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Analysis of System Operation Optimization In Steam Power Plants With the Lagrange Method

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ABSTRACT

A Steam Power Plant (PLTU) harnesses kinetic energy from hot steam to generate electrical power, exemplified by the Paiton Power Plant where thermal energy stems from coal combustion. Despite coal-fired power's global dominance, escalating fuel expenses underscore the significance of optimizing electric power system operations. The system comprises power generation units catering to load requirements, and cost-effective operation is achieved through Economic Dispatch. Economic Dispatch, a critical research area, utilizes diverse optimization methods. This study employs the Lagrange method, comparing its performance against the Firefly algorithm and genetic algorithm. Results reveal the Lagrange method's exceptional optimization capabilities, achieving a 7,043% cost difference, equating to $243,227,475/hour compared to actual costs. The Firefly algorithm closely follows with a 7.043% difference, amounting to $243,227,471/hour, while the genetic algorithm achieves a 7.011% difference, totaling $242,119,792/hour against actual costs. These findings underscore the efficacy of the Lagrange method in enhancing economic dispatch within steam power plants, offering valuable insights for efficient and cost-effective energy production.

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1. INTRODUCTION

Steam Power Plant (PLTU) is a plant that relies on kinetic energy from hot steam to produce electrical energy [1]. At the Paiton Power Plant, thermal energy is generated from burning a certain amount of coal. The use of coal-fired power plants still dominates most of the world's electricity supply. In 2020, as many as 9,452,492 GWh or 35% of the world's electricity suppliers were supplied by coal-fired power plants [2]. Indonesia still relies heavily on steam power plants, especially those that use coal to meet thermal energy needs. Coal-fired power plants supplied 61% of Indonesia's electricity supply in 2020[2]. This is because coal is still the cheapest energy source. This condition also makes Indonesia have quite a lot of coal-fired power plants spread across various provinces.

The optimal operation of electric power systems has grown in importance in recent years due to ever-increasing fuel costs [3,4,5]. An electric power system basically consists of power generation units that aim to serve the needs of the load. The amount of load supplied and the power produced or produced by the plant must be balanced so that the plant can be operated optimally with minimal operating costs [6,7,8]. Total production costs can be minimized by a combination of power loading in existing generating units so that an optimal or more economical loading is obtained [9,10]. This optimization process is called Economic Dispatch [11]. Economic Dispatch has conducted a lot of research using

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various optimization methods. Some of these methods are the Lagrange method [12,13,14,15] this method solves the economic dispatch problem by minimizing costs in meeting the needs of a given load and lagrange algorithm obtained the optimal solution with a cost value of 815.1807 $/hour and PSO with a cost value of 816.8095 $/hour, the particle swarm optimization (PSO) method [16] this method used 24 bus with generation cost obtained is 16.69 $/MWh. Generation cost after rescheduling to 13.89 $ / MWh, the firefly algorithm [17] can run the optimization well, optimization results obtained using firefly with modified firefly is 41 $/hour, and many other methods [18,19,20] Genetic algorithm gets a total cost of 17607.7 $/hour and 17608.4 $/hour for Lambda Iteration method (LIM). In this study, the optimization method to be used is the Lagrange method [21]. The choice of the Lagrange method is because this method has been proven to solve economic dispatch problems [22,23,24]. The Lagrange method will compare its optimization performance with the firefly algorithm method and genetics to obtain the most optimal optimization results. The selection of these two comparison methods is because from several references collected, no one has compared these two methods with the Lagrange method.

2. RESEARCH METHOD

This study seeks the minimum value of the cost of generation using the Lagrange method. The input parameters needed to obtain the cost value are the number of units, load power, unit limit power, and generation cost coefficient.

