

Optimal Placement of Unified Power Flow Controller Using Linear Decreasing Inertia Weight - Gravitational Search Algorithm

Purwoharjono
Departement of Electrical Engineering
University of Tanjungpura
Pontianak, Indonesia

Elang Derdian Marindani
Departement of Electrical Engineering
University of Tanjungpura
Pontianak, Indonesia

Abstract—This paper can serve to minimize the loss of power flow in the transmission line and to improve voltage profile of the electrical power system using the Unified Power Flow Controller (UPFC). This improvement was done by determining the optimal location and capacity rating of UPFC. The determination of the optimal location and capacity rating of UPFC utilized the Development of Gravitational Search Algorithm (GSA). The development of GSA used the Linear Decreasing Inertia Weight (LDIW). The LDIW was done by adjusting the optimal weight value of inertia which can be used to control the velocity of the particles of GSA to improve the performance of GSA. The implementation of LDIW-GSA used the electrical power system of Java-Bali 500 kV. The power flow simulation results before installation of UPFC using LDIW-GSA showed the loss of active power of 297.607 MW and reactive power of 2926.825 MVAR, and there were 8 bus voltages outside the tolerance, i.e. bus 12, bus 13, bus 14, bus 19, bus 20, bus 21, bus 24 and bus 25; the power flow simulation results after installation of UPFC using standard GSA indicated the loss of active power of 270.334 MW and loss of reactive power of 2913.298 MVAR; and power flow simulation results after installation of UPFC using LDIW-GSA showed the loss of active power of 266.526 MW and loss of reactive power of 2786.101 MVAR, and all the bus voltages on the electrical power system of Java-Bali were within the specified standard, i.e. in the range 0.95 ± 1.05 pu.

Keywords— *Unified Power Flow Controller; Linear Decreasing Inertia Weight; Gravitational Search Algorithm*

I. INTRODUCTION

The increase of reactive power on the transmission line may lead to increased power loss components on the line and can worsen the electrical voltage value. Therefore, the components capable of controlling and simultaneously compensating for power losses occurring in the electrical power system are needed especially on the transmission line. Among the tools that can be used to tackle these problems is FACTS device. The FACTS device is a component of the alternating current transmission system which uses power electronic control i.e. thyristor for switching control, compensating for voltage drop and increasing the power transfer capability [1-2].

One of the types of FACTS devices that will be used for modeling in this study is UPFC. UPFC can be used to adjust parameters and variables on the transmission line such as line impedance, terminal voltage and voltage angle rapidly and

effectively. In addition, it is also capable of making an electric power system operate in a more flexible, secure, and economical way. [3-4].

The methods used by experts to resolve problems related to UPFC include conventional methods, such as the Newton Raphson method, etc., and methods based on Artificial Intelligence (AI), such as: Particle Swarm Optimization (PSO), Genetic Algorithm (GA), NSGA, etc. [5-9].

The artificial intelligence method used in this study is the Gravitational Search Algorithm (GSA), that will be developed using the Linear Decreasing Inertia Weight (LDIW). The GSA is a metaheuristic method inspired by Newton's laws of gravity and motion [10]. The metaheuristic is a method to find a solution that combines the interaction between local search procedures and advanced strategies to create a process capable of getting out of local optima spots and doing search in the solution space to find global solutions [11].

LDIW is done by adjusting the optimum inertia weight value that can be used to control the particle velocity in GSA method in order to improve the performance of GSA method.

Several studies have been held by experts using this GSA method, such as on the voltage settings on the Java-Bali 500 kV power system, the location of the SVC placement, optimal placement and sizing using TCSC, and optimal design of TCPST [12].

This research finally concluded that the power flow simulations after the installation of UPFC using LDIW-GSA had better results compared to the power flow simulations prior to the installation of UPFC using the standard GSA and prior to the installation of UPFC using LDIW-GSA. The UPFC installation using LDIW-GSA with proper location and rating could also minimize power losses that occurred on the transmission lines and improve electrical voltage profile, so as to improve the stability of the power system of Java-Bali 500 kV.

II. UNIFIED POWER FLOW CONTROLLER (UPFC)

In this research, the type of Facts device used was UPFC. UPFC is one of the types of FACTS as a control which can simultaneously control three parameters of electrical power system (line impedance, terminal voltage and voltage angle). The UPFC type is shown in Figure 1.

