

Economic emission dispatch for thermal power plant in Indonesia

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Abstract

Industry in the power generation sector today has experienced a very significant development due to the increasing demand for electricity; hence an effort to optimize the generation of electricity is necessary. This study aims to optimize fuel costs and reduce the emissions of a gas and steam power plant in Indonesia, that is the Sengkang Power Plant. The method used is to conduct polynomial regression to find the functions of the fuel cost and the emission. To form an objective function of fuel cost with the consideration of emission, the weight sum method is used. With the newly acquired objective function, the Lagrange method is then employed to find the optimal point between the cost of electricity generation and the resulting NOx emissions. The optimization point of the generator is obtained by processing the operation data of the power plant in the form of peak load and base load that must be fulfilled by the plant on working days and public holidays and the NOx emissions generated at the same time. From the simulation results obtained, there are some combination of active power generation for 2 generator units that produce optimum operating costs with low emissions.

Keywords: active power, NOx emission, operation cost, sum weight method, Lagrange method.

1. Introduction

Currently, emission reductions are of concern to many parties in Indonesia. Indonesia's Second National Communication stated in 2005, that the total GHG emissions in Indonesia reached 1.1 Gton and the energy sector contributed 0.4 Gton or about 36% of the total greenhouse gas emissions [1]. Previously, electric power generation companies only focus on reducing plant operating costs to a minimum [2-4]. However, with the increasing attention of the Government of Indonesia and the society on the environment, there is a need to optimize the process of electric power generation that can meet the needs of the load but still take into account both the cost of fuel and emissions produced [5-7].

The Sengkang Gas and Steam Power Plant is the first IPP that provides electric power to the Southern Sulawesi interconnected power system in Indonesia for both the base and peak loads [8]. The Sengkang Power Plant consists of 2 blocks, i.e. block I and block II. The total power generated by the Sengkang Power Plant is 315 MW, where block I produces 135 MW and block II produces 180 MW. Each block has 2 gas generator units and 1 steam generator unit which are used to cover the load requirement. The generator unit generating emissions from the combustion process is the gas generator unit. Therefore, the optimization is done only on the gas generator units that is the gas generators namely, GT 11 and GT 12.

2. Economic and Emission Dispatch

The problems of economic dispatch and emission dispatch can be solved by a combined economic and emission dispatch (CEED) that is oriented to economic and emissions priority with varied problems [9-

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14]. Equations (1) and (2) inform the relationship between the fuel cost and the active power generated by the generator and the generated emission function, respectively [15].

$$C_i(P_i) = \alpha_i + \beta_i P_i + \gamma_i P_i^2 \quad (1)$$

$$E_i(P_i) = \delta_i + \varepsilon_i P_i + \zeta_i P_i^2 \quad (2)$$

where,

$C_i(P_i)$ is the operation cost of each generator unit (Rp/hour)

P_i is the power output of each generator unit (MW)

$\alpha_i, \beta_i, \gamma_i$ are the generator's operation cost coefficients

$E_i(P_i)$ is the emission of each generator unit (ppmvd)

$\delta_i, \varepsilon_i, \zeta_i$ are the generator's emission coefficients

The simplest method to complete the optimization of multi objective functions such as the economic emission dispatch is by the weight sum method which combines two or more objective functions into a single unit, by the multiplication of each objective function with the weight coefficient of each objective function, whereby the total sum of each weight coefficient must be equal to one [16]. The weight coefficient should not be zero and the magnitude of the coefficient indicates the priority. Price penalty factor (ρ) is used to form a new single objective function with the following equation [17], where price penalty factor is the ratio between the maximum fuel costs to the maximum emissions generated as shown in Eq. 5 [9].

