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# OPTIMAL PLACEMENT OF TCSC USING LINEAR DECREASING INERTIA WEIGHT GRAVITATIONAL SEARCH ALGORITHM

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**ABSTRACT**

This paper represents the improvement of the Gravitational Search Algorithm method (GSA) using Linear Decreasing Inertia Weight (LDIW) which is implemented to determine the optimal placement of TCSC locations and the best rating of the TCSC in the standard limit on the electric power transmission lines. TCSC is one of FACTS devices which can perform the compensation of the power system. GSA method is a new metaheuristic method inspired by Newton's laws of gravity and mass motion. LDIW-GSA is used to control the speed of the particles on the GSA, so as to improve the performance of the GSA method. The implementation of LDIW-GSA used the Java-Bali 500 kV power system. Before optimization, TCSC load flow results indicated that there was 297.607MW of active power losses and 2926.825 MVAR of reactive power losses. While the results of TCSC load flow was 279. 405 MW of active power losses and reactive power losses was 2082.203 MVAR after optimization using GSA standard. It was obtained 278.655 MW of active power losses and active power losses of 1768.374 MVAR with the use of LDIW-GSA. It was better to be used to minimize power losses in transmission line and also it can improve the value of the voltage in the range of 1 ± 0.95 compared to GSA standards prior to placement optimization of TCSC.

**Keywords:** *Gravitational Search Algorithm (GSA), Linear Decreasing Inertia Weight (LDIW), FACTS device, Thyristor Controlled Series Capacitor (TCSC), (AHPS)*

## 1. INTRODUCTION

The more increased business in the industrial sector has led to the more need for active and reactive power. Such increase in reactive power on transmission lines causes increased power loss component with which worsen the voltage conditions, as a result, it requires components to control and compensate simultaneously the power losses in electrical power systems, especially in the transmission line. Those currently being developed are the FACTS (Flexible Alternating Current Transmission System) devices. FACTS is a component of the transmission system of alternating current using a power electronic control of thyristor for switching control, compensating for voltage drop and increasing power transfer capability [1-2].

There are several types of FACTS devices including: SVC (Static Var Compensator), TCSC (Thyristor Controlled Series Capacitor), TCPST (Thyristor Controlled Phase Shifting Transformer), STATCOM (Static Compensator), UPFC (Unified Power Flow Controller), TCPS (Thyristor Controlled Phase Shifter), SSSC (Static Synchronous Series Compensator) and IPFC (Interline Power Flow Controller) and others [3-10].

Artificial intelligence method developed in this study was the Gravitational Search Algorithm (GSA) one that would be improved using the Linear Decreasing Inertia Weight (LDIW). This GSA method was first introduced by Rashedi in 2009. It is a metaheuristic method inspired by Newton's laws of gravity and motion of mass [11]. Metaheuristic is a method to find a solution that combines the interaction between local search procedures and higher strategies to create a process managed to be out of local optima points and perform a search in the solution space to find a global solution [12].

Several studies have been held by experts using this GSA method, such as on the location of the

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SVC placement [13], economic dispatch (ED) on the power system [14], the voltage settings on the Java-Bali 500 kV power system [15], and optimization of reactive power dispatch [16].

LDIW-GSA is done by regulating LDIW optimal value that can be used to control the speed of the particles on the GSA method, so as to improve the performance of GSA methods.

In this study, LDIW-GSA could be used to determine the most optimal location for TCSC placement and also the TCSC best rating in the standard limit on the transmission line of power system. Besides, optimization using TCSC was also used to obtain the minimal power losses in transmission lines and voltage values werein the range of 0.95 ± 1.05 per unit.

## 2. FACTS DEVICES

Power flow on interconnected systems meets the Kirchhoff's law. Resistance of the transmission line is smaller than the reactance, so the conduction was close to zero. Active power $P_{ij}$ is transmitted on a transmission line between bus $i$ and $j$ which can be written in the following ties:

$$P_{ij} = \frac{V_i \times V_j}{X_{ij}} \sin\theta_{ij} \quad (1)$$

$$Q_{ij} = \frac{1}{X_{ij}}\left(V_i^2 - V_i V_j \cos\theta_{ij}\right) \quad (2)$$

Where:

$V_i$ and $V_j$ = Voltage on the bus $i$ and $j$.
$X_{ij}$ = Reactance of the line.
$\theta_{ij}$ = Angle between $\overline{V_i}$ and $\overline{V_j}$ ($\overline{V}$ is phases)

The voltage difference of $V_i$ and $V_j$ on the transmission line in a normal operation state was very small, so is $\theta_{ij}$. The active power depends on the $\theta_{ij}$, and reactive power $Q_{ij}$ depends on the $V_i$ and $V_j$. While the reactance $X_{ij}$ change affects both.

## 3. THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

TCSC is a type of FACTS devices first developed. It has several components similar to the TCR, namely, among others, an inductor connected in series with the thyristor bipolar. A thyristor works by setting the firing angle, so it can obtain some variations of inductive reactance causing a rapid reactive power exchange between the TCSC and the system. To compensate for a system that requires a capacitive reactive power, TCSC is installed in parallel with a bank capacitor.

