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The Effect of Electrostatic Precipitator Operating Methods on Energy Consumption Efficiency

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***Abstract* - At the Coal Power Plant the Electrostatic Precipitator (ESP) functions as a catcher of fine dust that is in the exhaust ducts from coal combustion. It is known that the ash attached to the electrode which has an electric charge is difficult to drop using a vibrator, by using the Power Off Rapping (POR) method, which is to temporarily turn off the electric charge on the electrode; the ash attached to the electrode plate will be more easy to miss. This research is a quantitative research that aims to determine the effect of the ESP operating method on energy consumption, determine the energy consumption ratio of each current setting, determine the dust capture efficiency ratio of each current setting and find energy saving opportunities using the following data analysis techniques. The energy consumption calculation used is only the energy consumption of the rectifier transformer on the electrostatic precipitator excluding hopper heaters, box heaters and rappers. After getting the test results from the current setting simulation, it can be concluded that the current setting of 20% is the most optimal setting in accordance with Ministry of Environment and Forestry Regulation No. 15 of 2019 the threshold limit for particulate exhaust gases at coal fired power plants is 100 mg/Nm^3 where the dust reading value is 80.15 mg/m^3. By using a current setting of 20%, a savings of 38.97% can be made for the operating method without POR and 41.88% for the POR operating method. If the difference in energy consumption is converted to rupiah by using the electricity tariff for large industrial groups (I-4/TT) of IDR 996.74/kWh, then the savings in electricity costs in 1 month of operation are IDR 176,802,877 without the POR method and IDR 189,988,881 with the POR method.**

Keywords: coal power plant, electrostatic precipitator, efficiency, electricity, energy, power off rapping.

I. INTRODUCTION

The increasing number of industries that appear at this time causes the demand for electricity to increase. Currently, the most widely used power plant in Indonesia is the coal power plant. This is because in Indonesia there are still coal, oil and natural gas mines. However, what is used more is coal, because the amount is still quite large compared to oil and natural gas. The electricity industry is one of the industries that has the potential to pollute the environment, mainly due to dust emissions [1]. Ash from burning coal in a boiler produces fly ash and bottom ash. Fly ash is a material that cannot be completely burned and is carried away by hot gases. Meanwhile, bottom ash is a residual material from coal combustion that is not carried away by hot gases [2].

Air pollution is one of the pollution that is very dangerous for humans, living things and the environment. Air pollution is the entry or inclusion of substances, energy and/or other components into the ambient air by human activities so that the quality of the ambient air drops to a certain level which causes the ambient air to be unable to fulfill its function [3]. Based on the Regulation of the Minister of Environment No. 30 of 2009, fly ash or ash produced by the combustion process from boilers is categorized as a Hazardous and Toxic Material (B3). So that the handling of this ash must comply with government regulations so as not to pollute the environment [4]. Based on the standards set by the Ministry of Environment and Forestry Regulation No. 15 of 2019, the threshold limit for particulate exhaust gas at coal-fired power plants is 100 mg/Nm^3[5]. In a coal-fired power plant, there is an electrostatic precipitator (ESP) which functions as a catcher for fine dust in the exhaust ducts of coal combustion products. The ESP consists of several positive and negative electrode plates which are supplied with a maximum DC voltage source of 72 kV DC with a current of 2100 mA. When electricity is applied to the electrode plate, a corona will occur which will give a negative charge to the ashes. In simple terms, it can be said that ash which has negative ions will be attracted and

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stick to the positively charged plate. The ash attached to the electrodes will periodically be dropped by being vibrated by the vibrator contained in the ESP chamber. The ash that has been dropped will be accommodated in a hopper and will be moved to a larger shelter through the pipes by means of pressure. Furthermore, the ash will be disposed of at the ash disposal site using a transport truck [6].

The performance of electrostatic precipitators on ash capture efficiency ranges from 90 to 99.9% [7] [8] [9] [10]. The smallest ash particle size is <2 μC [11]. However, some existing researchers show results that only reach 60% to 80% [12] [13] and some other researchers get very low device performance results [14] [15]. The success of an ESP is determined by the supply of ions attached to the particles and the influence of the electric field so that the particles move towards the collector electrode [16].

Based on the background that has been described, it is known that the ash attached to the electrode which has an electric charge is difficult to drop using a vibrator, by using the Power Off Rapping (POR) method, which is to temporarily turn off the electric charge on the electrode, the ash attached to the electrode plate will be more easy to miss. Many research on ESP efficiency have been carried out including research on ESP efficiency in capturing dust by overhouling, research on ESP efficiency in capturing dust by changing the operating voltage, research on the relationship between DC voltage and efficiency but research on efficiency and energy saving using the Power Off Rapping method has never been carried out. This research aims to determine the effect of the ESP operating method on energy consumption, determine the energy consumption ratio of each current setting and determine the dust capture efficiency ratio of each current setting then discusses in detail the Power Off Rapping (POR) method on ESP which is expected to reduce energy use. Look for the most optimal current setting so that you get the potential for saving electricity consumption by taking into account the standard dust emission value in Indonesia based on the standards set by the Ministry of Environment and Forestry Regulation No. 15 of 2019 the threshold limit for particulate exhaust gas at coal power plants is 100 mg/Nm^3.

