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Analysis of the effect of using a variable speed drive on the power consumption of the ID fan drive motor

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Abstract. Cirebon Coal-Fired Power Plant Unit 1 uses an Induced Draft Fan (ID Fan) to regulate flue gas flow and maintain negative pressure inside the boiler. The current ID Fan control system still applies a blade pitch position mechanism with constant motor speed, resulting in high power consumption ranging from 2,547.9 kW to 4,311.2 kW. This condition is inefficient because the motor runs at constant speed regardless of changing load demands. This study aims to design a Variable Speed Drive (VSD) to control the ID Fan motor speed and analyze its impact on power consumption. The research was conducted using simulation with MATLAB/Simulink R2021a software. The VSD design consists of three main components: a three-phase rectifier, a buck converter-based DC link, and a three-phase PWM inverter, adjusted to meet the ID Fan operational pressure limit of 8.0 to 10.0 kPa. The simulation results show that with the implementation of VSD, the system pressure can be maintained within the safe range of 8.5 to 9.7 kPa, and the motor speed can be adjusted according to airflow demand. Power consumption decreased from 2,645.7 kW to 1,273.1 kW after implementing VSD, resulting in an energy saving of 62.1%. The application of VSD is proven to be effective in improving energy efficiency in the ID Fan system at the Cirebon Coal-Fired Power Plant Unit.

1 Introduction

Cirebon Steam Power Plant Unit 1 is a power plant operating with a capacity of 1 × 660 MW using coal as fuel. In the combustion system, the exhaust gas produced must be pressure controlled to ensure optimal combustion. One of the main tools used to maintain negative pressure in the boiler is the Induced Draft Fan (ID Fan). The ID Fan functions to suck exhaust gas from the boiler to the chimney. The current ID Fan control system still uses the blade pitch position method with a constant motor speed. Although the blade pitch position setting varies between 50.1% to 90.4% to adjust the air flow rate between 741.3 to 1,143.5 tons/hour,

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the motor speed remains in the range of 996.0–999.0 rpm. This causes motor power consumption to remain high, namely between 2,547.9 kW to 4,311.2 kW, making the system inefficient because the motor speed does not follow the current load requirements.

Therefore, a Variable Speed Drive (VSD) is needed to regulate the motor rotation speed based on the workload, thereby reducing electricity consumption [1]. Studies show that the use of VSD is more efficient compared to conventional contactor systems because it is able to dynamically adjust power requirements [2]. The implementation of an inverter as an induction motor driver can also reduce energy loss during the power conversion process [3]. Other analysis results show that the use of VSD on three-phase motors can reduce the average input power by up to 23.9% compared to conventional systems [4]. The addition of an inverter as a motor frequency and voltage regulator has a significant impact on saving electrical energy in variable load applications [5, 6]. In addition, regulating the rotational speed of the motor using a VSD has been proven to provide higher operational efficiency, especially in pump and fan systems [7, 8]. The research at PT Lestari Alam Segar shows that the use of VSD can save energy of 6,152.6 kWh per month [9]. Another study on the boiler fan system in a steam power plant showed that the use of VSDs succeeded in reducing energy consumption by up to 32.1% [10-11] leading to significantly higher efficiency compared to operation without VSD [12, 13]. In addition to energy savings, controlling motor loads with VSDs also extends the operational life of equipment and reduces maintenance costs [10].

Other research also states that the use of VSD has been proven to be able to reduce electrical power consumption in induction motor systems by adjusting the motor rotation speed to the workload [12]. Studies show that the use of VSD is more efficient compared to conventional systems because it is able to regulate the power and speed of the motor according to needs [13]. The use of a VSD allows linear control of motor speed with respect to frequency changes, which provides operational flexibility under varying loads [14, 15]. The results in [16] show that the motor with VSD is able to work efficiently at a speed of 1,434.0–1,496.0 rpm with a frequency adjustment of 25.6–26.6 Hz. The implementation of an inverter in a VSD system has been proven to reduce the motor's starting current and minimize load surges during starting [15]. VSD plays an important role in adjusting the fan speed to the exhaust gas flow rate to avoid energy waste [16]. The use of VSD in the flour industry has been proven to be able to reduce the electricity consumption ratio from 19.1 kWh/ton to 17.2 kWh/ton [17]. Comparative analysis shows that VSD-based drive systems produce lower CO_2 emissions than fixed-speed systems [16]. Motor speed controls with VSD has also shown to improve system efficiency and reduce excessive motor winding current [18, 19].

