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Research Article

The Speed Control of BLDC and Induction Motors Using PID and Pulse Width Modulation

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About Article

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ABSTRACT

In the context of rapid industrial growth, the demand for high-precision and robust motor control systems has become increasingly critical. Electric motors, particularly DC motors, are extensively used in various mechanical and industrial applications due to their high torque, compact size, and energy efficiency. Among available control techniques, Pulse Width Modulation (PWM) is commonly used for regulating motor speed by converting AC input to DC via a diode bridge rectifier. This study introduces a hybrid control approach that combines PWM and Proportional–Integral–Derivative (PID) techniques for controlling Brushless DC (BLDC) and AC induction motors. The research is structured into two main components: the first part implements PWM to control the speed of a BLDC motor, while the second uses a PID-controlled DC motor to regulate the operation of an AC induction motor. MATLAB/Simulink was employed to model, simulate, and analyze the proposed control systems. Hardware-level simulation results demonstrate the effectiveness of the control approach. The microprocessor dynamically adjusts PWM duty cycles to precisely manage BLDC motor speed. The control system comprises an 8051 microcontroller, a gate driver circuit (based on the IR2110 high-voltage MOSFET driver), and IRF540N N-channel MOSFETs operating at up to 100 kHz switching frequency. These components ensure fast, efficient, and reliable switching behavior aligned with the motor's voltage and current requirements. Performance analysis indicates substantial improvements in speed control accuracy, system response time, and dynamic stability across both motor types. The novelty of this work lies in the unified application of PID and PWM control strategies to both BLDC and induction motors, demonstrating a flexible and scalable solution suitable for advanced motor drive systems in automation and industrial environments.

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1. INTRODUCTION

An electrical grid is an interconnected network used to deliver electricity from producers to consumers (Bayaty & Hussein, 2022; Hamd-allah *et al.*, 2021). In most manufacturing sectors today, both AC and DC motors are directly powered through electrical distribution lines. Consequently, motor behavior depends heavily on the load connected to the motor's shaft (Eli, 2023; Vanchinathan, 2021; Sakama *et al.*, 2022; BEGUM, 2023). When the load is light, the motor runs at high speed with relatively low torque. Conversely, under heavy load conditions, the motor speed decreases while torque increases (Kumar, 2019; Bolam, 2020; Shukla, 2023; Guerrero-Ramírez, 2022; Kumar, 2023).

Motor performance is typically fixed for a given constant line voltage, whether the motor is connected to an AC or DC supply. However, many industrial operations require dynamic control over motor parameters such as speed and direction. While speed controllers for AC motors are widely available and affordable, similar controllers for DC motors remain costly and less accessible to many industries (Maghfiroh, 2022).

This study aims to design and simulate a speed control system for DC motors using MATLAB/Simulink and a PID controller. DC motors are known for their precise control, strong starting torque, and high efficiency at low speeds. Despite their advantages, traditional DC motors have limitations that led to the development of alternative types such as the Brushless DC (BLDC) motor (Maghfiroh, 2022).

A DC motor typically consists of mechanical and electrical components. Its electrical model includes a series connection of resistance R, inductance L, a voltage source V, and a back electromotive force constant Kb_ (Gerber, 2022; Nasir, 2023; SALİM, 2023). Classical speed controllers, such as Proportional–Integral (PI) controllers based on Ziegler-Nichols tuning, often suffer from overshoot and long tuning times (Selvi, 2020). To address this, advanced optimization algorithms are being used to tune PID parameters effectively.

One challenge in PID control is proper tuning of Kp_, Ki , and Kd to optimize system performance. In a previous study, Particle Swarm Optimization (PSO) was used to tune a PID controller for a DC motor in MATLAB/Simulink. The resulting parameters significantly improved rise time, settling time, and eliminated overshoot controls (Purnama, 2019) (Rahayu, 2022). These values were later implemented in an Arduino system to achieve stable motor operation.

Other studies have utilized optimization algorithms such as Grey Wolf Optimization (GWO), Atom Search Optimization (ASO), and Sine-Cosine Algorithm (SCA) to enhance PID performance. A recent approach using the Harris Hawks Optimization (HHO) algorithm outperformed other methods in terms of response speed and robustness under uncertainty (Zhang, 2023).

In parallel, the BLDC motor has emerged as an efficient alternative, offering high-speed operation, wide speed range, low maintenance, and a superior torque-to-size ratio. However, BLDC motors require accurate rotor position sensing and present challenges in controller design due to their nonlinear and discrete-time characteristics (Ma'arif, 2021).

Additionally, recent work has explored the use of PID controllers in applications like autonomous robotics, using Simulink-based simulations to maintain speed under load disturbances. This highlights the potential of PID control in dynamic and adaptive systems (Hammoodi, 2020).