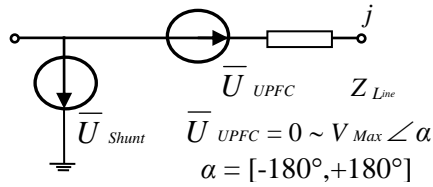


Fig. 1. Type of FACTS device using UPFC

The mathematical model of this UPFC type was developed especially to conduct steady-state research. Therefore, UPFC was modeled using power injection method. Subsequently, UPFC mathematical model was integrated into the transmission line model. Basically, UPFC has two voltage source inverters which divide the dc storage capacitor. This simulation used the following compensation series $\Delta \bar{U}_{FACTS} = \Delta \bar{U}_{UPFC}$. Current injection at bus i and bus j can be expressed as follows:

$$\Delta \bar{I}_{is} = \frac{\Delta \bar{U}_{UPFC}}{Z_{ij}} \quad \Delta \bar{I}_{js} = \frac{\Delta \bar{U}_{UPFC}}{Z_{ij}} \quad (1)$$

The UPFC operating modes can be classified into several basic operating modes as follows:

- Parallel converter mode

A parallel converter operates by drawing current from lines in a controlled manner. One of the current components is determined automatically to balance the active power of serial converter. The reactive current components can be set in a range of desired reference level (inductive or capacitive) within the constraint of the converter.

- Serial converter mode

The function of a serial converter is to control voltage magnitude and angle serially injected on the transmission lines. Voltage injection aims to affect the power flow on the lines.

- Alternative mode and separate mode

These types of operating modes depend on the needs of a particular installation. The switchgear can be set up so as to allow the two converters operate separately by removing the terminal common dc and split the capacitor bank. In this operation, a shunt converter operates separately as Static Synchronous Compensator (STATCOM) and the serial converter operates as Static Synchronous Series Compensator (SSSC). In a separate operating condition, the converter is unable to absorb or generate active power, so reactive power is more dominant. However, power on the line can still be controlled but P and Q cannot be altered freely. In the impedance equalization mode, only reactive impedance can be equalized.

III. IMPLEMENTATION OF THE PROPOSED METHOD TO THE SYSTEM

A. Encoding

This purpose of the encoding is to find the optimal location of UPFC. The configuration of UPFC is encoded by three parameters: location, type and value (rf). Each individual is represented by a total n_{UPFC} on a string, where n_{UPFC} is the number of equipment devices that need to be analyzed in the power system, as indicated in Figure 1.

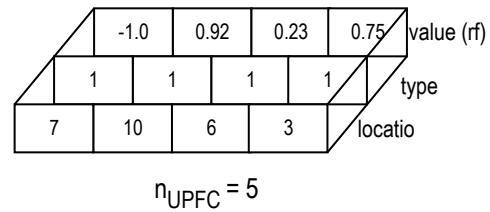


Fig. 2. Individual configuration of UPFC

The first value of each string corresponds to the information about the location. The value is the transmission line number of UPFC location. Each string has a different location value. In other words, it must be ensured that there is only one UPFC on each transmission line. The second value is the type of UPFC. The expressed value is 1 for UPFC and 0 for condition without UPFC. The final value rf expresses the identifier value of each UPFC. This value varies between -1 and +1. The UPFC working range is between -180° to $+180^\circ$. The value rf is then converted into the working angle $rupfc$, according to the following criteria.

$$rupfc = rf \times 180 \text{ (degrees)} \quad (2)$$

B. Population

Initial population is generated from the following parameters:

- n_{FACTS} = Number of UPFC is located
- n_{Type} = Types of UPFC
- $n_{Location}$ = Locations for UPFC
- n_{Ind} = The number of individuals from the population

The calculation of the whole population is shown in Figure 3

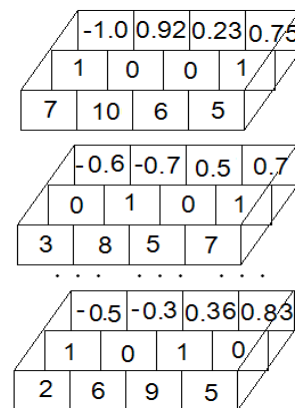


Fig. 3. Whole population calculation

C. Calculate Fitness

The objective functions for optimal configuration of UPFC are:

- Minimizing voltage deviation

Improvement of voltage index in electrical power system voltage is defined as the deviation of voltage magnitude of each bus in pu defined as:

$$L_v = \sum_{i=1}^b \left[\frac{V_{iref} - V_i}{V_{iref}} \right]^2 \quad (3)$$

where: n the number of buses, V_{iref} is reference voltage on bus i , V_i real voltage on bus i .