TCSC in principle was installed in series with the existing transmission line. Reactance of the transmission channel settings can be done by controlling the TCSC reactance, so that power flow can be increased in other word increasing capabilities of the transmission line.

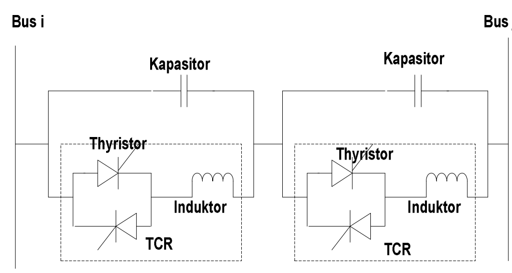


*Fig.1. Simplified circuit of TCSC one phase*

From Figure 1, it shows that TCSC is a combination of TCR components with a capacitor. TCR consists of a couple of inductors connected in series with the thyristor. So the $X_{eq}$ function is the result of the thyristor firing angle:

$$X_{eq}(\alpha) = \frac{-1}{B_L(\alpha) + B_C} \quad (3)$$

Where:

$$B_L(\alpha) = -\frac{1}{\omega L}\left[1 - \frac{2\alpha}{\pi} - \frac{\sin(2\alpha)}{\pi}\right] \quad (4)$$

$$B_C = \omega C \quad (5)$$

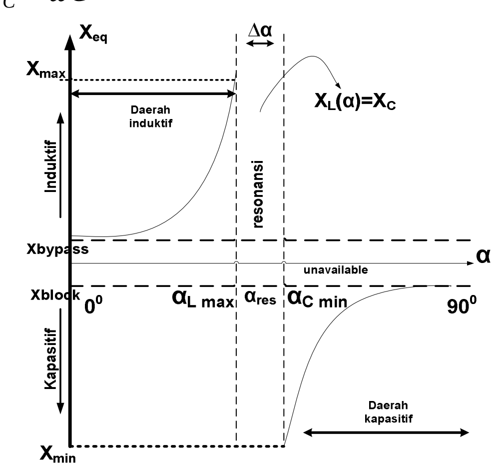


*Fig.2. Equivalent Reactance TCSC*

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In Figure 2, thyristor firing angle is 0° and 90°. It stays at a distance $\Delta\alpha$ from the point of resonance. In Figure 2, the maximum compensation limit of TCSC ($X_{\max}$) is determined by the firing angle $\alpha L_{\max}$ and the minimum compensation limit ($X_{\min}$) by the firing angle of $\alpha C_{\min}$.

To prevent excessive compensation, the compensation degree of TCSC allowed is in the range of 20% inductive and 70% capacitive, so it applies:

$$r_{TCSC\min} = -0.7 \quad (6)$$

$$r_{TCSC\max} = 0.2 \quad (7)$$

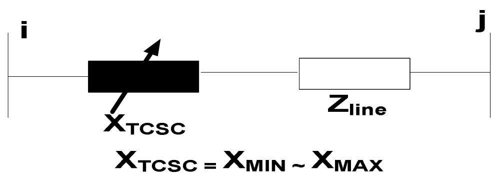


*Fig.3. Model of TCSC on Transmission Line*

In Figure 3, it can be determined the relationship between TCSC rating and reactance in the transmission line:

$$X_{ij} = X_{line} + X_{TCSC} \quad (8)$$

$$X_{TCSC} = rtsc\, X_{line} \quad (9)$$

Where:

$X_{line}$ = transmission line reactance

$r_{TCSC}$ = TCSC compensation rating

## 4. IMPLENTATION OF THE PROPOSED METHOD TO THE SYSTEM

Abbreviation and acronyms should be defined the first time they appear in the text, even after they have already been defined in the abstract. Do not use abbreviations in the title unless they are unavoidable.

The method used to set reactive power compensation is improved GSA using LDIW. LDIW-GSA can search several possible solutions simultaneously and also require none of any prior knowledge or the specific nature of the objective function. In addition, it is able to get the best solution to find optimal solutions in complex problems. It started in a random generation of initial population and then selected and mutated to get the best population.

### 4.1. Encoding

Goals of this coding are to find the optimal location of TCSC in the range of equations and inequalities. Therefore, the configuration of TCSC is encoded by three parameters: location, type and value (*rf*). Each individual is represented by the number of TCSC on the string n, where n is the number of TCSC devices that need to be analyzed in the power system, as shown in Figure 4.

