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Symbiotic Organisms Search Technique for SVC Installation in Voltage Control

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Abstract

Increasing demand experienced by electric utilities in many parts of the world involving developing country is a normal phenomenon. This can be due to the urbanization process of a system network, which may lead to possible voltage decay at the receiving buses if no proper offline study is conducted. Unplanned load increment can push the system to operate closes to its instability point. Various compensation schemes have been popularly invented and proposed in power system operation and planning. This would require offline studies, prior to real system implementation. This paper presents the implementation of Symbiotic Organisms Search (SOS) algorithm for solving optimal static VAr compensator (SVC) installation problem in power transmission systems. In this study, SOS was employed to perform voltage control study in a transmission system under several scenarios via the SVC installation scheme. This realizes the feasibility of SOS applications in addressing the compensating scheme for the voltage control study. Minimum and maximum bound of the voltage at all buses have been considered as the inequality constraints as one of the aspects. A validation process conducted on IEEE 26-Bus RTS realizes the feasibility of SOS in performing compensation scheme without violating system stability. Results obtained from the optimization process demonstrated that the proposed SOS optimization algorithm has successfully reduced the total voltage deviation index and improve the voltage profile in the test system. Comparative studies have been performed with respect to the established evolutionary programming (EP) and artificial immune system (AIS) algorithms, resulting in good agreement and has demonstrated its superiority. Results from this study could be beneficial to the power system community in the planning and operation departments in terms of giving offline information prior to real system implementation of the corresponding power system utility.

Keywords: *Symbiotic Organisms Search, Static VAr Compensator, Voltage Deviation Index*

1. Introduction

Power system stability is an important aspect in a power system operation. Due to power system expansion and increase in load demand, power transmission system is forced to be operated near to its stability limit [1]. Increase in load demand can cause voltage level at load buses to reduce, which then eventually will deviate the stability of the power system. Reduction in system voltage can cause voltage collapse to occur. Voltage collapse can be defined as monotonic voltage reduction of a heavily loaded power system, which then eventually leads to blackout [2]. To improve the power system stability, several methods can be implemented such as optimal reactive power dispatch and installation of capacitor banks.

Flexible AC Transmission System (FACTS) devices are known to be one of the suitable methods to improve the power system stability. FACTS devices can be classified into different types such as series FACTS devices, shunt FACTS devices or a combination of series and shunt FACTS devices [3]. SVC is classified as one of the shunt FACTS devices. SVC is a device which is made up of a Thyristor Controlled Reactor (TCR) and a fixed capacitor bank, connected in parallel with the TCR. SVC is capable of feeding reactive power or drawing reactive power from the system. Due to the flexible capability of SVC, it can be used to provide reactive power support to a power system [4]. Although a capacitor bank can be used to feed reactive power to the system, it is impossible for capacitor banks to draw excess reactive power from the system. Capacitor bank is designed to operate via series of steps. These steps represent the fixed values of reactive power supplied by the capacitor bank. SVC, on the other hand, allows finer control on the amount of reactive power to be injected in a power system since it does not operate in steps.

