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Optimization Placement and Sizing of Static Synchronous Compensator

YULIANTA SIREGAR, YOGA WAHYU PAMBUDI, ZULKARNAEN PANE

Department of Electrical Engineering, Universitas Sumatera Utara
Email : julianta_srg@yahoo.co.id

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ABSTRAK

Pertumbuhan ekonomi di indonesia berbanding lurus dengan permintaan energi listrik di masyarakat yang terus meningkat. Dampaknya adalah sistem tenaga listrik akan menimbulkan berbagai masalah dalam penyaluran energi listrik, seperti drop tegangan diluar batas yang diijinkan, dan rugi rugi daya bertambah besar pada saluran. Salah satu solusi yang dapat dilaksankan untuk mengurangi masalah rugi-rugi daya pada saluran dan memperbaiki profil tegangan adalah menggunakan Flexible AC Transmission System (FACTS) devices. Penelitian ini melakukan analisis Static Synchronous Compensator (STATCOM) sebagai salah satu jenis FACTS yang akan diimplementasikan pada sistem tenaga listrik Sumatera Bagian Utara (SUMBAGUT) 150 kV tahun 2020 untuk memperbaruhi profil tegangan dan meminimalisir rugi daya dengan menggunakan metode optimasi Artificial Bee Colony Hasil simulasi diperoleh bahwa pemasangan satu buah STATCOM dapat memperbaiki profil tegangan sistem yang awalnya terdapat 18 bus diluar batas yang diijinkan S-PLN menjadi 5 bus. Selain itu, terjadi penurunan rugi daya aktif dari 131,40 MW menjadi 121,56 MW.

***Kata kunci**: ABC algorithm, STATCOM, SUMBAGUT, FACTS, rugi-rugi daya, profil tegangan*

ABSTRACT

Indonesia's economic growth is directly proportional to the increasing demand for electrical energy in society. The electric power system causes various electrical energy distribution problems, such as voltage drops outside the allowable limits, greater power losses on the line, and even unbalanced loads. One solution to the problem of power losses and improving the voltage profile is to use Flexible AC Transmission System (FACTS) devices. In this research, an analysis of Static Synchronous Compensator (STATCOM) is implemented in the 150 kV North Sumatera (SUMBAGUT) electric power system to improve the voltage profile and minimize power loss by using the Artificial Bee Colony optimization method (ABC) Algorithm. The simulation results show that installing one STATCOM can improve the system voltage profile. In addition, there was a decrease in active power loss from 131.40 MW to 121.56 MW.

***Keywords**: ABC algorithm, STATCOM, SUMBAGUT, FACTS, power losses, voltage profile.*

1. INTRODUCTION

Economic growth in Indonesia is directly proportional to the community's increasing demand for electrical energy. The impact is that the electric power system will operate excessively to fulfill it. It can cause various problems in the distribution of electrical energy, such as voltage drop outside the allowable limit, greater power losses on the line, and even unbalanced load, in this case, PT. The State Electricity Company (PLN) Persero, as a company providing electrical energy, must ensure the availability of electricity in good quality in accordance with Law No. 30 of 2009. The distribution of electrical energy must maintain the power and voltage not exceeding the operating threshold based on the PLN Standard in 1995, research conducted by PT. PLN **(PT. PLN, 1995)**.

Reactive power (Q) that does not match the system's needs has an impact on the performance of the transmission system. It will affect the amount of real power (S) used by the load and the amount of power factor that works on the transmission system. To overcome these problems, we need a tool that can control the reactive power compensator required by the system with high reliability. One of the compensator technologies in the transmission system is Flexible Alternating Current Transmission System (FACTS) devices. FACTS equipment has several capabilities, including increasing operating flexibility, electrical system stability, and utilizing the existing network, research conducted by Siregar **(Siregar, 2012)**.

The voltage profile of the electric power system is one of the problems that the electricity supply company considers. The distribution of electrical energy must keep the power and voltage not exceeding the operating threshold. Reactive power (Q) that does not match the system's needs has an impact on the performance of the transmission system. This, of course, will affect the amount of real power (S) used by the load and the amount of power factor that works on the transmission system. In 2010, research conducted by Mohammed **(Mohammed, 2016)** and his team, to overcome these problems, we need a tool that can control the reactive power compensator required by the system with high reliability. One of the compensator technologies in the transmission system is Flexible Alternating Current Transmission System (FACTS) devices. In 2010, research conducted by Veleba **(Veleba, 2013)** and his team, the FACTS equipment has several capabilities, including increasing operating flexibility, electrical system stability, and utilizing existing networks.

Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM) are the most used types of FACTS because they have advantages compared to other types of FACTS, SVC and STATCOM are the best equipment in terms of improving the voltage profile and increasing the transmission capability of the electric power system. In 2010, research conducted by Shukla **(Shukla, 2013)** and his team, examination on steady-state voltage stability completion by optimal location of Static Var Compensator (SVC) device with the lowest level losses. However, research conducted by Shaikh **(Shaikh, 2020)** and his team, the other types of FACTS, the other types of FACTS, The comprehensive enhancement in STATCOM controller involves diverse solid-state converter terminologies, manage algorithms, self-commuting processing, magnetic design etc. The most optimal STATCOM placement and capacity are needed to improve the electric power system.

In this paper, the optimization method used is the Artificial Bee Colony (ABC) Algorithm in determining the optimal location and capacity of STATCOM. This simple and flexible optimization method makes the optimization process results faster than other optimization methods. The purpose of this research is to produce a voltage profile according to S-PLN from the location placement and determination the optimal STATCOM capacity, and reduce power losses.

2. RESEARCH METHODS

This study uses data from PT. PLN (Persero) Load Control Service Unit (UP2B) North Sumatra (SUMBAGUT) such as secondary data, which includes bus generation data, load bus data, transmission line data, and single line diagram data. The data are slack bus, generator bus (PV), and load bus (PQ). The data obtained is simulated into the ABC algorithm programming language in Matlab software.

2.1 *Load Flow Analysis*

Today the development of technology is growing rapidly along with the times. One of them is in the field of reactive power compensator, namely STATCOM. In 2012, research conducted by Youjie **(Youjie, 2015)** and his team, Static synchronous compensator (STATCOM) has been widely used in art dynamic shunt compensators for managing reactive power in distribution and transmission. In 2007, research conducted by Omkar **(Omkar, 2017)** and his team, besides compensation, one more attribute of STATCOM is its use for improving system stability, which is achieved through implementing various control. Further, in 2017, research conducted by Qatamin **(Qatamin, 2017)** and his team, the STATCOM also compensates for several other problems such as impedance of the transmission system, flicker, and phase angle differences.

Reactive power control by STATCOM occurs by a ratio of the magnitude of the terminal voltage measure between STATCOM and the system. The STATCOM will absorb reactive power in the system if the STATCOM voltage is lower. In 2021, research conducted by Zakarni **(Zakarni, 2021)** and his team, If the value is more significant than the system, it will produce reactive power. The working principle of STATCOM is shown in Figure 1.

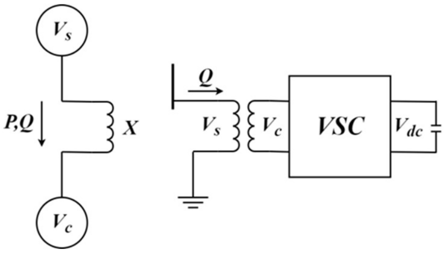

Figure 1. Working Principle of STATCOM

Equation (1-3) show the delivery of active power P and reactive power Q between system voltage Vs and STATCOM voltage Vc.

$$P = \frac{V_S V_C \sin}{X_L} \tag{1}$$

$$Q = \frac{V_S(V_S - V_C \cos\delta)}{X_L} \tag{2}$$

$$S = 3\frac{V_S V_C}{X_L}\sin\delta - j3(\frac{V_S V_C}{X_L}\cos\delta - \frac{V_S {V_C}^2}{X_L}) = P - jQ \tag{3}$$

The active power flow will reach its maximum when the phase angle δ is 90º. In practice, the power factor should be above 0.85 to 0.9 so that the power angle is small (about 25º). This is intended to keep the system stable from transients and dynamic oscillations. Therefore, the power angle directly affects the active power flow. In 2021, research conducted by Shaik **(Shaik, 2017)** and his team, this is contrast, changes in the voltage between buses affect the reactive power flow because cos δ approaches 1. Meanwhile, In 2021, research conducted by Aparna **(Aparna, 2016)** and his team, choosing the best location and size of the FACTS devices to benefit from improving voltage stability is a challenging task.