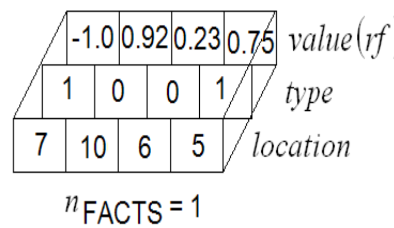


*Fig.4. Individual configuration of the TCSC*

The first values of each string correspond with location information. The value is the number of transmission line is the location of TCSC. Each string has a value different location. In other words, it must be ensured that in a transmission line there is only one TCSC. The second value is the type of TCSC. The values are expressed on a value of 1 for TCSC and the value 0 for the condition without TCSC equipment. Specifically, if there is no necessary TCSC on the transmission line, a value of 0 will work. Final value of $rf$ is the value of the identifier of each TCSC. This value varies between -1 and +1. Real value of each TCSC is then converted by type of TCSC. TCSC has a range between $-0.7X_{line}$ and $0.2X_{line}$, where $X_{line}$ is the reactance of the transmission line where the TCSC is installed. Therefore, it is converted into a real degree of compensation *rtcsc* using the following equation:

$$rt\csc = rf \times 0.45 - 0.25 \quad (10)$$

### 4.2. Population

Initial population is generated from the following parameters:

$n_{FACTS}$ = Number of TCSC is located

$n_{Type}$ = Types of TCSC

$n_{Location}$ = Possible locations for TCSC

$n_{Ind}$ = The number of individuals from the population

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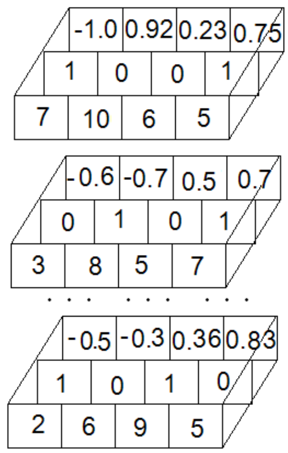


*Fig.5. The Calculation Of All Population*

First, as shown in Figure 5 created a group of TCSC resulting string. For each string, the first value is selected randomly from the possible locations $n_{lokasi}$. The second value, which is a type of TCSC, obtained by taking a number at random between the equipment has been selected. Specifically, after optimization, if no TCSC is required for this transmission line, the second value will be set to zero. The third value of each string, containing the value of the TCPST equipment, was chosen at random between -1 and +1. The above operation was repeated as $n_{ind}$ times to obtain the whole initial population.

### 4.3. Calculate Fitness

After encoding, each individual in the population was evaluated using the objective function. Optimization problem associated with the placement of TCSC, the objective function of this problem is used as fitness function. Fitness function is the calculation used to compare the quality of different solutions.

After encoding, each individual in the population was evaluated using the objective function. Optimization problem associated with the placement of TCSC, the objective function of this problem is used as fitness function. For this purpose, the TCSC is placed on the transmission line to pay attention to the power flow and voltage constraints. Objective function is used as the limit of TCSC placement to prevent under voltage or overvoltage on each bus and is able to reduce losses in power transmission line in the system.

Objective function for optimizing the placement of TCSC is to minimize losses on the transmission line. Objective functions for optimal configuration of TCSC are:

- **Active power loss minimization**

Minimization of active power loss ($P_{loss}$) in the transmission line:

$$P_{loss} = \sum_{\substack{k=1 \\ k=(i,j)}}^{n} g_k \left(V_i^2 + V_j^2 - 2V_iV_j \cos\theta_{ij}\right) \tag{11}$$

Where: $n$ = the number of transmission line, $g_k$ = conductance of k branch, $V_i$ and $V_j$ = the voltage magnitude on bus $i$ and bus $j$, $\theta_{ij}$ = voltage angle difference between bus $i$ and bus $j$.

- **Equality Constrain**

Power flow equation constrains is as follows:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{n} V_j \begin{bmatrix} G_{ij} \cos\theta_{ij} \\ + B_{ij} \sin\theta_{ij} \end{bmatrix} = 0,\ i = 1,2,\dots nb \tag{12}$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{n} V_j \begin{bmatrix} G_{ij} \sin\theta_{ij} \\ + B_{ij} \cos\theta_{ij} \end{bmatrix} = 0,\ i = 1,2,\dots nb \tag{13}$$

Where: $nb$ = number of buses, $P_G$ and $Q_G$ = active and reactive power from generators, $P_D$ and $Q_D$ = active and reactive load from the generator, $G_{ij}$ and $B_{ij}$ = joint conductance and susceptance between bus $i$ and bus $j$.

- **Inequality Constrain**

Load bus voltage constraints inequality ($Vi$):

$$VL = \begin{cases} 0.95 - 1.05 & if\ \ 0.95 \le V_i \le 1.05 \\ \quad \exp\left(\mu\left|1 - V_i\right|\right) & for\ \ V_i\ \ etc \end{cases} \tag{14}$$

Inequality constraints of switchable reactive power compensation ($Q_{ci}$):

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max}, i \in nc \tag{15}$$

Inequality constraint of reactive power generator ($Q_{Gi}$):

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, i \in ng \tag{16}$$

Inequality constraints of transformers tap setting ($T_i$):

$$T_i^{\min} \le T_i \le T_i^{\min}, i \in nt \tag{17}$$

Inequality constraint of transmission line flow

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($S_{li}$):

$$S_{li} \le S_{li}^{\max}, i \in nl \quad (18)$$

Where: $nc$, $ng$ and $nt$ = number of switchable reactive power sources, generators and transformers.

