Speed Control System of a Three-Phase Motor on a Paper Shredding Machine Using a VFD

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Abstract

Paper waste is one of the major components of the waste problem in Indonesia. Recycling serves as an effective solution to this issue, with the paper shredding process being a crucial stage in paper waste treatment. This study aims to design and test a paper shredding system that utilizes a three-phase motor controlled by an open-loop system based on a Programmable Logic Controller (PLC) and a Variable Frequency Drive (VFD). The VFD is used to regulate the motor's frequency and voltage according to operational needs, while the PLC functions as the main control unit that manages the motor's on-off operations. The use of a VFD allows the motor to operate with soft start and soft stop features, enhancing system safety and performance. Test results show that the system is capable of maintaining stable motor speed, both under no-load and load conditions, with an average speed variation of less than 1%.

Keywords : Paper shredding, PLC,VFD, Three- phase motor

1. INTRODUCTION

Paper waste is one of the largest contributors to the increasing volume of domestic waste in Indonesia. If not properly managed, this type of waste can have negative impacts on the environment, such as soil and water pollution. One effective and sustainable solution to reduce paper waste is through the recycling process. In this process, the paper shredding stage plays a crucial role, as it serves as the initial step in converting used paper into pulp that is ready for further processing.

During the shredding stage, a shredding machine is used to break down paper into small pieces. This machine is typically powered by a three-phase induction motor due to its reliable performance, durability, and energy efficiency. To flexibly control the motor's speed and performance, a control system based on a Variable Frequency Drive (VFD) is utilized. The VFD enables precise control of the motor's rotational speed by adjusting the supply frequency and voltage, allowing it to be tailored to the specific needs of the process.

In the context of systems with low complexity—such as paper shredders—an open-loop control configuration is an appropriate choice, as it offers a simpler control structure and lower implementation costs compared to closed-loop systems. Although it does not involve direct feedback from the system, the use of a VFD in an open-loop configuration can still provide stable and efficient speed control for this application.

This study aims to design and test a paper shredding system that uses a three-phase induction motor with an open-loop control system based on a VFD, and to evaluate the system's performance in terms of speed stability and its suitability for handling the load characteristics during the shredding process.

2. REVIEW OF LITERATURE

The paper shredding machine is a crucial component in the paper recycling process, functioning to break down waste paper into smaller pieces before it is processed into pulp. Fauzi et al. (2024) conducted an experimental study on a paper shredding machine with a capacity of 50 kg/hour. The study revealed that the machine’s efficiency and stability are significantly influenced by the characteristics of the drive motor and transmission system, as well as the importance of speed regulation based on the type and quantity of paper being shredded.

Three-phase induction motors are widely used in industrial applications due to their robustness, reliability, and energy efficiency. To support flexible operation of such motors, an appropriate speed control system is required. Firman et al. (2021) developed a three-phase induction motor control system based on a Programmable Logic Controller (PLC), integrated with a Variable Speed Drive (VSD) and a Human-Machine Interface (HMI). This system enables operators to easily control and monitor motor speed, while also improving operational efficiency.

Meanwhile, Aditya et al. (2023) investigated a remote control system for three-phase induction motors using the Internet of Things (IoT). The study showed that IoT-based control systems can enhance the flexibility of motor operation, although their implementation is more suitable for complex or large-scale systems. In the context of low-complexity machines like paper shredders, simpler control systems such as open-loop configurations with VFDs are considered more efficient and easier to implement.

Prastiko and Supardi (2022) developed a PLC-based motor speed control and monitoring system equipped with expansion modules and HMI. They emphasized the importance of real-time speed control to maintain process stability under varying loads, which is also relevant in paper shredding applications.

From a control engineering perspective, Al Tahtawi et al. (2024) proposed a speed control method using the LS SV0151G5A-2 VSD equipped with a Proportional Integral Anti-Windup algorithm for a 1.5 kW induction motor. Their results showed that the method was capable of maintaining accurate motor speed stability, even under disturbances or load variations, reinforcing the critical role of VFDs in motor control systems.

For more advanced control, Mugheri et al. (2021) implemented a Support Vector Regression (SVR) method for induction motor speed control. The results demonstrated improved precision in speed regulation; however, the complexity of this method makes it more suitable for large-scale or high-level automation systems.

