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Optimal Power Flow Model Integrated Electric Power System with Wind Power Generation - Case Study: Electricity System South Sulawesi-Indonesia

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Abstract: The large number of uses of electrical energy encourage humans to identify and utilize new primary energy sources such as wind power. However, wind energy is unstable which can affect the stability of power flow in conventional power systems. The intermittent wind energy prompted the development of power flow analysis methods. In this study, the IEEE 26 bus data system is used as a method validation, and the 150 KV 29 bus data system in South Sulawesi which is integrated with wind power plants as a case study. The method used is the hybrid update velocity inertia weight algorithm (IWA) and the constriction factor algorithm (CFA) abbreviated as PSOHIC. The simulation results of the South Sulawesi system data integrated with the wind power plant show that PSOHIC converges at the 9th iteration faster than IWA in the 29th iteration and CFA in the 20th iteration. The power loss using the PSOHIC method of 18,155 WM/h is lower than the existing system, which is 19,267 WM/h, or the power loss has decreased by 5,7691%. The generation cost using PSOHIC is 5.986,917 $/h, smaller than the existing system, which is 6.428,61 $/h, or the generation cost has decreased by 6,784%.

Keywords: PSOHIC, Optimal power flow, Update velocity.

Abbreviations

PSO	=	Particle swarm optimization.
IWA	=	Update velocity PSO using inertia weight algorithm.
CFA	=	Update velocity PSO using constriction factor algorithm.
IPSO	=	Improved particle swarm optimization using inertia weight algorithm.
PSOHIC	=	Particle swarm optimization of the velocity update hybrid using inertia weight algorithm and the constriction factor algorithm.

1. Introduction

Today's demand for electrical energy is increasing, which motivates humans to seek and use new primary energy sources. This is an indication that renewable energy is the best solution that can be accepted and implemented. Wind energy is one solution to overcome the increasing demand for electrical energy. However, energy of wind is not constant so it can cause instability in the power system. It is a challenge to research power system integration, energy conversion, and power quality for obtain optimal power flow in systems that are integrated with wind power plants.

The system of generation, transmission, and distribution is an integral part of the electrical system. To improve the quality of the power flow contained in the system can be done with various types of optimization methods [1 - 3]. The function of calculating the maximum power quality is to determine the best way of operating the power system [5 - 7]. In 1979 carpentier introduced the optimal power flow analysis as a continuation of the problem of economic dispatch in power generation systems [8]. Newton Raphson method is one method that is widely used to solve power flow [9].

Today the integration of renewable energy into power systems is a topic of much research. One of the primary energy sources that are challenging to research and analyze is wind energy. Wind energy

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Table 1. IEEE 26 generation limit data

Generators		Generator limits	
No.	Bus	Pmin (MW)	Pmax (MW)
1	1	100	500
2	2	50	200
3	3	80	300
4	4	50	150
5	5	50	200
6	26	50	120

Source: Power system analyst book, Hadi Saadat

produces unstable electrical energy, so a solution or method is needed to predict the power generated [10]. Intermittent wind energy can affect voltage stability [11, 12, 13]. Synchronization of the power system with unstable wind primary energy is something that must be met to achieve quality and optimal power flow.

From 1995 until now, the particle swarm optimization method is still widely used in electrical calculations. In solving multivariable optimization, each particle is assumed to have two habits, namely position, and velocity. The herd moves in a given space and always remembers the best position ever found for a food source or destination function. Particles provide information or their best position to other particles around them [14]. The combination of different methods with PSO on various objective functions in electrical analysis and evaluation [15, 16].