This study aims to design a VSD for the ID Fan motor at the Cirebon Steam Power Plant Unit 1 and analyze its effect on electrical power consumption. The VSD is designed to regulate the motor speed based on the required air flow rate. This design is expected to produce a more efficient system, with lower power consumption compared to conventional blade pitch position-based systems. The results of this study are expected to be a reference in the development of a high-power ID Fan motor drive system in a steam power plant unit.

2 Overview of VSD

A VSD is an electronic device used to control the speed and torque of an electric motor, particularly an induction motor, by changing the frequency and voltage of the power supplying the motor [15]. The basic structure of a VSD is shown in Figure 1.

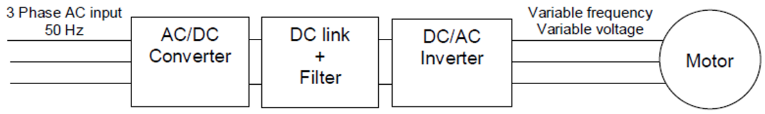

Fig. 1. Basic structure of a VSD.

The VSD system begins with a three-phase AC power/energy source supplying the rectifier unit to be converted into DC power/energy. The DC energy is then stored and stabilized in the DC link, which consists of capacitors and/or inductors. The inverter then converts the DC voltage back into AC with a controllable frequency using modulation techniques such as Pulse Width Modulation (PWM), allowing motor speed to be adjusted as needed. With this configuration, the VSD can improve energy efficiency and extend the lifespan of electrical equipment.

3 Method

3.1 Research flowchart

This research has several stages as shown in flowchart of Figure 2 below.

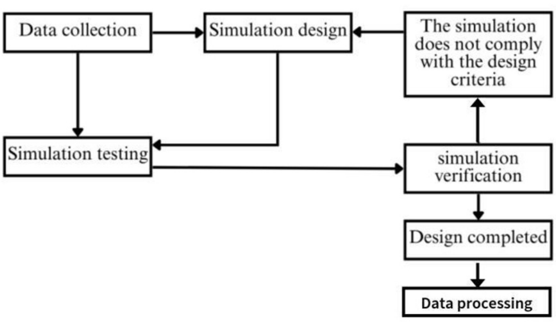

Fig. 2. Research flowchart.

This research begins with data collection in the form of existing data and specifications of the ID Fan drive motor. After the data collection, the research will continue with simulation design using Matlab/Simulink software, where two simulation models will be created, namely the ID Fan system without VSD and with VSD. After carrying out the simulation design, the simulation testing is carried out by taking data from the simulations. The simulation results will be verified to see whether they are in accordance with the expectation. If the simulation results do not match, the simulation model will be redesigned; for the simulation results that are in accordance with the expectation, the data processing can be carried out.

3.2 Data collections

There are several data needed to design the simulation models of the ID Fan system without and with VSD. The required data are in the form of motor specifications and existing ID Fan system data as shown by Table 1 below. Using data in Table 1, simulation models accurately represent the ID Fan system without VSD (the existing ID Fan system) and ID Fan system with VSD (the proposed ID Fan system to replace the existing one) are developed.

Table 1. Data for simulation design.

Parameters	Value	Unit
Rated output power	4,800.0	kW
Rated voltage	11,000.0	V
Current	298.2	A
Power factor	0.88	-
Frequency	50.0	Hz
Nominal speed	993.0	rpm
Air flow rate	741.3 – 1,143.5	ton/hr
Blade pitch position	50.1 – 90.4	%

3.3 Simulation design

In this stage, two simulations models are designed. The first model is the ID Fan system without VSD, while the second model is the ID Fan system with VSD. For the ID Fan system without VSD, a blade pitch position is set from 10.0%–100.0%, with reference to existing data of the air flow rate around 741.3–1,143.5 tons/hr. Figure 3 shows the ID Fan system model without VSD.