Table 1. Generating Unit Constants

Unit	Cash			Minimal (MW)	Maximum (MW)
	A	B	C		
5	6757,7	113,92	0,0088	350	640
6	6403,8	121,77	0,0001	350	640

Table 2. 24 Hours Load

Time	Load Demand	Time	Load Demand
01.00	709,47158	13.00	1115,08796
02.00	709,99995	14.00	1230,4375
03.00	709,67175	15.00	1219,81997
04.00	702,1616	16.00	1169,1987
05.00	741,38942	17.00	1068,4471
06.00	710,95492	18.00	1072,05586
07.00	703,5477	19.00	1116,13376
08.00	715,94657	20.00	1242,767
09.00	795,16464	21.00	1252,8876
10.00	1007,7563	22.00	1244,7508
11.00	1215,3938	23.00	1244,8125
12.00	1144,1701	00.00	1246,7528

After obtaining the parameters in Table 1 and Table 2, the calculation of economic dispatch is carried out using the Lagrange method. The Lagrange method is a method that can be used to solve cost optimization problems in plants. The equation used in the Lagrange method is as in the following equation:

$$\mathcal{L} = F_T + \lambda(P_D - \sum_{i=1}^{n} P_i) \tag{1}$$

The minimum value of the lagrange equation above occurs when the partial derivative is equal to zero:

$$\frac{\partial L}{\partial P_i} = 0 \tag{2}$$

$$\frac{\partial \mathcal{L}}{\partial P_i} = \frac{\partial F_T}{\partial P_i} + \frac{\partial \lambda P_D}{\partial P_i} - \frac{\partial \lambda \sum_{i=1}^{n} P_i}{\partial P_i} = 0 \tag{3}$$

From the above derivatives produce:

$$\frac{\partial F_T}{\partial P_i} + \lambda(0 - 1) = 0 \tag{4}$$

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Then:

$$\frac{\partial F_T}{\partial P_i} = \frac{dF_i}{dP_i} = \lambda \quad (5)$$

or

$$b_i + 2c_i P_i = \lambda \quad (6)$$

From equation (6) can be obtained the value by using P_i :

$$P_i = \frac{\lambda - b_i}{2c_i} \quad (7)$$

The solution to get the value λ can be by substituting the equation P_i :

$$P_D = \sum_{i=1}^{n} \frac{\lambda - b_i}{2c_i} \quad (8)$$

So, λ it can be written as:

$$\lambda = \frac{P_D + \sum_{i=1}^{n} \frac{b_i}{2c_i}}{\sum_{i=1}^{n} \frac{1}{2c_i}} \quad (9)$$

Figure 1 shows a flowchart of research conducted to complete the study. In the picture, the first thing to do is to obtain the required data. The next thing is to solve the economic dispatch problem with the Lagrange method.