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Various studies have been conducted on optimal placement and sizing of SVC in a power transmission system using various optimization techniques. Chang et al. has proposed optimal placement of SVC using Parallel Simulated Annealing for voltage stability reinforcement. According to Chang et al., Simulated Annealing (SA) suffers problem of slow convergence, hence causing him to implement Parallel Simulated Annealing in order to improve the performance of the algorithm as reported in [5]. In [6], voltage deviation and total real power loss are reduced while enhancing the voltage stability via optimal placement and sizing of SVC and Thyristor Controlled Series Compensator (TCSC) using Multi-Objective Particle Swarm Optimization (MOPSO). The same research has been conducted in [7] to minimize total active power loss and installation cost of SVC through optimal placement and sizing of SVC using Teaching Learning Based Optimization (TLBO) technique. Optimal placement and sizing of SVC has been conducted by Jumaat et al in [8] by using Particle Swarm Optimization (PSO) technique in order to reduce the transmission loss and SVC installation cost. An improved version of PSO known as Probabilistic Particle Swarm Optimization (PPSO) technique has been implemented in [9] by Sundareswaran et al. for optimal SVC placement in order to improve voltage stability index in the IEEE 30-bus power system. Nireekshana et al. has proposed a research in [10] to determine the optimal placement of FACTS devices such as SVC and TCSC via the implementation of Cat Swarm Optimization (CSO) algorithm, which is claimed to perform better compared to PSO. However, the authors did not conduct any comparative studies with respect to PSO in order to support the claim made by the authors. Genetic Algorithm (GA) has been widely implemented by various researchers in solving optimal SVC placement problem to achieve several objectives such as minimization of power losses [11-13], SVC sizing [11], investment cost [12], voltage deviation index [12], improvement of voltage profile [11] and maximization of voltage collapse point [13]. In [14], optimal placement and sizing of SVC has been achieved by Sirjani et al. with the implementation of Improved Harmony Search (IHS) technique to minimize active power loss, voltage deviation index and investment cost. Nagalakshmi et al. has conducted a comparative study of different optimization algorithms such as PSO, Differential Evolution (DE) and Composite Differential Evolution (CoDE) to solve optimal placement of SVCs [15]. In the study, robustness of DE has been proven via its low value of standard deviation, while CoDE has revealed its superiority over DE in terms of computational time. The same approach was implemented by Nguyen et al. where the authors have conducted a study to solve optimal SVC sizing and placement using Self-Organizing Hierarchical PSO with Time-Varying Acceleration Coefficients, IHS, and Cuckoo Search Algorithm (CSA) [16]. In the study conducted by Nguyen et al., CSA is found out to be more powerful as compared to other techniques discussed in [16] in terms of results quality. Ishak et al. [17] has proven the capability of Artificial Immune System (AIS) in improving voltage profile of transmission system while minimizing the total power loss via optimal sizing of SVC. In [18], Khaleghi et al. has implemented Modified Artificial Immune Network Algorithm (MAINetA) to minimize total power loss, cost of SVC and voltage deviation. The optimized results are compared with the implementation of Real Immune Algorithm (RIA), resulting in superiority of MAINetA over RIA since RIA yields unsatisfactory optimized results.

Although many optimization techniques can be implemented to solve such problem, each optimization algorithm has its own disadvantages, making it less feasible to be implemented to solve optimal SVC placement problems. Traditional optimization algorithm such as Sequential Quadratic Programming (SQP) is reported that it is sensitive to its initial point and tends to get trapped in the local optima [19]. Authors in [19] and [20] have reported that GA suffers slow convergence time. Selvarasu et al. [21] has reported that convergence of Firefly Algorithm (FA) depends greatly on its parameter; hence improper parameter setting can disturb the convergence of FA. Furthermore, an overview conducted by Dubey et al. has revealed that Evolutionary Strategy (ES) algorithm suffers from high computational burden and no certainty of global solution whereas SA is very sensitive to its parameter and demand high computational effort while it can provide global solution to the problem which is attempted to be solved by SA [4]. To overcome the drawback of these algorithms, the authors have proposed to solve optimal SVC sizing for voltage control by using Symbiotic Organisms Search (SOS) algorithm. SOS is developed by Min-Yuan Cheng and Doddy Prayogo [22] in 2014. In this algorithm, SOS simulates the behavior of organisms in nature since organisms does not usually live in isolation and relies to other species for sustenance and survival. The notable advantage of SOS compared to other metaheuristics algorithms is that, SOS requires no specific parameter for its algorithm. Since some optimization algorithms relies on its parameter for its convergence, improper choice of parameter may affect the convergence of the algorithm. With the absence of such parameter, the dependencies of convergence of an algorithm is reduced, thus improve the capability to produce higher quality results [23].

This paper presents the implementation of SOS technique to determine the optimal sizing of SVC in controlling the voltage profile of a power system. The main objective of this paper is to minimize the voltage deviation index and control the voltage profile of load buses in a system while satisfying all the constraints subjected to the optimization problem. The effect of the optimization is observed through voltage deviation index of load buses, voltage profile of the system as well as voltage level at which the SVC is to be installed. Comparative studies are also conducted with respect to Evolutionary Programming (EP) and AIS algorithm which has significantly revealed the superiority of SOS in terms of quality of the solution yielded by the optimization algorithm.

2. Methodology

In order to solve the problems as previously stated in section 1, SOS technique is employed in order to perform the optimization process to determine the optimal sizing of SVC to be installed in a power system. The detail of the optimization problem is discussed further in section 2.1 while the step-by-step procedure of the proposed optimization technique is discussed in detail in section 2.2.

