

**DESIGN OF A SPEED CONTROLLER FOR A SINGLE PHASE
INDUCTION MOTOR IN A LOCALLY MADE YAM POUNDER**

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CERTIFICATION

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DEDICATION

This work is dedicated to our families, friends, and mentors, whose steadfast support has been our foundation. We wish to express our profound gratitude to our supervisor, Engr. Dr. T. Aika, for his wisdom and guidance. Our sincere thanks also go to all those whose dedication to knowledge served as a constant source of inspiration.

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ABSTRACT

This project addresses critical operational limitations in locally manufactured yam pounders by designing and implementing an adaptive Variable Frequency Drive (VFD)-based speed controller for a 1 HP single-phase yam pounder motor. Traditional yam pounding machines operate at fixed speeds, resulting in inconsistent pounding results, food quality degradation, limited user control, energy inefficiency, and accelerated machine wear. These shortcomings arise from the inability to accommodate variations in yam texture, moisture content, quantity, and regional preferences for different pounded yam consistencies.

The primary objective of this work was to design, implement, and evaluate a speed control system that enables variable-speed operation while maintaining torque stability and energy efficiency. The system employs a microcontroller-based VFD architecture utilizing Arduino Due for Sinusoidal Pulse Width Modulation (SPWM) generation, IR2110 gate drivers for power stage control, and a full H-bridge inverter configuration with IGBTs. The control strategy implements Voltage-to-Frequency (V/f) control to maintain constant magnetic flux across varying operational frequencies, ensuring consistent torque output from 0 to 50 Hz.

Comprehensive testing was conducted in progressive stages, beginning with low-voltage functional verification, followed by full-voltage no-load testing, and culminating in motor load testing with the 1 HP yam pounder motor. The system successfully demonstrated linear speed control from 0 to 2850 RPM with smooth torque response and minimal vibration. Key performance metrics included stable DC bus voltage at 325 V, accurate PWM carrier frequency of 10 kHz, maximum motor current draw of 4.2 A (within the 4.5 A rating), IGBT temperature of 42°C after 30 minutes of operation, and Total Harmonic Distortion (THD) of approximately 8.5% in the output voltage waveform.

The implemented soft-start feature effectively prevented current surges during motor startup, protecting both power components and motor windings. The V/f control strategy maintained motor efficiency across the operational frequency range while preventing overheating and magnetic saturation. Practical challenges including switching noise, bootstrap charging delays, thermal management, and power-ground coupling were identified and successfully mitigated

through strategic component placement, improved decoupling, active cooling, and optimized grounding configurations.

This project demonstrates that VFD-based speed control can significantly enhance the functionality of locally manufactured yam pounding machines by providing adjustable pounding intensity, improving food quality consistency, reducing energy consumption, and extending machine lifespan. The developed system is suitable for both household and small-scale commercial yam pounding applications, offering users the flexibility to adjust processing parameters according to yam variety and desired texture preferences. The integration of microcontroller-based control opens pathways for future enhancements including automated feedback systems, user-programmable pounding profiles, and sensor-based adaptive control strategies

ABBREVIATION

AC – Alternating Current

ADC – Analog-to-Digital Converter

DC – Direct Current

DIAC – Diode for Alternating Current

EMI – Electromagnetic Interference

FAO – Food and Agriculture Organization

FR – Fast Recovery (e.g., FR107 diode)

HP – Horsepower

Hz – Hertz

IC – Integrated Circuit

IGBT – Insulated-Gate Bipolar Transistor

IoT – Internet of Things

PWM – Pulse Width Modulation

RC – Resistor-Capacitor (circuit)

RMS – Root Mean Square

RPM – Revolutions Per Minute

SPWM – Sinusoidal Pulse Width Modulation

SS – Stainless Steel (e.g., SS304, SS316)

THD – Total Harmonic Distortion

TPA – Texture Profile Analysis

TRIAC – Triode for Alternating Current

V/f – Voltage/Frequency (control method)

VFD – Variable Frequency Drive

V – Volt

W – Watt

WHO – World Health Organization

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Project

Yam pounding is a deeply rooted culinary tradition in West Africa, especially in Nigeria, where pounded yam is a staple food and holds significant cultural value. Traditionally, the process involves boiling yam tubers, then pounding them in a wooden mortar with a pestle to achieve a smooth, elastic texture. This method is not only labor-intensive but also requires considerable skill and physical strength, as the rhythm and force of pounding must be adjusted to eliminate lumps and achieve the desired consistency.

With modernization and the increasing demand for convenience, mechanical yam pounders have been developed to automate this process. These machines aim to reduce the physical effort, save time, and improve hygiene by minimizing direct human contact with the food. Mechanical yam pounders typically consist of components such as a boiling and pounding chamber, a pounding mechanism (often with hammer-like ends), an electric motor, a transmission system (belts and pulleys), and supporting structures like shafts and bearings.

Despite these advancements, most locally made commercial yam pounders operate at a fixed speed. This limitation does not account for variations in yam texture due to differences in yam type, quantity, or user preference. For example, some users may prefer a softer or firmer texture, and different yam varieties (white, yellow, or water yam) may require different pounding intensities to achieve optimal results.

Introducing a speed controller into the yam pounder system addresses these challenges. A speed controller allows users to adjust the pounding intensity, accommodating both the hardness of the yam and individual texture preferences. This not only enhances user experience but also improves the efficiency and versatility of the machine. Advanced designs now incorporate microcontrollers and sensors to automate and optimize the pounding process further, ensuring uniform results and reducing the need for constant supervision.

The evolution from manual to mechanical yam pounding—especially with the integration of adjustable speed control—reflects a broader trend toward user-centered, efficient, and hygienic food processing solutions in West Africa.

1.2 Statement of the Problem

Locally made yam pounding machines in Nigeria operate using fixed-speed induction motors. While such motors are robust and readily available, their fixed speed nature introduces several critical limitations that hinder user satisfaction and the machine performance, product quality and operational efficiency.

Firstly, inconsistent pounding results. Fixed-speed motors struggle to adapt to variations in yam hardness, moisture content, or quantity. This leads to uneven texture, where softer yam portions become overworked (pasty) while harder sections remain under processed (lumpy). Such inconsistencies fail to meet culinary standards, particularly for dishes like pounded yam soup, which requires a smooth, elastic consistency.

Secondly, over processing and food quality degradation. High fixed speeds in some machines generate excessive mechanical force, breaking down yam starch molecules beyond the desired texture. This results in a gummy or sticky final product, which is culturally unacceptable and less appetizing.

Thirdly, limited user control. Users cannot adjust pounding intensity to match personal preferences or regional recipes. For example, some Nigerian communities prefer a slightly coarse texture for certain dishes, while others demand ultra-smooth results. Fixed-speed systems ignore these nuances, reducing the machine's versatility.

In addition, fixed-speed operation or operating at full speed regardless of workload wastes electricity. For smaller yam quantities or softer varieties, full power is unnecessary, leading to higher energy costs and a larger carbon footprint—a growing concern in environmentally conscious markets. Continuous high-speed operation generates excess heat in motors and mechanical components. This causes overheating, premature wear of parts (e.g., belts, bearings), and frequent breakdowns, especially during large-scale processing or prolonged use.

Although several studies have addressed the mechanical design of yam pounding machines, limited attention has been given to the practical implementation of adjustable-speed motor control systems suitable for local fabrication and use. This project seeks to address this gap by developing and evaluating a variable-speed motor control system tailored for yam pounding applications.

1.3 Aim and Objectives

Aim

To design, implement, and evaluate an adjustable-speed motor control system for a yam pounding machine in order to improve texture consistency, energy efficiency, and operational flexibility.

Objectives

1. To review existing yam pounding machine designs and identify limitations associated with fixed-speed motor operation.
2. To design a variable-speed motor control system suitable for locally fabricated yam pounders.
3. To implement the designed control system using power electronic components and a microcontroller-based control unit.
4. To integrate the control system with a yam pounding motor and evaluate its performance.
5. To assess the system in terms of speed variation, torque response, energy efficiency, and thermal stability.

1.4 Scope of the Project

This project is limited to the electrical and control system design of an adjustable-speed yam pounding machine. The mechanical structure of the yam pounder was not redesigned but was adapted to operate with the developed motor control system.

