Research Article

Multi-Heuristic Based Technique in Multi-SVCs Installation Scheme for Loss Control in Transmission System

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Abstract: Increasing demand of power system has been identified as one of the dominant factors in under-voltage phenomenon, instability condition and increment of transmission loss in power system. To alleviate this condition for the purpose of maintaining secure delivery of electricity, appropriate remedial actions are mandatory to be performed in either real time or offline studies. Amongst the popular remedial actions to avoid the loss control is the installation of static VAR compensator (SVC) scheme. This scheme requires a robust optimization technique which should be able to achieve optimal solution with less computation burden. This paper presents the application of multi-heuristic techniques for optimizing the sizing and locations of the SVC installation. Two optimization techniques are proposed in this study; namely the evolutionary programming (EP) and artificial immune system (AIS) for the purpose of optimal determination of locations and sizing of SVCs. Several cases are considered, based on number of units for the installation process; solved under different loading conditions subjected to the system. A reliability test system (RTS) model was utilized as the test specimen in this study; which ultimately highlights the merit of the optimization techniques.

Keywords: Artificial Immune System (AIS), Evolutionary Programming (EP), loss control, fitness equation, objective function, optimization.

1. Introduction

In the last five decades, synchronous condenser was popularly used to compensate reactive power in the transmission system. At that time, the grid system is small due to accessibility, financial and technology constraints [1]–[3]. Nowadays, it is not suitable to use synchronous condenser as the modern power system is large and require more flexible device to control the power flow in the grid system. Furthermore, with the new invention of power system technology known as Flexible AC Transmission Systems (FACTS) devices, synchronous condenser is no longer used in transmission system. Unlike synchronous condenser, FACTS devices are static devices that involve power electronics components [4]–[6]. There are several types of FACTS devices available in the market, which are Static Synchronous Series Compensator (SSSC), Thyristor-Controlled Series Capacitor (TCSC), Static Synchronous Compensator (STATCOM) and Static VAR Compensator (SVC) [7], [8]. The difference between the FACTS devices on how they are connected to the transmission system. For example, SSSC and TCSC are connected in series with the transmission lines. While STATCOM SVC are connected in parallel with the transmission lines [9]–[13].

Among the FACTS devices, SVC is popularly used in transmission system as it is more economical compared to the others. SVC has the capability to supply and absorb reactive power from the buses in the transmission system [14], [15].

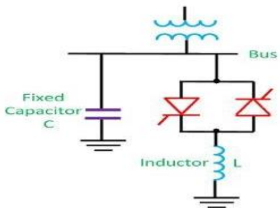

Figure 1: SVC circuit diagram [14].

From Figure 1, it can be seen that a capacitor and an inductor are connected in parallel. The inductor is connected with two thyristors. These two thyristors are used to control the current flowing through the inductor. This scheme is known as Thyristor controlled reactor (TCR). Normally this scheme is used for SVC that requires to supply reactive power to the buses in the transmission system for most of the time. Load at these buses absorb a lot of reactive power from the transmission system. Instead of getting the reactive power from the infinite bus, the SVC will supply the reactive power locally to the load. Therefore, there will be less transmission line current drawn by the buses and this will reduce the transmission losses and improve the voltage stability of the transmission system. At the same time, the power factor is also improved [6], [11], [16]–[19]. Many studies on SVC have been conducted by researchers and engineers. For instance, J. Zhu et al. [20] proposed multi-stage active management of renewable-rich power distribution network. SVC is used as one of the decentralized P/Q(V) control strategies in a distribution system with high penetration of renewable energy. SVC managed to regulate the voltage stability in the system. Meanwhile, Xiang et al. [21] proposed a metaheuristic method named as Second-Order Cone Programming (SOCP) to find optimal sizing of Distributed Wind Generation (DWG) with the fixed location in transmission system. In their study, two objective functions have been tested in finding the optimal sizing of the SVC, which are installation cost minimization and maintenance cost minimization. Ghiasi [22] evaluated the technical and economic of FACTS devices power quality performance considering the renewable energy generation. Two types of FACTS devices (STATCOM and SVC) are included in this study. It was found that by integrating the FACTS devices in the transmission system with renewable energy penetration together with his proposed mitigation scheme would be beneficial for power quality assurance and economic operation of transmission system for the long-term. In [23], voltage stability enhancement has been as the objective function in finding the optimal location and sizing of SVC in the transmission system with high penetration of wind energy. It was found that SVC is capable to enhance the stability of the voltage of the transmission system with the DWG variation. Ahmadinia and Sadeh [24] proposed a modified wide-area backup protection scheme for shunt-compensated transmission line. In this paper, SVC and STATCOM are used to compensate the reactive power loss due the faults in the transmission lines. There are several fault types were tested in this study such as single-line-to-ground fault, phase-to-phase fault and double line-to-ground-fault. From the review, it is discovered that the installation of SVC in power system highlighted its merit in terms of minimizing the total transmission losses, along with reducing the monetary effect to the utility.

