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# Generator Scheduling Optimization Involving Emission to Determine Emission Reduction Costs

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*ABSTRACT*

Climate change, greenhouse gases, and global warming are global issues today. Of course, this global issue cannot be separated from the issue of emissions. Various methods to solve generator scheduling problems by considering emissions or Economic Emission Dispatch (EED) have been published, but not to the extent of calculating the cost to reduce emissions. The main objective of this research is to determine the cost of reducing the emission of electricity generation in Indonesia through solving the EED problem. The method proposed to solve the EED problem is an annealing simulation algorithm and tested using an electrical system of eight generators, four different loads, and five combinations of cost and emission weights. This method is tested with various loads (conditions), and each condition is tested with various combinations of cost weights and emission weights. The obtained results were compared with the results of the calculation of the Cuckoo algorithm, and the whale optimization algorithm. The simulation results show that it costs US$258.81 to reduce 1 ton of emissions. This paper can be used as a material for further consideration for the government and generator providers in making policies related to the operation of power plants by considering emissions.

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**NOMENCLATURE**

| | | | |
|---|---|---|---|
| *ABC* | Artificial bee colony | *MOMA* | Multi-objectivemetaheuristic algorithm |
| *ANN* | Artificial neural network | *MOPSO* | Multi-objective particle swarm optimization |
| *BoMM* | Bi-objective mathematical model | *MOO* | Multi-objective optimization |
| *CA* | Cuckoo algorithm | *MOOHE* | Multi-objective optimal heat exchange |
| *CO2* | Carbon dioxide | *MOSTES* | Multi-objective solar thermal energy storage |
| *CSOA* | Cuckoo search optimization algorithm | *MW* | Mega watt |
| *DE* | Differential evolution | *NN* | Neural network |
| *DECQPSO* | Differential evolution crossover Quantum particle swarm optimization | *NPGA* | Niched pareto genetic algotithm |
| *ED* | Economic dispatch | *NRGA* | Non-dominated ranked genetic algorithm |
| *EED* | Economic emission dispatch | *NSGA* | Non-dominated sorting genetic algorithm |
| *EPS* | Electric power system | *PSO* | Particle swarm optimization |
| *EPSA* | Enhanced particle swarm algorithm | *QPSO* | Quantum particel swarm optimization |
| *FA* | Firefly algorithm | *SA* | Simulated annealing |
| *FO* | Objective function of EED | *SAA* | Simulated annealing algorithm |
| *GA* | Genetic algorithm | *SOA* | Spiral optimization algorithm |
| *GEP* | Gene expression programming | *WOA* | Whale optimization algorithm |
| *GHG* | Greenhouse gases | $a_i, b_i, c_i$ | Cost coefficient of the unit generator-i |
| *GO* | Global optimization | $d_i, e_i, f_i$ | Emission coefficient of the unit generator-i |
| *GSA* | Gravitational search algorithm | $FC_i$ | The cost function of generator-i |
| *HMGOA* | Hybrid modified grasshopper optimization algorithm | $FE_i$ | Emission function of generator-i |
| *IDR* | Indonesian rupiah (Indonesian Currency) | $P_D$ | Load demand |
| *MA* | Metaheuristic algorithm | $P_i$ | The output power of generator-i |
| *MAGO* | Metaheuristic algorithm for global optimization | $P_{i,max}, P_{i,min}$ | Maximum & minimum limit of generator output power-i |
| *MBFA* | Modified bacterial foraging algorithm | *P(t)* | The decrement power at time t |

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| | | | |
|---|---|---|---|
| *MHSA* | Modified harmony search algorithm | $w_C$, $w_S$ | Weight of cost, weight of emission |
| *MODE* | Multi-objective differential evolution | $\alpha$ | A constant close to 1 |
| *MOFA* | Multi-objective firefly algorithm | $\beta$ | A very small value |

## 1. INTRODUCTION

Climate change, greenhouse gases, and global warming are global issues today. Climate change is the biggest problem facing humankind in recent decades, one of the main causes of GHG. To mitigate it, an international agreement has been proposed in Paris 2016, known as COP21 by some countries [1]. Climate change is also a major challenge in local markets with its potentially harmful effects on the agricultural sector [2]. Research on emissions related to oil consumption, energy use, and economic growth, such as those conducted and reported in the literature [3, 4], as well as emissions associated with power generation [5], have been published.

The issue of environmental sustainability has also become a strategic issue recently. Various activities carried out by the community have started to care about the environment. Likewise, many studies focused on the environment, such as Fasihia et al. [6] and Chouhan et al. [7]. Development of a BoMM for designing a closed loop fish supply [6].

The relationship between economic growth, oil consumption, and emissions in Thailand using ARDL and Granger causality approach has been studied [8] used in this study are annual data from 1971 to 2014. Higher incomes and economic growth can increase $CO_2$ emissions in the long term [4].

Conventionally, optimizing the fuel mixture for the EPS components does not involve emission costs in the electrical system [5], so it is necessary to involve the costs of greenhouse gas emissions into the fuel cost function for power flow optimization calculations. Meanwhile [8] developed a new hybrid metaheuristic algorithm called Hybrid of WOA and SA, called HWS based on WOA and SA to Solve the optimization problem of production-distribution network taking into account carbon emissions, where the result is better than using WOA alone or SA only.

Optimization of multi-objective problems was also carried out by Fard et al. [9] for modeling and MOOHE through the Tube Bank using NN and GA. Many artificial methods have been implemented in the area of the power system, such as the work done by Sadafi et al. [10] in optimizing MOSTES using hybrid PSO, multiple crossovers, and operator mutation.

As the fourth largest country globally in terms of the population[1], Indonesia requires electrical energy consumption that continues to increase significantly from year to year. Indonesia has enormous potential for renewable energy sources, but until now, the contribution of renewable energy sources is still low compared to fossil energy sources. So that most of the power plants in Indonesia are still dominated by fossil fuels.

Various efforts have been made, including, for a long time, Indonesia has had a ministry specifically dealing with energy and mineral resources, the establishment of a national energy council, the government has targeted the energy mix from renewable energy sources in 2025 and 2050 at 23 and 31%, respectively (The Presidential Regulation No.22/2017). On the other hand, many publications have been related to optimizing generator scheduling, which is to obtain the cheapest fuel costs and consider the resulting low emissions, known as EED. Many research results have been published to solve the EED problem, namely solving the multi-objective optimization problem between costs and emissions using various methods based on metaheuristic algorithms.

Metaheuristic algorithms are divided into four, namely: evolutionary algorithms, physics-based algorithms, herd-based algorithms, and human-based algorithms [11]. Research on solving EED problems based on evolutionary algorithms such as genetic algorithms has been studied [12, 13]. This multi-objective problem becomes more complex in large-scale power systems because it is difficult to find an optimal solution. After all, it is a non-smooth and non-convex function and contains several local optima [13]. Using a NRGA can overcome the problem of convergence in GA, which is still slow and computational complexity is higher in solving EED problems [14].

