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OPTIMIZATION OF POWER GENERATION SYSTEMS FOR COST EFFICIENCY AND DECARBONIZATION USING ARTIFICIAL INTELLIGENCE METHODS AT PT PERTAMINA EP BUNYU FIELD

OPTIMASI SISTEM PEMBANGKIT LISTRIK UNTUK EFISIENSI BIAYA DAN DEKARBONISASI MENGGUNAKAN METODE KECERDASAN BUATAN DI PT PERTAMINA EP LAPANGAN BUNYU

Brando Sitinjak[1*], Benny Kawira[2], Ahmad Rafi Ramadhan[3], Gusti Rinaldi Zulkarnain[4]
PT. Pertamina EP Bunyu Field, Bunyu Island, Indonesia[1,2,3,4]
brando.sitinjak@pertamina.com[1*], benny.kawira@pertamina.com[2],
ahmad.ramadhan1@pertamina.com[3], gusti.zulkarnain@pertamina.com[4]

ABSTRACT

The oil and gas industry faces challenges in improving energy efficiency and reducing carbon emissions amid the global energy transition. PT Pertamina EP Bunyu Field operates a Gas Engine-based power generation system with potential inefficiencies due to low operational load factors. This research aims to optimize power plant operations by reducing the number of operating units and increasing the load factor by up to 80%, in order to reduce fuel consumption and production costs. The methods used include the optimization of PID control parameters using Genetic Algorithms (GA) and Proximal Policy Optimization (PPO) based on Reinforcement Learning (RL). The simulation results show that this optimization can improve the efficiency of the power generation system and reduce gas consumption by up to 40.15 MMSCFD per year, as well as result in a reduction in carbon emissions of 10,881.87 tons of CO_2eq per year. These findings show that the application of optimal control based on artificial intelligence can provide significant benefits in improving efficiency and supporting decarbonization targets in the oil and gas industry.

***Keyword**: Generation Optimization, Gas Engine, Energy Efficiency, Decarbonization, Artificial Intelligence.*

ABSTRAK

Industri minyak dan gas menghadapi tantangan dalam meningkatkan efisiensi energi dan mengurangi emisi karbon di tengah transisi energi global. PT Pertamina EP Bunyu Field mengoperasikan sistem pembangkit listrik berbasis mesin gas yang berpotensi tidak efisien akibat faktor beban operasional yang rendah. Penelitian ini bertujuan untuk mengoptimalkan operasi pembangkit listrik dengan mengurangi jumlah unit yang beroperasi dan meningkatkan faktor beban hingga 80%, guna mengurangi konsumsi bahan bakar dan biaya produksi. Metode yang digunakan meliputi optimasi parameter kontrol PID menggunakan Algoritma Genetika (GA) dan Optimasi Kebijakan Proksimal (PPO) berdasarkan Pembelajaran Penguatan (RL). Hasil simulasi menunjukkan bahwa optimasi ini dapat meningkatkan efisiensi sistem pembangkit listrik dan mengurangi konsumsi gas hingga 40,15 MMSCFD per tahun, serta menghasilkan pengurangan emisi karbon sebesar 10.881,87 ton CO_2eq per tahun. Temuan ini menunjukkan bahwa penerapan kontrol optimal berbasis kecerdasan buatan dapat memberikan manfaat signifikan dalam meningkatkan efisiensi dan mendukung target dekarbonisasi di industri minyak dan gas.

Kata Kunci: Optimasi Pembangkitan, Mesin Gas, Efisiensi Energi, Dekarbonisasi, Kecerdasan Buatan

INTRODUCTION

The oil and gas industry faces major challenges in improving energy efficiency and reducing carbon emissions amid global demands for a sustainable energy transition. PT Pertamina EP Bunyu Field, as one of the strategic oil and gas facilities in Indonesia, operates a Gas Engine-based power plant with a capacity of 1 MW per unit. However, with an operational load level of only 40-60%, this system still has considerable inefficiency potential. Optimizing power plant operations is an important step to reduce fuel consumption, reduce production costs, and support national decarbonization targets (IEA, 2023). The optimization efforts designed at Bunyu Field focus on reducing the number of operating units from four to three Gas Engines, by increasing operating load by up to 80%. This strategy aims to optimize fuel efficiency and reduce the cost per unit of energy produced. Recent studies show that an increase in load factor in a generation system can reduce *specific fuel consumption* (SFC) by up to 12%, which has a direct impact on reducing carbon emissions and improving operational efficiency (Zhao et al., 2021). In addition, this strategy also reduces maintenance costs due to the reduced number of units operating simultaneously, thereby improving overall cost efficiency (Wang et al., 2022).