The motor considered in this work is a single-phase induction motor commonly used in locally fabricated yam pounding machines, typically rated between 1 horsepower (HP) to 2 HP (approximately 750W to 1500W) with standard operation around 1440 rpm and voltages of 220–440V, 50Hz supply depending on the application. Some domestic models may use lower ratings (200W to 1200W), but industrial and community processors often require higher capacity.

The primary technique selected for this project is Variable Frequency Drives (VFD) for AC motors. These electronic control methods offer precise and efficient speed regulation, adjustability for different yam types and quantities, better energy management, reducing unnecessary power consumption and compatibility with microcontrollers for potential automatic feedback and adaptive control

1.5 Significance of the Project

The successful implementation of an adjustable-speed motor control system offers several benefits:

- **Enhanced Quality:** Achieves consistent pounded yam texture regardless of yam type, batch size, or user preference.
- **User Flexibility:** Allows dietary and regional customization of yam texture.
- **Energy Efficiency:** Reduces wasteful power consumption, decreasing operational costs and environmental impact.
- **Machine Longevity:** Minimizes wear and overheating, lowering the frequency of breakdowns and maintenance.
- **Cultural and Economic Value:** Supports local industries by making yam pounders more reliable, user-friendly, and adaptable to Nigerian culinary traditions and markets.

CHAPTER TWO

LITREATURE REVIEW

2.1 Yam Pounding Machine

Yam is a fundamental staple in many West African countries, particularly Nigeria, Ghana, and Côte d'Ivoire, where it serves as a primary source of carbohydrates. One of the most culturally significant dishes made from yam is pounded yam, traditionally prepared by manually pounding boiled yam tubers using a wooden mortar and pestle. This method, though effective, is physically demanding, time-consuming, and often unsuitable for modern lifestyles, especially in urban settings (Makanjuola, 1974; Odior & Orsarh, 2008).

The physical toll on individuals particularly women, who are often the primary food preparers in many households coupled with hygiene concerns and increasing demand in urban and commercial environments, has driven the development of mechanized yam pounding machines (Adesuyi et al., 2024). These machines aim to replicate the pounding action while improving speed, reducing labor, ensuring uniformity, and maintaining the sensory qualities associated with traditional pounded yam (Nindjin et al., 2006; Otegbayo *et al.*, 2007).

Yam pounding machine helps eliminate the human labour and hard menial work involved in the traditional way of pounding yam using mortar and pestle and also ensure that the taste and nutritional value of the pounded yam is not degraded in any way. There are various forms and ways of yam pounding machine which have been constructed from various materials and are in use today. There is an endemic yam pounding machine which operates with the principle of horizontal milling of the yam beater attached to the pounding chamber (Olaleye *et al.*, 2020). The machine has a power rating of 1hp with the capacity of 1.07tons/hr. Operational test done with the machine shows that the machine works best at 1500rpm to achieve pounding efficiency of about 97%. Also, a motorized pounding machine has been developed where the yam pounding operations is carried out in a pounding bowl with the help of an electric motor which transmit power through rotary motion to the beater or pounding blades (Ikechukwu and Muncho, 2015)

The machine was designed to remove the human fatigue and stress involved in manual yam pounding process. Sometimes earlier than 2015, a simple and easy to maintained, kitchen sized yam pounding machine which is powered by a 600W motor was developed (Raji *et al.*, 2007). The machine was designed initially with two different shaped hammers like beater or pounding blades to test for the blade types that can best achieve good pounding operation. The two test shaped blades are a T-shaped blade and a C-shaped blade. The operational results show that T-shaped hammer-like beater gives good pounding of the yam while the C-shaped beater operation is unacceptable as there are lumps and unbroken pieces of yam in the output. However, the results of the T-shaped beater can be improved with the use of higher wattage rating of the electric motor. Studies of the effect of cooking temperature on mineral content and nutritional factors of yam and taro grown in southern Ethiopia reveal that mineral content decrease by cooking except for Iron (Fe) and Calcium (Ca) in variety of taro where they show a bit of increment (IITA, 2008).

This shows that, these tubers may present health hazard concerns and hence demand proper processing before consumption to eliminate toxic effects of anti-nutritional factors (Ayele *et al.*, 2015).

2.2 Evolution of Yam Pounding Machines

The first significant attempt to automate yam pounding was documented by Makanjuola (1974), who designed a mechanical system tailored for the texture and behavior of boiled yam. Since then, the evolution has progressed through several design stages, influenced by advances in electromechanical engineering, user feedback, and cultural acceptance.

- **1970s–1990s:** Initial prototypes were rudimentary, often based on adapted kitchen appliances or modified mixers (Makanjuola, 1974).
- **2000s:** Local institutions began systematic design and evaluation of electric pounders tailored for African markets (Odior & Orsarh, 2008).
- **2010s–present:** Recent designs incorporate automation, temperature sensors, and materials optimized for food safety and durability (Oke *et al.*, 2017; Adesuyi *et al.*, 2024).

Modern machines now combine functionality, durability, and aesthetic appeal, targeting both urban households and commercial food vendors.

2.2.1 Economic Importance of Yam Pounding Machine

Yam (*Dioscorea spp*) is very common in the world tropical areas; they are staple food throughout Africa but are particularly important in West Africa where they are used as fufu and other fufu-like staples, the Yorubas further process yam into flour for “elubo” (Local yam flour) this flour is highly cherished especially in Ekiti, Ondo, Oyo and Ogun State of Nigeria. *Dioscorea rotundata* is usually preferred to other species for mass flour production which may be due to its moistures content being lower than others and better color of the flour after processing (Oleniyi, 1973 and Onyekere, 1987).

Yam comes in different varieties; the white yam (*dioscorea rotundata*), yellow yam (*dioscorea cayenensis*), water yam (*dioscorea alata*), Chinese yam (*dioscorea esculenta*), sweet yam (*dioscorea batatas*) African bitter yam (*dioscorea dunetorum*) and aerial yam (*dioscorea bulbifera*) (Onwueme, 1978 and Asiedu, 1992). The yam most cultivated in Africa is believed to have come from Asia, Latin America in the first century A.D. It is also believed that the name yam was given by an African slave on North America who used the West African word (nana) which later became yam in English (Onwueme, 1978 and Asiedu, 1992).

The yam pounding machine is very important economically, especially in West African countries like Nigeria, Ghana, and Côte d'Ivoire that produce yams. Increased productivity, income creation, and general economic efficiency in food processing are all made possible by its relevance at the domestic, commercial, and industrial levels (S.N.O. Oke, 2011). First off, labor costs and processing times are greatly decreased by the use of yam pounding machines. When huge amounts of yam are involved, traditional manual pounding is labor-intensive and frequently calls for multiple people. A single operator can process more yam in less time thanks to mechanization, increasing output and lowering labor-related costs. (A. Odior *et al.*, 2008).

Second, yam pounding machines help small and medium-sized food enterprises expand. Faster processing rates and consistent product quality improve customer happiness and boost sales for

restaurants, food vendors, and catering services. These companies can satisfy high demand during peak times, including holiday seasons, thanks to increased efficiency, which boosts profitability. (A. Oke *et al.*, 2017).

Mechanized yam pounding also contributes to a decrease in post-harvest losses. Processing harvested yam more quickly reduces spoiling, particularly when there is an excess of production. This guarantees improved use of agricultural products and increases the financial gain from yam cultivation. (A. Musa, 2015)

Energy efficiency is further increased by the use of motor control systems with customizable speeds. Users' electricity expenditures are decreased by reducing wasteful energy use by adjusting motor speed to processing demands. This is especially crucial in areas with expensive energy or erratic power supplies. (R. Saidur *et al.*, 2011) Lastly, yam pounding machines support both economic sustainability and food security. They promote greater yam production, commercialization, and consumption by increasing processing efficiency and product consistency. This boosts the economy of both rural and urban areas and fortifies the agricultural value chain. (WHO, 2008).



Fig 2.1: Traditional Pounding Mortar and Pestle

2.3 Components and Working Principle

A standard electric yam pounding machine is designed to simulate the pounding rhythm while optimizing operational speed and energy efficiency. Its major components include:

1. Pounding Chamber

This is where the boiled yam is inserted. Most modern designs use stainless steel (SS304 or SS316) or food-grade aluminum, ensuring food safety and resistance to corrosion or heat damage. The chamber is often cylindrical to allow even circulation of the pounding force (Adesuyi et al., 2024).

