Abstract

There has been an increasing emphasis on enhancing students' practical experience acquiring from the higher education, focusing not only on the development of academic and intellectual capabilities and subject knowledge, but also on the development of skills to equip students for employability. A practical training system that allows instruments to be monitored and controlled over LabVIEW leaves plenty of room to be studied. This training system can facilitate performing experiments in a safe environment and allows students to control and obtain real-time measurements or experimental data.

In this report the system was tested on several motor starter circuits like DOL and VFD starters with a three-phase induction motor who draws a high starting current and high torque during start-up which can damage the motor and here comes the role of the starters to protect it. This report will also provide a suggestion of which starter is most suitable for an application based on the stated constraints.

Aacknowledgments

First and foremost, we would like to thank Almighty Allah for enabling us to initiate the research, to put our best efforts and successfully conclude it.

Secondly, we would like to thank our supervisor Mr. MEDJOUDJ Rafik and Mr.METIDJI Brahim. Without their support, guidance and contribution we could not have done it. This paper has been completed due to their good supervision and inspiration. We are truly grateful to them.

We revere the patronage and moral support extended with love, by our parents as well as our friends. They helped us with their direct or indirect suggestions which aided in achieving our goal.

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Abbreviation	Definition
DOL	Direct On Line
PLC	Programmable Logic Control
NC	Normally Closed
NO	Normally Open
EMF	Electro Magnetic Force
VFD	Variable Frequency Derive
PWM	Pulse Width Modulation
CSI	Current Source inverter
VSI	Voltage Source Inverter
CPU	Central Processing Unit
SCC	Signal Conditioning Circuit
DSP	Digital Signal Processing
MCCB	Modeled Case Circuit Breaker

General introduction

Since the invention of motors, there was a wide usage of asynchronous motors in fields of machinery, chemical and petrochemical industries for its simple structure, reliable operation, high efficiency, low cost and ease of maintenance. In many applications, the motors are started directly or using DOL (Direct On Line) starters thus it draws high current at the starting period that can reaches up to 8 times the rated current which causes a mechanical stresses and overheating to the motors and voltage drop in supply lines. Thereby minimizing the life time and affecting the working of other equipments supplied from the same line. On the other side, energy saving has become a priority in the industrial sector. The real and reactive power drawn by inductive loads are not both useful. The reactive power affects the power factor which is the ratio of the real power to the apparent power thus it is needed to be reduced with less complicated circuits and costs. To prevent those damages and improve the power factor for more energy saving, motor starters are required in order to start the motor safely and reduce the high starting current.

There are several starters used to properly start the motor. Those detailed in this report are the direct online, star delta, soft starter and variable frequency drive. All the mentioned ones perform a primary function which is controlling the supply voltage during start up period, thereby controlling the starting current and torque. As for the improvement of power factor, capacitors are used in the soft starters and variable frequency drives.

However, each of these starters carries their own advantages and disadvantages. So to determine which starter is the best and most suitable for the motor a power training station is realized to implement the circuits of motor starters.

The power training station is found to assist in implementing and analyzing any circuit in both single and three phases as the circuits of direct current and voltages. It is equipped with multiple direct and alternative power sources, as it contains controlling switches and push buttons and a protection circuit breakers. To analyze the circuit implemented in the station, a power analyzer in the form of Ethernet socket is provided to be connected to the computer that displays the different data furnished by the circuit. Those data enters the power analyzer as current and voltage then it is processed and analyzed before going to the computer. The power analyzer circuit contains mainly voltage and current sensors, signal conditioning circuit and digital signal processing. Moreover the station is supported by programming logic controller (PLC) to manage the circuit by programming it using a ladder program.

The report organized as follow:

- In the first chapter theoretical background of motor starters and plc is presented
- The second chapter talks about the different parts of the power training system
- The third chapter is a realization of circuit's starters using the station and the collected data focused on the starting current for it effect on the motor.

CHAPTER 01:

Motor starters and PLC

1. Motor starters and PLC

1.1. Introduction

The first chapter provides a theoretical background about motor starters and their types in order to understand them so it will be easy to implement. Moreover a PLC is introduced because it will be used in the implementation of star delta control circuit to avoid complications in wiring. The chapter is divided to two main parts, motor starters and PLC.

1.2. Motor Starters

Motor starters are one of the major inventions for motor control applications .As the name suggests, motor starter is an electrical device that is used to start and stop a motor safely. Similar to a relay, the motor starter switches the power ON/OFF and unlike the relay it also provides a low voltage and an overcurrent protection.

The main function of a motor starter is to safely start and stop a motor, also to reverse the direction of a motor and to protect the motor from low voltage and overcurrent.

A motor starter is made of two main components that work together to control and protect the motor;

Electrical contactor: The purpose of the contactor is to switch ON/OFF the power supply to the motor by making or breaking the contact terminals.

Overload protection circuit: The purpose of this circuit is to protect the motor from potential harm due to the overload condition. Huge current through the rotor may damage the winding as well as other appliances connected to the supply. It senses the current and breaks the power supply.

1.3. Why a starter is needed with a motor?

A motor starter is essential for starting an induction motor. It is because of its low rotor impedance. The rotor impedance depends on the slip of the induction motor which is the relative speed between the rotor and stator. The impedance varies inversely with the slip.

The slip of the induction motor is at maximum i.e. at standstill (rest position), thus the impedance is at its minimum and it draws a huge amount of current called inrush current. The high inrush current magnetizes the air gap between the rotor and stator that induces an EMF in the rotor winding. This EMF produces an electrical current in rotor winding that creates a magnetic field to generate torque in the rotor. As the rotor speed increases the slip of the motor decreases and the current drawn by the motor is reduced.

The high inrush current is 5-8 times the normal rated full load current. So such amount of current can damage or burn the windings of the motor that will render the machine useless and it can cause a huge dip in voltage of the supply line that can damage other appliances connected to the same line.

In order to protect the motor from such a huge amount of currents, we use a starter that limits the initial current for a short duration at startup and once the motor attains a certain speed, the normal power supply to the motor is resumed. They also provide protection against fault conditions such as low voltage and overcurrent during normal operation. Although small motors rated below 1horsepower have high impedance and they can withstand the initial current thus they do not need such motor starter, however, they do need overcurrent protection system which is provided by the DOL starters [1].

1.4.How a motor starter works?

A starter is a control device that is used for switching the motor either manually or automatically. It is used for safe ON/OFF control of electrical motors by making or breaking its contacts.

Manual starters are devices that are operated manually. These starters are extremely easy and straightforward to operate and do not require expert intervention. The starter includes a button (or rotary knob) which enables a user to turn the connected equipment ON or OFF. The buttons feature mechanical linkages, which make the contacts open or close, starting or stopping the motor.

The manual starter is used for smaller motors where the hand operated lever is manually operated (move the contacts position) to the ON or OFF position. The disadvantage of these kinds of starters is that they need to switch ON after power frailer. In other words, they need manual control for each (ON or OFF) operation. Sometimes, this operation may leads to flow high currents in the motor winding which may burn the motor. This is why it is not recommended in most cases where other alternative motor starters with protection are used such as automatic or magnetic starters.

On the other hand, the magnetic motor starters are operated electromagnetically. It means that the motor load connected to the motor starter is typically started and stopped using a lower and safer voltage than the motor voltage. Just like other motor starters, the magnetic starter also has an electrical contactor and overload relay to protect the device from high current or overheating that are used to switch the motor ON/OFF operation. When current passes through the contactor coils, it energizes and produces the electromagnetic field which pulls or pushes the contacts to make the connection of motor windings to the power supply.

The start and stop push buttons connected to the motor and starter can be used for ON and OFF operation of motors. The contactor coils can be de-energized by pushing the stop button which leads to de-energize the coil. This way, the contactor contacts move back due to spring arrangement to its normal position which leads to switch off the motor. In case of power failure or manual switch-off operation, the motor won't start automatically until we manually start the motor by pressing the "start push button.

There are two circuits in a motor starter, which are as follows:

Power Circuit: The power circuit connects the line to the motor. It provides transmission of electricity through the starter contacts, overload relay, and then to the motor. The motor current is carried by the power (main) contacts of the contactor.

Control Circuit: This is the other motor starter circuit, which operates the contactor to turn it on or off. The contactor main contacts are responsible for allowing or interrupting the flow of current to the motor. To do this, the contacts in the control circuit are either opened or closed. The control circuit energizes the contactor coil, which creates an electromagnetic field. The power contacts are pulled by this electromagnetic field to a closed position. This completes the circuit between the motor and the line. This way, remote operations are made possible by the control circuit [1].

The control circuit can be wired in the following two ways:

Method 1: One of the most widely used methods employed for wiring the control circuit is referred to as the ”Two-wire method”. A maintained contact type of pilot device like presence sensor, thermostat, or float switch is used in the two-wire method of wiring the control circuit.

Two wire controls are generally designed to carry small amounts of current. This type of control system cannot sufficiently handle large amounts of current nor control loads that require more than one set of contacts that is required for single phase 220V to 240V circuit.

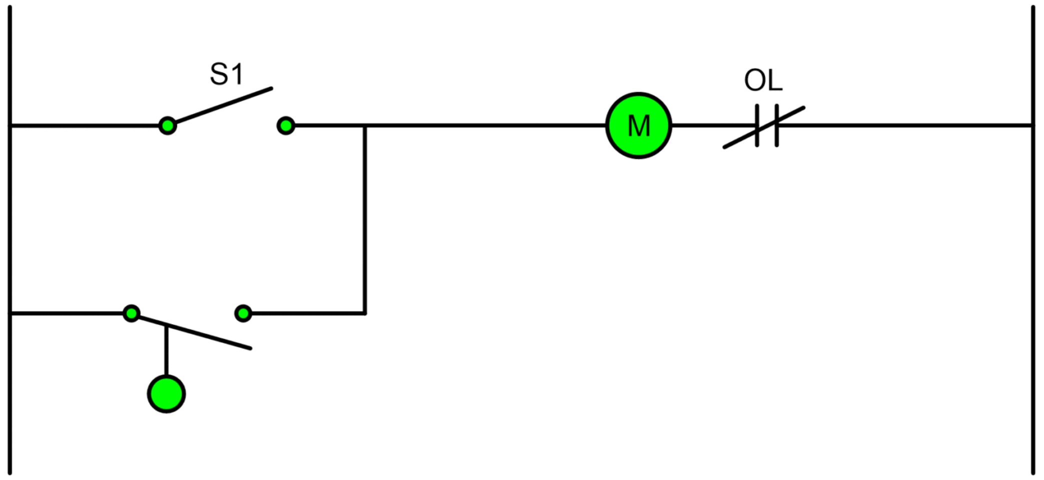


Figure 1-1. Two wire circuit.

The two wire circuit in figure 01 operates as follows:

If the single pole switch is toggle closed, the motor starter will start and stay on as long as the single pole switch is closed.

If the single pole switch marked S1 is left open, then the liquid level switch in the circuit will now be the control device that turns the motor starter on or off.

In this circuit, the load will always be on unless power is lost to the entire control circuit because either the single pole switch could be the activating factor or at any given moment the liquid level switch could energize the coil of the motor starter in the control circuit.

Method 2: Unlike the two-wire method, the “Three-wire method” of wiring the control circuit uses a holding circuit contact and the momentary contact pilot devices.

The most basic three wire control circuit is the start/stop circuit. The basic operation of the stop/start circuit is to provide a means of remotely controlling a motor operated load from a panel that only contains the low voltage control circuitry.

A three wire control circuit uses momentary contact, start/stop stations, and a normally open seal in contact connected in parallel with the start button to maintain voltage to the coil.

The set up for the three wire sire control circuit is different from the two wire operation because there are less components needed to operate the load. The three wire device's various parts may vary from one manufacturer's switch to another, but the basic circuit remains the same [3].

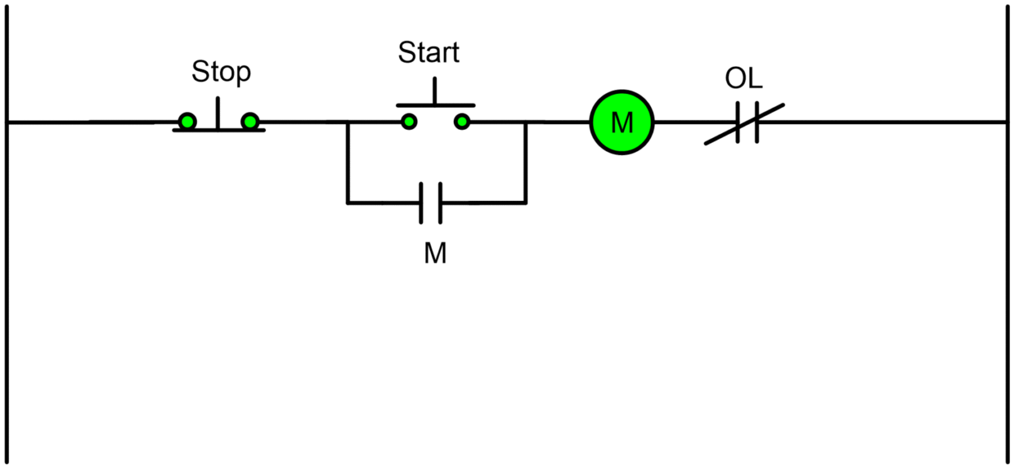


Figure 1-2. Stop/Start circuit

The Stop/Start circuit in figure 02 operates as follows:

The start pushbutton is pressed sending power to the coil.

Once the coil is energized the armature of the pilot device closes along with the memory/seal-in contact.

The seal-in contact maintains power to the coil overriding the need for the start pushbutton to continue being pressed.

The load connected to the motor starter (M) receives full voltage from the line and will continue running until the stop pushbutton is pressed or the motor should go into overload.

Pressing the stop pushbutton breaks the control voltage through the memory/seal-in contact causing the coil to de-energized which open the line voltage to the loads turning it off.

The control circuit can derive the power from either the following three ways:

Common Control: This type of control is when the power source of the control circuit is the same as the motor.

Separate Control: This is the most popular type of control. As the name suggests, the control circuit derives power from a separate source in this arrangement. Generally, the power derived is lower in voltage as compared to the motor's power source.

Transformer Control: As the name suggests, the control circuit derives power from a control circuit transformer. Generally, the power derived is lower in voltage as compared to the motor's power source.

1.5. Types of motor starters based on starting methods and techniques

In industries, various starting techniques are used to start an induction motor. Before discussing the types of motors, here are some of the techniques used in motor starters.

1.5.1. Full voltage or across the line starter:

Such starters directly connect the motor with the power line providing the full voltage. The motors connected through such starters have low power ratings so that they do not create a huge voltage drop in the power line. They are used in an application where motors have low ratings & need to run in one direction.

1.5.2. Full Voltage Reversing Starter:

Three phase induction motor's direction can be reversed by swapping any two phases. Such a starter incorporates two mechanically inter locked magnetic contactors with swapped phases for forward and reverse direction. It is used in an application where the motor needs to run in both directions and the contactors are used to control it.

1.5.3. Multispeed Starter:

In order to vary the speed of an AC motor, you need to vary the AC supply frequency or vary the number of poles (by reconnecting the windings in some) of the motor. Such types of starter run the motor in a few pre-selected speeds to meet its applications.

1.5.4. Reduced Voltage Starter

The most common type of starting technique is to reduce the voltage at the starting of the motor to reduce the inrush current that could damage the windings of the motor and also causes a huge dip in voltage. These starters are used for high rated motors [2].

1.6 Types of motor starters

There are several types of motor starters such as Direct online starter (DOL),Stator resistance and Rotor resistance starters, Autotransformer starter, Soft and Star/Delta starters and Variable frequency drive starter(VFD). In this report, only three motor starters are mentioned, which are:

- Direct online starter
- Star/delta starter
- Variable frequency drive starter

1.6.1 Direct online starter (DOL)

The Direct On Line starter is the simplest form of motor starter for the induction motor. The DOL starter consist an MCCB or circuit breaker, contactor and an overload relay for protection. Electromagnetic contact or can be opened by the thermal overload relay under fault conditions.

Typically, the contactor will be controlled by separate start and stop buttons, and an auxiliary contact on the contactor is used, across the start button, as a hold in contact. I.e. the contactor is electrically latched closed while the motor is operating.

1.6.1.1. Principle of DOL

To start, the contactor is closed, applying full line voltage to the motor windings. The motor will draw a very high inrush current for a very short time, the magnetic field in the iron, and then the current will be limited to the Locked Rotor Current of the motor. The motor will develop Locked Rotor Torque and begin to accelerate towards full speed.

As the motor accelerates, the current will begin to drop, but will not drop significantly until the motor is at a high speed, typically about 85% of synchronous speed. The actual starting current curve is a function of the motor design, and the terminal voltage, and is totally independent of the motor load.

The motor load will affect the time taken for the motor to accelerate to full speed and therefore the duration of the high starting current, but not the magnitude of the starting current. Provided the torque developed by the motor exceeds the load torque at all speeds during the start cycle, the motor will reach full speed. If the torque delivered by the motor is less than the torque of the load at any speed during the start cycle, the motor will stops accelerating.

If the starting torque with a DOL starter is insufficient for the load, the motor must be replaced with a motor which can develop a higher starting torque. The acceleration torque is the torque developed by the motor minus the load torque, and will change as the motor accelerates due to the motor speed torque curve and the load speed torque curve. The start time is dependent on the acceleration torque and the load inertia.

