

Analysis of Intermittent Electrical Shutdown Electrostatic Precipitator Method in Enhancing Energy Efficiency

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Abstrak

Presipitator Elektrostatis (ESP) merupakan komponen penting dalam Pembangkit Listrik Tenaga Uap (PLTU) berbahan bakar batubara, yang berfungsi untuk menangkap partikel debu halus dari gas buang hasil pembakaran batubara. ESP bekerja dengan menggunakan elektroda bermuatan listrik untuk menarik partikel debu; namun, proses melepaskan debu yang menempel pada elektroda sering kali menjadi tantangan, bahkan dengan bantuan sistem *Hammer Rapping*. Sebuah metode baru yang dikenal sebagai *Intermittent Shutdown* ESP (IES) dikembangkan dengan cara mematikan muatan listrik pada elektroda secara berkala, sehingga debu yang menempel pada pelat elektroda dapat terlepas lebih mudah. Studi teoretis ini bertujuan untuk menganalisis potensi manfaat metode IES dalam meningkatkan efisiensi energi dan kinerja pembersihan debu. Penelitian difokuskan pada perhitungan konsumsi energi dalam pengoperasian ESP, serta membandingkan kinerja ESP dengan dan tanpa penerapan metode IES. Dengan menggunakan pendekatan kuantitatif, penelitian ini memodelkan kinerja ESP dan menganalisis data konsumsi energi, terutama pada bagian transformator penyearah (*rectifier transformer*), dengan mengecualikan kontribusi dari pemanas hopper, pemanas boks, dan sistem rapper. Hasil penelitian menunjukkan bahwa penerapan metode IES secara signifikan mengurangi konsumsi energi, dengan penghematan sekitar 44,1 kWh per siklus operasi, serta potensi penghematan energi bulanan sebesar 31.717,5 kWh dan tahunan sebesar 380.610 kWh. Hal ini setara dengan penghematan biaya operasional sekitar Rp 53,3 juta per bulan dan Rp 640 juta per tahun. Selain itu, metode IES juga meningkatkan efisiensi dan keandalan sistem ESP secara keseluruhan dengan menurunkan beban energi pada seluruh bidang operasi. Sebagai kesimpulan, metode *Intermittent Shutdown* ESP (IES) merupakan strategi yang layak dan efektif secara biaya untuk mengoptimalkan operasi ESP, sekaligus berkontribusi terhadap peningkatan efisiensi energi dan penghematan biaya operasional pada PLTU berbahan bakar batubara.

Kata kunci: ESP, berkala, listrik, pemadaman.

Abstract

The Electrostatic Precipitator (ESP) is a critical component in Coal-Fired Power Plants, responsible for capturing fine dust particles from the exhaust gases produced during coal combustion. The ESP operates by using electrically charged electrodes to attract dust particles; however, dislodging the dust adhered to these electrodes can be challenging, even with the use of Hammer Rapping. A novel method known as Intermittent Shutdown ESP (IES) involves periodically turning off the electrical charge on the electrodes, making it easier for the adhered dust to be released from the electrode plates. This theoretical study aims to analyze the potential benefits of the Intermittent Shutdown ESP method in improving energy efficiency and dust removal performance. The research focuses on calculating energy consumption in the operation of the ESP and comparing the performance of ESP with and without the IES method. Utilizing a quantitative approach, this study models the performance of ESP and analyzes energy consumption data, primarily focusing on the rectifier transformers while excluding contributions from hopper heaters, box heaters, and rappers. The findings reveal that the IES method significantly reduces energy consumption, achieving savings of approximately 44.1 kWh per operational cycle, with monthly and annual energy savings of 31.717,5 kWh and 380.610 kWh, respectively. This translates to substantial cost reductions, with potential monthly savings of Rp 53,3 million and annual savings of Rp 640 million. The IES method also enhances the overall efficiency and reliability of ESP systems by reducing the energy load across all fields. In

conclusion, the IES method presents a viable and cost-effective strategy for optimizing ESP operations, contributing to both energy efficiency and cost savings in Coal-Fired Power Plants.