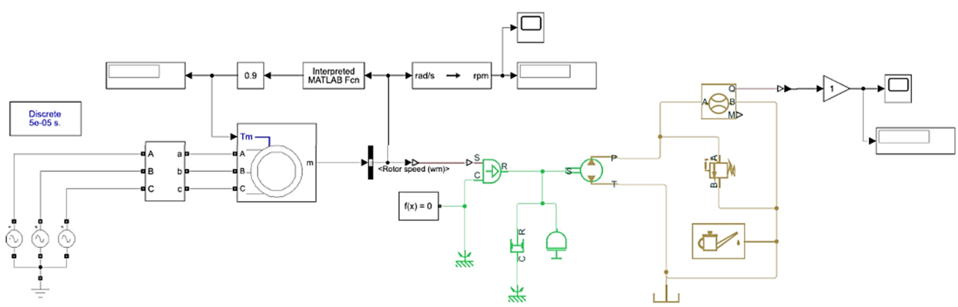

Fig. 3. Simulation circuit of the ID Fan system without VSD.

The next circuit is the ID Fan system model with VSD as shown in Figure 4. In this model, there are three main components, namely a three-phase full bridge rectifier, a buck converter, and a three-phase PWM inverter. The reference used to adjust the ID Fan system circuit with VSD is the similarity of the air flow rate value of the ID Fan system circuit without VSD, which is around 741.3 tons/hr. This value is the nominal value according to the existing data at a blade pitch position setting of 50% and a frequency of 25 Hz.

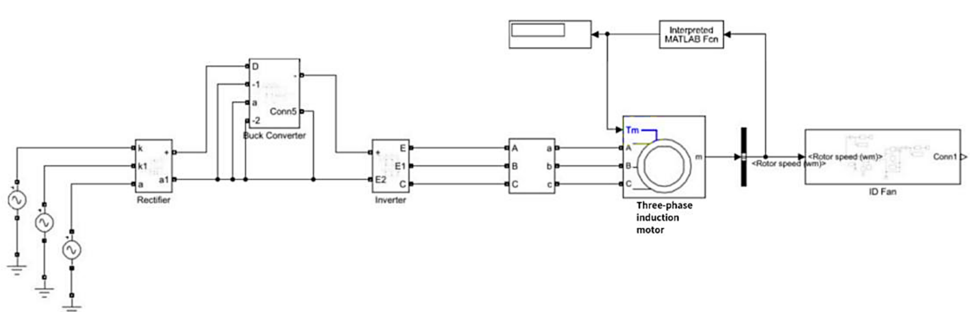

Fig. 4. Simulation circuit of the ID Fan system with VSD.

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3.4 Data processing

The data collected from the simulation series in this study includes air flow rate, current, voltage, and motor rotation speed, which will be used to determine electrical power consumption. To determine electrical power consumption, equation (1) will be used.

$$P_{input} = \sqrt{3} \times V \times I \times \cos \varphi \quad (1)$$

where: P_{input} is the electrical input power of the motor (kW), V is the terminal voltage of the motor (V), I is the input current of the motor (A) and cosφ is the power factor of the motor

4 Results and discussion

The simulation results of the two models are presented in Tables 2 and 3. Table 2 shows the results of the system without VSD, while Table 3 shows the results of the system with VSD.

Table 2. Simulation result data of the ID Fan system without VSD.

Blade Pitch Position (%)	Air Flow Rate (Ton/hr)	Current (Ampere)	Voltage (Volt)
10.0	333.1	76.2	11,000.0
20.0	466.1	89.3	11,000.0
30.0	582,3	107.7	11,000.0
40.0	665.0	129.1	11,000.0
50.0	742.7	152.5	11,000.0
60.0	863.5	177.1	11,000.0
70.0	984.0	202.6	11,000.0
80.0	1,078.0	228.8	11,000.0
90.0	1,145.0	255.8	11,000.0

Table 3. Simulation result data of the ID Fan system with VSD.

Frequency (Hz)	Air Flow Rate (Ton/hr)	Current (Ampere)	Voltage (Volt)
5.0	335.0	66.9	523.8
10.0	465.6	69.8	970.9
15.0	580.7	87.6	2,266.7
20.0	663.9	105.2	3,173.0
25.0	746.2	124.2	4,355.7
30.0	880.6	136.3	5,852.7
35.0	995.2	169.9	7,310.0
40.0	1,078.0	211.7	8,608.0
45.0	1,152.0	253.9	9,761.0

After obtaining the simulation results, the next step was to compare power consumption of the system without and with VSD at the same air flow rate. The comparison of power consumption shows a significant reduction in power consumption of 62.1% of the system with VSD compared to the system without VSD. The variable speed drives can regulate the motor rotation speed based on the air flow rate required by the ID Fan, so that the resulting voltage changes following the changes in motor rotation speed [19]. Table 4 shows the comparison of power consumption of the two systems.