Physics-based algorithms, such as the GSA, have been reported by Radosavljević, [14] to solve the EED problem. The simulation results show that the GSA approach provides a high-quality solution that is effective and better or comparable to that obtained data using other techniques such as GA, NSGA, NPGA, differential evolution (DE), MODE, ABC, PSO, MOPSO, SOA, and MBFA.

The metaheuristic method is used in a wide field because it can solve optimization problems on differentiable and non-differentiable functions. Projectiles Optimization: A Novel MAGO [15]. The fruit fly algorithm was applied to the Multi-Objective Unload Scheduling [16].

The application of the EPSA for supporting structure modal optimization is carried out by Shijing et al. [17]. Application of HMGOA and GA to detect and prevent DDoS Attacks [18]. Optimizing the placement of Bank Voltage Regulators and Capacitors based on FSM and MMOPSO [19]. Optimization of the Rubber Compound

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[1] https://www.statista.com/statistics/262879/countries-with-the larges-population

Design Process was conducted Using Artificial Neural Networks and Genetic Algorithms [20].

Modification of PSO-ANN and GEP to predict high-temperature oxidation behavior of Ni–Cr–W-Mo alloys [21]. Design of a multi-objective sustainable drug supply chain network using novel hybrid MOMA [22]. Parameter identification based on PSO applied to target tracking robot with flexible cation Isotherm Models for the Adsorption of $H_2$, $N_2$, CO, $CH_4$, and $CO_2$ Using the CSOA [23]. The MOO of Multi-vehicle Relief Logistics Considering Satisfaction Levels gone under Uncertainty [24].

Meanwhile, SA as a metaheuristic method has been widely used in solving optimization. SA is known as an effective single-point metaheuristic algorithm for finding global solutions in the presence of a large number of local optima. This concept evolved from the thermodynamics of the heating and cooling behavior of metals in which the metal is first heated to a certain temperature and cooled slowly. The implementation of this algorithm is very simple. Quests are based on random movement which is very similar to hill climbing. Initially, it was chosen a bad move instead of a good move. If the selected move fixes the solution, it is always accepted. Otherwise, the move will be considered based on a random probability of less than one to avoid falling into the local minimum.

Hybrid method between SA and other methods such as H-GASA, hybrid of GA with SA, H-KASA, hybrid of Keshtel Algorithm with SA, and H-RDASA, hybrid of Red Deer Algorithm with Simulated Annealing to handle the complexity of problems in sugarcane-based product supply chain network [25]. The application of SA to a sustainable sugarcane supply chain network taking into account the carbon tax on emissions from the industry was studied [7].

Solving the EED problem using a swarm-based algorithm such as PSO has also been proposed [26-28]. The MOPSO algorithm to solve the EED problem shows advantages in terms of the diversity of the Pareto optimal solutions obtained and produces high-quality non-dominant solutions [26]. Modulated PSO (MPSO) is a modification of conventional PSO by modulating particle velocity for better exploration and exploitation of search space, is proposed [28]. MPSO gives promising results for solving the EED problem compared to its comparison methods.

Meanwhile, the hybrid DE-CQPSO method resulted in fast convergence of the DE algorithm and the diversity of the genetic crossover algorithm operator particles. The parameter adaptive control method updates the crossover probability to get better optimization results. Moreover, the MOO problem is solved by introducing a penalty factor. The experimental results show that: the evaluation index and convergence speed of the DE-CQPSO algorithm is better than QPSO and other algorithms, be it single-objective optimization of fuel costs and emissions or multi-objective optimization considering both optimization objectives. A good compromise value was verified, which verifies the effectiveness and robustness of the DE-CQPSO algorithm in solving environmental, economic dispatch problems [29].

Planning and scheduling problems are the most significant problems in the world and have a major impact on increasing productivity [30]. Likewise, with optimization problems, especially applied in the field of power systems. The paper that introduced the theory of genetic algorithms into the control strategy used in the switching chain in wind turbines was studied [31], providing improved performance and efficiency. Hybrid GA for Integrated Production and Distribution Scheduling Problems with Allowed Outsourcing [32]. Such as the case is with optimizing power plant scheduling.

Research to reduce emissions has also been published such as the Emission Reduction Strategy for Small Single Cylinder Diesel Engines Using Valve Timing and Swirl Ratio [33]. The MHSA is a modification of the harmony search algorithm (HSA) as part of an artificial human-based algorithm proposed to solve the EED problem [34]. MHSA can provide a search for a more diverse solution space during the early stages of interim evolution and has been successfully applied to solve EEDs involving all constraints [35].

The solution of EED using a simulated annealing algorithm has been published [36], where the simulation results show a 20.14% reduction in the total fuel cost compared to the classical method of distributing power generation. This method assists the expert in preventive maintenance decision-making of machine downtime during multi-objective optimization, improving generation yields and emission reductions.

Solving the EED problem with the case of the electricity system in Indonesia has also been studied [37, 38]. Generator scheduling by considering emissions using MOPSO gives better results than the MOFA [37]. Meanwhile, the use of CA, FA and PSO algorithms for optimization of generator scheduling has been studied [38].

The main objective of this study is to determine the cost of reducing power generation emissions in Indonesia through solving the EED problem. The proposed method for solving the EED problem is a simulated annealing algorithm. The electrical system that is the test object is the 500 kV, 25 bus electrical system, Java-Bali, Indonesia. So far, many kinds of research on optimizing generator scheduling have only stopped at the EED results. On the other hand, the determination of the cost of reducing power plant emissions so far has not been through optimization of generator scheduling (EED). The novelty of this research is to determine the additional cost in reducing emissions through optimization of power plant scheduling (EED).

This paper consists of 4 main parts. The first part discusses the scheduling of power plants by considering emissions or known as EED. The second section briefly discusses the proposed method. The third part presents the simulation results and discussion, and the last part presents the conclusions.

## 2. ECONOMIC EMISSION DISPATCH

The EED was an optimization problem with two objectives: minimizing the total cost of generation and considering emissions. The problem in this research is optimization with two objectives: minimizing the total cost of generation and considering low emissions by including the minimization of emission reduction costs. The simulation process uses the simulated annealing method by including generator scheduling and calculating emission reduction costs. Next, our process will be named X_EED.

The process diagram is shown in Figure 1 by the block diagram.

**2. 1. Cost Function** Fuel cost is the most dominant component in thermal power plants. The fuel cost curve is approximated by a quadratic function [34]. The first objective function in the EED problem is to minimize generation cost function in US$ per hour [36]. The fuel cost function is shown in Equation (1).

$$FC_i(P_i) = a_i + b_iP_i + c_iP_i^2 \qquad (1)$$

where $FC_i(P_i)$ is a function of the cost of fuel of each generator (US$/Hours), and $a_i$, $b_i$, $c_i$ is the cost coefficient of the unit generator $i$, is output power of generator $i$.