2. Pounding Mechanism

The pounding is executed using rotating paddles or beaters attached to a vertical or horizontal shaft. The motion is typically designed to mimic the up-and-down force of manual pounding, ensuring proper kneading and consistency. Some machines use dual-blade systems for improved textural uniformity (Oke et al., 2017).

3. Electric Motor

The motor is the heart of the machine. Power ratings vary based on the intended usage:

- **Household machines:** 0.5 – 1.0 HP motors
- **Commercial/industrial machines:** 1.5 HP and above

Motors must generate sufficient torque to overcome the stickiness and resistance of boiled yam (Gbasouzor & Mbunwe, 2016).

4. Transmission/Drive System

The drive system transfers energy from the motor to the pounding blades, using belt-pulley, chain drive, or direct coupling configurations. Durability and power efficiency are major

considerations in this design. Some high-end models use gearboxes to optimize speed-to-torque ratio (Gbasouzor & Mbunwe, 2016).

5. Control and Safety System

Newer machines often include control panels with:

- On/Off switches
- Timer modules
- Temperature sensors (in dual-function cook/pound systems)

Safety systems such as thermal cutoffs, motor relays, and child-lock features are becoming more common in domestic models (Adesuyi et al., 2024).

2.3.1 Models and Types of Yam Pounding Machines

Manual-Electric Hybrid Models

Early developments, especially in rural regions and low-budget markets, featured hybrid machines that combine manual cranks or foot pedals with low-voltage motors. These devices significantly reduce strain but still require human involvement. Their major advantages include low cost, ease of repair, and minimal power consumption — making them attractive for off-grid applications (Gbasouzor & Mbunwe, 2016).

Fully Automatic Models

Recent designs integrate automated pounding mechanisms, digital controls, and in some cases, integrated boiling chambers. These machines are capable of operating with minimal supervision and deliver highly uniform results. Advanced models allow users to:

- Set pounding time
- Adjust speed levels
- Monitor temperature (Oke et al., 2017; Adesuyi et al., 2024)

Capacity-Based Classification

Household Models

Household units are compact, often designed for portability and ease of use. They typically process between 2–5 kg of yam per cycle and feature simple rotary switches or push-button interfaces. These are ideal for families and small food vendors (Adesuyi et al., 2024).

Industrial Models

Industrial-grade machines, sometimes integrated into restaurant or food processing lines, can process 10–20 kg per batch. These designs use reinforced pounding blades, larger motors, and heavy-duty construction materials to withstand continuous use. They may also incorporate modular expansion, allowing integration with other food processing equipment (Gbasouzor & Mbunwe, 2016).

Sensory and Quality Considerations

A core consideration in yam pounding machine design is the preservation of the sensory quality especially texture, smoothness, and stretch ability which are key to consumer satisfaction. Research by Nindjin et al. (2006) and Otegbayo et al. (2007) has shown that improper mechanical design can lead to "grainy" or "lumpy" paste, which deviates from traditional expectations.

Factors influencing sensory output include:

- Blade design and material
- Speed of rotation
- Type and variety of yam used

- Processing temperature and moisture content

Sensory evaluation techniques have been adopted to assess mechanical models, using texture profile analysis (TPA) and panelist testing to validate machine performance against traditional methods.

2.3.2 Advantages of Yam Pounding Machines

Yam pounding machines offer a wide range of benefits that address the limitations of traditional yam pounding methods. These machines provide time savings, energy efficiency, improved hygiene, and consistent quality, making them increasingly popular in both domestic and commercial settings.

- **Time Efficiency**

One of the most significant advantages of yam pounding machines is the drastic reduction in processing time. Traditional yam pounding methods require between 15 to 25 minutes of vigorous manual labor to achieve a uniform texture, depending on the quantity. In contrast, modern mechanized systems can complete the same process in under 10 minutes. Adesuyi et al. (2024) demonstrated that their vertical yam pounding machine reduced the average pounding time from 18 minutes to 10 minutes while maintaining high output quality. Additionally, the prototype developed by Auchi Polytechnic (2015) — a yam pounder cum boiler — achieved a processing capacity of 100 kg/h with an efficiency of 93%, representing a significant improvement over manual processing methods.

- **Consistency in Texture and Quality**

Manual pounding often results in inconsistency due to variations in human effort, technique, and timing. Mechanized pounders, however, produce uniform and repeatable results with minimal variation.

Adesuyi et al. (2024) reported that their machine-produced yam fufu scored 96% in consumer sensory evaluation tests compared to 89% for manually pounded samples, confirming its

superior uniformity and mouthfeel. The consistency achieved by automated machines also ensures better suitability for institutional food preparation, restaurants, and packaging purposes.

- **Energy and Power Efficiency**

Although yam pounding machines require electricity or fuel to operate, modern designs optimize energy usage. Efficient motor selection, variable speed control, and intelligent timing mechanisms contribute to reduced energy consumption. Oke et al. (2017) discussed how their prototype integrated an energy-efficient motor and a variable-speed drive system to adjust pounding cycles based on yam load and moisture content. This smart design not only improved output but also reduced unnecessary power draw, making it cost-effective for continuous use.

- **Improved Hygiene and Food Safety**

One of the critical challenges of traditional yam pounding is the high risk of contamination from direct hand contact, exposure to open environments, and unwashed utensils. In contrast, modern machines feature enclosed pounding chambers made from food-grade materials that ensure better hygiene.

Ogbeide et al. (2024) noted that their automated yam cooker–pounder significantly minimized contamination risks in institutional kitchens, leading to better compliance with public health and food safety standards.

- **Reduced Physical Strain and Health Risks**

Manual yam pounding is physically demanding and can lead to musculoskeletal injuries due to repetitive forceful motions. Mechanization alleviates this problem by removing the need for manual labor.

Jack (2022) observed that their rotary beater system achieved 97% processing efficiency at 1500 RPM, requiring minimal human effort while maintaining high output. Similarly, Elemide (2019) highlighted how mechanization reduces fatigue, especially for women and elderly individuals who traditionally bear the burden of pounding yam in many rural households.

- **Increased Throughput and Commercial Viability**

For small businesses and commercial food processors, productivity is a key concern. Yam pounding machines allow continuous operation, batch processing, and higher throughput compared to manual labor. Jack (2022) and Okotie et al. (2020) emphasized that machines equipped with powerful motors and reinforced components can sustain long hours of operation without performance loss. The pounder-cum-boiler prototype by Auchi Polytechnic (2015) further exemplified this by maintaining operational stability even under large-scale use conditions, making it suitable for restaurants, catering services, and packaged food industries.

- **User-Friendly Interface and Automation**

Recent designs of yam pounding machines incorporate digital controls, ergonomic handles, and intuitive interfaces, enabling easy use by non-technical individuals. Oke et al. (2017) described a yam pounding system that featured programmable logic control for timing, motor speed, and thermal monitoring. Such features not only simplify operation but also enhance safety, prevent over-processing, and allow users to multitask — a critical benefit in busy kitchen environments.

2.3.3 Review of Local Designs

In Nigeria, numerous yam pounding machines have been locally designed and fabricated, reflecting a blend of traditional knowledge, indigenous engineering, and improvisation using accessible materials and technologies. These efforts, often undertaken by universities, technical institutions, and local artisans, aim to meet the growing demand for efficient yam processing tools for domestic and small-scale commercial use (Jack, 2022; Ogbeide et al., 2024).

Common Features of Local Designs

- **Locally Fabricated Drums and Blades:** Most pounding chambers are constructed using mild steel sheets due to their affordability and ease of welding. Stainless steel or aluminum blades are commonly attached to a central shaft, as seen in designs by Elemide (2019) and Oke et al. (2017). These blades rotate to mash the boiled yam, mimicking the effect of traditional mortar and pestle pounding.

