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Optimal Power Flow Using Particle Swarm Optimization Hybrid Inertia Weight and Constriction Factor Algorithm (PSOHIC) Case Study: Thermal Generator System of 150 kV Sulbagsel

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Abstract. The increasing use of electricity encourages electricity scientists to create or build mathematical models to improve the quality of electric power. This study uses IEEE 26 bus system data to validate the method and 150 kV thermal generator data from the South Sulawesi (Sulbagsel) system as a case study. The method used is PSOHIC. The simulation results for the 150 kV Sulbagsel system data show that PSOHIC converges more quickly, namely in the 8th iteration. The standard PSO converges at the 25th iteration. The IPSO algorithm converges at the 20th iteration. At the same time, the MIPSO algorithm converges at the 12th iteration. The power flow simulation results show that with PSOHIC, the power loss of 16.48 MW is smaller than the current system of 19.10 MW, that is, the power loss is reduced by 0.1613%. The production cost with PSOHIC is IDR 281,860.91/hour, cheaper than MIPSO, IPSO and PSO.

Keywords: PSOHIC, optimal power flow, update velocity.

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1 Introduction

The fulfillment of electricity needs plays an important role in the development of the country in general and in particular as a driver of economic activity in realizing a just and prosperous society. Electricity demand increases from time to time along with increased economic activity in a region and the welfare of the population. The dynamics of electricity consumption growth can also be used as an indicator of regional development. Electricity needs that continue to increase absolutely must be prepared by offering a more appropriate electrical system in terms of quantity and quality.

Calculation of power flow is basically a calculation of the magnitude of the voltage and voltage phase angle at each substation at steady state and the three phases are balanced. Based on the results of these calculations, the amount of active and reactive power of each transmission device, the amount of active and reactive power of each generation center and the amount of power loss in the system are calculated. Each bus has 4 (four) operating variables, namely active power, reactive power, voltage magnitude and voltage phase angle. To calculate the power flow equation of each bus, 2 (two) of the 4 (four) variables above must be known, the remaining 2 (two) variables are calculated. The load bus is a known variable that is active power, reactive power. Voltage magnitude and voltage phase angle are calculated. Generator bus active power and voltage are known variables, while reactive power and voltage phase angle are the result of calculation. The slack bus is a known variable consisting of the magnitude of the voltage and the phase angle of the voltage, which is the reference angle, while the active power and reactive power to be compensated are the result of the calculation. There are two general methods used to solve power flow, namely the Gauss-Seidel method and the Newton-Raphson Method [1], [2].

1.1 Input output characteristics of thermal plants

This characteristic shows the relationship between the input of the generator as a function of the output of the generator. The equation of the input-output characteristics of a generator expresses the relationship between the amount of fuel required to produce a certain power of a power plant.

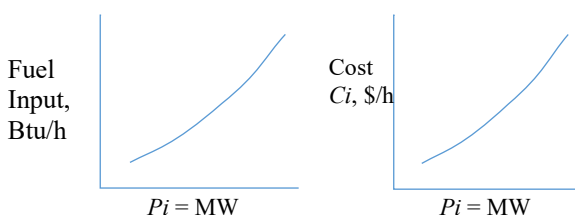


Fig.1. Thermal plant input-output curve
The figure above shows the input-output characteristics of an ideal thermal plant, which is represented as a

continuous nonlinear curve. The generator input is indicated on the vertical axis, that is, the thermal energy required in MBtu/h, since the British thermal unit is used (if SI is used, it becomes MJ/h or kcal/h), which can also be expressed as the total price per hour (Rp/h). The horizontal axis shows the limit minimum and maximum generator powers [1], [3], [4].

1.2 Gauss Seidel Method

Mathematically, the Gauss Seidel method can be illustrated as follows [1],

$$f(x) = 0 \quad (1)$$

The above function is reformulated and written as

$$x = g(x) \quad (2)$$

If $x^{(k)}$ is the initial estimate of the variable x , then the following iterative sequence can be formed as

$$x^{(k+1)} = g(x^{(k)}) \quad (3)$$

A completion can be obtained when the difference between the absolute values of successive iterations is less than the specified accuracy, i.e.,

$$|x^{(k+1)} - x^{(k)}| \leq \epsilon \quad (4)$$

1.3 Newton Raphson Method

Newton Raphson method is formulated as [1], [5], [6].