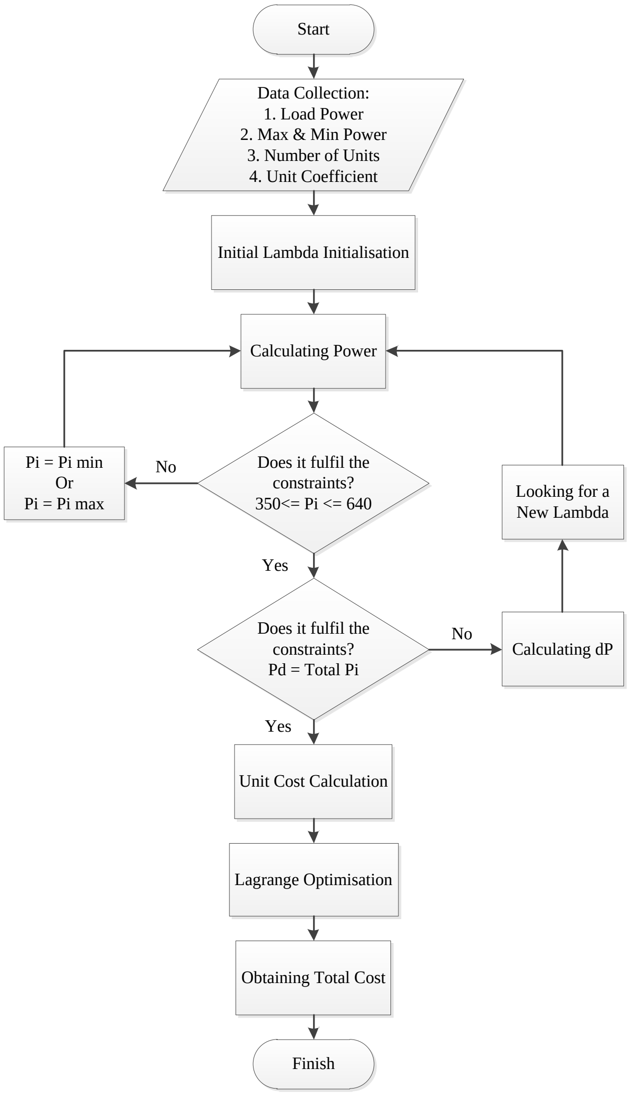

Figure 1. Research Flowchart

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3. RESULTS AND DISCUSSION

3.1. Account

Manual calculations are carried out using the Lagrange method to calculate plant optimization. The plant consists of 2 generating units whose characteristics have been described with a load power at 01.00 which is 709.47158 MW.

$$P_D = 709{,}47158\ MW$$

$$\lambda = \frac{P_D + \sum_{i=1}^{n} \frac{b_i}{2c_i}}{\sum_{i=1}^{n} \frac{1}{2c_i}}$$

$$\lambda = \frac{709{,}47158 + \frac{113{,}92}{2(0{,}0088)} + \frac{121{,}77}{2(0{,}0001)}}{\frac{1}{20{,}0088)} + \frac{1}{2(0{,}0001)}}$$

$$\lambda = \frac{83852509111528059}{68780937500000}$$

$$\lambda = 1219{,}12425$$

$$P_i = \frac{\lambda - b_i}{2c_i}$$

$$P_5 = \frac{1219{,}12425 - 113{,}92}{2(0{,}0088)}$$

$$P_5 = 62795{,}6960\ \mathrm{MW}$$

$$P_6 = \frac{1219{,}12425 - 121{,}77}{2(0{,}0001)}$$

$$P_6 = 5486771{,}25\ MW$$

Because the scheduling is not perfect, the rescheduling is done as below:

$$\frac{dF_i}{dP_i} = \lambda$$

$$\lambda = b_i + 2c_iP_i$$

Then the following function is obtained:

$$\frac{dF_i}{dP_i} = b_i + 2c_iP_i$$

Enter P_5= 350 MW into the function:

$$\frac{dF_5}{dP_5} = 113{,}92 + 2 * 0{,}0088 * 350$$

$$\frac{dF_5}{dP_5} = 120{,}08$$

$$P_5 = 350\ MW$$

From the function

$$P_D = \sum_{i=1}^{n} P_i$$

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Obtained values P_6 are:

$$P_6 + 350 = 709{,}47158\ MW$$

$$P_6 = 359{,}47158\ MW$$

$$\frac{\lambda - 121{,}77}{2(0{,}0001)} = 359{,}47158\ MW$$

$$\lambda = 121{,}841894316\ \$/MWh$$

$$\sum_{i=1}^{n} Pi = 709{,}47158 \text{ MW}$$

Find the cost function:

$$\boldsymbol{F_5 = 6757,7 + 113,92(359,47158) + 0,0088(359,47158)^2}$$

$$\boldsymbol{F_5 = 48845,83678\ \$/jam}$$

$$\boldsymbol{F_6 = 6403,8 + 121,77(350) + 0,0001(350)^2}$$

$$\boldsymbol{F_6 = 49035,55\ \$/jam}$$

$$\boldsymbol{F_T = \sum_{i=1}^{n} F_i}$$

$$F_T = 48845{,}83678 + 49035{,}55$$

$$F_T = 97.881{,}38678\ \$/jam$$

Find the Lagrange cost function:

$$\boldsymbol{\mathcal{L} = F_T + \lambda(P_D - \textstyle\sum_{i=1}^{n} P_i)}$$

$$\mathcal{L} = 97.881{,}38678 + 121{,}841894316\ (709{,}47158 - 709{,}47158)$$

$$\mathcal{L} = 97.881{,}38678 + 121{,}841894316\ (0)$$

$$\mathcal{L} = 97.881{,}38678\ \$/jam$$

3.2. Calculation of Optimization Method

The problem was also solved using the MATLAB application Table 3. 1. In the MATLAB application, the optimization results on the cost of generation are 97,881,387 $ / hour. The time needed to solve one problem in the MATLAB application is 0.00084 seconds. The use of the application certainly saves the time needed to solve the problem. The MATLAB application is also programmed to calculate problems using the firefly algorithm and genetic algorithm.