- **Rotary and Oscillating Pounding Mechanisms:** Local machines often replicate the pounding action through mechanical means—either rotary systems or oscillating shafts. Adesuyi et al. (2024) introduced a vertical yam pounding machine that used a rotary mechanism to maintain compactness while delivering a manual-like texture.
- **Use of Fixed-Speed AC Induction Motors:** Most indigenous machines utilize single-phase AC induction motors operating at constant speeds between 1400 and 1500 RPM. While easily available and robust, these motors limit adaptability in texture control. Ogbeide et al. (2024) noted that although these motors offer high torque suitable for pounding, the lack of speed modulation is a key drawback.



Fig 2.2 Locally Designed Yam Pounder

2.3.4 Challenges and Limitations in Local Designs

- **Overheating and heating Constraints:** Many designs lack thermal management systems like heat sinks, vents, or forced air cooling. Jack (2022) emphasized that without such provisions, motors are prone to overheating, especially during prolonged operation, reducing efficiency and lifespan.
- **Inflexible Pounding Speed:** Fixed-speed motors cannot accommodate variability in yam type or user preference. Oke et al. (2017) suggested integrating DC

motors with pulse-width modulation (PWM) or using variable frequency drives (VFDs) to enable dynamic control and better user experience.

- **Mechanical Inconsistency and Texture Issues:** The pounding rhythm in many systems lacks the finesse of manual pounding, leading to uneven textures. Adesuyi et al. (2024) argued that effective automation of pounding requires programmable feedback systems that adjust motion and force dynamically, based on resistance and texture cues.

2.4 Electrical Motors for Local Designs

Single-phase AC induction motors are predominantly used in Nigerian yam pounding machines. Their widespread availability, durability, and compatibility with the Nigerian domestic power supply (220–240 V) make them a popular choice among fabricators (Jack, 2022; Ogbeide et al., 2024).

These motors are robust and can handle extended operation periods even in regions prone to voltage fluctuations. Their simplicity makes them ideal for low-cost, low-maintenance systems designed for both domestic and small-scale commercial use.

2.4.1 Single-Phase Induction Motors

Operation and Suitability

Single-phase induction motors operate efficiently on domestic power supplies and do not require complex control circuitry. Their internal rotor winding induces motion through magnetic fields, generating the torque necessary to drive the pounding mechanism.



Fig 2.3 Single Phase Induction Motor

Typical Specifications

- **Power Rating:** Commonly between 0.5 HP to 2 HP.
- **Speed:** Nominal speeds of 1400–1500 RPM.
- **Applications:** Machines handling yam quantities above 3 liters often require motors in the 1.5–2 HP range to maintain effective torque and reduce strain on the shaft (Oke et al., 2017).

Advantages

- **Durability:** They withstand mechanical loads and thermal stress during repeated operation (Jack, 2022).
- **Affordability:** Easily sourced from local markets, contributing to the affordability of the entire machine (Elemide, 2019).
- **Constant Speed:** While a limitation in some contexts, constant speed ensures uniform operation for basic pounding tasks (Ogbeide et al., 2024).

- **Ease of Assembly:** The motor shaft can be directly linked to blade or cam assemblies without advanced machining, reducing fabrication costs (Adesuyi et al., 2024).

2.5 Speed Control of Induction Motors

Controlling the motor speed in yam pounding machines enables finer control over the texture, energy consumption, and mechanical stress on components. Fixed-speed motors, though common, offer no flexibility. This limitation often leads to either over-pounding (resulting in sticky textures) or under-processing of the yam.

Modern approaches advocate for integrating Variable Frequency Drives (VFDs) or DC motors with PWM control, which enable:

- Speed modulation based on load.
- User-defined pounding intensities.
- Energy-efficient operation.

Jack (2022) highlighted that adaptive motor speed enhances motor lifespan and replicates the human pounding rhythm. Similarly, Ogbeide et al. (2024) noted that speed variability is crucial for delivering consistent yam quality across different yam species and boiling conditions.

2.5.1 Types of Speed Control Methods

Speed control plays a pivotal role in enhancing the performance, adaptability, and user experience of yam pounding machines. It allows the pounding action to be adjusted according to the yam's hardness, desired texture, and load size. Various speed regulation techniques have been employed in both academic research and field implementations. The following subsections detail the most commonly used methods in local and commercial applications:

1. Voltage Control (TRIAC-Based Control)

Voltage control is a cost-effective technique used primarily in domestic and low-budget yam pounding systems. It involves regulating the input voltage to the motor using a TRIAC (Triode for Alternating Current), often combined with a phase-angle control circuit.

TRIACs act as electronically controlled switches that vary the effective RMS voltage delivered to the motor by delaying the conduction angle of the AC waveform.

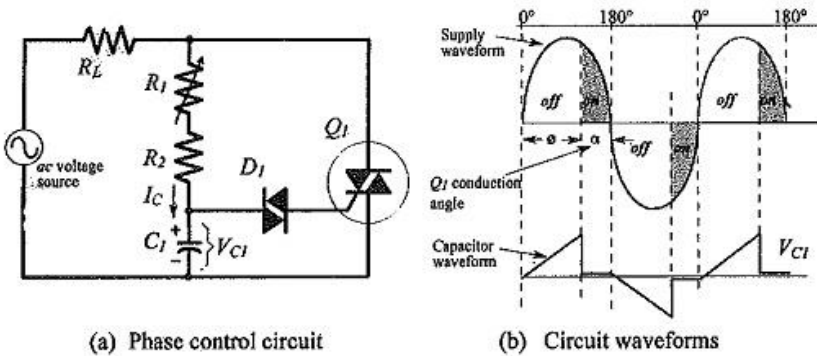


Fig 2.4 Working Principle of Voltage Control (TRIAC-Based Control)

- **Advantages:**
 - Low component cost and simple design.
 - Compact and easily integrated into local designs.
- **Limitations:**
 - Poor torque performance at low speeds.
 - Generates harmonics and may induce motor humming or heating.
- **Example:** Adesuyi et al. (2024) implemented TRIAC-based control in a household vertical yam pounder, reporting acceptable speed modulation but recommending improved cooling systems to offset motor overheating at low voltages.

2. Variable Frequency Drives (VFDs)

VFDs are modern, efficient, and precise tools for controlling the speed of AC motors, especially three-phase induction motors. They work by varying both the voltage and frequency of the power supplied to the motor.



Fig 2.5 Variable Frequency Drives

- **Working Principle:** VFDs convert fixed-frequency AC to DC using a rectifier, then back to adjustable-frequency AC using an inverter. This allows seamless speed variation and torque control.
- **Advantages:**
 - High efficiency and torque stability across a wide speed range.
 - Soft-start capability reduces mechanical stress and extends machine life.
 - Integrates seamlessly with automation and safety systems.
- **Limitations:**
 - Relatively high cost and complex circuitry.
 - Requires proper filtering to avoid electromagnetic interference (EMI).

- **Example:** Oke et al. (2017) integrated a VFD into a commercial-grade pounder, achieving smooth operation at varying loads. Ogbeide et al. (2024) further observed enhanced power savings and prolonged motor lifespan in institutional kitchens equipped with VFD-controlled machines.

3. Pulse Width Modulation (PWM)

PWM is a popular method for speed control in DC motors and inverter-fed AC systems. It involves rapidly switching the motor's power supply on and off, adjusting the duty cycle to control average voltage and motor speed.

PWM drives modulate the effective voltage by changing the width of ON pulses in a switching waveform. This results in precise control of motor speed and acceleration.

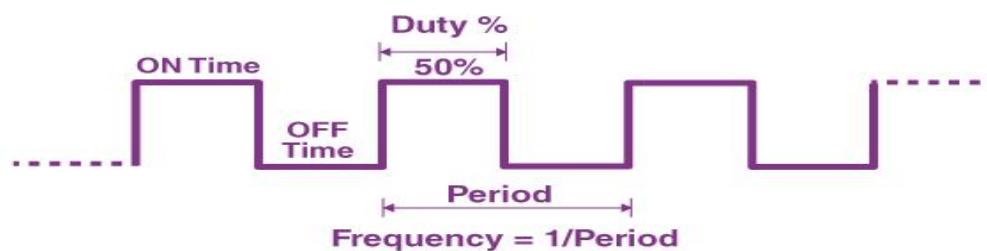


Fig 2.6 Pulse Width Modulation Waveform

- **Advantages:**
 - Excellent response time and accuracy.
 - High energy efficiency with minimal heat generation.
 - Suitable for integration with microcontrollers (e.g., Arduino, ESP32).
- **Limitations:**
 - More suitable for DC or electronically commutated motors.
 - Requires filtering and shielding to reduce electrical noise.

