

Optimal Power Flow

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Optimal Power Flow the Sulselrabar 150 KV system before and after the penetration of wind power plants considering power loss and generation costs

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Abstract. Optimal Power Flow (OPF) is to optimize power flow in interconnection systems to decrease production costs and increase system reliability, quality, and stability. This research was conducted on power generation 150 KV systems in South Sulawesi, Southeast Sulawesi, and West Sulawesi, abbreviated as Sulselrabar. The number of buses is 44, 15 generator buses before penetration with the Sidrap Wind Power Plant (PLTB), and 16 bus generators after penetration with PLTB. The method used in this study is Improved Particle Swarm Optimization (IPSO) and Lagrange. The results showed that IPSO showed better results compared to Lagrange and the results of existing systems.

1. Introduction

Optimal power flow aims to determine the best way to operate the power system [1-15]. Today more and more optimization methods and algorithms are developed for use in optimal power flows, including; Lambda Iteration [16], Particle Swarm Optimization (PSO) [17-19], Biogeography-based Optimization (BBO), Artificial Bee Colony algorithm (ABC) [20], Krill Herd Algorithm (KHA) [21], Cultural Algorithm (CA) [22], Charged System Search (CSS), Bat Algorithm (BA), Novel Bat Algorithm (NBA) [23], Genetic Algorithm (GA) [24].

Previous research used the Novel Bat Algorithm (NBA) method to discuss some Sulserabar systems, namely 29 buses, 5 interconnect generators for PLTB penetration thermal plants. In this study, the IPSO and Lagrange methods were used to solve optimal power flow in all Sulselrabar systems, which is 44 buses, 16 generators. Optimal power flow includes various optimization variables such as power balance constraints, generator capacity limits, voltage limits, and power losses. The mathematical equation in solving optimal power flow is as follows:

The Economic Dispatch Formula is:

$$F(P_g) = \sum_{n=1}^n (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad (1)$$

The Economic Dispatch limits are as follows.

Power balance limit:



$$\sum_{n=1}^n P_i = P_d + P_L \quad (2)$$

Optimal Power Flow Formula:

$$P_{Ga} - P_{Da} = V_a \sum_{n=1}^{NB} V_b (G_{ab} \cos(\theta_a - \theta_b) + B_{ab} \sin(\theta_a - \theta_b)) \quad (3)$$

$$Q_{Ga} - Q_{Da} = V_a \sum_{n=1}^{NB} V_b (G_{ab} \sin(\theta_a - \theta_b) + B_{ab} \cos(\theta_a - \theta_b)) \quad (4)$$

Limitation of generating capacity:

$$P_{Gi,min} \leq P_{Gi} \leq P_{Gi,max} \quad (5)$$

$$Q_{Gi,min} \leq Q_{Gi} \leq Q_{Gi,max} \quad (6)$$

Voltage limit:

$$V_{m,min} \leq V_m \leq V_{m,max} \quad \theta \quad (7)$$

Information:

$F(P_g)$	=	Total generation costs
a_i, b_i, c_i	=	The coefficient of fuel costs
P_d	=	Beban dayaPower load
P_L	=	Losses
P_{Gi}	=	Active power generated on the bus i
Q_{Gi}	=	Reactive power generated on the bus i
G_{ab}, B_{ab}	=	Admittance of line a, b
V_a, V_b	=	Voltage of bus a,b
θ_a, θ_b	=	Voltage bus phase angle a, b

In general, power losses as in the following formula.

$$P_L = I^2 R \quad (8)$$

Where:

P_L	=	power losses
I	=	current flowing on line (Ampere)
R	=	resistance on line (Ω)

2. Materials and methods

2.1. Sulsehrabar system

The Sulsehrabar 150 KV system consists of 44 buses and 14 conventional generator buses and 1 new renewable energy bus, namely the Wind Power Plant (PLTB) located in Sidrap Regency. The bus generators in question are: Bakaru as a slack bus and generator buses are Pinrang, Suppa, Sidrap (PLTB), Barru, Tello, Borongloe, Tellolama, Sungguminasa, Tallasa, Punagaya, Sinjai, Sengkang, Makale, Palopo, Poso, the remaining 28 the bus is a load bus. The results of this optimization are compared between before and after penetration with the Wind Power Plant PLTB considering voltage, emissions, generation costs, and power losses on the electricity network.