Table 3. Calculation At Load 709.47

Method	Load Demand (MW)	PG 5 (MW)	PG 6 (MW)	Cost ($/h)	F6 ($/hr)	F5 ($/hr)	Elapsed Time (s)
Real conditions	709,47	357,342	352,13	105.062,54	-	-	-
Lagrange	709,47	359,472	350	97.881,39	48.845,84	49.035,55	0,000084
Firefly	709,47	359,472	350	97.881,39	48.845,84	49.035,55	5,242561
Genetic	709,47	352,041	357,43	97.893,72	47.952,86	49.940,85	0,639069

3.3. Comparison

Comparison of the three methods used to solve the problem, there are some differences in optimization results. Performance comparison is based on the value of the cost generated and the time taken to solve the problem. This difference in optimization is caused by different ways of solving the three methods. The Lagrange method uses a Lagrange multiplier and rescheduling if it has not been achieved optimally. While the firefly method uses light intensity in the distribution of fireflies and the genetic method uses gene changes / mutations to find optimal values.

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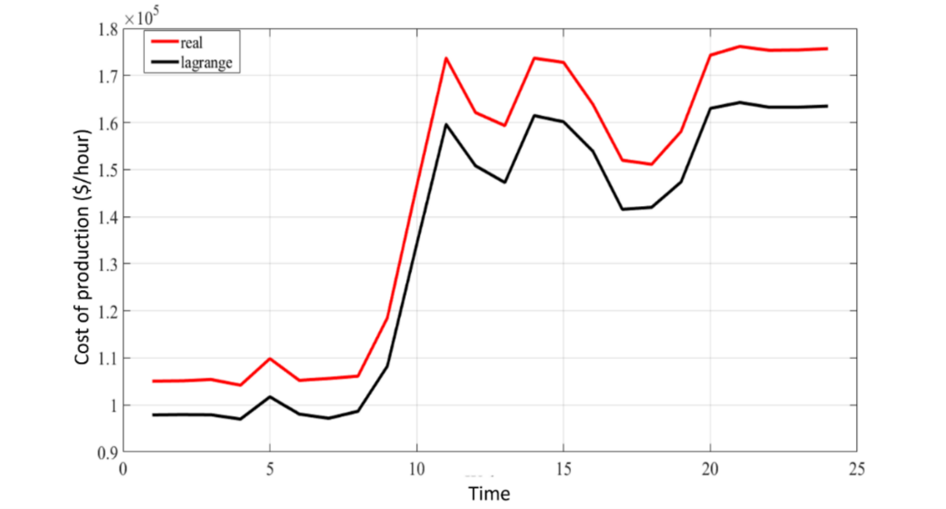

Figure 2. Real and Lagrange Cost Comparison Charts

The actual cost gets a total FT cost of 3,453,311.26$/hour while the Lagrange method gets a total FT cost of 3,210,083,790$/hour. In this way, the result of both methods is a difference of 243,227.475 $ / hour for the simulated data for 24 hours. In Figure 1 it can be seen that the cost generated by the Lagrange method is less than the actual cost of the generating unit. In Figure 2 and Figure 3 it can be seen that the cost generated by the firefly and genetic methods is less than the actual cost of the generating unit.