In the context of induction motors, another study applied a DSP-based system to model and characterize three-phase Linear Induction Motors (LIMs), which differ significantly from Rotary Induction Motors in structure and performance (Ekinci, 2020).

Despite extensive research, the design and tuning of PID controllers for DC motor speed control remain an open field with practical significance. This research is therefore structured into two parts: the first applies Pulse Width Modulation (PWM) to regulate BLDC motor speed, while the second employs a DC motor to control an AC induction motor. Both control models are developed and analyzed using MATLAB/Simulink.

2. LITERATURE REVIEW

The literature review presents a wide array of recent studies related to the speed control of BLDC and induction motors using PID and Pulse Width Modulation (PWM). This demonstrates a good awareness of the current state of research and highlights the technical diversity in control strategies. However, despite the breadth of references, the review lacks critical synthesis and comparative analysis.

Specifically:

- **Relevance and contextualization:** Many of the cited studies are listed descriptively without sufficient commentary on their direct relevance to the objectives of the current study. The review should explicitly link prior work to the research gap being addressed.
- **Comparative evaluation:** There is a missed opportunity to compare PID–PWM strategies to other modern control techniques such as Sliding Mode Control (SMC), Fuzzy Logic Controllers (FLC), Adaptive Control, or Hybrid Optimization-Based Controllers (e.g., PSO-PID). Highlighting the strengths and weaknesses of these methods in relation to the proposed approach would improve the clarity and justification of the study's novelty.
- **Positioning of contribution:** The literature review does not clearly articulate how this study advances the field. For instance, if the novelty lies in the dual application of PID and PWM to both BLDC and induction motors within a unified framework, that distinction should be emphasized in contrast to existing research that typically focuses on one motor type or one control technique.

2.1. Suggested improvements for the literature review section

To address the above issues, the Literature Review should:

i. Group and thematize studies: Organize prior work under clear subheadings (e.g., PID Control in DC Motors, PWM Techniques for BLDC Motors, Comparative Studies between PID and SMC) to enhance structure and readability.

ii. Provide critical commentary: After presenting each group of studies, include a synthesis paragraph that discusses what is known, what remains uncertain, and how the current study intends to bridge the gap.

iii. Clarify research gap and novelty: Explicitly state what differentiates this research. For example:

"While several studies have addressed PID control for individual motor types, few have proposed an integrated model combining PWM and PID for both BLDC and induction motors. This work attempts to unify these approaches and evaluate their performance through simulation-based validation."

3. METHODOLOGY

3.1. DC motor

A DC motor is a type of electrically motor that generates mechanical force by means of a direct current (DC). The most popular kinds rely on the magnetism generated by coil currents. Almost all varieties of DC motors contain an internal mechanism—electromechanical or electronic—that allows the motor's portion of the current to be periodically reversed. DC motor, as seen in Figure 1 below; the circuits depicted a comparable circuit for a conventional DC motor, as seen in Figure 2. Given Figure 1. and Newton and Kirchhoff principles, the DC motor is typically defined in terms of no steady state, as shown in equations 1 and 2 below (Kamal, 2018):

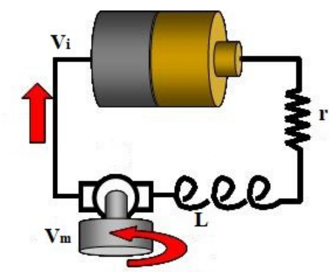


Figure 1. Conventional DC motor circuit

$L\,(di(t)/dt) = -r \times i(t) - K_h \times \Omega m\,(t) + Vi\,(t)$ ....(1)

$J\,(d\Omega m(t)/dt) = -T_L - b \times \Omega m\,(t) + K_i\, i\,(t)$ ....(2)

Where, i (t) is the current of the armature driven by the source, v (t) is the voltage driven by the source and the inductance and resistance of the armature can be described by L and r, respectively. The constant of back electromotive force and the constant of the torque are presented be (K_h) and (K_i), respectively. The load torque, the mechanical system damping and the shaft angular velocities are illustrated by T_L, b, and Ωm(t) respectively (Kommula, 2020).

