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Testing Pulse Width Modulation on a TRIAC Using the Duty Cycle Approach on a Smart Conveyor

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Abstract: Conveyor systems have been an important element in industrial operations for extended period of time, particularly in material management. The advantage of the conveyor developed in this research lies in its energy regulation that is modified to fit the current load, in the hope of increasing the efficiency of electrical energy use. The conveyor speed control method is based on PWM (pulse width modulation), which is the setting of pulse duration to deliver current to the motor. The ATMega328 microcontroller serves as the controller in the system. When the system starts, the controller shall drive the motor based on pulse width modulation (PWM). This TRIAC perform as a phase regulator which is linked to a single-phase induction motor to operates the conveyor. The outcome show that the power generated varies depending on the load and duty cycle. With a load of 0.4 kg and a duty cycle of 20%, the power generated is 50.4 watts. Conversely, if the load increases and the duty cycle is also large, the power generated will be higher; with a load of 9.6 kg and a duty cycle of 80%, the power generated reaches 113.4 watts.

Keywords: Conveyor; Duty Cycle; Microcontroller ATMega 328; Pulse Width Modulation; Triac

Introduction

Conveyor systems posses integral part of manufacturing sector, particularly in material management. Material management covers a wide range of activities from transportation, storage, to monitoring of materials and finished products. This procedure occur from the stages of creation, delivery, usage to waste management. The majority of substance management activities concentrate on the techniques utilized, the mechanical gadgets engaged, the management systems implemented, as well as the regulation required to achieve the longed-for function. The benefits of using conveyors are especially pronounced when managing weighty or bulky resources (Malak et al., 2024)This tool maybe an efficient answer for the conveyor of material in manufacturing areas, both at the creation, examination and packaging stages. The application of conveyors can indeed be the best choice for moving various types of products with varying forms and dimention. Induction motors are a type of asynchronous machine because these machines operate at a lower speed compared to synchronous speed. Synchronous speed is the rotation rate of the magnetic field inside the machine. Factors that affect synchronous speed include the frequency of the machine and the number of poles present. Induction motors always operate below synchronous speed because the magnetic field generated by the stator creates flux in the rotor that triggers rotor rotation (Gaiardelli et al., 2024). However, the flux generated by the rotor lags behind the flux from the stator, so the rotor speed cannot match the speed of the magnetic field. Single-phase induction motors are one of the most common types of motors used in industry(Ma et al., 2024), as they are the simplest mechanical energy conversion system in comparison to diesel or petrol engines. These motors are simple to manage and can be directed easily. The benefit of an induction motors lie in their efficacy in transforming energy into mechanical

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movement and their ease of manage. For instace the design for application of a single-phase motor using phase control that has been developed, it is utilized to a conveyor system(Parmar et al., 2024). The designed conveyor is called a smart conveyor, that has the capability to identify the weight, and saving energy.