Table 4. Comparison of power consumption of the ID Fan system without and with VSD.

Power consumption without VSD (kW)	Power consumption with VSD (kW)	Reduced power consumption (%)
1,277.8	53.4	95.8
1,497.1	103.3	93.1
1,805.7	302.5	83.2
2,164.5	508.8	76.5
2,556.9	824.8	67.7
2,969.3	1,215.6	59.1
3,396.8	1,893.0	44.3
3,836.1	2,777.6	27.6
4,288.8	3,777.9	11.9
Average: 2,643.7	Average: 1,273.1	Average: 62.1

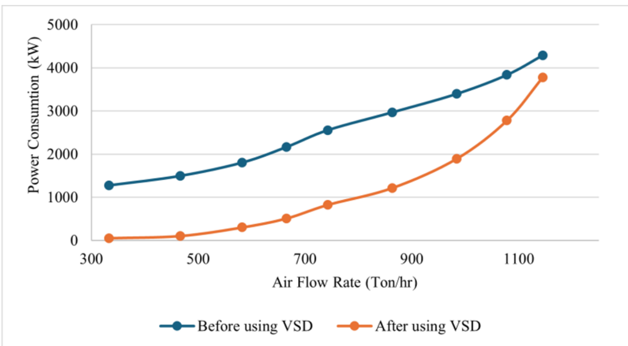

Fig. 5. Power consumption comparison chart.

The comparison of electrical power consumption in Figure 5 shows that electrical power consumption of the system without VSD is significantly higher than the system with VSD. The average electrical power consumption of the system without VSD is 2,643.7 kW, while it is only 1,273.1 kW for the system with VSD, which is more than 50% saving. This proves that the ID Fan system with VSD can reduce power consumption with the same air flow rate [16].

Further analysis shows that the lower the percentage of blade pitch position the higher saving of electrical power consumption. For 10.0% - 50.0% of blade pitch position of the ID Fan system without VSD, the saving of electrical power consumption is around 95.8% - 67.7% when the ID Fan system with VSD is used. Meanwhile, for 60.0% - 90.0% of blade pitch position of the ID Fan system without VSD, the saving of electrical power consumption drops to only 59.1% - 11.9% when the ID Fan system with VSD is used. Because the existing ID Fan system of the Cirebon Steam Power Plant Unit 1 is frequently operated at 40% - 70% of blade pitch position then significant saving of electrical power consumption from 83.2% to 44.3% will be obtained if the ID Fan system is changed to ID Fan system with VSD.

5 Conclusion

This research successfully designed and simulated the application of Variable Speed Drive (VSD) on the ID Fan drive motor in Cirebon PLTU to reduce electrical power consumption and increase system efficiency. The simulation results show that the ID Fan system with VSD can regulate the motor speed according to the required air flow rate. The average power consumption of the system without VSD was 2,643.7 kW, while it decreased to 1,273.1 kW after the VSD is installed, resulting in energy savings of 62.1%. These results prove that the application of VSD is effective in increasing energy efficiency in the electrical system in the steam power plant.