This paper presents the application of multi-heuristic techniques for optimizing the sizing and locations of the SVC installation. Two optimization techniques are applied in this study; namely the evolutionary programming (EP) and artificial immune system (AIS) for the purpose of optimal determination of locations and sizing of SVCs. Several cases are considered, based on number of units for the installation process; solved under different loading conditions subjected to the system. Based on the comparative studies conducted to the system, it is revealed that both the EP and AIS are comparable to achieve the optimal solution in loss minimization scheme.

2. Materials and method

Loss minimization scheme is a popular remedial action in power system planning and operation. This is due to the fact that, the increase of loss resulted due to the increase in current that flows in the system can be due to the decay of voltage at the receiving end of a transmission line. Transmission loss can be translated to monetary loss as not all electricity is delivered to the consumer. To alleviate the comparatively substantial voltage decay in a system, compensation scheme can be performed to the system. In this study, the installation of static VAR compensation (SVC) is of the interest. Installation of SVC requires a reliable and robust optimization technique. In this case, EP and AIS would be the possible technique to achieve the solutions. We may have choices either to set known location, known sizing or both are unknown which require optimization process. The conceptual model for the optimization process, involving the utility data, optimizer (EP and AIS) and control centre unit is illustrated in Figure 2.

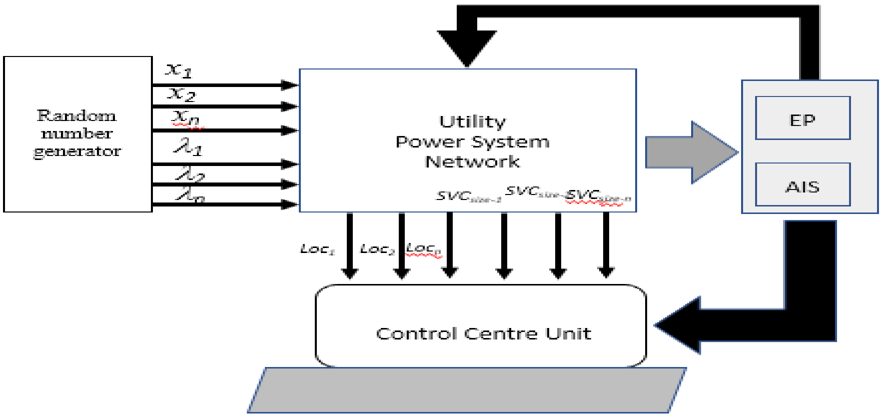

Figure 2: Conceptual model for optimization scheme in loss control in power system

From Figure 2, a data source or a random generator is one of the important components in the conceptual model. The random number generator will generate the random numbers within the specified control variables. This generator will generate the necessary individuals, which will be fed to the utility power system network. In this case, the random number will represent the locations and sizing of the SVC as the compensation device. These variables are symbolized by x_1, x_2, x_3,… x_n and $\square_1$, $\square_2$, … $\square_n$. The system data from the utility power system network will be utilized by the optimizers (i.e. the EP and AIS) for the optimization process. Results from the optimizer will be useful for the control centre unit. The original system data on the utility power system network will also be fed to the control centre unit for the purpose of system data monitoring.

A. Problem Formulation

In this study, loss minimization has been identified as the problem formulation which will be addressed by the SVC installation scheme. The control parameters will subject to several constraint equations.

The inequality constraint on voltage of each bus is given by:

$$|Vi|\min \leq Vi \leq |Vi|\max \tag{1}$$

Inequality constraints for the sizing of SVC is subject to the following equation: -

$$Q_{SVC,min} \leq Q_{SVC} \leq Q_{SVC,max} \tag{2}$$

Thus, the objective function for this study, in terms of loss is given by: -

$$\min f = \sum_{i=1}^{a} P_i \tag{3}$$

where

i = location transmission line

P_i = Power loss at transmission line i

a = total line number

B. Evolutionary Programming

The mechanics of Evolutionary Programming can be translated to several steps; which are the initialization, fitness calculation, mutation, combination and tournament. The detail of the process is given in the steps below: -

Step 1: Initialization Process - EP begins by generating the initial population x_{1i}^1, x_{2i}^2,…. x_{ni}^k; where k is the number of control variables, while a is the number if individuals. It depends on the number of SVCs to be installed in this study. It also depends on the number of SVC units to be installed into the system, subject to either known location or unknown location. It is generated using a uniformly distributed random number generation. Where x_1, x_2,…, x_n. are the individual numbers. Normally, the number of individuals is 20 for EP. In general, in MATLAB programming, the rand function generates random numbers whose elements are uniformly distributed in the interval (0, 1). The random numbers represent the value of x_i as the variable which control the optimization process.