$$f(x) = c \quad (5)$$

If $x^{(0)}$ is an initial approximation of the solution, and $\Delta x^{(0)}$ as a small difference from the proper solution, then

$$f(x^{(0)} + \Delta x^{(0)}) = c \quad (6)$$

if the left side in the Taylor series above is extended then make $x^{(0)}$ yields

$$f(x^{(0)}) + \left(\frac{df}{dx}\right)^{(0)} \Delta x^{(0)} + \frac{1}{2!} \left(\frac{d^2f}{dx^2}\right)^{(0)} (\Delta x^{(0)})^2 + \dots = c \quad (7)$$

with a very small approximate error of $\Delta x^{(0)}$, then the higher order terms can be ignored and produce

$$\Delta c^{(0)} \simeq \left(\frac{df}{dx}\right)^{(0)} \Delta x^{(0)} \quad (8)$$

where,

$$\Delta c^{(0)} = c - f(x^{(0)})$$

The addition of $\Delta x^{(0)}$ to the initial estimate can produce a second estimate

$$x^1 = x^{(0)} + \frac{\Delta c^{(0)}}{\left(\frac{df}{dx}\right)^{(0)}} \quad (9)$$

Successive applications of the above methods can produce the Newton-Raphson algorithm as follows.

$$\Delta c^{(k)} = c - f(x^{(k)}) \quad (10)$$

$$\Delta x^{(k)} = \frac{\Delta c^{(k)}}{\left(\frac{df}{dx}\right)^{(k)}} \quad (11)$$

$$x^{(k+1)} = x^{(k)} + \Delta x^{(k)} \quad (12)$$

$$\Delta c^{(k)} = j^{(k)} \Delta x^{(k)} \quad (13)$$

where,

$$j^{(k)} = \left(\frac{df}{dx}\right)^{(k)}$$

$$\Delta x^{(k)} = \frac{\Delta c^{(k)}}{\left(\frac{df}{dx}\right)^{(k)}} \quad (14)$$

1.4 Particle Swarm Optimization (PSO)

The computational algorithm and formula of the standard PSO algorithm introduced by James Kennedy and Russel Eberhart in 1995 can be seen in the following illustration and equation [7], [5], [8], [9].

$$vx[[] = vx[[] + 2 * rand() * (pbestx[[] - presentx[[]]) + 2 * rand() * pbestx[[] - presnt[[]]] \quad (15)$$

$$V_i^{k+1} = V_i^k + c_1 rand_1(Pbest_i^k - X_i^k) + c_2 rand_2(Gbest^k - X_i^k)$$

where:

- V_i^k = individual velocity i at iteration k
- c_1, c_2 = acceleration coefficient
- $rand_1, rand_2$ = random number between 0 and 1
- X_i^k = individual position i at iteration k
- $Pbest_i^k$ = $Pbest$, the best individual particle i to iteration k
- $Gbest^k$ = $Gbest$, the best group to iteration k

1.5 IPSO Formula

Improved particle swarm optimization (inertia weight method) [10], [11], [12], [13], can be seen as follows.

$$V_i^{k+1} = W * V_i^k + c_1 rand_1(Pbest_i^k - X_i^k) + c_2 rand_2(Gbest^k - X_i^k) \quad (17)$$

$$W = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \quad (18)$$

1.6 MIPSO Formula

Modified improved particle swarm optimization method [14], [15] [16], [2], [15], [17], [18], [19], can be seen as the following formula.

$$V_i^{k+1} = C * V_i^k + c_1 rand_1(Pbest_i^k - X_i^k) + c_2 rand_2(Gbest^k - X_i^k)$$

$$C = \frac{2k}{2 - \emptyset - \sqrt{|\emptyset^2 - 4\emptyset|}} \quad (20)$$

$$\emptyset = c_1 + c_2$$

for $k = 1$, and $c_1 = c_2 = 2,05$, C value = 0,729.

1.7 PSOHIC Formula

Particle Swarm Optimization Hybrid Inertia Weight and Constriction Factor (PSOHIC) Algorithm Method [10], formulated as follows.

$$V_i^{k+1} = C * w * V_i^k + (c_1 rand_1(Pbest_i^k - X_i^k) + c_2 rand_2(Gbest^k - X_i^k)) \quad (21)$$

2 Material and Method

2.1 IEEE 30-bus System Data

In this study, IEEE 30-bus [1] data was used as validation of PSOHIC method used in the case study.