DOL starting have a maximum start current and maximum start torque. This may cause an electrical problem with the supply, or it may cause a mechanical problem with the driven load. So this will be inconvenient for the users of the supply line, always experience a voltage drop when starting a motor. But if this motor is not a high power one it does not affect much[5].

1.6.1.2. Parts of DOL starter

1.6.1.2.1. Contactors and Coil

Magnetic contactors are electromagnetically operated switches that provide a safe and convenient means for connecting and interrupting branch circuits.

Magnetic motor controllers use electromagnetic energy for closing switches. The electromagnet consists of a coil of wire placed on an iron core. When a current flow through the coil, the iron of the magnet becomes magnetized, attracting an iron bar called the armature. An interruption of the current flow through the coil of wire causes the armature to drop out due to the presence of an air gap in the magnetic circuit.

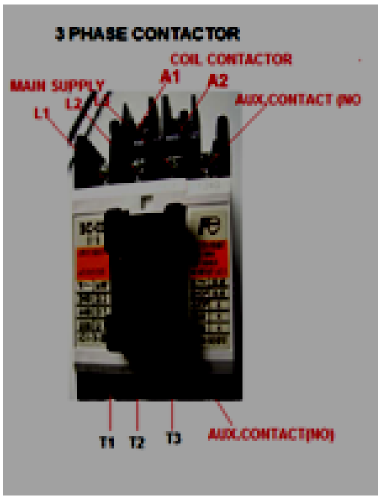


Figure 1-3. Three phase contactor.

Line-voltage magnetic motor starters are electromechanical devices that provide a safe, convenient, and economical means of starting and stopping motors, and have the advantage of being controlled remotely. The great bulk of motor controllers sold are of this type.

Contactors are mainly used to control machinery which uses electric motors. It consists of a coil which connects to a voltage source. Very often for Single phase Motors, 230V coils are used and for three phase motors, 415V coils are used. The contactor has three main NO contacts and lesser power rated contacts named as Auxiliary Contacts [NO and NC] used for the control circuit. A contact is conducting metal parts which completes or interrupt an electrical circuit [6].

- NO-normally open.
- NC-normally closed.

1.6.1.2.2. Over Load Relay (Overload protection)

Overload protection for an electric motor is necessary to prevent burnout and to ensure maximum operating life.

Under any condition of overload, a motor draws excessive current that causes overheating. Since motor winding insulation deteriorates due to overheating, there are established limits on motor operating temperatures to protect a motor from overheating. Overload relays are employed on a motor control to limit the amount of current drawn.

The overload relay does not provide short circuit protection. This is the function of over current protective equipment like fuses and circuit breakers, generally located in the disconnecting switch enclosure.

The ideal and easiest way for overload protection for a motor is an element with current-sensing properties very similar to the heating curve of the motor which would act to open the motor circuit when full-load current is exceeded. The operation of the protective device should be such that the motor is allowed to carry harmless over-loads but is quickly removed from the line when an overload has persisted too long.

Normally fuses are not designed to provide overload protection. Fuse is protecting against short circuits (over current protection). Motors draw a high inrush current when starting and conventional fuses have no way of distinguishing between this temporary and harmless inrush current and a damaging overload. Selection of Fuse is depend on motor full-load current, would “blow” every time the motor is started. On the other hand, if a fuse were chosen large enough to pass the starting or inrush current, it would not protect the motor against small, harmful overloads that might occur later.

The overload relay is the heart of motor protection. It has inverse-trip-time characteristics, permitting it to hold in during the accelerating period (when inrush current is drawn), yet providing protection on small overloads above the full-load current when the motor is running. Overload relays are renewable and can withstand repeated trip and reset cycles without need of replacement. Overload relays cannot, however, take the place of over current protection equipment.

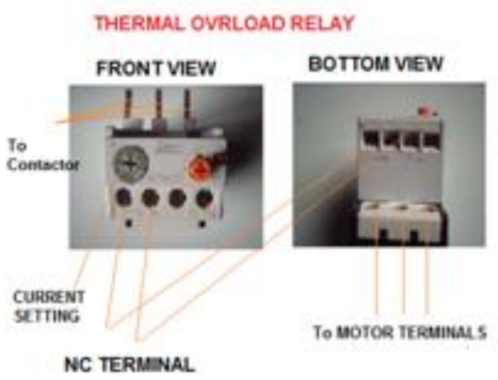


Figure 1-4. Thermal overload relay.

The overload relay consists of a current-sensing unit connected in the line to the motor, plus a mechanism, actuated by the sensing unit, which serves, directly or indirectly, to break the circuit. Overload relays can be classified as being thermal, magnetic, or electronic.

- **Thermal Relay**

As the name implies, thermal overload relays rely on the rising temperatures caused by the overload current to trip the overload mechanism

Thermal overload relays are designed to be combined with contactors to assemble motor starters. They are very reliable devices intended to protect motors, controllers and branchcircuit conductors against phase failures and overloads that cause excessive heating.

Motor overloads or phase failures increase the motor current. This current increase trips the mechanism and switches the auxiliary contacts. The auxiliary contacts, when properly wired in series with the coil of the contactor will de-energize the contactor when an overload occurs. Thus, the contactor disconnects the power to the motor and stops its operation. The bimetallic thermal overload relays have thermal memory. Once tripped, the relay will not reset until it has cooled down, allowing the motor to cool before it can be re-started [11].

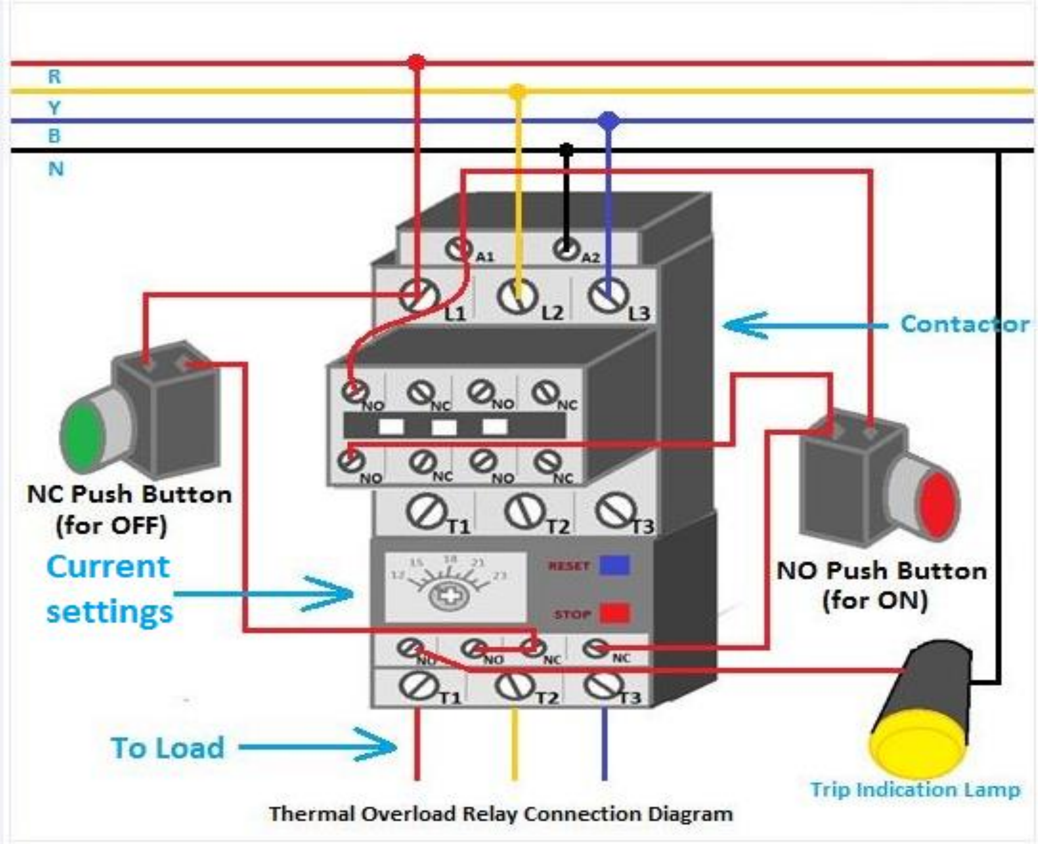


Figure 1-5. Thermal overload relay connection diagram.

- **Magnetic Relay:**

Magnetic overload relays react only to current excesses and are not affected by temperature.

Magnetic overload relays operate by sensing the strength of the magnetic field produced by the current flowing to the motor. The difference between magnetic type and thermal type overload relays is that the magnetic types are not sensitive to ambient temperature. Magnetic overload relays are generally used in areas that exhibit extreme changes in ambient temperature.

Figure 1-6. Magnetic relay.

- **Electronic Relay:**

Electronic or solid-state overload relays, provide the combination of high-speed trip, adjustability, and ease of installation. Electronic overload relays employ a current transformer to sense the motor current. The conductor that supplies power to motor passes through the core of a toroid transformer. As current flows through the conductor, the alternating magnetic field around the conductor induces a voltage into the toroid transformer. The amount of induced voltage is proportional to the amount of current flowing through the conductor. The induced voltage is transmitted through a connected electronic interface that provides the time delay necessary to permit the motor start. Many electronic relays are programmable and can be set for the amount of full-load motor current, maximum and minimum voltage levels, percentage of overload and other factors [12].

Figure 1-7. Three phase electronic overload relay.

1.6.1.3. Wiring diagram of DOL starter

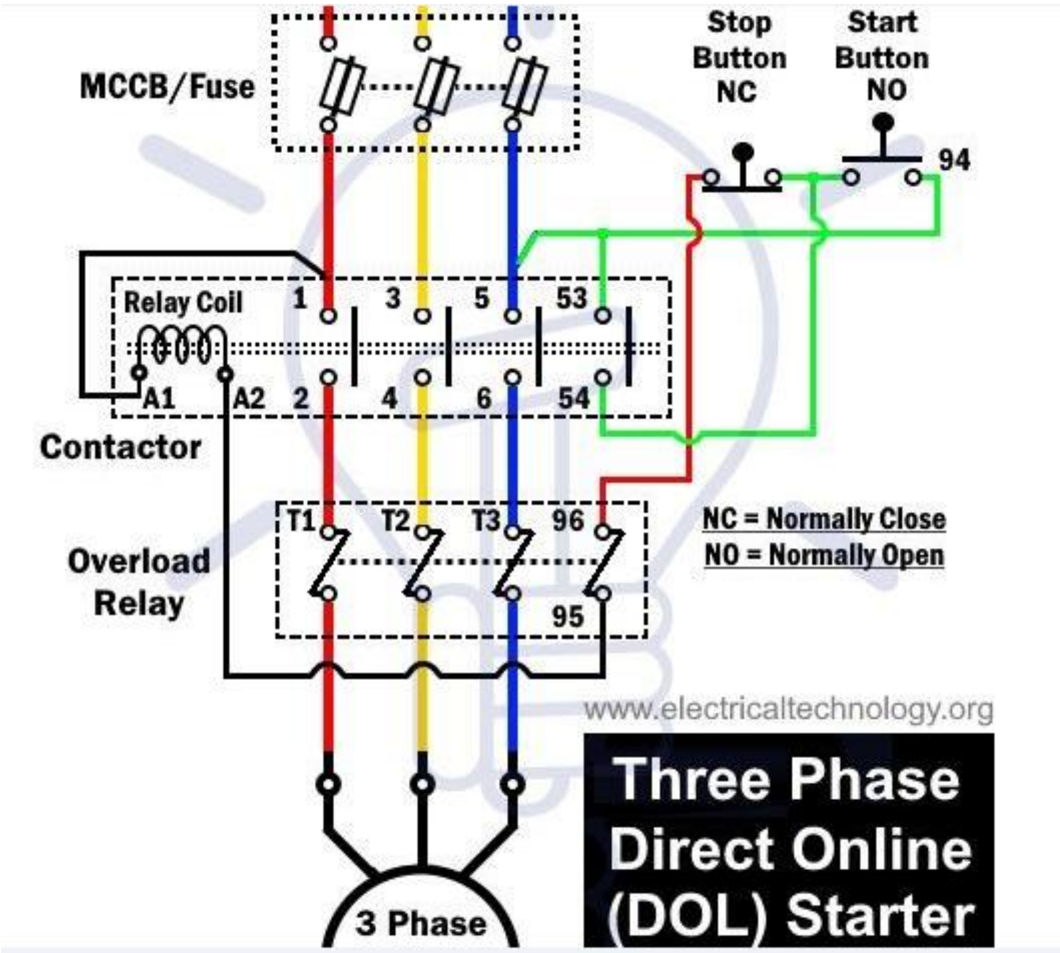


Figure 1-8. Wiring of DOL starter.

1.6.1.4. Operation of DOL starter

The main heart of DOL starter is relay coil. Normally it gets one phase constant from incoming supply voltage (A1).when coil gets second phase relay coil energizes and the magnet of contactor produce electromagnetic field and due to this plunger of contactor will move and main contactor of starter will be closed and the auxiliary will change its position NO to become NC.

Pushing start button:

When the start button is pushed, relay coil will get second phase from supply phase→main contactor(5)→Auxiliary Contact(53)→Start button→Stop button→96→95→To Relay Coil (A2).

Now coil energizes and magnetic field is produced by magnet and the plunger of contactor moves. Main contactor closes and the motor gets supply at the same time auxiliary contact become (53-54) from NO to NC.

Release Start button:

Relay coil gets supply even though we release start button. When the start push button is released, relay coil gets supply phase from main contactor (5)→Auxiliary contactor (53) → Auxiliary contactor (54)→stop Button→96→95→relay coil.

In overload condition, the motor will be stopped by intermission of control circuit at Point 96-95.

Pushing Stop button:

When the Stop Button is pushed, control circuit of the starter will be break at stop button and supply of relay coil is broken, plunger moves and the main contactor become open, therefore supply of the motor is disconnected.

1.6.1.5. Motor starting characteristics on DOL starter

Available starting current: 100%.
Peak starting current: 6 to 8 Full Load Current.
Peak starting torque:100%

1.6.1.6. Features, advantages and disadvantages of DOL starter

The direct online starter is the simplest starter to be established, operated and maintained, it is also the most economical one. Only one set of cables is required from starter to motor. Furthermore the DOL starter provides a full torque at the starting time.

On the other hand, DOL starters does not reduce the starting current of the motor (typically 6 to 8 times the full load current of the motor) which means a big voltage dip in the electrical installation and unnecessary high starting torque that not required by the load. All this leads to an increased thermal and mechanical stress on the mechanical systems such as rotor shaft, bearings, gearbox, coupling, chain drive and other connected equipments. This stresses minimizes the life time of the motor and the other equipments or premature failure and plant downtimes**.**

1.6.2. Star-Delta starter

Most induction motors are started directly on line, but when very large motors are started that way, they cause a disturbance of voltage on the supply lines due to large starting current surges. To limit the starting current surge, large induction motors are started at reduced voltage and then have full supply voltage reconnected when they run up to near rotated speed. Two methods are used for reduction of starting voltage are star delta starting and auto transformer stating.

Star-Delta starters are the most common reduced voltage starters. They are used in an attempt to reduce the start current applied to the motor as a means of reducing the disturbances and interference on the electrical supply.

Traditionally in many supply regions, there has been a requirement to fit a reduced voltage starter on all motors greater than 5HP (4KW). The Star-Delta (or Wye-Delta) starter is one of the lowest cost electromechanical reduced voltage starters that can be applied.

1.6.2.1. Operation of star-delta starter

This is the reduced voltage starting method. Voltage reduction during star-delta starting is achieved by physically reconfiguring the motor windings as illustrated in the figure below. During starting the motor windings are connected in star configuration and this reduces the voltage across each winding 3. This also reduces the torque by a factor of three. After a period of time the winding are reconfigured as delta and the motor runs normally.

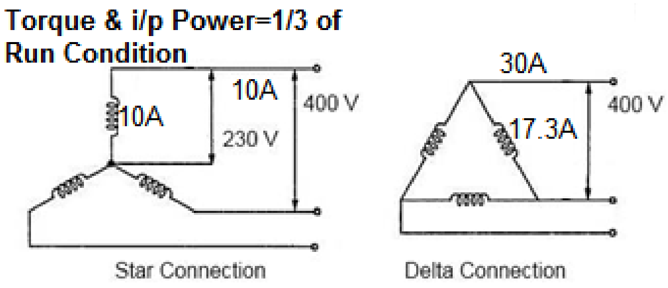


Figure 1-9. Star and delta connections.

The Star-Delta starter is generally manufactured from three contactors (main, star and delta contactors) for the open state starter or four contactors for the closed transient starter, a timer and a thermal overload relays in addition to fuses. The contactors are smaller than the single contactor used in a Direct on Line starter as they are controlling winding currents only. The currents through the winding are 1/√3 (58%) of the current in the line.

There are two contactors that are close during run, often referred to as the main contractor and the delta contactor. These are AC3 rated at 58% of the current rating of the motor. The third contactor is the star contactor and that only carries star current while the motor is connected in star. The current in star is one third of the current in delta, so this contactor can be AC3 rated at one third (33%) of the motor rating.

1.6.2.2. Power circuit of star-delta starter

The main circuit breaker serves as the main power supply switch that supplies electricity to the power circuit.

The main contactor connects the reference source voltage R, Y, B to the primary terminal of the motor U1, V1, W1.