Keywords: *ESP, intermittent, electrical, shutdown*

1. INTRODUCTION

Given the stringent environmental regulations, maintaining the efficiency of ESP systems is essential for reducing emissions and complying with environmental standards. In Indonesia, the Minister of Environment Regulation No. 15 of 2019 on the Emission Standards for Thermal Power Plants sets maximum allowable emission limits for various pollutants, including particulates, SO₂, and NO_x. Compliance with this regulation is mandatory for all power plants to ensure that their environmental impact is minimized.

An Electrostatic Precipitator (ESP) is a device used to control air pollution by capturing dust and ash particles from exhaust gases before they are released into the atmosphere. The internal working scheme of an ESP involves several key components, including discharge electrodes, collecting plates, and cleaning systems such as Hammer Rapping.

The process begins when exhaust gases containing fine particles enter the ESP chamber. Inside the ESP, the discharge electrodes, typically in the form of spirals or wires, impart an electrical charge to the dust particles. This ionization process creates a strong electric field that attracts the charged particles toward the oppositely charged collecting plates. The collecting plates, arranged parallel to the discharge electrodes, act as surfaces where the dust particles adhere.



Figure 1. Internal ESP (*Discharge Electrodes and Hammer Rapping*)

During continuous ESP operation, the accumulation of dust on the collecting plates and discharge electrodes can lead to operational issues, such as reduced dust collection efficiency and increased energy consumption. To address this, cleaning systems like Hammer Rapping are employed. Hammer Rapping functions as a hammering mechanism that periodically shakes or strikes the collecting plates and electrodes, causing the adhered dust particles to dislodge. These dislodged particles then fall into hoppers located at the bottom of the ESP, where they are collected for disposal or further processing.

Previous studies have demonstrated the effectiveness of ESPs in removing particulate matter, with some research focusing on optimizing operational parameters to improve dust collection efficiency (Finkelman *et al.*, 2021). For instance, continuous operation of ESPs has been shown to cause significant ash accumulation on collecting plates, leading to reduced efficiency and increased energy

consumption (Russell *et al.*, 2017). Traditional methods such as Hammer Rapping are commonly used to dislodge the accumulated dust, but these methods may not be sufficient in maintaining optimal ESP performance over time.

Moreover, recent research highlights that adjusting the current settings of the transformer in an ESP can also significantly reduce energy consumption (Guntoro and Berkah, 2023).

Problem Identification, one of the primary challenges in ESP operation is managing the accumulation of dust and ash on the collecting plates and discharge electrodes. This buildup can lead to several operational issues, including decreased dust collection efficiency, increased energy consumption, and potential damage to ESP components (Finkelman *et al.*, 2021). Continuous operation without effective cleaning can exacerbate these problems, ultimately compromise the performance of the ESP and leading to non-compliance with environmental regulations (Russell *et al.*, 2017).

The primary objective of this research is to evaluate the effectiveness of the Intermittent Shutdown ESP method in enhancing ESP performance. Specifically, the study seeks to:

- Analyze the impact of IES on energy consumption and dust collection efficiency.
- Compare the performance of ESPs with continuous operation and those using the IES method.
- Identify potential energy savings and operational improvements through the implementation of IES.

This study focuses on the theoretical analysis of ESP performance using the IES method. The analysis is based on data from rectifier transformer energy consumption, excluding contributions from auxiliary systems such as hopper heaters and rappers. While the findings provide valuable insights into the potential benefits of IES.

2. METHODOLOGY

When the ESP operates, the collecting plates are charged to attract and capture the dust particles carried in the exhaust gas. However, due to the strong electric field, the dust tends to adhere tightly to the plates, making the cleaning process less effective if the system runs continuously. Electrostatic forces within the ESP can cause ash to cling firmly to the plates (Reddy & Dayanand, 2013).

This study aims to evaluate the impact of operating Electrostatic Precipitators (ESP) with the Intermittent Electrical Shutdown (IES) method on energy consumption and dust collection effectiveness. Dust collection effectiveness is assessed qualitatively using particulate data.

The research object is ESP#2, which operates at a coal-fired power plant in Pelabuhan Ratu. The ESP is a critical component for capturing fine particulates from exhaust gases produced during combustion.

This study employs a simulation approach and field data collection to evaluate the performance of the ESP under various operational scenarios. Data collection was conducted for two scenarios: the non-IES method on March 19, 2024, and the IES method on March 25, 2024. The collected data includes operational parameters such as voltage, current, and dust collection efficiency.