**2. 2. Emission Function** The second objective function minimizes each unit's emission function in grams per hour [20]. The emission function is shown in Equation (2).

$$FE_i(P_i) = d_i + e_iP_i + f_iP_i^2 \qquad (2)$$

where $F_{Ei}(P_i)$ is the fuel emission of generator-i (grams), N is the number of generators, $P_i$ is the active power output of the generator-i (MW), whereas $d_i$ $[grams]$, $e_i$ $[\frac{grams}{MW}]$, and $f_i$ $[\frac{grams}{MW^2}]$ are the constants of input-output of generator-i.

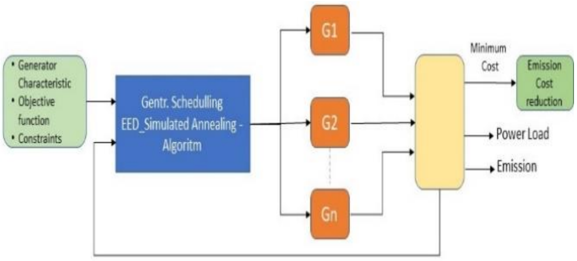

**Figure 1.** Generator Scheduling X_EED Simulated Annealing

**2. 3. The Multi-objective Function** Multi-objective optimization (MOO) consists of several goals that must be achieved simultaneously, so MOO is the process of reaching a compromise between various objective functions in a problem [37]. Because of the multi-objective function of simultaneously reducing the optimum operating emission for generating economic dispatch, these two objective functions must be combined to become the EED objective function, formulated in Equation (3).

$$FO = w_C . \sum_{i=1}^{n} FC_i(P_i) + w_s . \sum_{i=1}^{n} FE_i(P_i) \qquad (3)$$

where $w_C$+ $w_S$=1 (must be worth 1) and the weighting value of w based on the priority scale to be achieved [38]. The FO is EED to minimize cost function and emission function with different weighting values.

**2. 4. Constraints** Economic Emissions Dispatch is inseparable from several limitations that must be complied with to stabilize the system. The power generated by the generators must be equal to the demand if the system losses are neglected, as shown in Equation (4).

$$\sum P_i = P_D \qquad (4)$$

where the total supply must equal the power demand, and $P_D$ is a request, and Pi represents the summation of power volume generated by units [39]. The generator operating limits for each generator are limited by the minimum and maximum limits, which are shown in Equation (5).

$$P_{i\,min} \leq P_i \leq P_{i\,max} \qquad (5)$$

where Generator limit Constrains $\boldsymbol{P_i}$: Power generation unit $I$ must be between the minimum and maximum limits. $\boldsymbol{P_{i\,min}}$ and $\boldsymbol{P_{i\,max}}$ are the minimum and maximum generation limits unit-i, respectively [36].

Ramp rate measures how fast the increase and decrease in electric power output that the generator can generate in one unit of time. This value needed to be considered because if at any time there was a peak load occurs, the ramp rate can bear the power jumps quickly. Equations (6) and (7) illustrate the ramp rate.

$$Max\ P_{min,i}, P_{i,t-1} - ramp \leq P_{i,t-1} - ramp \leq Min\ P_{min,i}, P_{i,t-1} + ramp \qquad (6)$$

Ramp limit makes the first hour's generation automatic maximum and minimum, by Equation (7).

$$P_{min,i} = Max(P_{min,i}, P_{i,t-1} - ramp), for\ min. value$$
$$P_{max,i} = Max(P_{min,i}, P_{i,t-1} + ramp), for\ max. value \qquad (7)$$

## 3. RESEARCH METHOD

The SAA was developed in 1980s. It was one of the first metaheuristic algorithms to be inspired by physical phenomena occurring in statistical mechanics and metallurgical engineering. A metaheuristic is a method for finding solutions that combine the interaction between local search procedures and higher-level strategies to create a process that can exit the local optimal point and search in the solution space to find the global optimal solution [40]. The SAA is an algorithmic and rhythmic word that was first revealed by Abu Ja'far Mohammed Ibn Musa al Khwarizmi (825 AD) in Al-Jabr Wa-al Muqabla. The algorithm is defined as an appropriate method consisting of a structured and written series systematically to solve a problem with the help of a computer.

Simulated Annealing is a random optimization algorithm used to simulate crystal annealing processes. The problem solution region is represented as the crystalline state of the particle. This method is very stochastic, so convergence speed is slow [41]. The SAA can also simulate, calculate, and find the optimal solution between electricity generation costs and carbon emissions [39]. Optimization of the SA method is very significant for power plant scheduling [42]. SA is a search method that utilizes probability theory to find the global minimum of a problem [36].

In the initial process of the algorithm, the initial power must be set at a higher value, to get more possibilities of acceptance for the solution to be optimized and too high initial power makes the algorithm slow and inefficient. When working with the SAA, the final power drop is generally set to zero. The SAA can take longer to run operations if the exponential power drop. Therefore, this algorithm needs a constraint that limits the iteration process of selecting the final solution. Since the initial and final powers have values defined by constraints, it is important to find the path of the change in power loss from the beginning to the end because the algorithm's success depends on it. The decrement of power at time 't'.

$$P(t) = {}^{d}\!/_{\log(t)} \tag{8}$$

where $d$ is a positive constant.

$$P\,(t+1) = \alpha\, P(t) \tag{9}$$

$\alpha$ is a constant close to 1.

Algorithm efficiency can be increased by selecting the right number of iterations. Realization of only iterations for each power should occur at a very slow rate which can be denoted in Equation (10).

$$P(t) = {}^{t}\!/_{(1+\beta t)} \tag{10}$$

## 4. RESULTS AND DISCUSSION

**4. 1. Java-Bali Electricity System** The simulated annealing method was tested on the Java-Bali interconnection electrical system with four load variations. Record power data used for simulations on the Java-Bali Grid 500 kV generating system was taken on June 9, 2014, and divided into four times, namely at 18:00 with 13,096 MW, 19:00 with 13,108 MW, 20:00 with 12,863 MW, and 21:00 with 12,228 MW [34]. The analysis of the Economic Emission Dispatch simulation using the SA algorithm on the Java-Bali 500 kV electrical system based on the 2015-2024 RUPTL Objective Function, shows that the amount of power generated from the simulation process of each generating unit is very dependent on the objective cost function and objective emission function.

One-line diagram 500kV electrical system, Java-Bali, Indonesia consists of 25 buses, of which eight are generator buses. Of the eight generator buses, there are two hydroelectric power plants (PLTA) and the remaining six steam power plants (PLTU). The characteristics of generators are shown in Table 1, and the single line diagram of EPS is shown in Figure 2.

In EPS, generation must not exceed the ramp limit for each generator. The characteristic of each generator shown is Table 1.

