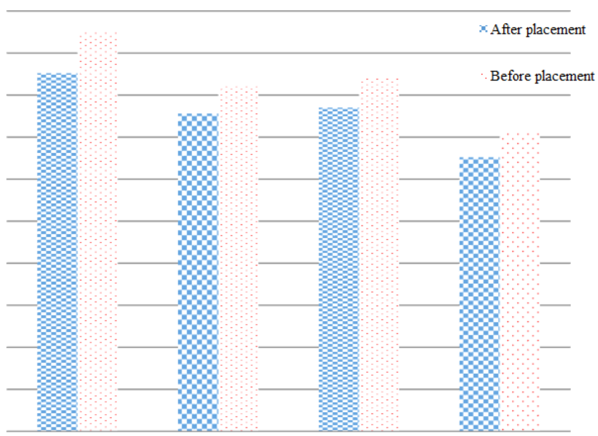

FIGURE 10. Comparison of the performance of FACTS devices.

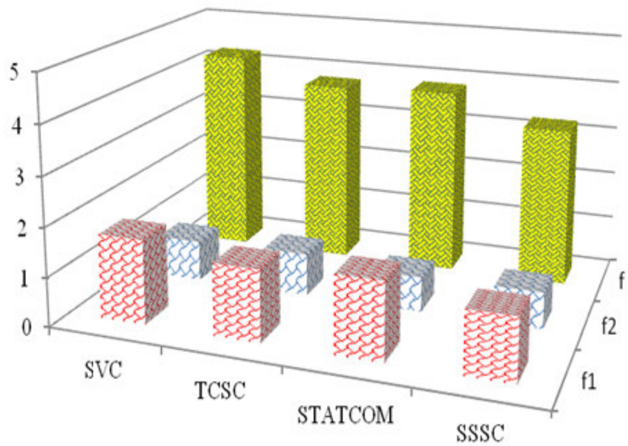

FIGURE 11. f1 and f2 values in the presence of FACTS devices.

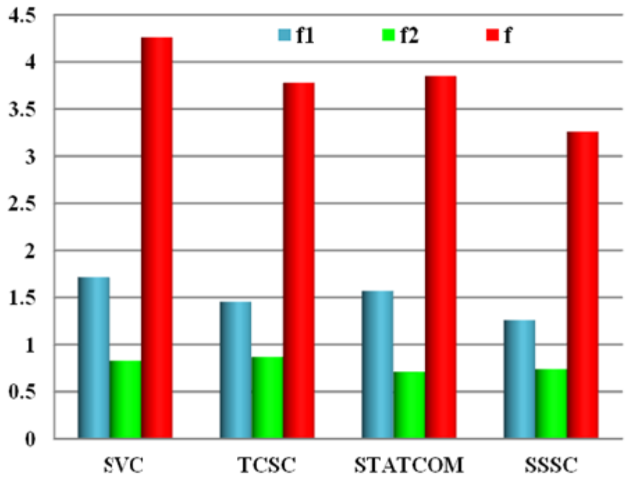

FIGURE 12. The value of the functions f1, f2 and f in the presence of FACTS devices.