$$x_i^{\alpha} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1k} \\ x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \cdots & \cdots & \vdots \\ x_{\alpha 1} & x_{\alpha 2} & \cdots & x_{\alpha k} \end{bmatrix} \quad (4)$$

$\alpha =$ Total number of individual
$k =$ Total variable

Step 2: Fitness Computation - Fitness computation is a process to compute the values from which the function is to be optimized. The objective function can be either to minimize or maximize the fitness value. In this study, the transmission loss in power system is the chosen fitness function. It is very much related to power balanced equation which also explains the conventional power flow equation.

The conventional power flow equation is as follows:

$$\left.\begin{aligned} P_i &= V_i \sum_{j\in i} V_j\left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) \\ Q_i &= V_i \sum_{j\in i} V_j\left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) \end{aligned}\right\}(i = 1, 2, \cdots, n) \quad (5)$$

Step 3: Mutation process: Mutation is a process to breed offspring. The deviation of the individual control variable will be controlled by mutation process. A new population is formed by performing mutation process. Several mutation operators can be used, such as gaussian mutation technique, levy mutation technique or Cauchy mutation techniques. These techniques are not unique to a general problem, rather depending on the nature of the problems to be solved. The mutation techniques also able to search for the optimal solution, searching through hill and valley. Mutation is the only variation operator used for generating the offspring (x_{mi}') from each individual. The fitness of the offspring is calculated using the same objective function and represent as y'.

$$X_{i+m,j} = X_{i,j} + (0, B(X_{jmax} - X_{jmin})(\frac{f_r}{fmax}) \quad (6)$$

Where
$X_{i+m,j}$= mutate parent
$X_{i,j}$=parents
β = range of mutation; 0<β<1
X_{jmax}=maximum random number for every variable
X_{jmin}=minimum random number for every variable
f_r=fitness for r^{th} random number
f_{max}= maximum fitness

N(0,1) denotes a normally distributed one-dimensional random number with mean 0 and 1. $N_j(0,1)$ indicates that the individuals will be new for each value of j.

Step 4: Combination and Selection Process - In this process, the offspring population with the corresponding fitness value resulted from the mutation process are combined with the parent's population to undergo the selection process. Selection process is responsible for the production of new individuals to undergo the next cycle of iteration; which eventually making the fitness reaching the optimal solution.

Step 5: Convergence Test - Mutation process for the first iteration utilizes all the individuals generated during initialization. On the other hand, mutation process for the second iteration onwards will make use the individuals prescribed during tournament and solution from the previous iteration. The coefficient being set as the convergence criterion depends on the level of accuracy desired by the optimization process. Depending on the case of optimization, the coefficient can be set higher or vice versa. It also depends on the search space during optimization, which also helps in determining the accuracy of the optimization process.

$$\Gamma_i = \left[x_{ik}^{\alpha} \;\; \vdots \;\; \psi_{ik} \right] \tag{7}$$

where: -

i	:	No of individuals
ψ	:	Fitness value
k	:	No of control variable

$$\Gamma_n = \left[x_{nk}^{\alpha} \;\; \vdots \;\; \psi_{nk} \right] \tag{8}$$

$$\Gamma_{combine} = \left[\frac{\Gamma_i}{\Gamma_n} \right] \tag{9}$$

$$= \begin{bmatrix} x_{ik}^{\alpha} & \vdots & \psi_{ik} \\ \cdots & & \cdots \\ x_{nk}^{\alpha} & \vdots & \psi_{nk} \end{bmatrix} \tag{10}$$

Matrix size = 2α by $(k+1)$

$$\text{maximum}_{\text{ fitness}} - \text{minimum}_{\text{ fitness}} \leq 0.0001 \tag{11}$$