1.1 Definition of Electrostatic Precipitator

Electrostatic precipitator is a power plant support equipment used to catch fly ash from burning coal in the PLTU combustion chamber. Dust (fly ash) is the result of the coal combustion process which is very fine so that it is easily carried by exhaust gas towards the chimney to the outside air. This dust is a material that can cause air pollution, therefore the amount of dust that comes out must be kept as small as possible. Exhaust gas from coal combustion will first pass through an electrostatic precipitator to reduce its particles as much as possible so as not to harm the environment when released into the atmosphere. The parts of the electrostatic precipitator are the hopper which is located at the bottom of the electrostatic precipitator to collect the captured ash, the housing or casing of the electrostatic precipitator, the internal parts which consist of discharge electrodes, collecting plates, and the rapping system. Based on technical data, electrostatic precipitators can reduce up to 99% of the ash produced from the combustion process in the coal fired power plant combustion chamber [1].

Based on the 2019 Minister of Environment and Forestry Regulation, fly ash produced by the combustion process from boilers is categorized as B3 Waste (Hazardous and Toxic Materials) so fly ash handling must comply with government regulations so as not to pollute the environment. On figure 1, the electrostatic precipitator each part is shown.

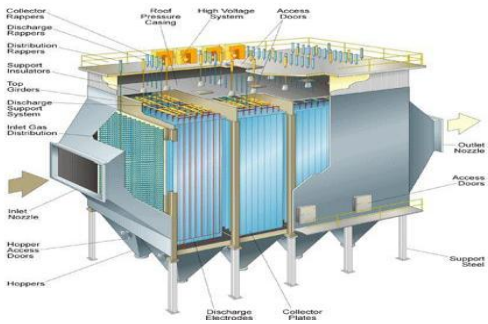

Figure 1: Electrostatic precipitator

When an electric potential is placed on two parallel plates, a uniform electric field will be formed. When the electric field is increased so that it is at its critical point, there will be an electric jump resembling lightning between the two plates and can also produce sound that can be felt through sight and hearing. This can cause a glowing thing known as a corona, without the flash. Corona generated from AC electricity is different from DC electricity. Because in AC electricity the potential at a point will alternate from positive to negative and so on. In DC electricity, the potential at that point will remain constant so as to produce a positive potential corona and a negative potential corona. If associated with the particle loading process. AC corona will produce oscillatory motion when loading particles. The DC corona will cause the charged particles to move towards the collector electrode. The ESP used in this research is the single stage ESP using a negative corona. So that the discharging electrode and collector electrode can function as a dust catcher. When the ESP single stage reaches a certain voltage, voltage saturation will occur, when the voltage value increases, the dust capture efficiency value will not change. In this research, the saturation voltage value will be sought so that the optimal ESP setting will be obtained [1].

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1.2 The Working Principle of Electrostatic Precipitator

On figure 2, the general principle of how electrostatic precipitator work is shown. Electrostatic precipitator is a dust catcher using an electric system consisting of steel plates which are the positive electrode (collecting electrode) and the negative electrode (discharge electrode) with a very high voltage difference. The electrostatic precipitator uses high voltage electricity to separate the dust contained in the flue gas stream from burning coal in the furnace. Broadly speaking, the performance of this electrostatic precipitator is to separate exhaust gases containing various gases from particulates such as fly ash. This dust is made negatively charged so that it can be captured by the negative charge from the collecting plate. Dust can be negatively charged because it passes through the discharge electrode which is given a HVDC voltage. The use of HVDC voltage because there is no inductance effect on HVDC causes the resulting voltage drop to be much smaller compared to HVAC, giving a good voltage value.

Discharge electrode is a component in the electrostatic precipitator which is negatively charged and suspended in each row between gas flow channels and located between each collecting plate. The high voltage system will make the discharge electrode produce a negatively charged electric field. Particulates passing through the system from the electrostatic precipitator will receive a negative charge from the discharge electrode and be attracted to the grounded collecting plate, and result in the formation of a dust layer on the collecting plate. Likewise, a layer of dust will form on the discharge electrode. Along the gas flow, little by little the dust particles will be attracted towards the plate, so that at the final plate close to the outlet, the concentration of dust contained in the gas will remain slightly. The rapping system that has been adjusted periodically will separate the dust layers that have accumulated, from the collecting plate and from the discharge electrode. The dust layer will fall off by the hammer from the working rapping system, and then it will be collected by the hopper as a temporary shelter which will later be continued to the ash handling system of the power plant [1].