In operation, the Main Contactor (KM3) and the Star Contactor (KM1) are closed initially, and then after a period of time, the star contactor is opened, and then the delta contactor (KM2) is closed. The control of the contactors is done by the timer (K1T) built into the starter. The Star and Delta are electrically interlocked and preferably mechanically interlocked as well.

The star contactor serves to initially short the secondary terminal of the motor U2, V2, W2 for the start sequence during the initial run of the motor from standstill. This provides one third of DOL current to the motor, thus reducing the high inrush current inherent with large capacity motors at startup.

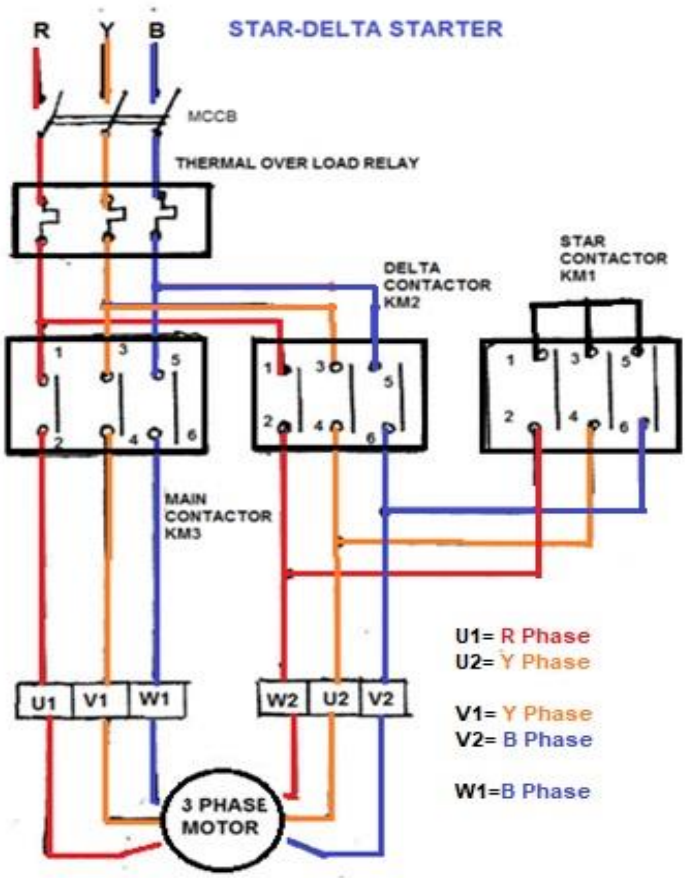


Figure 1-10. Power circuit.

1.6.2.3. Control circuit of star-delta starter(open transient)

Controlling the interchanging star connection and delta connection of an AC induction motor is achieved by means of a star delta control circuit. The control circuit consists of push button switches, auxiliary contacts and a timer.

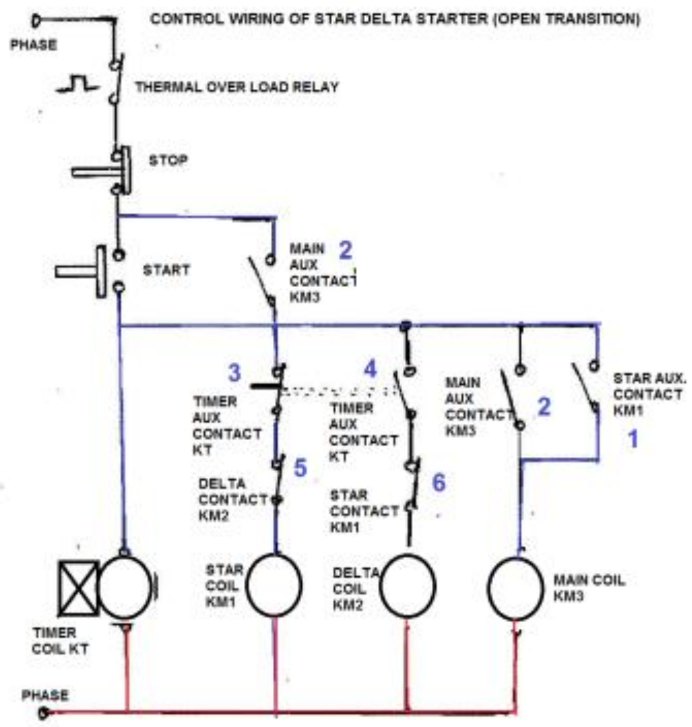


Figure 1-11. Control circuit

The **ON** push button starts the circuit by initially energizing star contactor coil (KM1) of star circuit and timer coil (KT) circuit.

When star contactor coil (KM1) energized, star main and auxiliary contactor change its position from NO to NC.

When star auxiliary contactor (1) (which is placed on main contactor coil circuit)became NC, the circuit of main contactor coil (KM3) is completed so main contactor coil energized and main and auxiliary contactors changes their positions from NO To NC. This sequence happens in a friction of time.

After pushing the **ON** push button switch, the auxiliary contact of the main contactor coil (2) which is connected in parallel across the ON push button will become NC, thereby providing a latch to hold the main contactor coil activated which eventually maintains the control circuit active even after releasing the ON push button switch.

When star main contactor (KM1) close, the motor is connected on STAR connectionuntil time delay auxiliary contact KT (3) become NO.

Once the time delay reaches its specified time, the timer's auxiliary contacts (KT)(3) in star coil circuit will change its position from NC to NO and at the same time auxiliary contactor (KT) in delta coil circuit(4) change its position from NO to NC so delta coil energized and delta main contactor becomes NC. Now the motor terminal connection changes from star to delta connection.

A normally close auxiliary contact from both star and delta contactors (5&6)are also placed opposite of both star and delta contactor coils, these interlock contacts serves as safety switches to prevent simultaneous activation of both star and delta contactor coils, so that one cannot be activated without the other deactivated first. Thus, the delta contactor coil cannot be active when the star contactor coil is active, and similarly, the star contactor coil cannot also be active while the delta contactor coil is active.

The control circuit above also provides two interrupting contacts to shutdown the motor. The OFF push button switch break the control circuit and the motor when necessary. The thermal overload contact is a protective device which automatically opens the STOP Control circuit in case when motor overload current is detected by the thermal overload relay, this is to prevent burning of the motor in case of excessive load beyond the rated capacity of the motor is detected by the thermal overload relay[7].

At some point during starting it is necessary to change from a star connected winding to a delta connected winding. Power and control circuits can be arranged to this in one of two ways(open transition or closed transition).

1.6.2.4. Open and closed transient starters

1.6.2.4.1. Open Transition Starters.

A "break before make" switch function. This means that the connection is established with the motor before the utility is shut off, and then the swap is made quickly once the connection has been safely established**,** it is called open transition switching because there is an open state between the star state and the delta state.

In open transition the power is disconnected from the motor while the winding are reconfigured via external switching.

When a motor is driven by the supply, either at full speed or at part speed, there is a rotating magnetic field in the stator. This field is rotating at line frequency. The flux from the stator field induces a current in the rotor and this in turn results in a rotor magnetic field.

When the motor is disconnected from the supply (open transition) there is a spinning rotor within the stator and the rotor has a magnetic field. Due to the low impedance of the rotor circuit, the time constant is quite long and the action of the spinning rotor field within the stator is that of a generator which generates voltage at a frequency determined by the speed of the rotor. When the motor is reconnected to the supply, it is reclosing onto an unsynchronized generator and this result in a very high current and torque transient. The magnitude of the transient is dependent on the phase relationship between the generated voltage and the line voltage at the point of closure can be much higher than DOL current and torque and can result in electrical and mechanical damage.

Open transition starting is the easiest to implement in terms or cost and circuitry and if the timing of the changeover is good, this method can work well. In practice though it is difficult to set the necessary timing to operate correctly and disconnection/reconnection of the supply can cause significant voltage/current transients.

In Open transition there are four states:

OFF State: All Contactors are open.

Star State: The Main [KM3] and the Star [KM1] contactors are closed and the delta [KM2] contactor is open. The motor is connected in star and will produce one third of DOL torque at one third of DOL current.

Open State: This type of operation is called open transition switching because there is an open state between the star state and the delta state. The Main contractor is closed and the Delta and Star contactors are open. There is voltage on one end of the motor windings, but the other end is open so no current can flow. The motor has a spinning rotor and behaves like a generator.

Delta State: The Main and the Delta contactors are closed. The Star contactor is open. The motor is connected to full line voltage and full power and torque are available.

1.6.2.4.2. Closed Transition Starter

There is a technique to reduce the magnitude of the switching transients. This requires the use of a fourth contactor and a set of three resistors. The resistors must be sized such that considerable current is able to flow in the motor windings while they are in circuit.

The auxiliary contactor and resistors are connected across the delta contactor. In operation, just before the star contactor opens, the auxiliary contactor closes resulting in current flow via the resistors into the star connection. Once the star contactor opens, current is able to flow round through the motor windings to the supply via the resistors. These resistors are then shorted by the delta contactor. If the resistance of the resistors is too high, they will not swap the voltage generated by the motor and will serve no purpose.

In closed transition the power is maintained to the motor at all time. This is achieved by introducing resistors to take up the current flow during the winding changeover. A fourth contractor is required to place the resistor in circuit before opening the star contactor and then removing the resistors once the delta contactor is closed. These resistors need to be sized to carry the motor current. In addition to requiring more switching devices, the control circuit is more complicated due to the need to carry out resistor switching.

In close transition there are five states:

OFF State: All Contactors are open

Star State: The Main [KM3] and the Star [KM1] contactors are closed and the delta [KM2] contactor is open. The motor is connected in star and will produce one third of DOL torque at one third of DOL current.

Star Transition State: The motor is connected in star and the resistors are connected across the delta contactor via the aux [KM4] contactor.

Closed Transition State: The Main [KM3] contactor is closed and the Delta [KM2] and Star [KM1] contactors are open. Current flows through the motor windings and the transition resistors via KM4.

Delta State: The Main and the Delta contactors are closed. The transition resistors are shorted out. The Star contactor is open. The motor is connected to full line voltage and full power and torque are available [4].

1.6.2.4.3. Effects of open transient starter

It is Important the pause between star contactor switch off and Delta contactor switch on is correct. This is because Star contactor must be reliably disconnected before Delta contactor is activated. It is also important that the switch over pause is not too long**.**

For 415V, star connection voltage is effectively reduced to 58% or 240V.

If star connection has sufficient torque to run up to 75% or 80% of full load speed, then the motor can be connected in Delta mode.

When connected to Delta configuration the phase voltage increases by a ratio of V3 or 173%. The phase currents increase by the same ratio. The line current increases three times its value in star connection.

During transition period of switchover, the motor must be free running with little deceleration. While this is happening, a voltage may be generated of its own, and on connection to the supply this voltage can randomly add to or subtract from the applied line voltage. This is known as transient current. Only lasting a few milliseconds it causes voltage surges and spikes, known as a changeover transient**.**

1.6.2.5. Motor starting characteristics on star-delta starter

Available starting current: 33% Full Load Current.
Peak starting current: 2 to 2.7 Full Load Current.
Peak starting torque: 33% Full Load Torque.

1.6.2.6. Features, advantages and disadvantages of star-delta starter

The star-delta starter provides a low surge current thus a low starting torque which is perfect for the motor performance and does not require maintenance, it is better to be used for long time acceleration. For the economic aspect, the star-delta is relatively cheap compared to others, as the connection and wiring is simple and easy to be installed.

However, the star-delta starting method controls whether the lead connections from the motor are configured in a star or delta electrical connection. The initial connection should be in the star pattern that results in a reduction of the line voltage by a factor of $1/\sqrt{3}$ (57.7%) to the motor and the current is reduced to 1/3 of the current at full voltage, but the starting torque is also reduced 1/3 to 1/5 of the DOL starting torque. So if a load is connected to the subject motor requires higher starting torque at the time of starting then very heavy transients and stresses are produced while changing from star to delta connections, and because of these transients and stresses many electrical and mechanical break-down occurs.

Generally Applications with a load torque higher than 50 % of the motor rated torque will not be able to start using the start-delta starter.

Moreover when starting up pumps and fans for example, the load torque is low at the beginning of the start and increases with the square of the speed. When the speed reaches approximately 80-85 % of the motor rated speed the load torque is equal to the motor torque and the acceleration increases. To reach the rated speed, a switch over to delta position is necessary, and this will very often result in high transmission and current peaks. In some cases the current peak can reach a value that is even bigger than for a D.O.L start.

The transition from star to delta transition usually occurs once nominal speed is reached, but is sometimes performed as low as 50% of nominal speed which make transient Sparks.

1.6.3. The Variable Frequency Drive (VFD)

Variable frequency drives (VFD) usage has increased dramatically in HVAC applications. The VFDs are now commonly applied to air handlers, pumps, chillers and tower fans. A better understanding of VFDs will lead to improved application and selection of both equipment and HVAC systems.

There are several terms used to describe devices that control speed. While the acronyms are often used interchangeably, the terms have different meanings such as: VFD (Variable Frequency Drive), VSD (Variable Speed Drive), and ASD (Adjustable Speed Drive).

Variable Frequency Drive is a device uses power electronics to vary the frequency of input power to the motor, thereby controlling the motor speed.

1.6.3.1. VFD operation

The basic principle of VFD operation requires three basic sections: the rectifier, dc bus and inverter.

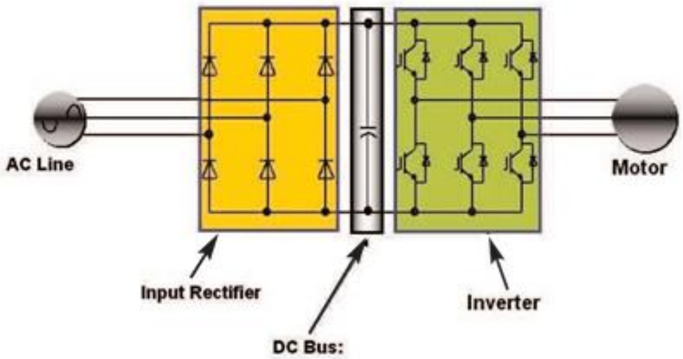


Figure 1-12. VFD operation.

The voltage on an alternating current (AC) power supply rises and falls in the pattern of a sine wave. When the voltage is positive, current flows in one direction and when the voltage is negative, the current flows in the opposite direction. This type of power system enables large amounts of energy to be efficiently transmitted over great distances.

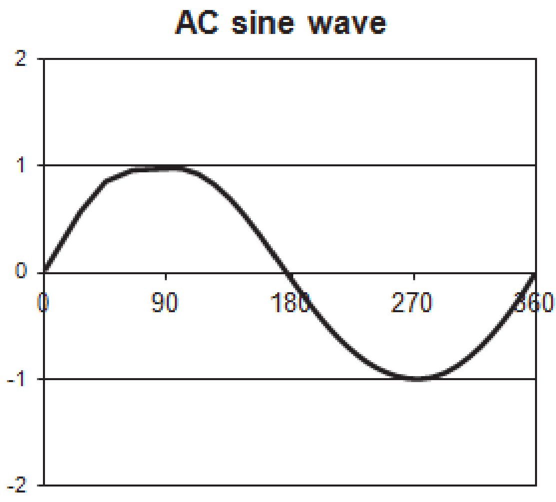


Figure 1-13. Input signal.

The rectifier in a VFD is used to convert in coming ac power into direct current (DC) power. One rectifier will allow power to pass through only when the voltage is positive. A second rectifier will allow power to pass through only when the voltage is negative. Two rectifiers are required for each phase of power. Since most large power supplies are three phase, there will be a minimum of 6 rectifiers used. Appropriately the term “6 pulse” is used to describe a drive with 6 rectifiers. A VFD may have multiple rectifier sections, with 6 rectifiers per section, enabling a VFD to be “12 pulse,”“18 pulse,” or “24 pulse.

Rectifiers may utilize diodes, silicon controlled rectifiers (SCR), or transistors to rectify power. Diodes are the simplest devices and allow power to flow any time voltage is of the proper polarity. Silicon con-trolled rectifiers include agate circuit that enables a micro processor to control when the power may begin to flow making this type of rectifier useful for solid-state starters as well. Transistors include a gate circuit that enables a microprocessor to open or close at any time, making the transistor the most useful device of the three [9].

After the power flows through the rectifiers it is stored on a dc bus. The dc bus contains capacitors to accept power from the rectifier, store it, and later deliver that power through the inverter section. The dc bus may also contain inductors, dc links, chokes, or similar items that add inductance, thereby smoothing the incoming power supply to the dc bus. The final section of the VFD is referred to as an inverter. The inverter contains transistors that deliver power to the motor. The Insulated Gate Bipolar Transistor (IGBT) is a common choice in modern VFDs. TheIGBTcanswitchonandoffseveralthousandtimespersecondandpreciselycontrolthe power delivered to the motor. The IGBT uses a method named “pulse width modulation” (PWM)to simulate a current sine wave at the desired frequency to the motor. Motor speed (rpm) is dependent upon frequency. Varying the frequency output of the VFD controls motor speed: Speed (rpm)=frequency(hertz)x120/no. of poles.

1.6.3.2. Different types of VFDs

Depending on how VFD converts AC power to DC power and make the rectification there are other types of VFDs are available in the market. The main types are VSI and PWM type and CSI type.