Data collection was performed directly in the field, including the measurement of ESP transformer operating parameters as well as references from the Manual Book and other technical documents. Operational data such as voltage and current were measured for each ESP transformer and averaged. Particulate emissions were measured through the CEMS (Continuous Emission Monitoring System), which monitors real-time particulate emissions from the exhaust gases output by the ESP.

A. Mechanism of Intermittent Shutdown

The mechanism involves temporarily cutting off the electrical supply to the ESP. This interruption allows the rapping hammers to strike the plates and electrodes without the interference of electrical forces. The collected ash falls off due to the mechanical impact, thus cleaning the plates. Once the ash is removed, the ESP system can be re-energized, and the process continues in the next chamber. This cyclic shutdown and cleaning process ensure that the ESP operates at optimal efficiency with minimal power consumption.

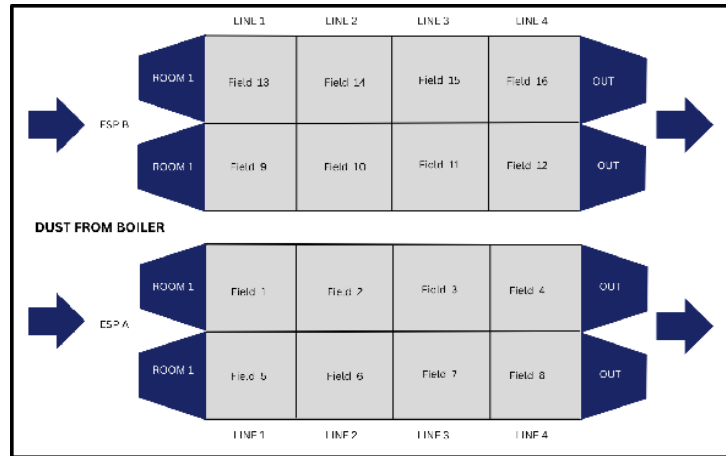


Figure 2. Transformer Configuration in ESP

The simulation of the Electrostatic Precipitator (ESP) operation with 4 lines involves alternating shutdown cycles. Each line stops at a designated time during a 60-minute cycle. The operational cycle is as follows:

Table 1. Cycle Time Operational IES Methode

Time (Minutes)	Status	Line 1	Line 2	Line 3	Line 4
0 - 5	Line 1 Stop	Stop	Operate	Operate	Operate
5 - 15	Normal	Operate	Operate	Operate	Operate
15 - 20	Line 2 Stop	Operate	Stop	Operate	Operate
20 - 30	Normal	Operate	Operate	Operate	Operate
30 - 35	Line 3 Stop	Operate	Operate	Stop	Operate
35 - 45	Normal	Operate	Operate	Operate	Operate
45 - 50	Line 4 Stop	Operate	Operate	Operate	Stop
50 - 60	Normal	Operate	Operate	Operate	Operate

This cycle repeats every 60 minutes, with each line alternately stopping to allow for electrode cleaning without interrupting the overall operation of the ESP.

B. Data Analysis

Data analysis was performed to calculate dust collection efficiency and energy consumption for each current setting and operating method. Dust collection efficiency was calculated based on the comparison between dust concentrations at the inlet and outlet of the ESP. Energy consumption was calculated using the formula:

$$Wh = V \times I \times \cos\phi \times t \quad (1)$$

- Wh is energy consumption (Wh)
- V is the voltage (V)
- I is the current (A)
- $\cos\phi$ is the power factor
- t is the operating time (hours)

3. RESULTS AND DISCUSSION

The analysis of the ESP's energy consumption under different operational conditions reveals significant differences between the standard operation without Intermittent Electrical Shutdown (IES) and the operation with the IES method. The data collected from 16 fields (F1 to F16) of the ESP system demonstrates the effectiveness of the IES method in reducing energy consumption.

Table 2. Result Consumption Energy

Field of Trafo	Current 1 (A)	Volt 1 (V)	Non IES (kWh)	IES (kWh)
F1	207	122	22,73	20,83
F2	227	183	37,39	34,27
F3	217	172	33,59	30,79
F4	218	267	52,39	48,02
F5	191	195	33,52	30,73
F6	194	233	40,68	37,29
F7	187	154	25,92	23,76
F8	223	163	32,71	29,99
F9	211	175	33,23	30,46
F10	216	198	38,49	35,28
F11	185	142	23,64	21,67
F12	228	182	37,35	34,23
F13	221	192	38,19	35,01
F14	194	122	21,30	19,53
F15	192	194	33,52	30,73
F16	192	138	23,85	21,86
Total kWh			528,5	484,4
Operating 1 Month (kWh)			380.519,9	348.802,4

The total energy consumption across all fields for one operation cycle using the Non-IES method is 528,5 kWh, while with the IES method, energy consumption is reduced to 484,4 kWh, resulting in energy savings of 44,1 kWh.