If there is no compensation, a typical transmission line is an inductive load where the current is lagging against the voltage. The system load line is depicted in figure 2. If the system load is more inductive, the current is left behind while Q is also getting bigger, meaning that it is increasingly absorbing reactive power. On the other hand, research conducted by Rostami **(Rostami, 2012)** and his team in 2012, if it is more capacitive, the current leads to the voltage V and supplies reactive power Q.

$$\Delta V = E - V = Z_s . I \tag{4}$$

The equation (5) defines the complex power of the load per phase.

$$I = \frac{P-jQ}{V} \tag{5}$$

V=V + j0 is taken as the reference phasor in Equation (6).

$$\Delta V = (R_s + jX_s)\left(\frac{P-jQ}{V}\right) + j\left(\frac{R_sP+X_sQ}{V}\right) - j\left(\frac{X_s-R_sQ}{V}\right) \tag{6}$$

$$\Delta V = \Delta VR \tag{7}$$

$$\frac{\Delta V}{V} = \frac{X_sQ}{X^2} \approx \frac{Q}{S} \tag{8}$$

$$V \approx \left(1 - \frac{Q}{S}\right) \tag{9}$$

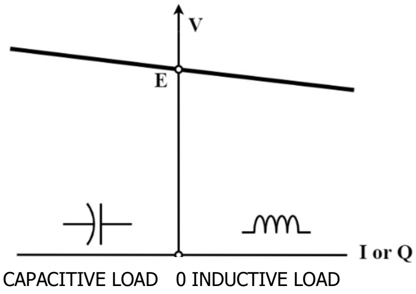

Figure 2. System Load Line

This means that changing the value of Q will affect the bus voltage. The higher the value of Q supplied, the higher the voltage V. Adding a compensating impedance or a compensator in parallel with the load makes it possible to keep |V| = |E|. In 2021, research conducted by Sengar **(Sengar, 2015)** and his team, the reactive power of the load is replaced by the sum of $QS = Q + Q\gamma$. Further, the reactive power of the compensator is set such that it rotates the phasor ΔV so that |V|.

$$|E|^2 = \left[V + \frac{R_sP+X_sQ_s}{V}\right]^2 + \left[\frac{X_sP+R_sQ_s}{V}\right]^2 \tag{10}$$

The power flow analysis calculation uses the Newton Raphson method, which aims to determine the buses with voltage profiles that are not following the SPLN standard and power losses in the initial conditions of the electrical system without using STATCOM. Then the Artificial Bee Colony (ABC) algorithm optimization method is used to determine the optimal placement location and capacity of STATCOM to improve the voltage profile and minimize power losses in the 150 kV SUMBAGUT electric power system. Meanwhile, this study limited the FACTS device to 80 MVar inductive and 200 MVar capacitive in the 150 kV SUMBAGUT transmission system. The number of STATCOM to be installed is one STATCOM.

2.2 Determination of Parameters ABC Algorithm

In the last decade, swarm intelligence has become a study interest by many researchers. Bonabeau has defined swarm intelligence as any experiment to design distributed problem-solving algorithms or equipment inspired by the common behavior of the social insect community and another animal colony. In 2021, research conducted by Alimuddin **(Alimuddin, 2018)** and his team, swarm is a general term that refers to a finite set of individual or agent interactions. One example of a swarm is a swarm of bees swarming their hive.

The minimal model of foraging selection, which leads to the emergence of the collective intelligence of honeybee swarms, consists of three important components: food sources, worker bees, and unemployed bees. In 2007, research conducted by Rahul **(Rahul, 2020)** and his team, the model defines the two most important modes of behavior, namely recruitment to nectar sources and source abandonment.

a. Food Source: The measure of a food source depends on many factors, such as proximity to the nest and the concentration energy of the food source. For easiness, the profitability of a food source can be represented by a single amount.

b. Employed Bees: They are associated with the specific food source they are utilizing or where they are employed. They also explain the location of the food source, the distance and direction from the nest, and the profitability of the food source and share this information with a characteristic profitability value.

c. Unemployed Bees: They are constantly looking for food sources to exploit. There are two types of unemployed bees: scout bees, which are tasked with searching the environment around the hive to find new food sources, and onlooker bees, which are tasked with waiting in the hive and obtaining food sources through information shared by worker bees. The average number of scout bees is equivalent to about 5% to 12% of the total bees. The replacement of information among bees is the most crucial event in forming mutual knowledge. When inspecting the whole hive, it is possible to discriminate some common parts in all packs. The essential part of the hive is related to information exchange in the area. Notification among bees regarding the quality of the food source occurs in the area. This bee dance is called the waggle dance.