1.6.3.2.1. VSI and PWM type

VSI stands for Voltage source inverter. This is the most common type of variable frequency driver. In this type of VFDs, a simple diode bridge is used to convert the AC signal into DC and a capacitor is used to store the energy. An inverter switching circuit uses the stored energy in the capacitor and provides the output.

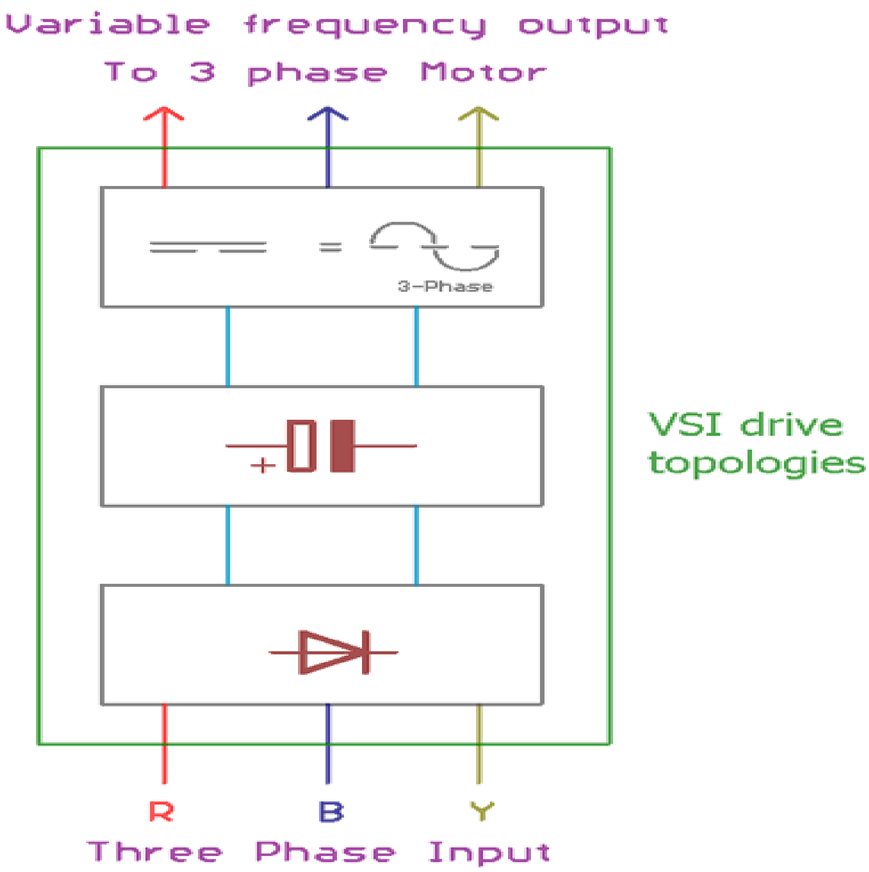


Figure 1-14. VSI type circuit.

VSI type has a good speed range and multiple control motor facility thus multiple motors can be connected to a single VSI type. In addition to its simple design VSIs has a low cost from the production and installation side.

On the hand, the load motor faces jerking during start and stop situation due to the cogging effect. Also the output provides different types of harmonics and noises if the motor speed is controlled or the speed is decreased, the overall power factor is largely get hampered which results in poor power factor.

PWM type is an improved and modified version of VSI type VFDs. PWM stands for pulse width modulation. Using the PWM technique the VFDs are capable to provide stable voltage output maintained with a frequency ratio. The construction uses a diode bridge to rectify the AC signal into a DC signal. The switching circuit controls the duty cycle in a variable frequency range. An additional regulator is used to regulate the PWM output to provide stable and proper voltage and current to the load.

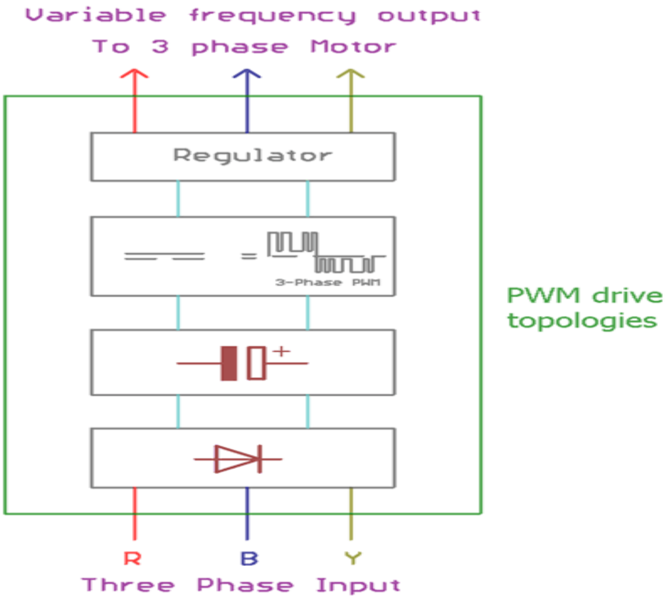


Figure 1-15. PWM topologie.

PWM offers wide speed and control range and a constant power factor with high efficiency that means efficient power. As it consists of different types of protection circuits thus no cogging or jerking effects.

Despite of this benefits the PWM comes with complex design compared to other types and require additional hardware, which means more costs [8].

1.6.3.2.2. CSI type

CSI stands for current source inverter. VSI type are designed in such a way that it could provide smooth voltage output depending on the variable frequency range but in CSI type, the construction is dependable on current instead of the voltage. Also, In the case of CSI, instead of the diode bridge rectifier, SCR bridge converter is used. The output energy is filtered using series inductors as an alternative of capacitors for smooth current output. CSI type act same as like constant current generator. Instead of a square wave of voltage, CSI type is capable to provide square wave of current.

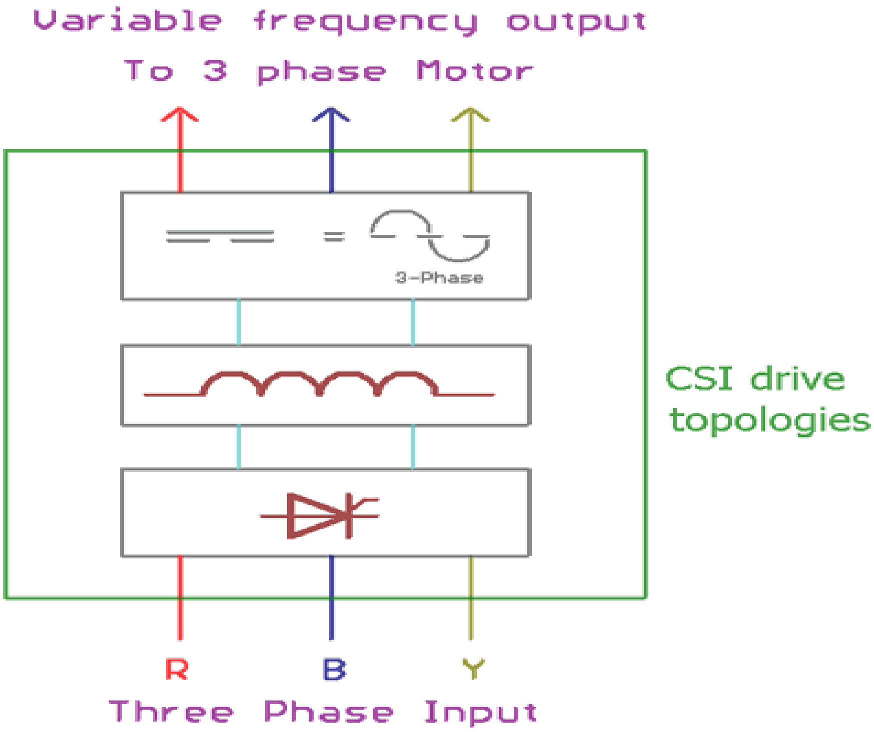


Figure 1-16. CSI type circuit.

CSI types are reliable and support higher horsepower induction motors where VSIs are not suitable choice besides to a good generation capabilities.

However, CSIs are not suitable for multiple motor operations in respect of VSI. Also the cogging effect exists and could vibrate the motor shaft while running as the overall power factor is poor especially at low RPM.

1.6.3.3. Wiring diagram of VFD starter

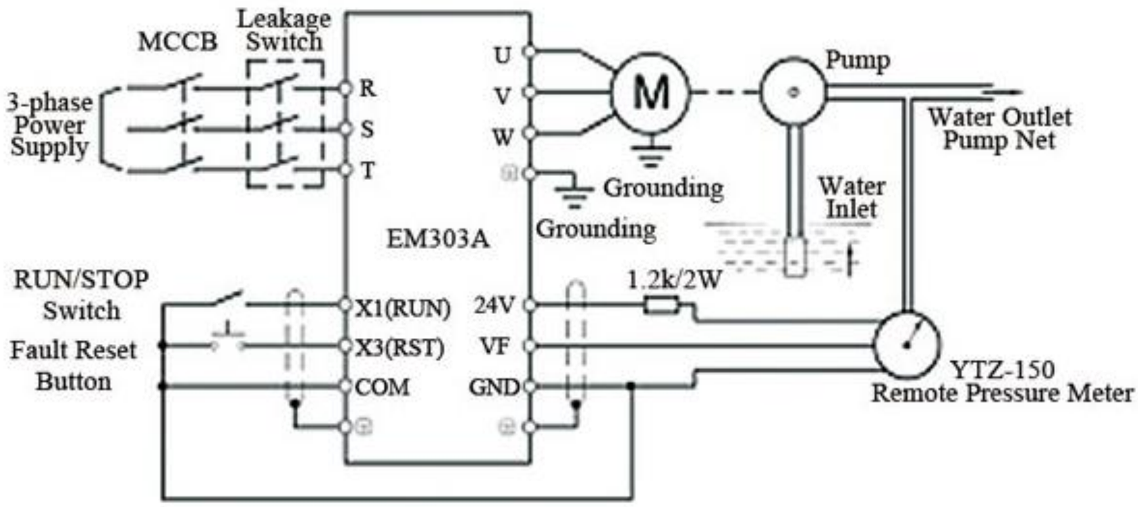


Figure 1-17. VFD connection for pressure water supply.

1.6.3.4. Advantages and disadvantages of VFD starter

VFD starters are most likely the best option in HVAC for its multiple benefits as the energy saving by enabling electric motors to operate at less than full speed. Reducing the motor speed by 25 % decreases energy consumption by nearly 60 % while reducing it by 50 % decrease the consumption by 90 %.In addition to the energy savings, VFD is the ideal soft starter since it provides the lowest inrush of any starter type. Unlike all other types of starters, the VFD can use frequency to limit the power and current delivered to the motor. The VFD will start the motor by delivering power at a low frequency. At this low frequency, the motor does not require a high level of current. The VFD incrementally increases the frequency and motor speed until the desired speed reached. The table below illustrates the inrush current provided by each starter in ideal case.

Starter Type	Starting Current(%of FLA)
VFD	100%
Star-Delta Starter	200-275%
Solid State Soft Starter	200%
Auto transformer Starter	400-500%
Part Winding Starter	400-500%
Across the Line Starter	600-800%

Table 1.1: Starting current with different motor starters.

To improve the power factor, the VFDs include capacitors in the DC Bus that perform the function of power factor correction and maintain high power factor on the line side of the VFD. This eliminates the need to add power factor correction's equipment to the motor or use expensive capacitor banks. In addition, VFDs often result in higher line side power factor values than constant speed motors equipped with correction capacitors. And since the power factor is improved, the KVA required by equipments can be reduced during periods of peak demand, and it will help alleviate voltage sags, brownouts, and power outages.

As for the installation, many pieces of equipment are factory shipped with unit mounted VFDs that arrives pre-programmed and factory wired. Motor leads, control power for auxiliaries, and communication lines are all factory wired. The VFD cooling lines on unit-mounted chiller VFDs are also factory installed. The installing contractor needs only to connect the line power supply to the VFD.

However, despite of the numerous advantages, there are a few disadvantages associated with VFDs. Mainly the high cost is the major drawback as for a factory or a plant where multiple high horsepower motors need to be controlled using VFDs, requires high investments.

Moreover, VFDs uses semiconductors what makes it sensitive to high temperature so there is a need of climate control and a dust free environment.

Furthermore, PWM types VFD has a rectifier circuit that convert AC current to DC current. This circuit has a non linear current (non-sinusoidal) that create a distortion on the ac supply line.

1.7. Programmable Logic Controller (PLC)

1.7.1. What is PLC?

PLC defined as digitally operating electronic apparatus which uses a programmable memory for the internal storage of instructions by implementing specific functions, such as logic, sequencing, timing, counting, and arithmetic to control through digital or analog I/O modules various types of machines or processes.

PLC is a ruggedized digital computer which is used for industrial automation to carry out typical industrial electromechanical processes such as control of machinery on factory assembly lines, amusement rides, or light fixtures. These controllers help to automate a specific process, machine function, or even an entire production line.

They are specifically designed for multiple arrangements of digital, analog inputs and outputs, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. The major purpose of PLCs is to monitor crucial process parameters and adjust process operations accordingly.

Figure 1-18. PLC drive.

1.7.2. Components of PLC

Programmable Logic Controllers have three main components. These components are: CPU module, power supply and an input/output (I/O) section.

1.7.2.1. The CPU module

CPU module contains the processor and the memory .The processor is the brain of the PLC system designed to perform a wide variety of process-control functions. Conventional electromechanical devices, relays and their associated wiring formerly performed these functions. Processors provide these same functions in a wider with minimal effort, making the PLC a much more suitable choice.

The processor operates on DC power (± 5V), that is supplied by the power supply. Internal DC power is also routed through the processor and operates a portion of the I/O and devices connected to the service port of the PLC.

Once the ladder-diagram program is entered into the processor, it remains stored in the memory until changed by the user with one of the programming devices. The program is unaltered through power failure or power off conditions.

1.7.2.2. The power supply

The Power Supply is an essential component to running the PLC. It converts the input source power into voltages required for internal circuitry. In some cases, it also provides an isolated VDC supply to power DC input circuits, switches and other indicators. Programmable Logic Controllers are available with operating voltages from 12V to 240V AC or DC, and I/O's up to 512.

1.7.2.3. The PLC input/output (I/O)

Electrical noise, such as spikes in the power lines or load kick-back would have serious impact on a PLC's internal circuits since its CPU operates at very low voltages levels. This is where the Input/output (I/O) portion of a PLC plays a critical role. Both inputs and outputs protect the CPU from electrical noise. The I/O section is where the status signals is filtered to remove noise, validate voltage levels, and CPU decisions are made and put into operation. The PLC Inputs provide their status to a storage area within the CPU and outputs are driven from similar stored status in the CPU.

Real world devices such as pushbuttons, limit switches and sensors are connected through the input modules in the PLC. These modules detect a change in the state of input signals and provide a stored image to input elements in ladder logic. The input elements simulate the actions of relay contacts within the Programmable Logic Controller. In turn, output elements are "energized," which produces desired output signals to drive loads such as motor controllers, contactors, solenoids, and pilot lights, via the output modules in the I/O's.[16]

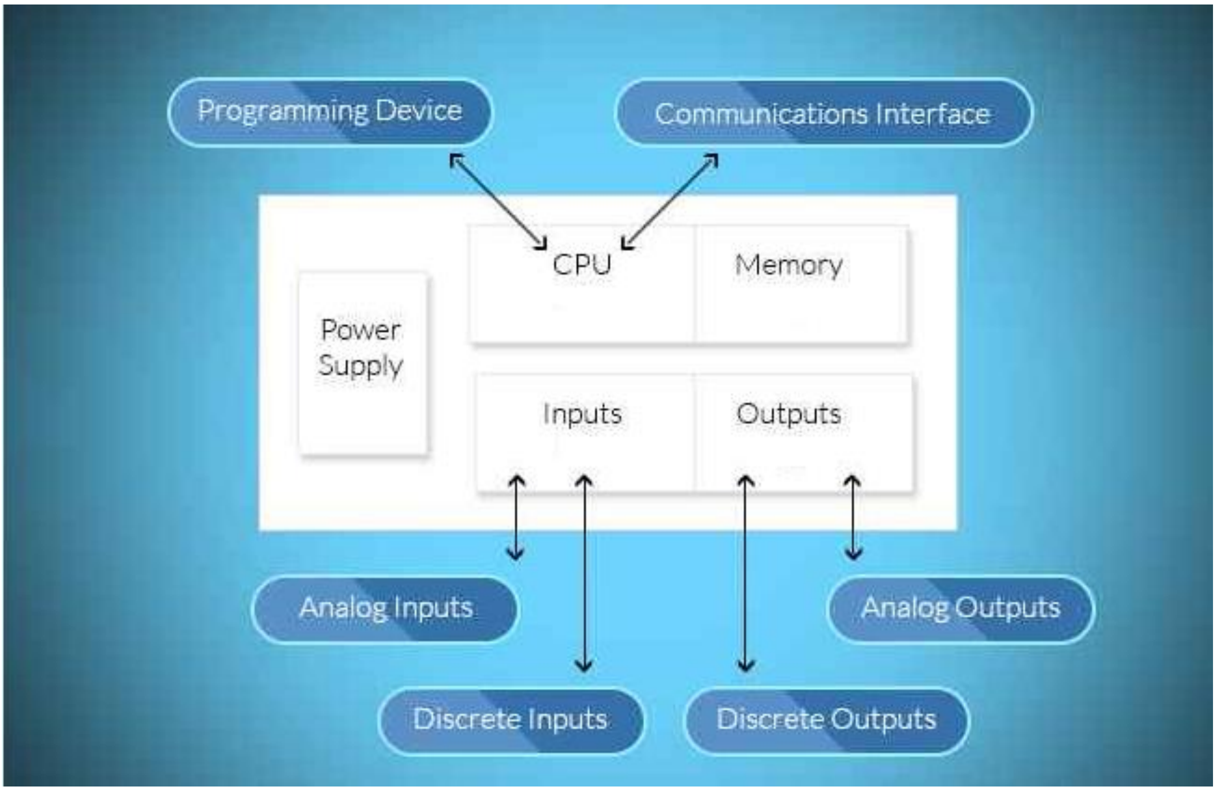


Figure 1-19. Main components of PLC.

