Energy saving of variable frequency drive in dust collector fan motors in the smelting process at the steel industry

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ABSTRACT

The dust removal system is a crucial component in the steel industry, designed to eliminate dust and gas generated during the smelting process. Its primary purpose is to prevent personnel in the surrounding area from inhaling harmful dust particles. A dust collector system is used to carry out this process before being removed from the chimney to the outside air. In the operation of the dust collector, there is still limited attention given to optimizing its operation to meet the needs of its load, where the dust collector still operates at maximum capacity continuously when the dust load decreases due to the smelting process, in an idle state. Setting the rotational speed of the fan motor to produce an airflow rate as required using a variable frequency drive (VFD). The Motor speed was varied in low and high conditions at 322 rpm and 879 rpm. The research results showed that the average airflow rate for the speed of 322 rpm was 150,326 m³/h, and it has 384.193 m³/h at the speed of 879 rpm. The energy savings obtained from the application of VFD to control the airflow rate value are 1,253,544 kWh/year, and the cost savings obtained are IDR 1,249,457,447 per year.

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1. INTRODUCTION

Dust pollution problems in the steel industry are the main source of air pollution emissions [1]. The main source of emissions is about 70% of the amount of dust generated from the smelting process, and the rest is generated from the steel forming and finishing process [2]. The pollution problem in the steel industry is of particular concern, so that the equipment used to capture dust is operated every time [3], [4]. However, one of the energy-consuming equipment in the smelting process is a dust collector system [5]–[7]. The dust collector in the steel industry is made of the electrical machine, and it always operates at maximum electrical energy consumption [8]. Many industries do not pay attention to their actual load requirements, so that the equipment works at maximum capacity without regard to varying load operating conditions [9], [10].

From the previous literature, energy-saving dust collector systems in industry are related to management systems, technology, and policies. In terms of technology, energy efficiency can be obtained through the use of high-efficiency motors [11] and variable frequency drives (VFDs) [12]–[14]. A VFD is a power electronic device used to control the rotational speed of an electric motor by controlling the frequency of the electrical power supplied to the electric motor. The device consists of a rectifier, an inverter, and control circuit components [15]. The output of the inverter is in the form of AC voltage and is grouped into three waveforms, namely square-wave, pulse width modulation (PWM) and sinusoidal. While the microcontroller is used to regulate the rotational speed of the induction motor, where the microcontroller regulates the output voltage and frequency to control the rotational speed of the induction motor [16], [17]. VFDs provide several advantages, the most significant of which is that they reduce the energy consumption and demand of electric motor-driven processes with high efficiency values even when the electric motor is operating at low capacity [18].

In research [10] did not calculate the airflow rate requirement based on static pressure conditions that occur in the dust collector system but only based on the minimum airflow rate requirement, while in research [13] did not take measurements in data collection, the estimate was only obtained from a formula where reducing motor speed by 10% would reduce power consumption by 27% [13], [14].

This research investigated the energy-saving analysis of a single unit of a dust collector fan motor utilized in an electric arc furnace (EAF) refining process within the steel industry. The motor has a power capacity of 1,100 kW. The VFD control system is proposed to be implemented by considering high and low load static pressure conditions. The high condition occurs during the maximum load when the melting process is active with 50 Hz controlled frequency from VFD. On the other hand, the low condition occurs during the minimum load, when the melting process is idle with 15 Hz set by VFD. The energy savings in this study are analyzed by a comparison of the real power consumption before and after the implementation of VFD, using actual measurements as the basis.

2. METHOD

Dust collectors remove and filter dust, gas, and smoke from smelting in the steel industry, ensuring that the air exiting the smelting chimney is safe for workers and the surrounding community [8], [19]. The dust collector operates continuously without interruption, whereas the smelting process operates on-idle, with the smelting furnace pouring smelted products into the ladle furnace to improve the metal structure content and replenish scrap into the smelting furnace [20]. A dust collector uses a motor fan to extract dust, gas, and smoke from the smelting process, which is then distributed to the chimney via a bag filter [21], [22].

