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A New Technique for Determining the Emission Costs: Evidence from Indonesia

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ABSTRACT

The energy crisis, the impact of emissions, the greenhouse effect, and climate change are global issues. The operation of power plants using fossil fuels impacts emissions harmful to the environment. This paper discusses a new technique for determining the cost of reducing emissions through optimizing generators operations by considering emissions, which is often named Economic Emission Dispatch. The optimization method used is a candidate area reduction technique. This technique was tested using 500 kV, 25 buses with various loads, and the Java-Bali electrical system. The ratio between the cost and emission difference is determined in various conditions from the combination of costs and emissions weights. The results are compared with several other methods such as the Firefly algorithm, Cuckoo algorithm, and particle swarm optimization. These various methods show that the emission reduction costs are USD41.8 to USD54.5 per ton of emission. This paper provides input to the government in making policies related to flexible power plant emission control. Considering that emission is a national issue in Indonesia, one of the efforts to reduce emissions from power plants is the implementation of regulations related to emission reductions in the power plants' operation. However, to avoid counter-productivity from the operation of electricity, the government can prepare funding to assist the electricity operator in implementing the policy limiting the power plant's emissions.

Keywords: Economic Emission Dispatch, Emission Cost, Area Reduction, Java-Bali Power Systems
JEL Classifications: Q42, Q52, Q54, Q58

1. INTRODUCTION

The energy crisis, the impact of emissions, the greenhouse effect, and climate change are global issues. Several studies related to emissions in several countries have been published (Adeleye et al., 2021), (Gunanto et al., 2021), (Omodero and Uwuigbe, 2021). Economic growth intensifies emissions; renewable energy (RE) exhibits emission-reducing properties; non-RE increases emissions; economic growth sustains the emission reduction impact of RE; and economic growth reduces the harmful effects of non-RE (Adeleye et al., 2021). Variables that have a significant effect on CO2/capita growth in ASEAN countries, according to (Gunanto et al., 2021), are human resources significantly reduce emissions, while physical capital investment and trade openness can increase emissions. Meanwhile (Omodero and Uwuigbe, 2021) said that economic growth was accompanied by pollution from burning fossil fuels. It should be underlined that the sustainability of economic growth in the future is not guaranteed, even though the economy is growing today. Evaporation of the ozone layer and environmental degradation are serious problems that must be a common concern. Because there is a non-causal relationship between economic growth and CO_2 in South Africa, a policy to reduce CO2 emissions from power plants is needed because it will increase economic growth in South Africa (Hlongwane and Daw, 2021). Meanwhile, climate change is becoming an increasingly pressing issue on political agendas worldwide because it concerns economic and financial sustainability, not only environmental sustainability issues (Estevao, 2021).

Various efforts to protect the environment have been carried out, both in the form of national policies (such as policies of the Ministry of the Environment, Indonesia), international policies (such as the Kyoto Protocol), as well as various studies to suppress or optimize exhaust emissions resulting from the operation of these fossil-fuel power plants. Optimizing exhaust emissions is one of the problems in the energy sector that must be resolved. So research related to the optimization of electricity generation costs today is not only to get low fuel costs but also involves optimizing the emissions it produces.

For this reason, the operation of the current generator unit is not only to get low costs, especially the cost of fuel, which is known as the Economic Dispatch (ED) problem but also to minimize the emissions it produces, which is known as the Economic Emission Dispatch (EED). Several methods for solving EED problems have been published, both numerical methods such as direct method (DM), gradient method (GM), Lagrange method (LM), lambda iteration (LI), and dynamic programming (DP), as well as artificial methods such as bat algorithm (BA), particle swarm optimization (PSO), genetic algorithm (GA), artificial bee colony (ABC), artificial neural network, firefly algorithm (FA), whale optimization algorithm (WOA), flower pollination algorithm (FPA), simulated annealing algorithm (SAA), JAYA Algorithm, gravitational search algorithm (GSA).