From the equations (1) and (2), the motor speed transfer function is given by equation (3):

the motor speed transfer function / K_i = $1 / (K_h K_i + r \times b + (L \times b + r \times J).S + J \times L \times S^2)$ ....(3)

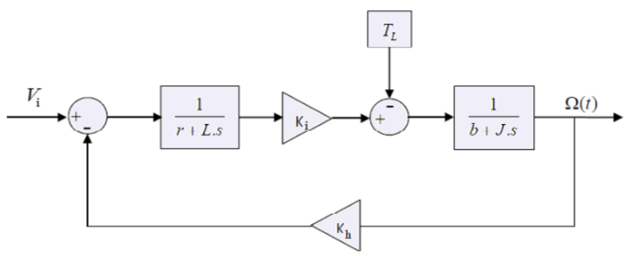


Figure 2. Equivalent circuit

3.2. Induction motors

In numerous applications, these motors are the most often utilised motors. Because an induction motor always operates at a speed lower than synchronous speed, these are also known as asynchronous motors. Synchronous speed refers to the stator's revolving magnetic field's speed. The equivalent circuit is as showing in Figure 3 (García, Parameter estimation of three-phase linear induction motor by a DSP-based electric-drives system, 2020).

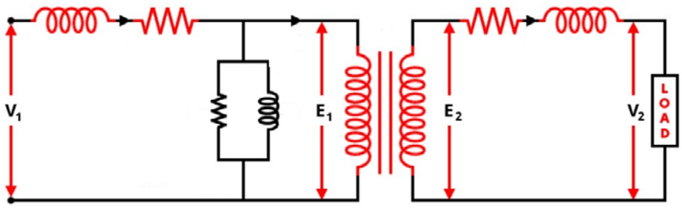


Figure 3. Equivalent circuit of induction motors.

3.3. Pulse width modulation (PWM)

Pulse width modulation, or PWM, converts input AC current to DC via a diode bridge rectifier. The DC Link's large capacitors are employed to reduce the ripples that the rectifier causes. Thus, a constant DC bus voltage is ensured.

3.4. PID control

The need for precise oversight, quick response times for automatic control systems, and system stability has increased due to the rapid advancement of science and technology. While traditional PID control primarily controls linear processes, most industrial processes are actually nonlinear in some way, and some processes are difficult or impossible to establish mathematical models for at the same time. For these reasons, general PID control is unable to achieve precise control over these processes. Due to its straightforward design and strong resilience, classic PID control has been applied extensively. PID control still has the upper hand in project practise. The basic idea of PID control is to create a control using a differential, proportions, and integration, and then select the appropriate linear combination to control the target. as seen in Figure 4. PID control's feature is that it merely requires changing the controller's parameters to produce acceptable outcomes. A linear controller is the PID controller. Regarding the control formula as shown in Equation (4):

$e(t) = -y(t) + x(t)$ ....(4)

The control law for PID is as shown in Equation (5):

$U(t) = (K_d\, de(t))/dt + K_i \int_0^t e_t\, dt + K_p\, e(t)$ ....(5)

Where integration time coefficient and the proportion gain coefficient can be illustrated by (K_d) and (K_p), respectively.

The PID procedures can be classified as:-

i. Proportion part: If a deviation is produced, the controller lessens it. The proportion link is proportionate to reflect the deviation signal.

ii. Integral part: primarily utilised to reduce static error and enhance system stability.

iii. Differential part: may show the deviation signal's changing trend (change rate), as well as prior the signal's value grows too high, the system introduces an efficient early corrective signal to quicken the system's response and shorten its adjustment time as shown in Figure 3 (Purnama, 2019).

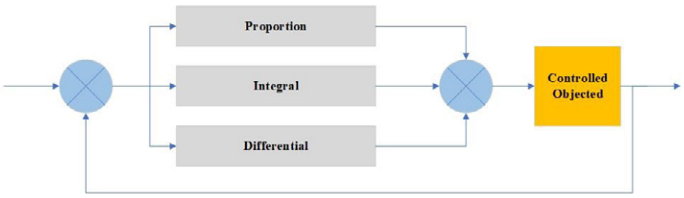


Figure 4. Schematic PID controller

The system functions by directly connecting an AC induction motor to a DC motor, allowing mechanical control of the AC orange. The shaft is powered by the DC motor, allowing the shaft to both turn swiftly and provide varying torque when connected to the induction motor's rotor. Using a special mechanism, the DC motor can affect the speed and workload of the AC motor by mechanical means, no inverter is required and on the DC motor side, its input is precisely controlled by an independent drive system to modify its output torque and rotation speed. Depending on the simulation case, the AC induction motor operates as either a load or as part of regenerative braking.

To accomplish this, the trial-and-error approach was employed to find the correct values for the main gain parameters in the PID controller. PID parameters were adjusted several times in simulation based on the system's response in the time domain until the behavior in the loop (stability, settling time, overshoot and steady-state error) met expectations. Although other systematic methods could be tried such as Ziegler-Nichols or PSO, we used the trial-and-error approach since the calculation process is simple and straightforward for our system. Figure 1 shows parameters of DC Motor, and AC Induction Motor.