1.7.3. Working of PLC

The PLC obtains information from connected sensors/input devices and then processes the data, and triggers outputs based on pre-programmed parameters. PLC can monitor and record run-time data such as machine productivity or operating temperature, depending on the inputs and outputs. It starts and stops processes automatically and generates alarms if a machine malfunctions. PLCs are a flexible and robust control solution that is adaptable to almost any application. The working of PLC includes sequential relay control, motion control, process control, distributed control systems, and networking. The most basic function of a programmable logic controller is to follow the functions of electromechanical relays. Separate inputs are given a unique address, and a PLC instruction is tested whether the input state is 'on' or 'off'.

In automation, TRUE or FALSE conditions can be considered as ON or OFF, CLOSED or OPEN. In the PLC, we will consider binary system (0 or 1). Typically, having a bit ON represents a TRUE condition while OFF is FALSE.

1.7.3.1. The AND function

The AND gate is associated with the following symbol that can have any number of inputs but only one output. The truth table below shows that the output is only turned on when all the inputs are true (1). In other words, AND works like multiplication.

Input A	Input B	Output
0	0	0
1	0	0
0	1	0
1	1	1

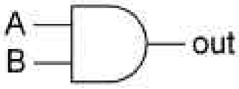


Figure 1-20. The AND function.

The ladder logic equivalent for an AND function looks like two normal contacts side by side.

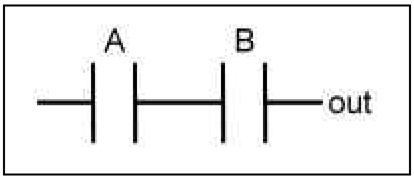


Figure 1-21. The ladder equivalent of AND function.

1.7.3.2. The OR function

The OR gate is associated with the following symbol that also can have any number of inputs but only one output. The truth table below shows that the output is turned on (1) when any of the inputs are true (1). In other word, OR Works like addition.

Input A	Input B	Output
0	0	0
1	0	1
0	1	1
1	1	1

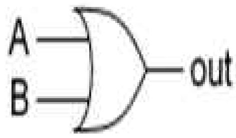


Figure 1-22.OR function.

The ladder logic equivalent to an OR function looks like two normal contacts on top of each other.

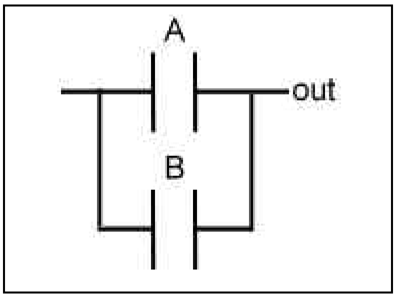


Figure 1-23. The OR equivalent.

A Logical AND function performs a series of relay contacts, not allowing the current to pass unless all the contacts are closed. The output storage bit will be energized when a series of ‘examine if on’ instructions are performed and if all the input bits are on.

Similarly, a logical OR function will be performed by a parallel set of instructions. A group of contacts controlling one coil is called a ‘rung’ of a ‘ladder diagram’. This concept is used to describe PLC logic. The output of each rung sets clears a storage bit. This may be associated with a physical output address. More advanced instructions of the PLC may be implemented as functional blocks, which carry out some operation when enabled by a logical input and which produce outputs to signal.

1.7.4. Programming on PLC

Programming in PLC is done using Ladder logic or other formats. There are various terms that are used in programming to identify how they will interact with other system:

Permissives: They are minimum perquisites that are required for drive or system to operate. Like lubrication system should be on before a drive starts etc.

Protections: They prevent a drive/logic from a harmful condition and stop system to prevent human or mechanical damage.

Interlocks: They are code or conditions that are executed when another action happens and change how the drive/code was working to provide a smooth running process. In other words, interlocks are often used to start auxiliary equipment, standby drives, or to prevent starting of systems for smooth operations.

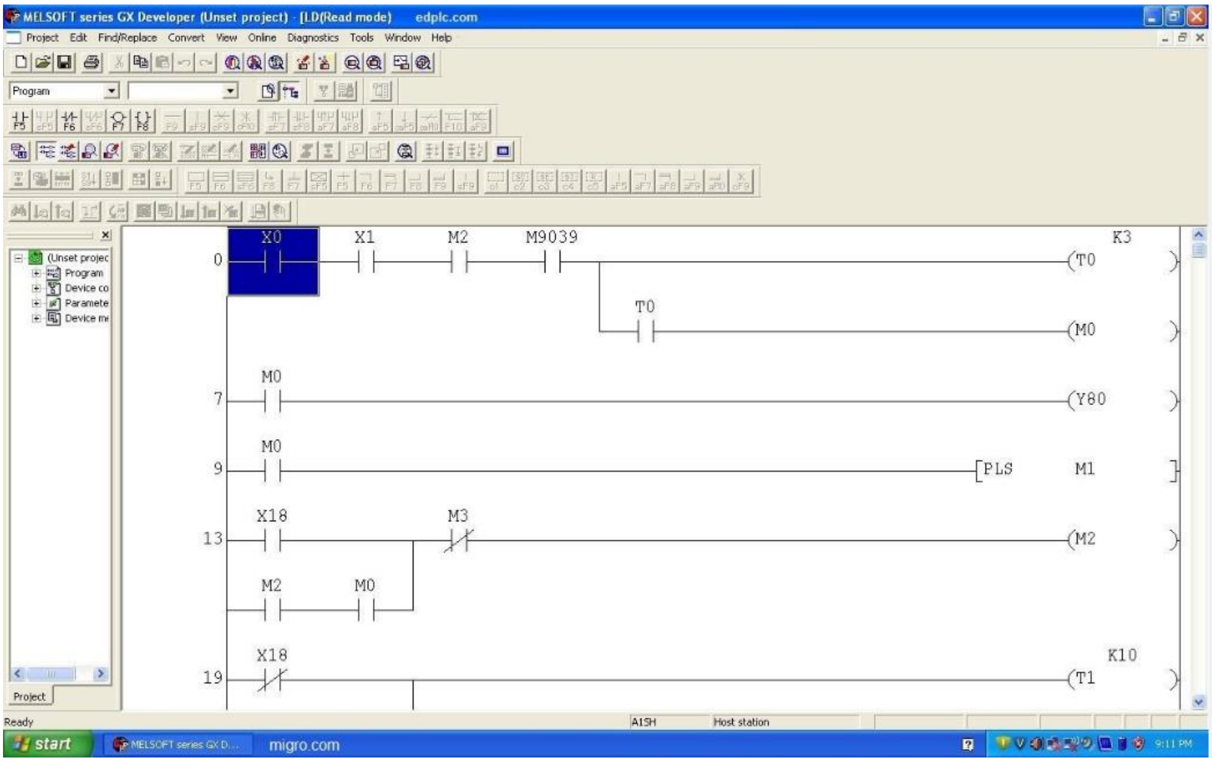


Figure 1-24. A ladder diagram.

1.7.5. Applications of PLC

PLCs are used in various places of automation because of its flexibility. As humans feel tedious to carry out all the tasks, relays were used to perform those activities. However, a relay can be used only for a specific and limited operation which makes their use bulky and uneconomic. There are many uses of PLCs as robotic arms in car manufacturing, air compressors, airport runway lighting control, traffic signal control, smoke alarm control, process valve control and vacuum pump system.

1.7.6. Advantages and disadvantages of PLC

PLCs can an easily run many machines and controlling any change in circuit design or sequence is as simple as retyping the logic, as correcting errors and troubleshooting a circuit is extremely quick, simple and cost effective. Also more contacts, coils, timers, counters and sequences can be generated using a single PLC and a program can be tested and evaluated in a lab which means saving very valuable time.

On the other hand, it is difficult to find errors and require skillful work-force to operate and in case of problem, hold up time usually long or indefinite. Furthermore, there will be too much work required in connecting wires or changes and replacements.

Generally, disadvantages are neglected to the various advantages of PLC [10].

1.8. Conclusion

This chapter discussed the theoretical background of motor starters and PLC. Motor starters used to start the motor safely and decrease the thermal and mechanical stresses thus increasing the lifetime. DOL starter is applicable in case of low three phase motors capacity such as water pumps and fans or in case of high starting torque is needed, but generally it is not favorable for its high starting current that cause harms to the motors. Star delta starters used to increase the current without harming the windings by starting the motor on star configuration that provides 1/3 of the rated current then changing to delta configuration that gives a full rated current, the inrush current theoretically reduced comparing to DOL starters.VFD starters used to increase the speed of the motor gradually by varying the frequency, this method insures a safe start to the motor and significantly reduce the starting current, VFD as a starter is the best choice comparing to other starters that introduced previously. PLC used to control circuits and avoid complicated implementations.

CHAPTER 02:

Description of power training system

2. Description of power training system

2.1 Introduction

The power training system is a station built to facilitate the implementations and the study of circuits in laboratories and facilities. The power ranges from 0 to 500 V and from 0 to 10A. The station uses data acquisition thatplays an important role in any monitoring system and used to collect data from different sensors of the station, thus more efficiency and less errors in results.It consists of four main parts: protection, power sources, controlling part and power analyzer.

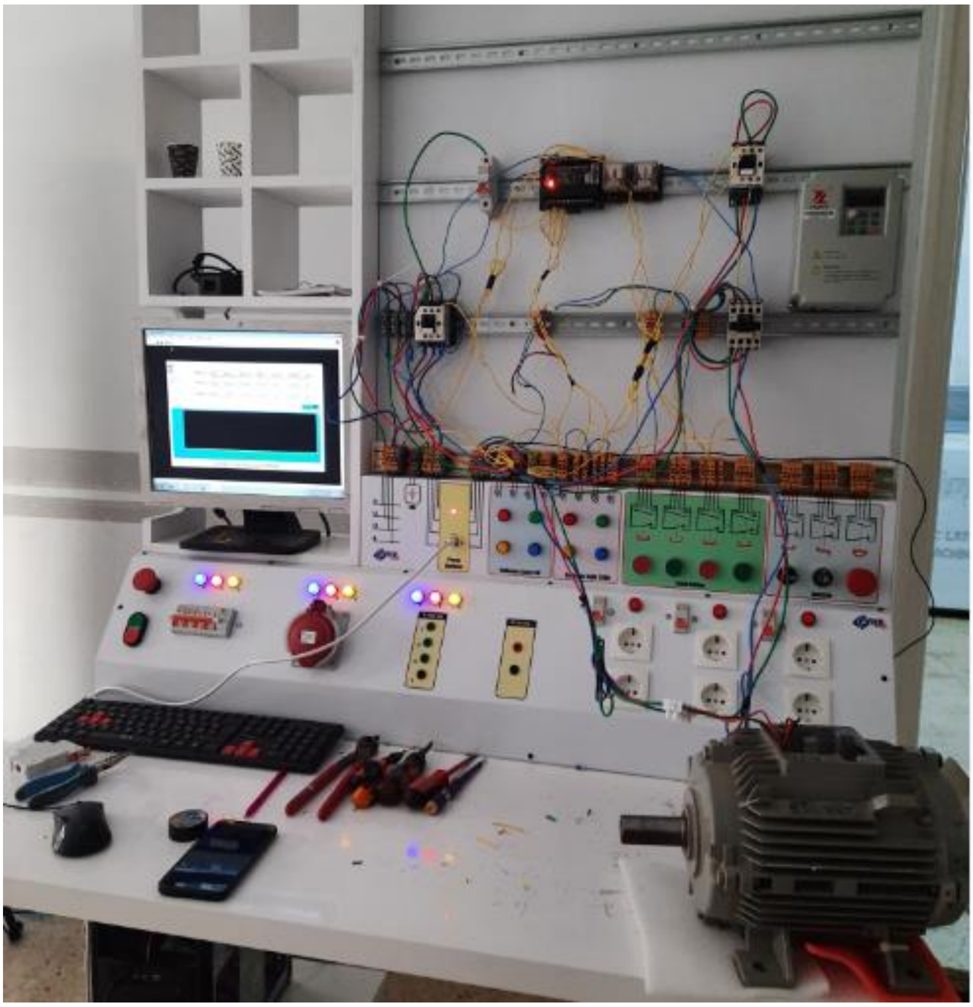


Figure 2-1.VFD current values at 30 Hz.

2.2 Main parts of power training station

2.2.1 Protection

In order to provide a safe environment, the station consists of three phase circuit breakers to cut off the power in case of sudden short circuit or an excess current from an overload and an emergency start/stop push button to stop operating when needed. As it is provided by a single phase circuit breakers for each pairs of the six sockets.

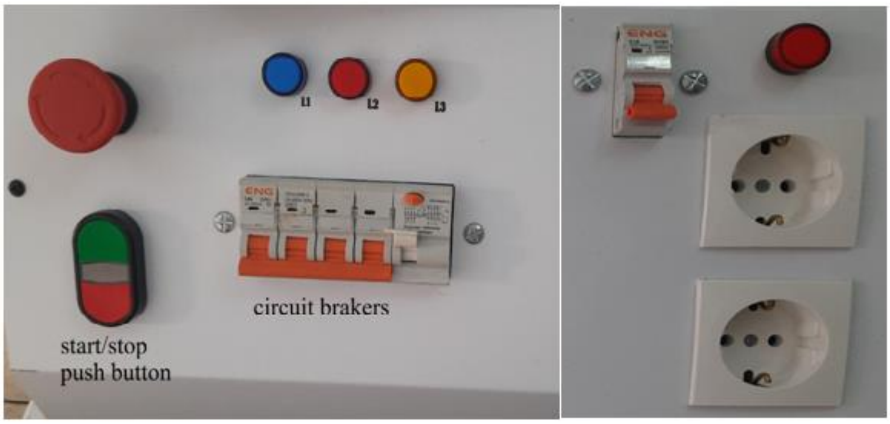


Figure 2-2. Protection instruments.

2.2.2 Power sources

It has a three power supplies of three phase that can be wired directly or using AC plugs, as it contains of six single phase power supply sockets, and they are protected in pairs with a circuit breaker. The station provides also a 24V/5A power supply.

Figure 2-3. Power sources.

2.2.3 Controlling part

When a circuit is implemented, there is a need to control it. Switching with push buttons and control switches is a simple way of operating. The user can switch a certain device or function with one hand control. The station equipped with four push buttons and three switches 550V 10A 50Hz in the normally open (NO) and normally closed (NC) cases.

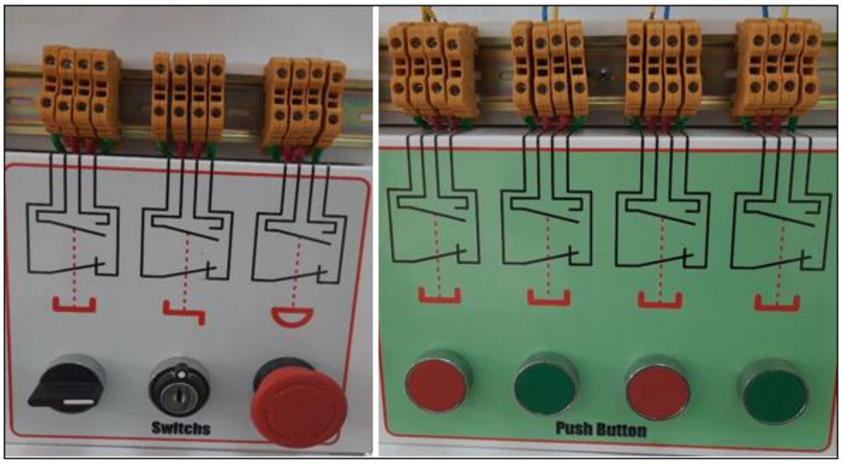


Figure 2-4. Control switches and push buttons

2.2.4 Light indicators

In addition to the above parts, light indicators are added to the station either to indicate the availability of each power source or to be used as testers when a circuit is implemented in the station (four lights of 220 V AC and four lights of 24 V DC).