EED problem solving using WOA has been published. Although WOA often falls to a local minimum for problems with high-order functions, WOA based on Lamarckian learning (WOALam) has better global optimization capabilities and faster convergence speed and can obtain more satisfactory optimization results in less time (Zhang and Liu, 2019). The WOA-BA hybrid method showed the best performance compared to WOA, GA, and ABC (Mohammad et al., 2019). Meanwhile (Kar et al., 2019) compared the optimization results of the whale optimization method with the results of other evolutionary methods. The WOA method works faster, and the generation and emission costs are lower than the comparison method.

The ABC method has also been applied to solve EED (Mehta et al., 2017). It has a better convergence ability compared to the evolutionary and PSO. There is only one population in each iteration that moves towards the optimal solution, and it is an advantage of the ABC method. Meanwhile, the FA has better performance in solving EED than the RGA, SGA, and Hybrid GA methods. The FA promises to solve complex problems in power systems (Reddy and Sekhar, 2014), while FPA has also been developed to solve EED (Abdelaziz et al., 2016). FPA performance is validated through comparison with various methods such as PSO, PPSO, APPSO, MPSO, ARCGA, TSCGA, CCPSO, CDE-SQP, EDA/DE, SOMA, CSOMA, DE/BBO, AND DHS. FPA has advantages over comparison methods, even for large-scale electrical system applications (Abdelaziz et al., 2016).

Meanwhile, the Gravitational PSO Algorithm (GPSOA) method to solve the EED problem between wind power and thermal power gives the best results when compared to the GA, PSO, GSA, and PSOGSA methods, both in terms of fuel costs and emissions released (Jiang et al., 2019). Comparison between the PSO, conventional method, and GA in solving the EED problem has been studied (Kumar et al., 2019). The conventional method cannot provide an accurate solution because the conventional method relies on adjusting the exact lambda value. While the GA method shows better performance than the conventional method because it can provide a globally optimal solution. The PSO method provides the right solution and better processing time than conventional and GA methods.

Economic and environmental multi-objective optimization was also studied by (Rojas et al., 2022), where this paper analyzes the net present cost and energy costs as a function of the system configuration between PV and wind turbines.

Several methods of solving EED problems in the electrical system in Indonesia have also been studied, namely multi-objective particle swarm optimization (Eliezer, 2016), Cuckoo algorithm (Rahmatullah, 2017), Whale optimization (Muflikhah, 2020), and Simulated Annealing (Puspitasari, 2021).

This study aims to apply a new technique in calculating the cost of reducing emissions in the operation of a power plant in the Java-Bali electricity system, Indonesia, from the results of the EED, which was carried out using a position reduction technique. Other previously studied methods validated these results. In order to know the costs needed to reduce generator emissions in the Java-Bali electricity system in Indonesia, the generator manager or the government as a regulator can take related policies.

This paper has three main sections. The first part describes the research method, which explains the proposed candidate area reduction technique's problem formulation and working principle. The second section displays the data and results of system testing, and these results are compared with other methods and end with a conclusion.

2. MATERIALS AND METHODS

2.1. Generator Scheduling Problem

Now, emissions are a hot topic because people have realized how essential emissions are as a destroyer of the earth. Thus, power delivery's main aim is to simultaneously reduce the fuel cost and emission levels without violating the system constraints (Guvenc et al., 2012) to meet load demands. The EED problem is the problem of multiobjective economic loading (Economic dispatch) and emission minimization. So, EED combines Economic Dispatch and emission minimization (Emission Dispatch). The total cost of generation and fuel emissions are formulated in a quadratic function.