In this study, the particle swarm optimization (PSO) method with the hybrid inertia weight (IWA) algorithm and the constriction factor (CFA) algorithm in velocity updates was used. In general, the use of IWA affects the search for solutions when approaching Pbest and Gbest. The weakness of this method is that the convergence process takes a long time, and the power flow is often out of the generating power limit. Update velocity with CFA results in faster convergence. Although this method converges faster, it also has problems in terms of power flow. Sometimes the generation costs and power losses are low, but the power flow to the system is out of the generation power limit. In general, these two methods can be used in the calculation of generation costs that consider power losses, but must take into account the limitations of generating power. The weaknesses described above are very common, so the generation power limit is rarely shown. The capabilities and weaknesses of IWA and CFA became the basic idea to combine these two methods so that the Pbest, Global, and convergent solution search results were obtained faster. The inertia weight algorithm which is hybridized with the constriction factor algorithm on PSO (PSOHIC) is expected to provide a solution to the personal best and global best which converges faster and the power flow in the interconnected system is at the power generation limit [17].

2. Materials and methods

2.1 Materials

The data used in this study are IEEE 26 buses taken from the book Power system analyst hadi saadat, and data from the South Sulawesi system which is integrated with the wind power plant, namely 29 buses, 4 thermal generators, 2 wind generators, and a 150 kV system. IEEE data simulation is used to validate the PSOHIC method. PSOHIC was applied to the data system of South Sulawesi Indonesia as a case study to determine the optimal power flow of the system.

2.1.1. IEEE 26 bus data system

The data used to validate the PSOHIC method is the IEEE 26 bus. This is taken from the book Power System Analysis compiled by Hadi Saadat. These data are widely used by researchers working in the electrical field to test methods in the process of compiling computational coding [18].

In calculating the optimal power flow, the data used include bus data, transmission network data, fuel data, generation limit data, and others. The generation limit data is used to assess the power flow in the system under test. The data on the generation limit can be seen in the following Table 1.

2.1.2. South Sulawesi electricity system

The South Sulawesi electricity system consists of 29 buses, 35 transmission lines, and 14 generators consisting of 9 thermal generators, 2 wind power plants, and 3 hydropower plants. In the simulation research, only 4 thermal generator buses and 2 wind generator buses are used. This is because several buses were not operating during data retrieval. The data used is the peak load data at 14.00 WITA. Data on thermal generator generators for 150 KV systems integrated with wind power plants, namely PLTD Tello, PLTU Punagaya (Slack bus), PLTU Suppa, and PLTU Sengkang. Meanwhile, data on wind power plants are PLTB Sidrap, and PLTB Tolo Jeneponto [19, 20]. The bus data, transmission line data, and generation limit data can be seen in the following Table 2.

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Table 2. South Sulawesi system data bus

Bus		Load		Generators	
No	Code	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	2	1.00	0.00	60.00	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	0	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	2	0.00	0.00	75.00	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

Table 3. Line data of South Sulawesi 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	0.01011
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. South Sulawesi 29 bus generation limit data

Generators		Generator limits	
No.	Bus	Pmin (MW)	Pmax (MW)
1	1	19.750	110.000
2	13	60.850	315.000
3	14	0.000	60.000
4	19	15.000	62.500
5	23	0.000	75.000
6	25	55.580	250.000

The data for the South Sulawesi transmission line system can be seen in the following Table 3.

The data on the generation limit of the South Sulawesi electricity system can be seen in the following Table 4.

2.2. Methods

2.2.1. Standard of particle swarm optimization

The rationale for PSO is the pattern of animal behavior, in this case birds or fish. Groups of birds or fish are observed in the process of foraging. Each bird remembers its best location or flight path and informs the group of the best flight path. This observation inspired Kennedy and Eberhart 1995 to develop the concept of optimization in mathematical form. The mathematical concepts can be seen as follows.

vx [ ][ ] = vx [ ][ ] + 2 × rand( ) × (pbestx [ ][ ] – present [ ][ ] + 2 × rand ( ) × (pbestx[ ][gbest] – present [ ][ ])

The above mathematical concepts are formulated as follows.

$$V_i^{k+1} = V_i^k + c_1 rand_1 \times \left(Pbest_i^k - X_i^k \right) + c_2 rand_2 \times \left(Gbest^k \; X_i^k \right) \quad (1)$$

2.2.2. Particle swarm optimization using inertia weight algorithm (IWA)

In 1998 Y. Shi and R. Eberhart in MPSO [21, 22, 23], modified the PSO velocity update using the energy weight algorithm. Each particle has a velocity *Vi*, and a position *Xi*. The velocity *Vi* and the position *Xi*, that *i-th* particle in the n-dimensional search space can be written as $V_i = (v_{i1}, v_{i2}, \dots, v_{in})$ and $X_i = (x_{i1}, x_{i2}, \dots, x_{in})$.