When calculated for one month of operation (assuming constant operation throughout the month), the energy consumption for the Non-IES method is 380.519,9 kWh, while the IES method consumes 348.802,4 kWh. This indicates energy savings of 31.717,5 kWh in one month.

A. Operating Costs

With an electricity tariff of Rp 1.699,53/kWh (PT PLN [Persero], 2024), the operating costs for one month are calculated as follows:

Non-IES Method:

- Energy Consumption: 380.519,9 kWh
- Operating Cost: $380.519,9 \text{ kWh} \times \text{Rp } 1.699,53/\text{kWh} = \text{Rp } 646.207.928,85$

IES Method:

- Energy Consumption: 348.802,4 kWh
- Operating Cost: $348.802,4 \text{ kWh} \times \text{Rp } 1.699,53/\text{kWh} = \text{Rp } 592.838.623,92$

Thus, the use of the IES method results in operational cost savings of Rp 53.369.304,93 in one month.

Based on the calculated monthly savings, the potential savings over one year (12 months) are as follows:

- Annual Energy Savings:
 $31.717,5 \text{ kWh/month} \times 12 \text{ months} = 380.610 \text{ kWh}$
- Annual Cost Savings:
 $\text{Rp } 53.369.304,93/\text{month} \times 12 \text{ months} = \text{Rp } 640.431.659,16$

The potential annual cost savings of Rp 640 million indicates that implementing the IES method not only significantly reduces operational costs but also provides substantial economic benefits in the long term.

The IES method has proven effective in reducing energy consumption across all fields, leading to significant operational cost savings. The reduction in energy consumption ranging from 6% to 13% in each field suggests that the IES method can be an efficient solution to reduce energy costs in power plants using ESP.

To further understand the impact of the Intermittent Electrical Shutdown (IES) method on particulate emissions generated by the Electrostatic Precipitator (ESP), measurements and analyses were conducted on the particulate levels in the exhaust gases produced. The graph below shows a comparison between the rated particulate levels generated by the IES method and the Non-IES method during the sampling period.

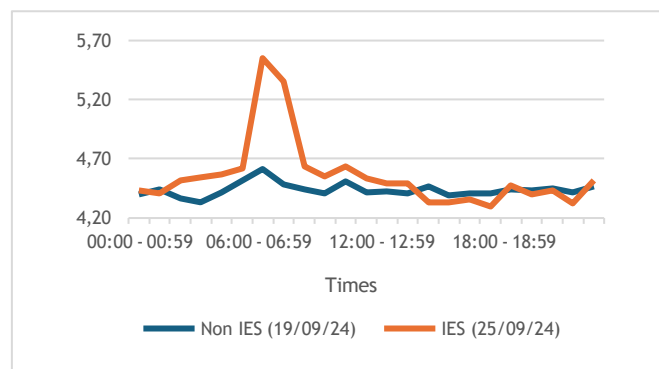


Figure 3. Graph Comparison of Particulate Emissions

Based on the data presented in the graph, it is evident that the particulate matter levels produced by both the Intermittent Electrical Shutdown (IES) method and the Non-IES method remain well below the regulatory limit of 100 mg/Nm^3 (Kementerian Lingkungan Hidup dan Kehutanan, 2019). Although there are fluctuations in particulate concentrations during the sampling period, both methods consistently show results that are significantly lower than the regulatory threshold. Specifically, even though the IES method exhibits some higher peaks compared to the Non-IES method, the highest particulate concentration recorded by the IES method is around 5.6 mg/Nm^3 , which is still far below the maximum allowable limit.

Moreover, even when the IES method involves shutting down one line or four transformers simultaneously, the particulate emissions remain below the regulatory emission standards. This indicates that the IES method, despite temporarily reducing the operational capacity of the ESP, is still effective in controlling particulate emissions and maintaining them within safe, compliant levels as per the applicable environmental regulations. This robustness further underscores the viability of the IES method in maintaining environmental standards while optimizing energy efficiency.