2.1.1. Economic dispatch

Economic dispatch (ED) aims to share the load on the generator unit in the electrical system to obtain the minimum generation cost. The objective functions of Economic Dispatch and Emission Dispatch are shown in Equations (1) and (2), respectively.

$$F_{CT}\left(P_G\right) = \sum_{i=1}^{N} F_{Ci}(P_{Gi}) \quad (1)$$

$$F_{Ci}\left(P_G\right) = \sum_{i=1}^{N} (\alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2) \quad (2)$$

where F_{CT} (P_G) is the total cost of power generation (IDR), F_{Ci} (P_G) is the cost of power generation-*i* (IDR), N is the total unit of generators, is the power of the generator-i (MW), whereas $\alpha_i [\frac{IDR}{MW}]$, $\beta_i [\frac{IDR}{MW}]$, and $\gamma_i [\frac{IDR}{MW^2}]$ are the constants of the cost characteristics of generator-i.

All generators must meet the constraints as shown in Equations (3) and (4).

$$\breve{P}_{Gi} \le P_{Gi} \le \hat{P}_{Gi} \quad (3)$$

$$P_{GT}=P_D+P_L \quad (4)$$

where $\breve{P}_{Gi}$ and $\hat{P}_{Gi}$ are the minimum and maximum power limit of generator-i (MW) respectively, P_{GT} is the total power of all generator units (MW), P_D is the demand load (MW), P_L are losses (MW). In this paper, the system losses are ignored.

2.1.2. Emission minimization

The objective function of emission minimization is shown in Equations (5) and (6).

$$F_{ET}\left(P_G\right) = \sum_{i=1}^{N} F_{Ei}(P_{Gi}) \quad (5)$$

$$F_{Ei}\left(P_G\right) = \sum_{i=1}^{N} (d_i + e_i P_{Gi} + f_i P_{Gi}^2) \quad (6)$$

where $F_{ET}(P_G)$ is the total fuel emission (grams), $F_{Ei}(P_G)$ is the emission of generator-i (grams), whereas $d_i [grams]$, $\beta_i [\frac{grams}{MW}]$, and $\gamma_i [\frac{grams}{MW^2}]$ are the constants of the emission characteristics of generator-i.

2.1.3. Economic emission dispatch

The objective function of EED is a combination of the objective function of economic dispatch and emission dispatch, as shown in Equation (7).

$$F(P_G)=w_C.F_{CT}+w_E.F_{ET} \quad (7)$$

where $F(P_G)$ is the objective function of EED, w_C is the weighted value for the fuel cost function, w_E is the weight value for the fuel emission function. These weight values must satisfy Equation (8).

$$w_C+w_E=1 \quad (8)$$

2.2. Candidates' Area Reduction Technique

The flow chart of the proposed method for calculating the cost of suppression of generation emissions is shown in Figure 1. The method proposed in this paper is the candidates' area reduction Technique (CART) (Raharjo, 2021). This method is included in the artificial method, but in reaching the optimal point (solution), it is not like the artificial method, which uses a point-to-point approach.