Each particle has a memory in its best position in the search zone it finds now *(Pbest$_i$)*, the particle remembers its best location and informs it, until all particles know it *(Gbest)*. $Pbest = (X_{i1}^{Pbest}, X_{i2}^{Pbest}, \dots, X_{in}^{Pbest})$ and $Gbest = (X_1^{Gbest}, X_2^{Gbest}, \dots, X_n^{Gbest})$ are the position of individual *i* and all individuals. Each stage, the *i-th* speed will be updated using the following formula.

$$V_i^{k+1} = W \times V_i^k + c_1 rand_1 \times \left(Pbest_i^k - X_i^k \right) + c_2 rand_2 \times \left(Gbest^k \; X_i^k \right) \quad (2)$$

Where: V_i^k is the velocity of individual *i* in iteration *k*, *W* is the inertia weight parameter, X_i^k is individual position *i* in iteration *k*, $Pbest_i^k$ is individual position *i* in iteration *k*, $Gbest^k$ is best position group in iteration *k*. In the process of updating this velocity, the coefficients of acceleration c_1, c_2, Meanwhile, r_1, r_2 is values 0 - 1. The formula for calculating the inertia weight is as follows.

$$W = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (3)$$

Where: The first inertia weight is symbolized by W_{max}, and the symbol for the final inertia weight is W_{min}. The iteration performed as a whole is given the symbol Ite_{rmax}, and the iteration performed now is given the symbol *Iter*.

The formula for calculating is Eq. (3) this formula is called the inertia weight algorithm (IWA). The use of the IWA formula affects the search for *Pbest* and *Gbest* solutions. All individuals move from their current position to the next. The movement is calculated using a modified position and velocity formula. The modified formula for movement and position can be seen as follows.

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (4)$$

2.2.3. Particle swarm optimization using constriction factor alogithm (CFA)

In 2002, Maurice Clerc and James Kennedy in the journal entitled "The Particle Swarm Explosion, Stability, and Convergence in a Multidimensional Complex Space introduced a narrowing factor algorithm for velocity updates in PSO" [24, 25]. He explained that the use of CFA was used to ensure the convergence speed of the PSO algorithm. The CFA formula can be seen as follows.

$$V_i^{k+1} = K\left[V_i^k + c_1 rand_1 \times \left(Pbest_i^k - X_i^k\right) + c_2 rand_2 \times \left(Gbest^k - X_i^k\right)\right] \quad (5)$$

The constriction factor is calculated using the following formula.

$$K = \frac{2k}{2 - \varphi - \sqrt{|\varphi^2 - 4\varphi|}} \quad (6)$$

Where: $\varphi = c_1 + c_2$, and φ must be greater than 4

In order for the system to converge faster, the p value can be adjusted. However, it should be noted that the CFA value must be greater than 4. However, when determining or setting the p value, it is important to remember that if the p value is too high, the CFA will decrease, resulting in diversification and slow response. To overcome this problem, the p value is adjusted in stages to get the most ideal CFA or K value, which is 0.729.