Table 1. Parameters of the proposed system

Parameter	DC Motor	AC Induction Motor
Rated Voltage (V)	220 V	380 V
Rated Power (W)	750 W	1.5 kW
Rated Speed (RPM)	1500 RPM	1450 RPM
Rated Torque (Nm)	4.77 Nm	9.9 Nm
Armature Resistance (Ra)	1.2 Ω	-
Armature Inductance (La)	0.03 H	-
Stator Resistance (Rs)	-	1.5 Ω
Rotor Resistance (Rr)	-	1.2 Ω
Stator Inductance (Ls)	-	0.02 H
Rotor Inductance (Lr)	-	0.02 H
Mutual Inductance (Lm)	-	0.06 H
Inertia (J)	0.01 kg·m²	0.02 kg·m²
Friction Coefficient (B)	0.001 N·m·s	0.0015 N·m·s
Supply Frequency (Hz)	-	50 Hz
Number of Poles	-	4

A Pulse Width Modulation (PWM) technique is applied to the control of voltage in the gate driver circuit of the motor in the suggested system. Setting the PWM frequency at 5 kHz smoothens the switching and lessens noises produced by the motor. It is possible to adjust the duty cycle from 10% to 90%, helping you better control the speed and torque of the motor. The selected values meet typical motor drive system requirements and were shown to provide stable and efficient performance when tested with a simulation.

4. RESULTS AND DISCUSSION

The microprocessor produces the appropriate output for changing the motor drives, which allows the speed of the BLDC motor to be controlled, by adjusting the duty cycles (PWM Pulses). The BLDC motor, microcontroller MOSFET module, gate driver circuit, and 8051 microcontrollers make up the majority of the MATLAB simulator for open loop control of a BLDC motor, as shown in Figure. 5. The 8051 microcontroller sends gate pulses (PWM) to the inverter's gate through the gate driver circuit, which is made up of an isolator, buffer, and gate driver. 12V batteries are used to power the gate driver circuit. A battery or regulated power supply provides a 12V dc supply to the inverter. The measures block diagram of Ta, Tb, and Tc and Hall recorder and control are shown in Figure.6 and Figure. 7, respectively. The gate driver circuit employs the IR2110 high-voltage, high-speed MOSFET driver, capable of driving N-channel MOSFETs with a switching frequency up to 100 kHz. The power stage consists of IRF540N N-channel MOSFETs, each rated for 100V drain-source voltage (Vds), 33A continuous drain current, and a typical rise time of 45 ns, ensuring fast and reliable switching. These specifications are suitable for the BLDC motor voltage and current requirements used in the system.

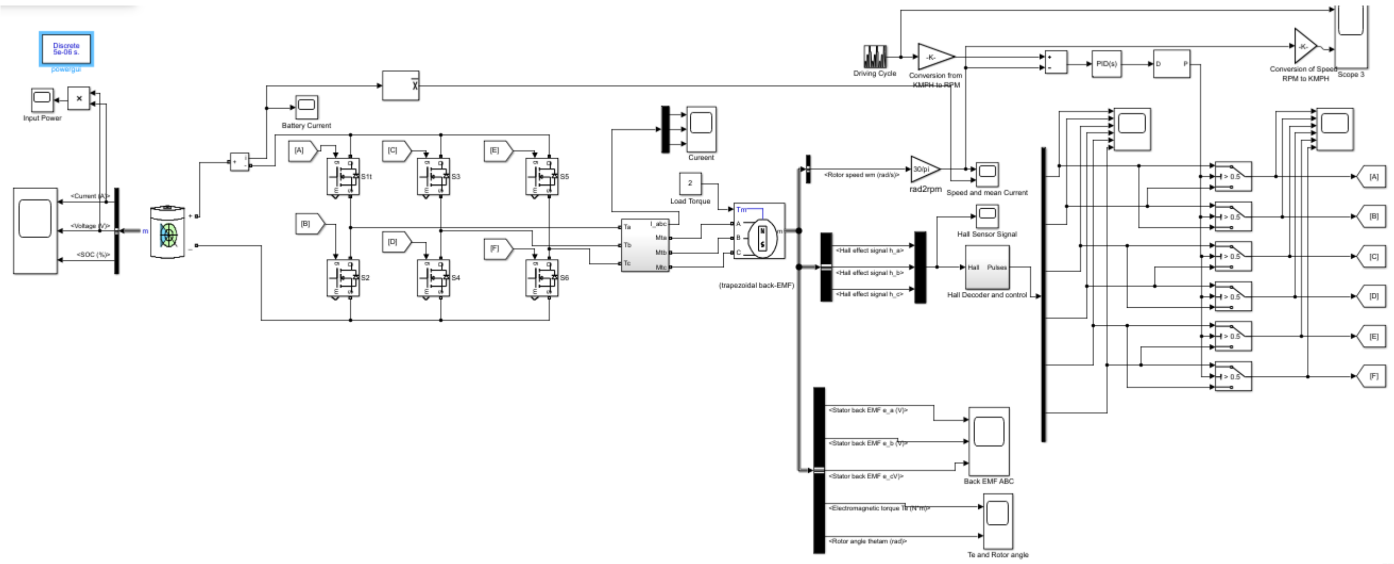


Figure 5. The proposed block diagram of the BLDC motor controlled by PWD using MATLAB simulink.