$$F_{Ti} = \psi_C \cdot FC_i + \psi_E \cdot (\rho_i \cdot FE_i) \quad (3)$$

$$\psi_C + \psi_E = 1 ; \quad \psi_C \neq 0 ; \quad \psi_E \neq 0 \quad (4)$$

$$\rho_i = \frac{FC_i(P_{iMax})}{FE_i(P_{iMax})} \quad (5)$$

Where,

F_{Ti} is the objective function

FC_i is the i^{th} generation cost

FE_i is the emissions produced by the i^{th} generator

ρ_i is the price penalty factor

ψ_C is the weight cost of generator

ψ_E is the weight emission of generator

To solve the problem of the objective function with unequal boundaries is by deriving the Lagrange function against each variable and it must be equal to zero [18]. The equation obtained from the partial derivative of the Lagrange function on the output power is formulated as follows [19]:

$$\frac{\partial \mathcal{L}}{\partial P_i} = \frac{dF_{Ti}}{dP_i} - \lambda = 0 \quad (6)$$

3. Results and Analysis

3.1. Fuel cost functions and emission functions

Both the fuel cost function and NOx emission function of the case study are expressed by an objective function and generator inequality in the Cartesian diagram are shown in Fig. 1 and Fig. 2, respectively.

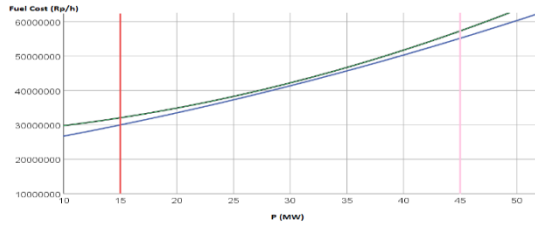


Fig. 1. Fuel cost functions for both generators

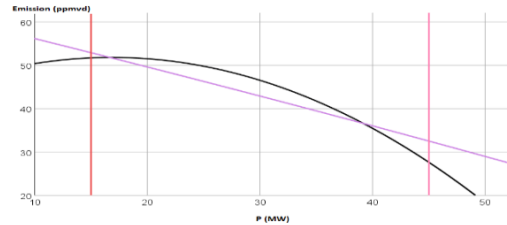


Fig. 2. Emission functions of NOx for both generators

3.2. Economic emission dispatch optimization

In optimizing fuel costs by considering economic and emission dispatch, it is necessary to change the optimization problem by creating a single objective function by using weight coefficient (ψ) and price penalty factor (ρ) as in Eq. 3. The price penalty factor compromises of the cost of emission and the cost of fuel. After determining the value of ρ , then the best weight ψ coefficient needs to be determined to obtain a function with the optimum fuel and emission results. The first step to do with the Weight Sum Method (WSM) is to determine the criteria that will affect the alternative function in the calculation, then produce a new single objective function for each generation [20]. The coefficients of the new objective function for different alternatives are presented in Table 1 which follow the pattern in Eq. 7.

$$\Phi_i(P_i) = \mu_i + \nu_i P_i + \varphi_i P_i^2 \quad (7)$$

Table 1. The coefficient of new objective function for generator 1 and 2

Alternative	ψ_c	ψ_E	$\Phi_1(P_1)$			$\Phi_2(P_2)$		
			μ_1	$\nu_1(P_1)$	$\varphi_1(P_1)^2$	μ_2	$\nu_2(P_2)$	$\varphi_2(P_2)^2$
A1	0.50	0.50	58847168.331	77842.558	-3015.957	58038300.823	1156549.808	-26587.788
A2	0.60	0.40	51282826.710	165354.349	-1330.044	51795630.557	962132.802	-19079.752
A3	0.70	0.30	43718485.088	252866.141	355.8685	45552960.291	767715.796	-11571.716
A4	0.80	0.20	36154143.467	340377.932	2041.781	39310290.025	573298.790	-4063.680
A5	0.90	0.10	28589801.846	427889.723	3727.694	33067619.759	378881.784	3444.355
A6	0.95	0.05	24807631.035	471645.618	4570.650	29946284.626	281673.281	7198.373
A7	0.96	0.04	24051196.868	480396.793	4739.241	29322017.596	262231.581	7949.176
A8	0.97	0.03	23294762.706	489147.972	4907.833	28697750.569	242789.880	8699.980
A9	0.98	0.02	22538328.544	497899.151	5076.424	28073483.543	223348.180	9450.783
A10	0.99	0.01	21781894.382	506650.330	5245.015	27449216.516	203906.479	10201.587

