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Optimization of SVC Placement and Capacity in the Electric Power System Transmission Networks using Multi-Objective Improved Sine Cosine Algorithm

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***Abstract*-Current technological developments are in line with the increasing consumption of electrical energy. There is a value of power losses of the electricity transmission process caused by an increase in the value of power losses, to overcome this, SVC (Static VAR Compensator) of the Flexible AC Transmission System (FACTS) can be used. From previous studies, the optimization of SVC placement in the transmission network has not been carried out to get better power losses. This research uses the Improved-Sine Cosine Algorithm (ISCA) that has a different function of r1 compared to the ordinary SCA, in which the use of the ISCA method is able to overcome the weaknesses of the SCA method. The determination of location and capacity can use more than one objective function. From the result, the optimization of SVC placement and capacity is able to reduce the value of power losses by up to 85%.**

***Keywords*—. FACTS, ISCA, Multi-objective, Optimization, Power losses, Reactive power, SVC, Transmission net, Voltage profile.**

I. Introduction

Current technological developments are in line with the increasing consumption of electrical energy. With the increasing demand for electricity, the value of the power generated must also increase, in which the increase in generating power has a bad impact on the electric power system. An increase in reactive power in the electrical system can cause an increase in the value of power loss in an electrical system which can result in worsening the value of the voltage profile. Increasing reactive power will also increase the current value. This causes an increase in line temperature and power losses. It results in a decrease in the value of the bus voltage [10]. For this reason, a reactive power compensator device is needed in the electrical system.

A flexible AC Transmission System (FACTS) device is a power compensator equipment that can work to deal with the problem of high power loss values in the transmission network [1][2]. Based on the type of connection, FACTS devices are divided into three types: series, parallel, and mixed series-parallel. The use of parallel-connected FACTS devices can reduce the value of power losses and improve the voltage profile so that it conforms to the specified standard [9]. Therefore, in the work of this paper, the FACTS devices can be used with parallel-connected types, namely SVC and STATCOM (Static Compensator). Both of those have a role as a regulator of reactive power by absorbing or injecting reactive power in an electricity transmission net [1][4]. However, in this paper, SVC is chosen because both have the same task and function, yet SVC has a lower initial investment value [10][11]. Previously. There has been researching on the optimization of SVC capacity to reduce the value of power loss. However, improvements can still be made by optimizing the position of the SVC used.

There are two methods to optimize the placement and capacity of SVC in an electrical system, namely conventional and artificial intelligence. However, the use of conventional methods is decreasing because of the length of time required to perform calculations and the relatively low level of accuracy [12]. Hence, it is better to use artificial intelligence methods. One of the methods that can be used is SCA (*Sine Cosine Algorithm*).

SCA is an algorithm based on a mathematical model of the *sin* and *cos* functions. However, even though SCA has a high-efficiency value, it turns out that the SCA method has problems. In some cases, the algorithm's ability to get out of the local optima value is weakened. [13]. Therefore, improvements can be made to the SCA for the optimization of the placement and capacity of the SVC. Moreover, it can also use the development

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of the algorithm, namely ISCA (Improved-Sine Cosine Algorithm). Because in its application, ISCA can also be used in real-world problems, such as setting adaptive fuzzy logic for frequency control in automatic power generation systems.

II. Literature Review

Static VAR Compensator (SVC) is one of the FACTS devices that has a function as a reactive power regulator in an electric power system, with a parallel circuit type [1][4]. By installing SVC on a transmission line, it can reduce the value of power losses and improve the voltage profile.

SVC also has several types of parameters that need to be set for each value. These parameters include the value of voltage, impedance, and phase angle. The determined value is based on a power flow study and aims to get the best power compensation value according to system requirements. The role played by SVC in changing the value of the voltage profile is by adjusting the reactive power value on the bus, whether by injection or by absorbing reactive power from the power flow system on the bus [1][4]. To perform the injection or absorption action, SVC has several main components, including Fixed Capacitors (FC) which will be connected in parallel with Thyristor Switch Capacitors (TSC) and Thyristor Controlled Reactor (TCR). The application in the form of setting the firing angle of the thyristor [14] will later be seen as a regulator of the SVC reactive power output.