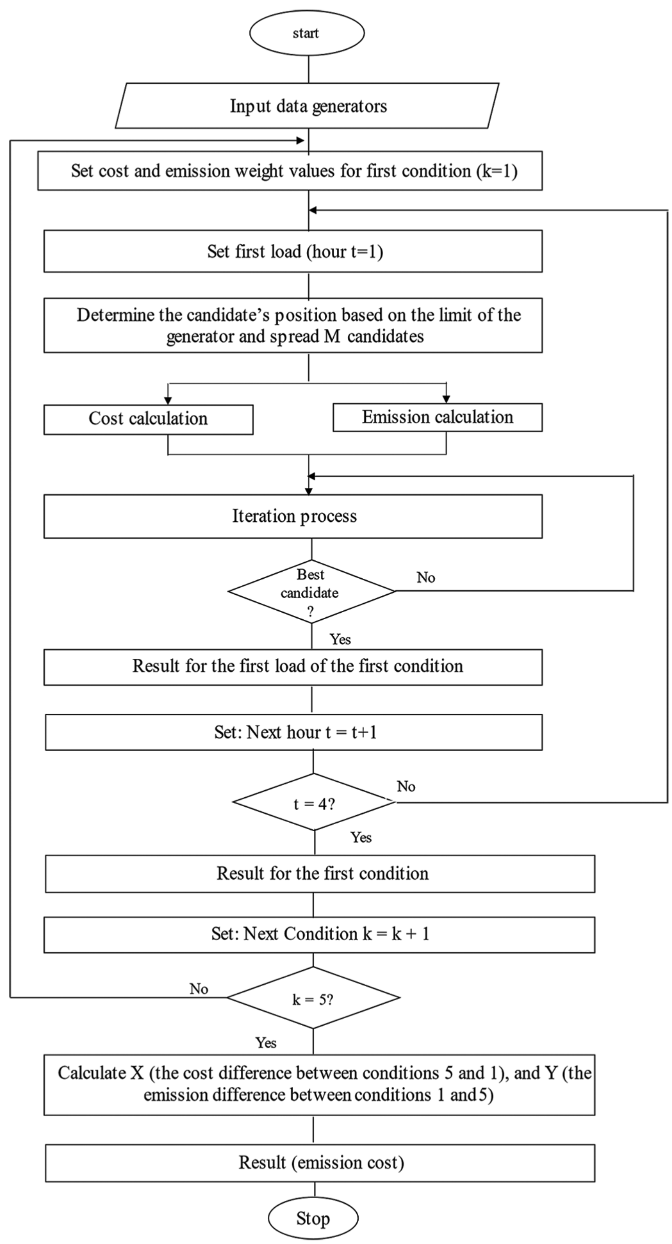
This method uses an area-to-area approach to reach the optimal point and will not fall on a local minimum point, unlike the WOA method, which often falls on a local minimum point for problems with high-order functions (Qiang and Lijie, 2019). It is the uniqueness as well as the advantage of this technique. The proposed method is an iteration method through the solution of the candidate's area to a smaller candidate's area. Solution candidates are spread on the domicile, and the best candidate is determined, namely the candidate with the lowest total cost (TC).

The area is reduced, the same number of candidate solutions is spread, and the best candidate is determined again. The process is repeated until a tiny area is reached, where the best candidate can be considered the optimal solution, and the iteration stops. The iteration stops when the difference between TC in the t iteration and TC in the t-1 iteration is no longer significant, as shown in Equation (9).

$$\delta=TC^t-TC^{t-1}\le\emptyset \quad (9)$$

where δ is the value difference between TC in the iteration-t and TC in the iteration t–1, $\emptyset$ is a very small value compared to TC.

Figure 1: Flowchart of the proposed method



The smaller Ø will certainly give more accurate results, but more iterations follow this. This study uses five variations of cost weights (w_C) and emissions (w_E), so there are five conditions. Each condition is tested with four kinds of load.