In 2007, research conducted by Shaik **(Shaik, 2017)** and his team, it is necessary to represent the ABC algorithm parameters used in determining the optimal location and capacity of STATCOM. The representation of the ABC algorithm in the system can be seen in Table 1.

Table 1. Representation of ABC Algorithm as STATCOM Optimization

ABC Algorithm	STATCOM Optimization
Number of employed bees or food source position (SN)	Bus candidate as the position of STATCOM capacity to be installed
Dimension (D)	The number of STATCOM to be installed on the system.
Objective Function	min F = Ploss
Fitness	$\frac{1}{1+\text{Objective Function}}$

In the optimization process, the bee population will determine the bus candidate to be installed by STATCOM and the installed capacity of STATCOM to obtain a fitness value that represents the loss value in the transmission system. At the same time, research conducted by Shahgholian **(Shahgholian, 2017)** and his team, the dimensions of the ABC algorithm represent the number of STATCOM that will be installed in the electric power system.

The bee colony will spread out and then look for food sources randomly. After finding a new food source, the bees will calculate the nectar from each food source found. The bees will select and remember the calculation results from each food source found to obtain the best food source. The best result is the minimum active power loss among the many solutions generated. Aparna

The objective function reduces power losses in the system, as seen in Equation (11).

$$\sum P_{loss} = \sum_{k=1}^{nl} G_k\left[V_i^2 + V_j^2 - 2V_iV_j \cos\theta_{ij}\right] \tag{11}$$

In these equations, the following variables were used : nl Number of transmission lines, G_k Line conductance to k, V_i,V_j Voltage on bus i and j on line k, θ_ij the phase angle of the voltage on the buses i and j.

In the desired power system performance, it is necessary to pay attention to several inequalities that will affect the system, namely:

a. The voltage of each bus is limited according to the allowable range as Equation (12)

$$V_i^{min} \leq V_i \leq V_i^{max} \text{ for i=1,2,3,..,N} \tag{12}$$

In these equations, the following variables were used : i Number of bus, V^{min} 0.95 pu, V^{max} 1.05, N amount of bus.

b. Safe operation limits for generation, where the generator's reactive power supply must be in a predetermined range, as describe in Equation (13).

$$Q^{min} \leq Q_i \leq Q^{max} \text{ for i=1,2,3,..,N} \tag{13}$$

c. The allowable reactive power at STATCOM for compensating components as Equation (14).

$$0 \leq Q_{stcm} \leq 200\, MVar \text{ for 1-j, …, D} \tag{14}$$

d. The voltage and phase angle of the STATCOM component has shown in the Equation (15) and (16).

$$0.9\, pu \leq V_{stcm} \leq 1.05\, pu \tag{15}$$

$$-180° \leq \delta_{stcm} \leq 180° \tag{16}$$

2.3 Design Simulation

After simulating the MATLAB 2019b software, both Newton Raphson power flow analysis and the Artificial Bee Colony (ABC) Algorithm as the method used to optimize STATCOM placement and capacity. Further, the next step is to analyze the simulation results to be able to answer the problem formulation in this study:

a. Get the most optimal location and capacity placement from STATCOM.
b. Knowing the comparison of the voltage profile before and after the STATCOM was installed.

c. Knowing the comparison of power losses in the system before and after the STATCOM installation.

This optimization process can be shown in the ABC Algorithm implementation flowchart for STATCOM optimization, as shown in Figure 3. In this paper, the electric power system used is the 150 kV North Sumatra electrical system (SUMBAGUT) in a steady-state condition. This system consists of 72 buses, as shown in figure 4. There is one slack bus, 14 generator buses, 57 load buses, and 88 lines.