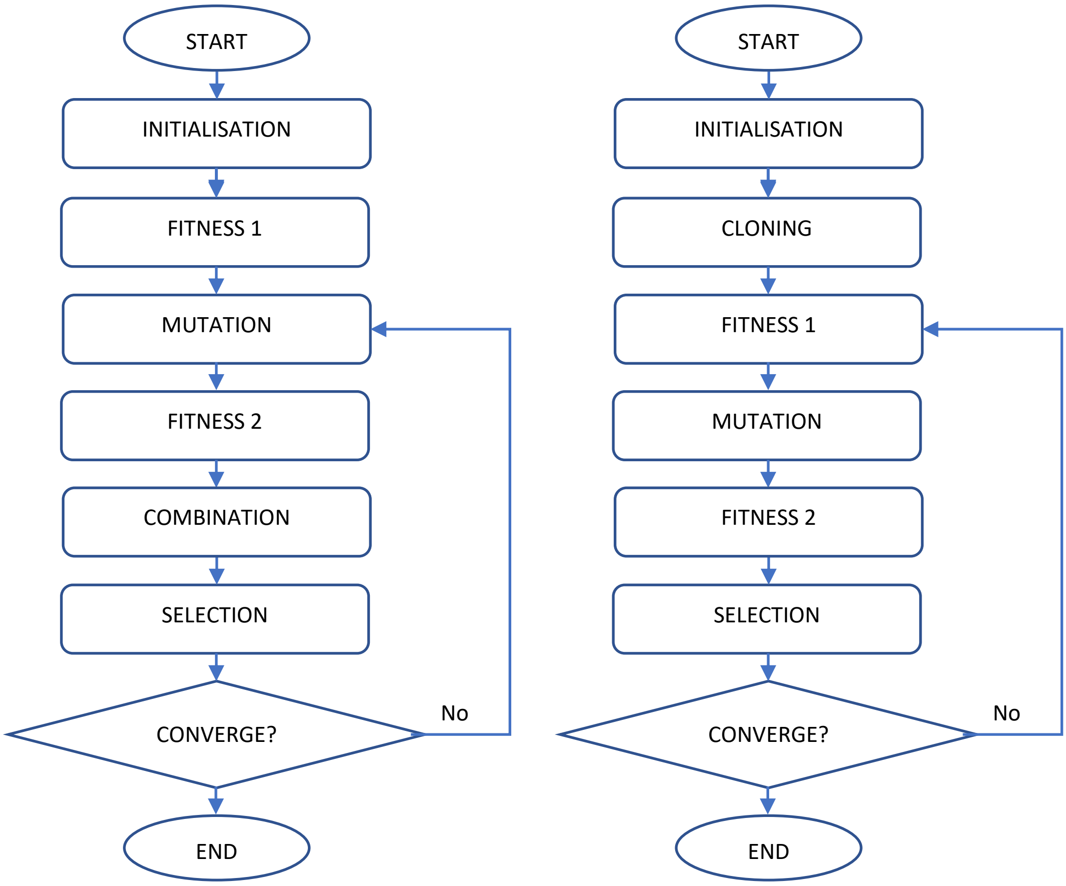

Figure 3: Flowchart of Evolutionary Programming (EP)

Figure 4: Flowchart of Artificial Immune System (AIS)

C. Artificial Immune System

The application of Static VAR Compensator (SVC) for power loss minimization starts by identifying the total power loss in the system. The power loss is determined by solving the load flow of the test system. The IEEE 30-Bus reliability test system (RTS) is used in this study. From the load flow solution, the number of SVC to be installed can be decided. Subsequently, the amount of reactive power to be injected and drawn can be obtained by using AIS optimization technique. The processes of AIS are as shown in Figure 4.

The steps of finding the optimal sizing and location of the SVCs can be determined by AIS are as follows:

Step 1: Randomize the location of the SVC and the size of reactive power injected or drawn is used in computing the fitness value of system loss.

Step 2: Compute fitness value of system loss using equation (6) with the load flow solution of the 30-Bus system.

Step 3: The best twenty individuals that give the best values of system loss then undergo cloning process to generate their clones. They are cloned by ten to become two hundred individuals.

Step 4: The cloned individuals then mutated using Gaussian mutation approach to produce new generation. This Gaussian mutation equation is as shown in (7).

Step 5: The mutated individuals are again evaluated by computing the fitness value of system loss.

Step 6: From the fitness 2 values, the best twenty individuals are selected from ranking process where the individuals are sorted ascendingly based on the value of system loss produced by the new generation.

Step 7: The processes will be repeating until the algorithm converge. It can only converge when the difference between the first and the twentieth fitness values of the best twenty is 0.0001.

3. Results and discussion

This section describes the results and discussion of the study, where the applied optimization techniques; EP and AIS were implemented in the IEEE 30-Bus RTS.

A. Test System

In this study, the IEEE-30 bus reliability test system (RTS) is taken as the test specimen for the study. It represents a simple approximation of the American Electric Power system as it was in December 1961 [23]. It comprises of complete set of data specification for each of the bus for 30 buses such as the bus code, voltage magnitude, load, generator and injected MVar. In addition, it also consists of resistance, R and reactance, X in per unit reactance from one bus to other buses. This system has 30 buses, with 6 generator buses and 41 transmission lines. The single line diagram is given in Figure 5.