Feeding air supply to the existing dust collector system during the smelting process idle is higher than the needs, so it is necessary to reduce the airflow rate by lowering the rotational speed of the electric motor fan using a VFD [23], [24]. In a fan motor characteristics, the airflow rate is directly proportional to the rotational speed of the fan motor, the pressure is proportional to the square of the rotational speed of the fan motor, and the power consumption is proportional to the third power of the rotational speed of the fan motor. Those relationships above are stated in (1), (2), and (3) subsequently [18], [25].

$$\frac{Q_2}{Q_1} = \frac{N_2}{N_1} \tag{1}$$

$$\frac{p_2}{p_1} = \left(\frac{Q_2}{Q_1}\right)^2 \tag{2}$$

$$\frac{P_2}{P_1} = \left(\frac{N_2}{N_1}\right)^3 \tag{3}$$

Where P_1 = power at high level, P_2 = power at low level, p_1 = static pressure at high level, p_2 = static pressure at low level, N_1 = motor speed at high level, N_2 = motor speed low level, Q_1 = airflow rate high level, and Q_2 = airflow rate low level.

The recording primary data from the dust collector fan motor. Data for electrical parameters, airflow rate, and static pressure were recorded simultaneously at for several days, before and after the installation of the VFD. Figure 1 shows a dust collector system with VFD to control the rotational speed of the fan motor according to the smelting conditions. In Figure 1, shows the process of withdrawing dust from the smelting process in the electric arc furnace through ducting using a fan motor installed after the baghouse filter which functions to filter the dust before it is discharged into the atmosphere. For electrical data collection, a power logger Hioki 3360-21 measuring instrument was installed on the 3.3 kV main panel with measurement time before and after VFD installation in a few days. While taking airflow rate data is taken at the distributed control system (DCS) with a sensor installed at the point of entry air before the bag filter as well as static pressure data with sensors installed in the incoming air and outgoing air from the bag filter. The detailed specification data of the motor fan dust collector and VFD is shown in Tables 1 and 2.

To find out the motor speed or speed reference that produces the required airflow rate can use (1), and to have the desired motor fan speed, is used (4) [26], [27].

$$Frequency\ reference = \frac{Speed\ reference}{P} \times 120 \quad (4)$$

Where the frequency reference is the frequency value needed to get the desired motor speed with a total of 6 poles as shown in Table 1. Reduced motor speed because of the VFD equipped with a static pressure sensor will automatically sense changes in pressure and will adjust the motor speed to return to the optimal airflow rate system. From previous research in [13] a decrease in motor speed will result in a decrease in power consumption. The following calculation can be used to calculate the annual energy consumption of a motor fan that does not use a VFD with data generated from measurement results before a VFD is installed.

$$AEC_1 = M_{AE}\ x\ OPH \quad (5)$$

Where AEC_1 = annual energy consumption without VFD, M_{AE} = motor fan's energy consumption average without VFD, and $OPH =$ operating hours in year.