To evaluate the optimization objective function on the placement of TCSC, the best and worst fitness is calculated each iterating as follows:

$$best(t) = \min_{j \in (1,\ldots N)} fit_j(t) \quad (19)$$

$$worst(t) = \max_{j \in (1,\ldots N)} fit_j(t) \quad (20)$$

Where: $fit_j(t)$ = Fitness in the $j^{th}$ agent at $t$ time, $best(t)$ and $worst(t)$ = the best fitness of all agents (the minimum) and worst (the maximum) fitness of all agents.

### 4.4. Calculate Of The Gravitational Constant

To update the $G$ gravitational constant in accordance with population fitness of the best agents (minimum) and worst (maximum) using equation (19) and (20). The gravitational constant $G(t)$ on $t$ time is calculated as follows.

$$G(t) = G_0 \exp\left(-\alpha \frac{t}{T}\right) \quad (21)$$

Where: $G_0$ = Initial value of the gravitational constant chosen at random, $\alpha$ = Constant, $t$ = The number of iterations, $T$ = Total number of iterations

### 4.5. Calculate Of Inertia Masses And Gravity

To calculate the value of inertial mass (M) for each agent, equation (22) and equation (23) are used

$$mg_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \quad (22)$$

Where: $fit_i(t)$ = Fitness to the agent $i$ at $t$ time.

$$Mg_i(t) = \frac{mg_i(t)}{\sum_{j=1}^{N} mg_j(t)} \quad (23)$$

Where: $Mg_i(t)$ = Mass of the agent $i$ at $t$ time.

### 4.6. Calculate Of The Total Force

In this step, the total force acting on the agent $i$ $\left(F_i^d(t)\right)$ is calculated as follows:

$$F_i^d(t) = \sum_{j \in kbest j \ne i} rand_j F_{ij}^d(t) \quad (24)$$

Where: $rand_j$ = Random number between the intervals [0.1], $kbest$ = the initial set of agent $K$ with the best fitness value and the largest mass.

Forces acting on the mass $i$ $(M_i(t))$ from the masses $j$ $(M_j(t))$ at specific $t$ time according to the gravity theory described as follows

$$F_{ij}^d(t) = G(t)\frac{M_i(t) \times M_j(t)}{R_{ij}(t) + \varepsilon}\left(x_j^d(t) - x_i^d(t)\right) \quad (25)$$

Where: $R_{ij}(t)$ = Euclidean distance between the agent $i$ and agent $j$ $\left(\left\|X_i(t), X_j(t)\right\|_2\right)$, $\varepsilon$ = a smack constant.

### 4.7. Calculate Of The Acceleration

In this step, acceleration of $\left(a_i^d(t)\right)$ from the agent $i$ at $t$ time in $d^{th}$ dimensions is calculated with the laws of gravity and the laws of motion as follows.

$$a_i^d(t) = \frac{F_i^d(t)}{Mg_i^d(t)} \quad (26)$$

### 4.8. Calculate Of Ldiw

LDIW was used to control speed and to maintain balance in influencing the trade-offs between global and local exploration abilities during the searching process. Furthermore, it was also a reduction of velocity parameters to avoid particle stagnation in the local optimum. If the value of LDIW is too large, the system will always be exploring new areas, consequently, the ability to explore the local value reduces. As a result, it fails to find a solution and if the value of inertia weight is too small then it can be stuck in local optimum. LDIW equation: [17-18]

$$w^k = \frac{w_{\max} - k\left(w_{\max} - w_{\min}\right)}{k_{\max}} \quad (27)$$

Where:

$w_{\max}$ = maximum value

$w_{\min}$ = minimum value

$k_{\max}$ = iteration maximum.

$k$ = iteration

In this study, LDIW value used started with a great value, namely 1.2 to explore global values. Then, it decreased dynamically to the minimum LDIW of 0.2 to explore the local value during the optimization process.

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### 4.9. Calculate Velocity

In this step, n the velocity $\left(v_i^d(t)\right)$ of $i^{th}$ agent at $t$ time in $d^{th}$ dimension is calculated through the law of gravity and the laws of motion and the LDIW ($\omega^t$) as follows.

$$v_i^d(t+1) = \omega^t \times v_i^d(t) + a_i^d(t) \quad (28)$$

Where:

$\omega^t$ = linear decreasing inertia weight [0.2 - 1.2].

### 4.10. Calculate Velocity

In this step, n the velocity $\left(v_i^d(t)\right)$ of $i^{th}$ agent at $t$ time in $d^{th}$ dimension is calculated through the law of gravity and the laws of motion and the LDIW ($\omega^t$) as follows.

$$v_i^d(t+1) = \omega^t \times v_i^d(t) + a_i^d(t) \quad (29)$$

Where:

$\omega^t$ = linear decreasing inertia weight [0.2 - 1.2].

### 4.11. Update Position Agent Updating

In this step the next position of $i^{th}$ agent in $d^{th}$ dimension $d$ $\left(x_i^d(t+1)\right)$ is updated as follows.

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (30)$$

### 4.12. Repetition

In this step, the steps from 4.2 to 4.11 are repeated until the iterations reach the criterion. At the end of the iteration, the algorithm returns the value associated with the position of the agent on a particular dimension. This value is the global solution of optimization problems as well.

LDIW-GSA algorithm, used to determine the optimal placement of TCSC locations and ratings, are shown in Figure 6.