Method

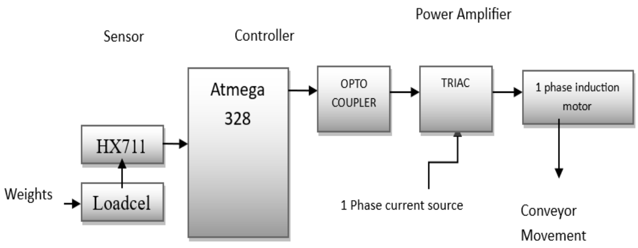

Figure 1. System operation block diagram

Illustration presents the system that describes the elements of the system, which includes the input, process, and output (results) sections. In this layout, the inputs come from sensors that measure the height and weight of the goods, namely ultrasonic and loadcell sensors. Both sensors provide data to the microcontroller to determine the conveyor's operational speed. Process is the part responsible for processing and control. This task is performed by the Arduino microcontroller. In this layout, the Arduino Uno was chosen as the controller due to its an adequate number of I/O for this application. The Arduino's functions include reading input data, processing the information, and managing the result. In this situation, the result refers to a motion mechanism that uses a single-phase induction motor. The motor is operated with a one-phase sine wave that is regulated by the microcontroller through a amplifier or driver. When initiated, the regulator starts functioning to begin the maintainer motor through setting the PWM pulse signal (Du et al., 2024). This PWM signal is adjusted to the current load. The PWM regulates the trigering of the TRIAC transistor, with the length of time related to the PWM width.The broader the PWM, the extended the active time of the TRIAC so that the power provided to the motor increases. Conversely, if the load is lighter, the pulse width will be decreased, resulting in a shorter duration of the TRIAC being on, which leads to a reduction in the energy flowing (Maklakov & Erdakov, 2023). The mechanical energy generated by the motor is then utilized to operate the conveyor. Initially passing through a speed reduction unit (gearbox) which functions to minimize speed while increasing torque. The microcontroller uses a calibrated loadcell sensor to detect the weight of the load in kilograms. In this situation, the microcontroller will control beats at specific frequency sent to the driver via an optocoupler. The result of the optocoupler is utilized to set the TRIAC's gate, what is a bias that serves to manage the cutting of the sine wave signal sent to the load. The results of TRIAC are then linked to an induction motor which functions to operate a conveyor (Wang et al., 2022). The PWM frequency value ranges from approximately 490-500Hz. The oscilloscope used is the UNI-T UTD2052 CL. The measurements taken include voltage, current, power, duty cycle and PWM measurements, time measurements, waveform measurements, as well as mechanical and load measurements. The load conditions used vary.

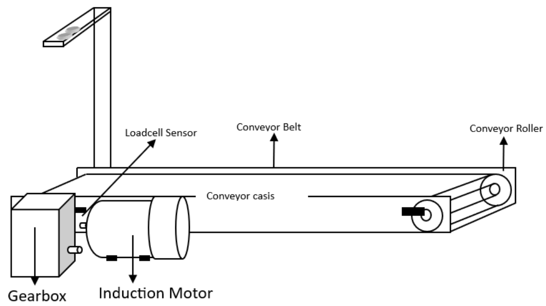

Figure 2. Smart Conveyor Design Sketch

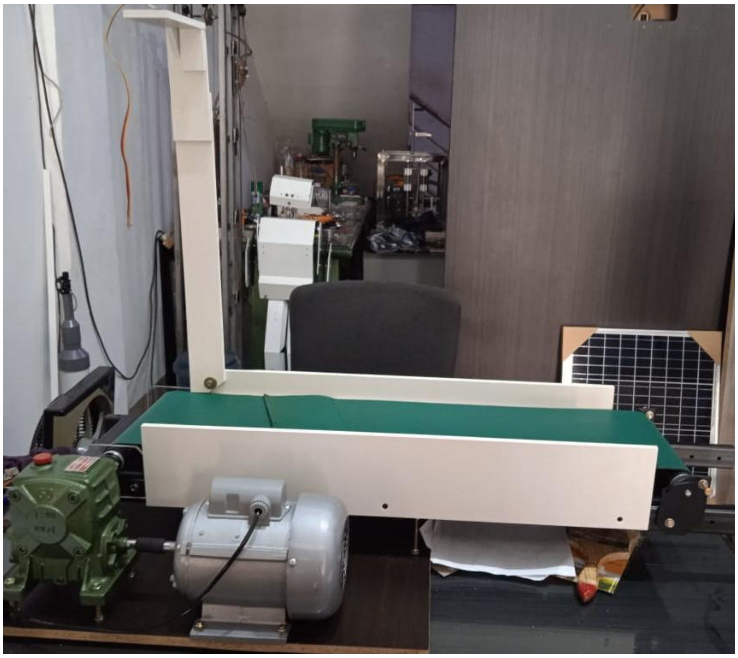

Figure 3. Physical form of Smart Conveyor

A single-phase induction motor is one of the most widely used types of motors in the industrial world because it is the simplest mechanical energy conversion system compared to diesel or gasoline engines. Motors are easy to control and easy to reverse. The advantages of induction motors also lie in their efficiency in converting energy into mechanical motion and their ease of control (Alharbi et al., 2023). In this design, the induction motor is used to drive a conveyor belt. The conveyor will continuously move goods from the beginning to the end of the conveyor. The motor's output, which is rotational motion, is connected to the conveyor shaft via a gearbox. The function of the gearbox is to reduce speed and increase torque.