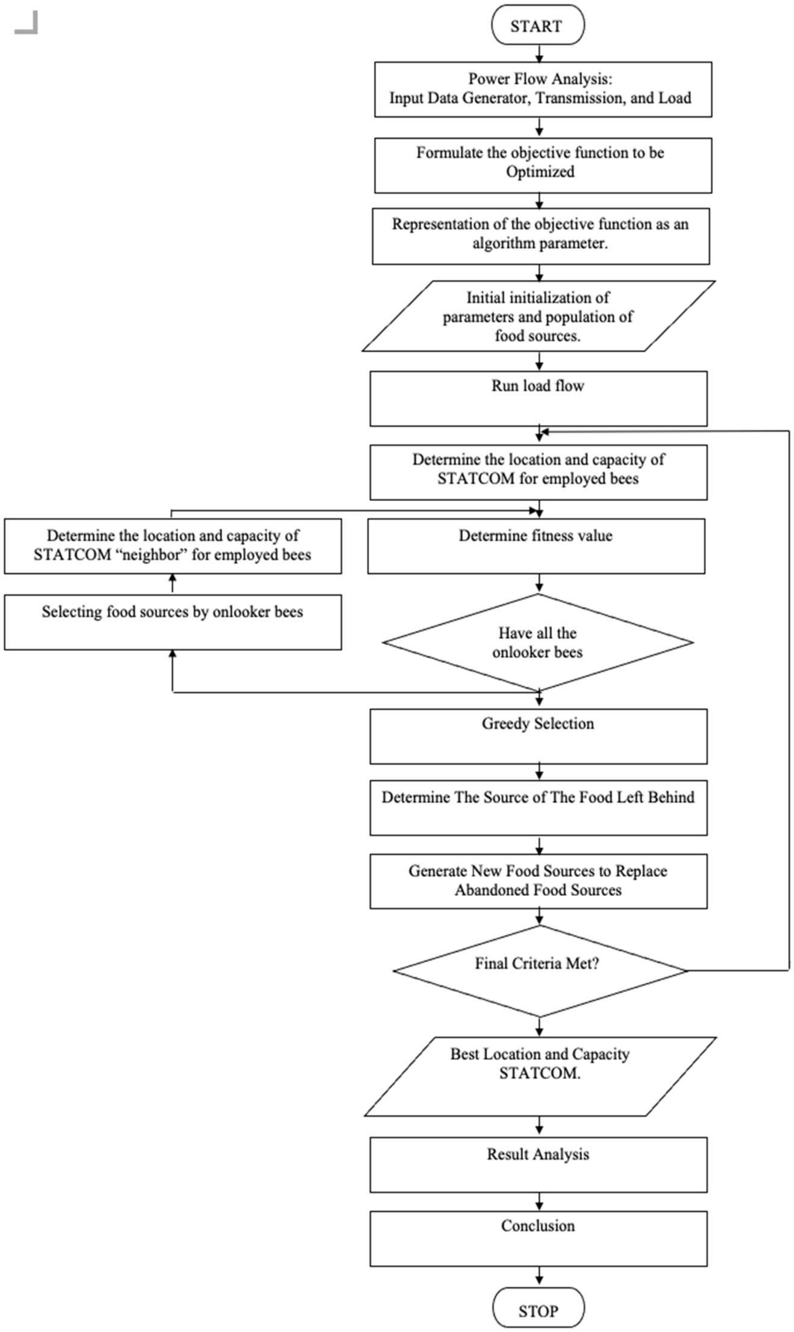

Figure 3. Flowchart of ABC Algorithm Optimization Method Implementation in STATCOM Installation