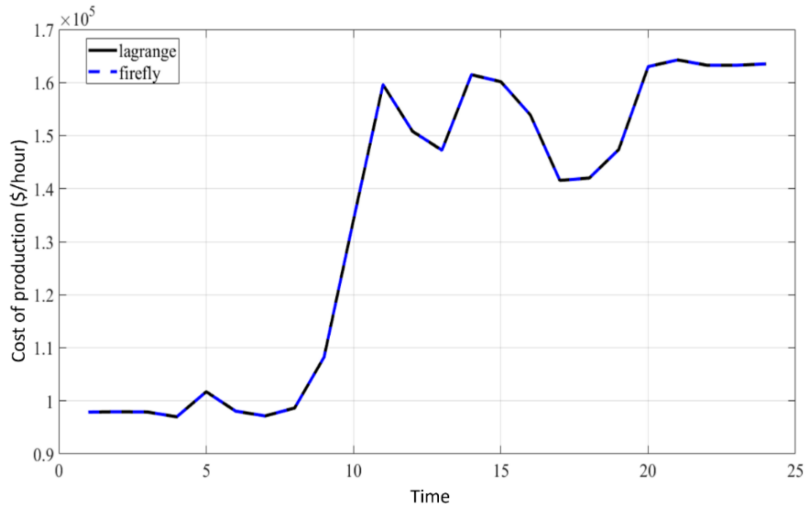

Figure 3. Firefly Cost Comparison Graph with Lagrange

Data discrepancies are also visible in the time it takes to resolve the issue. The difference in computational time performance is due to the Lagrange method which does not require random values for initial generation power. Random initial generation power means that firefly and genetic methods require more than one iteration to reach the most optimal power.

In Figure 4 It can be noted that the Lagrange method can solve problems faster than genetic algorithms and is followed by the Firefly algorithm with a longer computational time. It can be seen that the average time needed to solve the problem in the Lagrange method is 0.00011075 seconds. Meanwhile, the average time needed to solve problems in the firefly algorithm method is 2.465568083 seconds and 0.908159875 seconds in the genetic algorithm.

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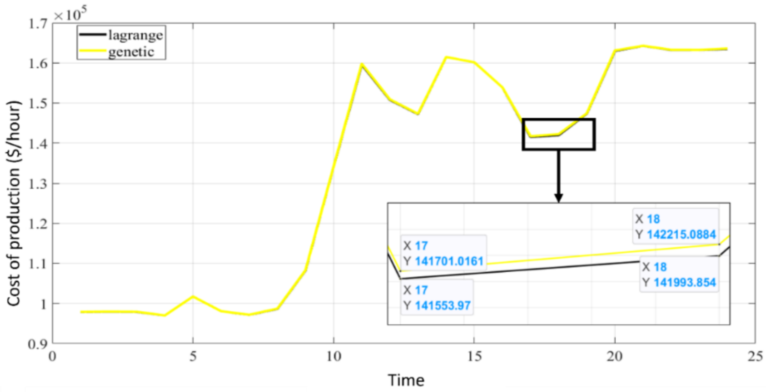

Figure 4. Genetic Cost Comparison Chart with Lagrange

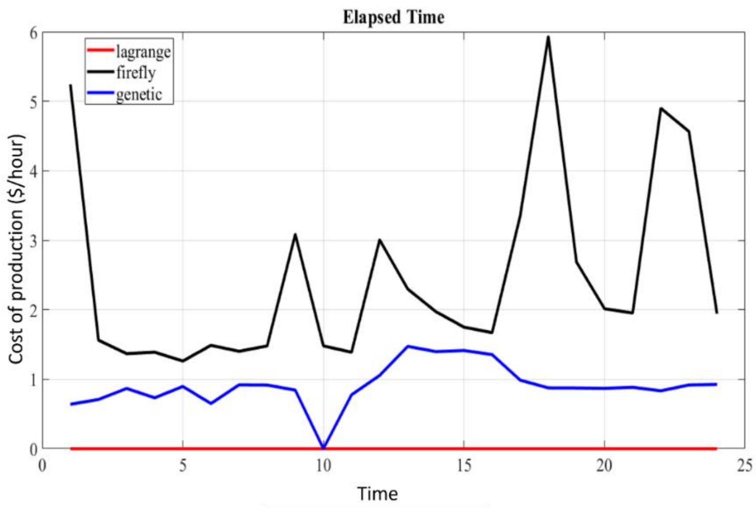

Figure 5. Graphic Elapsed Time

Data discrepancies are also visible in the time it takes to resolve the issue. In Figure 5. It can be noted that the Lagrange method can solve problems faster than genetic algorithms and is followed by the Firefly algorithm with a longer computational time. It can be seen that the average time needed to solve the problem in the Lagrange method is 0.00011075 seconds. Meanwhile, the average time needed to solve problems in the firefly algorithm method is 2.465568083 seconds and 0.908159875 seconds in the genetic algorithm.