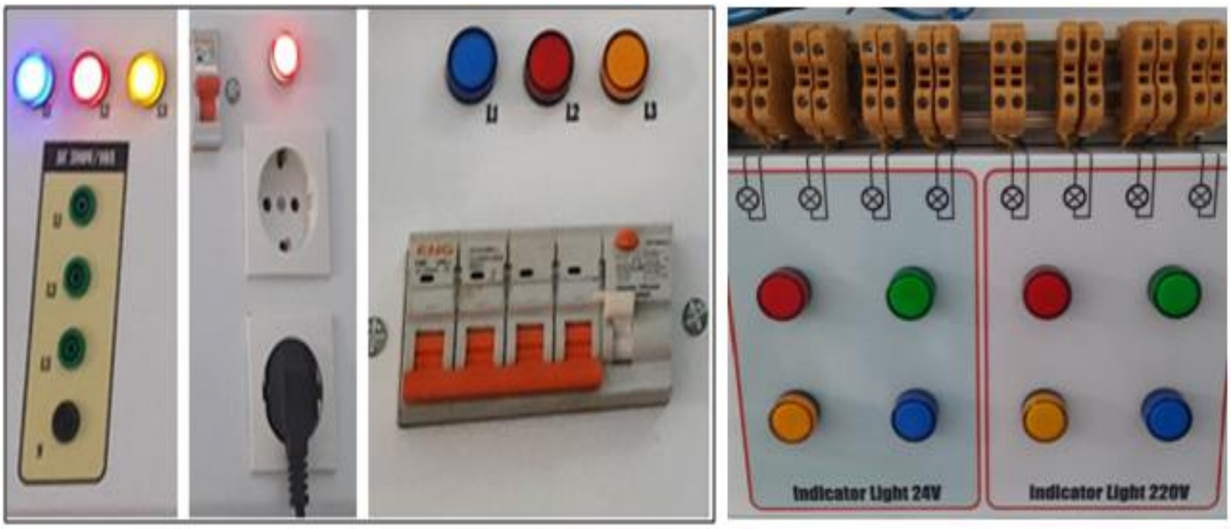


Figure 2-5. Light indicators.

2.2.5 Power analyzer

The most important part is the power analyser that is connected in series with the circuit in order to analyse the incoming signals.

Figure 2-6. Power analyzer.

Power analyser uses data acquisition process to analyse those signals. Data acquisition is the process of digitizing data, it consists of 3 main parts, sensors for current and voltage, signal conditioning circuit (SCC) that filters the signal before going to the digital signal processing (DSP) that processes and display it through lab view on the monitor screen.

2.2.5.1 Sensors

There are two sensors used in the power analyzer that are: voltage and current sensors.

Voltage sensor:used to calculate and monitor the amount of voltage in an object. Voltage sensors can determine the AC voltage or DC voltage level. The measurements are based on voltage divider. It can provide sine wave or pulse trains as an output [13].

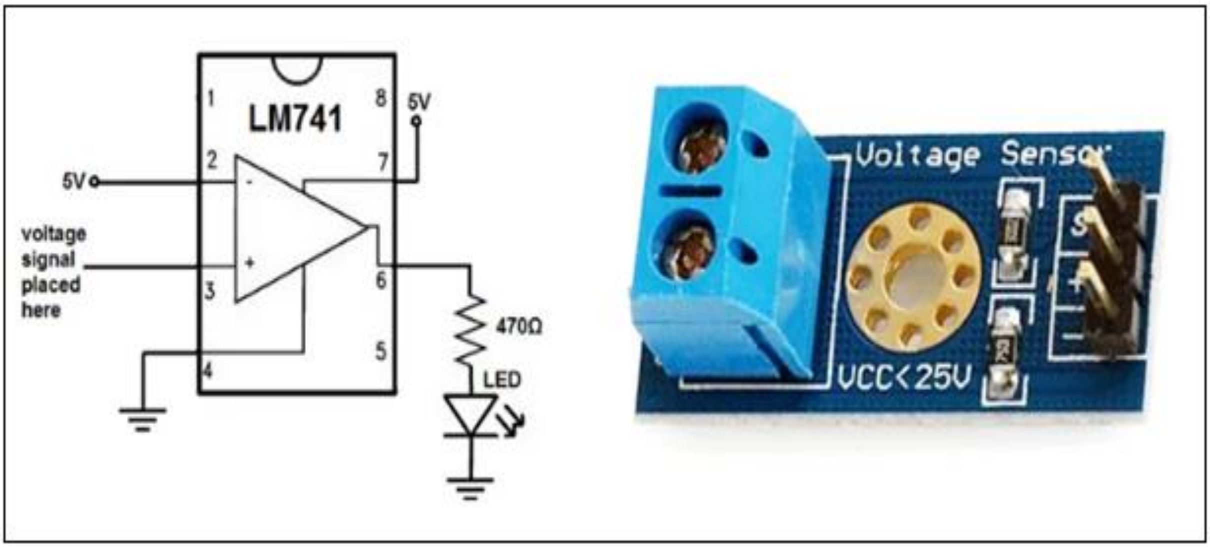


Figure 2-7. Voltage sensor.

Current sensor: it is a device that detects and converts current to an easily measurable output voltage, which is proportional to the current through the measured path. There are a wide variety of sensors, and each sensor is suitable for a specific current range and environmental condition.

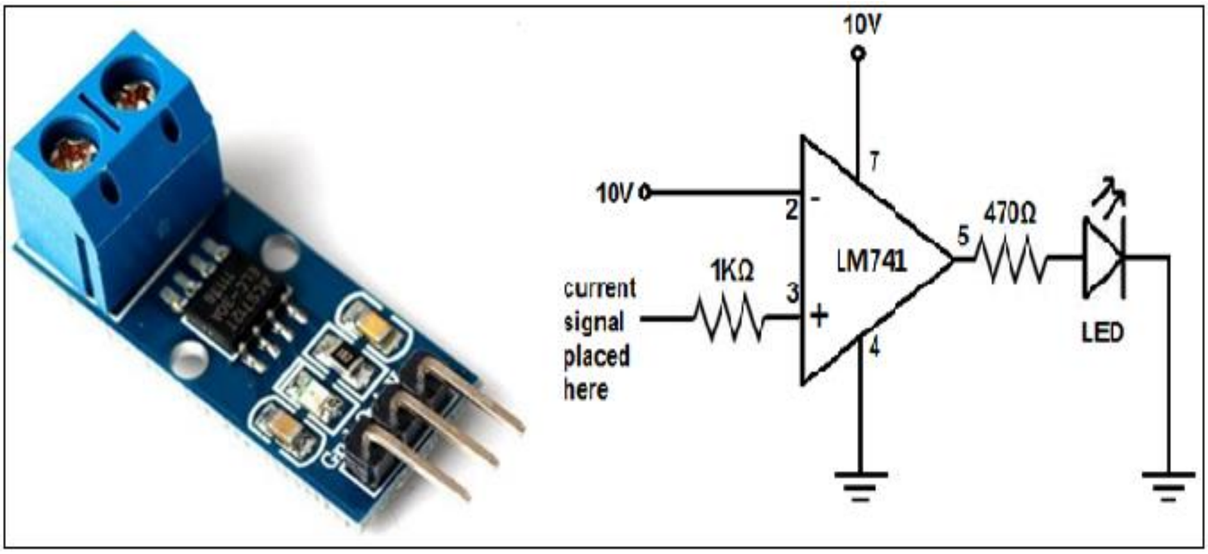


Figure 2-8. Currentsensor.

2.2.5.2 Signal conditioning circuit (SCC)

In electronics, signal conditioning is the manipulation of an analog signal in such a way that it meets the requirements of the next stage for further processing. It is common to have a sensing stage which consists of a sensor, a signal conditioning stage where usually amplification of the signal and noise removal is done and a processing stage often carried out by an ADC and a micro-controller. Signal inputs accepted by signal conditioners include DC voltage and current, AC voltage and current, frequency and electric charge.

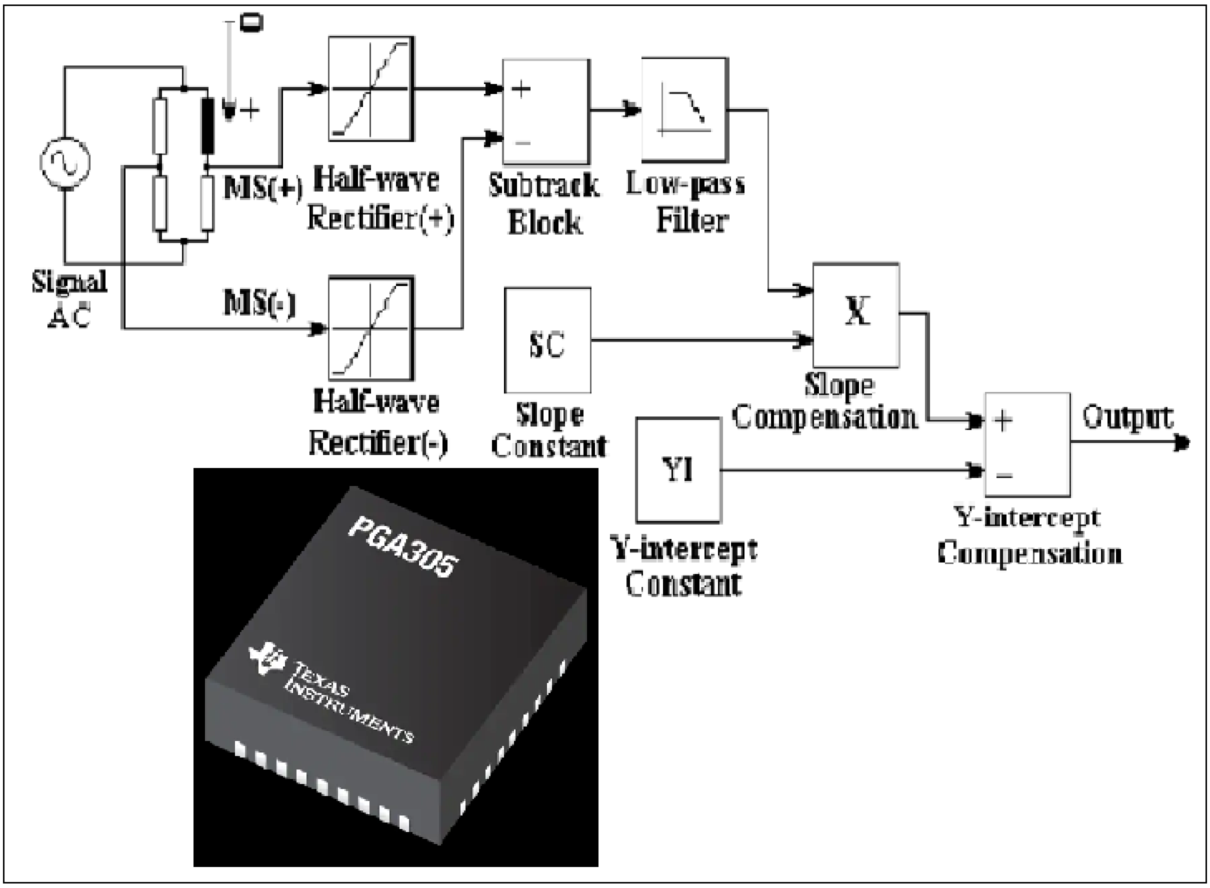


Figure 2-9. Signal conditioning circuit diagram.

2.2.5.3 Digital signal processing (DSP)

After the signal conditioning is done, it comes the digital signal processing, signals digitized using analog to digital converters (ADC) so it can be processed thus the information that it contains can be analyzed and displayed or converted to another type of signal that may be of use. DSP performs the complex mathematical operations with high speed and accuracy in very short time [14].

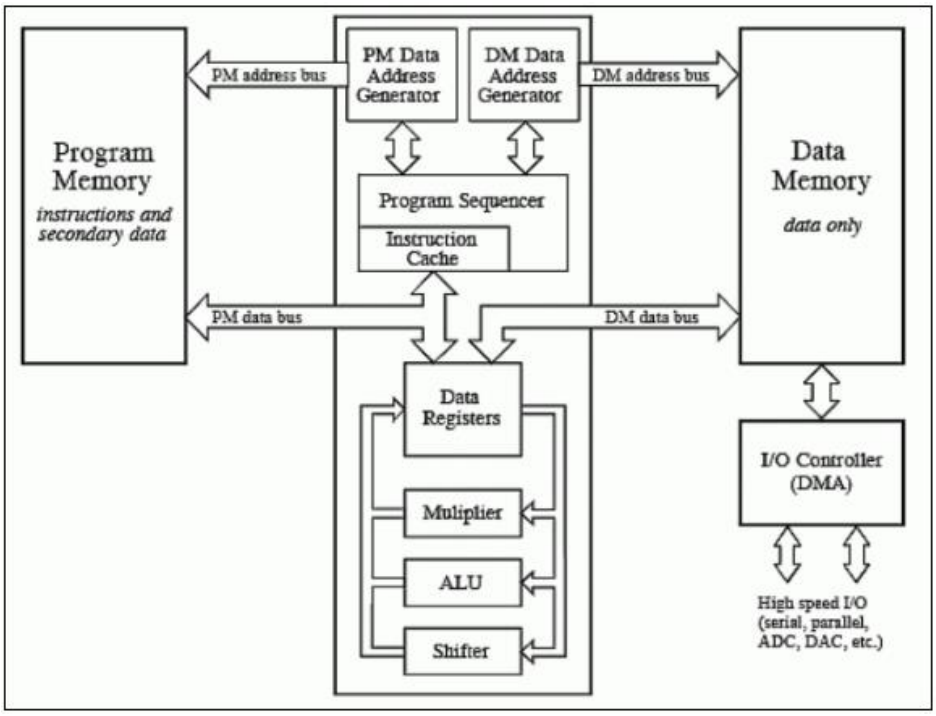


Figure 2-10. Digital signal processor diagram.

2.2.5.4 Data acquisition using LabVIEW

Computer-based data acquisition systems play an important role in clinical monitoring and in the development of new monitoring tools. LabVIEW is a data acquisition and programming environment that allows flexible acquisition and processing of analog and digital data. The main feature that distinguishes LabVIEW from other data acquisition programs is its highly modular graphical programming language, "G," and a large library of mathematical and statistical functions. The advantage of graphical programming is that the code is flexible, reusable, and self-documenting. Subroutines can be saved in a library and reused without modification in other programs. This dramatically reduces development time and enables researchers to develop or modify their own programs. LabVIEW uses a large amount of processing power and computer memory, thus requiring a powerful computer. A large-screen monitor is desirable when developing larger applications. LabVIEW is excellently suited by testing new monitoring paradigms, analysis algorithms, or user interfaces. The typical LabVIEW user is the researcher who wants to develop a new monitoring technique, a set of new (derived) variables by integrating signals from several existing patient monitors, closed-loop control of a physiological variable, or a physiological simulator [15].

