IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

MICROCONTROLLER BASED STEPPER MOTOR USING CLOSED LOOP CONTROLLER OF HIGH SPEED AND TORQUE REGULATION

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Abstract — This paper presents the modeling, simulation, and hardware implementation of a closed-loop speed control system for a two-phase hybrid stepper motor using an Arduino microcontroller. Stepper motors are widely used in robotics and automation systems due to their precise position control and high holding torque. However, open-loop operation may result in torque ripple, resonance, and step loss under varying load conditions. To overcome these limitations, a closed-loop control strategy is developed and evaluated. A mathematical model of the motor is implemented in MATLAB/Simulink to study voltage, current, speed, and torque characteristics under different operating conditions. The proposed control method improves dynamic performance and ensures stable operation across a broad speed range. Simulation results are validated through experimental hardware implementation using an Arduino Uno and driver interface circuitry. The results demonstrate improved speed regulation, reduced torque fluctuation, and reliable performance suitable for robotics applications.

Keywords — Controller, Power LED, PCB , Solar Panel, Resistor, Capacitor, Rectifier, PIC16F877A,

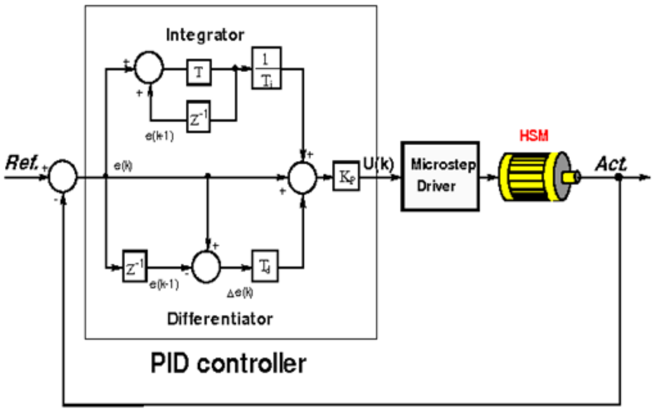
I. Introduction

Stepper motors are essential components in motion control systems requiring accurate positioning and repeatability. They are extensively used in CNC machines, robotic arms, medical equipment, and 3D printers. Unlike conventional DC motors, stepper motors rotate in discrete angular increments when electrical pulses are applied.

Most traditional stepper motor systems operate in open-loop mode without feedback. [1] Although simple and cost-effective, open-loop systems may suffer from missed steps, torque reduction, and instability under varying loads.

To address these issues, this paper proposes a closed-loop speed control system using an Arduino microcontroller. The study integrates modeling, simulation, and hardware validation to improve motor performance and reliability.

This work focuses on the performance enhancement of a PV–battery hybrid converter using active rectification and a Dual Active Bridge topology. The proposed approach aims to achieve efficient energy management between the PV source, battery storage, and load under varying operating conditions, making it well suited for next-generation renewable energy systems and DC microgrid applications.



II. OPERATION

The Operating Principle of Hybrid Stepper Motor
A hybrid stepper motor consists of:
A permanent magnet rotor.
A stator with multiple electromagnet windings
Sequential phase excitation

When pulses are applied in a specific sequence, magnetic interaction between stator and rotor produces controlled angular motion. The total angular displacement is: Motors rotate in discrete angular increments when electrical pulses are applied.

Most traditional stepper motor systems operate in open-loop mode without feedback. [2] Although simple and cost-effective, open-loop systems may suffer from missed steps, torque reduction, and instability under varying loads.

$$\theta = N \times \theta s$$

Where:
θ = total angular displacement
N = number of pulses
θs = step angle (typically 1.8°)

Motor speed is proportional to pulse frequency, while direction depends on excitation sequence.

III. PROPOSED SYSTEM

This paper proposes a modified photovoltaic (PV)– battery hybrid distributed power generation system in which the conventional diode rectifier on the secondary side of the high-frequency transformer is replaced by a full-bridge voltage source converter (VSC) [3]. This modification converts the originally unidirectional isolated DC–DC converter into a Dual Active Bridge (DAB) topology, thereby enabling fully bidirectional power flow among the PV source, battery energy storage system, and the DC bus. As a result, the system supports both battery charging and discharging, as well as regenerative power transfer, which is not possible in conventional diode-rectified systems.

3.1 Electrical Model

$$Va = Ria + L(dia/dt) + ea$$

$$Vb = Rib + L(dib/dt) + eb$$

Where:

Va, Vb = phase voltages

ia, ib = phase currents

R = winding resistance

L = winding inductance

ea, eb = back EMF

3.2 Mechanical Model

$J(d\omega/dt) + B\omega = T_e - T_L$

Where:

J = rotor inertia

B = friction coefficient

ω = angular velocity

Te = electromagnetic torque

TL = load torque

Torque is dependent on phase current and rotor position.