In (Kashki et al., 2008), the Continuous Action Reinforcement Learning Automata (CARLA) technique was developed to tune PID control in AVR systems, which has been shown to be better than other methods such as PSO and GA. In (Muduli et al., 2024), an adaptive PID controller based on actor-critic RL was introduced to automatically control power generation, which can adjust in real-time and work on both linear and non-linear systems. Meanwhile, in (Djalal & Kadir, 2021), the Ant Colony Optimization algorithm was used to adjust the PSS-PID control in the electrical system and obtain the optimal frequency response and rotor angle. Then, genetic algorithms (GA) have been successfully applied to optimize PID control parameters on various systems. In (Yusuf et al., 2015), this algorithm utilizes evolutionary principles such as crossover and mutation to find the optimal combination of Kp, Ki, and Kd values. Suprapto & Sariman, 2012), proposed modification of objective functions by including criteria such as Integral Time Weighted Absolute Error (ITAE) and Mean Squared Error (MSE) to improve performance. In (Suprapto & Sariman, 2012), GA is combined with a fuzzy logic system to determine genetic parameters such as crossover probabilities and mutations. GA-based PID alignment has been applied to a wide range of applications, including DC motors, and has been shown to provide better results than classical methods such as Ziegler-Nichols (Ahmmed et al., 2020; Zahir et al., 2018). The results showed that PID control optimized with GA was able to produce faster rise and fall times and reduce overshoot compared to conventional methods (Zahir et al., 2018, Suyanto et al., 2022, M. Regad et al., 2019, M. Rusydi, 2016). These studies as a whole prove the effectiveness of genetic algorithms in improving PID control performance in a variety of applications, including industrial processes, power systems, and aircraft control.

By considering the aspects of cost efficiency and decarbonization, optimizing the power generation system at PT Pertamina EP Bunyu Field is a strategic step to improve operational sustainability. The implementation of this strategy is expected not only to reduce energy costs but also to strengthen the role of the oil and gas industry in supporting the national energy transition. In the future, the adoption of digital technology and the integration of renewable energy can further accelerate the achievement of efficiency and decarbonization targets in Indonesia's oil and gas sector.

LITERATURE REVIEW

Optimal and intelligent control system

Penggunaan artis sebagai endorser di berbagai media, termasuk media cetak, media variabel, dan media digital, dikenal sebagai Celebrity Endorser. alasan mengapa artis sangat ingin mempromosikan produk mereka melalui Produsen adalah pesan yang diperoleh dari sumber daya yang menarik dan mudah dipahami (Pertiwi, 2019).

The formulation of the solution proposed in this study looks like Figure 1. This research aims to improve the efficiency of Gas Engine Generator (GEG) through control optimization based on Reinforcement Learning - Proximal Policy Optimization (RL-PPO). In this approach, the system was developed to automatically determine the optimal control parameters, namely Kp, Ki, and Kd, which are used in engine speed regulation to improve fuel consumption efficiency. The research process begins by determining Engine Speed as the main input variable in the system. The speed of this engine is controlled to ensure optimal operation, both in terms of fuel efficiency and the stability of the power produced. Furthermore, the Gas Engine Generator (GEG) model was developed as a simulation environment within the Reinforcement Learning (RL) framework. In this approach, RL agents explore and exploit various possible combinations of control parameters to find the values that provide the best performance. Proximal Policy Optimization (PPO) is used as the main learning algorithm because of its advantages in generating more stable and faster policies than conventional RL methods.