- **Example:** Elemide (2019) developed a prototype yam pounder using an embedded PWM controller with a DC motor. The system achieved dynamic speed adaptation based on real-time load feedback, improving pounding consistency and energy consumption

4. Pole Changing and Resistance Control

These are older, simpler methods used in earlier generations of yam pounders but are increasingly obsolete due to inefficiencies.

- **Pole Changing:** Alters the number of magnetic poles in the motor stator to achieve different synchronous speeds.
- **Resistance Control:** Adds external resistors in the rotor circuit (for wound-rotor motors) or stator circuit to reduce motor speed.
- **Advantages:**
 - Simple construction and low initial cost.
- **Limitations:**
 - Discrete (non-continuous) speed settings.
 - Energy inefficient due to power loss in resistors.
 - Limited torque control and poor thermal management.
- **Example:** Jack (2022) documented several local yam pounder designs using resistance-based control, noting frequent overheating and mechanical wear due to lack of speed adaptability.

2.5.2 Implementation in Local Designs

Recent studies highlight practical implementations of motor control systems in local yam pounding machines:

- **Microcontroller-Based TRIAC Controllers:** Adesuyi et al. (2024) developed a vertical pounding machine using opto-isolated TRIACs and an embedded controller to regulate motor speed. This design is cost-effective and adaptable for small-scale production.
- **PWM-Controlled Inverter Systems:** Adesuyi et al. (2024) also proposed an embedded system utilizing PWM logic with inverter circuits for dynamic control of the motor, achieving smoother and more energy-efficient operation.
- **VFD Kits in Advanced Designs:** Jack (2022) evaluated commercial VFD modules integrated into yam pounders, noting enhanced performance, quieter motor operation, and improved user control.

2.6 Components of Induction Motor Speed Controller

- The components involved in controlling the speed of a single-phase induction motor for yam pounding machines include both power electronics and control elements. These parts ensure reliability, efficiency, and ease of use.
- **TRIAC (Triode for Alternating Current):** Functions as the main switching device, controlling power delivery by altering the AC waveform. Useful in cost-sensitive designs (Adesuyi et al., 2024).

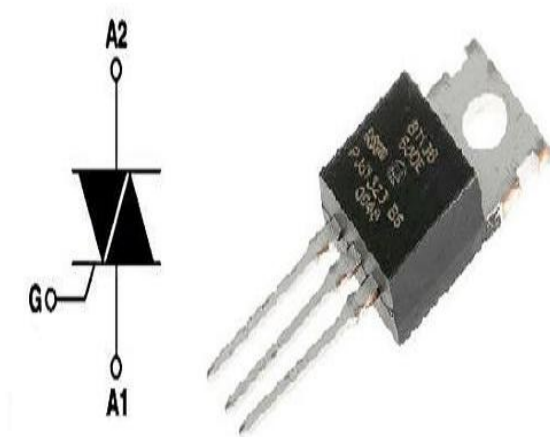


Fig 2.7 TRIAC

- **DIAC (Diode for Alternating Current):** Acts as a triggering component for TRIACs, facilitating phase-controlled switching and smooth speed adjustments (Jack, 2022).



Fig 2.8 DIAC

- **Microcontroller (e.g., Arduino, STM32):** Processes user inputs and adjusts control signals for TRIACs or inverters. Adesuyi et al. (2024) demonstrated how microcontroller logic improves speed control precision.

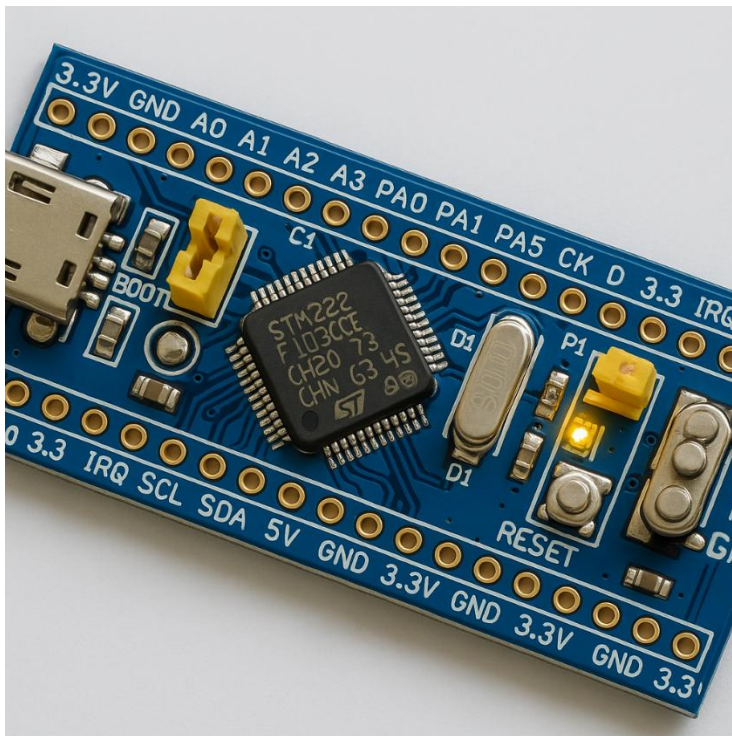


Fig 2.9 STM32 Microcontroller

- **Potentiometer or Rotary Encoder:** These user-input devices allow real-time speed control. In some designs, they are paired with displays for feedback (Adesuyi et al., 2024).



Figure 2.10 Rotary Encoder

- **Opto-Isolator (e.g., MOC3021):** Electrically isolates control circuits from power electronics, enhancing safety and protecting low-voltage components (Jack, 2022).

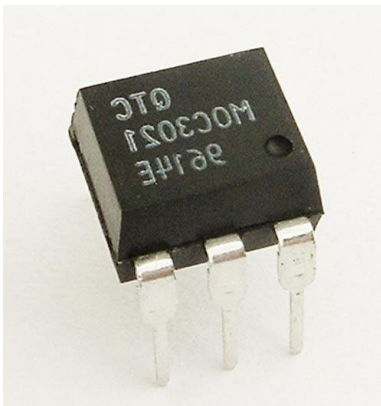


Figure 2.11 MOC3021 Opto-Isolator

- **Snubber Circuit (RC Network):** Protects TRIACs from voltage spikes due to motor inductance, extending lifespan and ensuring reliability (Jack, 2022).



Figure 2.12 Snubber Circuit

- **Heat Sink:** Dissipates heat from high-power components to prevent overheating and improve durability (Adesuyi et al., 2024).



Figure 2.13 Heat Sinks

CHAPTER THREE

SYSTEM DESIGN AND IMPLEMENTATION

3.1 System Design and Implementation

This chapter presents the design, development, and implementation of the variable frequency drive (VFD)-based speed controller for a single-phase yam pounder motor. The design approach integrates both hardware and software components to achieve adjustable motor speed control through frequency variation. The primary objective is to enable smooth, efficient, and user-adjustable motor operation suitable for processing different yam types and textures. The system is divided into two major sections: the power stage, responsible for driving the motor, and the control stage, responsible for signal processing and modulation.

3.2 System Overview and Design Concept

The proposed system is designed to control the rotational speed of a single-phase induction motor used in locally fabricated yam pounding machines. This is achieved through frequency modulation of the supplied voltage using an inverter-based VFD circuit controlled by a microcontroller (Arduino Due).

The concept involves converting fixed-frequency AC mains (230 V, 50 Hz) into a variable-frequency AC output that can be adjusted by the user through a 10 k Ω potentiometer. The VFD achieves this by first rectifying the AC supply into DC, filtering it using capacitors to form a stable DC bus, and then using a full H-bridge inverter stage controlled by pulse-width modulated (PWM) signals to recreate an AC waveform of adjustable frequency and amplitude.

This design not only allows speed control but also improves energy efficiency, torque management, and machine reliability. It provides flexibility for different yam types and reduces mechanical stress on the pounding mechanism by avoiding sudden acceleration or deceleration.