2.1. Problem Formulation

The aim of this research is to implement the SOS solving optimal sizing of SVC in a transmission system. The goal of the research is to control the voltage deviation of load buses in power system while satisfying all the constraints in the system. Thus, the objective function can be expressed as:

$$F = \min(V_{di}) \tag{1}$$

where V_{di} is the total voltage deviation index (VDI) of load buses in the system. The voltage deviation index is defined as the ratio of difference between the bus voltage with the reference voltage of the bus to the reference voltage of the bus. In [16], the voltage deviation index considers the voltage deviation at all buses. In this paper, the voltage deviation index only considers the voltage deviation of load buses only, while slack bus, P-V buses and connecting bus are not considered in the index. Therefore, it can be mathematically represented as:

$$V_{di} = \sum_{i=1}^{k} \left(\frac{V_{ref,i} - V_i}{V_{ref,i}} \right)^2 \tag{2}$$

where V_i is the i^{th} bus voltage and $V_{ref,i}$ is the reference voltage of i^{th} bus, and k is the total number of load bus in the system. In this paper, $V_{ref,i}$ is set at 1.00 per unit (p.u.).

An SVC is capable of injecting reactive power into the system and drawing reactive power from the system. In this paper, the rating of SVC is represented as negative reactive loads in the system. Positive values of SVC rating represent the value of reactive power to be injected to the system while negative values of SVC rating represent the value of reactive power to be drawn from the system. The range of sizing of SVC used in this paper is represented as:

$$Q_{SVC}^{\min} \le Q_{SVC} \le Q_{SVC}^{\max} \tag{3}$$

where $Q_{SVC}^{\min}$ is the minimum limit of SVC sizing and $Q_{SVC}^{\max}$ is the maximum limit of SVC sizing. In this paper, the minimum and maximum limit of each SVC installed are -100MVAr and 100MVAr respectively.

In a power system, the total power generated by a generation unit at a bus should cater the total power at a bus and the power injected to a bus. This constraint is known as power balance constraint. For each bus in the system, the active and reactive power balance is described as follows:

$$P_{inj,n} = P_{g,n} - P_{L,n} \quad (4)$$

$$Q_{inj,n} = Q_{g,n} - Q_{L,n} \quad (5)$$

where $P_{inj,n}$ is the active power injected at n^{th} bus, $P_{g,n}$ is the active power generated by generation unit connected at n^{th} bus and $P_{L,n}$ is the active power load at n^{th} bus. $Q_{inj,n}$ is defined as reactive power injected at n^{th} bus while $Q_{g,n}$ is the reactive power generated by generation unit connected at n^{th} bus and $Q_{L,n}$ is the reactive power load at n^{th} bus.

In order to maintain the acceptable voltage profile of a power system, the value of bus voltage should be maintained at the range of permissible value. Both under-voltage and over-voltage conditions are undesired since both conditions can cause harm to the power system. Therefore, the permissible value of bus voltage in a power system is expressed as:

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (6)$$

where $V_i^{\min}$ is the minimum value of i^{th} bus voltage, $V_i^{\max}$ is the maximum value of i^{th} bus voltage and V_i is the i^{th} bus voltage. Reference [14] suggested that the acceptable voltage deviation value in practice is up to 10%. Therefore, in this paper, $V_i^{\min}$ is set to 0.90 p.u while $V_i^{\max}$ is limited at 1.10 p.u.

2.2. Symbiotic Organisms Search for SVC Installation

To solve optimal SVC sizing for voltage control of a transmission system, the authors have implemented SOS algorithm to obtain the optimal solution. SOS is a metaheuristic algorithm developed by Min-Yuan Cheng and Doddy Prayogo, which is claimed to be a robust and powerful algorithm to solve numerical optimization problems. SOS simulates the interaction of organisms in a nature which relies on other species for its survival and sustenance. The developers of the algorithm claimed that the algorithm is superior to other metaheuristic algorithms due to the absence of specific algorithm parameter, which could influence the convergence of the algorithm. In SOS, the organisms will undergo 3 phases along the algorithm. The 3 processes are Mutualism phase, Commensalism phase and Parasitism phase. For each phase, the organisms are evaluated and modified in accordance to the nature of the process. In SOS, the organisms will try to seek the global optimal solution via iterative process in a specified search space. In this paper, the organisms of SOS algorithm are defined as the set of possible optimal SVC sizing while the fitness value is defined as the total voltage deviation index of load buses in the power system. The process of SOS in determining the optimal SVC sizing for voltage control is summarized as follows:

Step 1: Initialization Stage. During this stage, a set of SVC sizing are generated randomly in the range of allowable SVC sizing as stated in (3). The generated sizing should allow the load flow solution to converge for it to be accepted. In this paper, 20 individuals of acceptable SVC sizing are generated before the optimization process begins to form an ecosystem. Then, the fitness value of the organisms is evaluated.

Step 2: Best organism identification. At this stage, the set of SVC sizing which yield the lowest voltage deviation index are considered to be the best organisms.