In this RL system, there are two main components, namely state and environment. The state reflects the current state of the system, including parameters such as engine speed, load, and fuel efficiency, while the environment represents the operational dynamics of the Gas Engine Generator, which provides feedback on the actions performed by the RL agent. The result of this optimization process is a set of optimal control parameters consisting of Kp, Ki, and Kd, which are then applied to the control system to improve the operational efficiency of GEG. With this approach, the research is expected to reduce fuel consumption while improving the energy efficiency produced, thereby providing better economic and environmental benefits.

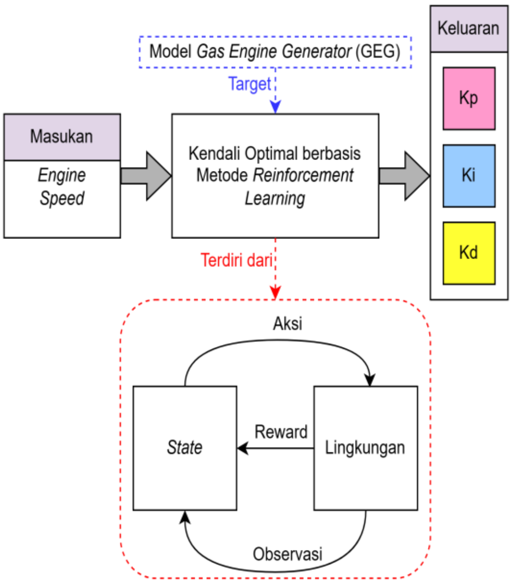

Figure 1. Research methodology

Search for Optimal PID Controlling Parameters Using Genetic Algorithms

After obtaining a mathematical model of the system, the next step is to determine the optimal PID controlling parameters. One of the reasons for this optimization is that it uses Genetic Algorithms (GA) to find the best combination of PID parameters: which minimizes errors $K_p, K_i,$ dan K_d between the system output and the reference value. The objective function in PID optimization with GA is designed to minimize J Integral Square Error (ISE), which is formulated as:

$$J = ISE = \int_0^\infty e^2(t)\ dt \qquad (1)$$

Is $e(t)$ *the error* between the reference value and the system output. ISE is used to optimize system performance by minimizing total *errors* quadratically so that system response is more stable and has smaller *errors* in the long run. Integral Square Error (ISE) is a function that is calculated by summing the squares of the *error* between the system being tested and the reference system. A smaller value indicates that the system is performing better and is getting closer to the reference.J

Finding of optimal PID controlling parameters using the PPO method

Reinforcement Learning (RL) is a branch of machine learning that focuses on repetitive decision-making in an environment to maximize cumulative rewards. One of the popular methods in RL is Proximal Policy Optimization (PPO) developed by OpenAI. PPO is a policy gradient-based method designed to overcome the weaknesses of previous algorithms such as Trust Region Policy Optimization (TRPO), by providing a balance between stability and efficiency in policy updates. PID (Proportional-Integral-Derivative) is one of the most commonly used control methods in dynamic systems. The PID parameter, and greatly affects the performance of the system. PPO can be used to optimize PID parameters with an RL-based approach as in Algorithm 1.$K_p K_i K_d$

Algorithm 1. Optimization of controller parameters, and $K_p K_i K_d$

Input:

- Read data from CSV files to get engine speed from generators E, F, and G.
- Equalize the length of the data and compile it as input-output for system identification.
- Estimating a *state-space* model uses the ssest method to get a representation of the system.
- Setpoint

RL Environment Definition:

- *State*: An error between the engine speed reference and the actual output.
- *Action*: The PID parameter to be adjusted (, ,).$K_p K_i K_d$
- *Reward*: Penalties based on *the Integral of Time-weighted Absolute Error* (ITAE) or *Mean Squared Error* (MSE) between the reference and the output.
- *Environment Reset*: Reset the system of each episode with random initial parameters.

Epoch←1 to Episode

error = setpoint - output

reward = error

Kp← Kp + alpha*reward

Ki← Ki + alpha*reward

Kd← Kd + alpha*reward

PID parameter updates

Exodus:

- PID parameters are optimal and for the system.$K_p^*, K_i^*\ K_d^*$

- A system response graph with optimal PID parameters and a reference system.
- Assess the system's performance after optimization.

