ASHESI UNIVERSITY

DESIGN OF A LOW-COST AUTOMATION SYSTEM FOR A BLOCK MAKING MACHINE

CAPSTONE

B.Sc. Electrical & Electronic Engineering

Tubare Kolah

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical & Electronic Engineering.

Tubare Kolah

2021

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

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I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor's Signature:

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Supervisor's Name:

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Abstract

The paper discusses a successful design of an Atmega328p based programmable logic controller (PLC). It describes how to use the PLC to fully automate a semi-automated block-making machine to provide a cheap and efficient alternative for Small Scale Enterprises in the block-making industry in Ghana. It also describes how to interface with a VFD which can be employed to good advantage for energy conservation.

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Chapter 1: Introduction

1.1 Introduction/Background

The block making industry in Ghana consists of mainly Small and Medium Enterprises (SMEs) [1]. They produce and serve building and construction companies with various masonry units such as concrete blocks and bricks. These SMEs often use semi-automated block-making machines that still require human inputs at some stages of the production line. There are instances where the mortar is mixed manually. It also requires a person to collect the block when it comes out from the machine. The most important part is the control of the machines, which human operators do. Human errors are inherently common in a production process that involves that much of manpower activities. The operators timing of critical activities is a major source of errors. They determine when the mould – a rectangular box that mortar goes in to be compressed – is full. With this, the chance of producing blocks of slightly different sizes is high. The operators also decide the compression time of the block – an amount of time pressure is exerted on the mortar to form the block. There is also the tendency of mortar not been thoroughly mixed when it is done manually. These inherent errors in the production process affect the quality of the blocks. Low-quality blocks are potentially dangerous and can cause failures in building structures. Boateng[2] identified low-quality materials as one of the major causes of the rampant collapsing of building infrastructures in Ghana.

Moreover, human fatigue hinders the productivity of the firms. Machines are quicker and effective in performing strenuous tasks such as mortar mixing and packing of the blocks. In a case where these activities are manual, production can only be increased by hiring more worker. It is costly and often less productive from the economic perspective, especially when the workers are crowded. The efficient alternatives are much expensive for Small and Medium Enterprises. It cost a lot of money to import fully automated machines.

Additionally, there has been a consistent power crisis in Ghana over the past ten years[3]. In the face of rapid economic growth, high industrialization, and the extension of rural electrification, the power utility company struggles to meet the recent national demand. Using highly efficient loads is one sure way that will reduce the power demand. Aside from that, minimizing the energy consumption rate will translate into a reduced operational cost. The unit price of concrete blocks will decline as production cost lowers, thereby improving affordability.

1.2 Problem Definition

The small-scale enterprises in the Ghana block-making industry need a simple and affordable, fully automated block-making machine to enhance their efficiency and productivity. It will enable them to produce high-quality blocks at affordable prices that low-income earners can afford.

1.3 Objectives of the project

- Implement low-cost, fully automated block making machine using low-cost cost PLC.
- Improve energy efficiency by using variable frequency drives.

1.4 Expected outcomes of the project

Based on the project objectives, the expected outcome is a low-cost version of a fully automated simple block-making machine. It runs on a low-cost Atmega-based PLC. Another desired outcome is a product that is power efficient in its operation. The solution uses variable speed drives to improve power efficiency.

1.5 Justification/Motivation for project topic

The motivation for the project comes from the desire to help the SMEs overcome the challenge of securing an efficient and productive machine by designing a locally made low-cost version for them. The current unit price of concrete blocks in Ghana ranges from GH₵ 2.50 to GH₵ 3.00, which is not very affordable for the homeless poor people. It is worthful contributing to making housing as cheap as possible. There have also been reports of rampant collapsing of building partly due to low-quality materials. The solution will improve the quality of the masonry units – one of the primary causes of building failures in Ghana.

1.6 Research Methodology

The research was carried out mainly through qualitative and quantitative research methods. The qualitative research focused on a literature review of journal and review papers, components datasheets, YouTube videos, and science discussion forums. The quantitative research method was undertaken through simulation of various circuit parts. Breadboard testing of some of the components was also carried out before a PCB was made and soldered.

1.7 Materials/Components used

The various materials required for the complete implementation of the project include a functional semi-automated block-making Machine, variable frequency drives, power transformers, Arduino based Programmable logic controller PLC. The PLC design requires inductive relays, solid-state relays, Atmega328P-PU, optocouplers, operational amplifiers, FT232RL, MAX485, screw terminal connectors, transistors, capacitors, and resistors.

1.8 Scope of Project

The project builds on an existing machine, implying that the block-making machine's mechanical design is not in the project's scope. The focus is on designing a PLC and integrating the PLC with the motors to achieve complete automation. The low-cost PLC is also built from scratch. The use of VFD is also justified in the quest to improve energy efficiency. The software part of the project relies on open-source software, OPEN PLC, that compiles ladder logic diagrams for the Atmega328p.

Chapter 2: Literature Review

2.1 Brief History Block-making machine.

The invention of block-making machines to simplify the concrete block-making process dates to the 1850s. Palmer developed the first commercial block-making machine for sandcrete blocks in 1900 [4]. It could make hollow blocks of adjustable sizes. This machine was improved in 1904, which consisted of a vertically placed core for easy removal of the blocks. However, the blocks produced varied in consistency and quality, and three men working at top speed made only 200 blocks in a 10-hour day. Herman Besser invented the first automatic block-making machine by incorporating a mixer, a skip loader, and a self discharger[5].

2.2 Existing Technologies.

2.2.1 Manual block machine

It uses manpower for most of the vigorous activities. The working staff mix the mortar and feed it into a mould. The compression is simple; a flat, heavy metal hits the mortar against the mould to compress it. Cost-wise it is the cheapest because of low maintenance cost and no electricity bills. It is suitable for rural areas without electricity. It also requires no skilled labour to operate it. However, it has the lowest productivity most error prone machine among the rest.

Figure 1 shows an example of the manual block machines.

Figure 1 Manual block-making machine

Source: Adapted from [7]

2.2.2 Semi-automated block-machine

The semi-automated machine is a bridge between manpower and full automation. Most of the strenuous activities are performed by motors, leaving mainly the control features which an operator handles. The timing control is still subjected to human errors and fatigue. However, this method is much more efficient than the manpower approach. It is a midbudget design between the manpower and the fully automated machine. The output per day is higher than the manually operated machine but less than the fully automated system. Figure 2 shows a semi-automated block-making machine.

Figure 2 Semi-automated block making machine

Source: Adapted from [7]

2.2.3 Fully automated block machines

Fully automated systems have every process automated from start to finish. A mortar mixer mixes the mortar in a rotating chamber. The mortar comes out through a valve after being thoroughly mixed. It travels to the mould on a conveyor belt, and sensors prompt the conveyor to stop when the mould is full. A hydraulic press takes over and compresses the block. Another hydraulic cylinder pushes the blocks out onto a dispatch carrier. The carrier takes them to a safe place for curing and drying. The machine has the highest output per day and makes the best quality blocks. However, these machines are much expensive. They also require highly skilled personnel to perform routine checks and maintenance on them. The running cost is relatively high. It is costly to operate in rural areas where it runs on fuel generators. An example of a fully automated block-making machine is shown in figure 3.

Figure 3 Fully automated block-making machine

Source: Adapted from [7]

2.3 Review of Papers

The block-making industry has evolved through series of improvements in how the block machine is designed. The recent trend towards automation of the machines is driven by the rising demand for high-quality blocks in large quantities. In a review paper, Singh and Kumar describe a simple automation process on how to produce building blocks using fly ash [5]. Flyash is a lightweight biproduct of thermal power plant. One of the objectives was to find a better way of managing the waste from the power plant, and another was to do that cost-efficiently. The design uses an industrial PLC, sensor feedback, and actuators – motors and hydraulic cylinders to achieve full automation of the process. The PLC controls the switching of the motors and solenoid valves based on sensor inputs and button press. It also gives a detailed description of the flow chart and ladder logic program that the PLC runs on. However, industrial PLC is quite expensive today. It also uses a circular rotating table in place of a conveyor belt common in many designs. The rotating table is suitable for lightweight materials and small distances. Another drawback is that it does not also include a dispatch system.

Ayyappan et al. [6] gave a detailed design of a hybrid-powered automatic compressed stabilized earth brick-making machine. It uses solar power – a green source of energy – in place of burning kiln o lessen the carbon footprint. It also utilizes a hydraulic power pack consisting of an A.C. motor, pump, and piston cylinder. The motor has a two-way power source. One is from the grid, and another one is from the solar modules. The pump connects to the shaft of the A.C. motor. The system consists of three hydraulic cylinders. The main one compresses the soil moisture, the second one pushes out the compressed earth brick when done, and the third opens and closes the mould box. Three solenoid valves control the movement and direction of the three cylinders. Magnetic sensors attached at vantage points help to locate the position of the piston. An industrial PLC links all these components together in a ladder logic program to achieve some level of automation. It was not a fully automated machine as it did not consider the mixing process and conveying the mortar mixture. Nevertheless, it still gives an insight on how to reduce cost by using hydraulic cylinders and solenoid valves instead of induction motors.

Furthermore, George et al. also developed an improved version of the low-cost semi-automated block-making machine [7]. Figure 4 shows the complete design they came out with. It uses two hydraulic cylinders instead three in most cases. Employing gravity to good advantage, one of the hydraulic cylinders could compress the block in one direction and eject it in the reverse direction. The design in [5] has two cylinders for the same tasks. Its moulding chamber is adjustable to allow changing of moulding plates in order to produce blocks of different shapes and sizes. It can also make blocks with and without grooves. Considering a safety factor of

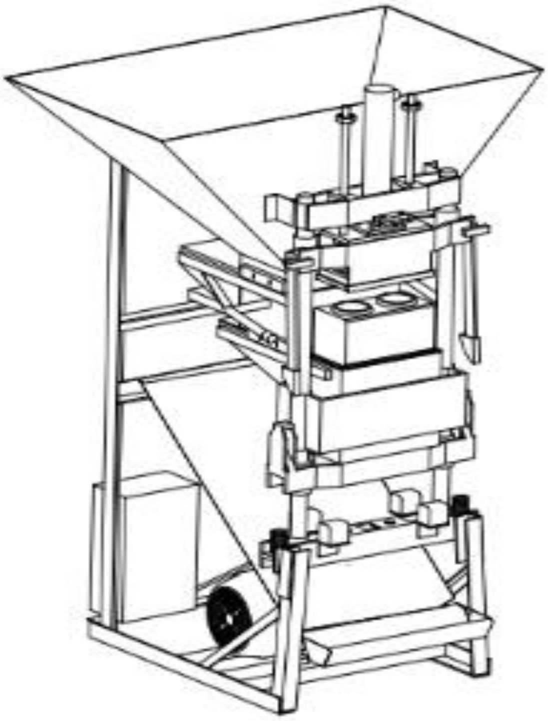

Figure 4 Diagram of the semi-automated block machine designed in [7]

Source: Adapted from [7].

five (5), the chamber has up to 50MPa yield strength. It also has a hopper in the form of truncated triangular pyramid that temporally holds mortar for the feeder. It opens at the top to allow the influx of mortar from a conveyor or a person. Below the hopper lies the feeder. The mortar mixture from the hopper enters the mould through the feeder. It is fixed and allows the exact amount of mortar that the mould can take.