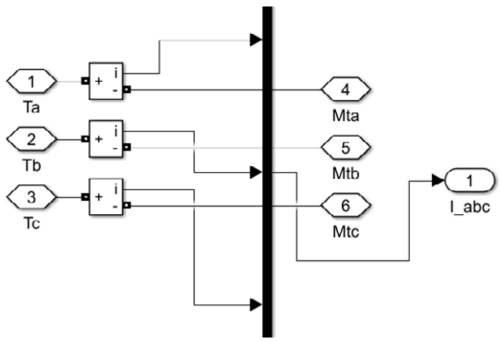


Figure 6. Block diagram for measures ta, tb, and tc using matlab simulink

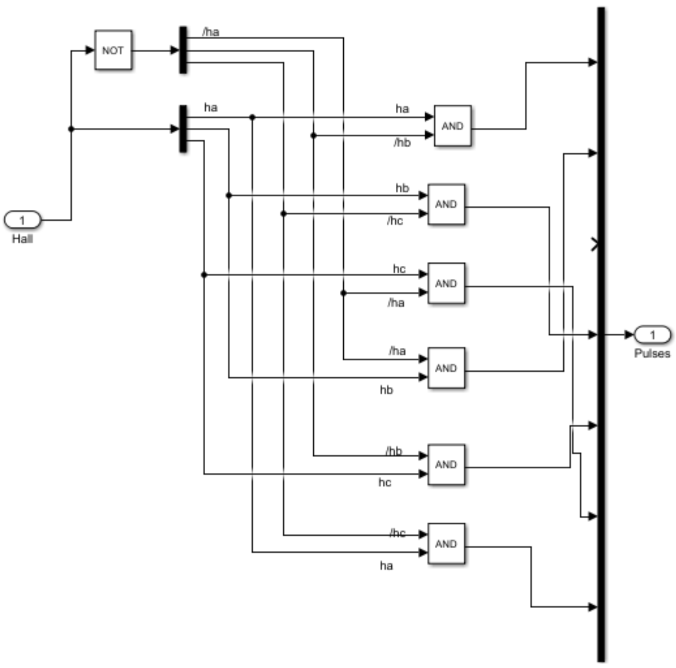


Figure 7. Block diagram for hall recorder and control using matlab simulink

The results shown that, the battery current and voltage are constant, except the pulse obtained at time 11 second, the battery SCO started at 80 and decreased by time. Figure 8 shows battery current, battery voltage, and battery SCO, respectively.

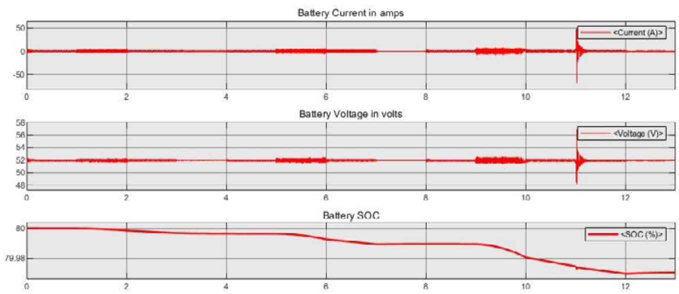


Figure 8. The battery current, battery voltage, and battery SCO.

Accordingly, the input power can be represented as shown in Figure 9 which insured the pulse obtained at time of 11 second. It is obtained by product the input current and input voltage. The current measures signal is obtained as in Figure 10. As showing, the peak for Ta reached to 60 in positive polarity and reached to 50 in negative polarity for Tb and Tc.