**TABLE 1.** The Generators Characteristic

| Generator | $a_i$ | $b_i$ | $c_i$ | $d_i$ | $e_i$ | $f_i$ | $P_{i,min}$ (MW) | $P_{i,max}$ (MW) | Ramp Rate (MW/h) |
|---|---|---|---|---|---|---|---|---|---|
| $P_1$ | 57,543,208.0 | 3,332,794.0 | -400.0 | 34,251,909.8 | 1,983,806.2 | -236.7 | 1,610.0 | 4,200.0 | 300 |
| $P_2$ | 519,353,767.1 | 3,047,098.0 | 691.0 | 72,202,664.7 | 423.6 | 96.2 | 934.0 | 2,308.0 | 510 |
| $P_3$ | 0.0 | 400.0 | 0.0 | 0.0 | 0.0 | 0.0 | 404.0 | 1,008.0 | 930 |
| $P_4$ | 0.0 | 660.0 | 0.0 | 0.0 | 0.0 | 0.0 | 208.0 | 700.0 | 660 |
| $P_5$ | 133,177,025.6 | 2,828,349.0 | -80.0 | 93,654,729.7 | 1,988,993.9 | -56.9 | 848.0 | 2,400.0 | 337 |
| $P_6$ | 180,205,527.9 | 2,104,640.0 | 218.0 | 123,428,443.8 | 1,441,534.9 | 149.5 | 1,080.0 | 4,714.0 | 420 |
| $P_7$ | 140,621,312.5 | 2,545,832.0 | 203.0 | 140,621,312.5 | 2,545,832.5 | 62.1 | 360.0 | 900.0 | 240 |
| $P_8$ | 112,522,922.1 | 5,877,235.0 | -73.0 | 24,146,549.8 | 1,261,209.3 | -15.8 | 305.0 | 1,610.0 | 420 |

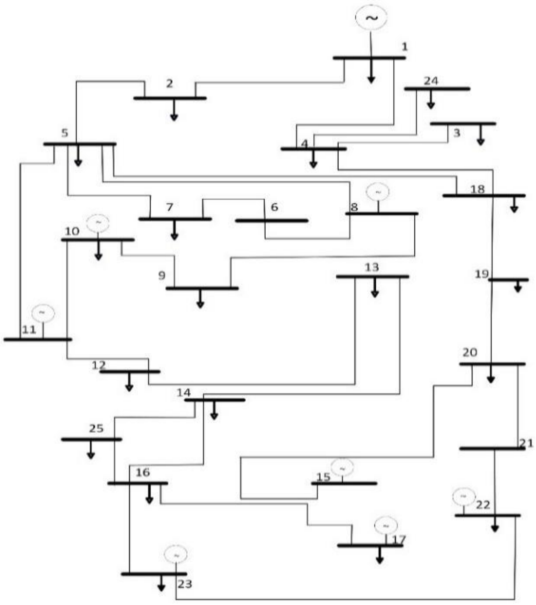

**Figure 2.** Java-Bali Electricity Systems

In each condition or at each load test, carried out with 5 variations of the combination of cost weight ($w_C$) and emission weight ($w_S$) as shown in Table 2.

**4. 2. Economic Emission Dispatch Results** The simulation was carried out using the MATLAB R2018b software. MATLAB R2018b software. The iteration process is shown in Figures 3 to 6.

**TABLE 2.** Weighted Value

| Condition | $w_C$ | $w_S$ |
|---|---|---|
| I | 1.00 | 0.00 |
| II | 0.75 | 0.25 |
| III | 0.50 | 0.50 |
| IV | 0.25 | 0.75 |
| V | 0.00 | 1.00 |

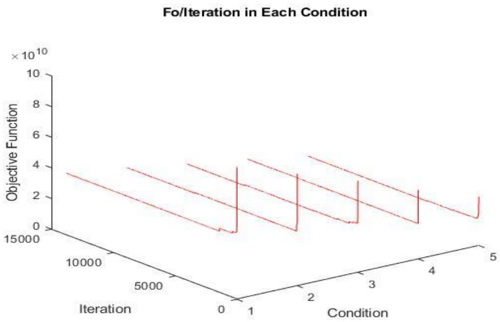

**Figure 3.** Iteration in each first-hour condition

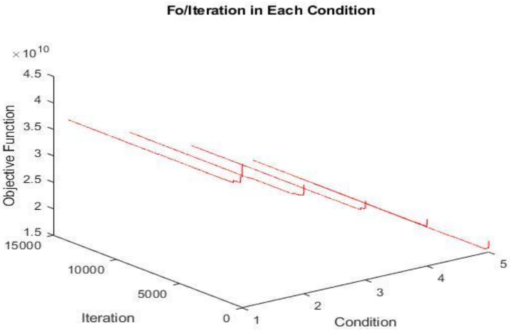

**Figure 4.** Iteration in each-second hour condition

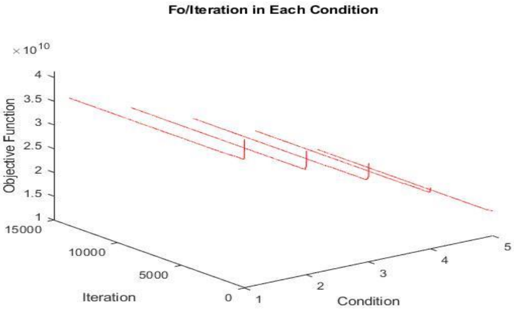

**Figure 5.** Iteration in each third-hour condition

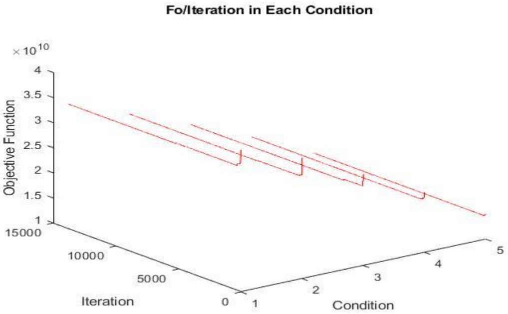

**Figure 6.** Iteration in each forth-hour condition

The total costs and emissions for various conditions and times are shown in Tables 3, 4, and 5. The results of the EED simulation using SA are shown in Table 3. The cost of power generation has been converted from Indonesian currency (IDR) to US$ (assuming an exchange rate of US$1=IDR 14385), on March 6, 2022. Table 3 power generated by each generator in optimal conditions. The power generated in supplying the load meets the limits of Equations (4) and (5), so that no generator operating limit is violated. Meanwhile, Table 4 shows the rate of change of power for each generator which is also appropriate with the constraints.