The hydraulic system consists of two double-acting hydraulic cylinders, a motor, pump, and valves. The motor connects to the pump. The two cylinders controlled by the solenoid valves also connect to the pump. One of the cylinders moves in the X-direction to push out the pressing box while the other moves in the Y-plane to press and eject the block. The motor, together with the pump, provides the working pressure to control the two cylinders. The vertical cylinder is ingeniously oriented to take advantage of gravity. The downward movement compresses the mortar mixture while the retraction of the ram rejects the block.

Chapter 3: Design

3.1 Existing Design

From the literature, most of the semi-automated block machines have common basic functional components. They primarily include an induction motor, a pump, at least two hydraulic cylinders and solenoid valves, moulding chamber, feeder, hopper, and body frame. The additional components required to achieve full automation of the system are discussed below.

3.2 Mortar Mixer

Instead of a person manually mixing the mortar, the mortar mixer does that. It has a stirring shaft connected to an induction motor. Induction motors are generally low-cost and simple to use due to their self-starting ability. They are rugged for dusty condition. They also require less maintenance due to the absence of brushes, commutators, and slip rings. Due to the large inertia of the mortar at the start, the motor needs to have high starting torque. An ideal motor will be a capacitor-start induction motor. However, the main objective is not to design the mixer from scratch. Other equally suitable motors that the mixer is shipped with may suffice. Figure 5 shows an example of a commercial Mortar mixer.

Figure 5 Mortar Mixer

Source: Adapted from [9].

3.3 Conveyor Belt

The conveyor belt takes the mortar from the mixer to the hopper. Operating unidirectionally and at constant torque and speed, a typical single-phase induction motor can provide the torque need. Alternative options like brushless DC motors and gear motors exist. But these are most suitable for high precision and higher speed application. A functional low-cost conveyor belt such as the one in figure 6 will be enough.

Figure 6 Portable Conveyor Belt

Source: Adapted from [10].

3.4 Proximity sensor

The distance sensor detects when the mould is full and sends a signal to the PLC. These sensors come in three categories: ultrasonic, infrared and laser sensors. The ultrasonic type is a low-cost but small range sensor. The others have higher precision and a wide range but more expensive. An ultrasonic sensor of a 2m range will be sufficient. It has to be a bit distant from the moist and dust particles. One of the industrial ultrasonic sensors is shown in figure 7.

Figure 7 Ultrasonic 4-20mA Sensor

Source: Adapted from [12].

3.5 Variable Frequency Drive VFD

Apart from providing power to the motor, the drive also controls the speed of the motor. It has an energy-saving advantage for variable torque loads. The torque required varies as the square of the speed, while power varies as the cube of the speed. Since the power reduction is much significant than that of the torque for reducing the speed, operating the motor at a slightly lower speed saves considerable energy. Constant load torque applications like the conveyor belt do not obey the centrifugal law. Usual starters such as Direct Online Starter, Star-Delta starters and Soft Starter will be best for saving cost. However, VFDs offers smooth speed control ability. The VFD will run the conveyor at are low and desired speed. Figure 8 shows a typical VFD that can perform the task.

Figure 8 Delta Variable Frequency Drive

Source: Adapted from [11].

3.6 List of additional components

The specific additional components proposed to be used are listed in Table 1. These components were in stock on indiamart.com as of 27th April 2021.

Table 1 Additional Components for full automation

Components	**Description**
JQ350 Mortar Mixer	It has 5.5KW single-phase induction. Its full capacity of 350L is quite enough. It is simple and requires less maintenance.
Portable Conveyor Belt	It has a single-phase replaceable induction motor. It is portable and user-friendly. It is mechanically robust with low maintenance.
5hp to 10hp Delta Variable Frequency Drive	It is a low-cost drive. It supports Modbus communication. It accepts both 0-10V and 4-20mA signals. It can be powered from a single-phase or three-phase source. The rated power is enough to power each of the motors.
UR18.DA0.2-IAMJ.9BF Ultrasonic sensor	It is a low-cost sensor with a 4-20mA output signal. It is rugged for industrial application. Its range of 70mm to 1m is sufficient for this application.

3.7 Programmable Controller

The PLC's role is to integrate all these components sequentially to achieve full automation of the system. It offers timely and reliable instructions to the out devices based on data it reads from the input devices. It should be able to control the single-phase induction motors of the mixer and conveyor belt through the VFD. It should also be able to read the analogue input signal from the sensor. Modbus communication is an advanced functionality required when the slave devices become too many to interface using pinout connection.

3.8 Context Diagram

The context diagram in figure 9 provides a visual representation of the setup. While the black arrows indicate the electrical connection, the red arrows show the flow of the mortar. The two curved black arrows indicate the connection between the PLC and the solenoid valves.

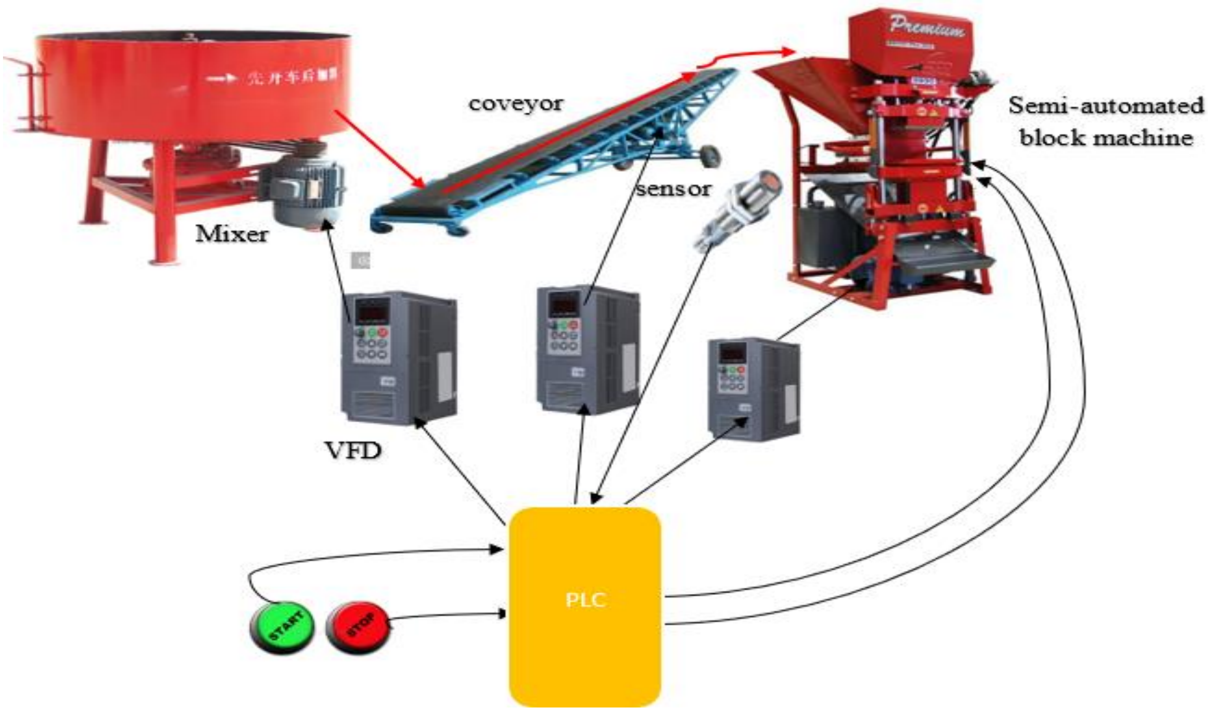

Figure 9 Context Diagram of the System

3.9 Block Diagram of the Electrical Wiring

Figure 10 shows how the electrical components connect. The output signals from the PLC points outwards while the input signals point inwards. The VDF receives three signals from the PLC, of which one controls the speed while two determine the direction of rotation of the motors. The PLC reads input signals from the pushbuttons and the proximity sensor. It sends out digital signals to the solenoid valves to activate the hydraulic cylinders.

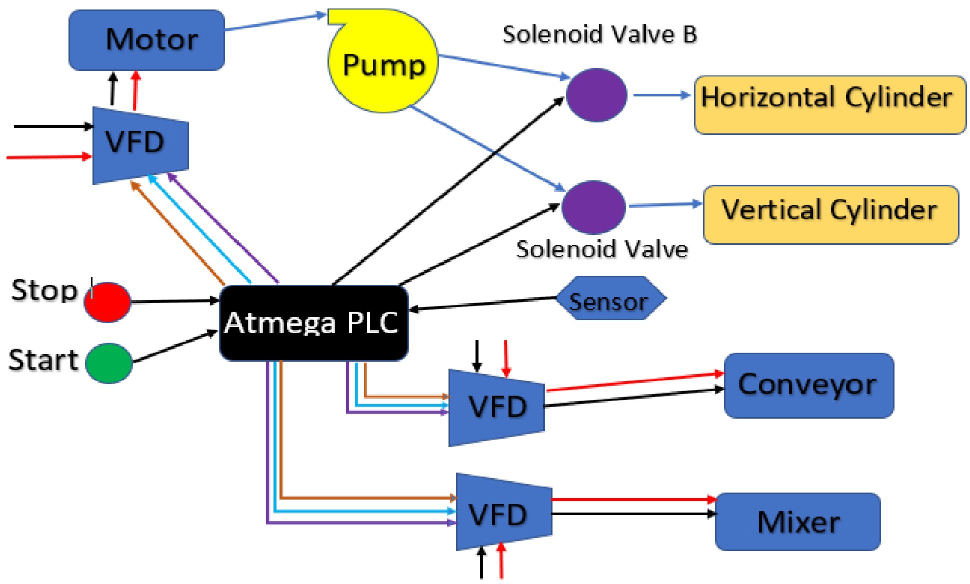

Figure 10 Block diagram showing an overview of the wiring of the components.

3.10 Chart Diagram

In a much-simplified description showing in figure 11, the process starts when the start push button is pressed. The mortar starts mixing, and when it is done, it goes to the conveyor, which takes them to the mould. The conveyor stops to allow for compression of the mortar. After a few seconds, the block is ready, and it is removed and taken away for curing. The cycle repeats and only breaks when the stop button is pressed. Figure 12 presents a detailed outline of how the program executes. Both the motor and the mixer start as soon as the start button turns on. While the motor, together with the pump, accumulates the working pressure, the mixer stirs the mortar mixture. The conveyor belt starts when the mortar is ready. Mortar comes to the

mould until it gets full, then the sensor triggers the PLC to stop the conveyor. Now two conditions must be true for the hydraulic press to start; the mould must be full, and valve A must be activated. The same applies to the hydraulic cylinder that dispatches the block. While dispatching the block, the conveyor starts filling the mould again. The blue arrows showing in figure 8 indicate two simultaneous events. The system finally quits when the stop button is pressed.