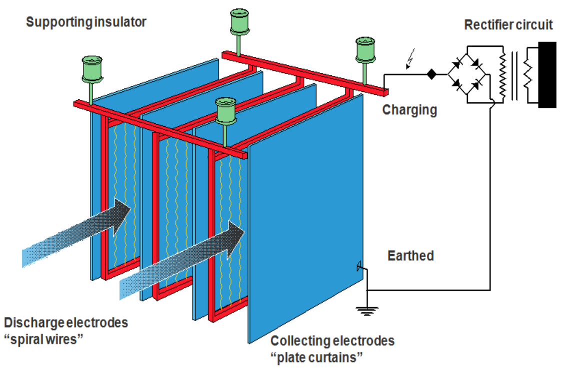

Figure 2: The working principle of electrostatic precipitator

1.3 Components of Electrostatic Precipitator

- **Transformer Step Up**

The step up transformer is used to increase the voltage. Then this voltage will ionize the particles that are in the exhaust gas. The function of the rectifier is to convert AC current into DC current. The voltage controller for the electrostatic precipitator uses a Silicon Control Rectifier (SCR), which is a linear automatic voltage controller on the primary side of the transformer. This automatic voltage control system is designed to maintain optimal voltage and current in response to changes in characteristics and concentration of dust passing through the electrostatic precipitator. Another function is to achieve the highest possible operating voltage for various combinations of ash and load [1].

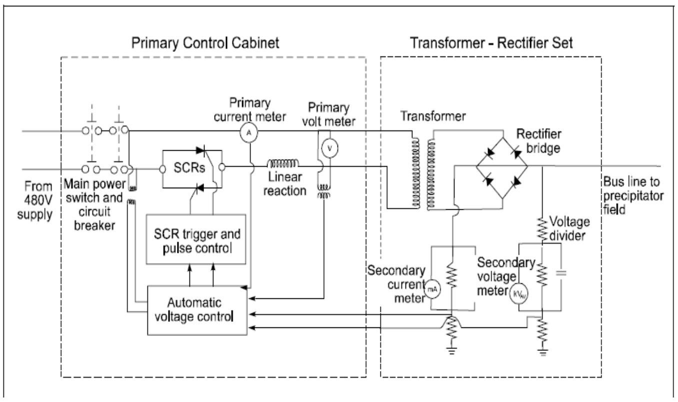

Figure 3: Transformer Step Up

- **Collecting Plate**

Collecting plates are vertically mounted plates to collect ionized fly ash particles. The collecting plate is in the form of a corrugated sheet with dimensions as shown in the figure below. After the exhaust gas passes through the inlet, then the exhaust gas will pass between these collecting plates [1].

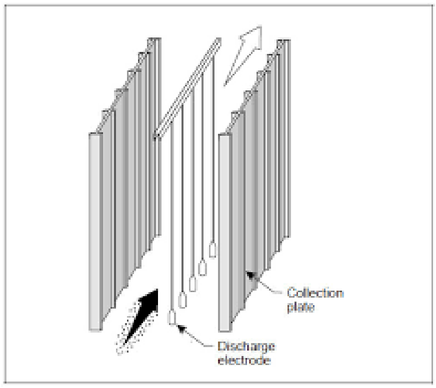

Figure 4: Collecting Plate

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- **Discharge Electrode**

Discharge electrode is a component of the electrostatic precipitator whose function is to provide a negative charge on the exhaust gas so that it can be captured by the positively charged collecting plate. There are various forms of discharge electrodes that have been designed and used in electrostatic precipitators, namely as follows [1].

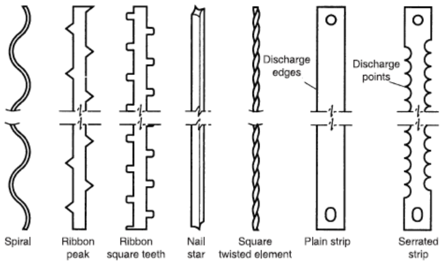

Figure 5: Discharge Electrode

- **Rapper**

Exhaust gas that collects and accumulates on the surface of the collecting plate and discharge electrode must be cleaned periodically by vibrating the collecting plate and discharge electrode. This rapping process cleans the trapped dust to be dropped into the hopper (shelter) for further disposal. This causes the discharge electrode and collecting plate to remain clean and operate normally. Without periodic rapping, the trapped dust layer will thicken rapidly and the performance of the electrostatic precipitator will decrease [1].

Figure 6: Rapper

- **Hopper**

When the discharge electrode and collecting plate have been cleaned by the Rapping system, the trapped dust will fall into the hopper and be stored temporarily before being transferred to the final disposal site. This dust must be removed as soon as possible so that it does not harden and accumulate, making removal difficult. The hopper is designed with a slope of 50° to 70° to allow easy transfer of dust from the top of the hopper to the discharge valve. A dust level detector in the hopper can help provide a warning when the hopper is almost full [1].

Figure 7: Hopper

II. RESEARCH METHOD

This research aims to find energy saving opportunities using the following data analysis techniques, energy usage calculation data that has been obtained from 2 operating methods using current settings of 20%, 30%, 35% and 40%, then compared to find the difference in energy consumption. The use of the current setting is to limit the current when the ESP operates, the current setting also affects the energy consumption of the ESP, the higher the current setting value, the higher the energy consumption. The results of energy calculations can be divided into 2, energy calculations using the Power Off Rapping method and energy calculations without using the Power Off Rapping method.