The data used in the simulation is the peak day load data at 14.00 WITA, December 4, 2018. The measuring parameters used in this study are bus data, generation data, and load data. The generator data and single line Sulsehrabar system can be seen in Figure 1.

2.2. Optimization methods

The optimization methods used are Improved Particle Swarm Optimization (IPSO), and Lagrange methods.

2.3. IPSO algorithm

$$V_i^{k+1} = \omega V_i^k + c_1 rand_1 (Pbest_i^k - X_i^k) + c_2 rand_2 (Gbest^k - X_i^k) \quad (9)$$

Where:

- V_i^k = velocity individual i in the iteration k
- ω = weight parameter
- c_1, c_2 = acceleration coefficient
- $rand_1, rand_2$ = random number between 0 and 1
- X_i^k = individual position i in the iteration k
- $Pbest_i^k$ = individual i to iteration k
- $Gbest^k$ = Gbest group until iteration k

For more details, see Flowchart's research in Figure 2.

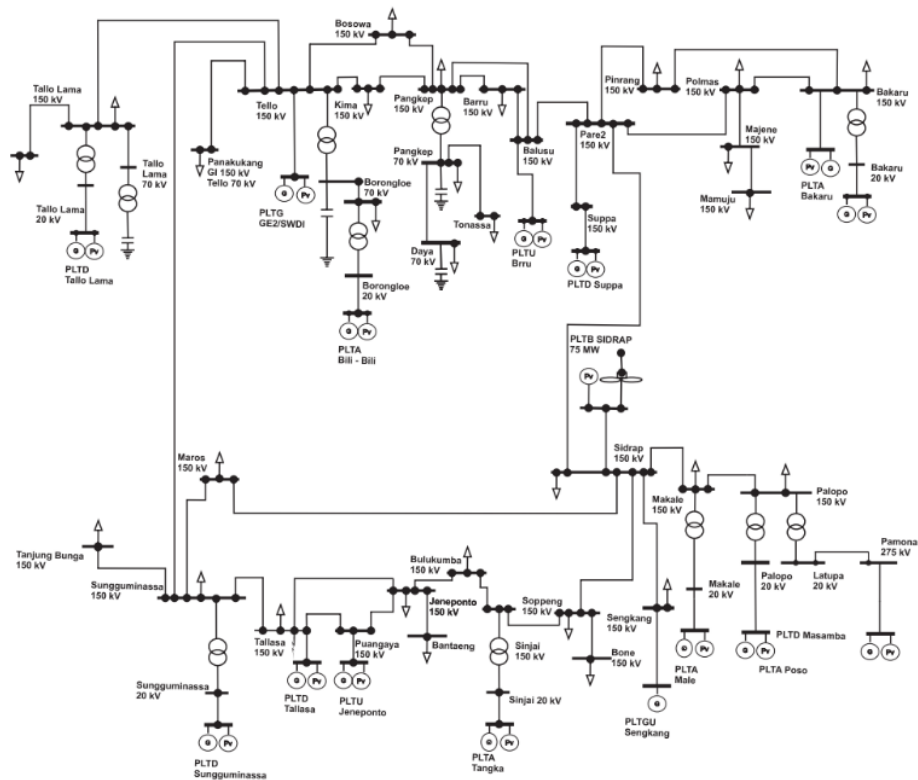


Figure 1. Sulselrabar single line system.