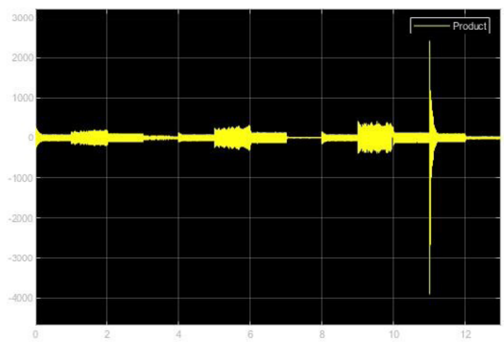


Figure 9. The Input Power

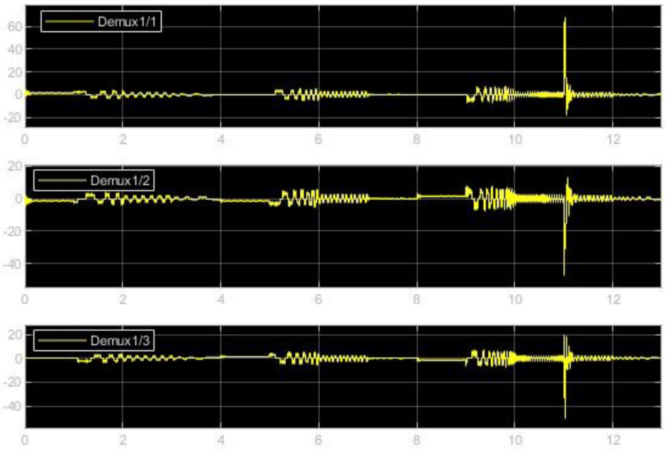
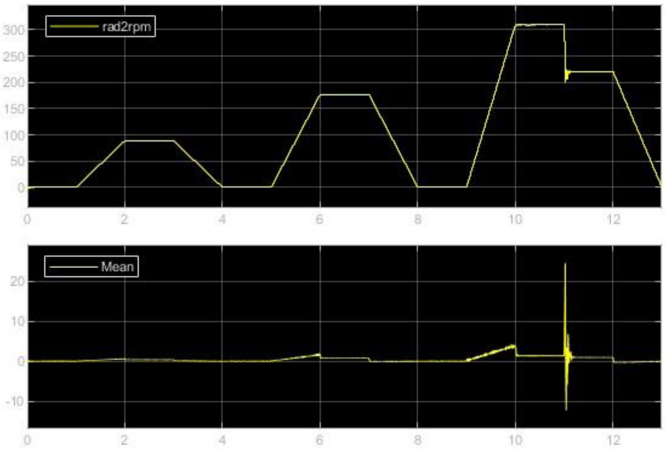


Figure 10. The current measurements Ta, Tb, and Tc

Figure 11 shows the speed in (r.p.m) in relation with time, as showing, the max speed reached to 309.7 r.p.m at time 10.010 s and the minimum value reached to 1.001 r.p.m in reverse direction at time 0.0036 s. while the mean current is still constant until reached to its maximum 24.56 A at time 11 s. The stator back EMF and torque with rotor angle are showing in Figure 12 1nd 13.



Figuer 11. The Speed and mean current

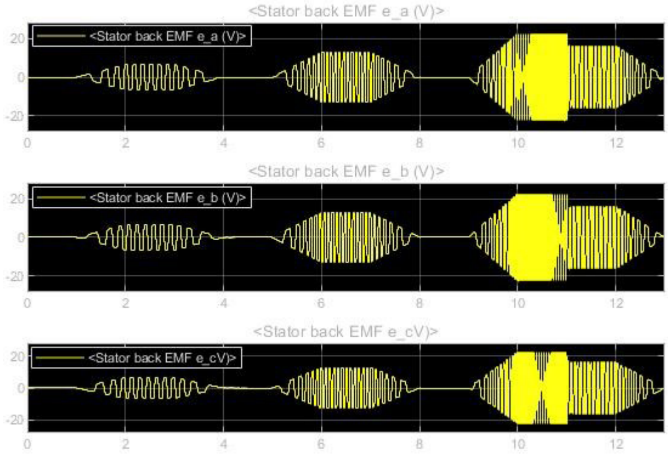


Figure 12. The stator back EMF

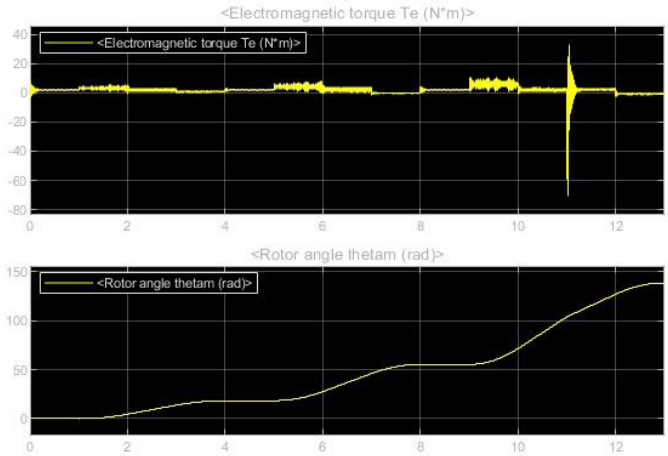


Figure 13. The electromagnetic torque te and rotor angle results

High power rated Insulated-Gate Bipolar Transistors (IGBTs) are turned on and off in the driver's multi-step inverter stage to modify the voltage and frequency provided to the motor in a sine-like waveform output. By altering the voltage pulse width, the average power voltage supplied to the motor is generated. The number of waveform transitions per second tells us what frequency the motor requires.