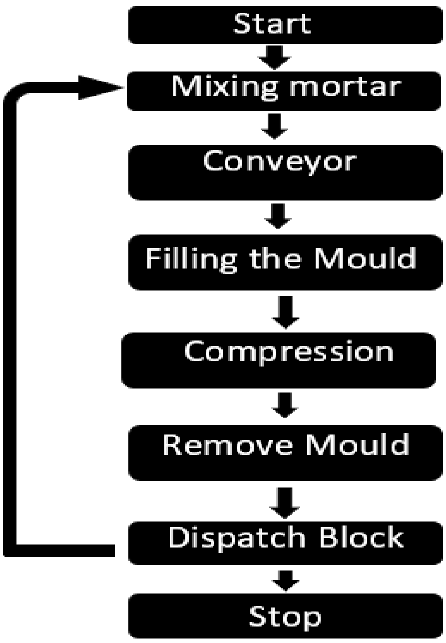

Figure 11 Simple flow chart diagram

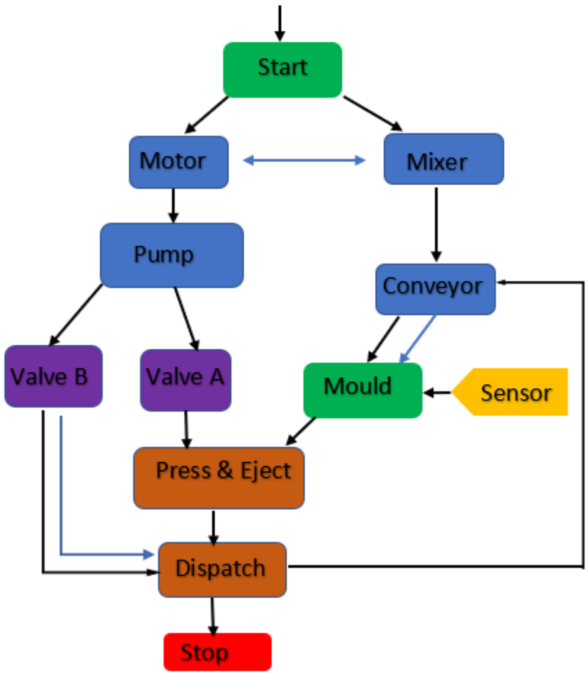

Figure 12 Detailed Flow chart diagram

3.11 Design of the low-cost PLC

The PLC needs to have the essential functionalities to be able to coordinate all the activities. The most common VFD can receive a control analogue voltage input of 0-10VDC or analogue current input of $4 - 20mA$. The design will consider a $4 - 20mA$ output control signal from the PLC. It has a simple circuit and very reliable due to the absence of losses. Aside from the $4 - 20mA$ output, the PLC also need to have digital outputs for specifying the direction of the motors and also for controlling the solenoid valves. Most Delta VFDs take digital inputs at 24VDC. Another required feature is the ability of the PLC to read digital inputs above 5VDC. The pushbuttons and other digital inputs often produce input signal above 5VDC, but the Atmega328p can only tolerate up to 5.5VDC. It also has to read the analogue current input from the ultrasonic sensor in the range of $4 - 20mA$. For situations where the PLC needs to control multiple devices beyond five, the Atmega328P pinout is not enough to do that. However, it supports Modbus communication can help reduce the complexity of extending the input-output pin. Finally, the PLC should have the ability to be powered socket's AC power of DV power source between 24VDC and 40VDC. It also needs to be programmed and reprogrammed through serial communication. Table 1 summarises all the basic functionalities.

Table 2 Functional units of the PLC

Functionality	**Description**
Ten digital outputs at 24V	Input to the VFD and solenoid valves.
Five 4-20MA output	Speed control signals to the VFD.
One 4-20mA analogue reader	Read the analogue signal from the ultrasonic sensor.
Digital input	Monitor start and stop pushbuttons.
Modbus Communication	Interconnect more devices if the need be.
USB Support	For programming the microcontroller.
Power supply	For powering the MCU and other electronic components.

3.12 Design choices.

In a pool of many components, the following choices are considered for the design of the PLC.

3.12.1 Atmega328P-PU

It is a low-cost and low-powered Atmel microcontrollers. Its fourteen I/O are enough to interface all the external devices. The size is suitably enough, and it is easy to programme. It comes with a watchdog timer to free up the microcontroller in lockup conditions for safety precautions. There are other Atmel chips with even more I/O but are a little bit expensive. PIC16F866 can also do except that it does not have in-circuit serial programming ICSP ability. Unlike the Atmel chips, its programming is quite involving. Another capable microcontroller is KLZ25. It has a faster speed and more pinout than the Atmega328p, but it is much more expensive. From the purge chart showing in Table 3, Atmega328p is the most suitable among the list of the microcontrollers.

3.12.2 Inductive Relay

It is an inexpensive electrical switch operating by the principles of electromagnetic induction. It consists of coil and contact. When the coil is energized, it closes a normally open contact, thereby switching a load of higher current demand. The Atmega328P cannot control the VFD with 20 mA at 5V from its pin. Instead, the small current energizes the coils, and VFD receives a signal at 24V. However, it is bulky and occupies ample space on the PCB. It also has a shorter lifespan compared to other alternatives.

Table 3 Purge chart of Microcontroller selection

Criteria	**Atmega328p**	**PIC16F866**	**KLZ25**	**Atemega2560**
Low-Cost	+2	+2	-2	-1
Reprogramming	+2	-1	+2	+2
Speed	+1	+2	+2	+1
I/O pins	+1	+1	+2	+2
Total	**+6**	**+4**	**+4**	**+4**

3.12.3 Solid-state Relay

Unlike the electromechanical relay, the solid-state relay is sizable and has no moving parts. As such, it has a longer lifespan and switches at a much higher frequency. It can also handle up to a hundred amperes. But it is more expensive than the electromechanical relay.

3.12.4 Optocoupler

Optocoupler is an electrical switch. It has complete isolation of current between the two circuits. It is suitable for the digital reading of the pushbuttons as a protection mechanism.

3.12.5 L358N

It is a low power dual operational amplifier with a high input impedance and open-loop gain. It is specifically selected for its high input impedance and low power. The 4-20 mA signal to the VFD can be produced using an Opam-transistor combination with a 250-ohm resistor.

3.12.6 FT232RL FTDI

It is an integrated circuit that is used to interface between the computer and the Atmega328p. It converts the USB signals to UART signals to enable serial communication between the P.C and the ATMEGA328P.

3.12.7 MAX485

It is a low power transceiver for RS-485 and RS-422. For the PLC to interact with slave devices connected to it through Modbus communication, it needs a transceiver to interface between the PLC and its slave devices.

3.12.8 16MHz crystal oscillator

The microcontroller needs an oscillator for precise and accurate timing.

3.12.9 Voltage regulators

Voltage regulators maintain a constant voltage at the output for a range of input voltages. The VFD requires 24V, the LM358 is powered with 12V and the microcontroller and relays take 5V. L7824CV, L7812CV and L7805CV regulators output 24V, 12V and 5V, respectively.

3.12 Wiring between VFD and Motor

The datasheet of the delta drive recommends the power supply passes through a fuse, contactor, and line reactor to the input of the drive. The fuse protects against inrush current, while the line reactors improve power factor, reduce harmonics, and protect against AC surge. As shown in figure 13, the drive can take three-phase power through L1, L2, and L3 and supply three-phase power through T1, T2, and T3. It can also take single-phase and give out three-phase power, as shown in figure 14. The motor can take single-phase power from the drive regardless of whether single-phase or three-phase power is input. Figure 15 shows an example. The drive also has forward and reverse switches that control the direction, as shown in figure 13. The speed control signal can come from a 0 -10V or 4-20mA supply. It can also be Modbus input indicated as RS-485 in figure 13. SG+ and SG- are interfaces for connecting to the master device during the Modbus communication.

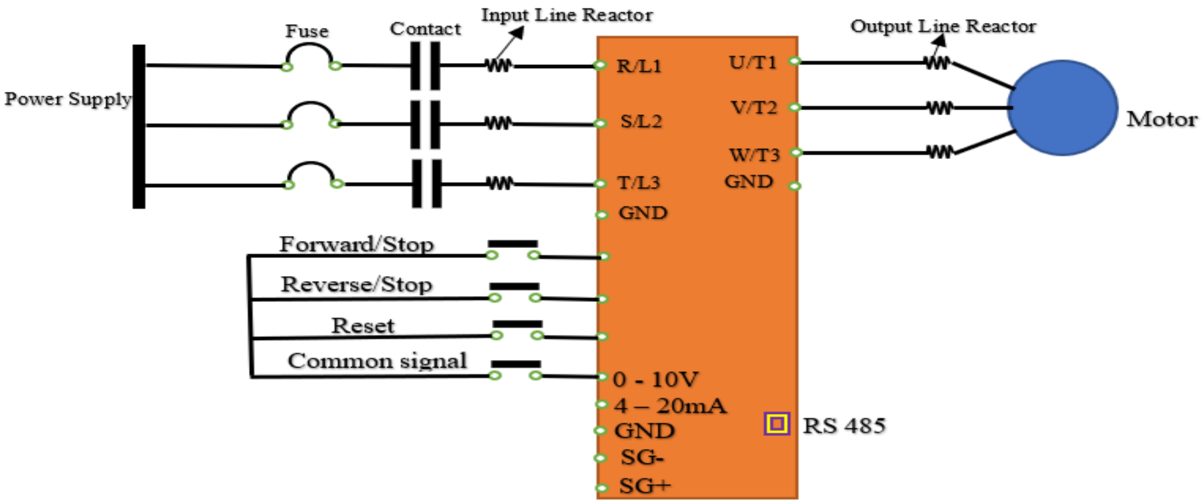

Figure 13 Three-phase supply to the Delta drive and three-phase output to motor.

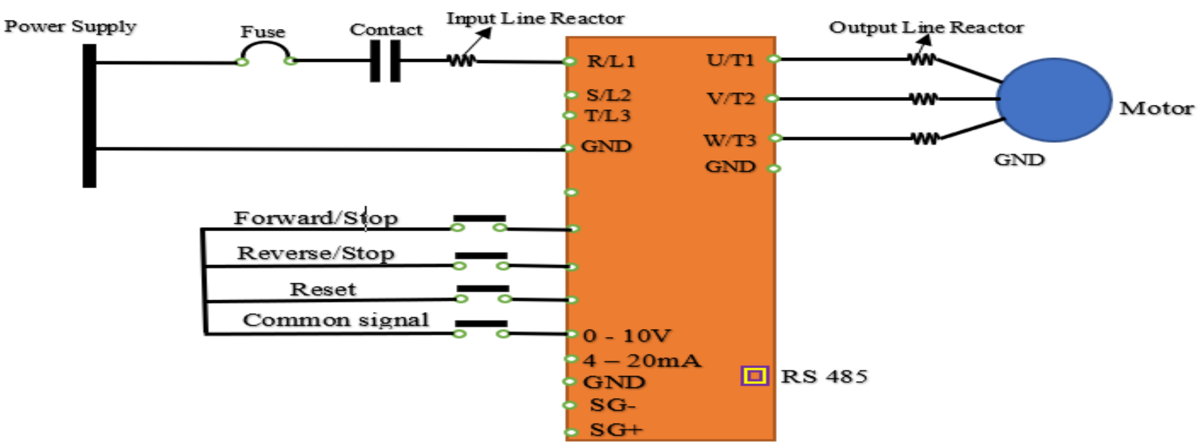

Figure 14 Single-phase Input to the Delta drive, three-phase output to motor.