Table 5 shows additional costs required to reduce emissions. It costs US$ 255.81 to reduce 1 ton of

**TABLE 3.** Total Cost and Emission per Hour

| Condition | Time | Load (MW) | Generator Power (MW) | | | | | | | | Power (MW) | Cost (US$) | Emission (tons) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ | $P_7$ | $P_8$ | | | |
| I | 18:00 | 13096 | 3109 | 934 | 1008 | 700 | 2030 | 3823 | 900 | 592 | 13096 | 2,338,676 | 19,034 |
| | 19:00 | 13108 | 3099 | 934 | 1008 | 700 | 2031 | 3843 | 900 | 593 | 13108 | 2,343,912 | 19,084 |
| | 20:00 | 12863 | 3099 | 801 | 998 | 700 | 2013 | 3812 | 898 | 542 | 12863 | 2,272,440 | 18,881 |
| | 21:00 | 12228 | 3025 | 589 | 998 | 700 | 2013 | 3465 | 898 | 540 | 12228 | 2,118,992 | 17,933 |
| Average | | | | | | | | | | | | 2,268,505 | 18,733 |
| II | 18:00 | 13096 | 3180 | 1008 | 1008 | 700 | 1831 | 3823 | 859 | 687 | 13096 | 2,360,357 | 18,740 |
| | 19:00 | 13108 | 3081 | 934 | 1008 | 700 | 2027 | 3865 | 900 | 593 | 13108 | 2,347,927 | 19,125 |
| | 20:00 | 12863 | 3082 | 801 | 998 | 700 | 2022 | 3810 | 900 | 550 | 12863 | 2,276,096 | 18,898 |
| | 21:00 | 12228 | 2998 | 571 | 998 | 700 | 2013 | 3465 | 898 | 585 | 12228 | 2,130,572 | 17,972 |
| Average | | | | | | | | | | | | 2,278,738 | 18,684 |
| III | 18:00 | 13096 | 3168 | 1008 | 1008 | 700 | 1812 | 3812 | 831 | 757 | 13096 | 2,375,926 | 18,685 |
| | 19:00 | 13108 | 3080 | 917 | 1008 | 700 | 2026 | 3865 | 900 | 612 | 13108 | 2,350,227 | 19,143 |
| | 20:00 | 12863 | 3071 | 801 | 998 | 700 | 2022 | 3814 | 900 | 557 | 12863 | 2,279,298 | 18,911 |
| | 21:00 | 12228 | 2974 | 571 | 998 | 700 | 2019 | 3465 | 900 | 601 | 12228 | 2,136,887 | 17,994 |
| Average | | | | | | | | | | | | 2,285,584 | 18,683 |
| IV | 18:00 | 13096 | 3110 | 1008 | 1008 | 700 | 1843 | 3823 | 839 | 765 | 13096 | 2,385,771 | 18,771 |
| | 19:00 | 13108 | 3080 | 902 | 1008 | 700 | 2018 | 3865 | 900 | 635 | 13108 | 2,353,597 | 19,155 |
| | 20:00 | 12863 | 3067 | 800 | 996 | 700 | 2017 | 3818 | 900 | 565 | 12863 | 2,282,165 | 18,921 |
| | 21:00 | 12228 | 3002 | 571 | 968 | 700 | 2019 | 3444 | 900 | 624 | 12228 | 2,142,704 | 17,986 |
| Average | | | | | | | | | | | | 2,291,059 | 18,708 |
| V | 18:00 | 13096 | 3110 | 999 | 1008 | 700 | 1827 | 3815 | 839 | 798 | 13096 | 2,391,302 | 18,760 |
| | 19:00 | 13108 | 3054 | 887 | 1008 | 700 | 2005 | 3850 | 900 | 704 | 13108 | 2,369,050 | 19,162 |
| | 20:00 | 12863 | 3050 | 806 | 996 | 700 | 2012 | 3818 | 900 | 581 | 12863 | 2,288,425 | 18,924 |
| | 21:00 | 12228 | 2998 | 571 | 968 | 700 | 2003 | 3405 | 900 | 683 | 12228 | 2,153,616 | 17,933 |
| Average | | | | | | | | | | | | 2,300,598 | 18,609 |

**TABLE 4.** Rate of Power Change

| Gen | Rate of Power Change | | | | | | | | | | | | | | | Ramp rate (MW/h) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cond. I | | | Cond. II | | | Cond. III | | | Cond. IV | | | Cond. V | | | |
| | 18:00 to 19:00 | 19:00 to 12:00 | 20:00 to 21:00 | 18:00 to 19:00 | 19:00 to 12:00 | 20:00 to 21:00 | 18:00 to 19:00 | 19:00 to 12:00 | 20:00 to 21:00 | 18:00 to 19:00 | 19:00 to 12:00 | 20:00 to 21:00 | 18:00 to 19:00 | 19:00 to 12:00 | 20:00 to 21:00 | |
| $P_1$ | 10 | 0 | 74 | 0 | -1 | 84 | 88 | 9 | 97 | 30 | 13 | 65 | 56 | 4 | 52 | 300 |
| $P_2$ | 0 | 133 | 212 | 74 | 133 | 230 | 91 | 116 | 230 | 106 | 102 | 229 | 112 | 81 | 235 | 510 |
| $P_3$ | 0 | 10 | 0 | 0 | 10 | 0 | 0 | 10 | 0 | 0 | 12 | 28 | 0 | 12 | 28 | 930 |
| $P_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 660 |
| $P_5$ | -1 | 18 | 0 | -196 | 5 | 9 | -214 | 4 | 3 | -175 | 1 | -2 | -178 | -7 | -1 | 337 |
| $P_6$ | -20 | 31 | 147 | -42 | 55 | 345 | -53 | 51 | 349 | -42 | 47 | 374 | -35 | 32 | 413 | 420 |
| $P_7$ | 0 | 2 | 96 | -41 | 0 | 2 | -69 | 0 | 0 | -61 | 0 | 0 | -61 | 0 | 0 | 240 |
| $P_8$ | -1 | 51 | 2 | 94 | 43 | -35 | 145 | 55 | -44 | 130 | 70 | -59 | 94 | 123 | -102 | 420 |

**TABLE 5.** Additional Cost to Reduce Emissions

| Condition | $w_C$ | $w_S$ | Cost (US$) | Emission (tons) | Emission Reduction (tons) | Additional Cost (US$) | Additional cost/tons of emission reduction (US$) |
|---|---|---|---|---|---|---|---|
| I | 1 | 0 | 2,268,505 | 18,733 | - | - | - |
| II | 0.75 | 0.25 | 2,278,738 | 18,684 | 49 | 10,233 | 208.84 |
| III | 0.5 | 0.5 | 2,285,584 | 18,683 | 50 | 17,079 | 341.58 |
| IV | 0.25 | 0.75 | 2,291,059 | 18,670 | 63 | 22,554 | 358.00 |
| V | 0 | 1 | 2,300,598 | 18,609 | 124 | 32,093 | 258.81 |

emissions. The execution time required for EED with eight generators is still under 1 minute. This is of course still quite feasible to be applied to the generator schedule for the next 1 hour, where generally the generator schedule is 1 hour ahead.

The simulation results of the SA method compared to other methods are shown in Table 6. In terms of generation costs, the SA method has the best performance compared to Cuckoo and WOA. Meanwhile, in terms of emissions, the WOA method has the best performance. Compared to the Cuckoo algorithm, SA is able to provide a cost-performance improvement of up to 10.568% and an emission performance improvement of up to 11.493%.

Meanwhile, when compared with WOA, SA provides a cost-performance improvement of up to 12.75%, but related to emission performance, WOA has better performance than SA as shown in Table 7.