Step 3: Mutualism phase. In mutualism phase, 2 different species are chosen in which benefits both species. X_i is defined as the i^{th} set of SVC sizing from the ecosystem. Then, another set of SVC sizing which is defined as X_j is selected randomly from the ecosystem where $j \neq i$. Mutual vector of the organisms are then computed. From the mutual vector, a new set of SVC sizing of X_i and X_j are produced. The calculation of mutual vector and production of X_i and X_j are expressed as:

$$MV = \frac{X_i + X_j}{2} \tag{7}$$

$$X_{i,new} = X_i + rand(0,1) \times (X_{best} - MV \times BF1) \tag{8}$$

$$X_{j,new} = X_j + rand(0,1) \times (X_{best} - MV \times BF2) \tag{9}$$

Where MV is the mutual vector, $X_{i,new}$ and $X_{j,new}$ are new set of SVC sizing produced by mutualism phase of X_i and X_j, *rand(0,1)* is a random number ranged from 0 to 1, X_{best} is the best SVC sizing with the best voltage deviation index value which is identified in stage 2, *BF1* and *BF2* are benefit factors, which is an random integer values ranged from 1 to 2. After the new SVC sizing has been produced, the fitness values of the newly-produced SVC sets are evaluated. Later, the fitness of new SVC sizing set ($X_{i,new}$ and $X_{j,new}$) are compared with the fitness value of the original SVC sizing set (X_i and X_j). If the newly-produced sets have a better fitness value compared to the original one, the newly-produced sets will replace the original set. Otherwise, the newly-produced sets are rejected and ignored.

Step 4: Commensalism phase. In commensalism phase, an organism is trying to gain benefit from its interaction with another organism. A set of SVC sizing is first randomly chosen from the ecosystem which is known as X_j where $j \neq i$. Then, the i^{th} set of SVC sizing is updated with the assistance of j^{th} set of SVC sizing. The update process is expressed as:

$$X_{i,new} = X_i + rand(-1,1) \times (X_{best} - X_j) \tag{10}$$

where *rand(-1,1)* is a random number in the range of -1 to 1, X_{best} is the best set of SVC sizing, X_i is the i^{th} set of SVC sizing, X_j is the j^{th} set of SVC sizing which has been selected randomly and $X_{i,new}$ is the updated i^{th} set of SVC sizing. After the set of SVC sizing has been updated, the fitness value is then computed. If the updated i^{th} set of SVC sizing yields lower total voltage deviation index compared to the original i^{th} set of SVC sizing, the updated i^{th} set of SVC sizing will replace the original i^{th} set of SVC. It can be noted that in this phase, the j^{th} organism only assist the update of i^{th} organism while j^{th} organism receive no benefit or harm from this interaction.

Step 5: Parasitism phase. In parasitism phase, a parasite is born and it will try to kill the original organism in the ecosystem. Firstly, a set of SVC sizing is randomly chosen to be X_j where $j \neq i$. Then, a parasite known as *parasite_vector* is born by duplicating the i^{th} set of SVC sizing. Then, the SVC sizing of *parasite_vector* is modified at random dimension with randomly generated SVC sizing. The fitness value of the *parasite_vector* is then evaluated. If the *parasite_vector* yields total voltage deviation index which is better than total voltage deviation index yielded by j^{th} set of SVC sizing, then the parasite will kill the j^{th} organism, meaning that the *parasite_vector* will replace the position of j^{th} set of SVC sizing in the ecosystem. If the opposite case occurs, then the j^{th} organism has the immunity from the parasite. Therefore, the j^{th} set of SVC sizing will remain at its position in the ecosystem while the *parasite_vector* is discarded.

Step 6: Convergence test. After mutualism, commensalism and parasitism phase have been done, the algorithm proceeds with the next i^{th} set of SVC sizing. The process continues until all sets of SVC sizing has been evaluated such that i is equal to the total number of organisms in the ecosystem. If the iteration counter has not reach the maximum number of iteration, then the process is repeated from step 2. Otherwise, the process stops.