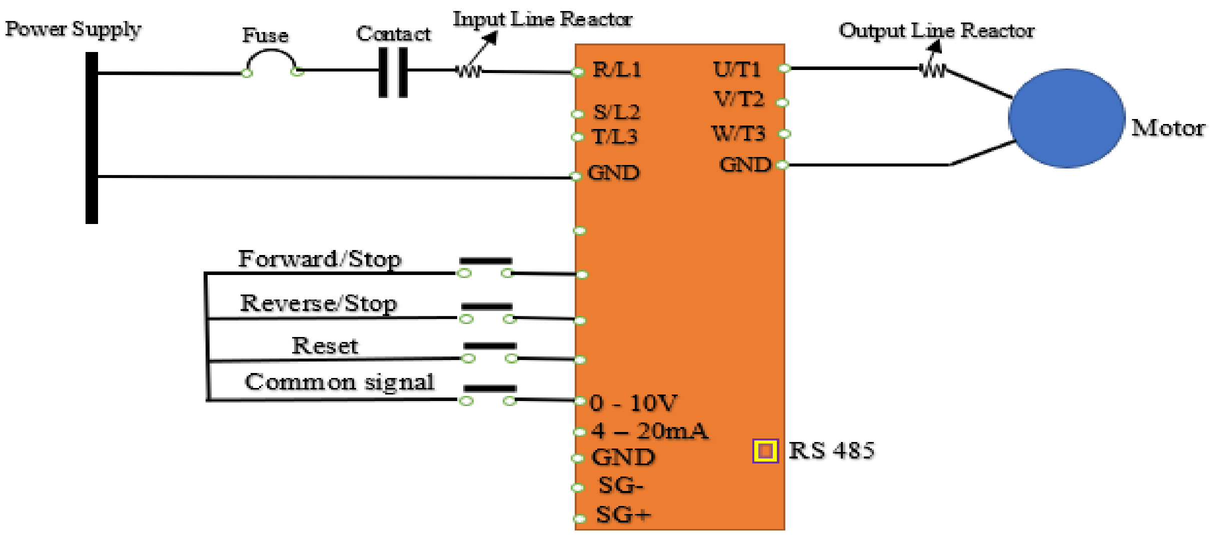

Figure 15 Single phase to Delta drive, Single phase to motor

Sizing of the Drive

The correct sizing of the driving is very crucial for smooth operation. The motor nameplate comes with rate voltage and full-load amps. (FLA) indicated. The VFD should be the rate at least as high as the FLA of the motor. While overload capacity of 110% - 120% of FLA is recommended for variable torque loads, constant torque application such as the conveyor belt should be sized at an overload capacity of 150% – 160% of overload current.

Chapter 4: Implementation

4.1 Overview of Components Network

Figure 16 shows a block diagram of how the various electronic components interconnect in the PLC design. The arrowheads indicate the direction of the signal. Each subsection interacts with an I/O pin of Atmega328p.

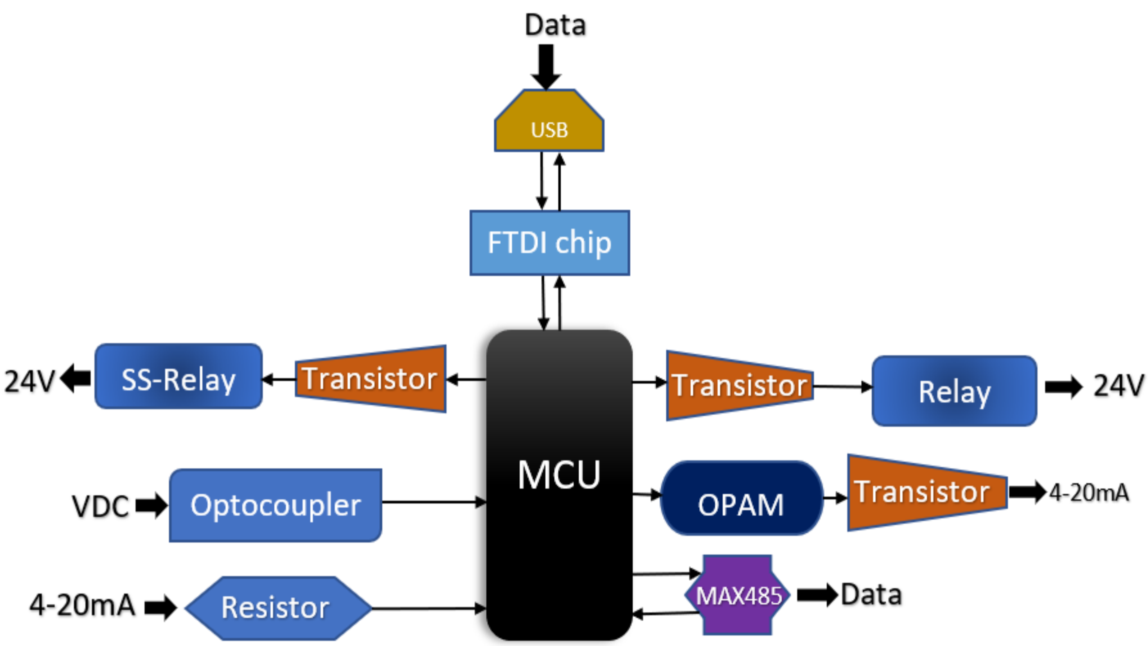

Figure 16 Block diagram of PLC overview

4.1.2 Basic Atmega328p Setup

The Atmega328p datasheet recommends a 5V power source for the Chip. It also takes a 16MHz crystal oscillator connected to the pins PB6 and PB7 with 22pF to the ground. The reset pin connects to a push button to 5V through a resistor. The L7805CV voltage regulator provides a stable 5V power source. The figure 17 shows the setup of the components.

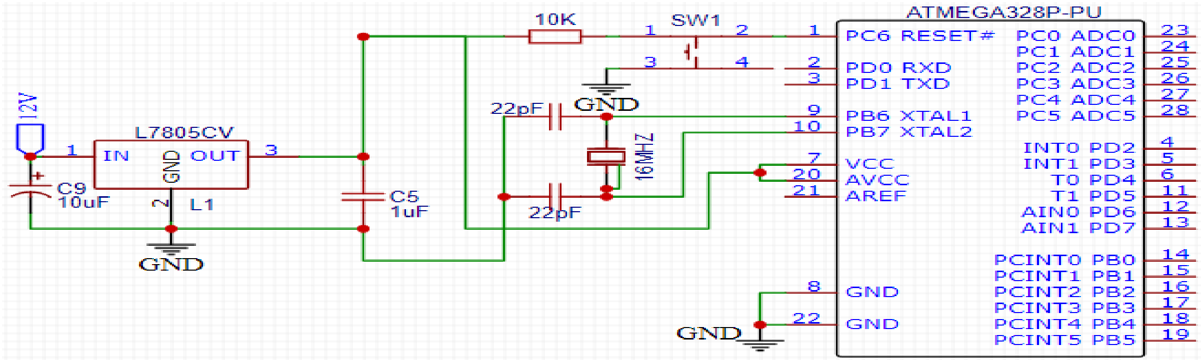

Figure 17 Basic setup of Atmega328p

4.1.3 UART Serial communication circuits

The USB type C is connected to the FT232RL integrated circuit, as shown in figure 18. FT232RL converts USB signals to UART signals to allow communication between the PC and the microcontroller. It eliminates the need for an external programmer. The FT232RL datasheet recommends the 5.1K ohms resistor and 100nF capacitor showing in the circuit.

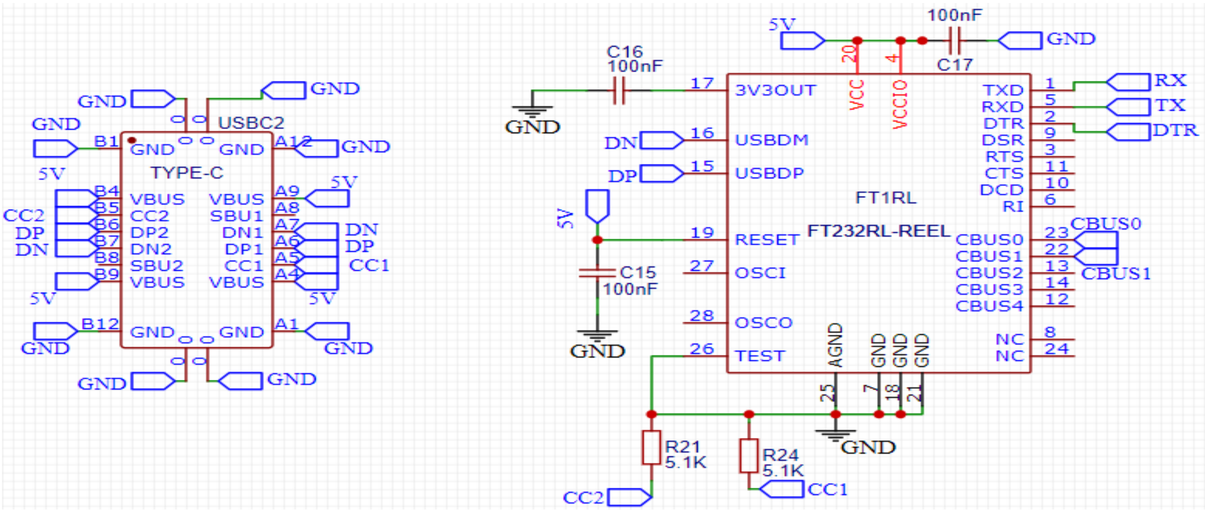

Figure 18 Wiring of FT232RL to USB Type C

4.1.4 Digital Output

The 5V from the digital output connects to the base of the 2N2222 transistor through a 10K resistor. The emitter is grounded while the collector connects to one coil of the SRD-05VDC-SL-C relay. The other coil goes to 5V. The common terminal of the relay connects to 24V to supply the 24V to the VFD when the coils are energized. The normally open (NO) and normally closed (NC) connect to screw terminal connectors. A diode across the relay coils prevents the backflow of current. The circuit connection is shown in figure 19.

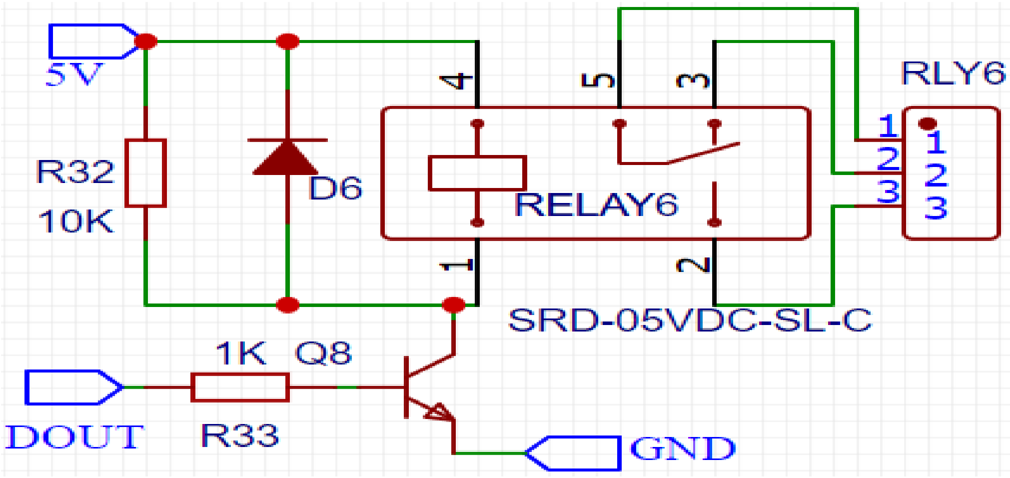

Figure 19 Induction relay wiring

The solid-state relay has similar wiring. A 2A fuse protects the relay against the high current. The setup is as shown in figure 20.