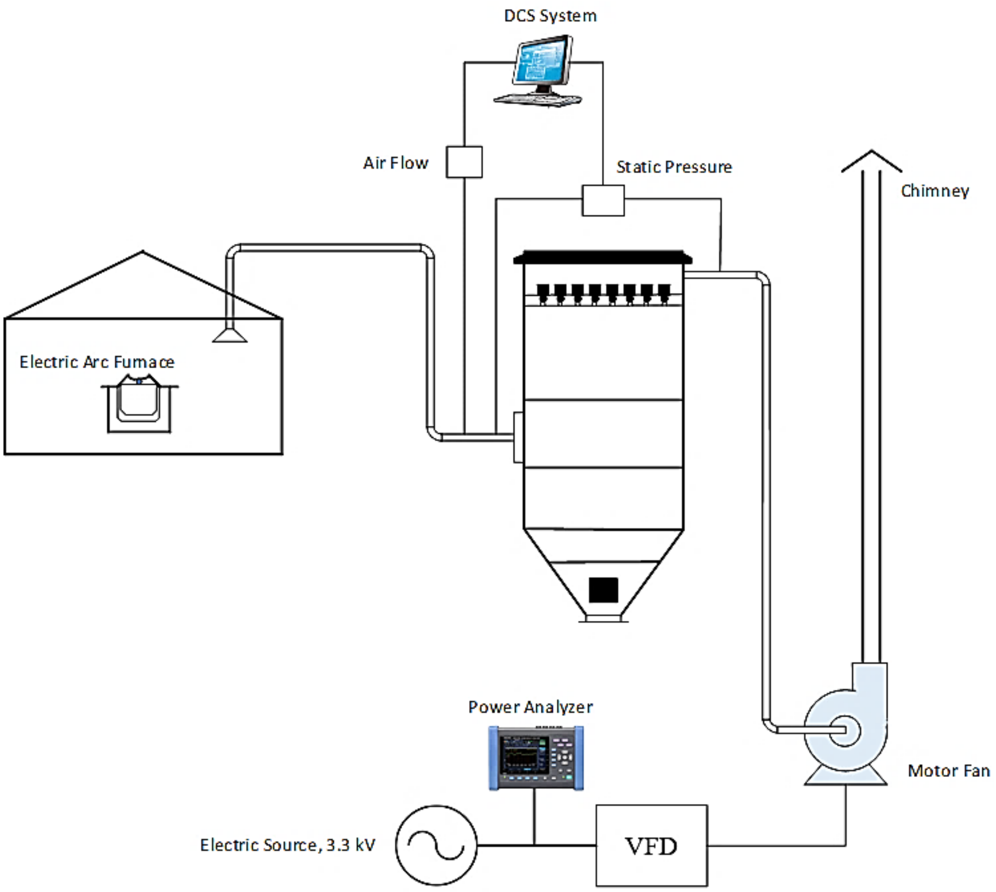

Figure 1. Dust collector system with VFD and measurement points

Table 1. Dust collector fan motor specifications

Parameters	Specification
Rpm	985
Power	1,100 kW
Voltage	3,300 Volt
Ampere	235 A
Freq	50 Hz
Pole	6
Flow rate	620,000 m³/h

Table 2. VFD Specification

Parameters	Specification
Nominal capacity	1,500 kVA/1,250 kW
Rated output	3 Phase, 3,300 V, 260 A
Power supply	Main circuit 3,300 V 50 Hz, -20% to -10%
Control circuit	1 phase 200/220 V, 50/60 Hz
Protection	IP 40
Panel dimension	3,500 W;1,200 D;2,550 H
Approx. weight	4,800 kg

The annual energy consumption when using VFD is obtained from measurement data and can be calculated with (6).

$$AEC_{VSD} = M_{AE1} \, x \, OPH \tag{6}$$

Where AEC_{VSD} = annual energy consumption with VFD, M_{AE1} = motor fan's energy consumption average with VFD, and $OPH =$ operating hours in a year. Energy savings obtained is the difference between the energy usage after the installation of the VFD minus the energy usage before the VFD is installed, as shown in (7) [25], [28], [29].

$$AES = AEC_1 - AEC_{VSD} \tag{7}$$

Where AES = annual energy saving, AEC_1 = annual energy before VFD, and AE_{VSD} = annual energy after VFD.

3. RESULTS AND DISCUSSION

3.1. Initial measurement data

Initial measurement data is carried out before the installation of the VFD, as shown in Table 3. Table 3 shows there are 11 cycles in one period of the smelting process and in one cycle there are two conditions, namely "on and idle", where the "on" is the condition of the smelting process and the "idle" condition is the process of pouring the smelted results and retrieving raw materials for the next smelting cycle. The measurement data shows that the static pressure value decreases during the smelting conditions is idle, but the airflow rate still flows in large quantities as well as the power consumption of the dust collector fan motor, which is the highest value of static pressure at idle is 0.28 kPa and the highest value static pressure at the melting process on is 1.63 kPa.