3. Results and Discussions

In this study, the IEEE 26-Bus RTS is used to test the SOS algorithm in solving optimal SVC installation problem. This power system consists of 6 generation units, 17 load buses and 3 connecting buses. The Single-line diagram of the system is illustrated in Figure 1. The parameters used in this optimization process are listed as follows:

Number of organisms : 20
Number of installed SVC : 3
Maximum number of iteration : 200

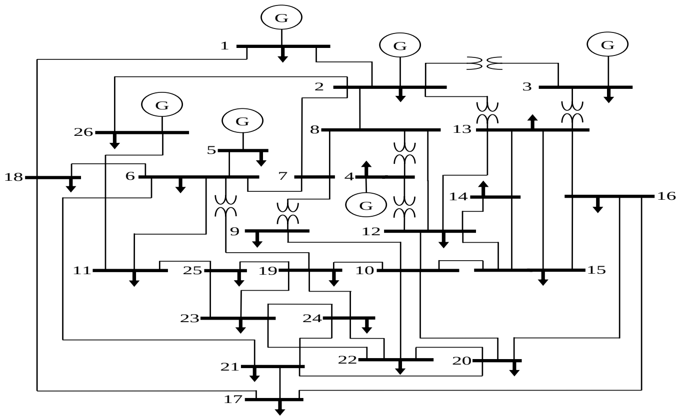

Figure 1. Single-line diagram for IEEE 26-Bus Reliability Test System (RTS)

To test the algorithm, different loading conditions of the power system which represents different case studies are implemented in order to determine whether the proposed optimization algorithm can perform the optimization process in different power system scenarios. The case studies used in this study are listed as follows:

Case 1 : In this case, the power system is operating at its normal condition. No change has been made on the parameters of the power system. This condition is known as base case condition.

Case 2 : In this case, the reactive power load demand at bus 9 of the transmission system is set to 10 MVAr. Other parameters are not changed. This condition is known as light-loading condition.

Case 3 : In this case, the reactive power load demand at bus 16 of the transmission system is increased to 100 MVAr. Other parameters are not changed. This condition is known as heavy-loading condition.

For all case studies, the optimization algorithm was executed for 20 times to observe any significant variation of the results. The data which are analysed during these case studies are bus voltages in the system, bus voltage in which the SVC was installed and the total voltage deviation index. To realize the effectiveness of SOS algorithm in solving such problem, EP and AIS are also applied to solve the same problem with similar case studies.

3.1. Base Case Condition

In this condition, the power system is operating normally at its nominal parameters. There is no change has been made to the parameter of the power system. The placement of the SVCs is determined based on the buses which have the worst (highest) voltage deviation index. In this case, buses 23, 24 and 25 indicated the highest voltage deviation index. Optimal SVC installation problem is then solved by using SOS algorithm. The optimization process is executed for 20 times to reveal any significant variation on the results yielded from the optimization process. Table 1 tabulates the voltage deviation index results for base case condition while Figure 2 illustrates the voltage level at all buses in the test system.

Table 1. Results of optimization process during base case condition

Parameter	Result		
	SOS	EP	AIS
Total voltage deviation index before optimization	0.00460	0.00460	0.00460
Best post-optimized voltage deviation index	0.00153	0.00318	0.00271
Worst post-optimized voltage deviation index	0.00153	0.00318	0.00276
Average post-optimized voltage deviation index	0.00153	0.00318	0.00271

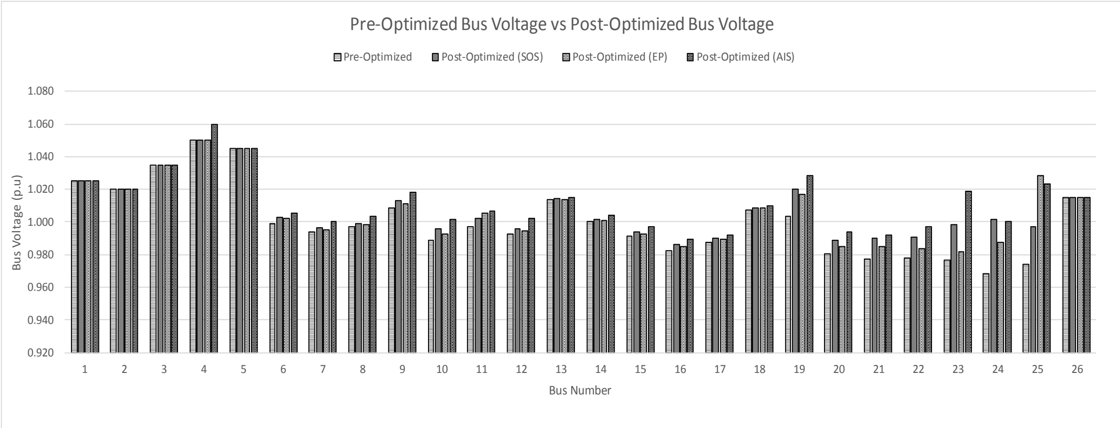

Figure 2. Voltage level at each bus during base case condition

From the results in Table 1, it can be observed that SOS is capable of solving optimal SVC installation problem at base case condition. The voltage level at all buses increase without violating the maximum limit, while maintaining the voltage level above the minimum limit. All the 3 algorithms (SOS, EP and AIS) have successfully reduced the total voltage deviation index with SOS yielded the lowest value of total voltage deviation index as compared to EP and AIS. Therefore, SOS has proven its superiority over EP and AIS in solving optimal SVC installation problem during base case condition.

