Correlation and Comparison between Economic Dispatch with CO_2 Emissions and Economic Emission Dispatch as Performance Optimization of Power Plants in Central Java Province with Particle Swarm Optimization (PSO) Methods.

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Abstract—**Power Plants use the process of changing energy to produce electricity. The most substantial electricity generation costs are derived from fuel costs. Among the existing power plants, steam power plants with coal fuel are power plants that supply the most significant electrical energy needs because this type of power plant is very economical and capable of producing high capacity electricity. Behind all that, this steam power plant is a power plant with very high emission factors when compared to other power plants so that it will have an impact on the environment. Therefore, it is necessary to limit the operation of Steam Power Plants by optimising economic deliveries and emissions to get the scheduling of plants with the smallest emission values with minimum operating costs. The simulation results are identical to the Lagrange multiplier method. At each expenditure, there will be a decrease in the value of emissions in the results of the optimisation of Economic and Emissions Dispatch when compared to emissions in the optimisation of Economic Dispatch.**

Keywords—Steam Power Plants, Optimization, Economic and Emission Dispatch, Emission Factor.

I. INTRODUCTION

Central Java is a province located on the island of Java. Based on PLN's Central Java APB data, the average electricity demand in Central Java Province in November 2018 was 3,422 MW. From the electrical energy needs, Central Java Province gets electricity supply from several power plants. Central Java Province has several power plants, namely: PLTU Tanjung Jati (Steam Power), PLTU Rembang (Steam Power), PLTU Cilacap (Steam Power), and PLTGU Tambak Lorok (Steam and Gas Power). Of all power plants, coal-fired power plants are large-capacity generators and provide basic electricity needs. That is because the price of coal is low and the cost of producing electricity using coal compared to other alternative energy sources. The use of coal in power plants will undoubtedly harm the environment because of the very high emissions from coal. Based on data from power plant emission factors in Indonesia, coal-fired power plants have an average emission factor value of 1.14 (kg / kWh) when compared to alternative energy that is more environmentally friendly which is less than 1 (kg / kWh).

High power generated at thermal power plants will be directly proportional to the CO2 emissions produced. To reduce CO2, a fitting schedule must be done between power plants. The government's target to reduce CO2 emissions by 2020 is 26%. The simple problem of Economic Dispatch is the case when transmission loss is neglected, and that also applies to dispatches Economic and Emission Dispatch. This model is a model that does not consider system configuration and impedance paths [1][15][2].

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II. SIMULATION DESIGN

A. Designing Correlation Simulation between Economic Dispatch with CO2 emissions and Economic Emission Dispatch

Flow chart diagram of the design method of correlation simulation between Economic Dispatch with CO2 emissions and Economic Emission Dispatch as performance optimisation of power plants in Central Java province with the Particle Swarm Optimization method as follows [3][4][5]:

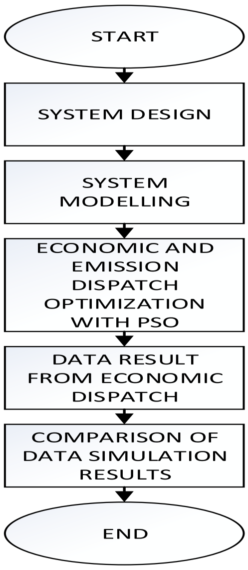

Fig. 1 Simulation Design Flowchart

B. Research Materials

1. Power Costs

The cost of generation at each power plant is used to determine the cost function of each power plant. The equation is obtained by carrying out a polynomial regression process by comparing the costs needed in the generation process (Rupiah) with the electricity generated (MWh) [6][7].

TABLE I. EQUATION OF POWER PLANT CHARACTERISTICS

No	*Power Plants*	*Cost Function*
1	Tambak Lorok GTG 1.1	C(1)=(-1938,7 + 2000000 P(1) – 7000000)
2	Tambak Lorok GTG 1.2	C(2)=(-2985 + 2000000 P(2) – 9000000)
3	Tambak Lorok GTG 1.3	C(3)=(-177 + 1000000 P(3) - 1000000
4	Tambak Lorok GTG 2.1	C(4)=(-1651,3 + 2000000 P(4) – 7000000)
5	Tambak Lorok GTG 2.2	C(5)=(613,54 + 1000000 P(5) + 2000000)
6	Tambak Lorok GTG 2.3	C(6)=(-460.38 + 1000000*P(6) – 40402)
7	Rembang 1	C(7)=(16,35+262802,39*P(7)+24448726,82
8	Rembang 2	C(8)=(16,35+262802,39*P(8)+24448726,82
9	Cilacap 1	C(9)=(42,58+349525,46*P(9)+10340167,7
10	Cilacap 2	C(10)=(42,58+349525,46*P(10)+10340167,7
11	Tanjung Jati 1	C(11)=(3,28+312517,01*P(11)+8370762,24
12	Tanjung Jati 2	C(12)=(53,28+312517,01P(12)+8370762,24
13	Tanjung Jati 3	C(13)=(73,83+194390,42P(13)+31893468,35
14	Tanjung Jati 4	C(14)=(73,83+194390,42P(14)+31893468,35