The data in Table 3 shows that there are two operating conditions in the smelting process, so the motor fan dust collector will be adjusted according to the conditions of the smelting process, namely high conditions when smelting work and low conditions when the smelting process stop/idle. The high-speed motor fan condition is selected when the smelting condition is operating because of the large amount of dust and gas due to the smelting process, which requires the motor fan to operate under maximum conditions. When the low-speed motor fan condition is selected as the smelter stops operating, there are still remnants of dust from the smelter that must be disposed of, so that the fan motor continues to operate at a low speed.

3.2. Calculation

From the measurement results, the data in Table 3 is the average data from each smelting process condition. In Table 3, it shows that when the static pressure is low, the motor fan will produce a higher airflow rate than needed, so that it will consume unnecessary energy and cause air to hit the filter at high velocity so that it can reduce the filter life lifetime.

The target is to reduce the airflow rate in accordance with the static pressure conditions for low level, to calculate the airflow rate in accordance with the static pressure conditions where from the initial measurement results, the lowest static pressure value is at cycle 10 of 0.16 kPa, the (2) and data from Table 3 is used.

$$Q_2{}^2 = 379{,}008^2 \times \frac{0.16\,kPa}{1.46\,kPa}$$
$$Q_2 = 125{,}468\,m^3/h$$

The calculation of the required motor speed to generate an airflow rate in accordance with low-level conditions can be determined based on (1) and the data provided in Table 3.

$$N_2 = 842 \times \frac{125{,}468\,m^3/h}{379{,}008\,m^3/h}$$

$$N_2 = 279\,rpm$$

To calculate the power consumed as the motor speed with VFD decreased, in (3) and data in Table 3 are used.

$$P_2 = 882\,kW \times \left(\frac{279\,rpm}{842\,rpm}\right)^3$$

P_2 = 32.1 kW

From the results of these calculations, it is concluded to set the VFD with two speed conditions, where in the low condition the VFD is set with a frequency reference of 15 Hz resulting in a motor rotation of 279 rpm and an airflow rate of 125.468 m³/h and its power consumption becomes 32 kW. While in the high condition, the VFD is set with a frequency of 50 Hz, or the fan motor works at full speed, which results in a motor speed of 842 rpm with an airflow rate of 379.008 m³/h and a power consumption of 882 kW, as found in Table 4.

With the two conditions of setting the rotational speed of the fan motor on the VFD, namely low and high, where when the VFD condition is low, the motor speed is at 279 rpm, and when the VFD condition is high, the motor speed is at 842 rpm or full speed. This motor speed is based on the results of the above calculations using the affinity law to produce the required airflow rate based on the static pressure conditions that occur in the dust collector system.

Table 3. Measurement results of each smelting cycle on the dust collector fan motor before the use of VFD

Cycle	Smelting process	Static pressure (kPa)	Airflow rate (m³/h)	Power (kW)	Speed (rpm)
Cycle1	On	1.60	401,308	847.4	969
	Idle	0.19	436,155	821.2	892
Cycle2	On	1.58	408,387	852.6	962
	Idle	0.20	433,095	827.3	907
Cycle3	On	1.63	398,191	856.8	978
	Idle	0.18	440,219	804.3	885
Cycle4	On	1.53	394,613	846.9	947
	Idle	0.17	426,345	790.9	877
Cycle5	On	1.51	391,966	845.8	941
	Idle	0.17	423,449	809.2	871
Cycle6	On	1.59	390,440	872.6	965
	Idle	0.17	434,204	828.7	867
Cycle7	On	1.55	395,442	853.2	954
	Idle	0.18	429,542	807.9	879
Cycle8	On	1.44	377,497	869.9	920
	Idle	0.16	413,945	817.3	839
Cycle9	On	1.63	395,445	866.4	978
	Idle	0.17	440,208	814.3	879
Cycle10	On	1.46	379,008	882	926
	Idle	0.16	416,852	795.4	842
Cycle11	On	1.43	378,181	845.6	914
	Idle	0.16	411,470	796.3	840