Table 1. IEEE 30-bus system data

Bus No	Bus code	Volt. Mag.	Angle Deg.	Load		Generator	
				(MW)	(MVAR)	(MW)	(MVAR)
1	1	1,06	0	0	0,0	0	0
2	2	1,043	0	21,70	12,7	40	0
3	0	1	0	1,2	1,2	0	0
4	0	1,06	0	7,6	1,6	0	0
5	2	1	0	94,2	19,0	0	0
6	0	1	0	0	0	0	0
7	0	1	0	10,9	10,9	0	0
8	2	1,01	0	30,0	30,0	0	0
9	0	1	0	0	0	0	0
10	0	1	0	5,8	2,0	0	0
11	2	1,082	0	0	0	0	0
12	0	1	0	11,2	7,5	0	0
13	2	1,71	0	0	0	0	0
14	0	1	0	6,2	1,6	0	0
15	0	1	0	8,2	2,5	0	0
16	0	1	0	3,5	1,8	0	0
17	0	1	0	9,0	5,8	0	0
18	0	1	0	3,2	0,9	0	0
19	0	1	0	9,5	3,4	0	0
20	0	1	0	2,2	0,7	0	0
21	0	1	0	17,5	11,2	0	0
22	0	1	0	0	0	0	0
23	0	1	0	3,2	1,6	0	0
24	0	1	0	8,7	6,7	0	0
25	0	1	0	0	0	0	0
26	0	1	0	3,5	2,3	0	0
27	0	1	0	0	0	0	0
28	0	1	0	0	0	0	0
29	0	1	0	2,4	0,9	0	0
30	0	1	0	10,6	1,9	0	0

Source : Hadi Saadat, page 226.

2.2 Sulbagsel Data

This system consists of 29 buses, 35 transmission lines and 12 generators consisting of 9 thermal generators, 2 wind power plants and 3 hydro power plants. Only 4 bus generators are used in the simulations, namely Bus 1 Tello (PLTD Tello), Bus 19 Punagaya (PLTU Jenepono), Bus 19 Parepare (PLTD Suppa) and Bus 25 Sengkang (PLTU Sengkang). This is because there are several buses that are not in operation at that time, namely the Balusu Bus, Tallasa Bus, Tallo Lama Bus, Masamba Bus and Sungguminasa Bus. The peak load bus data, transmission line data, thermal fuel cost function, and power limitation of each plant are shown in Table 2, 3, 4, and 5, respectively. For thermal fuel cost function is a cost function in the previous study on [2]. The Data used was at the peak load time at 14.00 WITA on December 4, 2017 [11].

Table 2. Daytime peak load bus data 150 kV 29 bus Sulbagsel system

No. bus	Code bus	Load		Generator	
		(MW)	(MVAR)	(MW)	(MVAR)
1	2	32,40	8,40	34,00	13,2

2	0	40,50	13,10	0,00	0,00
3	0	65,10	15,40	0,00	0,00
4	0	16,40	7,60	0,00	0,00
5	0	24,35	8,12	0,00	0,00
6	0	16,20	8,00	0,00	0,00
7	0	5,96	2,14	0,00	0,00
8	0	1,60	0,70	0,00	0,00
9	0	13,70	6,00	0,00	0,00
10	0	43,10	15,20	0,00	0,00
11	0	21,50	9,00	0,00	0,00
12	0	13,40	5,00	0,00	0,00
13	1	0,00	0,00	203,80	59,70
14	0	11,10	4,40	0,00	0,00
15	0	6,00	2,10	0,00	0,00
16	0	19,80	7,70	0,00	0,00
17	0	10,10	3,90	0,00	0,00
18	0	24,50	10,30	0,00	0,00
19	2	17,50	5,70	51,10	7,50
20	2	22,90	10,10	0,00	0,00
21	0	3,365	0,70	0,00	0,00
22	0	1,30	0,20	0,00	0,00
23	0	29,70	12,50	0,00	0,00
24	0	11,00	4,60	0,00	0,00
25	2	21,00	8,50	243,40	-5,80
26	0	4,10	3,50	0,00	0,00
27	0	18,00	8,10	0,00	0,00
28	0	8,40	2,50	0,00	0,00
29	0	10,49	2,60	0,00	0,00