2.2.4. Generation cost

Economic dispatch is an optimization objective function in the calculation of generation costs. The objective function in question is to reduce costs by considering the related variables are still being met [26]. More details about the ED formula can be seen as follows.

$$FT = \sum_{i=1}^{N} F_i(P_i) \quad (7)$$

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Where: *FT* is the analyzed generation cost, *N* is the number of generators in the system, *Fi* is the cost calculation performed for each generator *i*. In calculating the cost function of thermal generators, we can use the second-order polynomial formula with the following formula.

$$F_i(P_i) = a_i + b_iP_i + c_iP_i^2 \quad (8)$$

Where: *Pi* is every generator that is active and produces electrical power *i*. For *ai, bi, ci* is cost coefficients used to calculate the cost of each operating generator. Balanced power is generated by all generators in the system, which is equal to the total power losses of the network and the load. The power balance formula can be seen as follows.

$$\sum_{i=1}^{N} P_i = P_{demand} + P_{loss} \quad (9)$$

Where: P_{demand} is the total power of the load or demand, and P_{loss} is the power loss on the network. The operating limit of the generating unit is the maximum and minimum number of generating units. The generation input-output power shall not exceed the maximum power and not be less than the minimum power. The formula for the inequality of the generator input-output can be seen as follows.

$$P_{i,min} \leq P_i \leq P_{i,max} \quad (10)$$

Where: *Pi* is generating power on generator *i*, *Pi,min* is minimum power output in generator *i*, *Pi,max* is power output maximum of the generator *i*.

2.2.5. particle swarm optimization using hybrid IWA and CFA (PSOHIC)

In this study, hybrid inertia weight (IWA) and constriction factor algorithm (FCA) are used in velocity updates. The effect of IWA is the search for the best solution when approaching Pbest and Gbest. While CFA produces faster convergence. The thought underlying the combination of these two velocity update methods is to get the best solution and faster convergence. For more details, the formula for combining hybrid IWA and CFA or abbreviated HICPSO can be seen as follows.

$$V_i^{k+1} = C\left[W * V_i^k + c_1 rand_1 \times \left(Pbest_i^k - X_i^k\right) + c_2 rand_2 \times \left(Gbest^k - X_i^k\right)\right] \quad (11)$$

Update velocity on Hybrid IWA and CFA (PSOHIC) using Eq. (3) and Eq. (6) which are combined by entering IWA and CFA on standard PSO.

2.2.6. PSOHIC app on optimal power flow

2.2.6.1. Initialization of individuals

There are several initialization parameters in this study, namely power generation, and load power. Thus, individual *i* at iteration 0 can be represented as a vector *Pi*, where 0 = (*Pi1, Pi2, ...Pin*), and *n* is the number of generators. Parameters *c*, and *r* are also initialized in the compute m-file. The initialized individuals satisfy the constraints on Eq. (9), and Eq. (10). The maximum and minimum limits of elements are determined according to the following equation.

$$P_{ij}^{k+1} \begin{cases} P_{ij}^k + P_{ij}^{k+1} \; if \; P_{ij,min} \leq P_{ij}^k + V_{ij}^{k+1} \leq P_{ij,max} \\ P_{ij,min} \; if \; P_{ij}^k + V_{ij}^{k+1} < P_{ij,min} \\ P_{ij,max} \; if \; P_{ij}^k + V_{ij}^{k+1} < P_{ij,max} \end{cases} \quad (12)$$

The former methods can find a satisfactory position. However, on the problem of Eq. (9) and Eq. (10) the power generation still needs to be developed and improved. In this research the PSOHIC intelligent system strategy is proposed so that the individual element calculations are fulfilled Eq. (8). The following stages are used for each individual in the group.

Step 1: Set the value of *j = 1*,
Step 2: Select an element (i.e., generator) from individual *i* at random and store it in the index array *A(n)*,
Step 3: Generate a random element value (i.e., generator output) that satisfies the inequality constraint,
Step 4: If *j = n-1* proceed to 5, otherwise *j = j+1* and return to Step 2.
Step 5: The final value of individual i is determined by subtracting $\sum_{j=1}^{n-1} \boldsymbol{P_{ij}}$ from demand + loss. If it fits the constraint, go to step 8, otherwise adjust the value using formula (12)
Step 6: Set *l = 1*,
Step 7: Re-adjust the value of the *l* element in the index array *A(n)* to a value that satisfies the equality constraint (that is, demand + losses – $\sum_{j=1, j\neq 1}^{n-1} P_{ij}$). If the value is within the limit, then the initialization process stops or goes to step 8; otherwise, the *l* element is reset using Eq. (12).