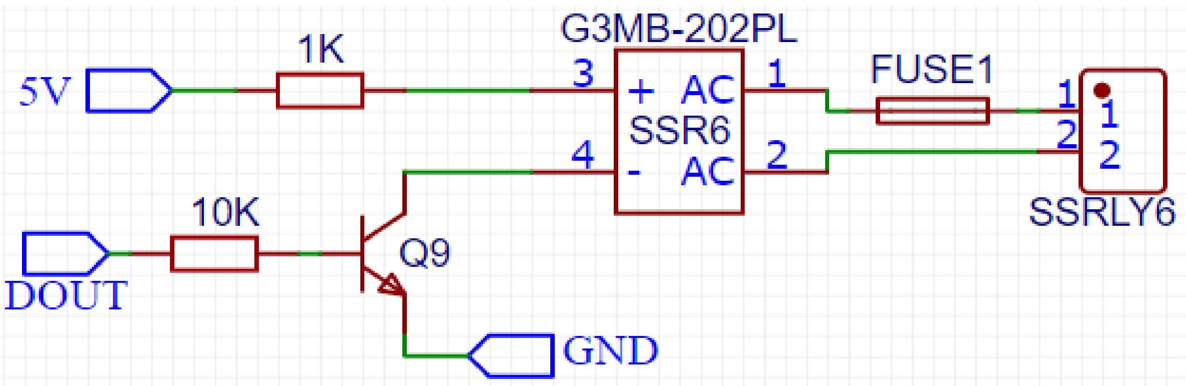

Figure 20 Wiring for solid-state relay

4.1.5 Circuitry for the 4-20 Ma current source.

The delta drive is controlled with the $4 - 20\ mA$ signal. By default, the microcontroller cannot produce this signal. However, most transmitters and sensors work with this signal. It is free from voltage drops over a long distance, so it is more reliable than its counterpart – the 0 -10V. The signal can be generated using a simple and low-cost circuit together with the PWM output from the Atmega328p. The PWM pin goes to the non-inverting pin of the LM358N operational amplifier in the circuit. The inverting pin is grounded through a 250 ohms resistor while the output goes to the base of a transistor through a $10k\Omega$ resistor. A 12V power supply powers the OPAM. As the duty cycle of the pulse width changes, the current through the 250Ω resistor is in the range of $4 - 20mA$. The circuit is as shown in figure 21.

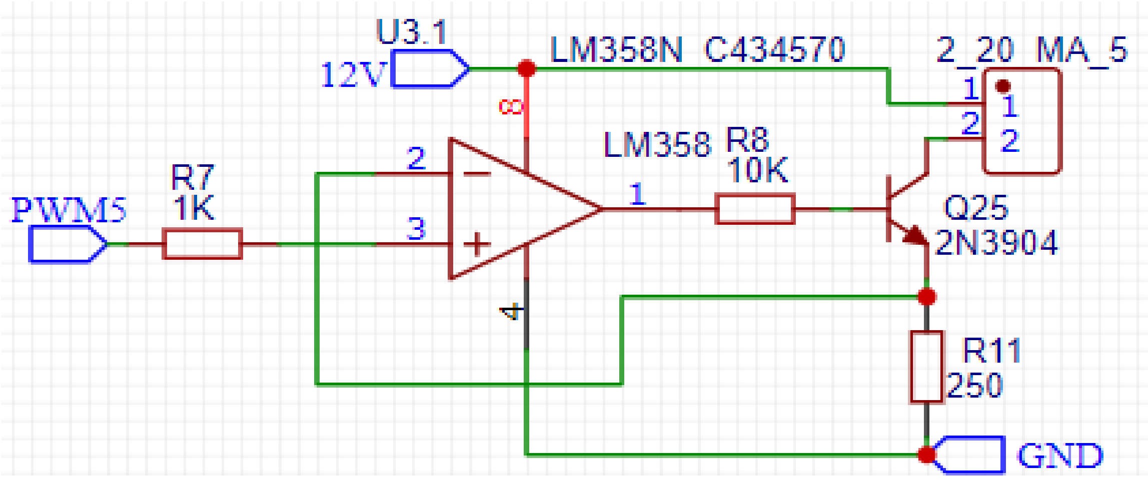

Figure 21 4-20mA circuit

4.1.6 Digital Input Reading Circuitry

The push button and other digital inputs may produce signals well above 5.5V, which will fry the microcontroller. A safe way to measure the signal is to use a reverse optocoupler. The higher voltage side connects to the sensor. Since the two circuits are completely isolated, the microcontroller is free from any excess current flow in the high voltage terminals. Figure 22 shows a detailed schematic.

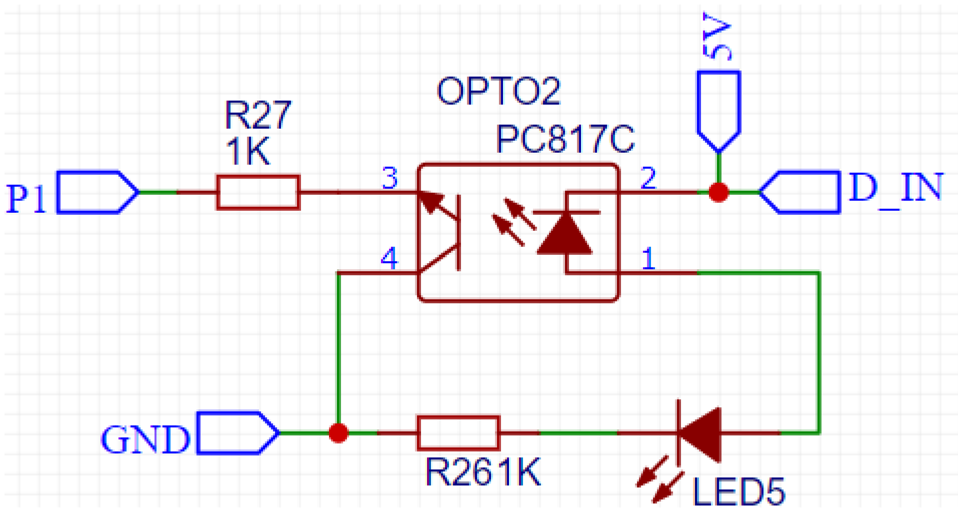

Figure 22 Circuit for reading Digital input

4.1.7 Analogue Input Sensor.

Most industrial analogue sensors generally provide 4-20mA output, including the proximity sensor for this project. Microcontrollers usually do not measure the current. It means the current has to be converted to voltage with a known resistor. A series 250 Ω resistor converts the current to a voltage in the range of 1V to 5V. The can then microcontroller read the voltage. Figure 23 shows a simple circuit for converting the current to voltage.

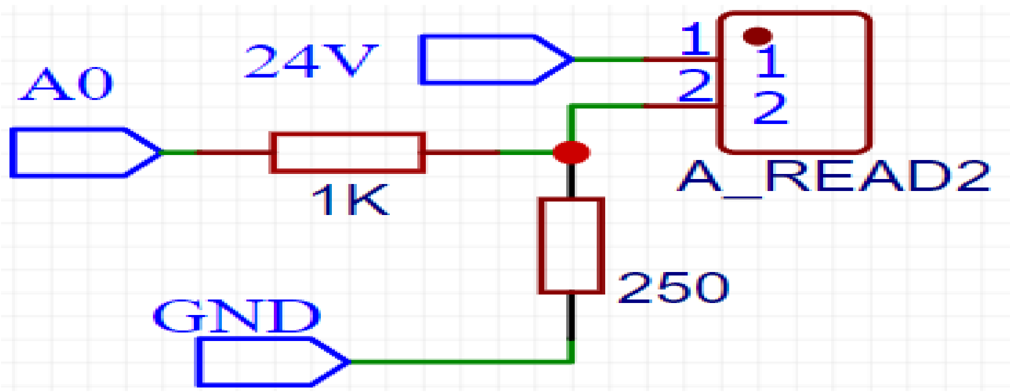

Figure 23 Circuit for reading Analogue input

4.1.8 Power circuitry

The AC power is stepped down from 230 V to 30V and then rectified with a diode bridge. The various decoupling capacitors smoothens the DC voltage. It uses L7824, L7812 and L7805 voltage regulators to provide power at 24V, 12V and 5V. The circuit is as shown in figure 24.

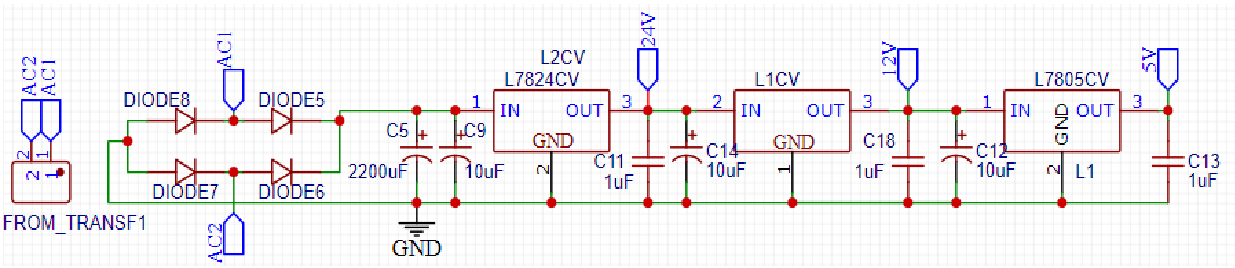

Figure 24 Rectification circuit

4.2 Simulation

Each of the circuits was simulated using appropriate software to ensure that the desired output is what each produces. Using Arduino UNO with the same microcontroller, a simple code was written to read the input pins and write the same values to the output pins. The digital read circuit supplies 5V to the microcontroller for various voltages between 5 and 24V. The analogue signal reader also produces a voltage between 0 and 5V for the microcontroller for current input in the range of $4-20mA$. A voltmeter connected across it measures and displays the voltage. The digital circuit was also tested by connecting a 24V lamp connected across the relay output terminals. The lamp turns on when the corresponding output pin is supplied 5V. Finally, an ammeter connects in series with the 250Ω in the $4-20mA$ circuit to measure the current. The output current varies between 0 and $20mA$ for a 0 – 100% duty cycle. It is not much of a concern that it falls below the $4mA$ because it can be limit to the desired range by the program. Everything works perfectly fine as expected in the simulation. Figure 25 shows the simulation results.