- Active power loss minimization

Minimization of active power loss (Ploss) in the transmission line:

$$P_{loss} = \sum_{k=1}^n g_k (V_i^2 + V_j^2 - 2V_i V_j \cos \theta_{ij}) \quad (4)$$

$k=(i,j)$

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 , θ_{ij} = voltage angle difference between bus i and bus j .

- Equality Constraint

Power flow equation constraint is as follows:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^n V_j \left[\begin{matrix} G_{ij} \cos \theta_{ij} \\ + B_{ij} \sin \theta_{ij} \end{matrix} \right] = 0, i = 1, 2, \dots, nb \quad (5)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^n V_j \left[\begin{matrix} G_{ij} \sin \theta_{ij} \\ + B_{ij} \cos \theta_{ij} \end{matrix} \right] = 0, i = 1, 2, \dots, nb \quad (6)$$

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 Constraint

Load bus voltage constraints inequality (V_i):

$$VL = \begin{cases} 0.95 - 1.05 & \text{if } 0.95 \leq V_i \leq 1.05 \\ \exp(\mu |1 - V_i|) & \text{for } V_i \text{ etc} \end{cases} \quad (7)$$

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

$$Q_{ci}^{\min} \leq Q_{ci} \leq Q_{ci}^{\max}, i \in nc \quad (8)$$

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

$$Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max}, i \in ng \quad (9)$$

Inequality constraints of transformers tap setting (T_i):

$$T_i^{\min} \leq T_i \leq T_i^{\max}, i \in nt \quad (10)$$

Inequality constraint of transmission line flow (S_{li}):

$$S_{li} \leq S_{li}^{\max}, i \in nl \quad (11)$$

Where: nc , ng and nt = number of switchable reactive

power sources, generators and transformers.

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

$$best(t) = \min_{j \in (1, \dots, N)} fit_j(t) \quad (12)$$

$$worst(t) = \max_{j \in (1, \dots, N)} fit_j(t) \quad (13)$$

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.

D. Calculation of the Gravitational Constant

To update the Gravitational Constant $G(t)$ the following equation is used:

$$G(t) = G_0 \exp\left(-\alpha \frac{t}{T}\right) \quad (14)$$

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

E. Calculation of the Gravitational Constant

To calculate the value of inertia mass (M) for each agent, the following equation is used:

$$mg_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \quad (15)$$

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

$$Mg_i(t) = \frac{mg_i(t)}{\sum_{j=1}^N mg_j(t)} \quad (16)$$

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

F. Calculation of Acceleration

Next, to calculate the value of acceleration (a) the following equation is used:

$$a_i^d(t) = \frac{F_i^d(t)}{Mg_i^d(t)} \quad (17)$$

G. Tuning of Linear Decreasing Weight (LDIW)

This LDIW is used to control the velocity and maintain balance in affecting the trade-offs between global and local exploration capabilities during the search process and is a parameter of speed decrease to avoid stagnation of particles in a local optimum. If the LDIW value is too large, the system will always explore new areas and consequently the ability to explore local values will diminish thereby failing to find a solution, and if the value of inertia weight is too small, it can get stuck in local optimum. The LDIW equation:

$$w^k = \frac{w_{\max} - k(w_{\max} - w_{\min})}{k_{\max}} \quad (18)$$

where: w_{max} = maximum value, w_{min} = minimum value, k_{max} = maximum iteration, and k = iteration.

In this research, the LDIW value used starts with a large value i.e. 1:02 to explore the global value then dynamically decreases to the minimum LDIW value of 0.2 to explore local values during the optimization process.