The trick is to set $l = l+1$, and the process runs in step 7. If $l = n+1$, then you have to go back to step 6, if the program runs to step 8.

Step 8: The initialization process stopped.

There are two variables that are updated randomly on the PSO, namely speed and position. After updating the initial position, the next step is to update the speed. As for how to randomly update the speed, you can use the following formula.

$$P_{ij,min} - P_{ij}^0 \leq V_{ij} \leq P_{ij,max} - P_{ij}^0 \quad (13)$$

The Update velocity of the particle, or individual j elements i, is generated in a random manner adjusted to the generation limit. The initialization *Pbest* of the particle (individual) i is determined assuming that as the initial position of individual i. Similarly, the initial *Gbest* uses the Eq. (8).

2.2.6.2. Updating individual speed and position

In order to change the velocity of each individual i, it is necessary to update the velocity for each individual at a later stage. Update velocity can be calculated using Eqs. (3) and (6). In the proposed PSOHIC method, simultaneously the inertia weight algorithm and the constriction factor algorithm are included in the solution search algorithm Eq. (12).

All individual positions i are changed, to change it use Eq. (4). However, the change in position does not always satisfy the equality, and inequality constraints. To guarantee the position and speed of the individual, Eq. (12) is used. In addition, individual positions must meet the equality constraint Eq. (9) simultaneously. To solve the equivalence constraint problem without disturbing the dynamic processes contained in the PSOHIC algorithm, the stages can be seen as follows.

Step 1: Set the value of $j = 1$,

Step 2: Select an element (that is, a generator) from individual i at random and store it in the index array $A(n)$,

Step 3: Change the value of element j using Eqs. (3), (4), (6), and (12),

Step 4: If $j = n-1$ then proceed to step 5, otherwise $j = j+1$ and return to step 2,

Step 5: The value of the last element of individual i is determined by $\sum_{j=1}^{n-1} P_{ij}$ from demand and losses. If the value is not within the limit, adjust the value using Eq. (12) and go to step 6, if not, go to step 8,

step 6: Set $l = 1$,

Step 7: Re-adjust the value of the l element in the index array $A(n)$ to a value that satisfies the equality constraint (that is, demand + Loss – $\sum_{j=1, j\neq 1}^{n-1} P_{ij}$. If the value is within the limit, go to step 8; otherwise change the value of the 1 element using the Eq. (12). set $l = l+1$, and go to step 7. If $l = n+1$, return to step 6,

Step 8: The initialization process stopped.

The fuel cost for each individual or generation taking into account the valve point effect, can be calculated according to the following formula.

$$F_i(P_i) = a_i + b_1 P_i + c_i P_i^2 + \left| e_i \times \sin\left(f_i \times \left(P_{i,min} - P_i\right)\right)\right| \quad (14)$$

Where: e_i and f_i are generator coefficients i.

The individual objective function i is obtained by adding up the fuel costs for each generator in the system as shown in Eq. (7).

2.2.6.3. Updating individual *Pbest* and *Gbest*

The *Pbest* of each individual in iteration $k+1$ are updated using the following equation:

$$Pbest_{ij}^{k+1} = X_{ij}^{k+1} \quad if\ F_i^{k+1} < F_i^k \quad (15)$$

$$Pbest_{ij}^{k+1} = Pbest_{ij}^k \quad if\ F_i^{k+1} > F_i^k \quad (16)$$

Where: F_i^k is the objective function evaluated at individual position i in k iterations. X_{ij}^{k+1} is the position of individual i in iteration $k+1$, $Pbest_{ij}^{k+1}$ is the best position of individual i in iteration $k+1$.