4. CONCLUSION

Based on the results and analysis of the conducted data, it can be concluded that the economic dispatch issues in power generation units can be resolved using the Lagrange method. Calculations at 01:00 were performed both manually and through simulation using the MATLAB application, resulting in a total cost of $97,881.387 per hour. The use of this application speeds up and enhances the efficiency of calculation time.

The economic dispatch program and simulation using the Lagrange method, firefly algorithm, and genetic algorithm have been successfully executed, yielding improved optimization of generation costs. The Lagrange method optimizes generation costs with a difference of $243,227.475 per hour or 7.043% from the actual cost. Meanwhile, the firefly algorithm and genetic algorithm also provide optimization results with differences of 7.043% and 7.011% from the actual cost, respectively.

There is a noticeable difference in optimization performance among the Lagrange method, firefly algorithm, and genetic algorithm in terms of the generated generation cost values and the average required time. The Lagrange method and the firefly algorithm produce nearly identical total FT costs, with only a $0.004 per hour difference. However, the genetic algorithm yields a different total FT cost, differing by $1,107.682 per hour compared to the Lagrange method. Furthermore, the average time

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required to solve the problem using the Lagrange method is very short, at 0.00011075 seconds, while the firefly algorithm requires 2.465568083 seconds, and the genetic algorithm requires 0.908159875 seconds.

Based on the results of the data analysis conducted, further research is needed with the utilization of environmentally friendly power generators. Analysis using different methods is also required to obtain a more optimal and efficient comparison of methods.

REFERENCES

[1] "Consumption Prediction on Steam Power Plant Using Data Mining Hybrid Particle Swarm Optimization (PSO) and Auto Regressive Integrated Moving Average (ARIMA)," 2019 Int. Work. Big Data Inf. Secur. IWBIS 2019, pp. 15–20, 2019, doi: 10.1109/IWBIS.2019.8935844.

[2] "Electricity Generation-World.". https://www.iea.org/fuels-and-technologies/electricity

[3] "Optimization of Economic Dispatch of 150 kV Sulselrabar System using Lagrange Approach," 2019 Int. Conf. Technol. Policies Electr. Power Energy, TPEPE 2019, 2019, doi: 10.1109/IEEECONF48524.2019.9102594.

[4] "Pengiriman Ekonomi Ideal dari Unit Tenaga Panas," vol. 1, no. 1, 2021.

[5] "Optimal Scheduling Algorithm for Coal-Powered Power Plants-Considering Coal Delivery Constraints," ICT-PEP 2021 - Int. Conf. Technol. Policy Energy Electr. Power Emerg. Energy Sustain. Smart Grid, Microgrid Technol. Futur. Power Syst. Proc., no. September, pp. 307–312, 2021, doi: 10.1109/ICT-PEP53949.2021.9601098.

[6] "Genetic Algorithm for Solving the Economic Load Dispatch," Int. J. Electron. Electr. Eng., vol. 7, no. 5, pp. 523–528, 2014.

[7] "A Wind Turbine Generator Design and Optimization for DC Collector Grids," IEEE J. Emerg. Sel. Top. Power Electron., vol. 10, no. 1, pp. 484–493, 2022, doi: 10.1109/JESTPE.2021.3066278.

[8] "Multi-Objective Optimization Design of Bearingless Permanent Magnet Synchronous Generator," IEEE Trans. Appl. Supercond., vol. 30, no. 4, 2020, doi: 10.1109/TASC.2020.2970661.

[9] "Combinatorial optimization of pulverizers for blended-coal-fired power plant," Proc. - Int. Conf. Comput. Distrib. Control Intell. Environ. Monit. CDCIEM 2011, pp. 413–418, 2011, doi: 10.1109/CDCIEM.2011.323.