**TABLE 6.** Comparison Results

| Condition | Time | Load (MW) | SA | | CA | | WOA | |
|---|---|---|---|---|---|---|---|---|
| | | | Cost (US$) | Emission (tons) | Cost (US) | Emission (tons) | Cost (US$) | Emission (tons) |
| I | 18:00 | 13096 | 2,338,676 | 19,034 | 2,394,530 | 19,791 | 2,341,963 | 17,632 |
| | 19:00 | 13108 | 2,343,912 | 19,084 | 2,471,776 | 20,173 | 2,341,963 | 17,544 |
| | 20:00 | 12863 | 2,272,440 | 18,881 | 2,506,295 | 22,502 | 2,336,913 | 17,338 |
| | 21:00 | 12228 | 2,118,992 | 17,933 | 2,339,840 | 21,079 | 2,247,200 | 16,494 |
| Average | | | 2,268,505 | 18,733 | 2,428,110 | 20,886 | 2,317,010 | 17,252 |
| II | 18:00 | 13096 | 2,360,357 | 18,740 | 2,457,356 | 19,205 | 2,507,661 | 17,865 |
| | 19:00 | 13108 | 2,347,927 | 19,125 | 2,369,426 | 19,470 | 2,342,943 | 17,114 |
| | 20:00 | 12863 | 2,276,096 | 18,898 | 2,267,626 | 17,906 | 2,302,329 | 16,775 |
| | 21:00 | 12228 | 2,130,572 | 17,972 | 2,224,815 | 18,163 | 2,282,456 | 16,603 |
| Average | | | 2,278,738 | 18,684 | 2,329,806 | 18,686 | 2,358,847 | 17,089 |
| III | 18:00 | 13096 | 2,375,926 | 18,685 | 2,561,731 | 19,779 | 2,633,410 | 16,897 |
| | 19:00 | 13108 | 2,350,227 | 19,143 | 2,477,518 | 21,519 | 2,350,769 | 15,893 |
| | 20:00 | 12863 | 2,279,298 | 18,911 | 2,432,040 | 19,571 | 2,308,521 | 15,462 |
| | 21:00 | 12228 | 2,136,887 | 17,994 | 2,277,238 | 18,085 | 2,298,513 | 15,373 |
| Average | | | 2,285,584 | 18,683 | 2,437,132 | 19,739 | 2,397,803 | 15,906 |
| IV | 18:00 | 13096 | 2,385,771 | 18,771 | 2,670,662 | 19,536 | 2,713,948 | 16,068 |
| | 19:00 | 13108 | 2,353,597 | 19,155 | 2,563,233 | 20,013 | 2,481,338 | 15,543 |
| | 20:00 | 12863 | 2,282,165 | 18,921 | 2,503,692 | 18,953 | 2,481,323 | 15,543 |
| | 21:00 | 12228 | 2,142,704 | 17,986 | 2,393,588 | 19,193 | 2,481,299 | 15,543 |
| Average | | | 2,291,059 | 18,670 | 2,532,794 | 19,424 | 2,539,477 | 15,674 |
| V | 18:00 | 13096 | 2,391,302 | 18,760 | 2,565,745 | 16,869 | 2,708,014 | 15,729 |
| | 19:00 | 13108 | 2,369,050 | 19,162 | 2,634,074 | 17,347 | 2,735,308 | 16,215 |
| | 20:00 | 12863 | 2,288,425 | 18,924 | 2,555,360 | 16,759 | 2,497,764 | 15,310 |
| | 21:00 | 12228 | 2,153,616 | 17,933 | 2,419,741 | 15,359 | 2,434,584 | 15,178 |
| Average | | | 2,300,598 | 18,609 | 2,543,730 | 16,584 | 2,593,917 | 15,608 |

**TABLE 7.** Performance Comparison

| Con | Cost (US$) | | | $\Delta_{SA-CA}$ | | $\Delta_{SA-WOA}$ | | Emission (tons) | | | $\Delta_{SA-CA}$ | | $\Delta_{SA-WOA}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SA | CA | WOA | US$ | % | US$ | % | SA | CA | WOA | tons | % | tons | % |
| I | 2,268,505 | 2,428,110 | 2,317,010 | -159,605 | -7.036 | -48,505 | -2.138 | 18,733 | 20,886 | 17,252 | -2,153 | -11.493 | 1,481 | 7.906 |
| II | 2,278,738 | 2,329,806 | 2,358,847 | -51,068 | -2.241 | -80,109 | -3.515 | 18,884 | 18,686 | 17,089 | 198 | 1.049 | 1,795 | 9.505 |
| III | 2,285,887 | 2,437,132 | 2,397,803 | -151,245 | -6.616 | -111,916 | -4.896 | 18,683 | 19,739 | 15,906 | -1,056 | -5.652 | 2,777 | 14.864 |
| IV | 2,291,059 | 2,532,794 | 2,539,477 | -241,735 | -10.551 | -248,418 | -10.843 | 18,670 | 19,424 | 15,674 | -754 | -4.039 | 2,996 | 16.047 |
| V | 2,300,598 | 2,543,730 | 2,593,917 | -243,132 | -10.568 | -293,319 | -12.750 | 18,609 | 16,584 | 15,608 | 2,025 | 10.882 | 3,001 | 16.127 |

## 5. CONCLUSION AND FUTURE WORK

From the optimization of the generator scheduling by considering emissions, it can be calculated the additional costs needed to reduce emissions. This study proposes to calculate the cost of reducing emissions from the operation of a power plant through optimization of generator scheduling by considering emissions or optimization of EED using SA.

This method was tested on Java-Bali electricity system, Indonesia, and tested with 4 different loads where each load is calculated for various combinations of fuel costs and emissions. The simulation results and calculations were compared with other methods, the Cuckoo and WOA algorithms. From the simulation results and calculations, to reduce 1 ton of electricity generation emissions, an additional cost of US$258.81 is required. The results of this study can be considered in formulating policies related to emission restrictions in the operation of power plants. On the one hand, limiting generator emissions follows the international spirit of controlling the greenhouse effect. On the other hand, emission restrictions on the operation of power plants will certainly provoke protest reactions from generator providers. So, there needs to be a wise policy; for example, the government provides support to managers or providers of power plants that reduce emissions in the operation of their plants. Government support can be in the form of tax breaks, financial assistance, or other forms of incentives. For this reason, it is deemed necessary to have an academic text or policy text that examines the matter in more detail by taking into account the interests of stakeholders as a whole.

Future work can be explained as follows: this research is still limited to testing with four consecutive loading hours, involving eight generators, and five combinations of cost and emission weights. Further, this research needs to be applied to a large-scale electrical system, tested with more varied loads and more (for example daily load), with a combination of cost and emission weights with a smaller observation range, to get more accurate results. In addition, for better optimization results in the future, the SA algorithm was developed by applying the SA concept based on predictive control.