Eqs. (15) and (16) compare the *Pbest* of each individual with his current fitness value. If the individual's new position performs better than the current *Pbest*, the *Pbest* is replaced by the new position. Conversely, if the individual's new position has a lower performance than the current *Pbest*, then the previous Pbest value is used. In addition, $Gbest_{ij}^{k+1}$ global best position in iteration $k+1$ is defined as the best evaluation position among all $Pbest_{ij}^{k+1}$.

2.2.6.4. Stop criteria

The method of hybrid update velocity inertia weight with constriction factor (PSOHIC) stops when the iteration approaches the predetermined criteria.

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3. Results and discussion

3.1 IEEE 26 bus data simulation results

IEEE data 26 buses, 6 generators in the book "Power System Analysis Hadi Saadat" used as validation of the PSOHIC method with each updated velocity: standard PSO, inertia weight algorithm (IWA), constriction factor algorithm (CFA), hybrid inertia weight algorithm with constriction factor algorithm (PSOHIC). The simulation results show differences in the speed of convergence for each update velocity. For more details about the convergent speed can be seen in the following Figs. 1, 2, 3, 4 and 5.

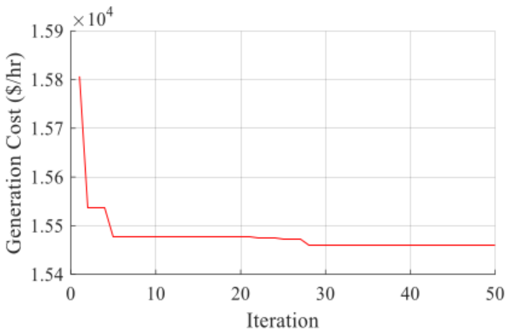

Figure. 1 Convergence graph of PSO standard

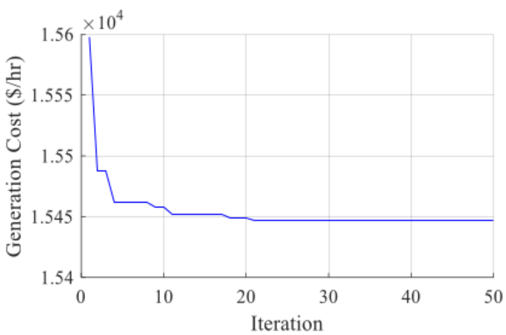

Figure. 2 Convergence graph of PSO IWA

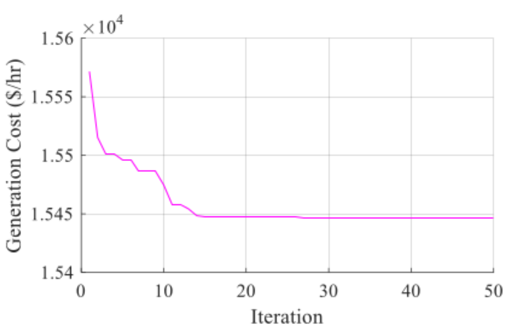

Figure. 3 Convergence graph of PSO CFA

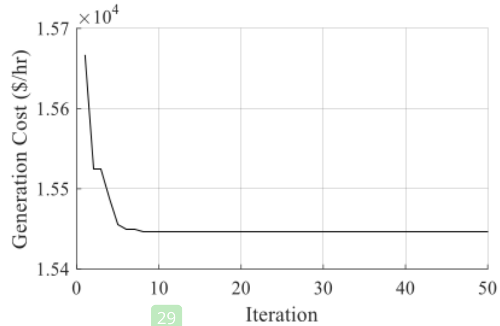

Figure. 4 Convergence graph of PSOHIC

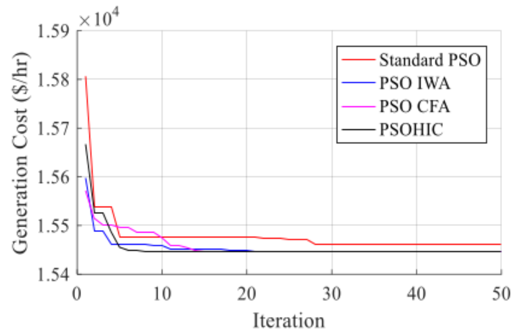

Figure. 5 Comparison of PSO standard, IWA, CFA, and PSOHIC velocity update simulation results