RESEARCH METHOD

This chapter discusses the testing process carried out to evaluate the effectiveness of optimization methods applied to Gas Engine-based power generation systems. The test was carried out by comparing the performance of the system before and after optimization, using parameters that had been obtained through Genetic Algorithms (GA) and *Proximal Policy Optimization* (PPO).

RESULT AND DISCUSSION

Testing with the GA Method

The results of the optimal PID parameter values with the GA method are as follows:

Results for GEG E with GA: Kp=1.1999, Ki=0.76003, Kd=2.2605
Results for GEG F with GA: Kp=1.02, Ki=1.02, Kd=2.5
Results for GEG G with GA: Kp=1.1406, Ki=1.1, Kd=0.90264

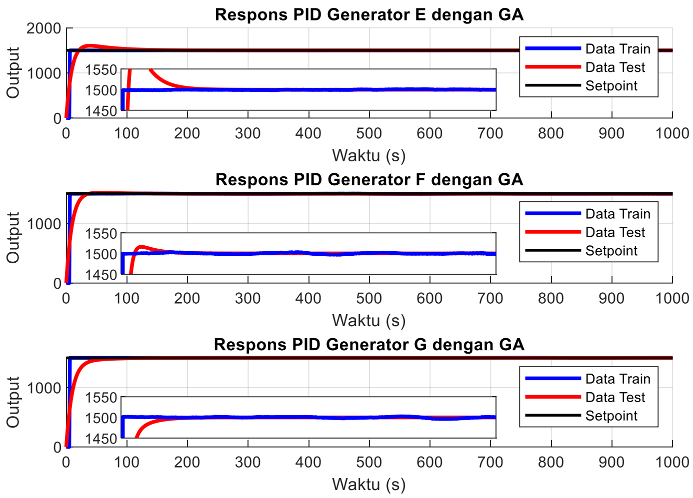

Figure 2. PID response of 3 Generators with GA

From the simulation results in Figure 2, it can be seen that the response of the generator system to the optimized PID control uses genetic algorithms (GA) for three different generators (E, F, and G). From the graph, it can be seen that each generator is able to reach the setpoint quickly and stably without excessive oscillation, showing the effectiveness and optimization of the PID parameters used, which are found from genetic algorithms (GA).

PPO Method Testing

The simulation results show that the system response with the PID-PPO method on Generators E, F, and G as shown in Figure 3 has fairly stable characteristics to setpoint changes. At the beginning of the simulation, there was a slight oscillation before the system reached stability, which can be seen from the pattern of output movement in all three generators. Comparisons between training data and test data showed similarities in patterns, although there were differences in amplitude and convergence times, especially in the 30 to 60 second time range. This indicates that the model used is able to make fairly good generalizations, but there are still slight differences that can be optimized to improve control performance. Based on the response from each chart, it can be observed that all three generators overshoot before finally reaching stability. The *settling time* also varied among the three generators, with Generator G showing a faster settling time than Generator F. Despite the deviation in the transient phase, the *steady-state* value of each generator was quite close to the predetermined setpoint, indicating that the PID-PPO method was quite effective in controlling the system. Overall, these results illustrate that the PID-PPO approach has good potential in improving the control response in generators. However, there are some minor differences between training and testing data that can be the focus of further optimization to improve system accuracy and efficiency.

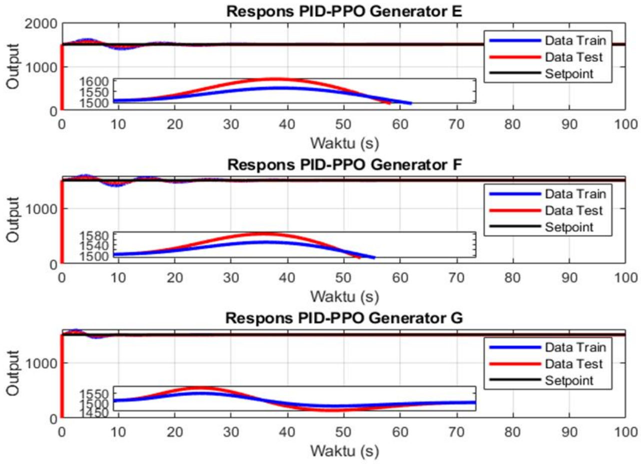

Figure 3. Testing on training data and testing with PID parameters by the RL-PPO method