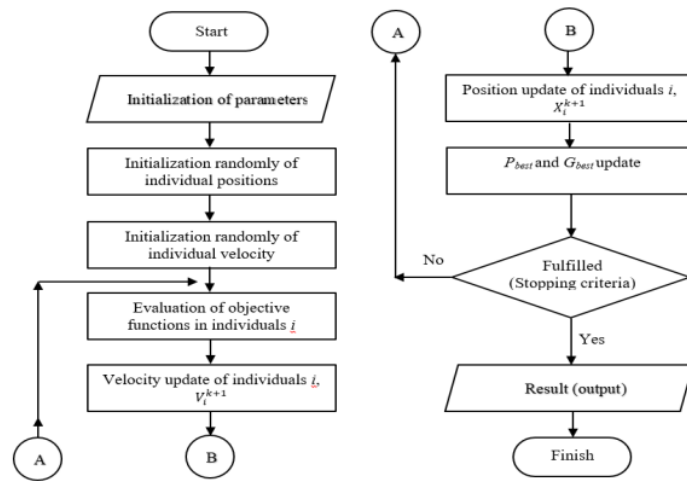


Figure 2. Research flowchart.

3. Results and discussion

3.1. Optimal power flow results, system 44 Sulselrabar bus before integration with PLTB wind power plants

The results obtained from the IPSO method, compared with the Lagrange method and the results of the existing system before penetration with the PLTB data are seen in Table 1 and Figure 3.

Table 1. Optimal power flow results of Sulselrabar system before PLTB integration.

Bus Number	Existing System (MW)	Lagrange (MW)	IPSO (MW)
1	62.10	50.05	78.69
5	14.30	32.51	14.32
7	31.10	35.77	29.25
9	60.30	74.61	67.46
16	21.00	66.76	23.55
19	15.20	16.07	18.30
24	12.60	22.82	11.40
27	20.00	24.38	21.59
29	79.00	36.49	73.78
31	193.10	228.50	197.00
34	14.00	11.21	6.83
37	265.20	218.47	251.41
38	8.20	7.05	7.69
39	4.00	6.59	3.75
41	190.00	157.75	184.08
Total Load (MW)	990.10	989.02	989.10
Losses (MW)	150.30	119.95	80.13
Load (MW)	839.80	869.07	908.97
Losses (%)	15%	12%	8%
Total Generation Cost (IDR/hr.)	995,709,690	962,519,367	945,924,206

The simulation results using the IPSO method show cheaper results compared to the results using the Lagrange method and the results of the existing system. The generation cost using the IPSO method is Rp. 945,924,206 per hour and the cost of the Lagrange method is Rp. 962,519,367 per hour, while the results of the existing system are Rp. 995,709,690 per hour. Generation costs that can be reduced using the IPSO method are Rp.49,785,485 per hour or around 5% when compared to the results of existing systems. Using the IPSO method, the power losses obtained are 80.13 MW or 8%, while those from the existing system are 150.30 MW or 15% and the Lagrange method is 119.95 MW or 12%.

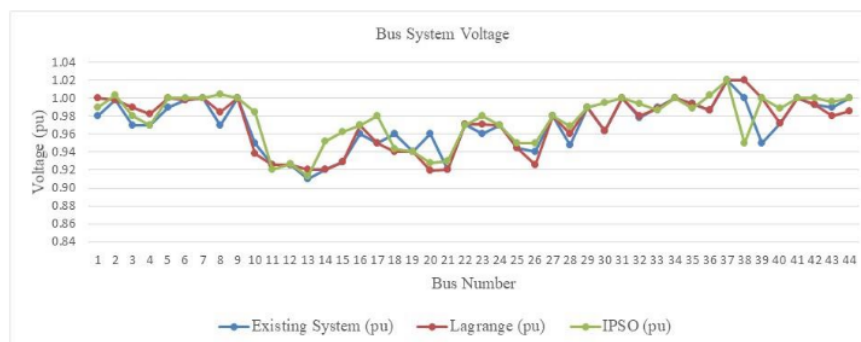


Figure 3. Comparison of bus voltage systems without integration of PLTB.

After observing the optimal results of power flow, voltage conditions are also considered. The stability of the voltage using IPSO shows quite good results because it is following PLN's regulatory limit, which is 0.9 to 1.04.