3.2. Light-Loading Condition

In light-loading condition, the reactive power load at bus 9 is reduced to 10MVAr while the loads at other buses are maintained at base case condition. The same method is used as those in the base case condition. In this case, buses 9, 24 and 25 have witnessed the highest values of voltage deviation index. Optimization process using SOS for SVC installation is also conducted to the system. The optimization process is executed for 20 times to observe the variation of results yielded from the optimization process. Table II tabulates the voltage deviation index during light-loading condition while Figure 3 illustrates the voltage level at all buses in the test system.

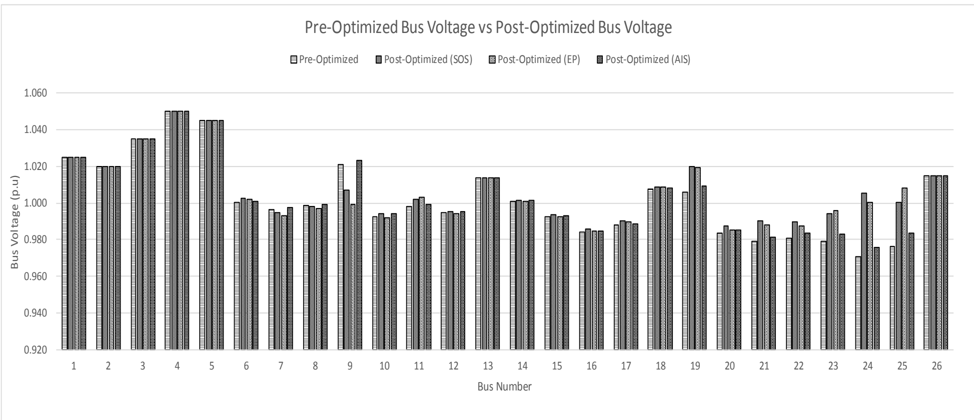

Figure 3. Voltage level at each bus during light-loading condition

Table 2. Results of optimization process during light-loading condition

Parameter	Result SOS	Result EP	Result AIS
Total voltage deviation index before optimization	0.00410	0.00410	0.00410
Best post-optimized voltage deviation index	0.00151	0.00169	0.00331
Worst post-optimized voltage deviation index	0.00151	0.00169	0.00331
Average post-optimized voltage deviation index	0.00151	0.00169	0.00331

From the results obtained after executing the optimization algorithm, it can be observed that SOS can solve the optimal SVC installation problem while the test system is operating on light-loading condition. Upon the completion of executing the optimization algorithm, it can be observed that bus with voltage higher than the bus reference voltage has been successfully reduced close to the reference value while bus with value lower than the reference value has been increased near to the reference value. It is also observed that no bus voltage has violated the maximum and minimum bus voltage limit, hence making the optimization results feasible to be implemented in the test system. From the results, SOS has yielded post-optimized results which is lower than EP and AIS, hence highlighting its superiority on solving optimal SVC installation problem during light loading condition.

3.3. Heavy-Loading Condition

During heavy-loading condition, the reactive power load at bus 16 is increased to 100MVAr while the loads at other buses are not changed. The buses with the highest voltage deviation index values are chosen for the location of SVC installation. Buses 23, 24 and 25 have witnessed the highest voltage deviation index values. To determine the optimal SVC sizing to be installed, SOS is applied as the optimization algorithm in the process. The optimization engine was executed for 20 times to monitor any variation on the results from the optimization engine. Table 3 summarizes the results during the optimization process while the voltage level at each bus in the system is depicted as in Figure 4.