A microcontroller is used as a controller for a 3-phase motor in a smart conveyor that has been designed. The microcontroller is in the form of an IC with several pins that function as inputs and outputs. This design uses a microcontroller on an Arduino Uno board that uses an atmega 328 chip. To function, the microcontroller must be programmed. This involves creating a program code on a computer and then uploading it to the microcontroller. Pin 8 is used as the output pin to control the motor by regulating the PWM pulse.

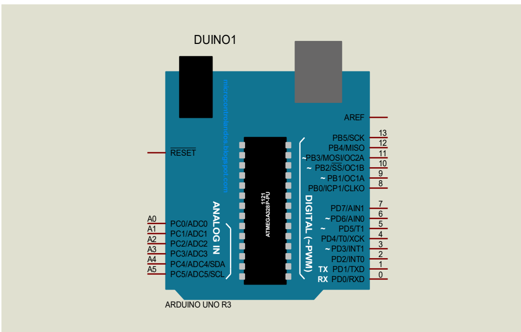

Figure 4. Arduino Microcontroller

A load cell sensor is a sensor used to detect pressure applied to a metal. Pressure causes mechanical stress, which can be converted into electrical resistance. Since the electrical resistance of the load cell changes due to pressure, this resistance can be used to measure weight with the help of a Wheatstone bridge. Using a Wheatstone bridge, the resistance is converted into voltage and read by a microcontroller. With specific calibration, the weight of the object being measured can be calculated. This design uses a conditioning circuit, namely the HX711 driver, which is a Wheatstone bridge circuit equipped with an amplifier and a weight-to-digital data converter, enabling the data to be transmitted to the microcontroller via a digital serial port (I2C).

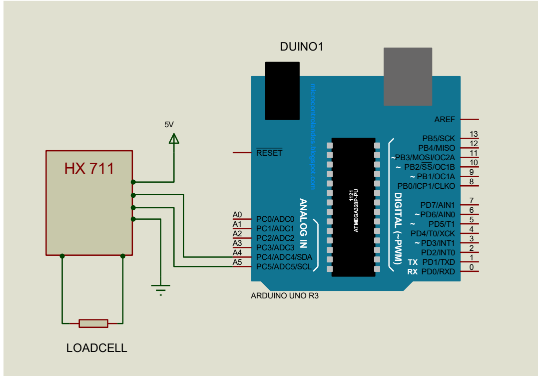

Figure 5. Loadcell sensor circuit on pins A4 and A5

A triac is an electronic component that has the ability to cut waveforms in AC current so that it can control the amount of power flowing to the load. The type of triac used is BT137 with a current capacity of 8A. Figure. This is a diagram of the circuit between the triac and the Arduino Uno module (AUDU et al., 2024).

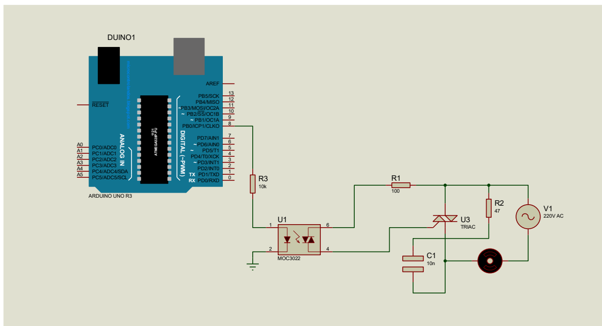

Figure 6. Power Amplifier circuit with Triac

Result dan Discussion

PWM Testing (*Pulse Width Modulation*)

PWM (*Pulse Width Modulation*) is a pulse-shaped signal with a specific voltage used to regulate the amount of energy supplied to a motor. By manipulating the width of the High and Low pulses of the PWM signal, the amount of electrical energy supplied to the load can be easily adjusted. Control using a PWM signal is one of the most effective and efficient methods for controlling motor speed (Shneen et al., 2024). The wider the high pulse width, the greater the energy received by the motor, and vice versa. The following are the test results and measurements of the PWM signal waveform used in the system.