References

1. A. Atmam, A. Tanjung, Zulfahri, Analysis of energy usage of an induction motor (in Bahasa). *J. Sain. Energi Teknol. Ind.* **2**, 52–59 (2018).
2. M. Prasta Mahrifatika, I. A. Darmawan, Comparison of energy consumption of a three-phase induction motor between contactor and variable speed drive (inverter) on a circular loom machine at PT. Murni Mapan Mandiri (in Bahasa). *J. Sains Teknol. (SAINTEK)* **1**, 35–46 (2022). https://doi.org/10.58169/saintek.v1i2.75
3. I. Kusuma, Application of VSD inverter in energy conversion efficiency (in Bahasa). *Sainstech J. Penelit. Pengkaj. Sains Teknol.* **26**, 25–32 (2020). https://doi.org/10.37277/stch.v26i2.507
4. D. F. de Souza, F. A. M. alotti, I. L. Sauer, H. Tatizawa, A. T. de Almeida, A. G. Kanashiro, A performance evaluation of three-phase induction electric motors between 1945 and 2020. *Energies* **15**, (2022). https://doi.org/10.3390/en15062002
5. I. P. A. Putra Novantara, I. W. A. Wijaya, I. M. Suartika, Analysis of three-phase induction motor speed control by adjusting frequency using variable speed drive at PT PDAM Tirta Mangutama, Badung Regency (in Bahasa). *J. SPEKTRUM* **8**, 103 (2022). https://doi.org/10.24843/spektrum.2021.v08.i04.p12
6. M. M. Ismail, B. M. Elhady, A. Bendary, Variable voltage control of three-phase induction motor for energy saving. *Eng. Res. J.* **44**, 377–383 (2021). https://doi.org/10.21608/erjm.2021.74659.1093
7. O. E. Omorogiuwa, A. Christian, Energy efficiency optimization of three phase induction motor drives for industrial applications. *Int. J. Eng. Appl. Sci. (IJEAS)* **5**, 42–49 (2018).
8. T. M. A. Al-Quraan, O. Vovk, S. Halko, S. Kvitka, O.Suprun, O. Miroshnyk, K. A. Islam, Energy-saving load control of induction electric motors for drives of working machines to reduce thermal wear. *Inventions* **7**, 92 (2022). https://doi.org/10.3390/inventions7040092
9. I. Roza, F. I. Pasaribu, A. Yanie, A. Almi, T. S. Sinaga, Analysis of the impact of using variable speed drive (VSD) on energy consumption of PT. Lestari Alam Segar (in Bahasa). *J. Teknik Elektro* **4**, 0–7 (2021).
10. P. M. Wibowo, M. Haddin, A. Marwanto, Energy saving analysis of air fan motor in power plant boiler controlled by variable frequency drive. *Int. J. Power Electron. Drive Syst.* **12**, 2059–2069 (2021). https://doi.org/10.11591/ijpeds.v12.i4.pp2059-2069
11. M. A. E. Salama, N. M. El-Naggar, S. Abu-Zaid, Energy saving analysis for pump-motor set in water purification plant using variable speed drive. *Sci. Rep.* **14**, (2024).
12. J. Narkhede, S. Naik, Boiler feed pump control using variable frequency drive. *Int. Res. J. Eng. Technol. (IRJET)* **3**, 2444–2449 (2016).
13. R. N. Rachmadita, F. W. N. Rahman, E. Setiawan, A. I. Juniani, W. Wiediartini, L. J. Satrianata, Energy saving opportunities in three-phase induction motors with variable speed drive (VSD) drives. *J. Teknik Elektro Komput. TRIAC* **11**, 51–57 (2024). https://doi.org/10.21107/triac.v11i2.26971

14. S.-H. Lu, Electric motor control: DC, AC, and BLDC motors (Elsevier, 2017).
15. K. M. Ibrahim, H. Hasanuddin, A. Sumarwanto, Analysis application of integrated variable frequency drive with radar sensor for silo optimization to reduce electricity consumption ratio. *Motivection: J. Mech. Electr. Ind. Eng.* **4**, 253–268 (2022). https://doi.org/10.46574/motivection.v4i3.149
16. V. Goman, V. Prakht, V. Kazakbaev, V. Dmitrievskii, Comparative study of energy consumption and CO_2 emissions of variable-speed electric drives with induction and synchronous reluctance motors in pump units. *Mathematics* **9**, 1267 (2021). https://doi.org/10.3390/math9212679
17. A. Joseph, T. R. Chelliah, S. S. Lee, K. B. Lee, Reliability of variable speed pumped-storage plant. *Electronics* **7**, 1–14 (2018). https://doi.org/10.3390/elecssstronics7100265
18. S.-M. Lu, A review of high-efficiency motors: specification, policy, and technology. *Renew. Sustain. Energy Rev.* **59**, 1–12 (2016). https://doi.org/10.1016/j.rser.2015.12.360
19. M. Yang, B. T. Phung, Motor winding insulation degradation under repetitive voltage pulses. *IEEE Access* **12**, 77658–77674 (2024). https://doi.org/10.1109/ACCESS.2024.3406490