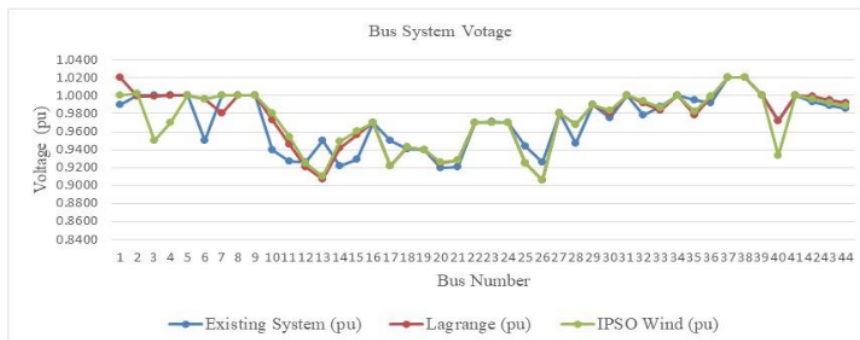
3.2. Optimal results of power flow system 44 Sulsebarab buses after integration with PLTB wind power plants

The integration of PLTB in the Sulsebarab system has a good impact on the system, especially concerning generation costs. The results obtained using the IPSO method are compared with the Lagrange method and the results of the existing system. The bus generator on this system increases, from 15 bus generators to 16 generator buses. The load bus in serial number 8 is converted into a bus generator by integrating Sidrap PLTB on the system. For more details about optimal power flow in systems integrated with PLTB can be seen in Table 2, and Figure 4.

The simulation results of the 44 bus 16 generator system, after PLTB integration there was a decrease in the cost of generation and power loss on the network. The generation cost using the IPSO method is Rp. 927,005,722 per hour, while the yield from Lagrange is Rp. 933,643,786 per hour and the proceeds from the existing system are Rp. 975,795,496 per hour. The generation cost is reduced in the IPSO method by Rp. 48,789,774 per hour or about 5% when compared to the results of the existing system. By using the large IPSO method power losses of as much as 49.28 MW or 5%, while the Lagrange method is 109.08 MW or 10%, and the results of the existing system are 149.07 MW or 14%.

Table 2. Optimal power flow results of Sulsebarar system after PLTB integration.

Bus Number	Existing System (MW)	Lagrange (MW)	IPSO + Wind (MW)
1	62.07	55.00	57.53
5	14.30	32.51	32.53
7	31.10	35.77	56.79
8	75.00	70.00	36.81
9	60.40	74.61	94.53
16	22.00	66.77	65.45
19	15.20	32.07	30.24
24	12.56	22.82	21.83
27	20.00	24.38	16.05
29	79.00	76.49	4.56
31	196.10	135.58	192.55
34	5.00	11.22	4.38
37	265.17	239.54	256.75
38	8.20	27.05	5.85
39	4.00	6.59	5.47
41	195.00	148.75	183.58
Total Load (MW)	1,065.10	1,059.13	1,064.88
Losses (MW)	149.07	109.08	49.28
Load (MW)	916.03	950.05	1,015.60
Losses (%)	14%	10%	5%
Total Generation Cost (IDR/hr.)	975,795,496	933,643,786	927,005,722

**Figure 4.** Comparison of Bus System Integration Voltage with PLTB.

The voltage profile based on the optimal results of power flow using the IPSO method shows better results than the results of the existing system. The stability of the voltage using IPSO shows good results because it is in the range that is under PLN's regulatory limit, which is 0.9 to 1.04.

4. Conclusion

The results showed that IPSO showed better results compared to Lagrange and the results of the existing system. Before integration with PLTB, IPSO was able to reduce costs by IDR 49,785,485 per hour or about 5% compared to the results of the existing system results. The loss of power using IPSO is 80.13 MW or 8%, using Lagrange is 119.95 MW or 12% and the results of the existing system are 150.30 MW or 15%.

After integration with PLTB, IPSO can reduce costs by Rp. 48,789,774 per hour or 5% of the results of the existing system, Lagrange reduced costs by IDR 42,151,710 per hour or 4% of the results of the existing system. While the IPSO simulation power loss is 49.28 MW or 6% and Lagrange is 109.08 MW or 13%.

The difference or decrease in power loss between before and after integration with PLTB uses the IPSO method of 30.85 MW, the Lagrange method of 10.89 MW, and the results of the existing system 1.23 MW.

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