A. SVC work area [14][15]

There are three working areas of SVC which can be depicted on the voltage versus reactive power curve. The curve can be described as follows

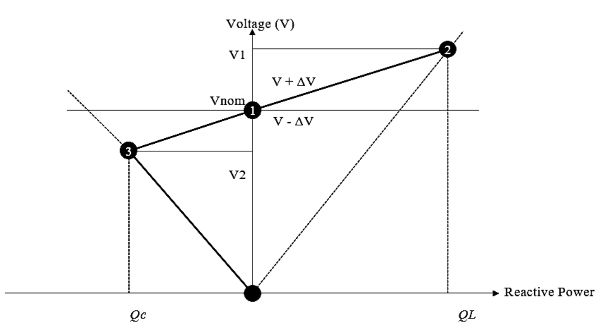

Figure.1 Reactive Power and Voltage Curves at SVC

- **Working zone 1** is located between V1 and V2. In this area, the nature of SVC is flexible, which means it can be capacitive or inductive. Afterward, the reactive power generated will follow or adjust to system needs.
- **Working zone 2** will occur if there is a condition where the bus voltage exceeds the value of V1. Hence, in the work zone 2 areas, SVC will only have Inductive properties and absorb reactive power.
- **Working zone 3** will occur if there is a condition where the bus voltage is less than V2. Under these conditions, the SVC will act as a fixed capacitor that will provide reactive power injection.

B. SVC modeling on power flow [7]

SVC, as already explained, is a FACTS device that is installed in a parallel configuration on the bus. Afterward, the installation of SVC must be conducted on the load bus. This is because if it is installed on the generator bus, the value of the reduced power loss due to reactive power compensation will increase again. This is also because of the distance factor from the transmission network. Hence, the SVC installation is conducted on the load bus so that the power can be immediately used by the load without experiencing high losses. The following is a form of modeling the placement of SVC on a two-bus transmission line.

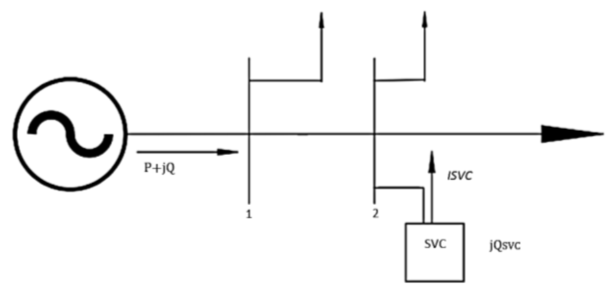

Figure.2 SVC Modeling on Power Flow

After the SVC installation is done, as shown in Fig. 2, then the value of the current flowing on the i bus (which contains SVC) can be calculated using the following general equation.

$$I_i = Y_{ii}V_i + \sum_{k=1}^{n} Y_{ik}V_k + B_{SVC}V_i \quad ; k \neq i \qquad (1)$$

The power flow equation can be written as follows.

$$\frac{P_I - jQ_i}{V_i^*} = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \qquad (2)$$

Hence, if the current value in Eq. (1) is substituted into Eq. (2), it will get the power flow equation as follows.

$$\frac{P_i - jQ_j}{V_i^*} = (Y_{ii}V_i + \sum_{k=1}^{n} Y_{ik}V_k + B_{SVC}V_i); k \neq 1 \quad (3)$$

The value of the voltage after the use of the new SVC can be determined after the value of the power flow has been determined by Eq. (3). The voltage equation after the use of SVC can be written as follows.

$$V_i = \frac{1}{Y_{ii}} \left(\frac{P_i - jQ_i}{V_i^*} + \sum_{k=1}^{n} Y_{ik}V_k \right); k \neq i \qquad (4)$$

C. Improved Sine Cosine Algorithm (ISCA)

Sine Cosine Algorithm (SCA) is an optimization method based on a stochastic population that uses a mathematical model of the *sin* and *cos* functions that can solve multi-dimensional problems. The process will be conducted in several iteration stages. The iteration stage will only stop if the system has reached the maximum iteration value and finds the optimum solution value [16].

In the process of finding the best solution candidate value in each iteration, it is done using the equations sin and cos. The following are the equations used in the SCA algorithm.

$$X_i^{t+1} = \begin{cases} X_i^t + r_1 \times \sin(r_2) \times \left|r_3 p_i^t - x_i^t\right|, & r_4 < 0.5 \\ X_i^t + r_1 \times \cos(r_2) \times \left|r_3 p_i^t - x_i^t\right|, & r_4 \geq 0.5 \end{cases} \tag{5}$$

In the SCA or ISCA method, the possibility of finding the optimum value occurs in the exploration phase. Afterward, in the exploitation phase, the algorithm will gradually reduce the value of the candidate solution until the optimum solution value is found [16]. The value of the parameter r_1 in ISCA has a different type of transition from the usual SCA method. In the ISCA method, the value of the parameter r_1 will decrease non-linearly. This happens because, in this paper, the optimization problem is included in the non-linear optimization type. In the exploration phase, the possibility of memory to store the search results is more and able to reduce the possibility of optima local solution results [13]. The following is the equation for the parameter value $r_1$in the ISCA method.

$$r_1 = a \times sin\left(\left(1 - \frac{t}{T}\right) \times \frac{\pi}{2}\right) + b \tag{6}$$

To represent SCA or ISCA, the following image can be used.