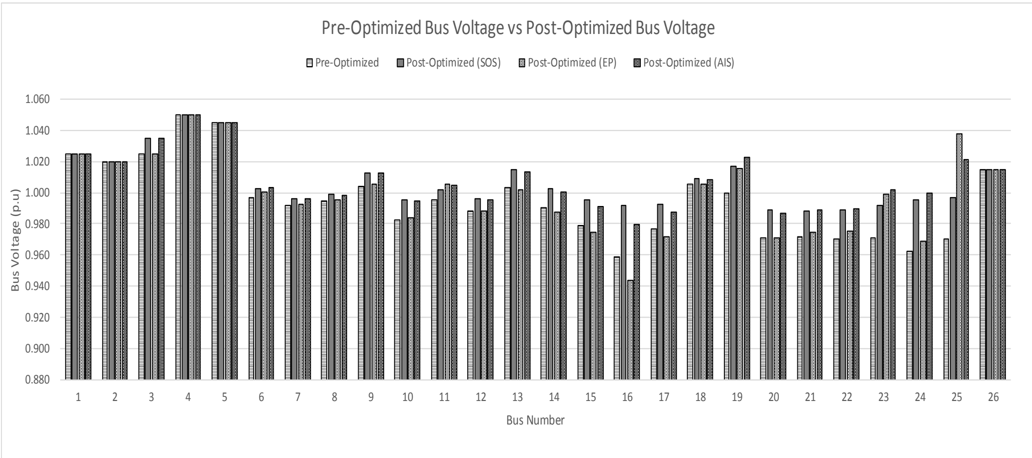

Figure 4. Voltage level at each bus during heavy-loading condition

Table 3. Results of optimization process during heavy-loading condition

Parameter	Results		
	SOS	EP	AIS
Total voltage deviation index before optimization	0.00860	0.00860	0.00860
Best post-optimized voltage deviation index	0.00142	0.00364	0.00250
Worst post-optimized voltage deviation index	0.00142	0.00364	0.00269
Average post-optimized voltage deviation index	0.00142	0.00364	0.00252

From the table, it can be observed that SOS is capable of solving optimal SVC installation problem when the system is heavily loaded. The total voltage deviation index value is significantly reduced. The bus voltage with low voltage value has been successfully increased near the reference value. While the bus voltage in the system has been increased from the pre-optimized value, some bus voltage has been increased beyond 1.00 p.u. However, all bus voltages are maintained within the range of its permissible voltage level. From the results, SOS exhibited the lowest value of total voltage deviation index as compared to EP and AIS. Therefore, the superiority of SOS over EP and AIS has been proven while solving optimal SVC installation problem during heavy-loading condition.

3.4. Optimal Location and Sizing of SVC

In this paper, SOS is implemented to determine the optimal sizing of the SVC to improve the voltage profile while the location of SVC installation is determined by the worst value of voltage deviation index. At base case, buses 23, 24 and 25 witnessed the highest voltage deviation index. Therefore, SVC are installed at these locations. The results of minimum voltage before and after the optimization process for base case condition are tabulated in Table 4.

Table 4. Results of minimum voltage in the test system for case 1

Technique	SVC Location	SVC Sizing (MVAr)	Minimum Voltage (p.u.)	
			Pre-Optimized	Post-Optimized
	23	12.4830		
SOS	24	49.6693	0.9682	0.9860
	25	10.0148		
	23	-45.4580		
EP	24	26.3269	0.9682	0.9820
	25	76.9414		
	23	30.7826		
AIS	24	30.7826	0.9682	0.9890
	25	30.7826		

From the results, installation of SVC, optimized using SOS has successfully increased the minimum voltage in the system. AIS has recorded the highest minimum voltage compared to SOS and EP. Despite of that, SOS has provided the most optimal solution since the voltage level at buses 23, 24 and 25 have been brought up close to 1.00 p.u., hence minimizing the voltage deviation index. The voltage level of buses with SVC installed during base case is illustrated as in Figure 5.

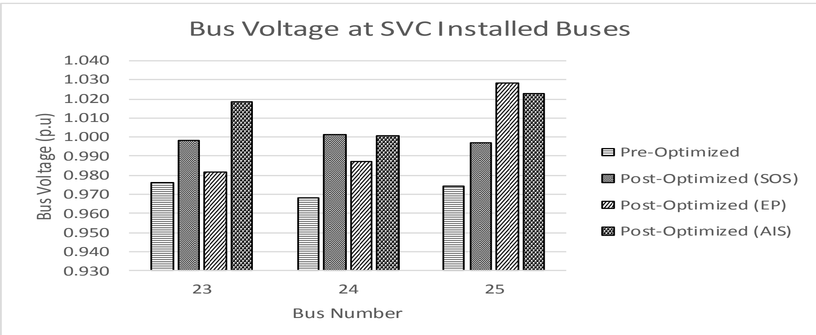

Figure 5. Voltage level at the bus with SVC installed for case 1

During light-loading condition, SVC is installed at buses 9, bus 24 and bus 25 since these buses recorded the highest value of voltage deviation index. The result of minimum voltage before and after the optimization process are tabulated in Table 5. In case 2, optimization process using SOS has been able to increase the minimum voltage in the test system. SOS has recorded the highest minimum voltage as compared to EP and AIS. It can be observed that SOS better optimal solution since voltage levels at buses 9, 24, and 25 have been brought close to 1.00 p.u. while minimizing the voltage deviation index. The voltage level of SVC installed buses in case 2 is illustrated in Figure 6.