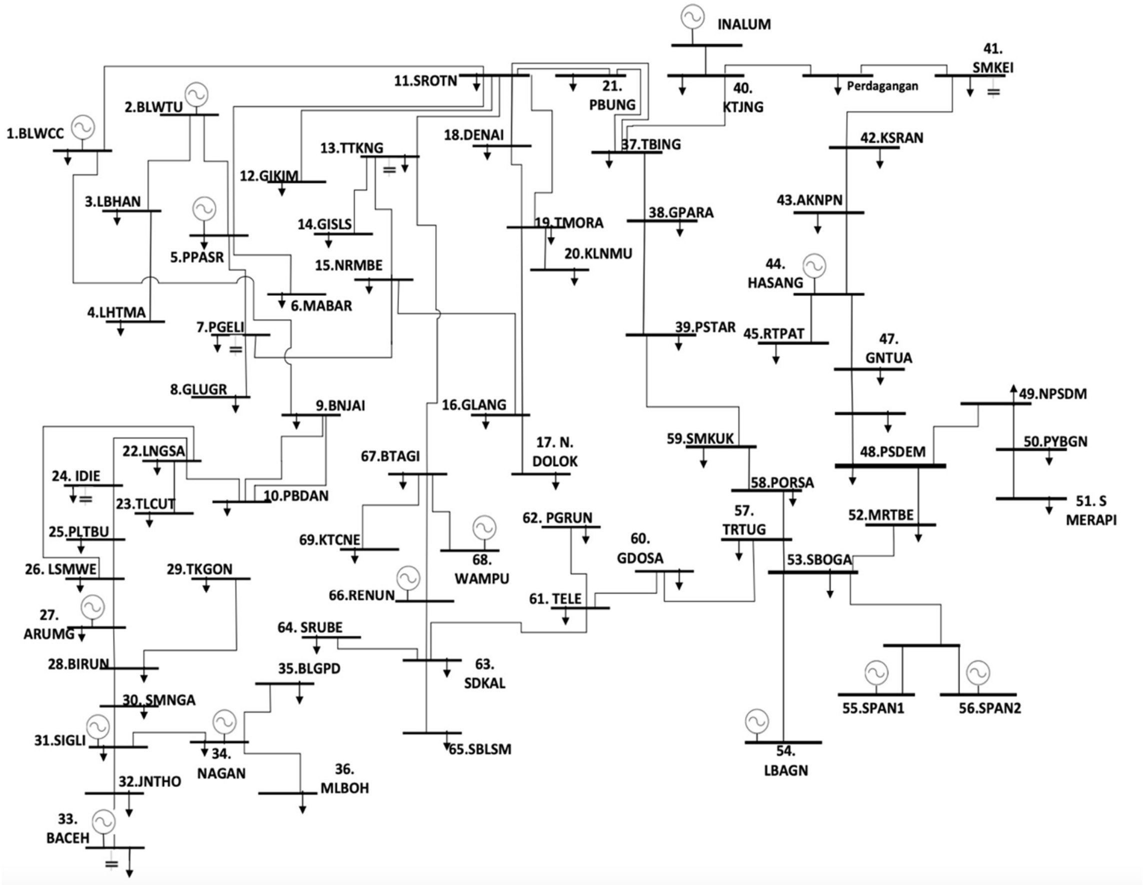

Figure 4. Electrical System in SUMBAGUT 150 kV

3. RESULTS AND DISCUSSION

3.1 Load Flow Analysis without STATCOM

The simulation of the power flow of the SUMBAGUT 150 electric power system without using STATCOM is based on the base power = 100 MVA, the base voltage = 150 kV, and the maximum iteration = 100.