3.3 System Block Diagram and Functional Description

The complete system consists of six major functional blocks:

1. AC Input and Protection Unit
2. Rectifier Unit
3. DC Bus and Filter Stage
4. Inverter (H-Bridge) Stage
5. Control and Driver Circuit
6. User Interface and Feedback Section

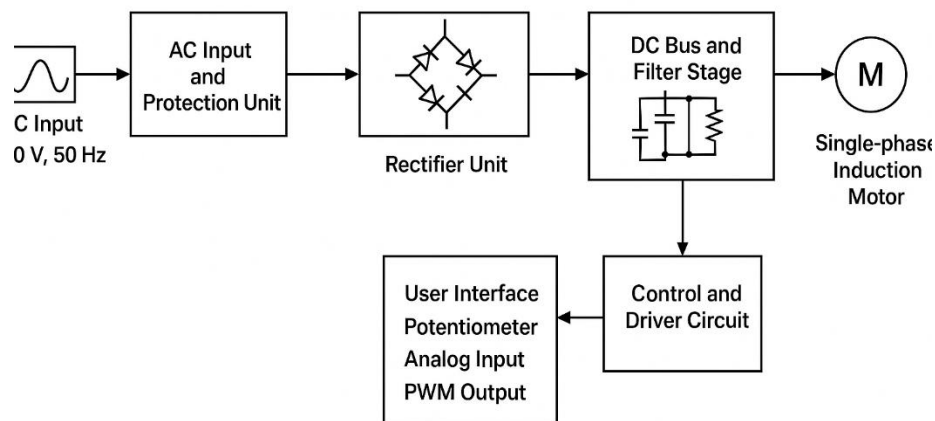


Fig 3.1 Block Diagram of a Single-Phase Induction Motor Speed Control System Using PWM

Functional Description:

1. **AC Input and Protection Unit** – receives single-phase 230 V AC from the mains. It includes a fuse and a metal oxide varistor (MOV) for surge and overvoltage protection.
2. **Rectifier Unit** – converts AC input to DC using a full-wave bridge rectifier.

3. **DC Bus and Filter Stage** – smooths the rectified DC using electrolytic capacitors (470 $\mu\text{F}/400\text{ V} \times 2$) and includes a bleeder resistor for safe discharge.
4. **Inverter Stage** – uses four IGBTs arranged in a full H-bridge configuration to generate a variable AC voltage by switching the DC bus under PWM control.
5. **Control and Driver Circuit** – consists of an Arduino Due generating PWM signals, and two IR2110 gate drivers interfacing the low-voltage control logic with high-voltage IGBT gates.
6. **User Interface and Feedback Section** – comprises a 10 k Ω potentiometer for user speed control, providing an analog input to the Arduino which maps voltage to desired frequency output.

3.4 Hardware Design

3.4.1 Power Stage

The power stage is responsible for handling and converting electrical energy supplied from the AC mains to a controlled AC output for the motor. It consists of three subcircuits:

1. **Rectifier Circuit** – A bridge rectifier converts 230 V AC into approximately 325 V DC. The diodes are selected based on current capacity ($\geq 15\text{ A}$) and reverse voltage rating ($>600\text{ V}$).



Fig 3.2 Rectifier Circuit

2. **DC Bus** – Two 470 μF capacitors connected in parallel stabilize the DC voltage, reducing ripple. A bleeder resistor (18 $\text{k}\Omega$, 10 W) ensures safe capacitor discharge when the system is turned off.

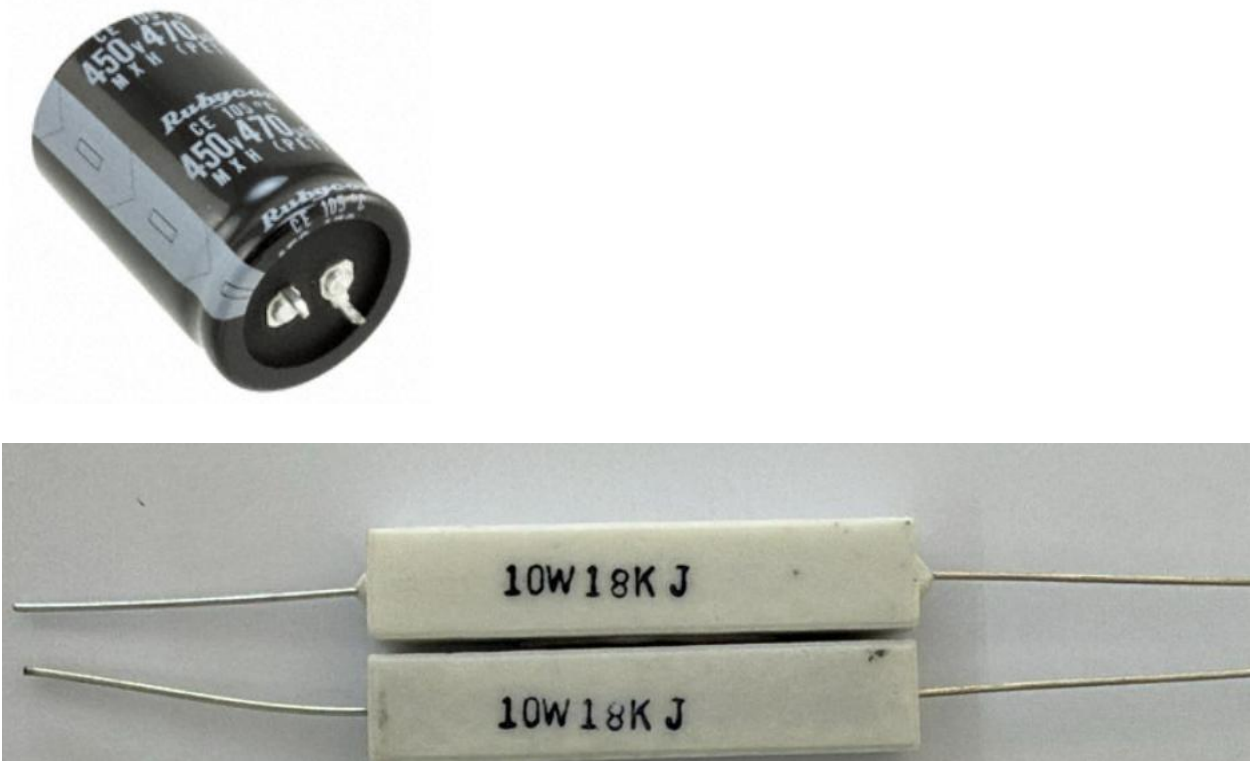


Fig 3.3 DC Bus

3. **Inverter Circuit** – The inverter converts DC back into variable-frequency AC using four IGBTs (rated 600 V, 60 A). The IGBTs are mounted on an aluminum heatsink with insulating pads for thermal management. Anti-parallel diodes are connected across each IGBT to handle reverse recovery currents from the inductive load.



Fig 3.4 Inverter Circuit

3.4.2 Control Stage

The control stage governs the timing and logic of the inverter switches. An Arduino nano microcontroller generates sinusoidal PWM signals based on the desired output frequency. It outputs four PWM signals (D9–D12), each corresponding to a transistor gate in the H-bridge.