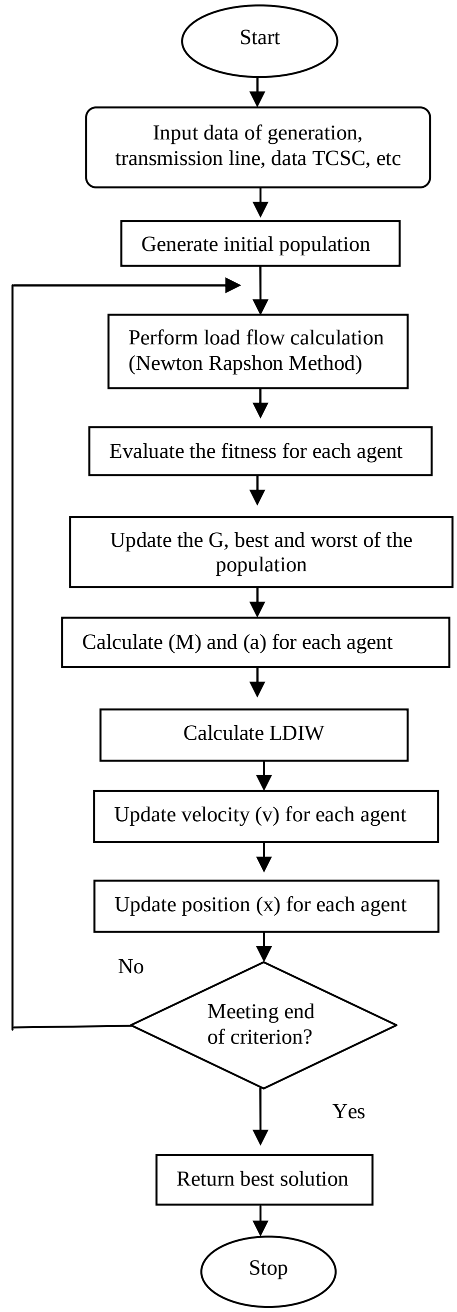


*Fig.6. Flowchart LDIW-GSA using TCSC*

## 5. RESULT AND ANALYSIS

### 5.1. Data Of Java-Bali 500 Kv Power System

The Java-Bali 500 kV power system is an interconnection system that delivers the power to customers in various areas in Java and Bali. The power is supplied from the electrical power produced by various sources of hydroelectric plants (located at the power plant of Cirata and

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Saguling), steam power plant (located on the plant of Suralaya, Tanjung Jati, Paiton) and steam gas power plants (consisted of Grati, Muaratawar and Gresik plants). Single line diagram of power system can be seen in Figure 7.

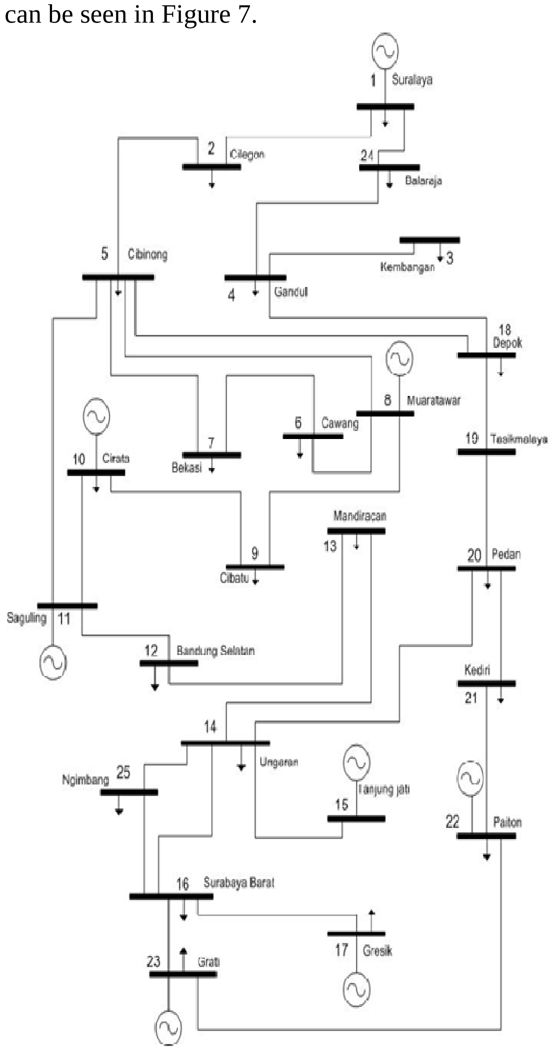


*Fig.7. Single Line Diagram Of Java-Bali 500 Kv Power System*

This study used MVA base of 1000 MVA and kV base of 500 kV as the base of the Java-Bali 500 kV power system.

Transmission line parameters used in this study using per unit. Data line system of Java-Bali 500 kV system before using ohm. Therefore, it must first be converted into units of per unit.