The energy efficiency achieved through the implementation of the Intermittent Electrical Shutdown (IES) method is purely due to the periodic shutdowns of the operation. In this method, the electrical supply to the ESP electrodes is alternately interrupted in specific cycles, which directly reduces energy consumption. This reduction occurs because certain parts of the ESP system are not operating during the shutdown periods, thereby decreasing the amount of energy used in the dust collection process. Therefore, the improvement in energy efficiency is not due to enhanced dust removal performance but rather the reduced operational time, leading to significant energy savings.

4. CONCLUSION

The Intermittent Electrical Shutdown (IES) method has proven to be highly effective in reducing energy consumption in Electrostatic Precipitator (ESP) operations, with an average savings of about 44,1 kWh per cycle. This method achieves significant energy savings, amounting to 31.717,5 kWh monthly and 380.610 kWh annually. With an electricity tariff of Rp 1.699,53/kWh, the adoption of IES can lead to substantial cost reductions, saving up to Rp 53,3 million per month and Rp 640 million per year. Additionally, IES enhances the overall efficiency and reliability of ESP systems by reducing

the energy load across all operational fields. Beyond its economic benefits, IES supports sustainable practices within power plants by lowering energy consumption. Future research has the potential to further optimize the IES method, enabling even greater energy and cost savings.

The results show that there was no significant increase in particulate levels during the application of both methods. Thus, even though the IES method involves periodic operational shutdowns, dust collection efficiency remains consistent, and the results are comparable to the conventional method. Based on this CEMS data, it can be qualitatively concluded that the IES method and the conventional method provide the same results in terms of dust collection efficiency, with particulate emission levels remaining within the regulatory limits.

Experimental validation and field testing are recommended for future research to confirm the results in practical settings (Lu & Streets, 2014).

5. REFERENCES

- Environmental Protection Agency (EPA). (n.d.). *Monitoring by control technique – electrostatic precipitators*. U.S. Environmental Protection Agency. Retrieved August 20, 2024, from <https://www.epa.gov/air-emissions-monitoring-knowledge-base/monitoring-control-technique-electrostatic-precipitators>
- Finkelman, R., Brown, J., & Lee, S. (2021). Updated emissions of major air pollutants and their ecological impacts. *Clean Technologies and Environmental Policy*. [Data volume, issue, dan DOI belum tersedia secara publik].
- Guntoro, F., & Berkah, T. (2023). Pengaruh metode pengoperasian electrostatic precipitator terhadap efisiensi penangkapan debu dan konsumsi energi. *Jurnal Penelitian Internasional Inovasi dalam Rekayasa dan Teknologi (IRJIET)*, 7(8), 36–47. <https://doi.org/10.47001/IRJIET/2023.708006>
- Kementerian Lingkungan Hidup dan Kehutanan. (2019). *Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor 15 Tahun 2019 tentang baku mutu emisi pembangkit listrik tenaga termal*. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan.
- Lu, Z., & Streets, D. G. (2014). Increase in NO_x emissions from Indian thermal power plants during 1996–2010. *Environmental Science & Technology*, 46(7), 7463–7470. <https://doi.org/10.1021/es300831w>
- PT PLN (Persero). (2024). *Dokumen penetapan penyesuaian tarif tenaga listrik (Tariff Adjustment) Juli–September 2024*. PLN. Retrieved August 20, 2024, from <https://web.pln.co.id/statics/uploads/2024/07/Penetapan-Tariff-Adjustment-Juli-September-2024.jpg>
- Reddy, S. M., & Dayanand, G. (2013). Review on development of an automated system for gas distribution test of ESP. *International Journal of Mechanical Engineering and Robotics Research*, 2(3), 211–223.
- Russell, M. C., Belle, J. H., & Liu, Y. (2017). The impact of three recent coal-fired power plant closings on Pittsburgh air quality: A natural experiment. *Journal of the Air & Waste Management Association*, 67(1), 3–16. <https://doi.org/10.1080/10962247.2016.1170738>
- Shanghai Electric. (n.d.). *Operation and maintenance manual for electrostatic precipitators*. Shanghai Electric Group Company. [Unpublished company manual].