Table 1. Explanation of Motor Test Results Table with PWM

Duty cycle	Motor Voltage (V)	Motor Current (A)	RPM	Power (W)
20%	88	0,91	897	80.08
40%	137	1,01	1347	138.37
60%	169	1,11	1786	187.59
80%	219	1,73	2341	378.87

Based on the data above, it can be concluded that there is a linear relationship between the duty cycle and the electrical and mechanical factors tested, namely input voltage, current, rotational speed, and motor power. Increasing the duty cycle from 20% to 80% resulted in an increase in motor voltage from 88V to 219V. This was also accompanied by an increase in current from 0.91A to 1.73A. Mechanically, this is directly increased motor speed, from 897 RPM at a 20% duty cycle to 2341 RPM at an 80% duty cycle.

The electrical power consumed by the motor also increased significantly (Maklakov & Erdakov, 2023). From an initial power of 80.08W at a 20% duty cycle, it increased to 378.87W at an 80% duty cycle. This demonstrates that the higher the duty cycle, the greater the electrical energy required by the motor. This trend aligns with the operating principle of pulse width modulation (PWM), commonly used in induction motor control. PWM controls the average voltage applied to the motor based on the pulse width (duty cycle). The larger the pulse width, the greater the energy transmitted to the motor. This ultimately increases the motor's rotational speed and power consumption in the conveyor system (Bahadur et al., n.d.).

So, based on observations, it is clear that the duty cycle plays a critical role in motor performance. Increases in duty cycle are linearly proportional to voltage, current, motor rotational speed (RPM), and power consumption. Therefore, duty cycle regulation is a key parameter in optimizing efficiency in PWM-based control system applications.

Table 2. Motor Test Results with PWM on the microcontroller output

Duty Cycle	Voltage (V)	Current (A)	Duty Cycle Power (W)
20%	1	0,01	0,04
40%	2	0,02	0,32
60%	3	0,03	1,08
80%	4	0,04	2,56

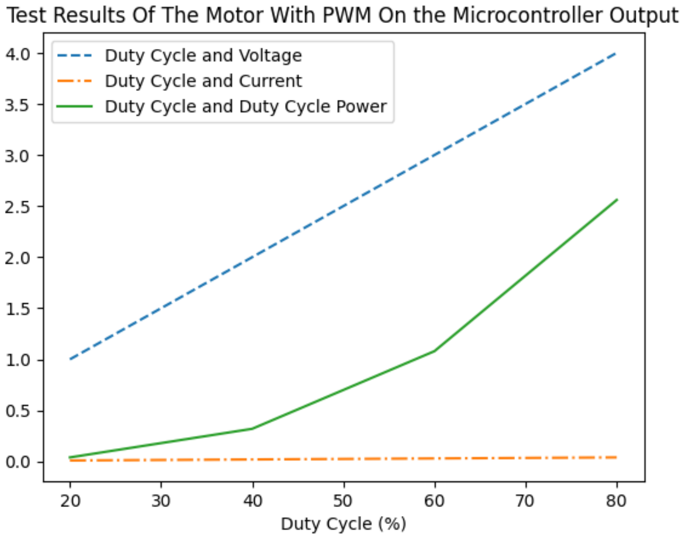

Figure 7. Test Results of the Motor with PWM on the Microcontroller Output

Figure 7 shows the results of the characteristic experiments based on variations in the duty cycle of the PWM signal generated by the microcontroller. The three main factors analyzed are voltage, current, and power based on the duty cycle (duty cycle power). The graph shows how changes in duty cycle affect the electrical output transmitted by the actuator (induction motor). The dashed blue line shows a linear relationship between duty cycle and output voltage. Increasing the duty cycle from 20% to 80% results in a proportional increase in voltage. This aligns with the principle of pulse width modulation (PWM), where the average output voltage increases as the active pulse width increases. The increased voltage likely supplies more power to the motor, creating faster rotation. The dashed orange line shows the relationship between duty cycle and current, which tends to be constant or increases slowly. The current increases from an initial level at a low duty cycle to a high duty cycle level. This indicates that the motor system under test has a balanced load. This current stability also indicates relatively high power transfer efficiency during testing. The green line shows the increase in power as the duty cycle increases. Power is calculated based on the product of the current and voltage associated with each duty cycle. The power increase is linear, accompanied by a linear increase in voltage and a gradual increase in current. This indicates that the PWM control successfully increased the power delivered to the motor without excessive current surges. The test results show that the PWM duty cycle is an important parameter in regulating the power and performance of an induction motor. The voltage increases linearly, the current tends to be constant, and the power increases efficiently. These characteristics are crucial in designing microcontroller-based control systems, especially in motor applications that require efficient energy use and high-speed control.