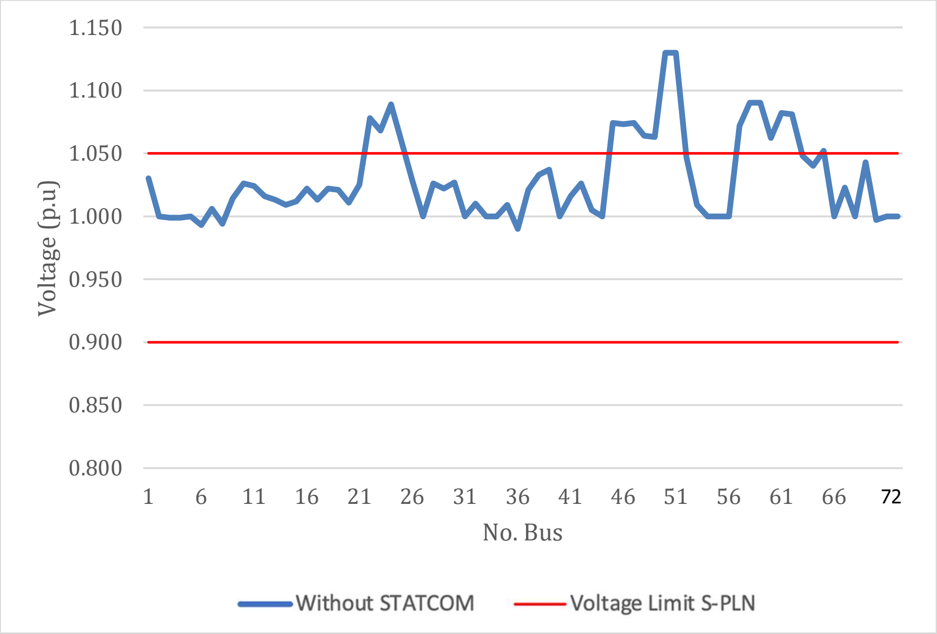

Figure 4. Voltage Profile Without STATCOM Installation in SUMBAGUT 150 kV

Figure 4 can be seen that many buses are outside the S-PLN voltage limit with the buses that are farthest from the SPLN, namely buses 50 and 51 with a voltage value of 1,130 p.u on each bus, and buses 58 and 59 with a voltage value of 1,090 p.u. on each bus. As for the value of the power flow loss in the initial condition system without any reactive power compensation, it is shown in Table 2 below:

Table 2. Power Loss Without STATCOM Installation

Description	Power Loss	
	MW	Mvar
Initial State of System without STATCOM	129.22	-2998.36

3.2 Optimization of STATCOM Location and Capacity Placement using ABC Algorithm

In this simulation of the 150 kV SUMBAGUT electric power system, the addition of FACTS devices, namely STATCOM, has been optimized for location and capacity placement using the ABC Algorithm method. The number of STATCOM to be implemented is one STATCOM.

This test is carried out to obtain the smallest loss value. The optimal location of STATCOM obtained is on bus 61, with an optimal capacity of -78.31 MVar.

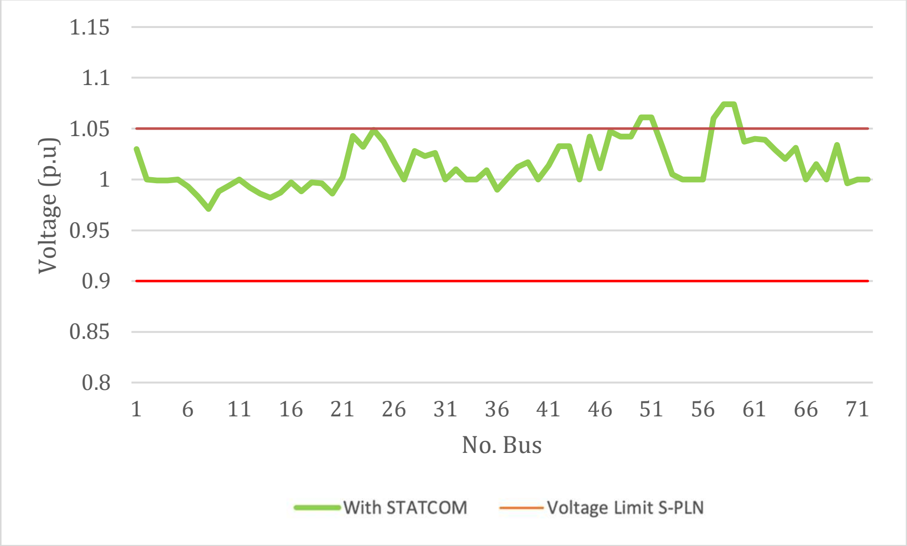

Figure 5. Voltage Profile With STATCOM Installation in SUMBAGUT 150 kV

As seen in Figure 5, the system voltage profile changed significantly after installing the SUMBAGUT 150 kV electric power system, STATCOM was installed. The bus with the highest voltage is buses 59 and 60, with each bus of 1,074, and the bus with the lowest voltage value is bus 8, which is 0.971 p.u. The value of the loss of system power flow after the installation of STATCOM can be seen in Table 3 below:

Table 3. Power Loss with STATCOM Installation

Description	Rugi-Rugi Daya	
	MW	Mvar
Initial State of System with STATCOM	121.55	-2902.82

3.3 Comparison of 150 kV SUMBAGUT Electric Power System Simulation Before and After Installation of STATCOM

The optimal location of STATCOM is obtained on bus 61 with an optimal capacity of -144 MVAR, which improves the voltage profile and minimizes active power loss in the system. Figure 5 shows the result of comparing the voltage values without and with the STATCOM installation.