## 6. REFERENCES

1. Ramírez-Tovar, A., Moreno, R. and Carrillo-Rodríguez, L.A., "The colombian energy policy challenges in front of climate change", ***International Journal of Energy Economics and Policy***, Vol. 11, No. 6, (2021), 401, doi: 10.32479/ijeep.10517.
2. Mumuh, M.Z., Herlina, N., Falah, M., Saringendyanti, E., Sofianto, K. and Zin, N.M., "Impact of climate change on agriculture sector of malaysia", ***International Journal of Energy Economics and Policy***, Vol. 11, No. 6, (2021), 138, doi: 10.32479/ijeep.10939.
3. Bunnag, T., "The causal relationship among $CO_2$ emission, oil consumption and economic growth in thailand: Ardl bound testing approach", ***International Journal of Energy Economics and Policy***, Vol. 11, No. 6, (2021), 427, doi: 10.32479/ijeep.11811.
4. Shaari, M.S., "The impacts of rural population growth, energy use and economic growth on $CO_2$ emissions", ***670216917***, (2021), doi: 10.32479/ijeep.11566.
5. Mardiyanto, I.R., Zein, H. and Soeprijanto, A., "Combining parameters of fuel and greenhouse gas costs as single objective function for optimization of power flow", ***Telkomnika***, Vol. 15, No. 4, (2017), 1585-1600, doi: 10.12928/TELKOMNIKA.v15i4.5769.
6. Fasihi, M., Tavakkoli-Moghaddam, R., Najafi, S.E. and Hajiaghaei-Keshteli, M., "Developing a bi-objective mathematical model to design the fish closed-loop supply chain", ***International Journal of Engineering***, ***Transaction B: Applications,*** Vol. 34, No. 5, (2021), 1257-1268, doi: 10.5829/IJE.2021.34.05B.19.
7. Chouhan, V.K., Khan, S.H. and Hajiaghaei-Keshteli, M., "Sustainable planning and decision-making model for sugarcane mills considering environmental issues", ***Journal of Environmental Management***, Vol. 303, (2022), 114252, doi: 10.1016/j.jenvman.2021.114252.
8. Mehranfar, N., Hajiaghaei-Keshteli, M. and Fathollahi-Fard, A.M., "A novel hybrid whale optimization algorithm to solve a production-distribution network problem considering carbon emissions", ***International Journal of Engineering***, ***Transaction C: Aspects,*** Vol. 32, No. 12, (2019), 1781-1789, doi: 10.5829/ije.2019.32.12c.11.
9. Fard ,N.A., Hajiloo, A. and Tohidi, N., "Using neural network and genetic algorithm for modeling and multi-objective optimal heat exchange through a tube bank", doi: 10.5829/idosi.ije.2012.25.04c.07.

10. Sadafi, M., Hosseini, R., Safikhani, H., Bagheri, A. and Mahmoodabadi, M., "Multi-objective optimization of solar thermal energy storage using hybrid of particle swarm optimization and multiple crossover and mutation operator", (2011), doi: 10.5829/idosi.ije.2011.24.04b.07.

11. El-Henawy, I. and Abdelmegeed, N.A., "Meta-heuristics algorithms: A survey", ***International Journal of Computer Applications***, Vol. 179, No. 22, (2018), 45-54, doi: 10.5120/ijca2018916427.

12. Arthur, J.K., Frimpong, E.A. and Adjei, J.O., "Optimization algorithms for solving combined economic emission dispatch: A review", in Proceedings of the World Congress on Engineering and Computer Science. (2019), 22-24.

13. Gopalakrishnan, R. and Krishnan, A., "An advanced genetic optimization algorithm to solve combined economic and emission dispatch problem", ***Bonfring International Journal of Man Machine Interface***, Vol. 2, No. 1, (2012), 11-19.

14. Radosavljević, J., "Gravitational search algorithm for solving combined economic and emission dispatch", in Proc. XIV Int. Scientific-Professional Symposium Infoteh. (٢٠١٥).

15. Kahrizi, M. and Kabudian, S., "Projectiles optimization: A novel metaheuristic algorithm for global optimization", ***International Journal of Engineering***, ***Transaction A: Basics,*** Vol ,٣٣ .No. 10, (2020), 1924-1938, doi: 10.5829/ije.2020.33.10a.11.

16. Yuan, G., Yang, Y., Tian, G. and Fathollahi-Fard, A.M., "Capacitated multi-objective disassembly scheduling with fuzzy processing time via a fruit fly optimization algorithm", ***Environmental Science and Pollution Research***, (2022), 1-18, doi: 10.1007/s11356-022-18883-y.

17. Shijing, D., Hongru, C., Xudong, W., Deshi, W. and Yongyong, Z., "Modal optimization design of supporting structure based on the improved particle swarm algorithm", ***International Journal of Engineering***, ***Transaction A: Basics,*** Vol. 35, No. 4, (2022), 740-749, doi: 10.5829/ije.2022.35.04a.14.

18. Mohammadi, S. and Babagoli, M., "A hybrid modified grasshopper optimization algorithm and genetic algorithm to detect and prevent ddos attacks", ***International Journal of Engineering***, ***Transaction A: Basics,*** Vol. 34, No. 4, (2021), 811-824, doi: 10.5829/ije.2021.34.04a.07.

19. Shafiee, M., Amirahmadi, M., Farzinfar, M. and Lapthorn, A., "Voltage stability improvement in optimal placement of voltage regulators and capacitor banks based on fsm and mmopso approach", ***International Journal of Engineering***, ***Transaction A: Basics,*** Vol. 34, No. 4, (2021), 881-890, doi: 10.5829/ije.2021.34.04a.14.

20. Ghaffarian, N. and Hamedi, M., "Optimization of rubber compound design process using artificial neural network and genetic algorithm", ***International Journal of Engineering***, ***Transaction B: Applications,*** Vol. 33, No. 11, (2020), 2319-2326, doi: 10.5829/ije.2020.33.11b.22.

21. Hasibi, H., Mahmoudian, A. and Khayati, G., "Modified particle swarm optimization-artificial neural network and gene expression programing for predicting high temperature oxidation behavior of Ni–Cr–W-MO alloys", ***International Journal of Engineering***, ***Transaction B: Applications,*** Vol. 33, No. 11, (2020), 2327-2338, doi: 10.5829/IJE.2020.33.11B.23.

22. Goodarzian, F., Hosseini-Nasab, H. and Fakhrzad, M., "A multi-objective sustainable medicine supply chain network design using a novel hybrid multi-objective metaheuristic algorithm", ***International Journal of Engineering***, ***Transaction A: Basics,*** Vol. 33, No. 10, (2020), 1986-1995, doi: 10.5829/IJE.2020٣٣،١٠.A.17.

23. Esfandian, H., Esfandian, N. and Rezazadeh, M., "Modeling and comparison of optimized isotherm models for $H_2$, $N_2$, CO, $CH_4$ and $CO_2$ adsorption using cuckoo search optimization algorithm", ***International Journal of Engineering***, ***Transaction B: Applications,*** Vol. 33, No. 5, (2020), 712-719, doi: 10.5829/IJE.2020.33.05B.01.

24. Beiki, H., Seyedhosseini, S., Ghezavati, V. and Seyedaliakbar, S., "Multi-objective optimization of multi-vehicle relief logistics considering satisfaction levels under uncertainty", ***International Journal of Engineering***, ***Transaction B: Applications,*** Vol. 33, No. 5, (2020), 814-824, doi: 10.5829/ije.2020.33.05b.13.