The results showed that the hybrid inertia weight with constriction factor (PSOHIC) converged faster in the 7th iteration. The PSO standard converges on the 28th iteration. The inertia weight convergence on the 21st iteration. While the constriction factor converges on the 15th iteration. The results power flow simulation are shown in the following Table 5.

The results of the research on the optimal power flow of the IEEE 26 bus system, show that the power flow is within the power generation limit. The results of the convergence of the velocity update methods vary, namely: PSO Standard convergence on the 28th iteration, and update velocity with inertia weight convergence on the 21st iteration. Update velocity with constriction factor convergence on iteration 15. Update velocity using hybrid inertia weight with constriction factor convergence in the 7th iteration. The power loss using the PSOHIC method, which is 12,800 WM/h, is smaller than the existing system, which is 15,530 WM/h, or the power loss has decreased by 17,579%. The cost of generating using the PSOHIC method is 15.446,700 $/h, which is smaller than the existing system, which is 16.767,730 $/h. This results in a savings of 7,878%.

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3.2 Simulation results of the South Sulawesi system data integration with wind power plants

After the PSOHIC method was tested or validated using the IEEE 26 data bus, the method was applied to the South Sulawesi 29 data bus system which is integrated with a wind power plant as a case study. This optimal power flow study uses data from 4 thermal plants, namely: Power plants at Tello, Punagaya, Suppa, and Sengkang. There are two wind power plants, namely the wind power plant at PLTB Sidrap and PLTB Jeneponto. The results of the power flow research can be seen in the following Fig. 6.

The results of the study on the optimal power flow of the South Sulawesi system which is integrated with the wind power plant show that each velocity update produces generating power that meets the generation power limit. The power loss using PSOHIC of 18,1550 MW is smaller than the existing system, which is 19,2665 MW or there is a decrease in power loss of 5,7691%. The generation cost using PSOHIC is 5.986,917 $/hour, smaller than the existing system, which is 6.428,61 $/hour, or the generation cost has decreased by 6,784%. For more details about the research results, can be seen in the following table.

Table 5. Comparison of the optimal power flow of IEEE 26 bus data

Bus		Generators		Existing System (MW)	Velocity Update			
No.	Code	MW min	MW max		Standard PSO (MW)	PSO IWA (MW)	PSO CFA (MW)	PSOHIC (MW)
1	1	100	500	719,534	451,824	446,597	446,993	447,100
2	2	50	200	79,000	165,292	172,016	171,390	171,400
3	2	80	300	20,000	259,537	262,330	262,095	262,100
4	2	50	150	100,000	131,167	134,634	135,225	135,200
5	2	50	200	300,000	159,690	175,842	175,954	175,900
26	2	50	120	60,000	108,509	84,398	84,150	84,300
Power generation (MW)				1.278,534	1.276,019	1.275,817	1.275,808	1.275,800
Losses (MW)				15,530	13,019	12,817	12,808	12,800
Power load (MW)				1.263,004	1.263,000	1.263,000	1.263,000	1.263,000
Cost ($/h)				16.767,730	15.455,400	15.446,750	15.446,740	15.446,700
Convergence (iteration)				-	28	21	15	7

Table 6. Comparison of the power flow of the South Sulawesi system integrated wind power plant