Description of bus name number:

1.Tello (PLTD Tello), 2.Tallo Lama, 3.Panakukang, 4.Kima, 5.Bosowa, 6.Pangkep, 7.Barru, 8.Balusu, 9.Sungguminasa, 10.Tanjung Bunga, 11.Maros, 12.Tallasa, 13.Punagaya (PLTU Jeneponto), 14.Jeneponto, 15.Bantaeng, 16.Bulukumba, 17.Sinjai, 18.Bone, 19.Parepare (PLTD Suppa), 20.Pinrang, 21.Polmas, 22.Bakaru, 23.Sidrap, 24.Soppeng, 25.Sengkang (PLTU Sengkang), 26.Makale, 27.Palopo, 28.Majene, 29.Mamuju.

Table 3. Data transmission 150 kV 29 bus Sulbagesel system

From Bus	To Bus	R (pu)	X (pu)	1/2B (pu)
1	2	0,00726	0,02600	0,00088
1	3	0,04334	0,07958	0,00006
1	9	0,00385	0,02635	0,00124
4	1	0,00845	0,03024	0,00380
5	1	0,04764	0,17071	0,00575
6	4	0,00845	0,03024	0,00380
6	5	0,04764	0,17071	0,00575
7	6	0,02419	0,08667	0,01167
8	7	0,01173	0,03919	0,00493
9	10	0,00707	0,04256	0,00136
9	11	0,05433	0,37234	0,01756
9	12	0,00970	0,06649	0,00314
12	13	0,01756	0,04609	0,00217
12	14	0,03241	0,13837	0,01973
13	14	0,00970	0,06649	0,00314
14	15	0,02000	0,08000	0,00000
15	16	0,03000	0,09000	0,00000
16	17	0,03120	0,11211	0,00882

16	18	0,03120	0,11211	0,00882
17	18	0,01149	0,14603	0,01149
18	24	0,04578	0,16306	0,00402
19	8	0,01000	0,07946	0,00396
19	23	0,02003	0,07198	0,00142
20	19	0,01388	0,04974	0,00067
21	19	0,03663	0,13159	0,01819
21	28	0,05261	0,18902	0,00372
22	20	0,03076	0,11023	0,010112
22	21	0,02627	0,09440	0,00743
23	24	0,02106	0,20275	0,00482
23	25	0,01058	0,07259	0,00342
23	26	0,06274	0,37753	0,01203
23	11	0,01235	0,08464	0,00399
24	25	0,02106	0,12670	0,00402
26	27	0,03917	0,14076	0,00277
28	29	0,03076	0,11023	0,01012

Table 4. Thermal generator cost function

No Bus	Cost Function (Rp/Jam)x1000
1	$5391,25165 + 125,126P + 8,6506P^2$
13	$1984,8054118 + 36,403P + 2,0000P^2$
19	$2088,05767 + 79,751P + 7,5896P^2$
25	$613,69908739 + 37,951P + 7,5896P^2$

Table 5. Thermal generating power limitation

Unit Bus	Pmax (MW)	Pmin (MW)
1	19,75	110,00
13	55,58	250,00
19	15,00	62,50
25	60,85	315,00

2.3 Method

The method used in this study is particle swarm optimization hybrid inertia weight and constriction factor (PSOHIC).

The stages of research can be seen in the following flow chart.