2. System Modeling Process

Following is a simulation of modelling the correlation system between economic dispatch with CO2 emissions compared to Economic And Emission Dispatch as a Performance Optimization of Power Plants in Central Java Province with Particle Swarm Optimization (PSO) Method. The steps in modelling can be explained as follows [17]:

Step 1:

Declaring conformity values based on the sum of each equation in two generic unit characteristic equations (cost and emissions), as follows:

$$\sum F = F1+F2+F3+F4+F5+F6+F7+F8+F9+F10+F11F12+F13+F14 \qquad (1)$$

Step 2:

Enter the parameters of the Multi-Objective Optimization algorithm, which is the number of iterations, population size, and power requirements.

TABLE II. INITIAL PARAMETER VALUES IN THE OPTIMIZATION

No	*Parameter*	*Value*
1	Maximum Number of Iterations	100
2	Population Size (Swarm Size)	50
3	Intertia Coefficient	1
4	Damping Ratio of Inertia Coefficient	0.99
5	Personal Acceleration Coefficient (C1)	2
6	Social Acceleration Coefficient (C2)	2
7	Load Demand	4000

Step 3:

Evaluate the objective function values for each new particle.

Step 4:

Check the difference between the current solution and the previous solution. If the difference in the target value is minimal, then the iteration will stop.

Step 5:

Of the many processes running the program, check whether the results are the minimum total cost.

Step 6:

If already have obtained the results, record the results of the best solution with a minimum cost and following the minimum and maximum limits of the generating unit.

III. SIMULATION AND ANALYSIS

The success of this program is measured by its ability to analyze the optimal load distribution so that the power produced in each unit meets the specified limits and suitability reaches a minimum value. The results of this test are compared with the Lagrange method to see the accuracy of the optimization program with the PSO method. In this case, the loss of the transmission line is ignored, and all simulations are carried out using MATLAB R2018a software [8][9]

A. *PSO Validation Method*

For comparison of manual calculations using the Lagrange method, three units of the generator are taken, and the results will be compared between the manual and the PSO program. The load used is 1000 MW.

Equation costs of each generating unit:

1. PLTU Rembang 2
   $C(1)=(16{,}35\, P(1)^2 + 262802{,}39\, P(1)+24448726{,}82$
2. PLTU Cilacap 1
   $C(2)=(42{,}58\, P(2)^2 + 349525{,}46\, P(2)+10340167{,}7$
3. PLTU Tanjung Jati 3
   $C(3)=(73{,}83 P(3)^2 + 194390{,}42\, P(3) + 31893468{,}35$

Emission Equation of each generating unit:

1. PLTU Rembang 2
   $E(1)=(0{,}0005\, P(1)^2 + 0{,}8381\, P(1) + 27{,}287)$
2. PLTU Cilacap 1
   $E(2)=(0{,}00006\, P(2)^2 + 1{,}0716\, P(2) + 3{,}6693)$
3. PLTU Tanjung Jati 3
   $E(3)=(-0{,}0000007\, P(3)^2 + 1{,}155\, P(3) + 8{,}2707)$

Determination of the combined emission and cost function of each plant based on the Economic Emission Dispatch equation with a value of Wc = 0.25 and We 0.75 then for the emission equation multiplied by 400000 to equalize the units of emissions and also the costs, the multi-objective equation can be calculated as follows [10][11][12]:

$C(1)=(16{,}35\, P(1)^2 + 262802{,}39\, P(1)+ 24448726{,}82$

$E(1)=(0{,}0005\, P(1)^2 + 0{,}8381\, P(1) + 27{,}287)$

$F(1) = 0{,}25\, C(1) + 0{,}75 \times 400000 \times E(1)$

$= (0{,}25 \times 16{,}35 + 0{,}75 \times 400000 \times 0{,}0005)\, P(1)^2 + (0{,}25 \times 262802{,}39 + 0{,}75 \times 400000 \times 0{,}8381)\, P(1) + (0{,}25 \times 24448726{,}82 + 0{,}75 \times 400000 \times 27{,}287)$