4. Control Scheme

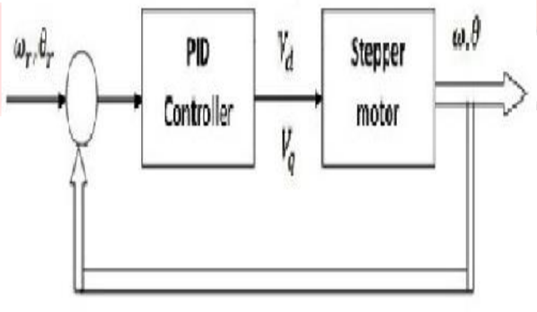
A closed-loop speed control system is implemented using a PI controller.

$\text{Error} = \omega_{ref} - \omega_{actual}$

$\text{Control Output} = K_p(e) + K_i \int e\, dt$

The controller adjusts pulse frequency based on speed error, reducing steady-state error and improving dynamic response. The proposed system is modelled and simulated in MATLAB/Simulink, and the results confirm stable DC bus voltage regulation, smooth bidirectional power control, and enhanced operational flexibility compared to conventional diode-based PV–battery hybrid converters[4]. This DAB-based architecture is highly suitable for renewable energy integration, DC microgrids, and electric vehicle charging applications.

IV. BLOCK DIAGRAM



The block diagram represents a PV–battery hybrid power conversion system in which energy from both the solar PV source and the battery is managed through a coordinated converter structure to supply a stable output to the load. [5]The PV source delivers variable DC power to the primary converter, which performs maximum power point tracking (MPPT), voltage regulation, and initial DC–DC conditioning. The battery is connected to the same primary side, enabling bidirectional power exchange for charging during excess PV generation and discharging when solar power is insufficient, thereby ensuring continuous and reliable energy availability[6]. The conditioned power from the primary converter is fed into a high-frequency transformer, which provides electrical isolation, reduces transformer size through high-frequency operation, and adjusts voltage levels between the primary and secondary sides. On the secondary side, the AC output of the transformer is processed by a secondary converter that performs active rectification, voltage stabilization, and final DC regulation to match the requirements of the load. Overall, this architecture allows efficient energy transfer, improved control flexibility, and enhanced reliability, making it suitable for modern renewable energy and storage-integrated applications.

V. CONTROL SCHEME

The closed loop control of stepper motor. The servo system model consists of a motor with position feedback obtained from an optical encoder. Current control is achieved through a digital PI current loop with proportional gain (Kp) and integration gain (Ki). An external torque is applied to the motor shaft for testing. The identified constants, after tuning, include Kd4, Kd2, and Kd1 for torque ripple reduction, along with phase angles φ2 and φ1, and Fs values for clockwise and anticlockwise motion. Surprisingly, the first- and second-harmonic torque ripples are more significant than the fourth-harmonic ripple, despite conventional expectations. Additionally, static friction contributes to damping motor vibrations.

VI. RESULTS AND DISCUSSION

The stepper motor simulation diagram. The stepper motor moves in steps, unlike other machines where the motor rotates. They are not the one that where gives out power but they give torque. Here we have a torque a force a displacement which gives torque in pulses. It is not a continuous energy conversion device[8]. An electromechanical device that transforms electrical pulses into distinct mechanical movements is called a stepper motor. When electrical command pulses are supplied to the stepper motor in the correct order, the shaft rotates in discrete step increments. Incredibly dependable because the motor lacks contact brushes. As a result, the motor's life is solely dependent upon the bearing's longevity. Open-loop control was made possible by the motor's reaction to digital input pulses, which made controlling it easier and less expensive. The stepper motor simulation parameters are displayed.

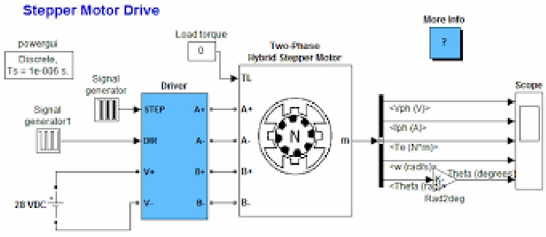


Fig:3 Stepper motor using MATLAB Simulink.

the stepper motor input voltage the magnitude of the voltage is 25 volts. This voltage determines the strength of the magnetic field generated within the coils, which in turn controls the movement of the motor's rotor. The input wave is a square wave. A square wave is a type of two distinct voltage levels, typically a high voltage level and a low voltage level. The red color shows the A phase and the blue color shows the B phase. Figure 5 shows the stepper motor input current wave from the magnitude of the current is 2.5 Amps. The amount of electric current flowing through the coils of the stepper motor. In this waveform, the A phase and B phase operate in a complementary manner. One phase is energized with current, and the other phase is de-energized. When one phase is energized, the current rises to the specified magnitude, and when the phase is de-energized, the current drops back down.