Based on these studies, it can be concluded that the use of a three-phase induction motor with a VFD-based open-loop control system is an efficient and practical solution for applications such as paper shredding machines. This system offers reliability, energy efficiency, and simplicity in implementation, without the need for complex or costly control systems.

3. METHOD

This study was conducted experimentally by selecting an open-loop configuration, which features a simpler control structure, thereby improving system efficiency and making it suitable for low-complexity applications such as paper shredding machines. The block diagram of the three-phase motor speed control system for the paper shredder is shown in Figure 1.

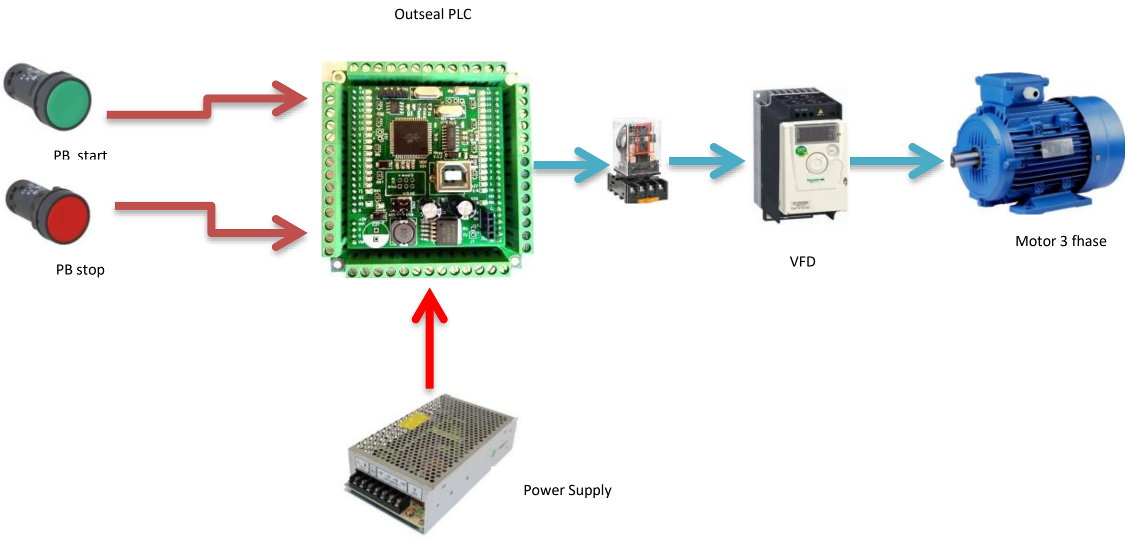

Fig. 1. Diagram Block of the system

Figure 1 shows a system that uses an Outseal V2-type PLC as the main controller. The PLC receives input from push buttons and controls when the shredder motor should be activated or deactivated. By utilizing a VFD, the three-phase motor can perform smooth starting and stopping operations, which contributes to increased motor longevity. The design layout of the motor position in the paper shredding machine is shown in Figure 2.