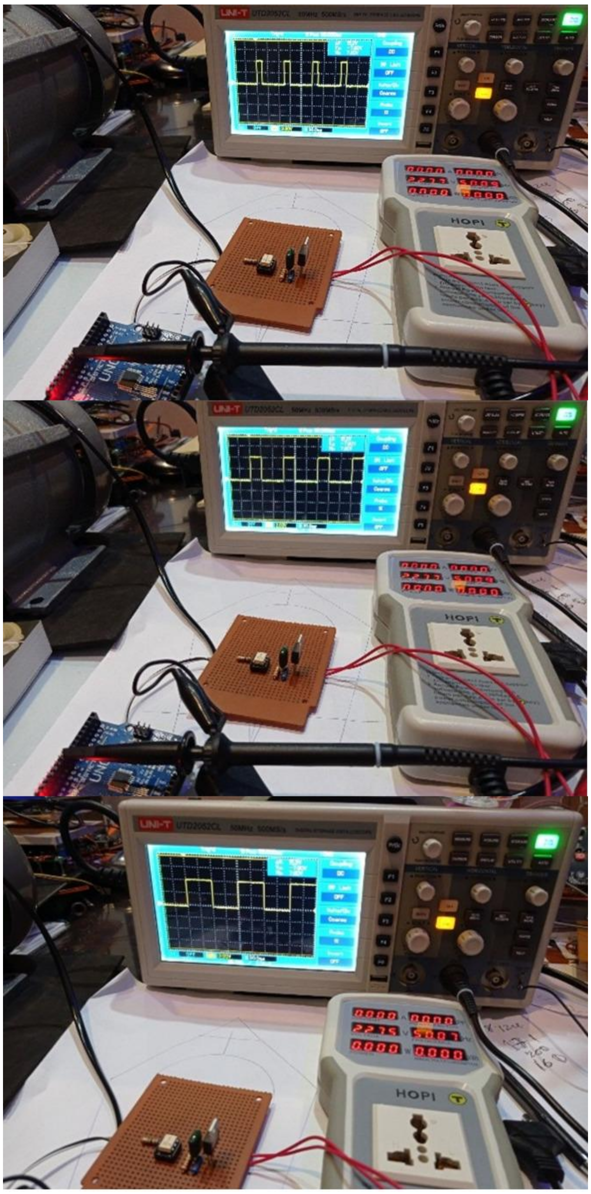

Figure 8. Output waveform at 40%, 60%, and 80% duty cycles measured with an oscilloscope

PWM testing on TRIAC

This test was conducted directly by placing a load on the conveyor. Before the load was placed on the conveyor, the motor and load were still stationary or not moving. Then, the load was placed on the conveyor, starting with a light load weighing 0.4 kg. Shortly after the load was placed, the conveyor started moving at the lowest speed. The object is moved to the end of the conveyor and stops. The test is then continued by applying a second load with a greater weight, namely 4.8 kg. The conveyor moves at a higher speed with a PWM duty cycle of 40%. The conveyor stops when the object reaches the end of the conveyor. The test continues by placing a different load on the conveyor. This time, the weight of the object is 7.6 kg. The conveyor will move faster with a duty cycle of 60%. The test continues again with a load of 9.6 kg. The conveyor moves at a duty cycle of 80%, which is the fastest speed. The following is a table of the test results conducted on the *smart* conveyor.