After obtaining the efficiency value and energy consumption value of each current setting variant, an analysis is then carried out to find the most optimal current setting taking into account the standard dust emission values in Indonesia based on the standards stipulated by the Ministry of Environment and Forestry Regulation No. 15 of 2019 the threshold limit for particulate exhaust gases in a coal power plant is 100 mg/Nm^3. The optimal current setting is the best current setting that can be done without compromising other factors, which in this study is an example of the dust emission value. On figure 8, the research schematics are shown.

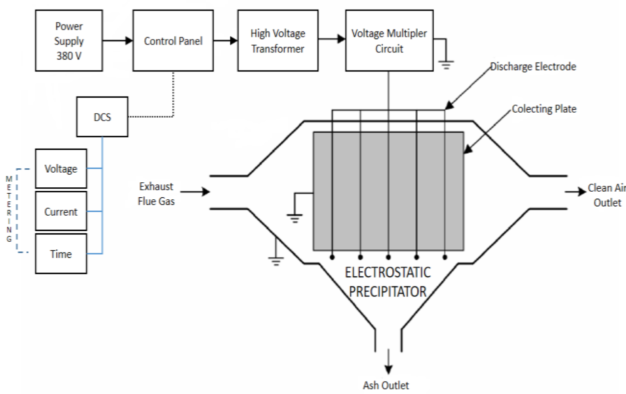

Figure 8: Research Schematic

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2.1 Electrostatic Precipitator Specification Data

The specifications of the electrostatic transformer used include data on the area of the collecting plate, the distance between the plates, the gas flow rate and the efficiency of dust capture.

Table 1: Specification of Electrostatic Precipitator

Collecting Plate Length(mm)	7000
Collecting Plate Width (mm)	2500
Number of Plates	576
Gas Flow Rate (m^3/s)	584
Total Area of Collecting Plate (m^2)	20.160
Wire-Plate Distance (mm)	150
Distance Between Plates (mm)	300
Removal Efficiency (%)	Up to 99.9
Availability (%)	Up to 98
Gas Temperature (^{o}C)	70-400

2.2 Calculation of Electrostatic Precipitator Performance

Calculation of the performance of the electrostatic precipitator explains the efficiency of the electrostatic precipitator in capturing dust and the efficiency of the electrostatic precipitator in energy consumption before and after using the Power Off Rapping (POR) method.

- **Calculation of Collector Plate Surface Area**

The calculation of the surface area of the collecting plate is formulated by the following equation:

$$A = w \times l \times 2 \ (surface) \qquad (1)$$

Where A is the effective area of the collecting plate (m^2), P is the length of the plate (m), l is the width of the plate (m). While the calculation of the number of fly ash collection plates inside ESP is formulated by the following equation:

$$Number\ of\ plates = Row \times Column \times Field \times Number\ of\ Side\ ESP \qquad (2)$$

So to find the area of the collector plate is formulated using the following equation:

$$At = Plate\ surface\ area \times number\ of\ plates \qquad (3)$$

- **Calculation of Particle Migration Speed**

The particle migration velocity is the speed at which the particles move when given a negative charge moving towards the collecting plate electrode. Variables that influence it are particle size, electric field strength and gas viscosity. So that the speed of particle migration can be expressed by the following equation [17]:

$$\omega = \frac{2\ K0\ P\ a\ Ec\ Ep}{3\mu} \qquad (4)$$

Where is ω the particle migration velocity (m/s), K0 is the permittivity (8.854 × 10^{-12} F•m^{-1}), P is pressure (1 atm), a is the particle radius (10^{-6}m), Ec is the electric field strength (v/m), Ep is the precipitator field strength (v/m), μ is the gas viscosity (pascal. second) and can be considered Ec = Ep = E.

- **Calculation of Dust Catcher Efficiency**

The particle collection efficiency of the electrostatic precipitator (ESP) was first developed empirically by Evald Anderson in 1919 and then theoretically developed by W. Deutsch in 1922. Thus, the equation for the collection efficiency of the electrostatic precipitator (ESP) is usually known as the Deutsch Equation -Anderson with the following equation [6]:

$$\eta = 1\text{-}e\text{-}w(A/Q) \qquad (5)$$

Where η is the ESP efficiency, e is the natural number (2,718), A is the effective area of the collecting plate in ESP (m^2), Q is the gas flow rate (m^3/s) and W is the migration velocity (m/s).

- **Calculation of the operating time of the Power Off Rapping method**

Calculation of the operating time of the POR method with the following equation:

$$t = \frac{(\,tm\ /\ tt\,)\ x\ t1}{60} \qquad (6)$$

Where t is the POR operating time for 1 month (hours), t1 is the POR operating time for 1 cycle (100 minutes), t2 is the POR Stopping time for 1 cycle (5 minutes), tt is the POR operating time for 1 cycle (105 minutes) and tm is within 1 month of operation (43,200 minutes).

- **Calculation of Energy Consumption**

Calculation of energy consumption on the electrostatic precipitator (ESP) with the following equation:

$$Wh = V \times I \times Cos\varphi \times t \qquad (7)$$

Where Wh is the energy consumption value (Wh), V is the voltage value (V), I is the current value (A), Cos is the power factor value and t is the operating time (hours).