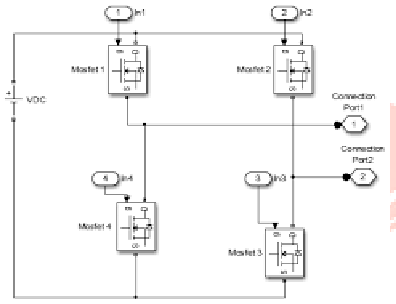


Fig:4 Hybrid model in Simulink

that we compared all the input motor voltage, current, torque, and speed [7]. Speed and torque look like an inverse proportion in this waveform. Figure (5) shows the input voltage and the magnitude of voltage is 25 volts. The input waveform is a square wave.in Figure (6) current is 0 to 1 sec. The current is steady state after 1 sec the current is dynamic state. The waveform takes time 2 cycles for stability. The Figure (5) shows the torque wave form. In Figure (6) the speed waveform increases from 0 to 6000. Time taken for the increase is 0.005 sec.

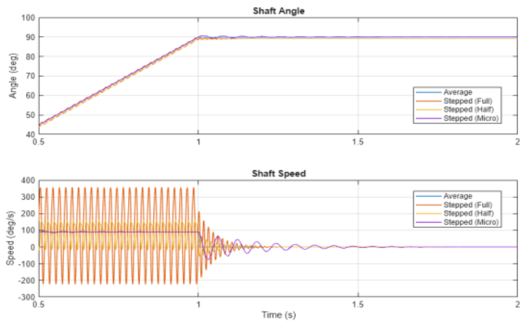
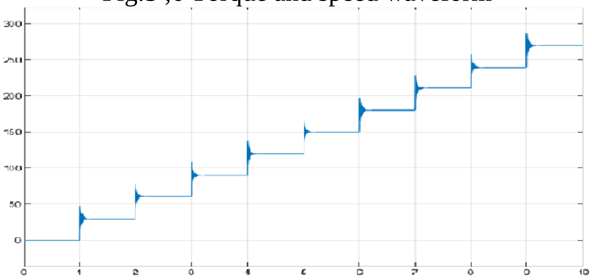


Fig:5 ,6 Torque and speed waveform



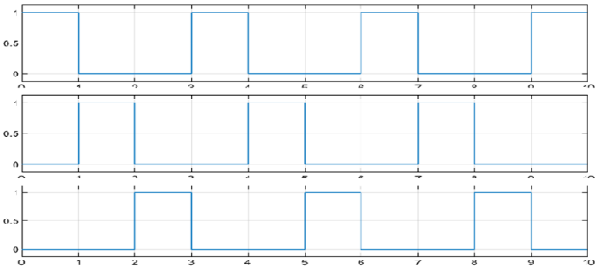


Fig:7 Step angle of pulse and output wave form

The major components in this diagram are the motor, battery, and IC ULN2004A. Its used for generating pulses for the stepper motor. The battery gives a supply to the motor. The resister controls the current[9]. This hardware implementation of the stepper motor. In this hardware Arduino Uno board 5 k ohm stepper motor: the primary actuator that converts electrical pulses into rotational movement. It has coils or phases that need specific signals to move. Battery: provides the power supply to the motor. Ensure it's suitable for the motor's voltage and current requirements. IC ULN2004A: A motor driver IC that acts as a buffer between the Arduino and the motor coils[10][11]. It amplifies the signals and handles the higher current requirements.

Fig:8 final hardware circuit of stepper motor

Components :

L293D Motor Driver
Arduino microcontroller
16X2 LCD Display
11.0592 MHz Quartz Crystal ,10KΩ Resistors
X 2 10KΩ POT 8x, 1KΩ Resistor Pack 33pF Ceramic Capacitors X 2 10µF/16V Capacitor Push Buttons X 4

Comparison of stepper and microcontroller

S/NO	CONVERTER	MICROCONTROLLER
1.	Uses hardware pulse generator circuit	Using the programing (software control)
2.	Motor runs at fixed speed	Motor runs at variable speed
3.	Limited control (basic stepping only)	Full control (direction,speed,stepping mode)
4.	Cannot easily change step angle (fixed operation)	Can control step angle indirectly (full/half/micro step)
5.	Less flexible, simple design	Highly flexible, more advanced and programmable

VII. CONCLUSION

This paper presented speed control of stepper motor using controller. There are many special purpose motors are available in market, like brush less dc motor, switched reluctance motor and servo motor. Comparing to all this special purpose motors stepper motor has special features, this is highly reliable and there no contact brushes in motor. This paper stepper motor simulation results are verified in MATLAB/Simulink. The verified results are speed, torque, and current. The steady-state simulation results are shown in results section.

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