Table 3. PWM testing on TRIAC

Weights (Kg)	Duty cycle	Motor RPM	Travel Time	Conveyor Speed
0,4	20%	823	29,4 detik	3,41 cm/s
4,8	40%	1096	21,8 detik	4,58 cm/s
7,6	60%	1674	14,4 detik	6,99 cm/s
9,2	80%	2248	10,6 detik	9,39 cm/s

This test aimed to study the impact of load variations on induction motor performance in a conveyor system using a duty cycle control approach. The experiment was conducted with four load modifications, each accompanied by duty cycle adaptations to monitor system performance stability. Based on the monitoring results, it was found that increasing the workload in the conveyor system naturally decreased motor performance (Van Geest et al., 2022). However, increasing the duty cycle further improved motor performance. This was evident in the significant increase in motor rotational speed (RPM), from 823 RPM with a load of 0.4 kg (20% duty cycle) to 2248 RPM with a load of 9.2 kg (80% duty cycle). This increase in RPM directly affected the conveyor's travel time and linear speed. It can be concluded that ideal duty cycle control over the load is essential to maintain and increase the efficiency of the conveyor system. This study demonstrates the critical role of duty cycle in regulating induction motors, particularly in industrial applications involving dynamic load modifications.

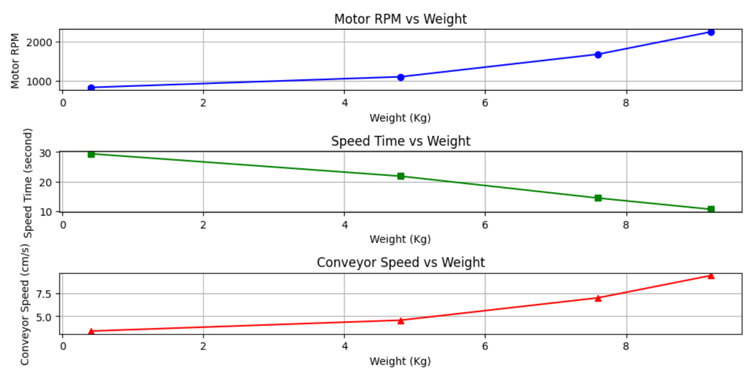

Figure 9. The relationship between load (kg) and the three main parameters of the conveyor system, namely motor rotation (RPM), travel time (seconds), and conveyor speed (cm/s)

The first graph shows that the greater the load added to the system, the higher the motor speed (RPM). This increase in motor speed indicates that the motor's performance is more robust in compensating for the increased load. With a load of 0.4 kg, the motor produces 823 RPM, while with a load of 9.2 kg, the RPM value increases substantially to 2248 RPM. This indicates that the motor's control system (with duty cycle) successfully increases the power supply to maintain conveyor system performance despite the increased load.The second graph shows a degradation in travel time as the load increases. This indicates that the conveyor system moves faster when subjected to a lighter load. This pattern is related to the increase in motor speed (RPM) and the higher duty cycle, which results in higher belt movement speeds in the conveyor system.

The third graph shows a tendency for conveyor speed to increase with increasing load. With a load of 0.4 kg, the conveyor speed is 3.41 cm/s and increases to 9.39 cm/s with a load of 9.2 kg. This corresponds to a mode of decreasing travel time, coupled with an increase in motor RPM. The combination of increasing duty cycle and motor torque allows the system to move more precisely under larger loads. The three graphs show that the conveyor system exhibits adaptive results in response to load modifications. Increased load is responded to by increasing RPM, decreasing travel time, and increasing conveyor system speed. This phenomenon demonstrates that motor speed regulation using the duty cycle approach works well in controlling dynamic loads in the conveyor system (Parmar et al., 2024).

Figure 10. The output waveform of the TRIAC when the PWM duty cycle is 40%, 60%, and 80% as measured with an oscilloscope.

Table 4. Measurement of Conveyor Voltage and Current Under Load

Duty Cycle	Voltage (V)	Current (A)	RPM	Power (W)	Duty Cycle Power (W)
20%	89	1,26	823	112,4	50,4
40%	134	1,47	1096	196,9	66,5
60%	156	1,75	1674	273	78,5
80%	217	1,89	2248	410,13	113,4