In case 3, SVC is installed at buses 16, 24, and 26 since these buses yielded the highest voltage deviation index. The result of minimum voltage before and after the optimization process are tabulated as in Table 6. During case 3, SOS has been implemented to increase the minimum voltage in the test system. Among all optimization methods implemented, SOS has provided the highest minimum voltage level compared to AIS and EP. From Figure 7, it can be observed that optimization using SOS has successfully improved the voltage level at buses 16, 24, and 25 by bringing the voltage levels close to 1.00 p.u.

Table 5. Results of minimum voltage in the test system for case 2

Technique	SVC Location	SVC Sizing (MVAr)	Minimum Voltage (p.u.)	
			Pre-Optimized	Post-Optimized
SOS	9	-60.8218	0.9709	0.9860
	24	60.1528		
	25	18.2539		
EP	9	-85.4649	0.9709	0.9850
	24	50.6689		
	25	30.3014		
AIS	9	5.9374	0.9709	0.9760
	24	5.9374		
	25	5.9374		

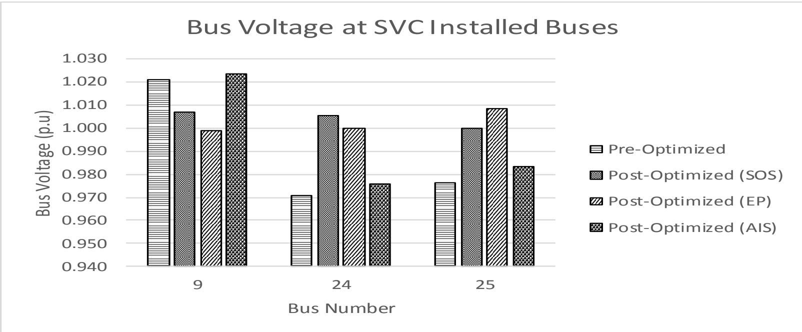

Figure 6. Voltage level at the bus with SVC installed for case 2

Table 6. Results of minimum voltage in the test system for case 3

Technique	SVC Location	SVC Sizing (MVAr)	Minimum Voltage (p.u.)	
			Pre-Optimized	Post-Optimized
SOS	16	97.1566	0.9589	0.9880
	24	38.7994		
	25	16.4992		
EP	16	51.2821	0.9589	0.9630
	24	98.2075		
	25	-26.9323		
AIS	16	44.5307	0.9589	0.9800
	24	44.5307		
	25	44.5307		

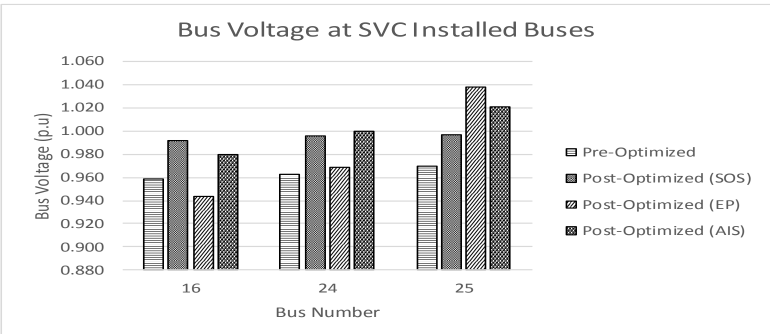

Figure 7. Voltage level at the bus with SVC installed for case 3

4. Conclusion

This paper has presented the implementation of Symbiotic Organisms Search technique for SVC installation in voltage control study. Maintaining a good voltage profile is vital since voltage profile can affect the stability of a power system. To achieve a good voltage profile, the sizing of SVC should be optimal to avoid under-compensation or over-compensation. From all the case studies conducted in the paper, it can be concluded that the proposed optimization algorithm can solve optimal SVC installation problem for voltage control. Through the optimization process, it can be observed that the total voltage deviation index value has been minimized and the minimum voltage in the test system has been increased. Comparative studies conducted among SOS, EP and AIS have revealed that SOS has proven its superiority over EP and AIS by achieving the best performance in solving optimal SVC installation problem.

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