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III. RESULTS AND DISCUSSIONS

Electrostatic precipitator (ESP) operational data was taken on March 1, 2023 at the Java 7 Unit 1 coal fired power plant. The calculation result for the power consumption and optimum current setting can be seen in the following.

3.1 Calculation of Energy Consumption Data with POR and without POR

The current limit settings that will be used in calculating energy consumption data using POR and without POR are 20%, 30%, 35% and 40%.

- **Setting Current Limit 20%**

The current limit setting used is 20% and the ESP dust capture efficiency value compared to the voltage value when viewed in graphical form is:

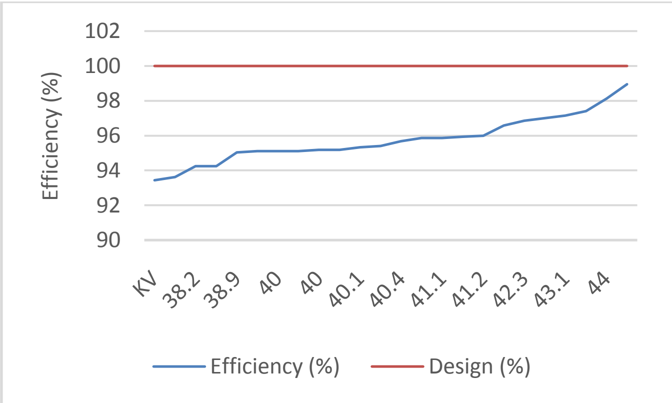

Figure 9: ESP Efficiency against voltage current limit 20%

Table 2: Setting current limit 20%

Side	Column	Volt 1 (V)	Current 1 (A)	POR (kWh)	Non POR (kWh)
A	11	520	40	11,410.05	11,980.80
	12	516	39	11,039.22	11,591.42
	13	517	38	10,777.01	11,316.10
	14	516	40	11,322.28	11,888.64
	21	516	39	11,039.22	11,591.42
	22	518	33	9,377.08	9,846.14
	23	518	41	11,650.32	12,233.09
	24	520	40	11,410.05	11,980.80
	31	519	39	11,103.40	11,658.82
	32	516	36	10,190.05	10,699.78
	33	518	39	11,082.01	11,636.35
	34	518	40	11,366.16	11,934.72
B	11	518	40	11,366.16	11,934.72
	12	519	41	11,672.81	12,256.70
	13	520	38	10,839.55	11,381.76
	14	521	37	10,574.59	11,103.55
	21	515	38	10,735.32	11,272.32
	22	517	37	10,493.40	11,018.30
	23	517	40	11,344.22	11,911.68
	24	518	40	11,366.16	11,934.72
	31	515	38	10,735.32	11,272.32
	32	521	39	11,146.19	11,703.74
	33	517	40	11,344.22	11,911.68

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	34	518	39	11,082.01	11,636.35
Total kWh				264,466.81	277,695.94

Table 2 shows the results of energy consumption with a current limit of 20% with the explanation "side" is the side of the ESP, "column" is the location of the transformer, "Volt 1" is the primary transformer voltage, "Current 1" is the primary transformer current , "POR" is energy consumption with POR method, "non POR" is energy consumption without POR method. If the results of energy consumption are converted into rupiah using the electricity tariff for large industrial groups (I-4/TT) of IDR 996.74/kWh, the total cost of electricity using the POR method in 1 month of operation is IDR 263,604,648.36 and without POR in 1 month of operation is IDR 276,790,647.25.

- **Setting Current Limit 30%**

The current limit setting used is 30% and the ESP dust capture efficiency value compared to the voltage value when viewed in graphical form is:

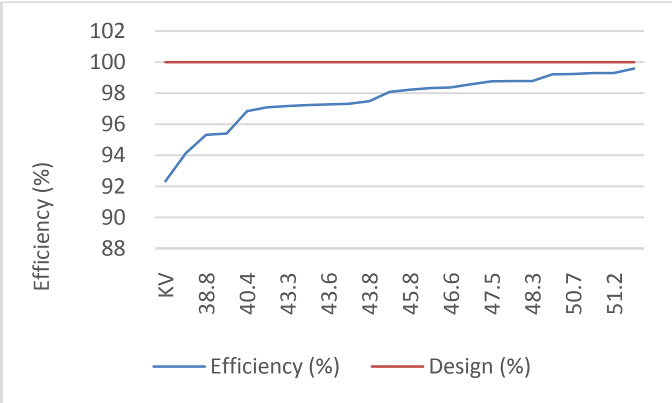

Figure 10: ESP Efficiency against voltage current limit 30%

Table 3: Setting current limit 30%

Side	Column	Volt 1 (V)	Current 1 (A)	POR (kWh)	Non POR (kWh)
A	11	521	61	18,523.40	19,449.97
	12	515	60	18,009.91	18,910.80
	13	517	62	18,682.51	19,617.05
	14	520	65	19,700.16	20,685.60
	21	519	64	19,359.78	20,328.19
	22	522	53	16,124.99	16,931.59
	23	518	61	18,416.74	19,337.98
	24	517	59	17,778.52	18,667.84
	31	522	64	19,471.69	20,445.70
	32	521	56	17,005.09	17,855.71
	33	518	58	17,511.00	18,386.93
	34	519	59	17,847.30	18,740.05
B	11	517	56	16,874.53	17,718.62
	12	521	67	20,345.37	21,363.08
	13	520	59	17,881.68	18,776.16
	14	519	61	18,452.29	19,375.31
	21	514	57	17,076.19	17,930.38
	22	518	58	17,511.00	18,386.93
	23	514	61	18,274.52	19,188.65
	24	517	62	18,682.51	19,617.05
	31	512	73	21,784.41	22,874.11
	32	520	39	11,820.10	12,411.36
	33	518	61	18,416.74	19,337.98

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	34	519	59	17,847.30	18,740.05
Total kWh				433,397.71	455,077.08

If the results of energy consumption are converted into rupiah using the electricity tariff for large industrial groups (I-4/TT) of IDR 996.74/kWh, the total cost of electricity using the POR method in 1 month of operation is IDR 431,984,837.00 and without POR in 1 month of operation is IDR 453,593,528.72.

- **Setting Current Limit 35%**

The current limit setting used is 35% and the ESP dust capture efficiency value compared to the voltage value when viewed in graphical form is:

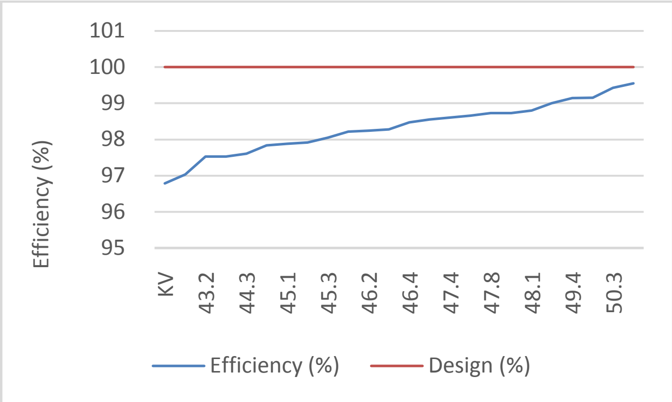

Figure 11: ESP Efficiency against voltage current limit 35%

Table 4: Setting current limit 35%

Side	Column	Volt 1 (V)	Current 1 (A)	POR (kWh)	Non POR (kWh)
A	11	517	78	23,503.81	24,679.51
	12	514	77	23,067.84	24,221.74
	13	515	76	22,812.55	23,953.68
	14	516	72	21,653.86	22,737.02
	21	517	83	25,010.46	26,261.53
	22	515	76	22,812.55	23,953.68
	23	513	79	23,620.96	24,802.52
	24	514	78	23,367.42	24,536.30
	31	522	85	25,860.83	27,154.44
	32	518	80	24,153.10	25,361.28
	33	519	81	24,502.22	25,727.87
	34	516	78	23,458.35	24,631.78
B	11	513	63	18,836.97	19,779.23
	12	515	68	20,411.23	21,432.24
	13	516	70	21,052.36	22,105.44
	14	517	76	22,901.15	24,046.70
	21	510	73	21,699.32	22,784.76
	22	517	77	23,202.48	24,363.11
	23	515	75	22,512.39	23,638.50
	24	514	74	22,169.09	23,278.03
	31	509	82	24,326.78	25,543.66
	32	513	80	23,919.96	25,116.48
	33	519	81	24,502.22	25,727.87
	34	518	81	24,455.01	25,678.30
Total kWh				553,812.9	455,077.08

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If the results of energy consumption are converted into rupiah by using the electricity tariff for large industrial groups (I-4/TT) of IDR 996.74/kWh, the total cost of electricity using the POR method in 1 month of operation is IDR 552,007,477.63 and without POR in 1 month of operation is IDR 579,619,926.92.

- **Setting Current Limit 40%**

The current limit setting used is 40% and the ESP dust capture efficiency value compared to the voltage value when viewed in graphical form is:

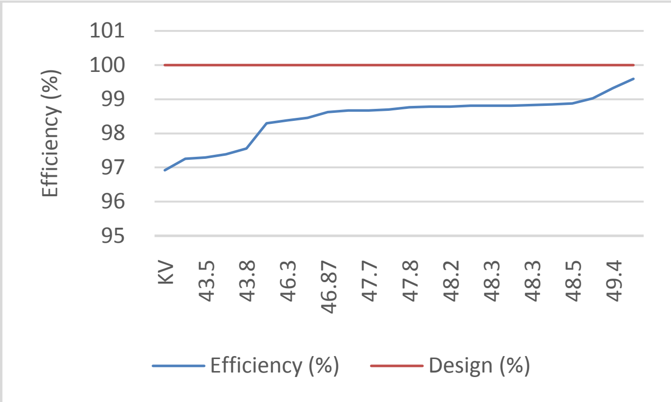

Figure 12: ESP Efficiency against voltage current limit 40%

Table 5: Setting current limit 40%

Side	Column	Volt 1 (V)	Current 1 (A)	POR (kWh)	Non POR (kWh)
A	11	515	90	25,425.76	26,697.60
	12	511	92	25,788.90	27,078.91
	13	514	91	25,658.35	26,941.82
	14	515	88	24,860.74	26,104.32
	21	514	81	22,838.75	23,981.18
	22	514	80	22,556.79	23,685.12
	23	511	88	24,667.65	25,901.57
	24	513	89	25,045.60	26,298.43
	31	518	87	24,721.40	25,958.02
	32	516	88	24,909.01	26,155.01
	33	515	86	24,295.72	25,511.04
	34	515	85	24,013.21	25,214.40
B	11	517	88	24,957.29	26,205.70
	12	517	87	24,673.68	25,907.90
	13	516	89	25,192.07	26,452.22
	14	516	91	25,758.18	27,046.66
	21	514	90	25,376.39	26,645.76
	22	514	87	24,530.51	25,757.57
	23	515	88	24,860.74	26,104.32
	24	511	86	24,107.02	25,312.90
	31	514	84	23,684.63	24,869.38
	32	516	88	24,909.01	26,155.01
	33	517	89	25,240.89	26,503.49
	34	518	90	25,573.87	26,853.12
Total kWh				593,646.1	623,341.4

If the results of energy consumption are converted into rupiah using the electricity tariff for large industrial groups (I-4/TT) of IDR 996.74/kWh, the total cost of electricity using the POR method in 1 month of operation is IDR 591,710,859.96 and without POR in 1 month of operation is IDR 621,309,346.91.

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3.2 Comparison of Energy Efficiency and Consumption Based on Current Settings and Operating Methods

After testing several current limit settings and operating methods, the efficiency and energy consumption values were obtained from each current limit setting of 20%, 30%, 35% and 40% as well as the operating method of power off rapping and without power off rapping.

Table 6: Comparison of energy efficiency and consumption based on current settings and operating methods

No	Current Limit (%)	Efficiency (%)	Non POR (kWh)	Energi POR (kWh)
1	20	95.98	277,695.94	264,466.81
2	30	98.05	455,077.08	433,397.71
3	35	98.46	581,515.67	553,812.91
4	40	98.56	623,341.44	593,646.15

On figure 13, comparison of energy efficiency and consumption based on current settings and operating methods is shown.

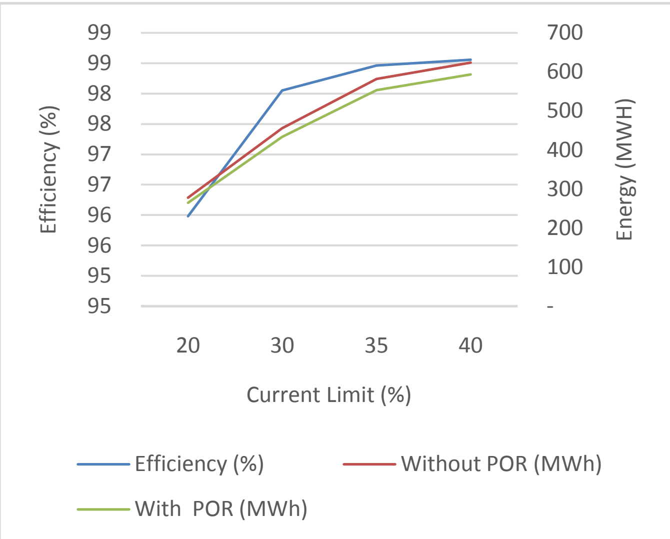

Figure 13: Comparison of energy efficiency and consumption based on current settings and operating methods

From the figure 13, it can be seen that the higher the current limit setting, the dust capture efficiency will also increase as well as the energy consumption used will also increase.

3.3 Calculation of ESP Inlet Dust Emissions

In this section a simulation of the value of dust emission at the ESP inlet will be carried out because there are no dust emission readings at the ESP inlet. The simulation is carried out with the ESP default setting, the current limit of 30% and dust emission readings in 1 working day with samples every 2 hours. On table 8 Emissions based on load is shown.

Table 7: Emissions based on load

Hours	Load (MW)	Dust (mg/m^3)
0:00	739	27.68
2:00	729	28.48
4:00	635	19.63
6:00	727	25.01
8:00	874	40.43
10:00	1012	52.5
12:00	972	53.24
14:00	1010	55.69
16:00	1014	51.86
18:00	935	43.38
20:00	944	44.57
22:00	889	34.2
0:00	783	28.95
Average		38.89

The average result of dust readings with samples every 2 hours is 38.89 mg/m^3 with the default ESP setting, the current limit of 30%. The current limit of 30% has a dust capture efficiency of 98.05%, knowing the efficiency and dust values at the default setting, the dust value on the inlet side can be determined by the following calculation:

$$Dust\ Inlet = \frac{100\%}{1.95\%}\ x\ Dust\ Outlet$$

$$= 1994\ mg/m^3 \quad (8)$$

From the calculation above it can be seen that the value of the dust inlet using the simulation is 1994 mg/m^3.