Table 4. Calculation results of changes in airflow rate, motor speed, and power with the affinity law

No	VFD level	Set point (%)	Frequency reference (Hz)	Speed reference (rpm)	Airflow rate (m³/h)	Power (kW)
1	Low	0	15	279	125,468	32
2	High	100	50	842	379,008	882

3.3. Measurement data VFD

The data in Table 4 is used as the frequency input that supplies the fan motor for high and low speed conditions. The measurement results after VFD installation can be seen in Table 5. Table 5 shows measurement data with a low frequency input of 15 Hz and a high frequency of 50 Hz, the average power during low (idle) conditions is 41.2 kW and the average power during high (on) conditions is 756.3 kW, the average motor speed during low conditions is 353 rpm and the average motor speed during high conditions is 937 rpm and airflow during low conditions is 158,446 m^3/h and airflow during high conditions is 421,523 m^3/h. The differences in the static pressure and airflow graphs before and after installation of the VFD are shown in Figures 2 and 3.

Figure 2 shows the static pressure and airflow of the smelting process, where it can be seen before the installation of the VFD. Static pressure has decreased by an average of 0.16 kPa every time the smelting process stops. This is because the amount of dust and gas produced is reduced, and there is a pulse jet cleaning operation on the bag filter every time the smelting process stops, as previously conducted research [30]. It can also be seen that the airflow tends to increase at an average rate of 427,771 m³/h when the smelting process stops because the static pressure decreases, whereas when static pressure conditions are reduced, airflow requirements should also be reduced because there is no dust and gas generated when the smelting process stops. The desired condition is that the airflow rate decreases when the static pressure value decreases, because the amount of dust and gas decreases as the smelting process stops, so that the power consumption of the fan motor can be reduced.

Table 5. Measurement results of each smelting cycle on the dust collector fan motor after installing the VFD

Cycle	Smelting process	Static pressure (kPa)	Airflow rate (m³/h)	Power (kW)	Speed (rpm)
Cycle1	On	1.53	426,189	783.0	947
	Idle	0.20	153,703	36.8	342
Cycle2	On	1.53	426,107	779.3	947
	Idle	0.21	157,404	39.5	350
Cycle3	On	1.50	422,017	758.9	942
	Idle	0.24	168,460	50.3	381
Cycle4	On	1.49	421,150	752.9	940
	Idle	0.23	162,868	45.5	369
Cycle5	On	1.48	419,249	744.3	931
	Idle	0.19	150,941	34.5	334
Cycle6	On	1.54	427,097	784.5	948
	Idle	0.30	186,129	67.4	418
Cycle7	On	1.46	415,578	726.8	923
	Idle	0.20	153,875	36.6	341
Cycle8	On	1.51	423,543	768.5	941
	Idle	0.20	152,421	35.5	338
Cycle9	On	1.46	416,560	730.2	926
	Idle	0.20	152,781	36.0	340
Cycle10	On	1.48	419,560	744.9	931
	Idle	0.20	153,923	37.0	342
Cycle11	On	1.48	419,700	745.5	931
	Idle	0.19	150,401	34.1	333