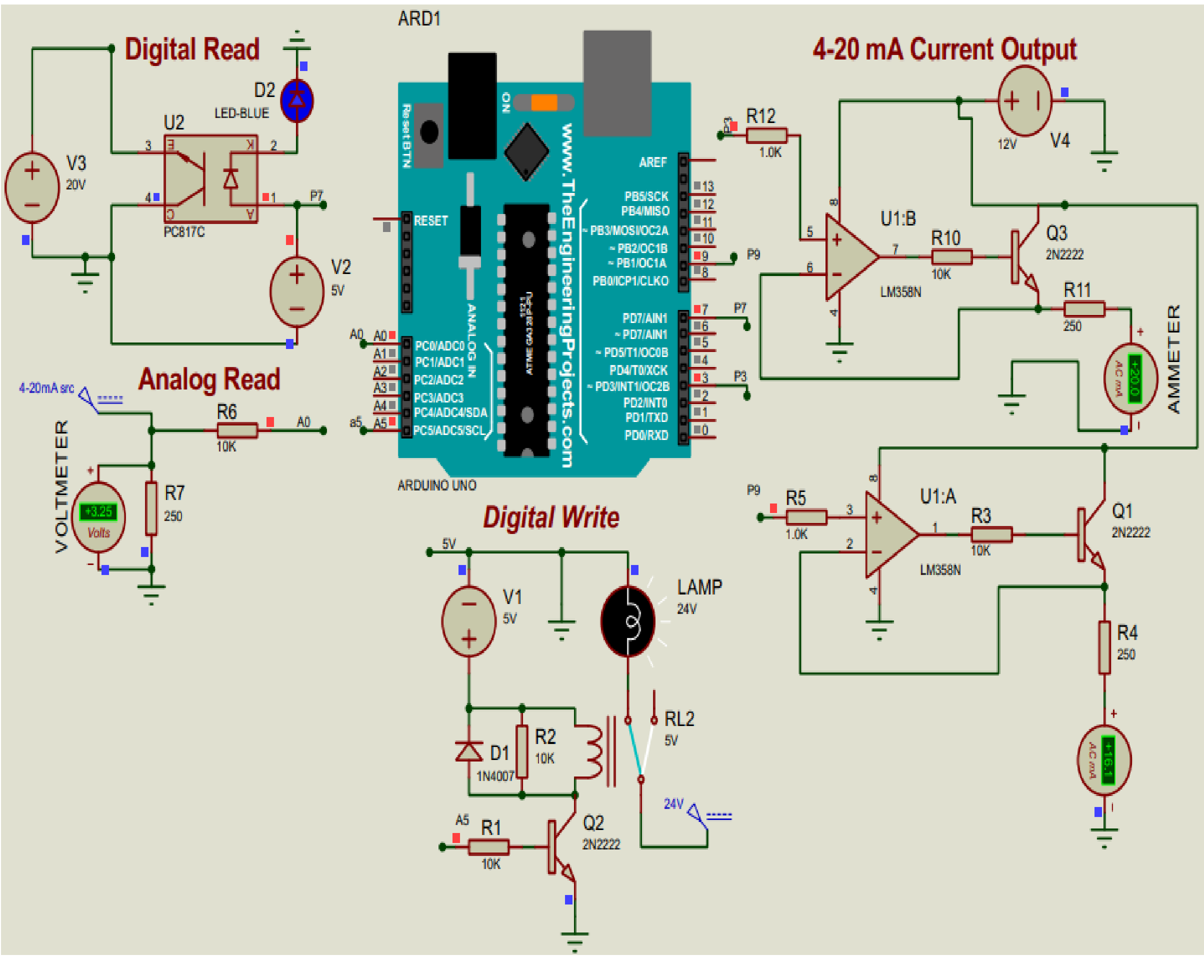

Figure 25 Simulation outputs for each circuit design

The power supply circuit was also simulated with the various voltage regulators. Figure 26 shows the results, which is as expected.

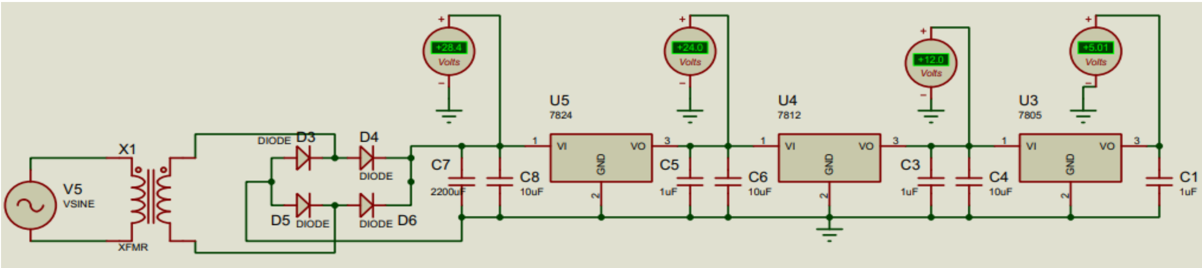

Figure 26 Simulation results for the power supply

4.3 PCB Design

The schematics figure 29 and 30 were converted to PCB design using EasyEDA software. The PCB comes in two designs: one with SRD-05VDC-SC-L relays throughout, and the other has five G3MB-202PL relays as the solid-state relay (SSR) and SRD-05VDC-SC-L relays. The one with both SSRs and inductive relays is the desired design. However, at the point of ordering the electronic components, G3MB-202PL was out of stock in most available shops. Most of the SSR alternatives were either much expensive or larger. Therefore, a constrained design was made with only the inductive relays. Figure 27 shows the PCB of the desired design, and figure 28 shows the constrained design PCB.

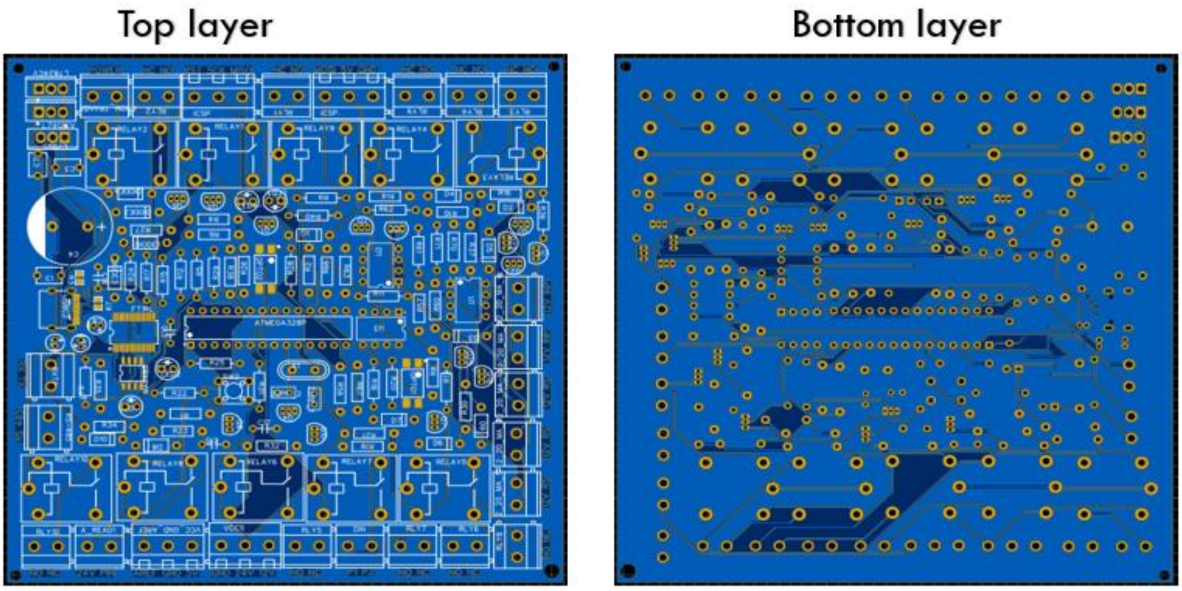

Figure 27 PCB without G3MB-202PL

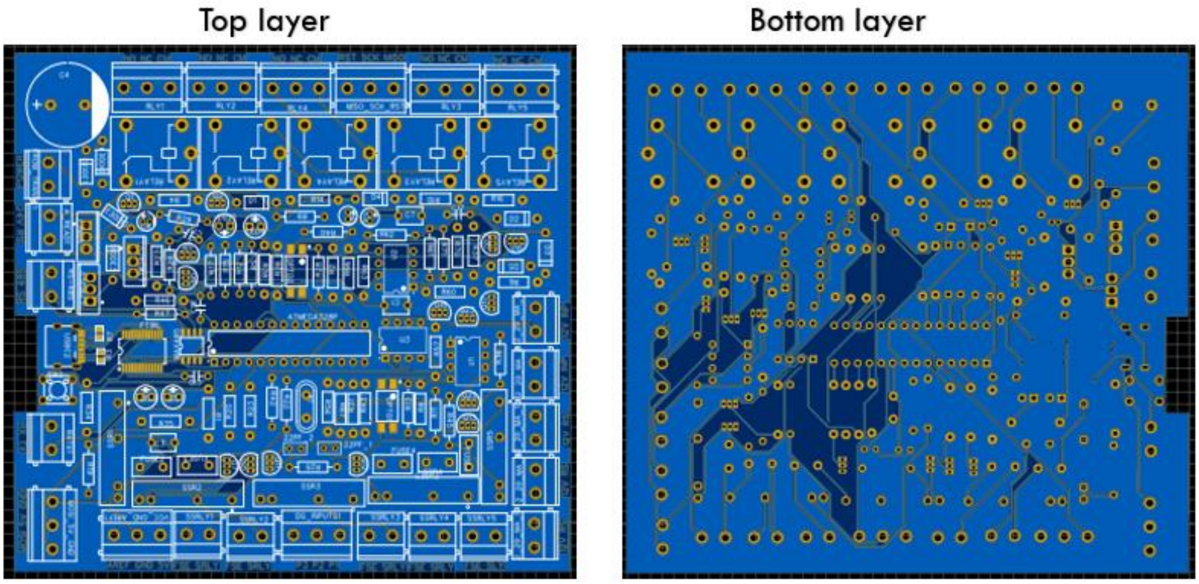

Figure 28 PCB with G3MB-202PL

The hardware PCB is in figure 31 in the appendix. Figure 32 shows the PCB with some of the components mounted on it.

4.4 Soldering of the Components

Before the soldering to of the components, a breadboard simulation was carried out to ensure that no faulty component was used on the PCB. The simulation was successful and produce same results as obtained in the software simulation. There were a few challenges with the soldering of the components onto the PCB board. The first thing was that surface mount components could not be easily soldered with the available soldering wire. Efforts were made to secure a liquid solder, but it has not yet arrived at the point of reporting this due to circumstances beyond human control. Figure 32 shows some of the components that were soldered successfully. The rest will await the soldering of the surface mount components. Therefore, the board is not yet finished.

Chapter 5: Results

5.1 Testing for basic functionalities

The board could still be tested regardless of the surface mount components not yet soldered. The microcontroller was programmed by mounting it on Arduino UNO since the FT232RL and USB ports were not ready. A 30VDC was applied to the power input terminals. A voltmeter was used to measure the voltages at some of the terminals. Zero volts was recorded in all the pins that were supposed to be energized. And surprisingly, the voltage from the power supply quickly runs from 30VDC to 1.66 VDC. It steps up to 30VDC as soon as it is disconnected from the board. While it is connected to the board, a voltmeter connected across the output L7805CV regulator reads zero volts. The same reading was recorded at the input. It was evident that a short circuit was caused on one or more of the components, especially the transistors. The transistors legs were quite close to each other. As a novice in soldering, it was challenging, especially with the thick soldering wire used.

5.2 Next steps after the board failed to work.

The next plan is to desolder the board and place them on another board. The thick soldering wire will be replaced with a thinner one. There at least three tools needed to do the desoldering. It could be a desoldering pump, desoldering gun or desoldering copper wire (wick). However, these tools are no assessable yet. The desoldering wick will be the best option to prevent overheating the electronic components.

Chapter 6: Conclusion

6.1 Discussion

The next phase of the project is to interface the VFD and the PLC on one of the semi-automated block-making machines in the Ghanaian block factory. However, the failure of the PCB board has caused a delay. The hope is to fix the components on a new PCB board as soon as possible. There will be caution on the second attempt to prevent any short circuit problems. Given that both the software and the breadboard simulations worked fine, for the same components, the fault can be from the schematic design.

6.2 Limitations

Currently the main limitation is the appropriate tools for soldering the board.