25. Chouhan, V.K., Khan, S.H. and Hajiaghaei-Keshteli, M., "Metaheuristic approaches to design and address multi-echelon sugarcane closed-loop supply chain network ,"***Soft Computing***, Vol. 25, No. 16, (2021), 11377-11404, doi: 10.1007/s00500-021-05943-7.

26. Abido, M., "Multiobjective particle swarm optimization for environmental/economic dispatch problem", ***Electric Power Systems Research***, Vol. 79, No. 7, (2009), 1 ,١١١٣-١٠٥doi: 10.1016/j.epsr.2009.02.005.

27. Xin-gang, Z., Ji, L., Jin, M. and Ying, Z., "An improved quantum particle swarm optimization algorithm for environmental economic dispatch", ***Expert Systems with Applications***, Vol. 152, (2020), 113370 ,doi: 10.1016/j.eswa.2020.113370.

28. Jadoun, V.K., Gupta, N., Niazi, K. and Swarnkar, A., "Modulated particle swarm optimization for economic emission dispatch", ***International Journal of Electrical Power & Energy Systems***, Vol. 73, (2015), 80-88, doi: 10.1016/j.ijepes.2015.04.004.

29. Maghzi, P., Mohammadi, M., Pasandideh, S. and Naderi, B., "Operating room scheduling optimization based on a fuzzy uncertainty approach and metaheuristic algorithms", ***International Journal of Engineering***, ***Transaction B: Applications,*** Vol. 35, (2022), 275-258, doi: 10.5829/IJE.2022.35.02B.01.

30. Izadi, L., Ahmadizar, F. and Arkat, J., "A hybrid genetic algorithm for integrated production and distribution scheduling problem with outsourcing allowed", ***International Journal of Engineering***, ***Transaction B: Applications,*** Vol. 33, No. 11, (2020), 2285-2298, doi: 10.5829/ije.2020.33.11b.19.

31. Jain, A., Porpatham, E. and Thipse, S., "Emission reduction strategies for small single cylinder diesel engine using valve timing and swirl ratio", ***International Journal of Engineering***, ***Transaction B: Applications,*** Vol. 33, No. 8, (2020), 1608-1619, doi: 10.5829/ije.2020.33.08b.19 .

32. Jeddi, B. and Vahidinasab, V., "A modified harmony search method for environmental/economic load dispatch of real-world power systems", ***Energy Conversion and Management***, Vol. 78, (2014), 661-675, doi: 10.1016/j.enconman.2013.11.027 .

33. Júnior, J.d.A.B., Nunes, M.V.A., Nascimento, M.H.R., Rodríguez, J.L.M. and Leite, J.C., "Solution to economic emission load dispatch by simulated annealing: Case study", ***Electrical Engineering***, Vol. 100, No. 2, (2018), 749-761, doi: 10.1007/s00202-017-0544-0 .

34. Eliezer, I., "Dynamic economic emission dispatch pada sistem transmisi jawa-bali 500 kv berdasarkan ruptl tahun 2015-2024 menggunakan metode multi-objective particle swarm optimization (MOPSO)", Institut Teknologi Sepuluh Nopember Surabaya ,(٢٠١٦) .

35. Rahmatullah, A.D., "Pendekatan dengan cuckoo optimization algorithm untuk solusi permasalahan economic emission dispatch", Institut Teknologi Sepuluh Nopember ,(٢٠١٧)

36. Ziane, I., Benhamida, F. and Graa, A., "Simulated annealing optimization for multi-objective economic dispatch solution", ***Leonardo Journal of Sciences***, Vol. 13, No. 25, (2014), 43-56

37. Phommixay, S., Doumbia, M.L. and Lupien St-Pierre, D., "Review on the cost optimization of microgrids via particle swarm optimization", ***International Journal of Energy and Environmental Engineering***, Vol. 11, No. 1, (2020), 73-89, doi: 10.1007/s40095-019-00332-1.

38. Daqaq, F., Ouassaid, M. and Ellaia, R., "Wind thermal economic emission dispatch solution using multi-objective backtracking search algorithm", in 2017 International Renewable and Sustainable Energy Conference (IRSEC), IEEE., (2017), 1-6.

39. Kuo, M.-T., Lu, S.-D. and Tsou, M.-C., "Considering carbon emissions in economic dispatch planning for isolated power systems: A case study of the taiwan power system", ***IEEE Transactions on Industry Applications***, Vol. 54, No. 2, (2017), 987-997, doi: 10.1109/TIA.2017.2771338.

40. Muhaddad, R.A" ,.Pengembangan algoritma simulated annealing untuk penyelesaian permasalahan alokasi pada closed loop supply chain (CLSC)", Institut Technology Sepuluh Nopember ,(٢٠١٤)

41. Lu, S.-D., Wang, M.-H., Kuo, M.-T., Tsou, M.-C. and Liao, R.-M., "Optimal unit commitment by considering high penetration of renewable energy and ramp rate of thermal units-a case study in taiwan", ***Applied Sciences***, Vol. 9, No. 3, (2019), 421, doi: 10.3390/app9030421 .

42. Wicaksono, B., Abdullah, A. and Saputra, W., "Coordination hydrothermal interconnection java-bali using simulated annealing", in IOP Conference Series: Materials Science and Engineering, IOP Publishing. Vol. 128, (2016), 012005.

## Persian Abstract

### **چکیده**

تغییرات اقلیمی، گازهای گلخانه ای و گرم شدن زمین از مسائل جهانی امروز هستند. البته این موضوع جهانی را نمی توان از بحث انتشار گازهای گلخانه ای جدا کرد. روش‌های مختلفی برای حل مشکلات زمان‌بندی ژنراتور با در نظر گرفتن انتشار گازهای گلخانه‌ای یا توزیع انتشار اقتصادی (EED) منتشر شده است، اما نه در حد محاسبه هزینه برای کاهش انتشار. هدف اصلی این تحقیق تعیین هزینه کاهش انتشار تولید برق در اندونزی از طریق حل مشکل EED است. روش پیشنهادی برای حل مشکل EED یک الگوریتم شبیه‌سازی بازپخت است و با استفاده از یک سیستم الکتریکی از هشت ژنراتور، چهار بار مختلف و پنج ترکیب وزن هزینه و انتشار آزمایش شده است. این روش با بارها (شرایط) مختلف آزمایش می شود و هر شرایط با ترکیب های مختلف وزن هزینه و وزن انتشار آزمایش می شود. نتایج به‌دست‌آمده با نتایج محاسبه الگوریتم فاخته و الگوریتم بهینه‌سازی نهنگ مقایسه شد. نتایج شبیه سازی نشان می دهد که برای کاهش ۱ تن آلاینده ها ۲۵۸.۸۱ دلار آمریکا هزینه دارد. این مقاله می تواند به عنوان ماده ای برای بررسی بیشتر برای دولت و ارائه دهندگان ژنراتور در اتخاذ سیاست های مربوط به بهره برداری از نیروگاه ها با در نظر گرفتن انتشار گازهای گلخانه ای مورد استفاده قرار گیرد.