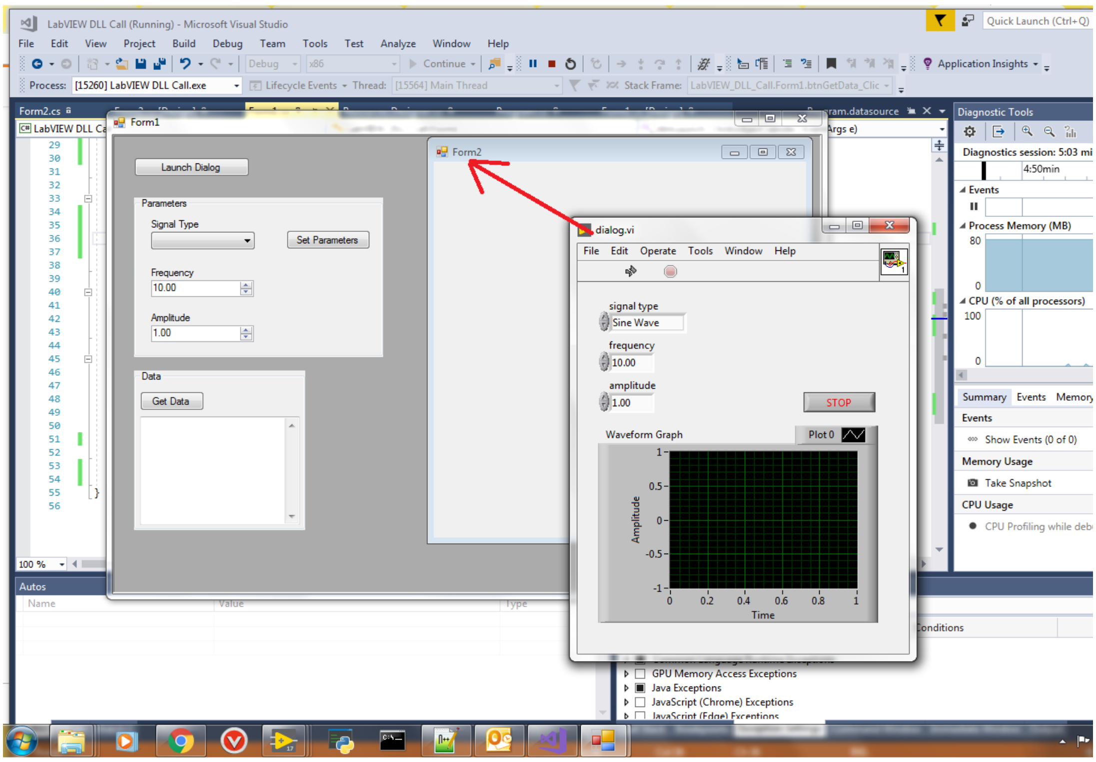


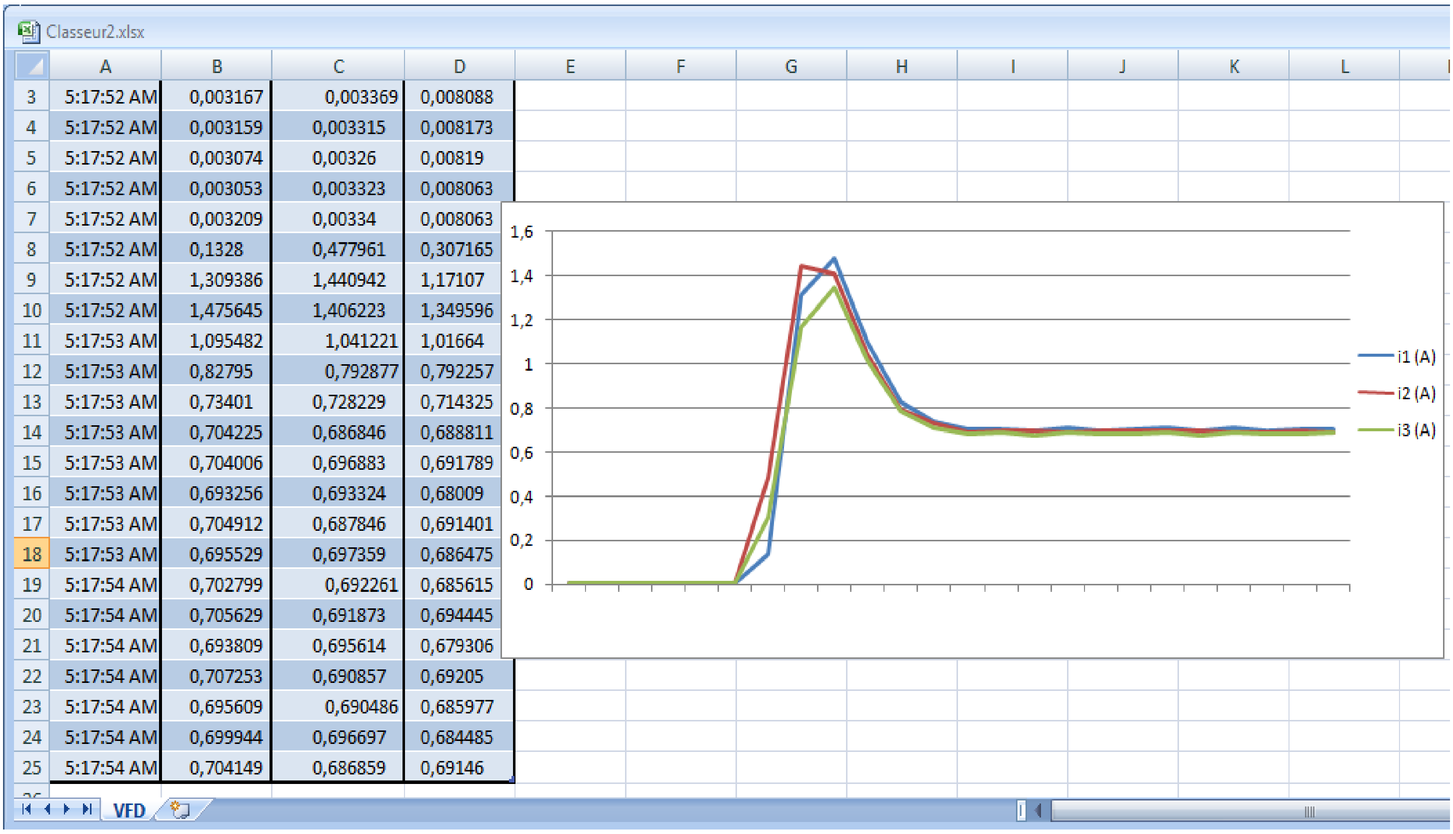
Figure 2-11. Front of LABView.

In addition to the graphs provided by LABView, precise data can be assembled in a bloc-notes file or an excel document for each simulation. Those data can be used later in order to sketch graphs using excel or matlab software. In the case of motor starters, data has been collected approximately each 118ms.

```
Tue, Sep 28, 2021  5-17-48 AM.txt - Bloc-notes
Fichier  Edition  Format  Affichage  ?
9/28/2021   5:17:57 AM    i1: 0.698861 ,i2: 0.690831  ,i3: 0.690911
9/28/2021   5:17:57 AM    i1: 0.706329 ,i2: 0.701129  ,i3: 0.690414
9/28/2021   5:17:57 AM    i1: 0.704394 ,i2: 0.688457  ,i3: 0.696621
9/28/2021   5:17:57 AM    i1: 0.704313 ,i2: 0.702724  ,i3: 0.688137
9/28/2021   5:17:58 AM    i1: 0.709450 ,i2: 0.691856  ,i3: 0.697549
9/28/2021   5:17:58 AM    i1: 0.698114 ,i2: 0.698144  ,i3: 0.683464
9/28/2021   5:17:58 AM    i1: 0.711444 ,i2: 0.697503  ,i3: 0.697946
9/28/2021   5:17:58 AM    i1: 0.693551 ,i2: 0.694956  ,i3: 0.685261
9/28/2021   5:17:58 AM    i1: 0.710462 ,i2: 0.696018  ,i3: 0.693374
9/28/2021   5:17:58 AM    i1: 0.699050 ,i2: 0.696242  ,i3: 0.690591
9/28/2021   5:17:58 AM    i1: 0.702243 ,i2: 0.691586  ,i3: 0.685826
9/28/2021   5:17:58 AM    i1: 0.704866 ,i2: 0.698156  ,i3: 0.694665
9/28/2021   5:17:58 AM    i1: 0.697815 ,i2: 0.689853  ,i3: 0.681153
9/28/2021   5:17:59 AM    i1: 0.707577 ,i2: 0.697372  ,i3: 0.694968
9/28/2021   5:17:59 AM    i1: 0.696111 ,i2: 0.693581  ,i3: 0.681558
9/28/2021   5:17:59 AM    i1: 0.707750 ,i2: 0.694639  ,i3: 0.691991
9/28/2021   5:17:59 AM    i1: 0.705026 ,i2: 0.703537  ,i3: 0.690878
9/28/2021   5:17:59 AM    i1: 0.698304 ,i2: 0.685615  ,i3: 0.685210
9/28/2021   5:17:59 AM    i1: 0.710761 ,i2: 0.707215  ,i3: 0.697591
9/28/2021   5:17:59 AM    i1: 0.694985 ,i2: 0.686235  ,i3: 0.685657
9/28/2021   5:17:59 AM    i1: 0.710622 ,i2: 0.704035  ,i3: 0.694538
9/28/2021   5:18:00 AM    i1: 0.697490 ,i2: 0.693345  ,i3: 0.689840
9/28/2021   5:18:00 AM    i1: 0.710314 ,i2: 0.699805  ,i3: 0.693383
9/28/2021   5:18:00 AM    i1: 0.700801 ,i2: 0.699287  ,i3: 0.690895
9/28/2021   5:18:00 AM    i1: 0.706641 ,i2: 0.691915  ,i3: 0.690245
9/28/2021   5:18:00 AM    i1: 0.702711 ,i2: 0.704107  ,i3: 0.689781
9/28/2021   5:18:00 AM    i1: 0.706266 ,i2: 0.689444  ,i3: 0.692354
9/28/2021   5:18:00 AM    i1: 0.703622 ,i2: 0.703499  ,i3: 0.688837
9/28/2021   5:18:00 AM    i1: 0.705254 ,i2: 0.688727  ,i3: 0.692539
9/28/2021   5:18:00 AM    i1: 0.703272 ,i2: 0.702462  ,i3: 0.691055
```

Figure 2-12. Collected data by LABView.

The figure below offers the graph of VFD starter using the mentioned data drawn by excel.


Classeur2.xlsx

	A	B	C	D
3	5:17:52 AM	0,003167	0,003369	0,008088
4	5:17:52 AM	0,003159	0,003315	0,008173
5	5:17:52 AM	0,003074	0,00326	0,00819
6	5:17:52 AM	0,003053	0,003323	0,008063
7	5:17:52 AM	0,003209	0,00334	0,008063
8	5:17:52 AM	0,1328	0,477961	0,307165
9	5:17:52 AM	1,309386	1,440942	1,17107
10	5:17:52 AM	1,475645	1,406223	1,349596
11	5:17:53 AM	1,095482	1,041221	1,01664
12	5:17:53 AM	0,82795	0,792877	0,792257
13	5:17:53 AM	0,73401	0,728229	0,714325
14	5:17:53 AM	0,704225	0,686846	0,688811
15	5:17:53 AM	0,704006	0,696883	0,691789
16	5:17:53 AM	0,693256	0,693324	0,68009
17	5:17:53 AM	0,704912	0,687846	0,691401
18	5:17:53 AM	0,695529	0,697359	0,686475
19	5:17:54 AM	0,702799	0,692261	0,685615
20	5:17:54 AM	0,705629	0,691873	0,694445
21	5:17:54 AM	0,693809	0,695614	0,679306
22	5:17:54 AM	0,707253	0,690857	0,69205
23	5:17:54 AM	0,695609	0,690486	0,685977
24	5:17:54 AM	0,699944	0,696697	0,684485
25	5:17:54 AM	0,704149	0,686859	0,69146

Figure 2-13. Transferred Data to a graph.

2.2.6 PLC JL1N-20MR

The station is also equipped with a programmable logic controller (PLC JL1N-20MR). This module is programmable control, can achieve thousands of functions, stable and reliable working performance, built-in watchdog timer circuit, to ensure that the module for a long time to run. It consists of a high speed pulse input C235, C251 and FX1N compatible. Output relay 1A output, Rated current 5A, can directly drive DC solenoid valve, AC solenoid valve, AC contactor, AC motor.

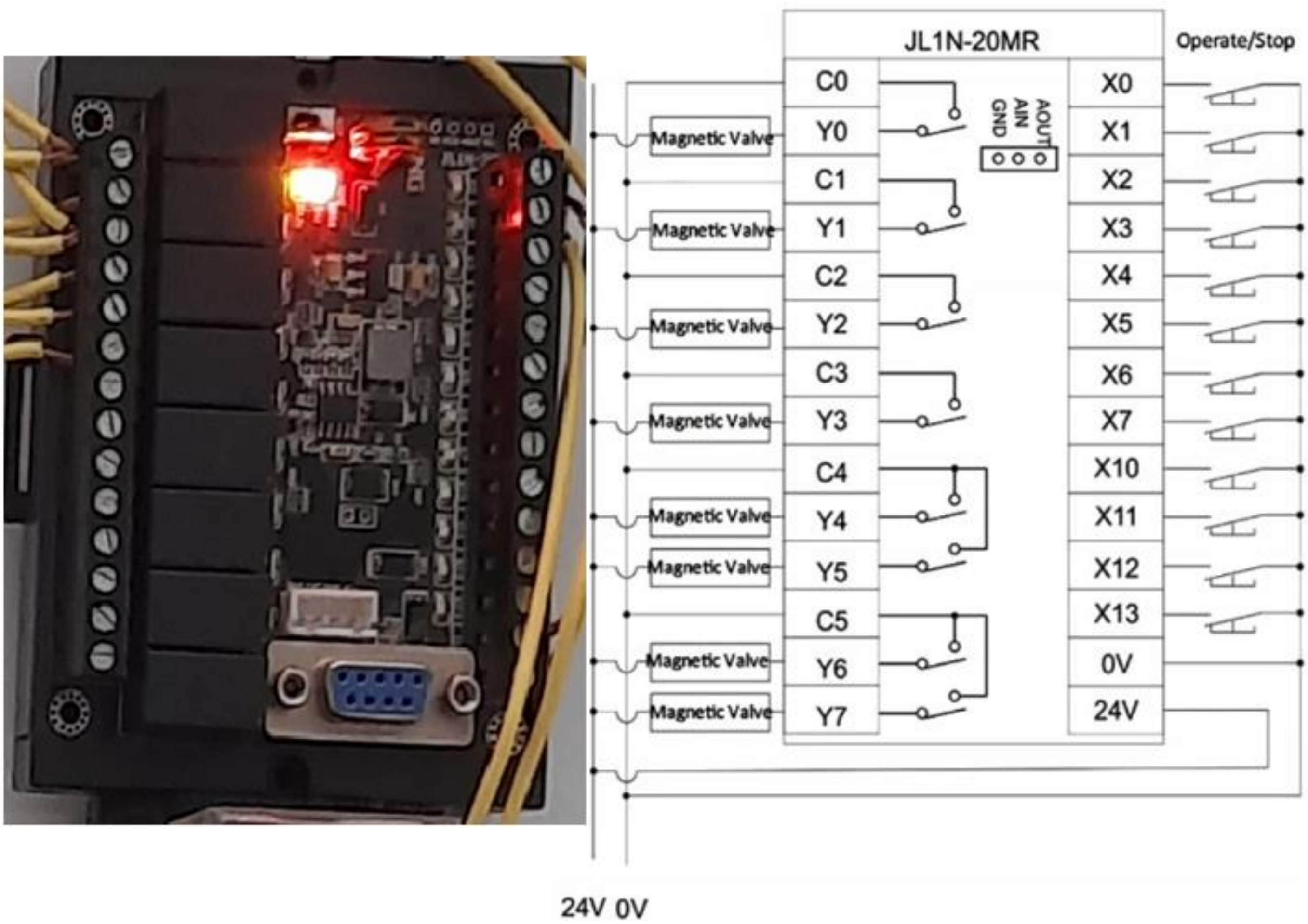


Figure 2-14. PLC drive and its wiring diagram.

2.3 Conclusion

The power training system provides the most suitable working conditions in terms of safety and equipment saving, which means less time and efforts, as the use of data acquisition gives the best results with mostly zero errors unlike the usual measuring methods.

CHAPTER 03: Implementation of motor starters using power training system.

3. Implementation of motor starters using power training station

3.1 The DOL starter

The Direct on Line motor starter (DOL) is designed to switch a single or three phase induction motor at rated voltage. It comprises a contactor, overload relay, link wires and stop/start buttons.

The three phase power supply (L1 L2 L3) is connected to the entries of the contactor 1, 3 and 5 respectively and the exits 2, 4 and 6 to the power analyzer then to the motor. The overload relays are not implemented because they are not available. To start and stop the motor, the first end of NO push button is connected to entry of the coil contactor A1 which is connected to NC end 13 and the other end 14 to the second end of NO push button, the exit of contactor coil A2 is grounded. To feed the coil a phase is taken to first end of NC push button that is connected to second end of NO push button. The second end of NC push button is connected to the second end of NO push button. The order of phases must be taken in consideration and the output phases of the motor are shorted (connected in star configuration).

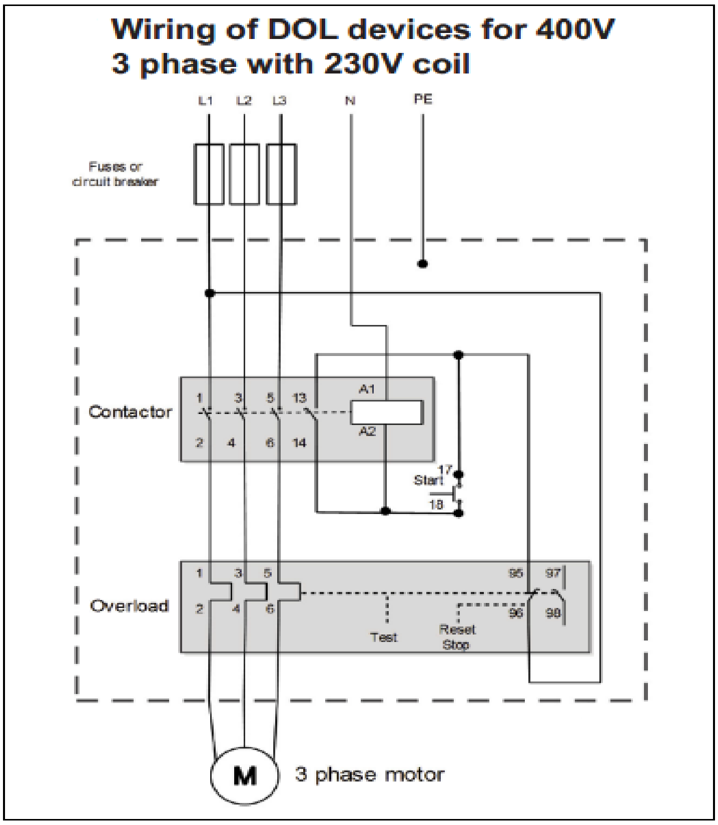


Figure 3-1. DOL wiring.