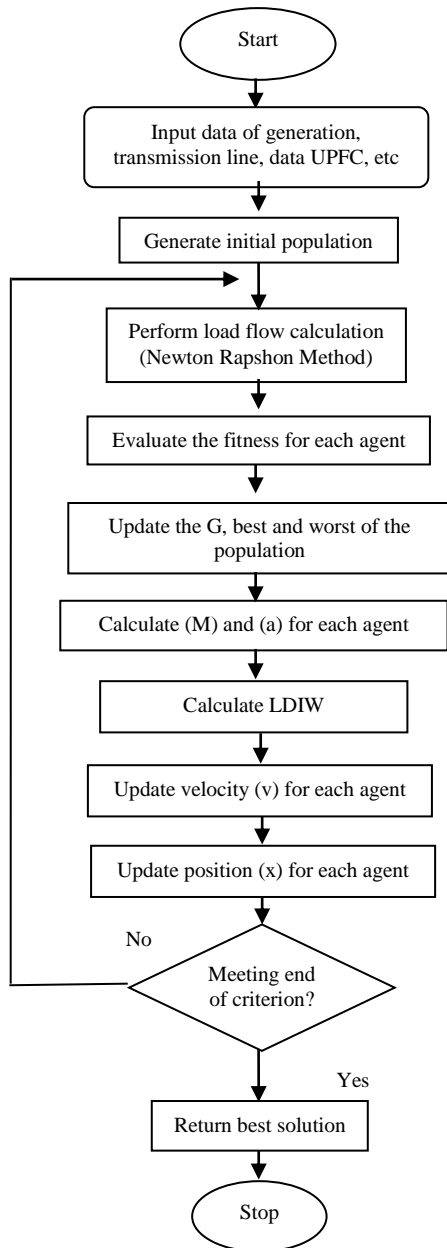


Fig. 4. Flowchart LDIW-GSA

H. Calculation of the Gravitational Constant

To update the velocity (v) the following equation is used:

$$v_i^d(t+1) = \omega^t \times v_i^d(t) + a_i^d(t) \tag{19}$$

Where:

ω^t = linear decreasing inertia weight [0.5 - 0.9].

I. Calculation of Agent Position Mutation

To do agen position mutation (x) the equation is used:

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \tag{20}$$

J. Iteration

In these steps, steps B to I are repeated until the iteration fits the criteria.

The LDIW-GSA algorithm used to determine placement of UPFC location can be seen in Figure 4.

IV. RESULTS AND ANALYSIS

A. Data of Java-Bali 500kV

The Java-Bali 500 kV electrical power system is an interconnected system that transmits power to customers in various areas in Java and Bali. The distributed power comes from the electrical power produced from various sources of hydroelectric power plant (located at Cirata and Saguling plant), steam power plant (located at Suralaya plant, Tanjung Jati, Paiton) and steam gas power plant (consisting of Grati, Muaratawar and Gresik plants). The single line diagram of the electrical power system can be seen in Figure 5.

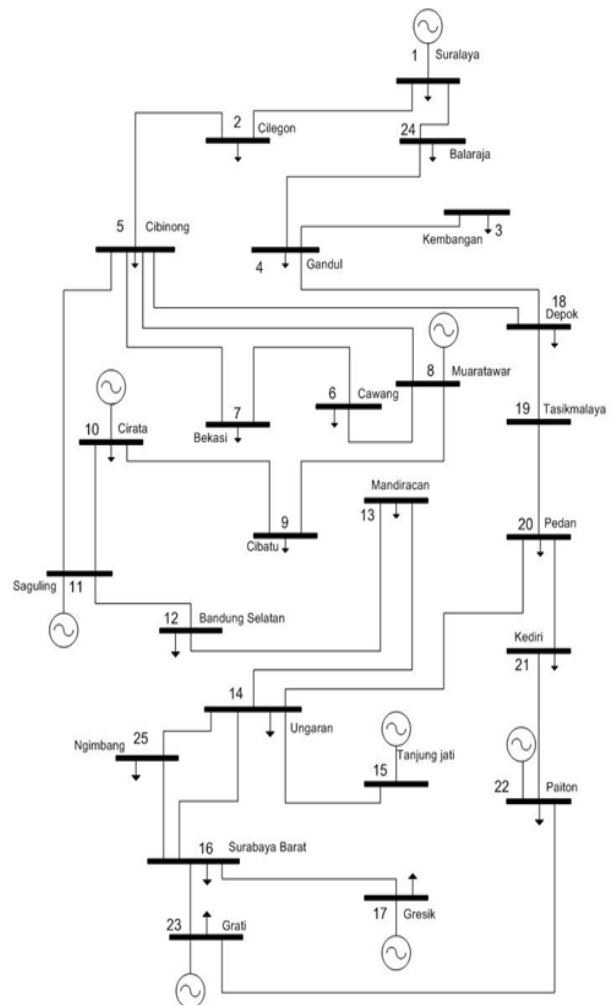


Fig. 5. Single line diagram of Java-Bali 500 kV power system

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 1. DATA LOAD AND GENERATION INTERCONNECTION SYSTEM JAVA-BALI 500 KV

Bus No	Bus Name	Bus code	Generator		Load	
			MW	MVAR	MW	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	1/2 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

B. Result of power flow simulation after installation of UPFC using GSA

The results of convergence curve after UPFC installation using GSA is shown in figure 6, 7, 8 and 9.