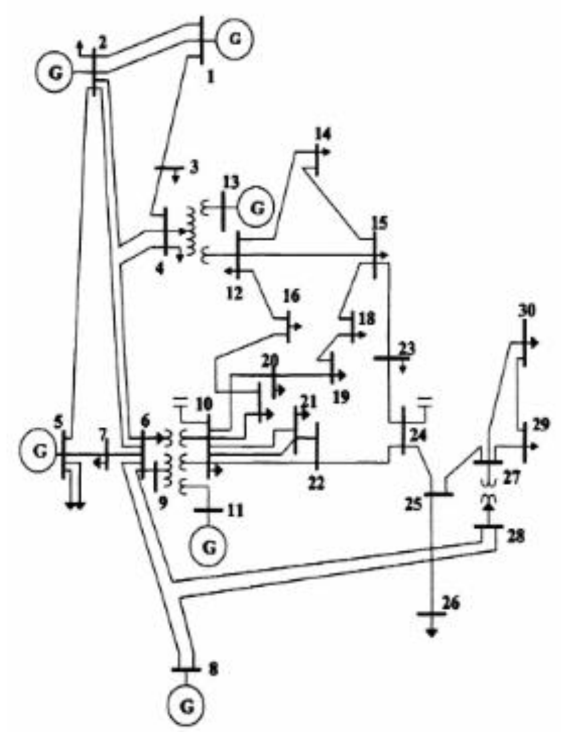

Figure 5: Single line diagram for IEEE 30-Bus Reliability Test System (RTS)

B. Implementation Scope

Table 1 tabulates the implementation scope for SVC installation. There are three cases introduced to study the performance of the proposed method in finding the optimal location and sizing of SVCs in the IEEE 30-Bus RTS with the objective function of total system loss minimization.

Table 1: Implementation Scope

	Installation Schemes	Evolutionary Programming (EP)		Artificial Immune System (AIS)		No of Control Variables
Case 1	Single SVC installation	Loc_1	$Sizing_1$	Loc_1	$Sizing_1$	2
Case 2	2 SVCs installation	Loc_1, Loc_2	$Sizing_1$ $Sizing_2$	Loc_1, Loc_2	$Sizing_1$, $Sizing_2$	4
Case 3	3 SVCs installation	Loc_1, Loc_2, Loc_3	$Sizing_1$, $Sizing_2$, $Sizing_3$	Loc_1, Loc_2, Loc_3	$Sizing_1$, $Sizing_2$, $Sizing_3$	6

C. Case 1: Single SVC Installation

Figure 6, 7 and 8 shows the random individuals for the sizing, location and initial fitness values respectively. All the values are taken during the initialization process. Apparently, 2 variables are responsible for the compensating process in the attempt to minimize total transmission loss in the system. In Figure 6, 20 individuals were originally generated to represent random sizing for the SVC, ranging from the minimum bound to the maximum bound. The distribution on random numbers in Figure 7 represent the random locations, with 20 individuals initially generated. The random location for each individual correlate to each SVC sizing and fitness value in Figure 8. Apparently, random location and sizing correlate to the computed fitness in the first case. These random numbers have been tested for the violation test such that all the generated individuals, also termed as parents will make sure that the losses resulted from these parents are lower than the one set in the normal ac load flow where SVC has not been installed into the system. The randomness appeared in these three figures (Figs. 6, 7 and 8) will reach to an optimal solution ultimately.