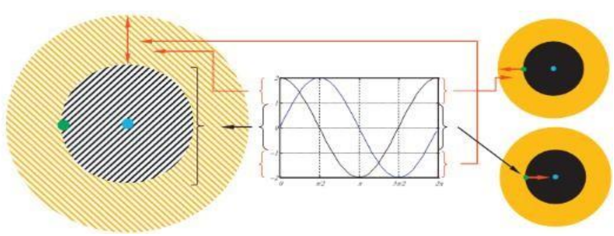

Figure.3 Representation of SCA / ISCA

III. Design Concept

In this paper, ISCA will be applied to two different electrical systems, namely the IEEE 6-bus system, and the IEEE 30-bus system. Each system will take two types of data, namely generation data, and interconnection channel data.

To perform the optimization process of determining the location and capacity of the SVC in this Paper, there are several steps that must be passed, namely as follows.

1) Obtaining the required electrical system data
2) Performing power flow analysis modeling prior to the optimization process
3) Initializing ISCA parameters (Maximum number of iterations, candidate solutions, serial number of non-generator buses, and number of devices to be used)
4) Performing power flow simulation using a pre-designed algorithm
5) Evaluating each candidate the best (temporary) solution based on a multi-objective function and defined constraints
6) Updating the value of r_1 to determine the direction of movement of the best (temporary) solution candidate and also the values of 2, 3, and 4 because they are still related to the position of the candidate solution
7) Fixing the position of the solution candidate using the jacobian equation
8) The algorithm will stop iterating when it reaches the maximum number of iterations that have been determined

In the entire conducted design process, there are several things that must be considered, such as the multi-objective function used, the limits applied, and the standards used.

IV. Result and Discussion

After simulating the power flow prior to the placement of the SVC, the data on the value of the power loss, and the location of the load (a bus allowed for SVC installation) has been obtained.

Table 1. Power Loss Data and Load Bus List

System	IEEE 6-Bus	IEEE 30-Bus
Load Bus	4, 5, and 6	3, 4, 6, 7, 9, 10, 12, 14 - 30
Total Power Loss	3.303 MW	19.434 MW

Furthermore, several case studies have been conducted for each electrical system. The following results have been obtained.

A. IEEE 6-Bus

After conducting several case studies in the form of variations in the number of candidate solutions and variations in the use of the number of SVCs, it turns out that the algorithm is able to determine the best position of SVC with the lowest power loss value. The conditions of use 1, 2, or 3 SVC algorithm determines the placement of the device on the 4th bus. Hence, it is found that the variation of candidate solutions and the number of SVCs do not affect the value of power loss. However, the algorithm can still reduce the value of power loss up to 85.92%. The following is an image of the ISCA convergence curve when performing the optimization process.

Changes in value on the Y-axis only occur until the 3rd iteration. It indicates that the algorithm has been able to find the optimum solution since the 3rd one. The value does not change until the 100th iteration or the last iteration. The decrease in the value of the power loss also affects the value of the voltage profile. Hence, each bus experiences an improvement in the voltage level. Fig. 4 shows the comparison of the voltage profile values of each bus between before and after the use of SVC. Where the green line indicated the condition without SVC, while the Blue line indicated the condition with SVC.

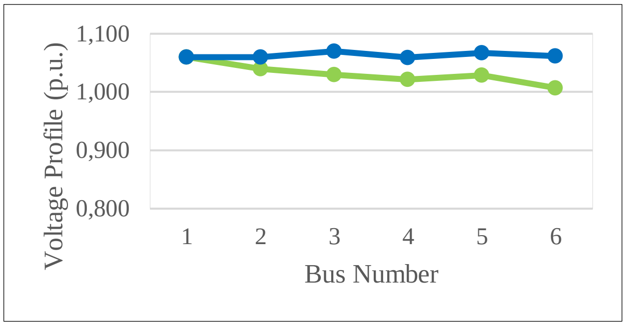

Figure.4 Comparison of IEEE 6-Bus system bus voltage values

It can be seen that decreasing the value of power losses can cause an effect on the value of the voltage profile. If the power losses have a large value, then it can be caused by heat in the line. The generation of heat in the line is a result of the high value of the current caused by the low value of the voltage. However, in the IEEE 6-bus system, the voltage profile value from the beginning does not experience problems. Hence, the use of SVC will have more impact on the decrease in the value of the power loss. The SVC takes reactive power absorption so that it reduces the current value, which will reduce the power loss value. Although the decrease in the value of the power loss still affects the voltage profile, in this condition, the effect on the value of the voltage profile is not too significant.

B. IEEE 30-Bus

After conducting several case studies in the form of variations in the number of candidate solutions, variations in the use of the number of SVCs, and variations in the value of loading with the specified parameter values, it turns out that the algorithm is still able to determine the best position of SVC with the lowest power loss value up to 89.57% lower than the initial power loss value with using 5 SVCs placed on buses 3, 20, and 22. However, it turns out that the position, the value of reactive power injection, and the value of power loss are not affected by the number of candidate solutions and the number of SVC usages. This can happen because the results obtained from this optimization method are stochastic.