$F(1) = 154{,}0875\, P(1)^2+317130{,}5975\, P(1) + 14298282$

In the same method, we get the following equation:

1. PLTU Rembang 2
$F(1)=(154{,}0875\, P(1)^2+317130{,}5975\, P(1) + 14298282)$
2. PLTU Cilacap 2
$F(2)=(28{,}645\, P(2)^2+408861{,}365\, P(2) + 3685831{,}925)$
3. PLTU Tanjung Jati 3
$F(3)=(18{,}2475\, P(3)^2+ 395097{,}61\, P(3) + 10454577)$

Determine the limits of each generating unit:

$75 \leq P1 \leq 280$
$75 \leq P2 \leq 282$
$182{,}5 \leq P3 \leq 660{,}2$

Iteration 1:
Set the initial lambda value λ = 417000. Using equation (2), we can find the P-value for each power plant as follows:

$$\sum_{i=1}^{ng} \frac{\lambda - \beta i}{2\gamma i} = P_D \tag{2}$$

$$\Delta\lambda = \frac{\Delta P}{\sum_{i=1}^{ng} \frac{1}{2\gamma i}} \tag{3}$$

P1 = 324,0677
Because the maximum limit is 280 MW then P1 = 280
P2 = 142,06
P3 = 600,147
Calculates the error value in the first iteration

$\Delta P^1 = 22{,}208$
By equation (3) we get a new lambda is 416702,227

Iteration 2:

$\lambda 2 = 416702{,}227$
Using equation (2), we can find the P-value for each power plant as follows:
P1 = 280
P2 = 136,8627
P3 =561,98
Calculates the error value in the second iteration

$\Delta P^2 = 8{,}85121$
By equation (3) we get a new lambda is 416583,5475

Iteration 3:

$\lambda 2 = 416583{,}5475$
Using equation (2), we can find the P-value for each power plant as follows:
P1 = 280
P2 = 134,7911
P3 =588,736
Calculates the error value in the third iteration

$\Delta P^3 = 3{,}527$
The value of delta P approaches 0, which is 3,527 or 0.003% of the target value of 1000 MW and the results of each generator P1 280 MW, P2 134.79 MW and P3 588.73 MW. From the results of the iteration by entering the power value of each generator into the cost and emission equation, the total cost is Rp. 329,470,448 and total emissions of 1138,375 tons of CO_2 obtained. Then the Lagrange manual calculation data can be compared with the PSO simulation results data in table 3.

TABLE III. COMPARISON OF MANUAL CALCULATIONS LAGRANGE WITH PSO

Power Plant	***PSO***	***Lagrange Multiplier***
RBG2	280	280
CLCP2	130,007	134,7911
TJATI3	589,993	588,7366
Total Cost	Rp 328.097.908	Rp 341.700.775
Total Emission	1.134,6 Ton CO2	1.138,3 Ton CO2
Fitness	422.411.335,4	426.937.815,9

From table 3 it can be seen the comparison between optimisation on PSO with Manual Lagrange, which has almost the same results on the total cost of total emissions and also the value of fitness. Thus the PSO simulation is suitable and can be used as an optimisation process for generating scheduling operations.

B. Simulation Results

The parameters used in the simulation using the Multi-Objective Particle Swarm Optimization method for economic emission dispatch and also economic dispatch are using the same value for each parameter. The simulation is carried out for 24 hours using data that has been projected in 2020. By using the same parameters, it can be compared between the results of the optimisation of Economic Dispatch and Economic Emission Dispatch [13].

1. Simulation Results of Economic Dispatch Optimization

Simulation results at low load for power economic dispatch at PLTGU Tambak Lorok and PLTU Cilacap which show a minimum value of 27 MW and 75 MW. While for Tanjung Jati PLTU it shows an average maximum power of 660.2 MW. Load requirements can be met for 3093.62 MW. The total cost for generation is Rp1,139,723,888 while the resulting emissions are 3468,642 Tons of CO2. Simulation results can be seen in Table 4.