[10] "Individual Thermal Generator and Battery Storage Bidding Strategies Based on Robust Optimization," IEEE Access, vol. 9, pp. 66829–66838, 2021, doi: 10.1109/ACCESS.2021.3076872.

[11] "Investigation and optimization of a Co-Generation plant integrated of gasifier, gas turbine and heat pipes using minimization of Gibbs free energy, Lagrange method and response surface methodology," Int. J. Hydrogen Energy, vol. 45, no. 38, pp. 19027–19044, 2020, doi: 10.1016/j.ijhydene.2020.04.278.

[12] "Analytical optimization of photovoltaic output with Lagrange Multiplier Method," Optik (Stuttg)., vol. 199, no. June, p. 163379, 2019, doi: 10.1016/j.ijleo.2019.163379.

[13] "Multi-layered optimization of demand resources using lagrange dual decomposition," IEEE Trans. Smart Grid, vol. 4, no. 4, pp. 2081–2088, 2013, doi: 10.1109/TSG.2013.2261565.

[14] "Passivity-Based Control of photovoltaic-wind hybrid system with Euler-Lagrange modeling," IECON Proc. (Industrial Electron. Conf., pp. 1126–1131, 2012, doi: 10.1109/IECON.2012.6388614.

Volume 11, Issue 1, April 2024, pp. 29-37
ISSN 2355-5068 ; e-ISSN 2622-4852
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[15] “Comparison of the Lagrange’ s and Particle Swarm Optimisation Solutions of an Economic Emission Dispatch Problem” pp. 1–8, 2012.

[16] “Power System Optimization Model Using Economic Load Dispatch,” 2020 IEEE Reg. 10 Symp. TENSYMP 2020, no. June, pp. 469–472, 2020, doi: 10.1109/TENSYMP50017.2020.9230967.

[17] "Comparison of Firefly and Hybrid Firefly-APSO Algorithm for Power Economic Dispatch Problem," 2020 International Conference on Technology and Policy in Energy and Electric Power (ICT-PEP), Bandung, Indonesia, 2020, pp. 94-99, doi: 10.1109/ICT-PEP50916.2020.9249799.

[18] “Penggunaan Algoritma Genetika Dalam Peningkatan Kinerja Fuzzy Clustering Untuk (Application of Genetic Algorithm to Enhance the Performance of Clustering,” Berk. MIPA, vol. 17, no. 2, pp. 1–14, 2007.

[19] “A statistical energy efficiency optimization method for coal-fired power generation systems,” Proc. 2015 IEEE Innov. Smart Grid Technol. - Asia, ISGT ASIA 2015, 2016, doi: 10.1109/ISGT-Asia.2015.7387118.

[20] “Power systems optimization under uncertainty: A review of methods and applications,” Electr. Power Syst. Res., vol. 214, no. May 2022, 2023, doi: 10.1016/j.epsr.2022.108725.

[21] T. De Paula Machado Bazzo, J. F. Kölzer, R. Carlson, F. Wurtz, and L. Gerbaud, “Multiphysics Design Optimization of a Permanent Magnet Synchronous Generator,” IEEE Trans. Ind. Electron., vol. 64, no. 12, pp. 9815–9823, 2017, doi: 10.1109/TIE.2017.2726983.

[22] “An Energy Management System for Isolated Microgrids with Thermal Energy Resources,” IEEE Trans. Smart Grid, vol. 11, no. 4, pp. 2880–2891, 2020, doi: 10.1109/TSG.2020.2973321.

[23] “Comparison of ship power systems from an optimal economic operation point of view,” 2015 IEEE Electr. Sh. Technol. Symp. ESTS 2015, pp. 256–260, 2015, doi: 10.1109/ESTS.2015.7157900.

[24] “PSO Based Controlled Six-phase Grid Connected Induction Generator for Wind Energy Generation,” CES Trans. Electr. Mach. Syst., vol. 5, no. 1, pp. 41–49, 2021, doi: 10.30941/CESTEMS.2021.00006.