*Table I*
*Data Load And Generation Interconnection System Java-Bali 500 Kv*

| Bus No | Bus Name | Bus code | Generator MW | Generator MVAR | Load MW | Load MVAR |
|---|---|---|---|---|---|---|
| 1 | Suralaya | Swing | 3211.6 | 1074.1 | 219 | 67 |
| 2 | Cilegon | Load | 0 | 0 | 333 | 179 |
| 3 | Kembangan | Load | 0 | 0 | 202 | 39 |
| 4 | Gandul | Load | 0 | 0 | 814 | 171 |
| 5 | Cibinong | Load | 0 | 0 | 638 | 336 |
| 6 | Cawang | Load | 0 | 0 | 720 | 217 |
| 7 | Bekasi | Load | 0 | 0 | 1126 | 331 |
| 8 | Muaratawar | Generator | 1760.0 | 645.0 | 0 | 0 |
| 9 | Cibatu | Load | 0 | 0 | 1152 | 345 |
| 10 | Cirata | Generator | 948.0 | 200.0 | 597 | 201 |
| 11 | Saguling | Generator | 698.4 | 150.0 | 0 | 0 |
| 12 | Bandung Selatan | Load | 0 | 0 | 477 | 254 |
| 13 | Mandiracan | Load | 0 | 0 | 293 | 65 |
| 14 | Ungaran | Load | 0 | 0 | 193 | 118 |
| 15 | Tanjung Jati | Generator | 1321.6 | 90.0 | 0 | 0 |
| 16 | Surabaya Barat | Load | 0 | 0 | 508 | 265 |
| 17 | Gresik | Generator | 900.0 | 366.3 | 127 | 92 |
| 18 | Depok | Load | 0 | 0 | 342 | 95 |
| 19 | Tasikmalaya | Load | 0 | 0 | 133 | 33 |
| 20 | Pedan | Load | 0 | 0 | 365 | 101 |
| 21 | Kediri | Load | 0 | 0 | 498 | 124 |
| 22 | Paiton | Generator | 3180.0 | 917.3 | 448 | 55 |
| 23 | Grati | Generator | 398.6 | 100.0 | 180 | 132 |
| 24 | Balaraja | Load | 0 | 0 | 732 | 287 |
| 25 | Ngimbang | Load | 0 | 0 | 264 | 58 |

*Table 2*
*Line Data Of Java-Bali 500 Kv Power Systems*

| No | From Bus | To Bus | R p.u | X p.u | ½ B p.u |
|---|---|---|---|---|---|
| 1 | 1 | 2 | 0.000626496 | 0.007008768 | 0 |
| 2 | 1 | 24 | 0.003677677 | 0.035333317 | 0 |
| 3 | 2 | 5 | 0.013133324 | 0.146925792 | 0.003530571 |
| 4 | 3 | 4 | 0.001513179 | 0.016928308 | 0 |
| 5 | 4 | 18 | 0.000694176 | 0.006669298 | 0 |
| 6 | 5 | 7 | 0.004441880 | 0.042675400 | 0 |
| 7 | 5 | 8 | 0.006211600 | 0.059678000 | 0 |
| 8 | 5 | 11 | 0.004111380 | 0.045995040 | 0.004420973 |
| 9 | 6 | 7 | 0.001973648 | 0.018961840 | 0 |
| 10 | 6 | 8 | 0.005625600 | 0.054048000 | 0 |
| 11 | 8 | 9 | 0.002822059 | 0.027112954 | 0 |
| 12 | 9 | 10 | 0.002739960 | 0.026324191 | 0 |
| 13 | 10 | 11 | 0.001474728 | 0.014168458 | 0 |
| 14 | 11 | 12 | 0.001957800 | 0.021902400 | 0 |
| 15 | 12 | 13 | 0.006990980 | 0.067165900 | 0.006429135 |
| 16 | 13 | 14 | 0.013478000 | 0.129490000 | 0.012394812 |
| 17 | 14 | 15 | 0.013533920 | 0.151407360 | 0.003638261 |
| 18 | 14 | 16 | 0.015798560 | 0.151784800 | 0.003632219 |
| 19 | 14 | 20 | 0.009036120 | 0.086814600 | 0 |
| 20 | 16 | 17 | 0.001394680 | 0.013399400 | 0 |
| 21 | 16 | 23 | 0.003986382 | 0.044596656 | 0 |
| 22 | 18 | 5 | 0.000818994 | 0.007868488 | 0 |
| 23 | 18 | 19 | 0.014056000 | 0.157248000 | 0.015114437 |
| 24 | 19 | 20 | 0.015311000 | 0.171288000 | 0.016463941 |
| 25 | 20 | 21 | 0.010291000 | 0.115128000 | 0.011065927 |

## 5.2. Experimental Result

- **The Load flow results before optimization using TCSC**

To know the initial conditions of the Java-Bali 500 KV power systems before optimization using TCSC, the power flow analysis was performed using the Newton Raphson method. The results of

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the analysis before optimization using TCSC is shown in Figure 8 and Figure 9.