Figure 2: 500kV Electrical System Diagram, Java-Bali, Indonesia

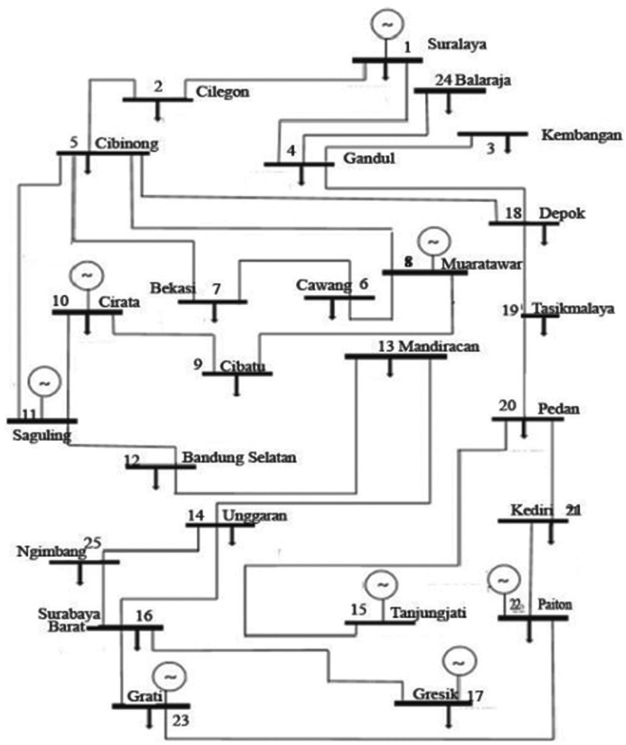


Table 1: Variation of weight values

Scheme (k)	w_C	w_E
1	1.00	0.00
2	0.75	0.25
3	0.50	0.50
4	0.25	0.75
5	0.00	1.00

Table 2: Test load

t	Hour	Load (MW)
1	18:00	13,096
2	19:00	13,108
3	20:00	12,863
4	21:00	12,228

3. SIMULATION RESULTS AND DISCUSSION

3.1. Simulation Data

This study uses five schemes which are five variations of the weights of costs and emissions, as shown in Table 1.

Each scheme was tested with loads taken hourly for 4 h, which are shown in Table 2.

This simulation uses data from Indonesia's Java-Bali electricity system, with a single line diagram shown in Figure 2. Eight of the 25 buses in the Java-Bali electricity system are generator buses. Two buses are for hydroelectric power (Cirata and Saguling), and the other six buses are thermal generators. The generator characteristics data in the form of cost functions, emission functions, maximum and minimum power limits, and ramp rates are presented in Table 3.

3.2. Simulation Results and Discussion

The results simulation using the CART for various conditions are shown in Figure 3. The cost in condition 1 is obtained from the sum of the costs for each hour for 4 h with the load in Table 2, as well as the emission in condition 1 is also the sum of emissions for 4 h. So that the costs and emissions per 4 h are obtained. Conditions 2 to 5 are carried out like conditions 1. From each condition, the X value is sought, namely the cost difference between condition 5 and condition 1, and the Y value is the difference in emissions between condition 1 and condition 5 as in equations (10) and (11).

$$X = \text{Cost in scheme } 5 - \text{Cost in scheme } 1 \quad (10)$$

$$Y = \text{Cost in scheme } 1 - \text{Cost in scheme } 5 \quad (11)$$

Emission costs are obtained from Equation (12).

$$C_{emission} = \frac{X}{Y} \quad (12)$$

The results of the simulation and comparison of various methods are shown in Table 4. The Cuckoo Algorithm, FA, and PSO methods as a comparison method are quoted from (Rahmatullah, 2017), to validate the method proposed in this paper.

From Table 4 and Equation (12) the emission price for each method can be determined, as shown in Table 5 (USD 1.0 = Rp. 14,255, February 17, 2022).

Table 3: Characteristic of generators

Unit	Cost functions			Emission functions			$\breve{P}_{Gi}$ (MW)	$\breve{P}_{Gi}$ (MW)	Ramp rate (MW/hour)
	α	β	γ	d	e	f			
PLTU Suralaya	44,455,587.75	391,059.27	11,008,313.00	−6.53435	232,126.27	26,388,095.96	1610	4200	300
PLTU Muaratawar	447,887,239.80	673,189.59	−5,565,550.00	−0.77370	93,584.00	62,263,614.50	934	2308	510
PLTA Cirata	0.00	6,000.00	0.00	0.00000	0.00	0.00	404	1008	930
PLTA Saguling	0.00	660.00	0.00	0.00000	0.00	0.00	208	700	660
PLTU Tanjungjati	192,669,508.00	125,456.19	35.80	25.15782	8,816.75	135,397,090.20	848	2119	337
PLTU Gresik	78,152,917.59	459,705.07	7.59	1.62795	98,632.00	16,768,083.00	1149	2872	420
PLTU Paiton	17,209,148.67	382,129.48	−19.37	−13.26677	261,721.95	11,786,612.11	1080	2700	240
PLTU Grati	25,244,481.54	371,803.55	8.09	2.46700	113,442.50	7,702,435.50	360	900	420