Implementation

In gas-based energy generation systems, operational efficiency is the main factor in optimizing fuel consumption and reducing carbon emissions. One approach that can be applied to improve efficiency is the use of *the Reinforcement Learning - Proximal Policy Optimization* (RL-PPO) method to optimize the control parameters K_p, , $K_i K_d$ in the *gas engine generator* (GEG) control system. This study aims to evaluate the efficiency improvement and emission reduction obtained by applying 3 GEG units that have been controlled using the optimal parameters of the RL-PPO method. This study uses an optimal control-based approach through the RL-PPO algorithm, which is applied to determine the values of Kp, Ki, and Kd parameters in gas-based generation systems. The gas consumption data as well as the energy generated are then converted in various energy units, such as mmbtu, GJ, and kWh, to evaluate the efficiency of the system. In addition, emission reductions are calculated based on the conversion from kWh to tons of CO_2eq, taking into account standard emission factors. The simulation results show that the use of 3 GEG units optimized with RL-PPO results in a significant increase in efficiency. Annual gas consumption was recorded at 40.15 mmscfd, with the total energy produced reaching 12,213,094.67 kWh per year.

The efficiency of the system is indicated by the conversion value as follows:

- 41,635.55 mmbtu per year
- 43,967.14 GJ per year
- 120,46 GJ per hari

In addition, this optimization also contributes to a reduction in carbon emissions of 10,881.87 tons of CO_2eq per year. The following is a graph illustrating the comparison of energy efficiency and emission reduction before and after optimization as shown in Figure 4.

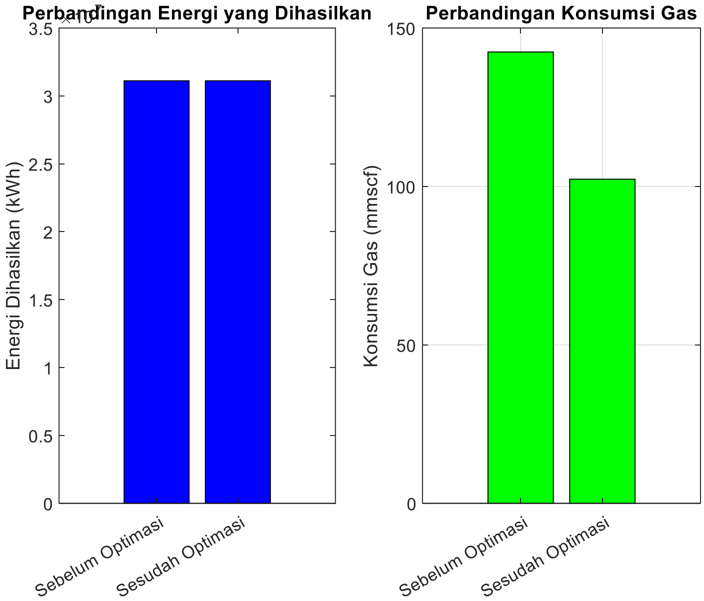

Figure 4. Comparative efficiency graph before and after optimization

CONCLUSION

The simulation results showed that the use of genetic algorithms (GA) and the PID-PPO method in the generator control system provided a fast and stable response to the setpoint, although there was still little oscillation and differences in the convergence time between the generators. The PID-PPO approach is able to produce a fairly good response in controlling the system, with Generator G having a faster uptime than Generator F. In addition, the application of the Reinforcement Learning - Proximal Policy Optimization (RL-PPO) method for the optimization of control parameters K_p , and $K_i K_d$ on the *generator* engine gas generation system (GEG) successfully improves operational efficiency and significantly reduces carbon emissions. With an annual gas consumption of 40.15 mmscfd and a total energy output of 12,213,094.67 kWh per year, the efficiency of the system is reflected in various energy units, such as 41,635.55 mmbtu per year, 43,967.14 GJ per year, and 120.46 GJ per day. In addition, this optimization also contributes to a reduction in carbon emissions of 10,881.87 tons of CO_2eq per year, showing that the RL-PPO approach has great potential in improving the performance of gas-based energy generation systems.

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