However, the voltage profile values on some buses that are previously not good have improved due to the decrease in the value of the resulting power loss, whether it's under loading conditions 100%, 102%, up to 104%. The following is the ISCA convergence curve under 104% loading conditions.

A change in position on the Y-axis due to a change in the position of the best (temporary) solution candidate will affect the value of power loss. Meanwhile, changes in the X-axis indicate that the process of finding the optimum solution has been conducted since the first iteration and gets a convergent value before the last iteration.

It can be stated that each loading condition experienced a decrease in the value of the power loss. Fig. 5 shows the comparison of the value of the power loss in several loading conditions. In Fig. 5 the blue colour indicated the condition without SVC under 100% load, the green colour indicated with SVC under 100%. Moreover, the red and yellow colour indicated the condition of 102% load with and without SVC.

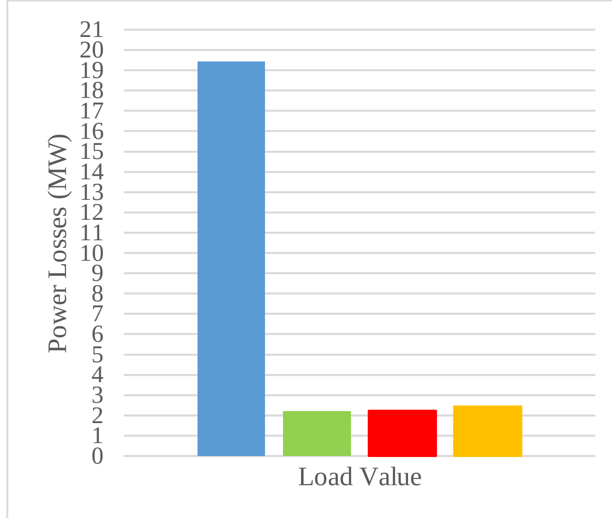

Figure.5 Comparison of Power Loss in Variation of Loading

It can be proven that the optimization of SVC placement and capacity using the ISCA method is able to provide an average power loss value of 88.57% even though under loading variations of 100%, 102%, and 104%. The same as before that the decrease in the value of the power loss also affects the value of the voltage profile. Therefore, ton some buses, there is an improvement in the voltage level. Fig. 6 shows the voltage profile values on several buses under various loading conditions. It should be noted that the red colour indicated the condition without SVC under 100% load, the blue colour indicated with SVC under 100%. Moreover, the black indicated the condition of 102% load with SVC, while the purple colour shows the condition of 104% load with SVC.

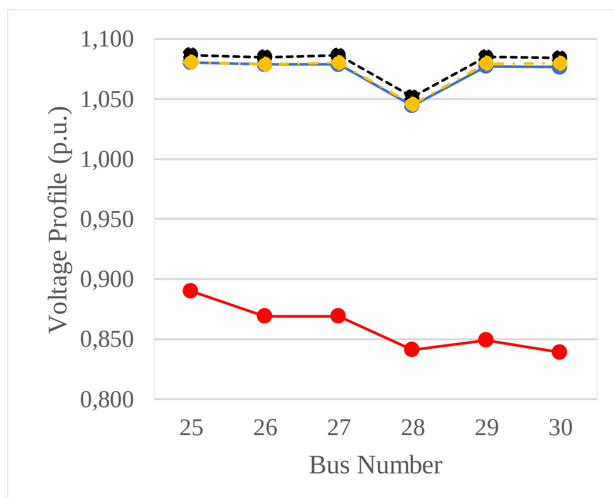

Figure.6 Comparison of Voltage Profiles in Variation of Loading

With the role played by SVC as a reactive power regulator on the line, the lowest power losses have been obtained of 2,026 MW. Thus, it causes an improvement in the value of the voltage profile on the bus. Fig. 6 is a graph of the comparison of the IEEE 30-bus voltage profile values with variations in the loading values between conditions before and after the use of SVC. With the simulation results, it can also be explained that

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even though the loading value is varied, the SVC is still able to compensate for the power on the line. Hence, the initial voltage profile value is below 0.9 p.u. It is increased to more than 1.0 p.u. The value has entered the standard IEEE voltage profile value.

V. Conclusion

Based on the simulation results and data analysis in the work of this Final Project, it can be concluded that the ISCA method is proven to be able to handle optimization problems that require more than one output simultaneously or are multi-objective. Thus, the use of SVC on the IEEE 6 and IEEE 30 bus systems is able to have an effect on reducing the power loss value by more than 85%, as well as can help improve the voltage profile value.

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