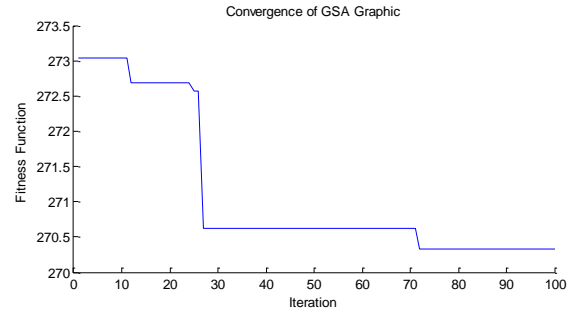


Fig. 6. Convergence after installation of UPFC using GSA

Figure 6 shows the convergence characteristics after UPFC installation using GSA. The convergence characteristics indicate that the tuning of UPFC using GSA is capable of generating a minimum value of active power losses when compared to the condition before the UPFC installation. The value of active power losses is 270.334 MW, and reactive power losses 2913.298 MVAR.

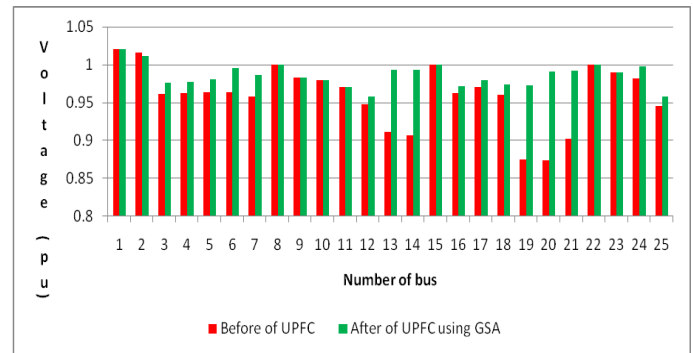


Fig. 7. Comparison of voltage profile before and after installation of UPFC using GSA

Figure 7 shows the results of the comparison between voltage profiles before and after installation of UPFC using the GSA. The rated voltage of the electrical system of Java Bali 500 KV falls on the range of 0.958 pu to 1.020 pu. The highest voltage occurs on bus 1 (Suralaya), i.e. 1.020 pu and the lowest voltage is found on bus 12 (South Bandung) with 0.958 pu. Figure 7 also shows that all the voltages are within the voltage range of 0.95 pu± 1.05 after the installation of UPFC using GSA.

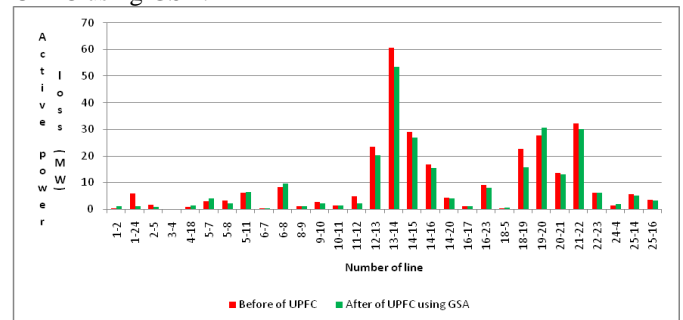


Fig. 8. Comparison of active power losses on the line before and after installation of UPFC using GSA

Figure 8 shows the results of the comparison before and after the installation of UPFC using GSA. The value of active power losses prior to the installation of UPFC was 270.334 MW and reactive power losses 2913.298 MVAR with a power supply of active power plant of 10631.33 MW and reactive power plant 7343.744 MVAR.

C. Result of power flow simulation after installation of UPFC using LDIW-GSA

Results of convergence curve after installation of UPFC using LDIW-GSA is shown in figures 9, 10, and 11.