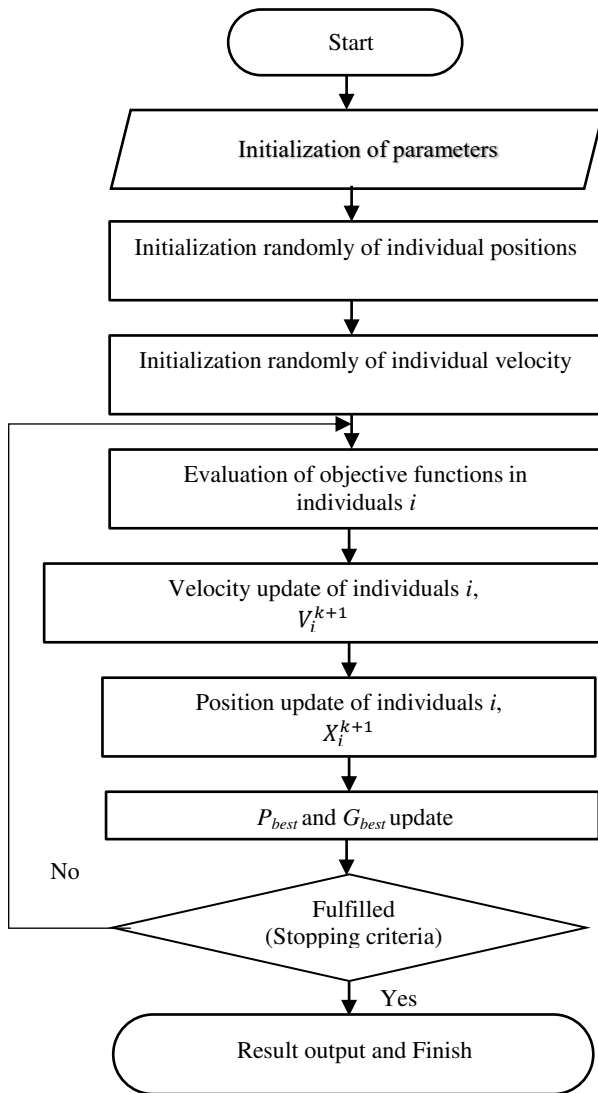


Fig.2 PSOHIC Flowchart

3 Results and Discussion

The results of the study present the IEEE system data as validation of the model used, and the 150 kV Sulbagsel system data. The first step in this study is to test the power flow solution with IEEE 30 bus data as validation of PSOHIC method, the second step is to calculate the power flow solution using particle swarm optimization hybrid inertia weight algorithm and constriction factor algorithm as a case study.

3.1 Results of 30-bus IEEE data simulation

30-bus IEEE data used as validation of PSOHIC method by comparing the standard PSO, update velocity using inertia weight and update velocity using constriction factor. For more details can be seen in the convergence graph of each of the following methods.

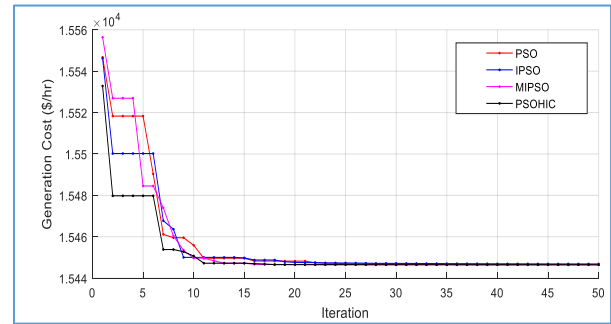


Fig.3. Comparison of data simulation results IEEE update velocity standard PSO, IWA, CFA, and PSOHIC.

The graph of the research results shows that PSOHIC (Hybrid Inertia Weight with Constriction Factor) converges faster in the 11th iteration. The standard PSO converges on the 23rd iteration. The IPSO algorithm converges at the 20th iteration. At the same time, the MIPSO algorithm converges at the 15th iteration. The power flow simulation results are shown in the following table.

Table 6. 26-bus IEEE data power flow comparison

Bus		Generator		Velocity Update			
No.	Kode	MW min	MW max	PSO (MW)	IPSO (MW)	MIPSO (MW)	PSOHIC (MW)
1	1	100	500	476.24	447.04	446.01	447.04
2	2	50	200	184.55	171.45	171.61	171.43
3	2	80	300	247.13	262.06	261.12	262.06
4	2	50	150	146.91	135.22	134.69	135.16
5	2	50	200	145.99	175.81	180.61	175.89
26	2	50	120	75.03	84.24	81.76	84.25
Power generation (MW)				1,275.85	1,275.81	1,275.80	1,275.81
Power losses (MW)				12.85	12.81	12.80	12.81
Generation costs (\$/hr)				15,466.89	15,446.74	15,447.02	15,446.74
Convergence (iteration)				23	20	15	11

The results of the IEEE 30-bus system power flow study show that the power flow is within the generation limit. The results of the convergence of each update velocity are different, namely: the standard PSO converges at the 23rd iteration, the IPSO algorithm at the 20th iteration, the MIPSO algorithm converges at the 15th iteration. At the same time, the 11th iteration of the PSOHIC (Particle Swarm Optimization Hybrid Inertia Weight and Constriction Factor) algorithm converges. The power loss using the PSOHIC method is 12.81 MW/hour, less than 15.53 MW/hour in the current system (Hadi Saadat), or the power loss is reduced by 0.1751%. The cost of generation using the PSOHIC method is \$ 15,446.74 per hour, lower than the current system of \$ 16,760.73 per hour (Hadi Saadat) or a cost savings of 0.0789%. PSOHIC's success in the IEEE system power flow solution will be used as an indicator for testing or use in a case study of the Sulbagsel 150 kV system.