Appendix

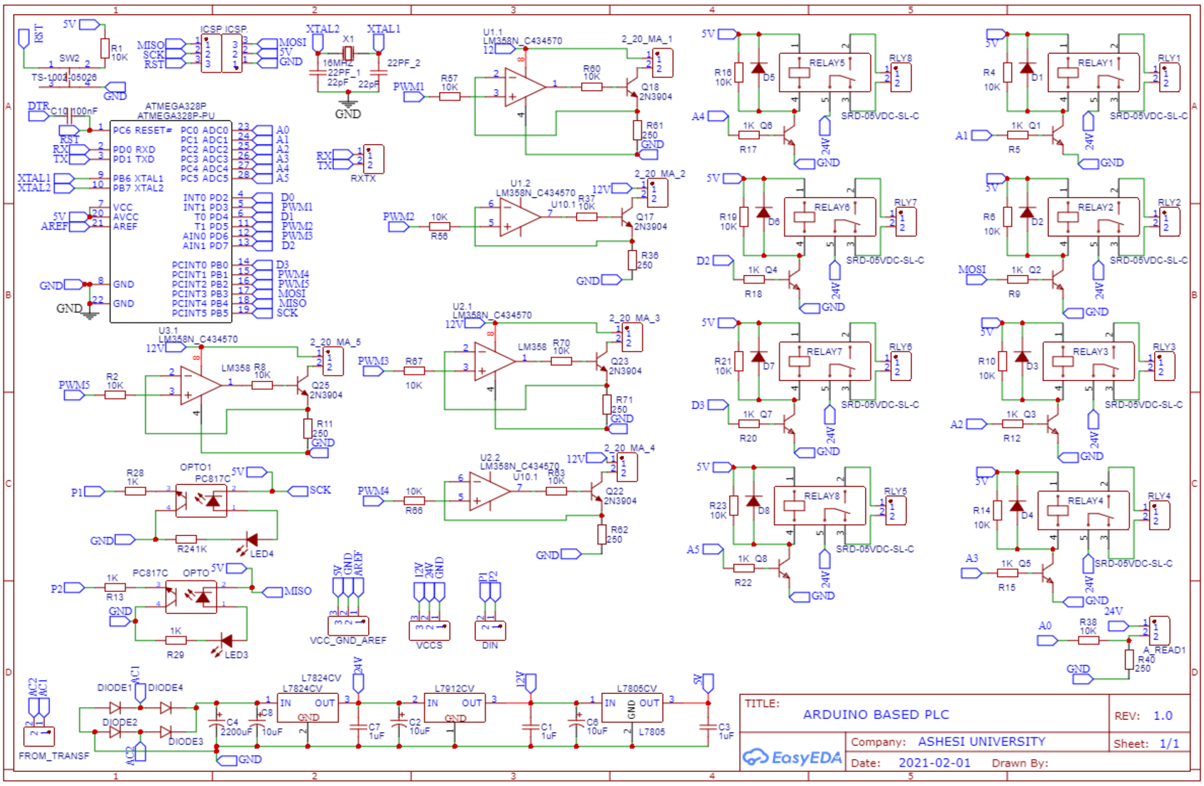

Figure 29 Sheet 1 of the Design with only inductive relays

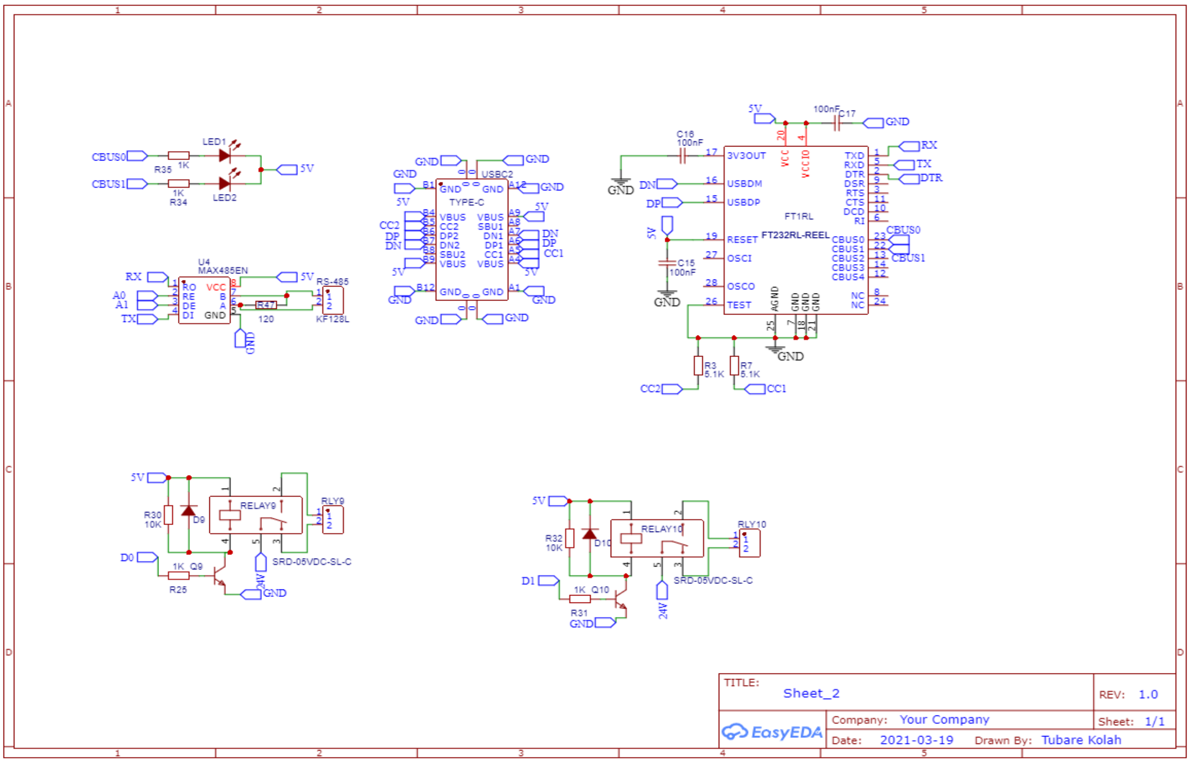

Figure 30 Sheet 2 of Design with only inductive relays

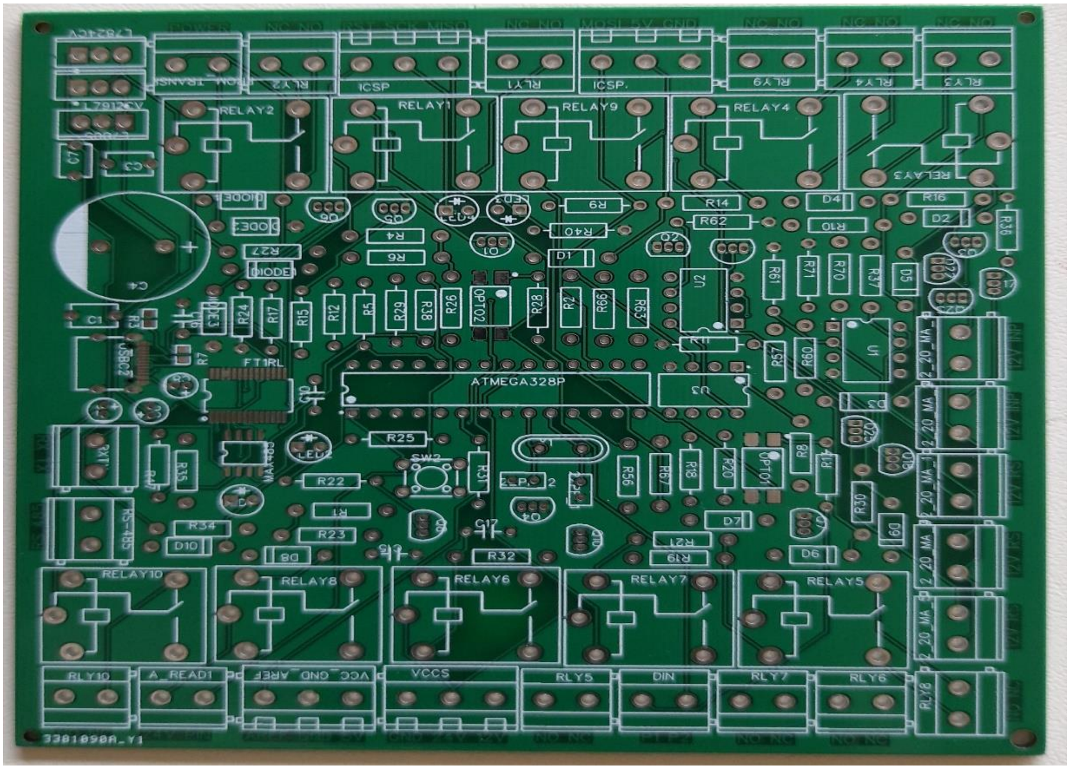

Figure 31 Hardware PCB of the Design with only inductive relays

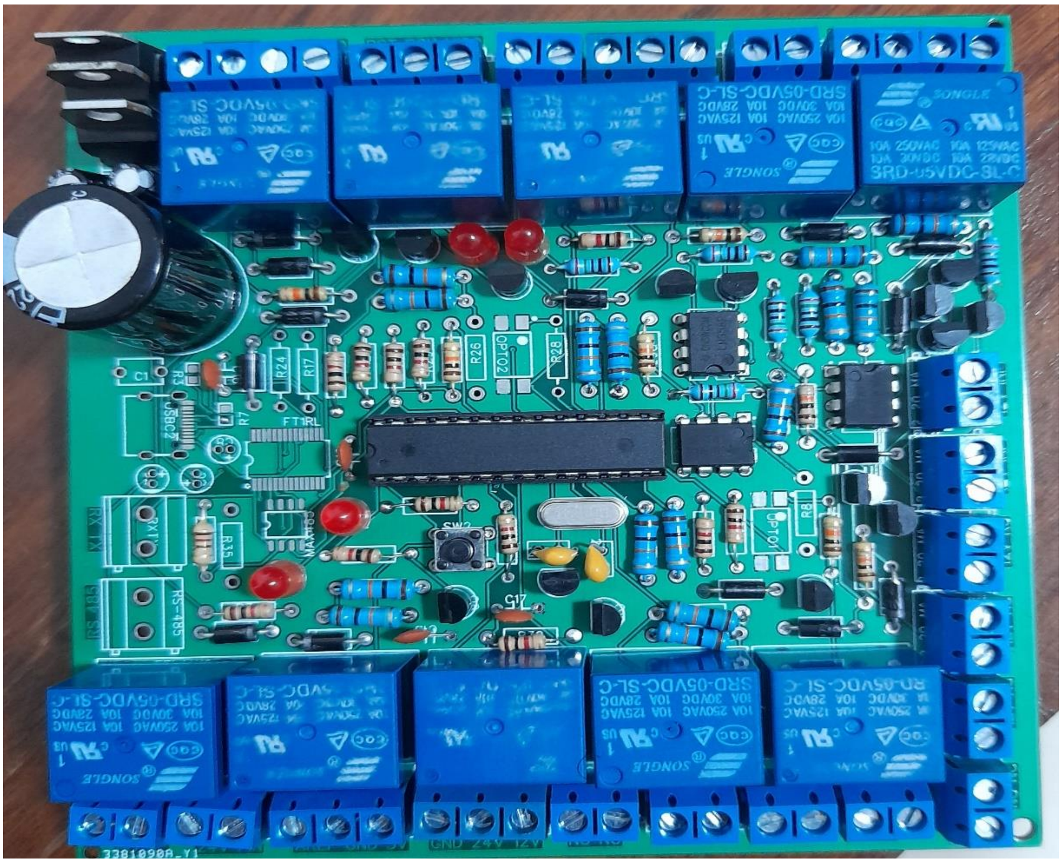

Figure 32 PCB with components mounted

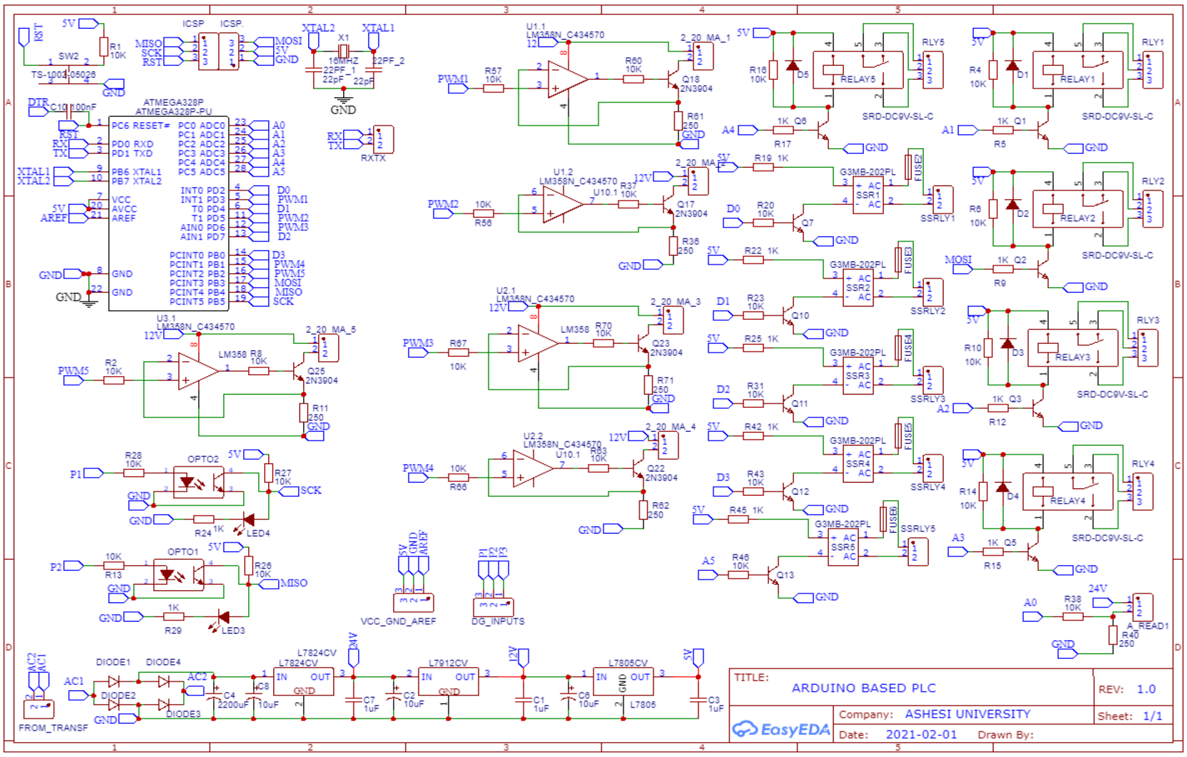