The second section aims to create a model for controlling the speed of an induction motor using a DC motor as showing in Fig.14. In this part, the speed of an induction motor is controlled by a DC motor, which yields faster computation results (Figures 15 & 16).

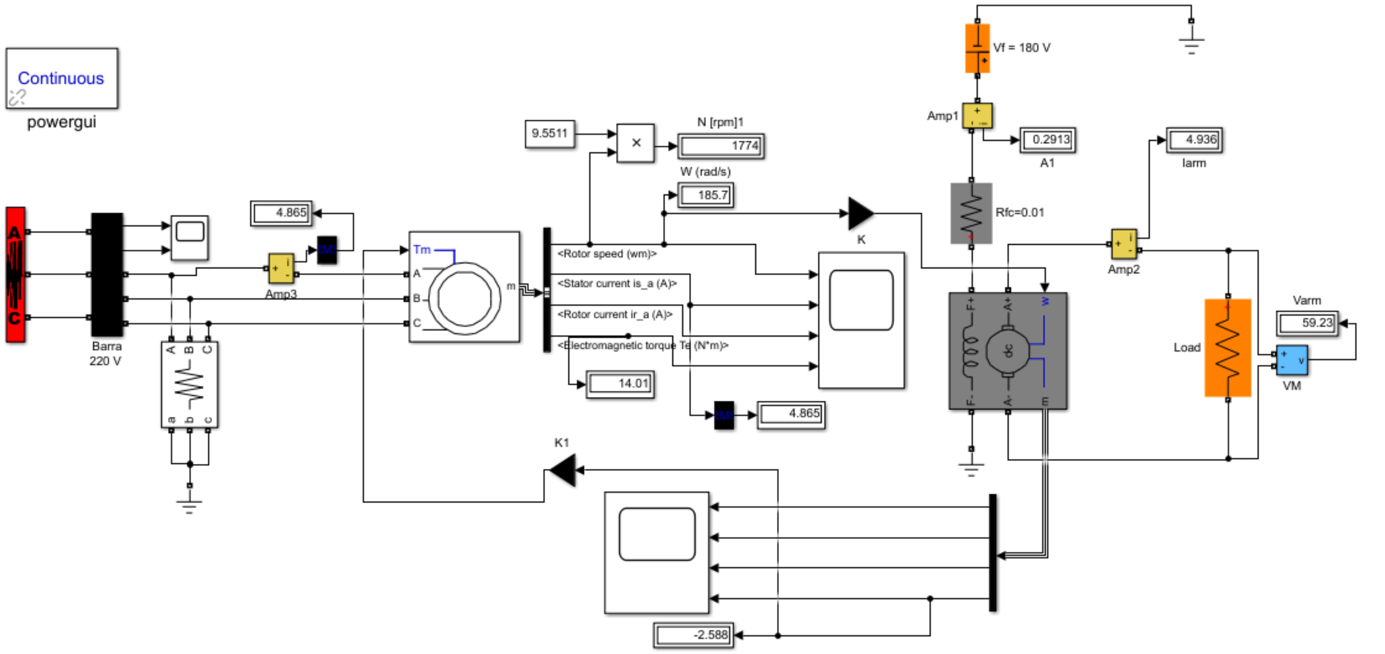


Figure 14. The proposed block diagram of the induction motor controlled by DC motor using MATLAB Simulink