This observation aimed to assess the effect of duty cycle modification on the electrical parameters and mechanical performance of an induction motor used in a conveyor system. The experiment was conducted by adjusting the duty cycle to four levels: 20%, 40%, 60%, and 80%. This was done to observe changes in voltage, current, motor speed (RPM), and electrical power consumption. The measurement results are shown in Table 4 below. Based on this data, a positive relationship appears between the duty cycle (Grella et al., 2022) and other variables, such as input voltage, current, motor speed (RPM), and electrical power. Increasing the duty cycle from 20% to 80% resulted in an increase in voltage from 89 V to 217 V, and a current increase from 1.26 A to 1.89 A. This phenomenon corresponds to the motor speed increasing from 823 RPM to 2248 RPM. Total electrical power (voltage multiplied by current) also experienced a significant increase, from 112.4 W at a 20% duty cycle to 410.13 W at an 80% duty cycle. To measure the efficiency of power usage relative to the duty cycle, efficient power calculations were performed based on the duty cycle, resulting in an increase from 50.4 W to 113.4 W. This finding demonstrates that increasing the duty cycle not only increases the electrical power supplied by the motor but also directly impacts the mechanical performance of industrial motors. Therefore, the duty cycle is a critical parameter in regulating speed and energy consumption in conveyor systems (Ratib & Rashwan, 2021).

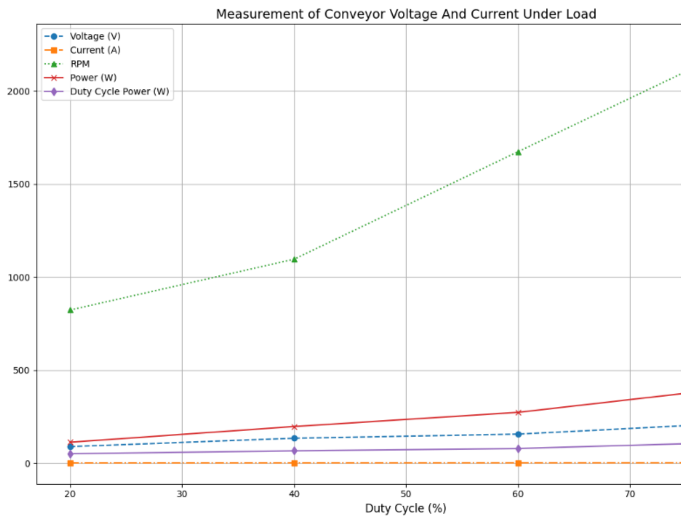

Figure 11. Measurement of Conveyor Voltage and Current Under Load

Figure 11 shows the relationship between differences in duty cycle (%) and the parameters of the conveyor system that have been designed and tested under load conditions, namely voltage (V), current (A), motor speed (RPM), electrical power, and power based on duty cycle. Data were taken at a duty cycle range between 20% and 80%, controlled by pulse width modulation (PWM) settings on the microcontroller (Arduino Uno).

The dashed blue line (voltage) shows an increase in voltage with increasing duty cycle. The voltage increases from 89V at 20% duty cycle to 217V at 80% duty cycle, with a linear increase. This demonstrates the characteristics of the PWM signal: the average output voltage increases linearly with the pulse width. This increase in voltage represents the system's response to the greater power supply requirements associated with the increased duty cycle. The dashed orange line (current) shows a steady increase in current, from 1.26A to 1.89A. Although the duty cycle increases significantly, the current change is not the same as the voltage. This indicates that the motor system operates with a relatively consistent load and has the advantage of efficient current consumption under loaded conditions. The dotted green line (RPM) shows a contrasting increase in RPM versus duty cycle. RPM jumps from 823 at a 20% duty cycle to 2248 at an 80% duty cycle. This pattern indicates that the conveyor system's mechanical response is sensitive to changes in duty cycle. This means that the higher the duty cycle percentage, the faster the motor rotates. This reinforces the effectiveness of PWM as a method for controlling motor speed in automation systems. The red line shows the increase in electrical power from 112.4W to 410.3W. This increase is linear, indicating that increased power consumption at high duty cycles results from increased voltage and current. This value represents the total electrical energy required by the motor to maintain the conveyor at a given load level. Therefore, it can be concluded that this graph demonstrates that the duty cycle is a fundamental control factor that directly impacts and influences all conveyor performance, from the electrical components to the rotational speed. The voltage and motor rotational speed (RPM) increase constantly. The interaction shown in this graph supports the implementation of the pulse width modulation (PWM) method as an effective and robust approach for microcontroller-based actuator systems under load conditions.