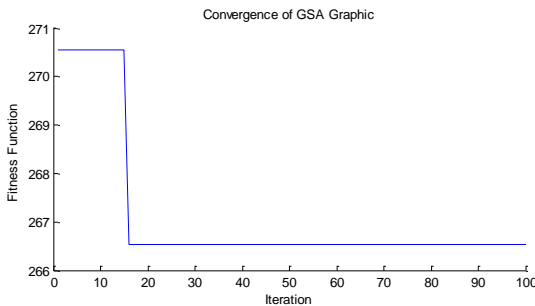


Fig. 9. Convergence after installation of UPFC using LDIW-GSA

Figure 9 shows the convergence characteristics after installation of UPFC using LDIW-GSA. The convergence characteristics indicate that the tuning of UPFC using LDIW-GSA is capable of producing the value of minimum active power losses, when compared to the prior installation of UPFC. The value of active power losses was 266.526 MW and reactive power losses 2786.101 MVAR.

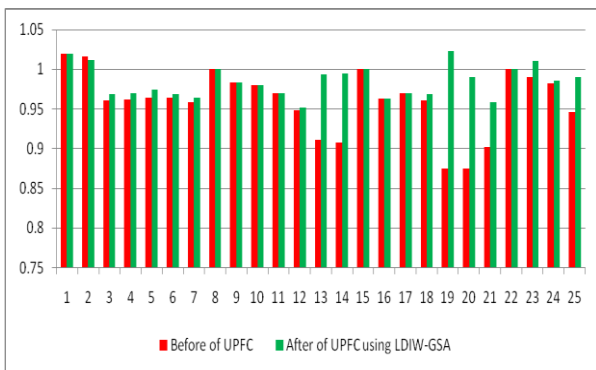


Fig. 10. Comparison of voltage profile before and after installation of UPFC using LDIW-GSA

Figure 10 shows the results of comparison of the voltage profile before and after installation of UPFC using LDIW-GSA. The rated voltage of Java-Bali electrical system is 500 KV which is in the range of 0.952 pu to 1.020 pu. The highest voltage occurs on bus 1 (Suralaya), i.e. 1.020 pu and most lowest voltage occurs on bus 12 (South Bandung) which is 0.952 pu. Figure 11 also shows that all the voltages are within the voltage range of 0.95 ± 1.05 pu after installation of UPFC using the GSA.

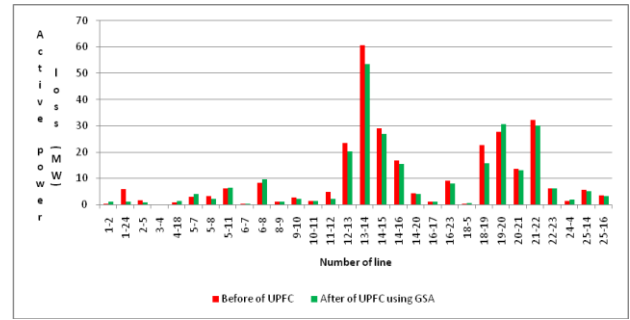


Fig. 11. Comparison of active power losses before and after installation of UPFC using LDIW-GSA

Figure 11 shows the comparison results before and after installation of UPFC using LDIW-GSA. The value of active power losses before installation of UPFC was 266.526 MW and reactive power losses 2786.101 MVAR with a power supply of active power plant of 10627.53 MW and reactive power plant of 7198.201 MVAR.

D. Result of comparison of power flow simulation before UPFC and after installation of UPFC using GSA and LDIW-GSA

To keep the voltage on each bus in the range of 0.95 ± 1.05 pu, and the power flowing on each line smaller than the maximum power, it is necessary to compensate for reactive power by using the UPFC on the transmission line of Java-Bali and the optimization results are indicated in Figures 12 and 14.

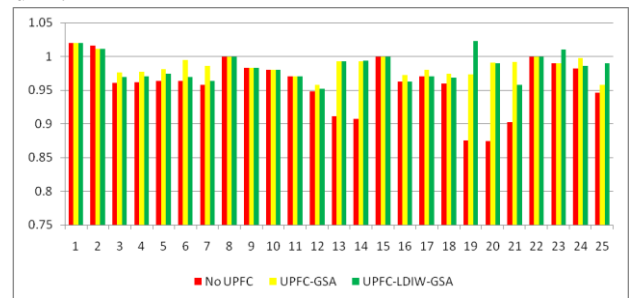


Fig. 12. Comparison of voltage profile before and after installation of UPFC using GSA and LDIW-GSA

Figure 12 shows that after the installation of UPFC using GSA and LDIW-GSA, all rated voltages on the electrical system of Java-Bali 500 KV is better and all the voltages are within the range of 0.95 ± 1.05 pu.