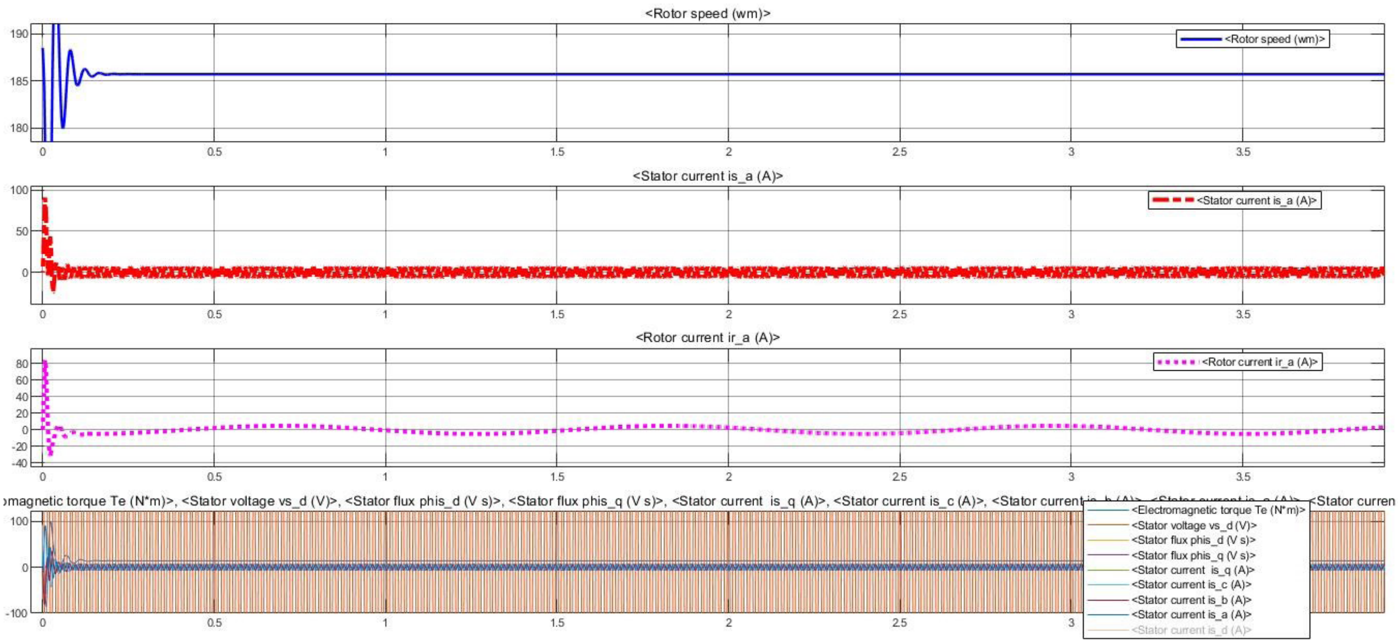


Figure 15. The Rotor speed, stator current and the rotor current results.

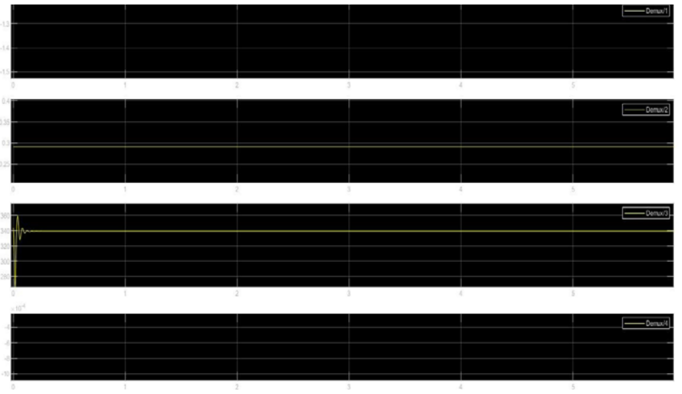


Figure 16. The MATLAB Simulink results

From Table 2, the existing PID-based control performs smaller improvement of the sensor value outcome compared to Fuzzy Logic, Neural Networks and Sliding Mode Control which achieve a larger improvement of the sensor value outcome. Robustness and easy operation were demonstrated by the PID controller in this study, reaching a maximum speed of 309.7 RPM and pulling a peak current of 24.56 A. That being said, the main weakness is that it cannot change on its own, unlike controllers such as Neural Networks which can. New studies indicate that Fuzzy Logic controllers provide strong control responses, with a minimal degree of overshoot, though the tuning protocols can be quite complicated. In the same way, Sliding Mode Control gives fast convergence and strong robustness, but it can lead to chattering and require a complicated implementation. As a result, we can see that PID controllers are practical and still meeting needs, but adding hybrid or adaptive elements may enhance both performance and stability in different loads.

Table 2. Comparison with advanced controllers from recent literature

Study / Controller Type	Accuracy / Perfor-mance	Key Feature / Limita-tion
Current Study (PID)	Max speed: 309.7 RPM, Imax: 24.56 A	Simple, robust, but no dynamic adap-tation
Fuzzy Logic Controller [28]	Faster rise time, overshoot < 2%	Handles nonlinearity better, requires fuzzy rule tuning
Neural Network [29]	Learns complex dynamics, adaptive	Requires large training data, higher computational cost
Sliding Mode Control [30]	High robustness, fast convergence	Sensitive to chattering, implementation complexity

5. CONCLUSION

In summary, this work successfully demonstrates a dual-model control approach for BLDC and AC induction motors using PWM and PID techniques. Simulation results confirm that the proposed system achieves efficient and stable speed regulation. However, this study is limited to MATLAB-based simulations, and real-world implementation challenges—such as hardware non-idealities and dynamic disturbances—remain unaddressed. Future work will focus on deploying the system on embedded platforms and comparing its performance with advanced control strategies. The results suggest strong potential for practical applications in low-cost motor drive systems and industrial automation environments.

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