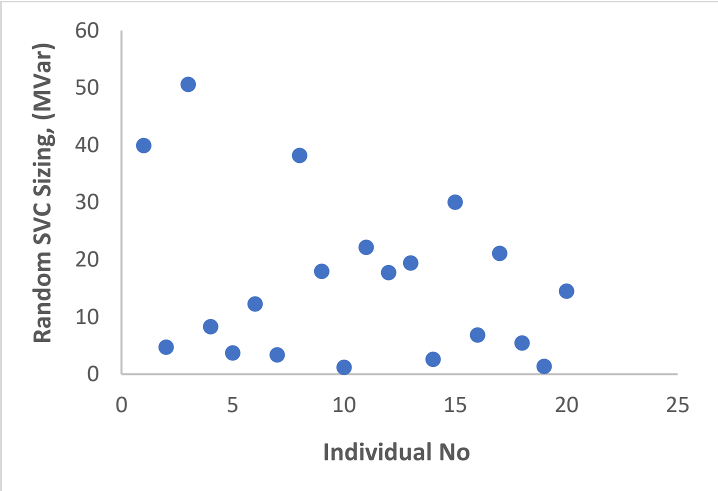

Figure 6: Random individuals for single SVC sizing in MVAR during Initialization

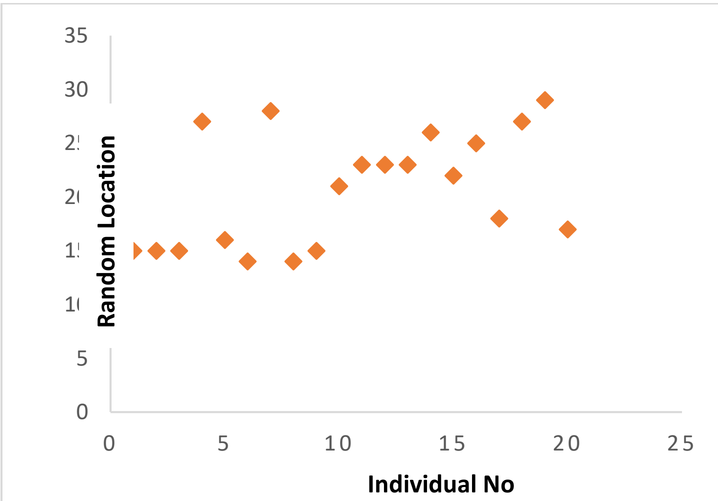

Figure 7: Random individuals for location in single SVC installation during Initialization

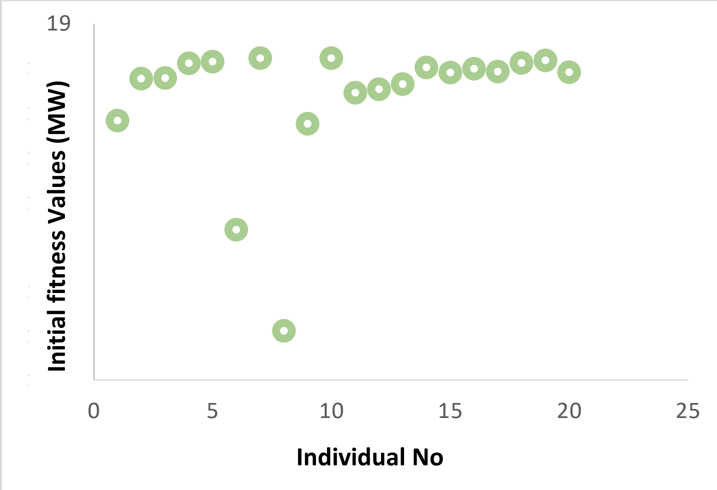

Figure 8: Fitness values in Watts for single SVC installation during Initialization process

Table 2 tabulates the optimization results of single SVC installation in the attempt to minimize the total transmission loss in the system. Apparently, the performance of EP and AIS is comparable in terms of achieving optimal solution. The optimal location of the SVC is at Bus 15 with the sizing of 26.33MVar. This produces the total system loss of 18.86MW. This loss is much better than the loss before the optimization process.

Table 2: Single SVC Installation

	Sizing	Location	P_{loss} (MW)
Before OPT			18.86
EP	26.33	15.00	18.46
AIS	26.33	15.00	18.46

D. Case 2: 2 Units of SVCs Installation

Figures 9, 10 and 11 present the random individuals for the sizing, location and initial fitness values respectively for 2 SVCs installation scheme. In this case, 4 control variables have been initially generated with population size of 20 by 4. This means that 20 individuals were initially generated; in which 2 variables represent the random locations; while the other 2 variables represent the random sizing of SVCs. Apparently, the four control variables are responsible for the compensating process in the attempt to minimize total transmission loss in the system. The distribution on random numbers in Figure 9 represent the random locations, with 20 individuals initially generated. The random location for each individual correlate to each SVC sizing and fitness value in Figure 10. Apparently, the random location and sizing correlate to the computed fitness in the second case. These random numbers have been tested for the violation test such that all the generated individuals, also termed as parents will make sure that the losses resulted from these parents are lower than the one set in the normal ac load flow where SVC has not been installed into the system. The randomness appeared in these three figures (Figs. 9, 10 and 11) will reach to an optimal solution once the solution gets converged.