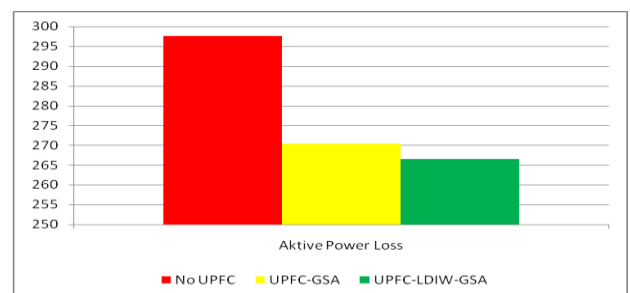


Fig. 13. Comparison of active power losses before and after installation of UPFC using GSA and LDIW-GSA

Figure 13 shows that the comparison results of the lowest active power losses occur on the installation of UPFC using LDIW-GSA UPFC i.e. 266.524 MW and active power losses occur before the installation of UPFC i.e. 297.607 MW.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the Government of Indonesia, especially the Directorate General of Higher Education and the Tanjungpura University for the Competitive Grant of the Research on Decentralization of Higher Educational Institutions. Special thanks also go to the Distribution and Transmission Laboratory, Department of Electrical Engineering, Tanjungpura University, Pontianak, Indonesia for all the facilities made available during this research.

REFERENCES

- [1] Hadi Saadat, "Power System Analysis", Mc.Graw Hill Companies, Singapore, 2004.
- [2] Imam Robandi, "Modern Power System Design", Andi, Yogyakarta, 2006 (Indonesian language).
- [3] Narain G. Hingorani, Laszlo Gyugyi, Mohamed E. El-Hawary, "Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems". John Wiley & Sons, Inc, New York, 2000.
- [4] M. A. Abido, "Power System Stability Enhancement Using Facts Cotrollers: a Review. The Arabian Journal for Science and Engineering", Vol 34, No 2, pp.153-172, ISSN 1319-8025, 2009.
- [5] Umar, Adi Soeprijanto, Mauridhi Hery Purnomo, "Placement Optimization of Multi Facts Devices In South Sulawesi Electrical System Using Genetic Algorithm", National Seminar on Information Technology Applications, Yogyakarta, 2008, ISSN: 1907-5022 (Indonesian language).
- [6] L.J. Cai, I. Erlich, "Optimal Choice and Allocation of FACTS devices using Genetic Algorithms," Proc. on Twelfth Intelligent Systems Application to Power Systems Conference", pp. 1-6, 2003.
- [7] Pisica, C. Bulac, L. Toma, M. Eremia, "Optimal UPFC Placement in Electric Power Systems Using a Genetic Algorithms Based Method", Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania.
- [8] B. Bhattacharyya, B.S.K. Goswami, "Optimal Placement of Facts Devices Genetic Algorithm for the Increased Load ability of a Power System", World Academy of Science, Engineering and Technology, 2011.
- [9] Siti Amely Jumaat, Ismail Musirin, Muhammad Mutadha Othman, dan Hazlie Mokhlis, "Optimal Location and Sizing of UPFC Using Particle Swarm Optimization Technique", First International Conference on Informatics and Computational Intelligence (ICI), Universitas Parahyangan, Bandung, 2011.
- [10] E. Rashedi, H. Nezamabadi-pour, S. Saryazdi, "GSA: A gravitational search algorithm," Information Sciences, 2009, vol. 179, pp. 2232-2248.
- [11] Budi Santosa dan Paul Willy, "Metaheuristics Method Concepts and Implementation", Guna Widya Publishers, 2011, ISBN: 979545049-2 (Indonesian language).
- [12] Purwoharjono, Ontoseno Penangsang, Muhammad Abdillah dan Adi Soeprijanto, "Voltage Control on Java-Bali 500kV Electrical Power System for Reducing Power Losses Using Gravitational Search Algorithm" , International conference on informatics and computational