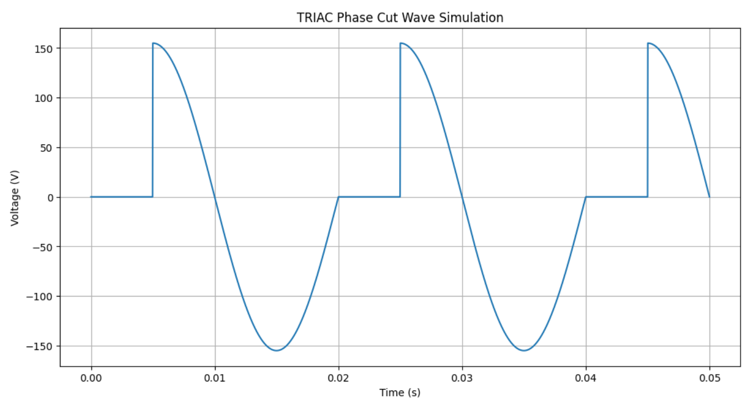

Figure 12. TRIAC Phase Cut Wave Simulation

The waves generated by phase cutting are electrical waves used to control AC power (for example, to dim lights or control motor speed). However, in terms of power quality, these waves are relatively low compared to pure sinusoidal waves. This is because they significantly produce harmonics and cause distortion, which can cause problems in the electrical systems of electronic equipment. Nevertheless, in many simple applications (example, incandescent lamp dimmers), the negative effects of these harmonics are acceptable because they offer advantages in terms of ease of control and low cost. For applications requiring higher power, power control procedures that produce cleaner waves (example PWM control using filters) may be applicable. Based on the measurement data obtained in this study, an increase in the duty cycle shows a significant correlation with an increase in energy consumption. Basically, the output power value increases in line with the increase in the duty cycle. This can be understood by the characteristics of TRIAC-based power control using the phase-angle control method, where the amount of energy received is relatively low. However, when the duty cycle increases, the TRIAC turns on first in each cycle so that the ratio of the sine wave transmitted to the load increases significantly. Because AC signal energy depends on the amplitude of the sinusoidal signal, the portion of the wave transmitted by power participation is greater than the increase in the low duty cycle. In addition to the waveform cutting factor, motor characteristics also have an impact. When the voltage increases, the current and losses in the motor also increase rapidly. This condition affects the increase in harmonic distortion due to waveform angle cutting by the TRIAC. As a result, the total power received by the motor increases at a rate proportional to the increase in the duty cycle.

The observation results show that the PWM signal generated by the microcontroller has very stable and clean quality, but after passing through the TRIAC, the waveform changes to phase-cut AC which experiences distortion. This wave angle cutting produces notching. This condition creates a relationship between the duty cycle and output power, especially in the high duty cycle range where the current and power increase faster than the effective voltage change.

Conclusion

Based on observations and testing, it was concluded that controlling the duty cycle in a pulse width modulation (PWM) system significantly impacts the performance of induction motors in microcontroller-based smart conveyors. Increasing the duty cycle directly increases the voltage, current, and motor rotational speed (RPM), which in turn increases electrical power and conveyor speed. Tests with different load modifications demonstrated that the system can easily respond to load transformations, adapting to changing conditions. Adjustments to the duty cycle are necessary to maintain stability and efficient performance. The relationship between the duty cycle and mechanical parameters demonstrates that the pulse width modulation (PWM) method is a positive, effective, and appropriate approach to motor control, particularly in actuator systems that require adaptability (flexibility) to load changes. Furthermore, the use of an Arduino microcontroller with PWM control and load cell sensors allows the control system to operate automatically and accurately in responding to load modifications. Therefore, this conveyor system design is suitable for industrial-scale implementation, especially in automation processes that require direct speed and load control. Overall, this research demonstrates that duty cycle is a key control parameter in optimizing the performance of control systems using industrial motors, and that implementing pulse width modulation (PWM) techniques can be a suitable solution for speed and energy control systems in electromechanical instruments. This study has limitations, namely the absence of a temperature sensor on the induction motor used, so that it is not yet possible to map the relationship between the duty cycle, total harmonic distortion, and temperature when the system is operating. The author's suggestion for the continuation of this research is to conduct a comparison with other AC power control methods to obtain a comparative perspective. The research can be expanded by comparing the TRIAC method with inverters or wave cutters using Mosfet or IGBT.

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