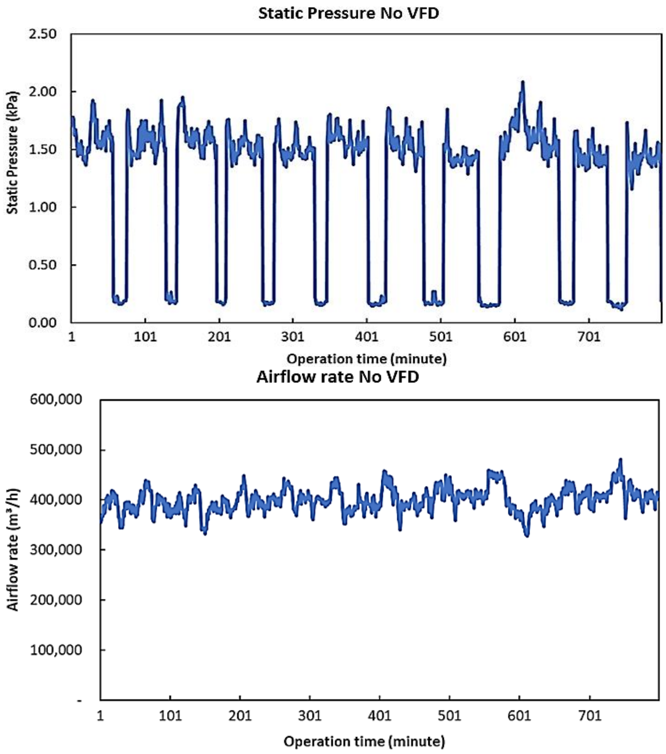

Figure 2. Static pressure and airflow rate of the dust collector system before the installation of VFD

After the installation of the VFD, as can be seen in Figure 3, the decreased motor fan speed with the VFD when the smelting process stopped resulted in the airflow rate being reduced to an average of 150,326 m³/h. This value is higher than the calculated airflow rate value of 124,195 m³/h in Table 4. The result of the decrease in airflow rate with VFD control, which is still above the calculated airflow rate value, shows that the airflow rate is still sufficient to overcome if there is still dust and gas remaining in the dust collector.

The result of reducing the airflow rate through changing the motor speed with VFD control results in a decrease in power consumption, as shown in Figure 4. This proves the literature review of previous research conducted in the wood industry [13] and simulation research on the use of VFDs [28]. At low-level conditions without VFD, the average power consumption is 764.5 kW. After reducing the motor speed using VFD, the power consumption decreases to 34.4 kW in another word there is a reduction of 730.1 kW. This measurement result is slightly greater in amount of 31 kV than the calculation result by using the equation of the affinity law shown in Table 4.

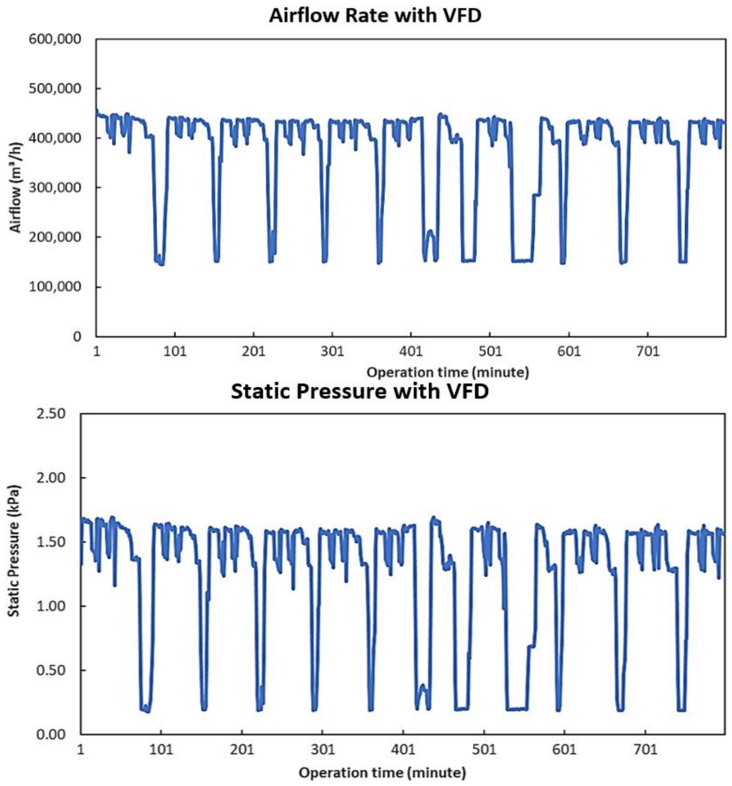

Figure 3. Static pressure and airflow rate of the dust collector system after installation of VFD