Table 4: Comparison of several methods

Scheme (k)	Firefly Algorithm				Cuckoo Algorithm			
	Cost (IDR/hour)	X	Emission (grams/hour)	Y	Cost (IDR/hour)	X	Emission (grams/hour)	Y
1	4,794,010,718	251,331,912	2,169,470,351	95,832,567	4,661,464,021	486,263,742	2,144,324,359	203,840,616
2	4,808,396,936	2,157,121,297	4,706,065,481		2,122,342,879			
3	4,812,848,133	2,130,759,323	4,711,404,808		2,097,476,058			
4	4,884,793,370	2,120,066,593	4,735,102,171		1,990,293,940			
5	5,045,342,631	2,073,637,784	5,147,727,763		1,940,483,743			
Scheme (k)	**PSO**				**CART**			
	Cost (IDR/hour)	**X**	**Emission (grams/hour)**	**Y**	**Cost (IDR/hour)**	**X**	**Emission (grams/hour)**	**Y**
1	4,554,072,063	617,329,918	2,048,226,668	198,564,982	4,551,244,991	604,687,298	2,051,468,361	213,590,904
2	4,564,469,251		2,003,831,166		4,557,977,819		2,002,639,413	
3	4,590,215,984		1,990,558,655		4,589,498,539		1,987,602,327	
4	4,629,494,157		1,967,241,358		4,627,522,239		1,957,744,385	
5	5,171,401,981		1,849,661,686		5,155,932,288		1,837,877,458	

Table 5: Emission reduction cost

Method	Emission Cost (USD/gram)
Firefly Algorithm	0.0000460
Cuckoo Algorithm	0.0000418
Particle Swarm Optimization	0.0000545
Candidates' Area Reduction Technique	0.0000497

Figure 3: Costs and emission for each condition

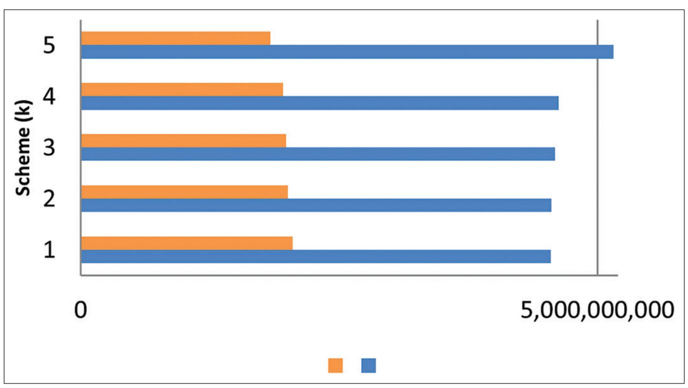


Table 5 shows that it costs USD 0.0000418 to USD 0.0000545 to reduce one gram of emissions or USD 41.8 to USD 54.5 for reducing one ton of emissions.

The emission problem is a national problem in Indonesia. This paper provides input to the government in making regulations on flexible power plant emission control. To avoid counterproductivity from electricity operations, the government can prepare funding to assist electricity providers if a policy of limiting power plant emissions needs to be implemented.

4. CONCLUSION

This paper proposes the determination of emission reduction costs preceded by solving the economic emission dispatch problem using a candidate area reduction technique with five cost and emission weights combinations, each from 0; 0.25; 0.50; 0.75, and 1. Of course, the more variations in the combination of cost and emission weights, the more accurate the results. The simulation results of the proposed method and other methods show that it costs USD 0.0000418 to USD 0.0000545 for reducing one gram of emissions or USD 41.8 to USD 54.5 for reducing one ton of emissions. The more variations in load and variations in the combination of cost and emission weights, as well as variations in load will give more accurate results.

On the one hand, the results of this study illustrate that if the government implements a policy of operating a power plant by paying attention to emissions, the plant's operating costs will be more expensive than without considering emissions.

However, on the other hand, it will certainly be able to trigger protests from power plant providers. For this reason, the government can allocate funds to assist power plant providers if the emission reduction policy is implemented in the operation of the power plant. So, preparing an academic paper that comprehensively examines emission suppression in power plants' operations is deemed necessary.

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