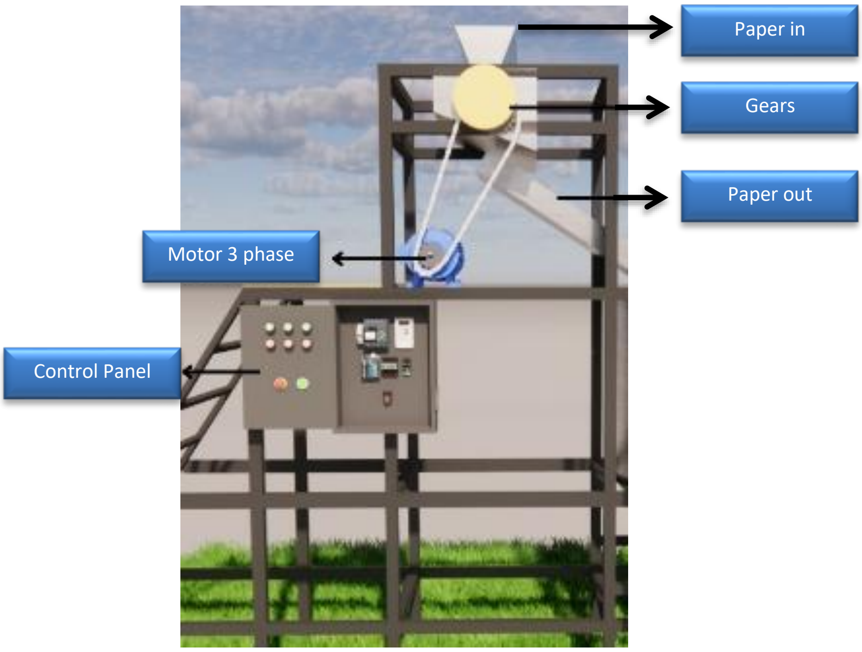

Fig. 2. Prototype design

The operating system of the paper shredding machine begins with the initialization of input and output (I/O) processes on the PLC control unit. After initialization, the system enters standby mode and waits for an input signal from the push button to trigger operation. When the start button is pressed and sends a high logic signal (value of one), the signal is processed by the PLC and transmitted as an output signal to the VFD. The VFD then activates the three-phase motor according to the preset frequency, which in turn drives the paper shredding mechanism. This process is illustrated in the flowchart shown in Figure 3.

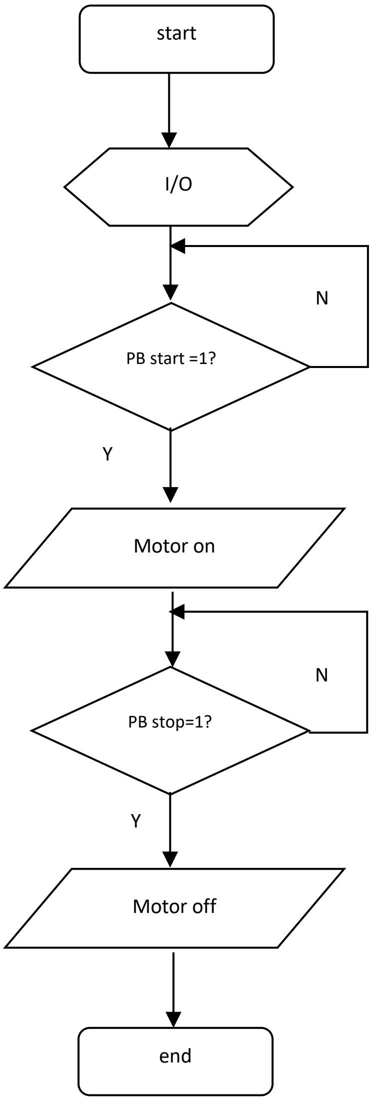

Fig. 3. Flowcahart

4. RESULT & DISCUSSION

In general, the implementation of the three-phase motor was successfully realized according to the design. The main component, a three-phase electric motor, functions as the driving force for the paper shredding machine. This motor drives the gears via a chain to transmit mechanical power to the shredding blades. Waste paper inserted through the input chute is fed into the shredding blades, and the shredded material exits through the output channel into a mixing tank for further processing into paper pulp. The realized paper shredding machine is shown in Figure 4.

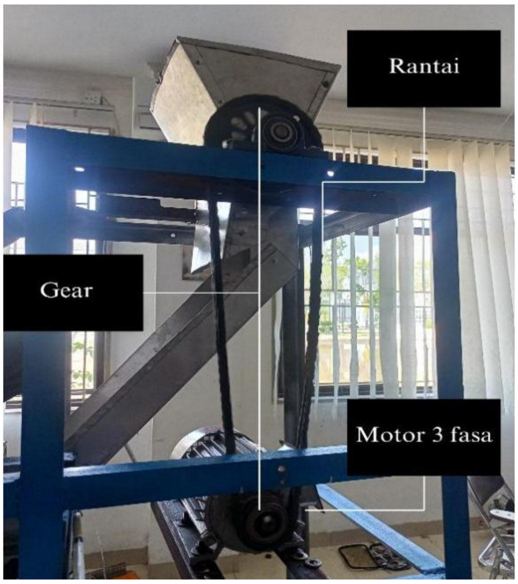

Fig. 4. Prototype

Testing of the motor was conducted under no-load and loaded conditions. In the first stage, the motor was tested without load, meaning no paper was fed into the machine. The second stage involved testing the motor with paper as the load on the machine. This was done to observe the motor's performance under both conditions. The test data are presented in Tables 1 and 2.