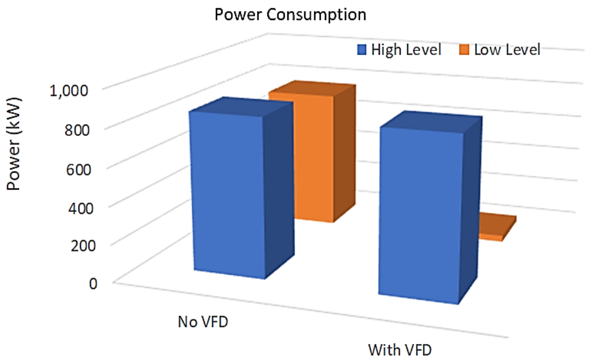

Figure 4. Power consumption of the motor fan dust collector before and after installation VFD

The energy savings obtained from installing a VFD on the dust collector fan motor, calculated by (5)-(7), with the number of operating hours for one year is 5,760 hours, the energy savings obtained are:

$$AES = AEC_1 - AEC_{VSD}$$
$$= 4{,}401{,}860 - 3{,}148{,}316$$
$$= 1{,}253{,}544\ kWh/year$$

$$Cost\ Saving = 1{,}253{,}544\ kWh \times \text{IDR } 996.74$$
$$= \text{IDR } 1{,}249{,}457{,}447$$

In Table 6, changes in energy consumption also occur as power consumption decreases after the installation of the VFD [31]. The energy savings obtained from using VFD control on the dust collector fan motor is 1,253,544 kWh / year or in a percentage of 28.5%. Financially, the cost saving is IDR 1,249,457,447. A summary of the overall research data results is shown in Table 6.

Table 6. Summary of research data results

No	Parameter	Before installing VFD		After installing VFD		Saving opportunity
		High level*	Low level*	High level	Low level	
1	Running hour	5,760		5,760		
2	Airflow rate (m³/h)	391,862	427,771	384,193	150,326	
3	Frequency (Hz)	50	50	50	14	
4	Speed motor (rpm)	871	950	879	322	
5	Average power (kW)	851.2	764.5	849	34.4	
6	Energy consumption (kWh/Year)	4,401,860		3,148,316		1,253,544
7	Electrical cost/kWh (IDR)	996.74		996.74		
8	Total operation cost (IDR/Year)	4,387,509,936		3,138,052,490		1,249,457,447

*High level = Smelting process is on
*Low level = Smelting process is idle

4. CONCLUSION

This study investigates the performance comparison of dust collector fan motors in a steel company with VFD and without VFD. Measurements have been conducted on the airflow rate, static pressure, power consumption, and energy consumption of the dust collector fan. Electrical measurements were also taken to see the power quality as a effect of the VFD installation that can be further researched. The research results showed that the average airflow rate for the speed of 322 rpm was 150,326 m³/h, and it was 384,193 m³/h at the speed of 879 rpm.

The energy consumption of the dust collector fan motor for one year before the use of VFD was 4,401,860 kWh/year, while after the VFD was installed, the energy consumption was 3,148,316 kWh/year. The comparison of the power consumption for the use of VFD and non-VFD shows that that the dust collection fan motor saves 1,253,544 kWh of energy per year, and the cost savings obtained are Rp. 1,249,457,447/year. As the energy savings is multiplied by the greenhouse gas emission factor in Indonesia i.e., 0.819 tCO_2/MWh, then the reduction in Greenhouse gas emissions equals 1,026 tCO_2.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration. All authors contributed to the conception, design, and finalization of the work. The detail contribution of research work and manuscript is shown in the table.

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Cahyadi	✓		✓	✓			✓			✓	✓		✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest and no competing financial interests. The manuscript was independently submitted to blind system review.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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