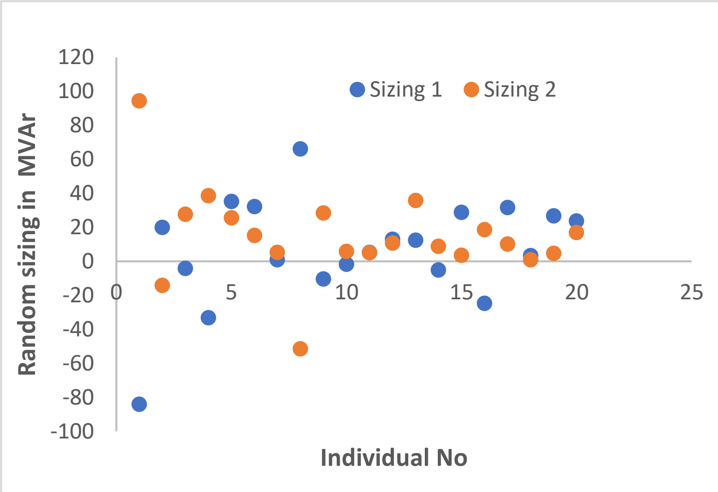

Figure 9: Random individuals sizing in MVAR for 2 SVCs installation during Initialization

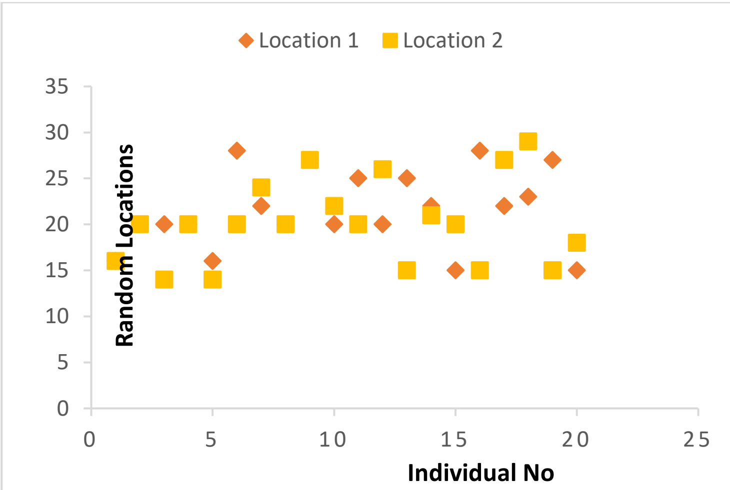

Figure 10: Random individuals for location in 2 SVCs installation during Initialization

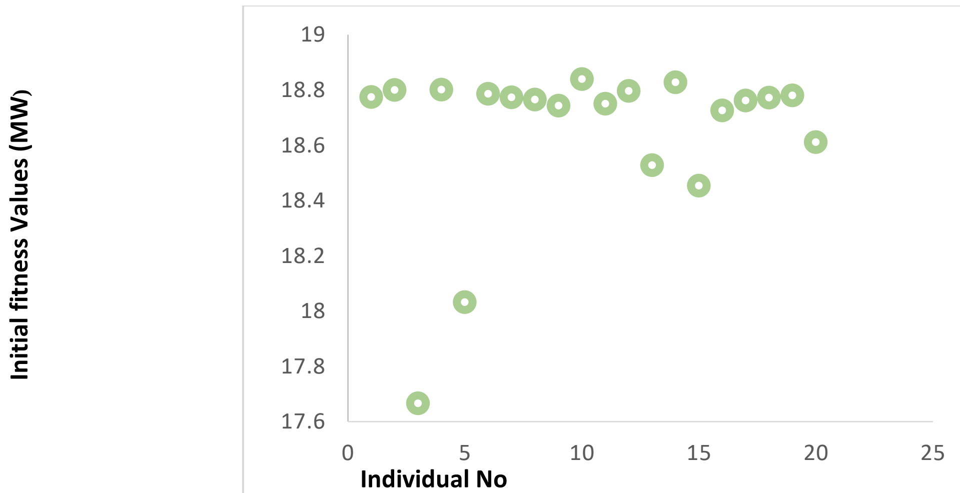

Figure 11: Fitness values in Watts for 2 SVCs installation during Initialization process

Table 3 shows the optimization results of 2 units of SVC installation. EP and AIS perform equally well and comparable in minimizing the total transmission loss in the system. The optimal location of the SVC is at Bus 20 and Bus 14 with the corresponding sizing of 4.04 MVar (injecting) and 27.81MVar (absorbing) respectively. This produces the total system loss of 17.67MW. However, the installation of two SVCs, with optimal locations and sizing managed to reduce the total transmission loss using both techniques.

Table 3: 2 Units of SVCs Installation

	Sizing		Locations		P_{loss} (MW)
Before OPT					18.86
EP	-4.04	27.81	20.00	14.00	17.67
AIS	-4.04	27.81	20.00	14.00	17.67

E. Case 3: 3 Units of SVCs Installation

The results for the installation of 3 SVCs, i.e. Case 3 are presented in Figures 12, 13 and 14; which correspond to the random individuals for the sizing, location and initial fitness values. In this case, 6 control variables have been initially generated with population size of 20 by 6. This means that 20 individuals were initially generated; in which 3 variables represent the random locations; while the other 3 variables represent the random sizing of SVCs. Apparently, the four control variables are responsible for the compensating process in the attempt to minimize the total transmission loss in the system. The distribution on random numbers in Figure 12 represent the random locations, with 20 individuals initially generated. The random location for each individual correlate to each SVC sizing and fitness value in Figure 13. Apparently, the random location and sizing correlate to the computed fitness in the third case. These random numbers have been tested for the violation test such that all the generated individuals, also termed as parents will make sure that the losses resulted from these parents are lower than the one set in the normal ac load flow where SVC has not been installed into the system. The randomness appeared in these three figures will reach to an optimal solution once the solution gets converged.