TABLE IV. ECONOMIC DISPATCH SIMULATION RESULTS ON BAU METHOD PROJECTION WITH A LOAD OF 3093.62 MW

Power Plant	***Power (MW)***	***Fuel Cost (Rupiah)***	***Emission (TonCo₂)***
GTG11	27,000	45586687,700	16,916
GTG12	27,000	42823935,000	16,134
GTG13	27,000	25870967,000	18,034
GTG21	27,000	45796202,300	16,448
GTG22	27,000	29447270,660	16,490
GTG23	27,000	26623980,980	16,468
RBG1	236,426	87495964,772	248,723
RBG2	159,328	66735557,493	173,513
CLCP1	75,000	36794089,700	84,377
CLCP2	75,000	36794089,700	84,377
TJATI1	660,200	191471656,191	765,203
TJATI2	660,200	191471656,191	765,203
TJATI3	529,103	155414730,107	619,189
TJATI4	536,363	157397100,512	627,569
Total	**3093,62**	**Rp1.139.723.888**	**3468,642**

2. Simulation Results of Economic and Emission Dispatch Optimization.

Simulation results at low loads for Economic and Emission Dispatch power at each plant varies. Load requirements can be met for 3093.62 MW. The total cost for generation is Rp1,282,416,017,382 while the resulting emissions are 3339,942 tons of CO_2. Simulation results can be seen in Table 5.

TABLE V. ECONOMIC AND EMISSION DISPATCH SIMULATION RESULTS ON BAU METHOD PROJECTION WITH A LOAD OF 3093.62 MW

Power Plant	***Power (MW)***	***Fuel Cost (Rupiah)***	***Emission (TonCo₂)***
GTG11	39,245	68504072,373	23,856
GTG12	27,000	42823935,000	16,134
GTG13	50,181	48735290,501	30,451
GTG21	41,600	73342326,272	25,198
GTG22	39,715	42682725,123	24,436
GTG23	100,000	95355798,000	61,203
RBG1	280,000	99315236,020	266,674
RBG2	280,000	99315236,020	301,155
CLCP1	75,919	37121209,212	85,370
CLCP2	282,000	112292479,340	310,632
TJATI1	182,500	63630559,565	217,781
TJATI2	632,274	184667374,719	732,950
TJATI3	402,986	122219909,531	473,606
TJATI4	660,200	192409865,707	770,497
Total	**3093,62**	**Rp1.282.416.017,382**	**3339,942**

3. Comparison Power of each Power Plant in Economic Dispatch with Economic and Emission Dispatch.

In this sub-chapter, we will describe the comparison of the power of each generator resulting from Economic Dispatch simulation and Economic Emission Dispatch at low, medium and peak loads on projected loads using the BAU method only. Power comparison data for each generator can be seen in table 6 below.

TABLE VI. COMPARISON THE POWER OF EACH GENERATOR RESULTING FROM AN ECONOMIC DISPATCH SIMULATION AND ECONOMIC EMISSION DISPATCH AT LOW, MEDIUM AND PEAK LOAD USING BAU METHOD

Power Plants	Power (MW)					
	Low		Medium		Peak	
	ED	EED	ED	EED	ED	EED
GTG11	27	39	27	55,3	88	97
GTG12	27	27	27	56,7	97	97
GTG13	27	50,1	27	97	97	97
GTG21	27	41,6	27	100	100	100
GTG22	27	39	27	100	100	100
GTG23	27	100	27	100	100	100
RBG1	236	280	280	280	280	280
RBG2	159	280	280	280	280	280
CLCP1	75	75,9	197,7	282	282	282
CLCP2	75	282	75	282	282	282
TJATI1	660,2	182,5	660,2	278	660,2	660,2
TJATI2	660,2	632,2	660,2	660,2	660,2	660,2
TJATI3	529,1	402,9	660,2	418,2	660,2	660,1
TJATI4	536,3	660,2	660,2	645,4	660,2	651,2

Note : ED = Economic Dispatch ; EED = Economic and Emission Dispatch

In table 6, it can be seen the comparison of power at each plant under conditions of low to medium load and also high between economic dispatch with economic and emission dispatch. The economic dispatch shows the power value at the Tambak Lorok power plant, which is at the minimum operating limit of 27 MW for low and medium load conditions. While for Tanjung Jati PLTU, it shows the maximum value for each load. That is because the cost of fuel at the Tanjung Jati PLTU is the cheapest generator while the Tambak Lorok PLTU is the most expensive generator. However, the results of the economic emission dispatch optimisation of power in the Tambak Lorok power plant experienced an increase when compared to the results of economic emission dispatch optimisation and the Tanjung Jati power plant experienced a decrease in power at each load. That is because the emissions produced by PLTGU Tambak Lorok are the lowest and the Tanjung Jati PLTU is the highest when compared to the other fourteen power plants.