It can be seen in Table 1 that after the weight method is performed to combine the functions of fuel cost and the emission into a new single objective function, only the alternatives A5-A10 produces all positive μ , ν and φ constants for the functions $\Phi_1(P_1)$ and $\Phi_2(P_2)$ that can form a positive polynomial function. The objective function characteristics that can be optimized to find the minimum value of fuel costs and emissions using the Lagrange method must be a positive polynomial function. Therefore functions A5-A10 are used to perform economic optimization of dispatch. The results of fuel cost optimization with the consideration of emissions can be seen in Fig. 3. The working day peak load is used in this simulation.

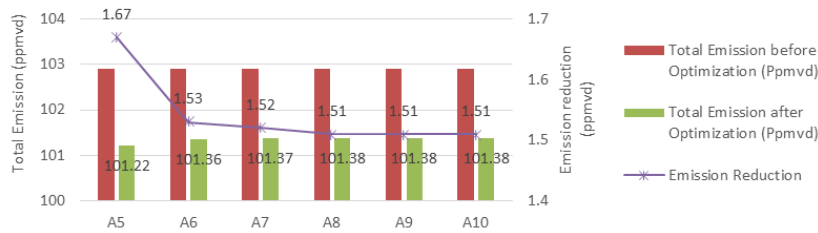


Fig. 3. Optimization results of fuel costs with emission considerations for different alternatives

As can be seen from Fig.3, the weight values of the ψ_C and the ψ_E shows the priority scale that will affect the generation cost and the amount of emissions generated. If the ψ_C gets smaller and the ψ_E gets bigger, the generation cost will be higher, but the resulting emission will be reduced. On the contrary if the ψ_C is bigger and the ψ_E is smaller, the generation cost will be smaller but the resulting emission will be increased. The emission prior to optimization was 102.89 ppmvd or proportional to 193.580 $\mu\text{g}/\text{m}^3$, which, if standardized, exceed the WHO standard, but is still within the Indonesian Ministry of Environment standards.

Based on the optimization results, alternative A5 with the ψ_C of 90% and the ψ_E of 10% produced the largest emissions savings compared to other alternatives, that is as much as 1.67 ppmvd, however it is the least economically, with the fuel cost amounting to Rp 83,341,500.094. On the other hand, alternative A10 with the ψ_C of 99% and the ψ_E of 1% resulted in the most economical options from fuel cost perspectives but has the smallest emission reduction of only 1.51 ppmvd. Therefore with the A10 alternative, it gives the smallest operating fuel cost with a reduced emission and it is recommended for economic emission dispatch at Sengkang Power Plant.

Further research needs to be done for the economic emission dispatch in the Southern Sulawesi power system is the economic emission dispatch considering network losses and transmission congestion [21-25]. In addition, study in reactive power compensating devices also important in optimizing the dispatch [26-28] as well as the stability studies [29-31].

4. Conclusions

This study performs economic emission dispatch for gas and steam power plant in Indonesia, that is the Sengkang power plant. By optimizing the economic emission dispatch, an optimal fuel cost that was obtained produces the less emission in the Sengkang power plant. Alternative A10 with the ψ_C of 99% and the ψ_E of 1% resulted in the cheapest fuel cost options but with emission reduction of only 1.51 ppmvd. Eventhough alternative A5 with the ψ_C of 90% and the ψ_E of 10% yielded the biggest emission saving compared to other alternatives but this option comes with significant large fuel cost, hence it is more recommended for applying the A10 alternative in the economic emission dispatch of the Sengkang power plant.

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