3.4 Determination of Optimal Flow Settings Based on Dust Emission Standards

After obtaining data from several tests of ESP current settings and from the value of dust emissions, it can be seen that the optimal current setting for dust emission standards in Indonesia is based on the standards set by the Ministry of Environment and Forestry Regulation No. 15 of 2019 the threshold limit for particulate exhaust gas at a coal power plant is 100 mg/Nm^3 [18].

If it is known, the current limit is 20% compared with 95.98%, then the calculation of the dust outlet is as follows:

$$Dust\ Outlet = (100 - Efficiency)\ x\ Dust\ Inlet$$

$$= 80.1588\ \text{mg/m}^3 \quad (9)$$

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From the calculation above, the data is then entered into the table 9, so that the following results are obtained:

Table 8: Setting current to the value of dust

No	Current Limit (%)	Efficiency (%)	non POR (kWh)	POR (kWh)	Dust (mg/m^3)
1	20	95.98	277,695.94	264,466.81	80.1588
2	30	98.05	455,077.08	433,397.71	38.883
3	35	98.46	581,515.67	553,812.91	30.7076
4	40	98.56	623,341.44	593,646.15	28.7136

On figure 14, setting the current to the value of dust is shown.

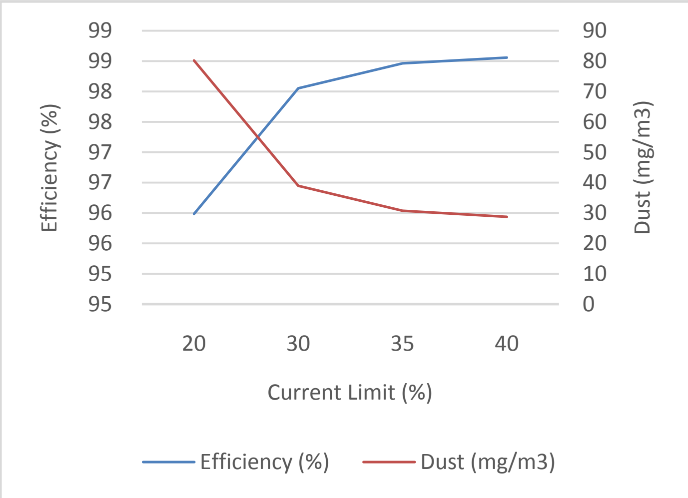

Figure 14: Comparison of energy efficiency and consumption based on current settings and operating methods

From the figure 14, it can be seen that the higher the current limit setting, the dust capture efficiency will increase and the dust value at the ESP outlet will decrease. Then it can be concluded that the current setting of 20% is the most optimal setting in accordance with Ministry of Environment and Forestry Regulation No. 15 of 2019 the threshold limit for particulate exhaust gases at coal fired power plants is 100 mg/Nm^3 where the dust reading value is 80.15 mg/m^3. Using a current setting of 20% can save energy consumption of 38.97% for the non-POR operating method and 41.88% for the POR operating method. If the difference in energy consumption is converted to rupiah by using the electricity tariff for large industrial groups (I-4/TT) of IDR 996.74/kWh, then the savings in electricity costs in 1 month of operation are IDR 176,802,877 with the no POR method and IDR 189,988,881 with the POR method.

IV. CONCLUSION

Based on the research results and analysis, several conclusions can be drawn, namely:

1) After calculating the default current setting of 30% in the electrostatic precipitator at PLTU Jawa 7 Unit 1, the particle migration speed is so that the dust capture efficiency is 98%.
2) After doing the calculations and analysis on the electrostatic precipitator current settings, where the current settings used are 20%, 30%, 35% and 40%. The efficiency value obtained at the current setting of 20% is 95.98%, the current setting is 30% which is 98%, the current setting is 35% which is 98.46%, the current setting is 40% which is 98.56%.
3) In the Power Off Rapping operation method and without Power Off Rapping, the value of energy consumption is obtained at a current setting of 20%, namely 264,466.81 kWh for POR and 277,695.94 kWh without POR, 30% current setting, namely 433,397.71 kWh for POR and 455,077.08 kWh without POR, setting 35% current is 553,812.91 kWh for POR and 581,515.67 without POR, 40% current setting is 593,646.15 kWh for POR and 623,341.44 without POR.
4) After getting the test results from the current setting simulation and the Power Off Rapping operating method, it can be concluded that the higher the current limit setting, the dust capture efficiency will increase and the dust value at the ESP outlet will decrease. Then it can be concluded that the current setting of 20% is the most optimal setting in accordance with Ministry of Environment and Forestry Regulation No. 15 of 2019 the threshold limit for particulate exhaust gases at coal fired power plants is 100 mg/Nm^3 where the dust reading value is 80.15 mg/m^3. By using a current setting of 20%, a savings of 38.97% can be made for the operating method without POR and 41.88% for the POR operating method. If the difference in energy consumption is converted to rupiah by using the electricity tariff for large industrial groups (I-4/TT) of IDR 996.74/kWh, then the savings in electricity costs in 1 month of operation are IDR 176,802,877 with the no POR method and IDR 189,988,881 with the POR method.

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