Bus		Generators		Existing System (MW)	Velocity Update			
No.	Code	MW min	MW max		Standard PSO	PSO IWA (MW)	PSO CFA (MW)	PSOHIC (MW)
1	2	19,75	110,00	34,0000	67,4278	71,8458	85,4224	72,7180
13	1	60,85	315,00	95,9450	273,4960	287,9032	290,9117	293,6061
14	2	0,00	60,00	60,0000	33,2563	24,5417	13,6809	5,6498
19	2	15,00	62,50	51,1000	50,5535	60,1290	61,8583	54,8728
23	2	0,00	75,00	75,0000	24,8878	7,2803	9,8199	14,6648
25	2	55,00	250,00	243,4000	108,7082	107,5945	97,0323	116,8084
Power generation (MW)				559,4450	558,3296	559,2945	558,7255	558,3199
Losses (MW)				19,2665	18,1650	19,1300	18,5600	18,1550
Power load (MW)				540,1650	540,1646	540,1650	540,1655	540,1649
Cost ($/h)				6.428,6100	6.098,5447	6.040,5012	6.047,9272	5.986,6917
Convergence (iteration)				-	41	29	20	9

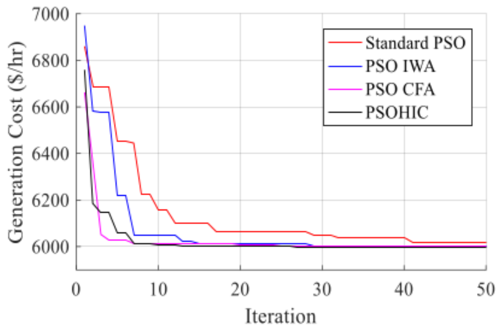

Figure. 6 Comparison of PSO Standard, IWA, CFA, and PSOHIC velocity update simulation results

4. Conclusion

From the simulation results using the PSOHIC method on IEEE 26 bus data as validation, and the application of this method to the South Sulawesi system data integrated with the wind power plant as a case study, it can be concluded as follows.

1. The results of the IEEE data simulation using PSO with an updated velocity inertia weight algorithm (IWA) which converges on the 21st iteration, and the velocity update using the constriction factor algorithm (CFA) converges on the 15th iteration, while the velocity update uses an inertia weight algorithm that is hybridized with The constriction factor algorithm (PSOHIC) converges faster at the 7th iteration. The power loss for PSOHIC 12,800 MW is lower than the existing system, which is 15,530 or a decrease of 17,579%. The cost of generating with PSOHIC is 15,446,700 MW/h smaller than the existing system which is 16,767,730 MW/h or there is a decrease in costs of 7.878%
2. The simulation results of the South Sulawesi integrated wind power generation system data show that PSOHIC converges faster in the 9th iteration compared to IWA converges on the 29th iteration, CFA in the 20th iteration. The power loss using PSOHIC 18,155 WM/hour is lower than the existing system, which is 19,267 WM/hour, or the power loss has decreased by 5,7691%. The generation cost using PSOHIC is 5.986,917 $/hour, smaller than the existing system, which is 6.428,61 $/hour, or the generation cost has decreased by 6,784%.
3. For research on optimal power flow in systems that are integrated with wind power plants, the optimal power flow will be calculated in real time.

Conflicts of interest

The authors state that there is no conflict of interest in this study.

Authors contributions

In general, all members of the research team contributed to this research. Conceptualization, Ansar Suyuti, Sri Mawar Said and Indar Chaerah Gunadin; methodology, Indar Chaerah Gunadin and Andi Muhammad Ilyas; software, Andi Muhammad Ilyas and Indar Chaerah Gunadin; validation, Indar Chaerah Gunadin and Sri Mawar Said; formal analysis, Andi Muhammad Ilyas and Ansar Suyuti; investigation, Sri Mawar Said and Ansar Suyuti; data curation, Andi Muhammad Ilyas and Sri Mawar Said; the original drafts, Andi Muhammad Ilyas and Indar Chaerah Gunadin; review-writing and editing, Andi Muhammad Ilyas and Indar Chaerah Gunadin; visualization, Indar Chaerah Gunadin and Andi Muhammad Ilyas.

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