Figure 33 *Sheet 1 of the Schematics Design with inductive and Solid-state Relays*

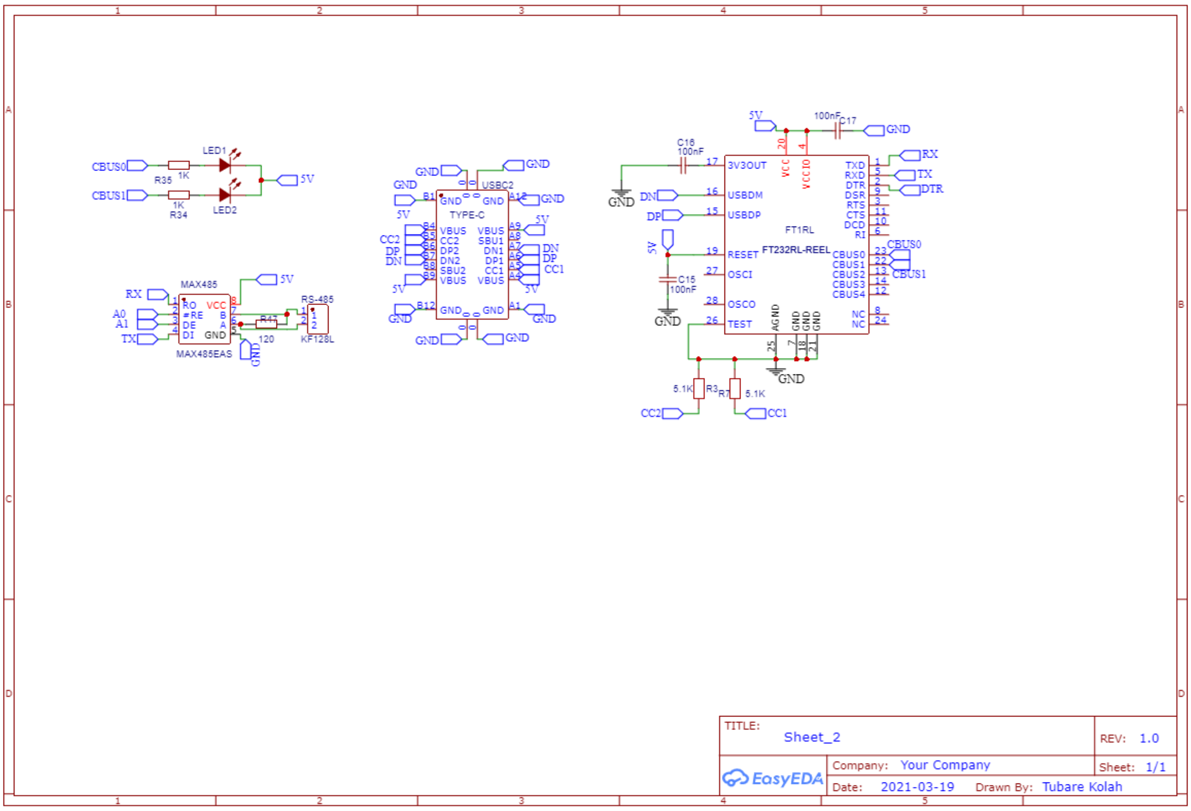

Figure 34 Sheet 2 of the Schematics Design with inductive and Solid-state Relays

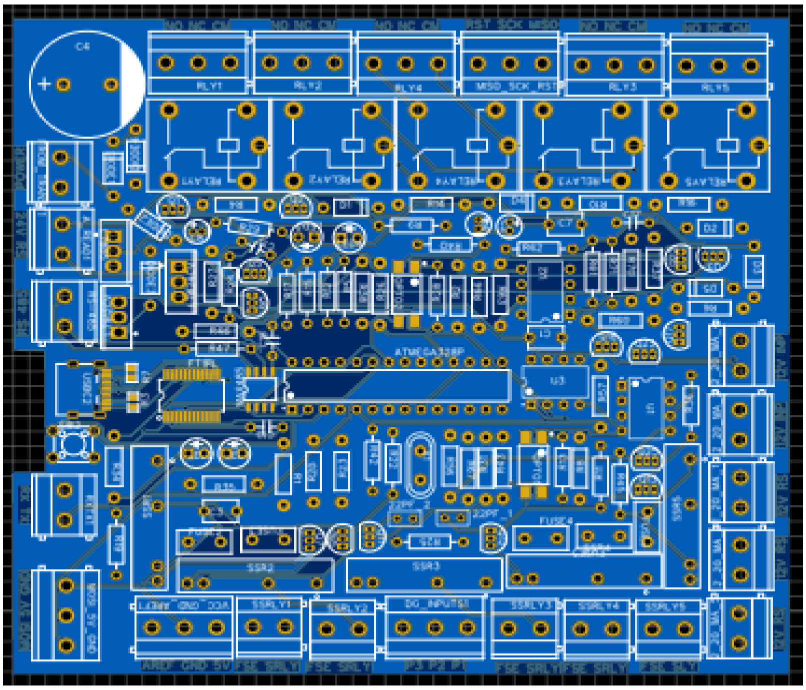

Figure 35 2D View of the PCB of the Design with inductive and Solid-state relays

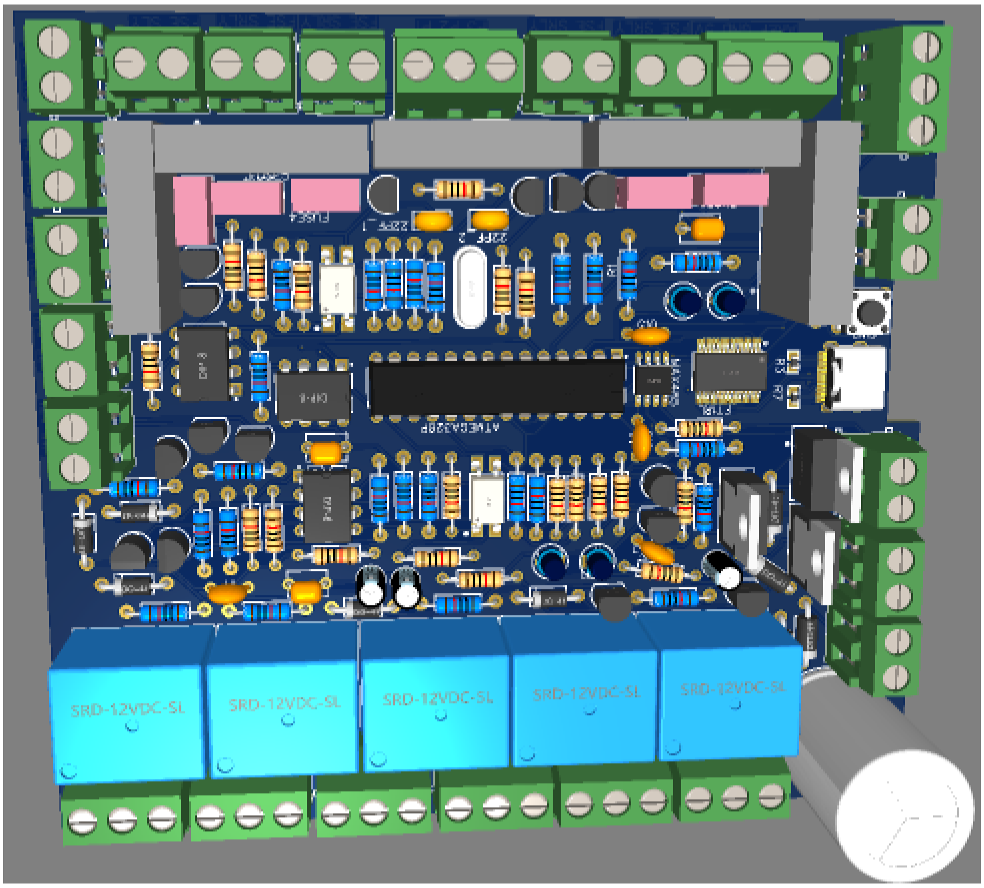

Figure 36 3D View of the PCB of the Design with SSR and inductive relays

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