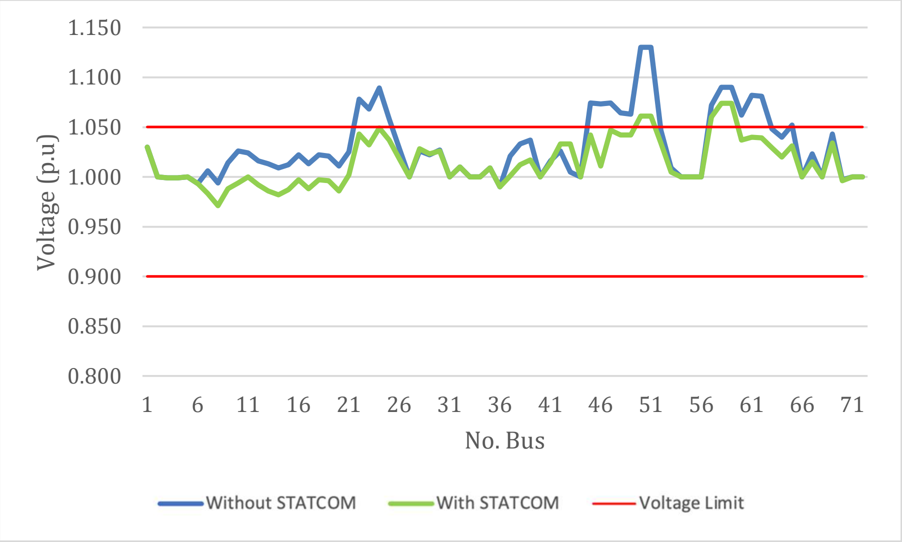

Figure 5. Electrical System in SUMBAGUT 150 kV

Figure 5 the simulation results on the 150 kV SUMBAGUT electrical power system without STATCOM are known to have several voltage variations ranging from 1.000 p.u. up to 1.233 p.u., 38 buses are outside the rated voltage limit of +5% p.u. and -10% p.u. i.e. on buses 10, 21, 22, 23, 24, 25, 26, 28, 29, 30, 32, 35, 37, 38, 39, 41, 42, 43, 45, 46, 47, 48, 49, 50 , 51, 52, 53, 57, 58, 59, 60, 61, 62, 63, 64, 65, 67, and 69. With buses that have the most out of bounds values are buses 50 and 51 with a voltage value of 1,233 p.u on each bus, and buses 58 and 59 with a voltage value of 1,145 p.u on each bus. Meanwhile, the SUMBAGUT 150 kV transmission system with STATCOM made the system voltage profile change significantly. The bus with the highest voltage is on bus 59 and 60 with each bus of 1.074 p.u, and the bus with the lowest voltage value is on bus 8, which is 0.971 p.u.

Table 4. Result Of Optimization STATCOM

	Without STATCOM	**With STATCOM (ABC Solution)**
STATCOM Location	-	61
STATCOM Size	-	-144 MVAR
Active power Loss	131.40 MW	121.56 MW
Reactive Power Loss	-3293.16 MVAR	-2902.82 MVAR

The value of the active power loss in the 150 kV SUMBAGUT transmission system without STATCOM installation is 131.40 MW, and the active power loss with STATCOM is 121.56 MW. On the other hand, the value of reactive power loss in the 150 kV SUMBAGUT transmission without STATCOM installation is -3293.16 MVAR, and the reactive power loss with STATCOM is -2902.82 MVAR. Table 4 describes the simulation results.

4. CONCLUSIONS

In this study, the ABC algorithm optimization method is proposed to determine the placement location and optimal capacity of STATCOM. The goal is to improve the voltage profile and minimize power losses in the SUMBAGUT 150 kV electric power system. The simulation results show that the optimal location and capacity of STATCOM can improve the system voltage profile (+5% p.u, and -10% p.u) and minimize active power loss (121.56 MW) and system reactive power loss (-2902.82 MVAR).

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