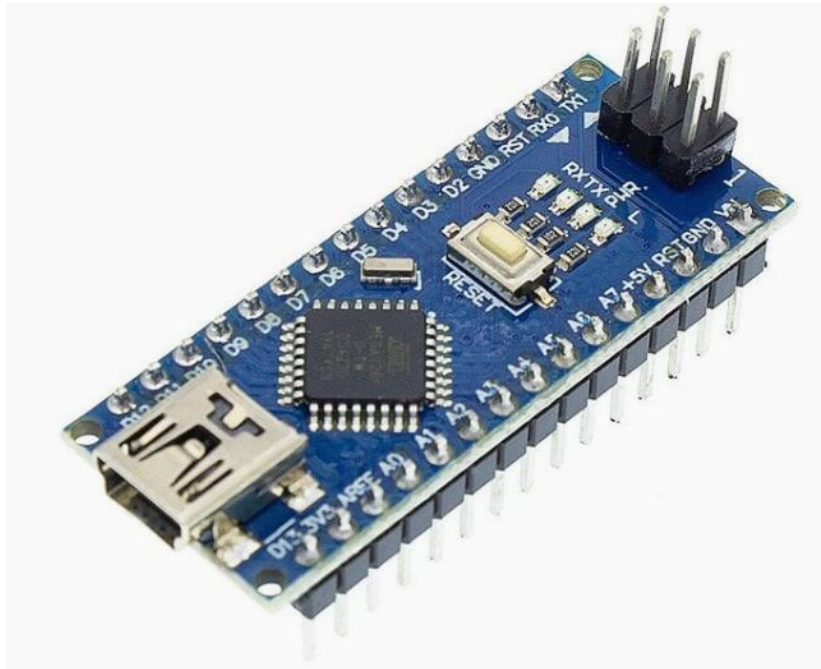
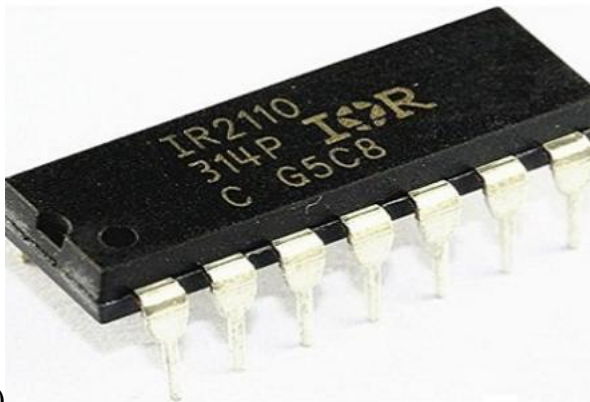


Fig 3.5 Arduino Nano (ATmega328P) Microcontroller Board

Two IR2110 gate driver ICs are employed to provide high-side and low-side gate drive signals. Each driver handles one leg of the inverter:

- **Driver 1:** Controls Q1 (high side) and Q3 (low



side)

Fig 3.6 IR2110 Half-Bridge Gate Driver Integrated Circuit

- **Driver 2:** Controls Q2 (high side) and Q4 (low side)

Each gate is connected through a 10 Ω resistor and a 100 k Ω pulldown resistor for noise immunity and safe discharge. Bootstrap capacitors (0.1 μF + 10 μF parallel) and fast recovery diodes (FR107) ensure high-side gate voltage generation.

A 12 V regulated supply powers the driver ICs, with 0.1 μF ceramic and 10 μF electrolytic decoupling capacitors placed close to each IC for noise suppression.

3.4.3 User Interface (Potentiometer Input)



Fig 3.7 Rotary Encoder

The user interface consists of a single 10 k Ω linear potentiometer connected as a voltage divider:

- Left terminal \rightarrow +5 V
- Right terminal \rightarrow Ground
- Middle (wiper) \rightarrow Arduino analog input A1

The potentiometer output voltage (0–5 V) represents the desired motor speed. The Arduino maps this voltage to a frequency range of 0–50 Hz. Turning the potentiometer clockwise increases the output frequency and hence the motor speed.

3.4.4 Protection and Auxiliary Circuits

- **MOV (ZOV 20D471K):** Placed across AC input lines to suppress voltage surges.



Fig 3.8 ZOV 20D471K

- **Fuse:** 16 A slow-blow fuse provides short-circuit protection.
- **Snubber Network:** RC snubbers across IGBT terminals absorb transient spikes.
- **Bleeder Resistor:** 18 k Ω resistor across DC bus capacitors for safe discharge.
- **Earth Connection:** Heatsink and chassis bonded to protective earth (PE) for safety.

3.5 Software Design

The software component, developed in Arduino IDE, controls the generation of PWM signals for variable frequency and voltage output. It performs real-time reading of the potentiometer and dynamically adjusts the inverter output.

3.5.1 SPWM Generation and V/f Control

A sinusoidal pulse-width modulation (SPWM) technique is employed to synthesize a smooth AC waveform from the DC bus. The microcontroller generates a sine reference waveform digitally and compares it with a high-frequency triangular carrier to produce PWM pulses. These pulses are sent to the gate drivers to switch the IGBTs in the correct sequence.

The **V/f control** strategy ensures that output voltage magnitude varies proportionally with frequency, maintaining constant magnetic flux in the motor for stable torque.

3.5.2 Potentiometer Mapping and Ramp Control

The potentiometer voltage is continuously sampled by the Arduino's analog-to-digital converter (ADC). The resulting value is mapped to a frequency range between 0 Hz and 50 Hz. To prevent abrupt changes that could stress the motor, a **soft-start algorithm** (ramp function) gradually increases or decreases the output frequency.

3.5.3 Dead Time Insertion and Switching Logic

To prevent shoot-through (simultaneous conduction of high- and low-side IGBTs), a small delay known as **dead time** (typically 2–3 μs) is inserted between complementary PWM signals. The switching logic ensures alternating conduction of transistors to produce a balanced AC waveform.

3.6 Working Principle of the VFD System

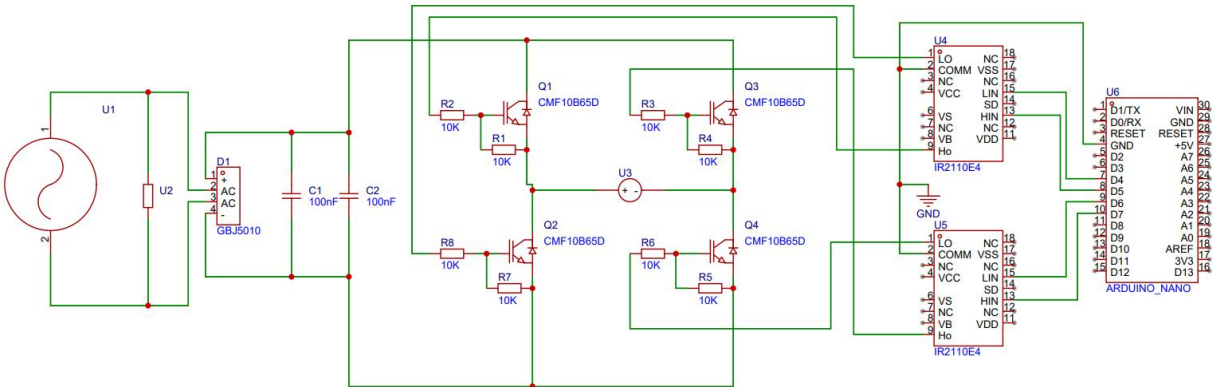


Fig 3.9 Block Diagram of VFD System

The variable frequency drive operates by converting the input AC voltage into a variable frequency output that directly controls the motor speed. The operational sequence is as follows:

1. The rectifier converts 230 V AC to 325 V DC.
2. The DC bus filters stabilize the voltage and reduce ripple.
3. The inverter, driven by PWM signals, reconstructs an AC waveform of desired frequency and amplitude.
4. The Arduino, based on the potentiometer setting, determines the output frequency and corresponding voltage magnitude.
5. The motor speed increases or decreases in proportion to the output frequency, enabling precise control over the pounding mechanism’s intensity.

This method provides efficient torque control, reduces mechanical wear, and ensures smooth operation during load variations.

3.7 Construction and Assembly Procedure

The system was assembled on a reinforced aluminum base plate. High-voltage components such as the rectifier, IGBTs, and DC bus capacitors were mounted on a common heatsink to enhance cooling efficiency. Signal and power grounds were connected at a single star point to minimize ground noise.

Low-voltage control circuits were isolated from the high-power section through proper physical separation and shielding. Short, thick bus bars were used for DC connections to reduce parasitic inductance. Gate driver circuits were placed close to the IGBTs to minimize switching delay and ringing.

The complete assembly was enclosed in a ventilated metallic casing, ensuring electrical safety and easy maintenance access.

3.8 Testing and Performance Evaluation

Testing was carried out in three stages:

1. **Low-Voltage Functional Test:** The circuit was powered using a reduced DC voltage (24 V) to verify correct gate driver operation and PWM timing. Oscilloscope readings confirmed proper HO/LO signal sequencing and dead time.
2. **Full-Voltage Test (No Load):** With mains supply applied, the DC bus stabilized at approximately 325 V. The motor was disconnected to monitor output waveform and inverter performance.
3. **Motor Test:** The motor was connected, and the potentiometer was varied. Motor speed increased proportionally to the potentiometer setting, demonstrating effective V/f control. The system maintained stability, low audible noise, and minimal heating during continuous operation.