Table 1. Measurement of Three-Phase Motor Parameters Under No-Load Condition

Frekuensi (Hz)	V_{R-S} (Volt)	V_{R-T} (Volt)	V_{S-T} (Volt)	I_R (A)	I_S (A)	I_T (A)	RPM	P (Watt)
2	61	62	61	1.6	1.7	1.6	156	454
4	63	63	63	2.3	2.0	2.2	275	739
6	77	76	77	2.3	2.3	2.3	384	1014

Table 2. Measurement of Three-Phase Motor Parameters Loaded Condition

Frekuensi (Hz)	V_{R-S} (Volt)	V_{R-T} (Volt)	V_{S-T} (Volt)	I_R (A)	I_S (A)	I_T (A)	RPM	P (Watt)
2	63	62	62	2.1	2.2	2.3	130	460
4	67	64	66	2.3	2.2	2.2	258	745
6	78	78	78	2.3	2.4	2.4	413	1016

Tables 1 and 2 show that the motor speed is directly proportional to the frequency, while the voltage and current in each phase remain relatively balanced. Meanwhile, the motor speed under both conditions does not differ significantly, indicating that implementing an open-loop system in the paper shredder is sufficient for shredding/cutting paper. The difference in motor speed between the two conditions is illustrated in Figure 5.

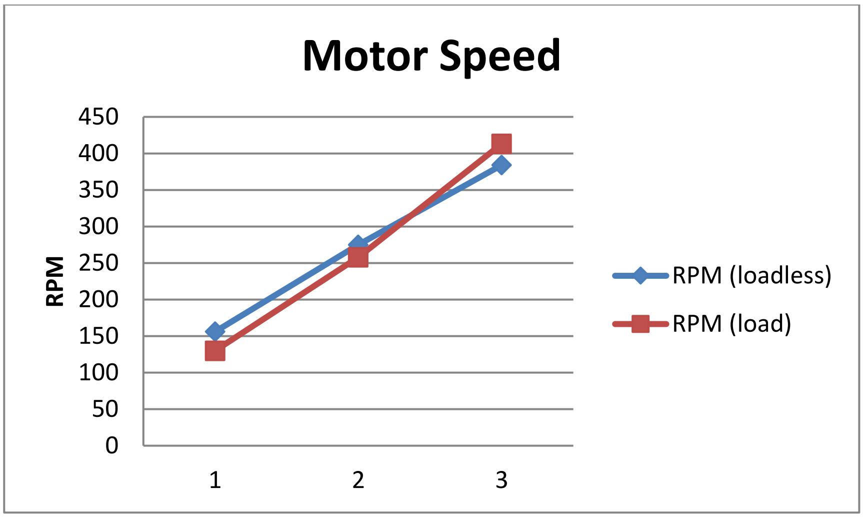

Fig. 4. Motor Speed Comparison Graph

Mathematically, the motor speed can be calculated using Equation 1 as follows:

$$n = \frac{120\,.f}{P} \tag{1}$$

Notation:
n = motor speed
f = frequency
P = pole

$$n_1 = \frac{120\,.\,2}{2} = 120\;rpm$$

$$n_2 = \frac{120\,.\,4}{2} = 240\;rpm$$

$$n_3 = \frac{120\,.\,6}{2} = 360\;rpm$$

The calculated motor speed above can be compared with the measured motor speed results, which are presented in Tables 3 and 4. From these tables, it can be seen that the relative percentage error is small, below 1%. This condition indicates that the motor is operating properly.

Table 3. Motor Speed Comparison (No-Load Condition)

Frequency (Hz)	RPM (measurement)	RPM (calculation)	Error (%)
2	156	120	0.3
4	275	240	0.14
6	384	360	0.06

Table 4. Motor Speed Comparison (Loaded Condition)

Frequency (Hz)	RPM (measurement)	RPM (calculation)	Error (%)
2	130	120	0.08
4	258	240	0.07
6	413	360	0.14

In the motor load test, the load used consisted of recycled paper sheets sized A4, 70 gsm, each weighing 4.37 grams. For each test, four sheets were used, resulting in a total weight of 17.46 grams, which corresponds to the capacity of the shredder blades. The test results showed that this relatively small paper load did not significantly affect the motor's performance. Therefore, for this type of paper shredder, an open-loop system with a simple control structure is appropriate.

5. CONCLUSION

Based on the test results and analysis of the three-phase motor speed control system in the paper shredding machine, it is shown that by implementing an open-loop system, the three-phase motor can operate well under both no-load and loaded conditions, with an average speed difference below 1%. This indicates that the motor runs more stably when subjected to a paper load of 17.46 grams.

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