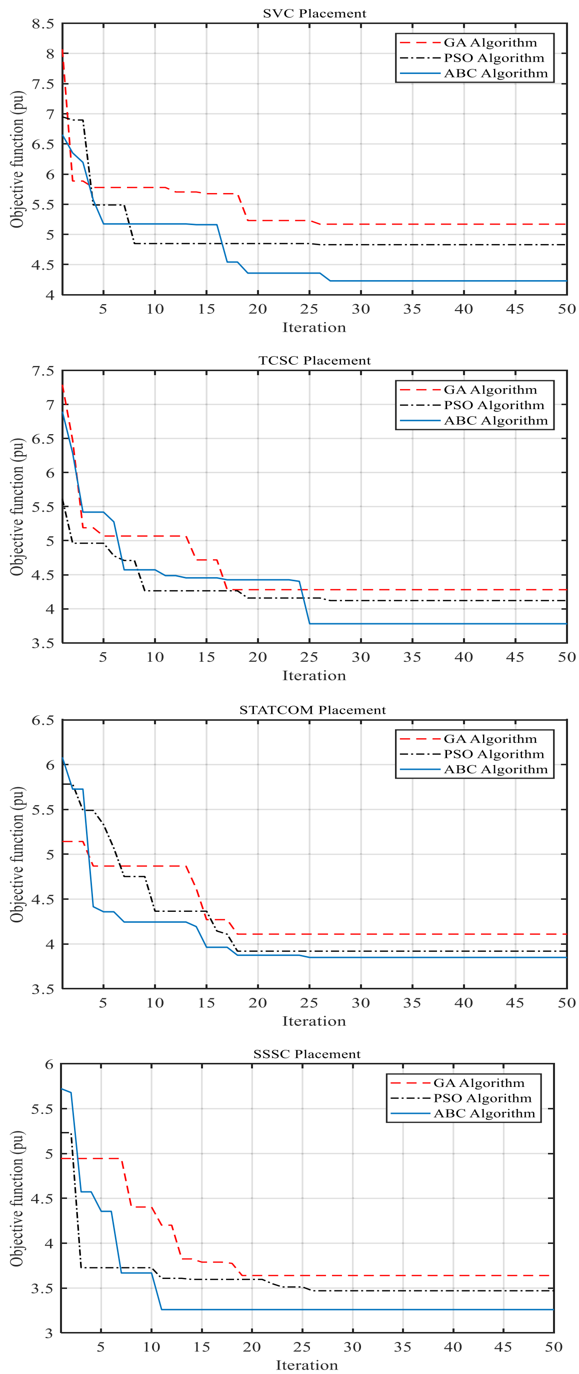

FIGURE 13. Convergence curve of the algorithms.

a higher stability and lower losses than the first generation. As observed in Fig. 12, if the second-generation FACTS devices are used, the f_1 and f_2 values of the power system relative to the FACTS generation of the first generation are lower. On the other hand, series elements in the transmission line are very suitable for increasing the stability margin of the system. The loading limit of the line in the case of using SSSC has increased significantly and the ability to transmit electrical power has been created with an acceptable reliability in the power system. This led to the lowest value of f_1 for the SSSC compensator. All compensators have had roughly the same performance in terms of reducing losses, as a result, the value of the objective function f_2 was almost nearly equal for all of them.

In order to confirm the results obtained from the optimization by artificial bee colony algorithm, a comparison was made with particle swarm optimization (PSO) and genetic (GA) algorithms. For this purpose, the values of the objective functions have been compared with each other.

TABLE 5. Parameters of GA and PSO algorithms.

GA	Population	Iteration	Mutation	Crossover	gama	
	100	50	0.3	0.8	0.05	
PSO	Population	Iteration	C1=C2	Vmin	Vmax	ω
	100	50	2	0.4	0.9	0.7

TABLE 6. Optimization results by GA, PSO and ABC algorithms.

		SVC	TCSC	STATCOM	SSSC
GA	Installation location (Km)	27.6	23.7	115	31.9
	The value of the objective function	5.17	4.28	4.11	3.64
PSO	Installation location (Km)	18.4	78.6	84.2	86.4
	The value of the objective function	4.83	4.12	3.92	3.47
ABC	Installation location (Km)	14	33.8	73.2	56
	The value of the objective function	4.23	3.78	3.85	3.26

The parameters of the GA and PSO algorithms have been presented in Table 5. It is worthy mention that, the algorithms parameters are chosen by trial-and-error method to have the best performance.

After performing the algorithms several times and adjusting the parameters of the optimization algorithms, it was found that the algorithms converged to their final value in less than 30 iterations. As a result, choosing 50 repetitions seems to be enough for them. The convergence curve of the algorithms is shown in Figure (13).

The optimization results are collected in Table 6. The installation location of each compensator and the value of the objective function have been given. Table 6 has considered the distance from the bus 7 as the decision variable for installing the compensator. As shown in the results, the performance of the ABC algorithm is more appropriate than the other methods in minimizing the objective function and has been able to minimize its value. The particle swarm algorithm has been more accurate than the genetic algorithm. The minimum value of the objective function for all three algorithms is obtained in the case of using the SSSC compensator, while the maximum is related to the power system, which used SVC as the compensator.

VII. CONCLUSION

Three types of problems of operating point settings and installation locations must be considered simultaneously to optimize the performance of the FACTS devices in the power system. In fact, several methods are used to solve the problem of FACTS devices placement but the inability to find a global optimum has impeded the solution of such a problem. Methods using the optimal global solution have low convergence rate. What causes this problem is the random and linear action of the methods in choosing the optimal results. In this paper, the FACTS devices placement in the power system is studied with the aim of increasing the loading limit of transmission line and also reducing the losses using the Artificial Bee colony algorithm (ABC). Studies have been done on the standard four-machine system in the presence of compensators of SVC TCSC, STATCOM and SSSC. The results indicate that the series compensators have shown more appropriate performance in reducing the objective function and thereby improving the line loading limit. Also, second-generation FACTS devices have a more favorable response than the first generation. In order to confirm the results of the ABC algorithm, The results are compared with widely used particle swarm optimization (PSO) and genetic (GA) algorithms. The results show that in the power system where the compensator placement was performed by ABC algorithm, the responses are more appropriate and, the value of the objective function in the case of using this algorithm is less than two GA and PSO algorithms. In future, the power system engineers can choose the best option based on the results obtained in this paper (the impact of each of the FACTS on power system stability and transmission line losses) and FACTS prices.

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