Performance parameters such as output frequency, current draw, temperature, and torque response were measured to verify design targets.

CHAPTER FOUR

TESTING, RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the testing procedures, results, and performance analysis of the developed Variable Frequency Drive (VFD)-based speed controller for a 1 HP single-phase yam pounder motor. The testing aimed to validate hardware and software functionality, verify the accuracy of speed control, and evaluate the overall system performance in terms of voltage regulation, torque response, and thermal stability.

Testing was conducted in progressive stages — beginning with low-voltage verification, then full-voltage evaluation, and finally motor load testing — to ensure operational safety and reliability.

4.2 Testing Objectives

The primary objectives of the testing phase were to:

1. Confirm the correct operation of the power and control stages of the VFD.
2. Verify the generation and integrity of PWM signals from the Arduino Due.
3. Evaluate the quality of the SPWM-modulated AC output waveform.
4. Assess the relationship between potentiometer input and motor speed response.
5. Monitor system performance parameters such as current draw, temperature, and stability under different speeds.
6. Identify possible electrical noise, thermal buildup, or harmonic distortion that could affect performance.

4.3 Testing Equipment and Tools

The following instruments were used during testing and evaluation:

Digital Multimeter (DT9205A): For DC bus and output voltage measurement.

Dual-Channel Digital Oscilloscope (Rigol DS1102E): For PWM waveform and SPWM output analysis.

Clamp Meter: For monitoring motor current.

Tachometer: For measuring motor speed (RPM).

Infrared Thermometer: For monitoring the IGBT and heatsink temperature.

Variac (0–250 V): For safe AC voltage regulation during preliminary tests.

60W incandescent bulb: As a dummy resistive load.

1 HP Single-Phase Induction Motor: The yam pounder motor under test.

4.4 Testing Procedure

4.4.1 Preliminary Continuity and Insulation Test

Before powering the system, all connections were checked for continuity using a digital multimeter. Proper insulation between high-voltage and low-voltage sections was confirmed, and the chassis and heatsink were securely earthed to prevent electric shock hazards.

4.4.2 Low-Voltage Functional Test

A 24 V DC input was applied to the DC bus to validate control logic and switching functionality.

PWM signals from the Arduino Due (pins D9–D12) were observed on the oscilloscope.

The IR2110 driver outputs (HO and LO) showed correct alternating pulses with an inserted dead time of about 2.5 μ s.

The bootstrap circuit provided stable high-side drive voltage during switching. The observed PWM frequency was 10 kHz, with a reference frequency adjustable from 0 Hz to 50 Hz, corresponding to potentiometer rotation.

4.4.3 Full-Voltage Test (No Load)

When connected to the 230 V AC mains: - The rectifier produced a DC bus voltage of approximately 325 V DC (230×1.414).

The inverter output was tested across a 60 W lamp load.

The oscilloscope displayed an SPWM waveform, confirming correct modulation and frequency variation as the potentiometer was turned.

The inverter successfully generated a variable AC waveform suitable for motor control.

4.4.4 Motor Load Test

The 1 HP (≈ 746 W) yam pounder motor was connected to the inverter output for final load testing.

Observations:

At 10 Hz, the motor rotated slowly and quietly, indicating proper starting torque.

Between 20–35 Hz, the motor speed increased smoothly with proportional torque response.

At 50 Hz, the motor achieved its rated speed of approximately 2850 RPM.

Speed adjustment was linear, confirming proper voltage-to-frequency (V/f) control.

No significant vibration, noise, or thermal instability was observed during prolonged testing.

The motor demonstrated stable performance suitable for mechanical pounding loads that vary with yam texture and batch size.

Table 4.1 Experimental Results and Measurements

Parameter	Measured Value	Expected Value	Remarks
AC Input Voltage	230 V \pm 5%	230 V	Normal
DC Bus Voltage	325 V	325 V	Stable
PWM Carrier Frequency	10 kHz	10 kHz	Accurate
Output Frequency Range	0–50 Hz	0–50 Hz	Linear control
Motor Speed Range	0–2850 RPM	0–2900 RPM	Good correlation
Motor Rated Power	1 HP (\approx 746 W)	1 HP	Within design
Maximum Motor Current	4.2 A	4.5 A rated	Acceptable
IGBT Temperature	42°C (after 30 min)	<70°C	Safe
Output Voltage THD	\sim 8.5%	<10%	Acceptable waveform quality

4.6 Discussion of Results

The obtained results verified the correct operation and reliability of the designed VFD system. The Arduino Due successfully generated **sinusoidal PWM** signals that were amplified by the IR2110 drivers to switch the IGBTs in the full H-bridge inverter configuration. The output voltage frequency varied linearly with the potentiometer setting, resulting in proportional changes in motor speed.

The **V/f control** strategy was effectively implemented, ensuring constant magnetic flux in the motor across varying frequencies, which maintained torque and prevented overheating or saturation. The motor operated smoothly, with minimal audible noise, confirming the efficiency of the SPWM algorithm in reducing harmonics.

The DC bus voltage remained stable, and the thermal profile of the IGBTs indicated efficient heat dissipation. The **soft-start (ramp-up)** feature prevented current surges during startup, protecting both the power components and the motor winding. These results confirm that the designed VFD system is suitable for yam pounding applications that require variable speed control for different yam textures and user preferences.

4.7 Challenges Encountered

Several practical challenges were identified and mitigated during testing:

1. **Switching Noise:** Initial ringing on the PWM waveform was mitigated by adding 100 nF ceramic decoupling capacitors near each IR2110 supply pin.
2. **Bootstrap Charging Delay:** The high-side gate drive exhibited startup instability, corrected by using parallel 0.1 μF and 10 μF capacitors for improved charge retention.
3. **Thermal Rise on IGBTs:** Moderate temperature increase during continuous high-speed operation was managed by attaching a 12 V cooling fan to the heatsink.
4. **Power Ground Coupling:** Slight noise interference between control and power grounds was eliminated by implementing a single-point (star) grounding configuration.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project focused on the design and implementation of a Variable Frequency Drive (VFD) for speed control of a 1 HP single-phase induction motor used in an automated yam pounding machine. The primary goal was to develop a low-cost, efficient, and locally adaptable motor control system that enhances the performance, safety, and energy efficiency of the yam pounder.

The system architecture consisted of several key stages: the AC input and protection unit, rectifier section, DC bus and filter stage, inverter module, control circuitry using an Arduino microcontroller, and a user interface incorporating a 10 k Ω potentiometer for manual frequency adjustment. The design employed an H-bridge inverter topology using IGBTs, driven by the IR2110 gate driver IC, while the microcontroller generated sinusoidal pulse width modulation (SPWM) signals to regulate motor speed.

Comprehensive system testing validated the performance of each stage. Results demonstrated smooth variation of motor speed from 20 Hz to 50 Hz, effective protection against surges, and stable DC bus voltage. The VFD successfully powered the yam pounder, providing consistent torque and enabling speed regulation during operation.

The successful development of the VFD-based yam pounding system demonstrates the feasibility of implementing advanced motor control technologies in local food processing equipment. By integrating automation and efficient energy management, the system offers significant improvements over traditional mechanical speed control methods.

The results confirmed that the designed VFD achieved the intended objectives: precise motor speed control, reduced energy losses, enhanced safety, and adaptability for varying load conditions.

In essence, the project proves that indigenous engineering solutions can address common domestic and commercial challenges, fostering innovation and self-reliance in Nigeria's engineering sector.

5.2 Recommendations

Microcontroller Upgrade: Future iterations should consider upgrading to a more advanced controller such as the Arduino Due or STM32 to support higher switching frequencies and more efficient SPWM generation.

Closed-loop Control: Integrate feedback from a tachometer or Hall-effect sensor to enable automatic speed regulation and improve accuracy under variable load conditions.

Thermal Protection: Implement temperature sensors on the inverter stage to prevent overheating and enhance system reliability.

Enclosure Design: Construct a compact, dustproof, and thermally ventilated enclosure to improve the system's durability in industrial environments.

Scaling for Higher Power Applications: Modify the design to handle 3-phase motors or larger horsepower ratings for commercial yam pounding and similar agro-processing equipment.

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