3.2 Simulation results of 150 kV Sulbagsel bus thermal plant data system

After testing or validating the PSOHC method using IEEE-30-bus data, the method is applied to the Sulbagsel 150 kV 29-bus system which is integrated with a wind power plant (PLTB) as a case study. This power flow simulation uses data from four thermal generators, namely the Tello, Punagaya, Suppa and Sengkang generators. The power flow study results are shown in the following diagram.

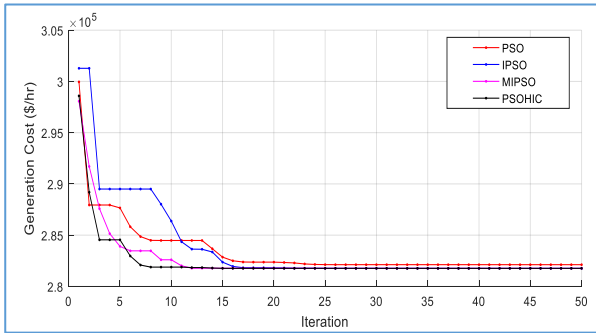


Fig.4. Comparison of data simulation of Sulbagsel update velocity PSO standar, IWA, CFA, dan PSOHC.

The results of the research plot show that PSOHC converges faster, namely in the 8th iteration. The standard PSO converges at the 25th iteration. The IPSO algorithm converges at the 20th iteration. At the same time, the 12th iteration of the MIPSO algorithm converges. The power flow simulation results are shown in the following table.

Tabel 7. 29-bus 150 kV thermal of Sulbagsel system data power flow comparison

Bus		Generator		Velocity Update			
No	Kode	MW min	WM max	PSO (MW)	IPSO (MW)	MIPSO (MW)	PSOHC (MW)
1	2	19.8	110.0	57.33	53.61	52.57	53.20
13	1	55.6	250.0	229.70	229.05	228.49	228.25
19	2	15.0	62.5	56.64	61.14	61.76	61.73
25	2	60.9	315.0	186.24	186.17	187.19	186.77
Power generation (MW)				529.92	529.96	530.00	529.95
Power losses (MW)				16.45	16.50	16.54	16.48
Generation costs (Rp/hr)				282,220.82	281,868.02	281,865.10	281,860.91
Convergence (iteration)				25	20	12	8

The power flow simulation results in the table above show that with PSOHC, the power loss is 16.48 MW less than 19.27 MW with the existing system. The cost of generating using PSOHC is 281,860.91 Rp/hour, cheaper than MIPSO, IPSO and PSO.

4 Conclusions

Research analysis of the Sulbagsel 150 kV thermal generating system was carried out in two stages using the PSOHC method. Each step is carried out with two types of data, namely IEEE data in the Power System Analysis book by Hadi Saadat as a validation for the PSOHC method. While the 150 kv system data from

Sulbagsel as a case study. The results of power flow research using PSOHC can be concluded as follows.

1. The PSOHC method validation results show that the power loss of 12.81 MW/hour is lower than the current IEEE system data of 15.53 MW/hour. At the same time, the production cost for the PSOHC method is 15,446.77 \$ per hour, lower than the current IEEE data of 16,767.73 \$ per hour. From the validation results of the PSOHC method used, it was concluded that PSOHC can be applied to a case study of the 150 kV Sulbagsel system.
2. The power flow simulation results in the case study of the Sulbagsel 150 kV thermal generating system using PSOHC show a generation power of 529.95 MW, with a power loss of 16.48 MW per hour. The generation cost is Rp. 281,860.91 per hour. PSOHC converges on the 8th iteration lower than MIPSO on the 12th iteration, IPSO on the 20th iteration, and PSO on the 25th iteration.

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