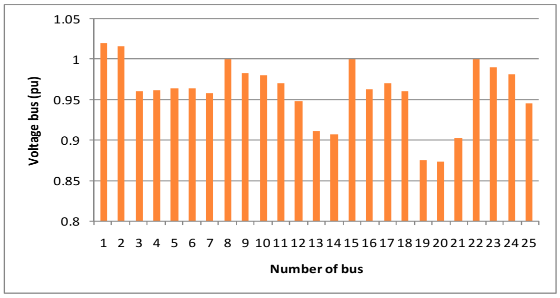


*Fig.8. Voltage Profile Before Optimization Using TCSC*

In Figure 8, it shows that the voltage variation of the Java-Bali 500 kV power system is in the range of 0.874 to 1.020 per unit. The highest voltage occurs at bus 1 (Suralaya), which is 1.020 per unit and the lowest voltage is found on the bus 20 (Pedan). Figure 6 also shows that there are eight buses having a voltage outside the range of 0.95 ± 1.05 per unit, namely: bus 12 (South London) = 0.948 per unit, bus 13 (Mandiracan) = 0.911 per unit, bus 14 (Ungaran) = 0.907 per unit, bus 19 (Tasikmalaya) = 0.875 per unit, bus 20 (Pedan)= 0.874 per unit, bus 21 (Karachi) = 0.902 per unit, bus 24 (Balaraja) = 0.982 per unit and bus 25 (Ngimbang) = 0.946 per unit.

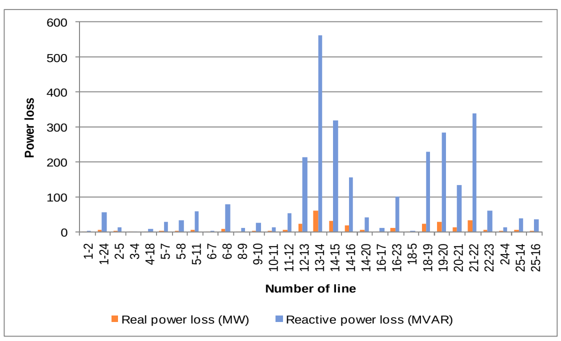


*Fig.9. Power Losses On The Transmission Line Before The Optimization Using The TCSC*

Figure 9 shows the result of active power loss in transmission lines obtained before optimization using TCSC is 297.607 MW and the reactive power loss of 2926.825 MVAR with power supply from an active power plant for 10658.607 MW and reactive power of 7338.924 MVAR. The largest active and reactive power losses occur in lines 13-14 for 60.593 MV and 561.663 MVAR. While the smallest active and reactive power losses occur in 3-4 lines of 0.069 MW and 0.775 MVAR.

**- The load flow results after optimization of using TCSC placement**

Parameters used were the standard GSA and LDIW-GSA to determine the optimal placement of TCSC locations and its rating on the system Java-Bali 500 kV as shown in Table 3.

*Table 3: Parameter In The Gsa And Ldiw-Gsa*

| No | Parameter | Value |
|---|---|---|
| 1 | Number of population | 100 |
| 2 | Number of iterations | 100 |
| 3 | Number of bus | 25 |
| 4 | Number of lines | 30 |

The results of the convergence curve after optimization using the TCSC from GSA standard and LDIW-GSA are shown in Figure 10 and Figure 11.

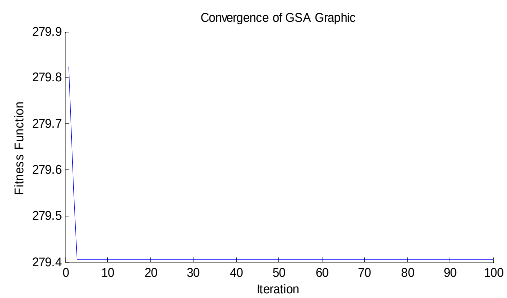


*Fig.10. Convergence After Optimization Using TCSC Of GSA Standard*

Figure 10 shows that the convergent characteristics after optimization using TCSC from the standard GSA are able to produce more minimum values of the active power losses in transmission lines, when compared with the results before optimization using TCSC 279.405 MW and 2082.203 MVAR.

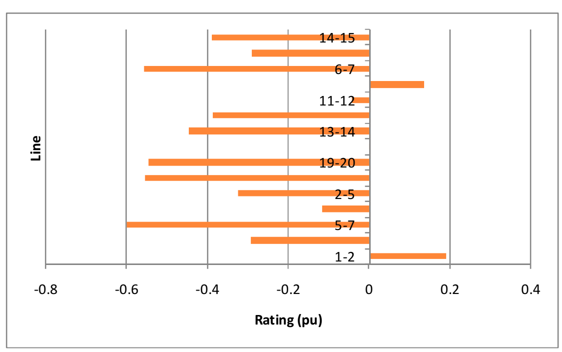


*Fig.11. Location And Rating After Optimization Using TCSC From Standard GSA*

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In the Figure 11, it can be seen that the TCSC location and rating system in transmission system lines of Java-Bali 500 kV using standard GSA are the greatest on lines 1-2 at 0.1885 per unit and the smallest rating capacity occurs in lines 11-12 at -0.0447 per unit.

The results of the convergence curve after optimization using the TCSC from LDIW-GSA are shown in Figure 12 and Figure 13.