Figure 12: Random individuals for 3 SVCs sizing in MVAR during Initialization

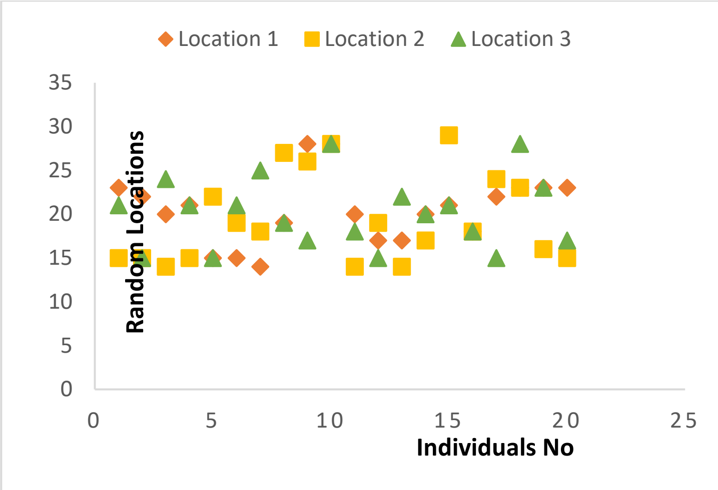

Figure 13: Random individuals for location in 3 SVCs installation during

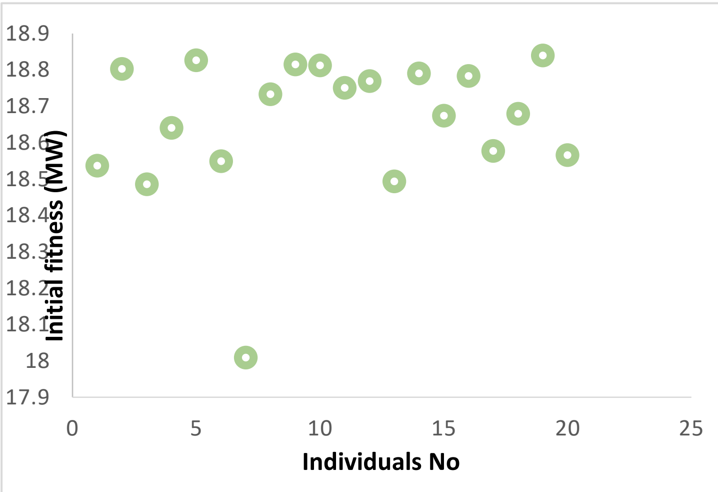

Figure 14: Fitness values in Watts for 3 SVCs installation during Initialization process

Table 4 shows the optimization results of 3 units of SVC installation. It can be observed from the table that EP and AIS identical. The optimal locations for are SVC Buse 14, Bus 17 and Bus 25 with the corresponding sizing of 41.56MVar (absorbing), 12.67MVar (injecting) and 16.48MVar (absorbing). This produces the total system loss of 17.86MW. This shows a much better value than the loss before the optimization process and single SVC installation but slightly higher than 3 units SVC installation by 1.1%.

Table 4: 3 Units of SVCs Installation

		Sizing			Location		Ploss MW
Before OPT							18.86
EP	41.56	-12.67	16.48	14.00	17.00	25.00	17.86
AIS	41.56	-12.67	16.48	14.00	17.00	25.00	17.86

4. Conclusion

This paper has presented multi-heuristic-based technique in multi-SVCs installation scheme for loss control in transmission system. In this study, the implementation of EP and AIS for solving SVC installation has been conducted in the attempt to manage the loss in power system. Optimization engines for both EP and AIS being developed to address has been implemented in the IEEE 30-Bus RTS. From the results, it shows that EP and AIS are comparable. However, EP and AIS managed to provide better solution of SVC installation in terms of low total system loss compared to the pre-optimized solution. It is also observed that the IEEE 30-Bus RTS is suitable to be installed with maximum of two SVC units. Further exploration can be conducted in the attempt to solve more complicated optimization problems with higher control parameters in either the single objective or multi-objective modes. The results could be beneficial to power system operators and planners in the utility.

5. Acknowledgement

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