C. Comparison of Economic Dispatch with Economic Emission Dispatch

In the optimisation results that have been done can be seen the comparison of results on the Economic Dispatch and Economic Emission Dispatch. With the same burden, the optimisation of Economic Emission Dispatch emissions resulting from generation can be reduced when compared to the optimisation of Economic Dispatch. However, with the reduction in emissions, there is an increase in the generation cost of optimising the Economic Emission Dispatch.

This can be seen when the condition of low load emits a reduction of 2.4807% and an increase in generation costs of 9.4202% as well as in the condition of medium load and also peak load which also increases the cost of generation. The comparison of Economic Dispatch and Economic Emission Dispatch can be seen in the following table 7.

TABLE VII. COMPARISON OF THE RESULT ECONOMIC DISPATCH OPTIMIZATION AND ECONOMIC EMISSION DISPATCH AT BAU PROJECTION LOAD

Load Conditon	*economic dispatch*		*economic emission dispatch*		Reduced Emission (%)	Additional Cost (%)
	Cost (Rupiah)	CO2 Emission (Ton Co_2)	Cost (Rupiah)	*C02 Emission (Ton Co_2)*		
Low	Rp1.139.723.888	3468,6	Rp1.282.416.017	3339	3,71	12,5
Medium	Rp1.300.471.561	4042	Rp1.687.046.891	3834	5,1	29,7
Peak	Rp1.976.308.227	4612	Rp1.988.347.864	4607	0,11	0,6

From table 7 a comparison chart of costs and emissions can be made between Economic Dispatch optimization and Economic Emission Dispatch in figures 2 and 3 below

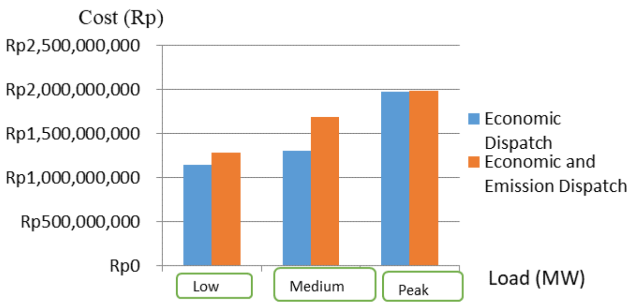

Fig. 2 Comparison of cost charts on Economic Dispatch and Economic Emission Dispatch optimization

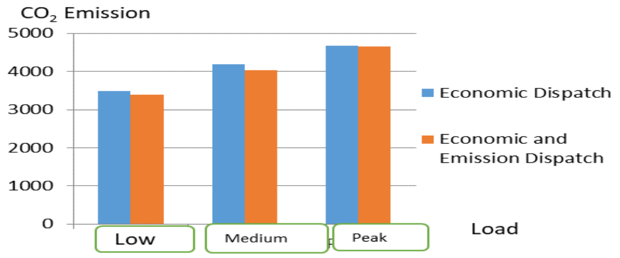

Fig. 3 Comparison of emission charts on Economic Dispatch and Economic Emission Dispatch optimization

From figure 2, it is found that the cost of the Economic Dispatch at each load is smaller when compared to the Economic Emission Dispatch. This can be seen in the low-cost burden on Economic Dispatch amounting to Rp1,139,723,888 while in Economic Emission Dispatch amounting to Rp1,282,416,017.38 as well as in medium load and also peak load it is found that Economic Dispatch costs were cheaper than Economic Emission Dispatch.

From figure 3, it is found that the emissions in the Economic Dispatch at each load are higher when compared to the Economic Emission Dispatch. This can be seen in the low emission load at Economic Dispatch of 3468,642 Tons of CO2 while in the Economic Emission Dispatch of 3339,942 Tons of CO2 as well as at medium loads and also the peak load obtained by higher Economic Dispatch emissions. However, at the peak load, the difference in the Economic Dispatch with the Economic Emission Dispatch is quite small at 5.3 Tons of CO2. That is because at the peak load and power that can be supplied is almost the same so that each plant is operated at maximum conditions.

IV. CONCLUSION

1. The problem of Economic Emission Dispatch can be solved by Multi-Objective Particle Swam Optimization
2. By considering the emission function and also the cost function in the optimisation process (economic and emission dispatch), it can be obtained scheduling plants with the smallest possible emissions with the lowest possible cost.
3. Using Economic and Emission Dispatch optimisation can reduce CO_2 emissions by 3.71% for low load, 5.1% for medium load and 0.11% for peak load when compared to economic dispatch optimisation.
4. The reduction in CO_2 emissions that occurred in Economic and Emission Dispatch optimisation will have an impact on the addition of generation costs by 12.5% at low load, 29.7% at medium load and 0.6% at peak load when compared to Economic Dispatch optimisation.

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