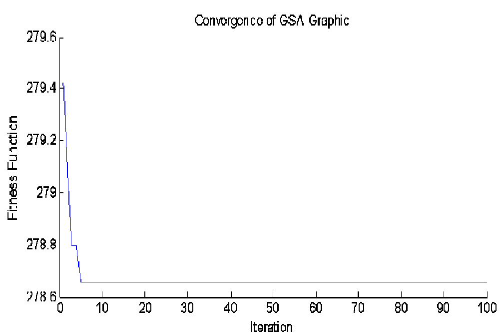


*Fig.12. Convergence After Optimization Using The TCSC From LDIW-GSA*

In Figure 12, it shows that the convergence characteristics after optimization using the TCSC from LDIW-GSA is able to produce more minimum values of the active power losses in transmission lines, when compared with load flow results before optimization using TCSC 278.655 MW and 1768.374 MVAR.

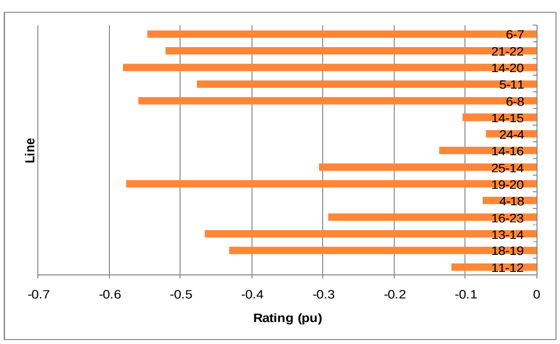


*Fig.13. Convergence After Optimization Using The TCSC From LDIW-GSA*

Figure 13 shows that the location and rating of TCSC on and rating on transmission system lines of Java-Bali 500 kV using LDIW-GSA occur in channels 14-20 at -0.5804 per unit and occurs at the smallest rating for the channel 24-4 at -0.0723 per unit.

To keep the voltage at each bus in the range of 0.95 – 1.05 per unit, along with the smaller flowing power in each line than the maximum power, compensation using the TCSC on the transmission line was carried out. The success of GSA standard and LDIW-GSA with the same parameter values is shown in Table 3 in completing optimization of the optimal location and rating placement using TCSC on Java-Bali 500 kV power system. It is shown in Figure 14 and Figure 15.

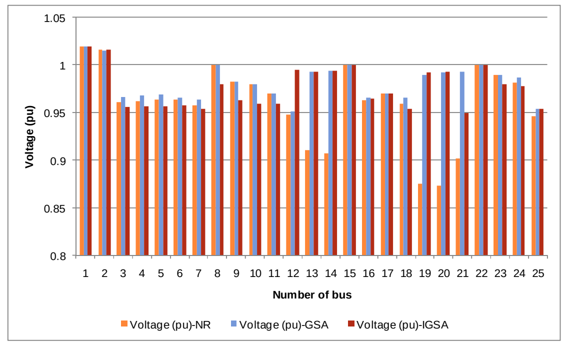


*Fig.14. Comparison Of The Voltage Profile After Optimization Of TCSC Using The GSA, And GSA-LDIW Before Optimization Of TCSC*

Figure 14 shows that after optimization using TCSC, there is no more violation on voltage levels (0.95 ± 1.05 per unit), using either standard GSA or LDIW-GSA. This indicates that after optimization using the TCSC, the voltage profile on the electric power transmission line is getting better.

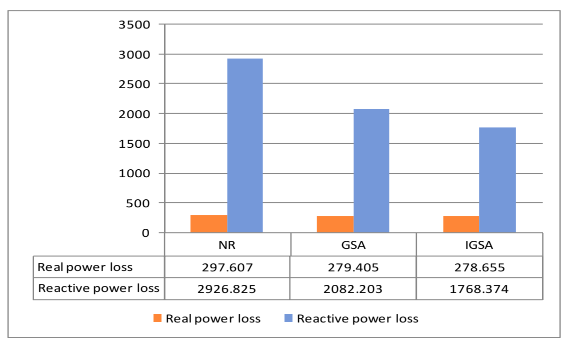


*Fig.15. Comparison Of Power Line Losses After TCSC Optimization Using The GSA, GSA-LDIW And Before Optimization TCSC*

In the Figure 15 shows that after optimization using the TCSC, the power losses on transmission lines became minimal, whether using standard GSA and LDIW-GSA. The results of the power losses in electrical power transmission lines after optimization using TCSC from LDIW-GSA were smaller than the GSA result and before optimization using TCSC.

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## 6. CALCULATION

In this paper, the proposed LDIW-GSA was used for the placement of TCSC optimal location and rating on power system transmission line. The method used in this paper included methods of GSA standards and the improved one using the Linear Decreasing Inertia Weight (LDIW). Test results using Java-Bali 500 kV power system showed that the placement of the optimal location and the rating on TCSC using GSA standard and LDIW-GSA could improve the voltage value on the bus having a voltage drop to 0.95 ± 1.05 per unit and reduce the power losses in Java-Bali 500 kV electrical power system. Voltage improvement and power loss reduction in the Java-Bali 500 kV power system using LDIW-GSA is better than using the GSA standard and before optimization placement of TCSC.

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