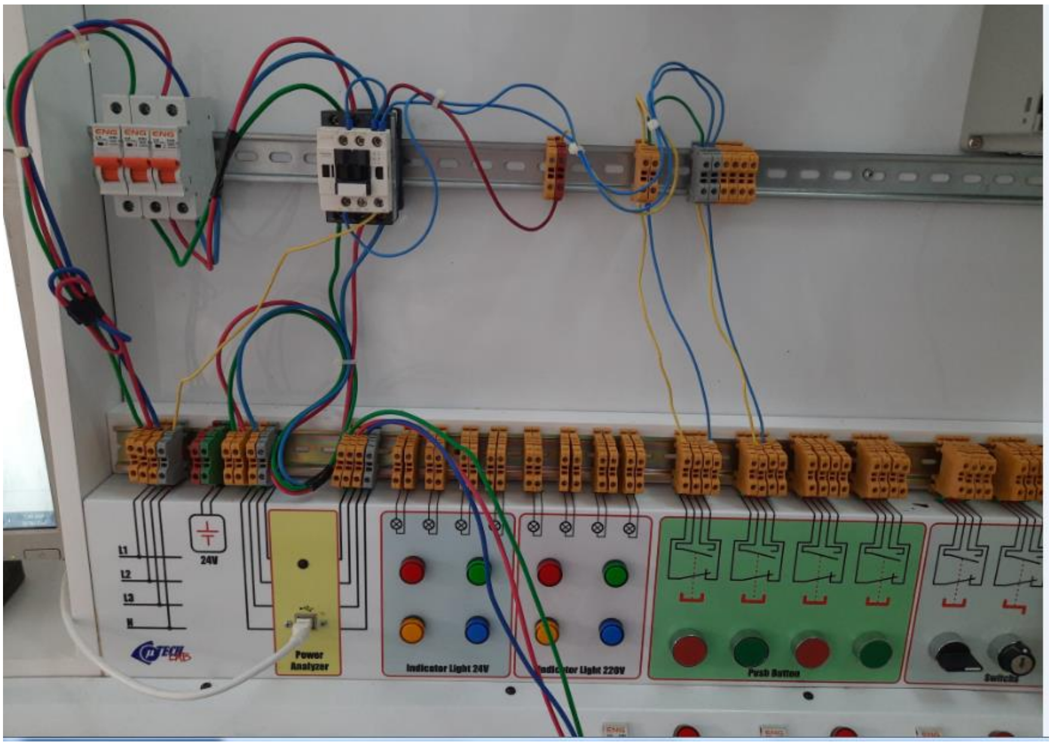


Figure 3-2. Figure 3.2 DOL implementation.

The starting current graph was displayed using LABView through data acquisition in the figure below.

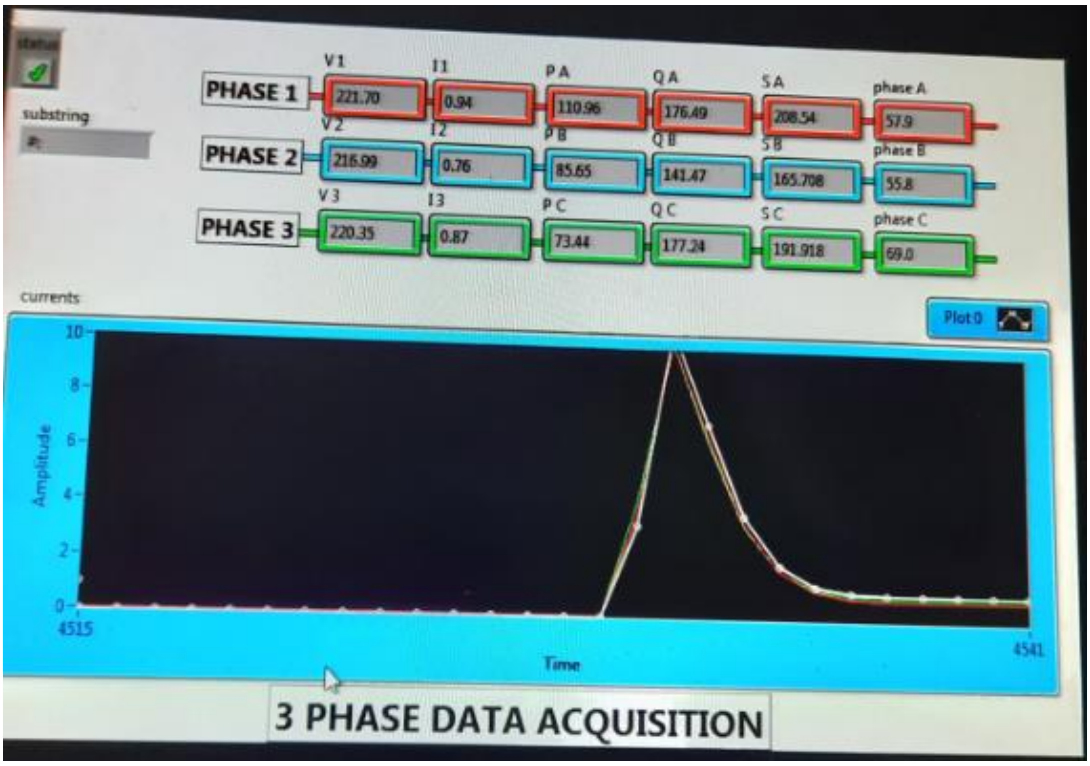


Figure 3-3. Figure 3.3 Three phase DOL current graph.

The exact values were saved as block note file.

```
9/28/2021   3:41:54 AM   i1: 0.000000 ,i2: 0.000000  ,i3: 0.000000
9/28/2021   3:41:54 AM   i1: 10.872489 ,i2: 10.781868  ,i3: 10.628396
9/28/2021   3:41:54 AM   i1: 7.382104 ,i2: 7.060871  ,i3: 6.818262
9/28/2021   3:41:54 AM   i1: 3.864484 ,i2: 3.657028  ,i3: 3.529318
9/28/2021   3:41:54 AM   i1: 1.989847 ,i2: 1.851177  ,i3: 1.813990
9/28/2021   3:41:54 AM   i1: 1.210031 ,i2: 1.089372  ,i3: 1.111136
9/28/2021   3:41:55 AM   i1: 0.973166 ,i2: 0.840420  ,i3: 0.908041
9/28/2021   3:41:55 AM   i1: 0.923956 ,i2: 0.779378  ,i3: 0.863222
9/28/2021   3:41:55 AM   i1: 0.915598 ,i2: 0.769746  ,i3: 0.855926
9/28/2021   3:41:55 AM   i1: 0.913987 ,i2: 0.767186  ,i3: 0.855530
9/28/2021   3:41:55 AM   i1: 0.915181 ,i2: 0.767882  ,i3: 0.855471
9/28/2021   3:41:55 AM   i1: 0.915973 ,i2: 0.768434  ,i3: 0.855800
9/28/2021   3:41:55 AM   i1: 0.916349 ,i2: 0.767671  ,i3: 0.855429
9/28/2021   3:41:55 AM   i1: 0.917399 ,i2: 0.770526  ,i3: 0.856137
9/28/2021   3:41:56 AM   i1: 0.914375 ,i2: 0.771255  ,i3: 0.853413
9/28/2021   3:41:56 AM   i1: 0.915100 ,i2: 0.770159  ,i3: 0.855285
9/28/2021   3:41:56 AM   i1: 0.916652 ,i2: 0.767540  ,i3: 0.854805
9/28/2021   3:41:56 AM   i1: 0.915919 ,i2: 0.763433  ,i3: 0.852274
9/28/2021   3:41:56 AM   i1: 0.912039 ,i2: 0.760430  ,i3: 0.850824
9/28/2021   3:41:56 AM   i1: 0.911027 ,i2: 0.762121  ,i3: 0.851119
9/28/2021   3:41:56 AM   i1: 0.908623 ,i2: 0.763251  ,i3: 0.850309
9/28/2021   3:41:56 AM   i1: 0.906228 ,i2: 0.762256  ,i3: 0.851287
9/28/2021   3:41:56 AM   i1: 0.904748 ,i2: 0.761463  ,i3: 0.851110
9/28/2021   3:41:57 AM   i1: 0.903107 ,i2: 0.760692  ,i3: 0.848867
9/28/2021   3:41:57 AM   i1: 0.902310 ,i2: 0.762319  ,i3: 0.849820
9/28/2021   3:41:57 AM   i1: 0.900092 ,i2: 0.762602  ,i3: 0.847340
9/28/2021   3:41:57 AM   i1: 0.901564 ,i2: 0.764242  ,i3: 0.846396
9/28/2021   3:41:57 AM   i1: 0.903765 ,i2: 0.764428  ,i3: 0.846084
```

Peak starting current

Figure 3-4. Figure 3.4 DOL currents values.

Discussion

As the above file illustrates, the peak starting current value is about 10A, which is higher than the normal state by about 10 times, the high starting current caused a vibration at the first two seconds and some heat in the motor, as the power factor is very low (about 30%). In order to avoid this issue the starter must be replaced with another one that reduces those effects and enhance the power factor.

3.2 The start delta starter

The star delta starter is used to minimize the current to 1/3 of its rated value in the starting period. It needs three contactors (main, star and delta). For the control circuit and because of lack of equipments, the PLC is mounted.

For the power circuit the phase lines (L1, L2 and L3) are connected to entries of main and delta contactors (1, 3 and 5) respectively, exits of main contactor (2, 4 and 6) connected to the entry of power analyzer and its exit to the motor (L1 to W1, L2 to V1 and L3 to U1). Exits of delta contactor connected to the exit of motor (2 to V2, 4 to U2 and 6 to W1), at the same time they are connected to exits of delta contactor (2 to 2, 4 to 4 and 6 to 6). The entries of delta contactor (1, 3 and 5) are shorted.

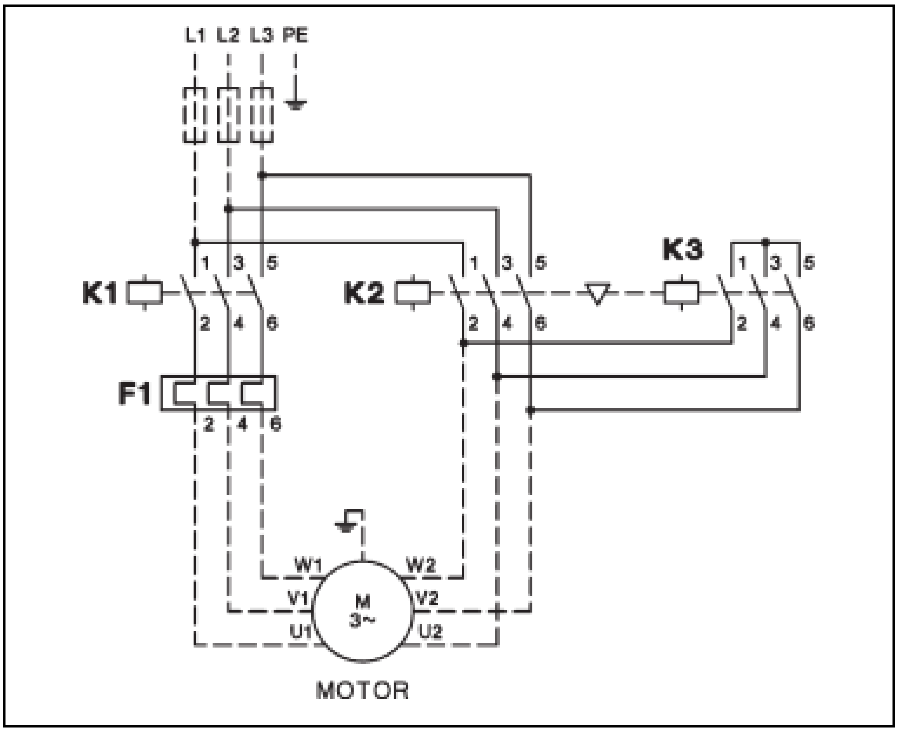


Figure 3-5.power circuit wiring.

To control the circuit, both first ends of start and stop push buttons connected to the entries of PLC device X0 and X1 respectively and second ends are grounded. The exits of PLC Y0 to A1 of main contactor, Y1 to A1 of star contactor and Y2 to entry NC (13) of star contactor and its exit (14) to A1 of delta contactor, and all the three A2 are grounded. The exit Y2was not connected directly to A1 of delta contactor to avoid the short circuiting which means ensuring the opening of star contactor. In order to feed the control circuit, a single phase 220V is connected to C0, C1 and C2 switches to energize the coils. The PLC is fed by 24V DC.

The PLC programmed using GX Works2 software to realize the control circuit taking the time delay 5 seconds.

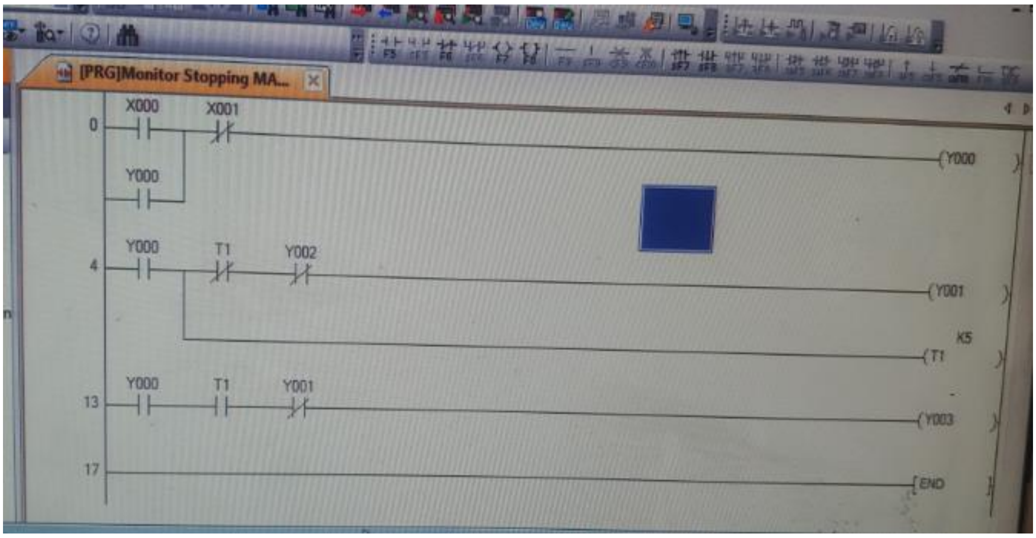


Figure 3-6. The ladder diagram of control circuit.

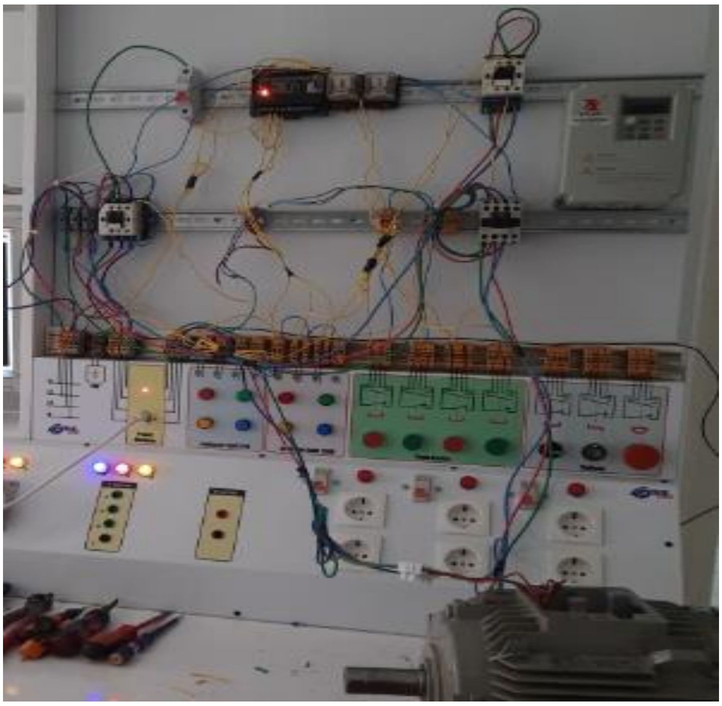


Figure 3-7. Star delta implementation.

The graphs of current are shown in the figures below, figure 3.8 displays the star current before time delay (5s) and the delta current is shown in figure 3.9.

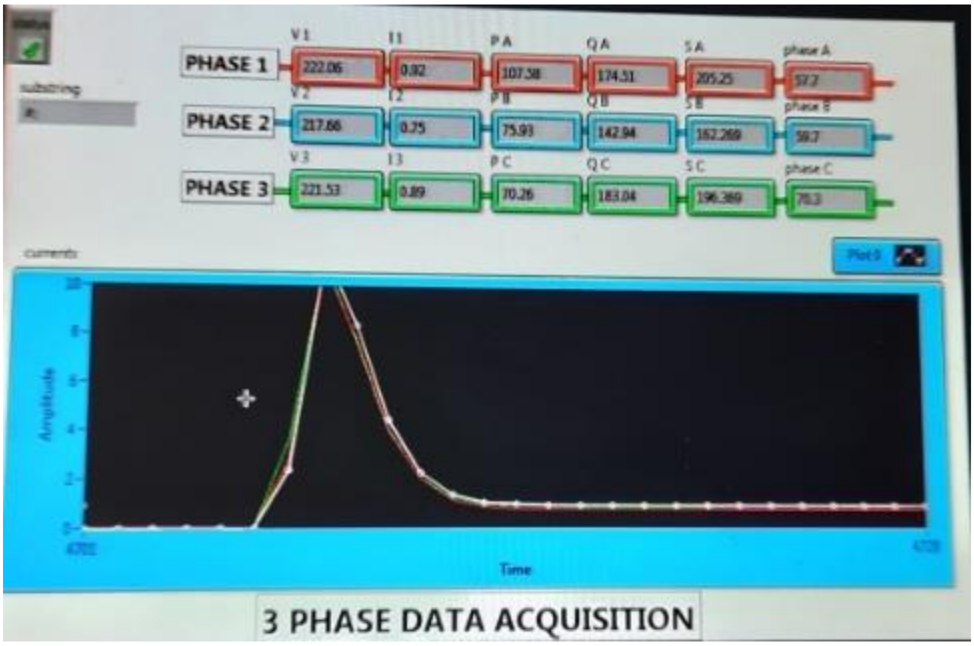


Figure 3-8. Three phase star current graph.

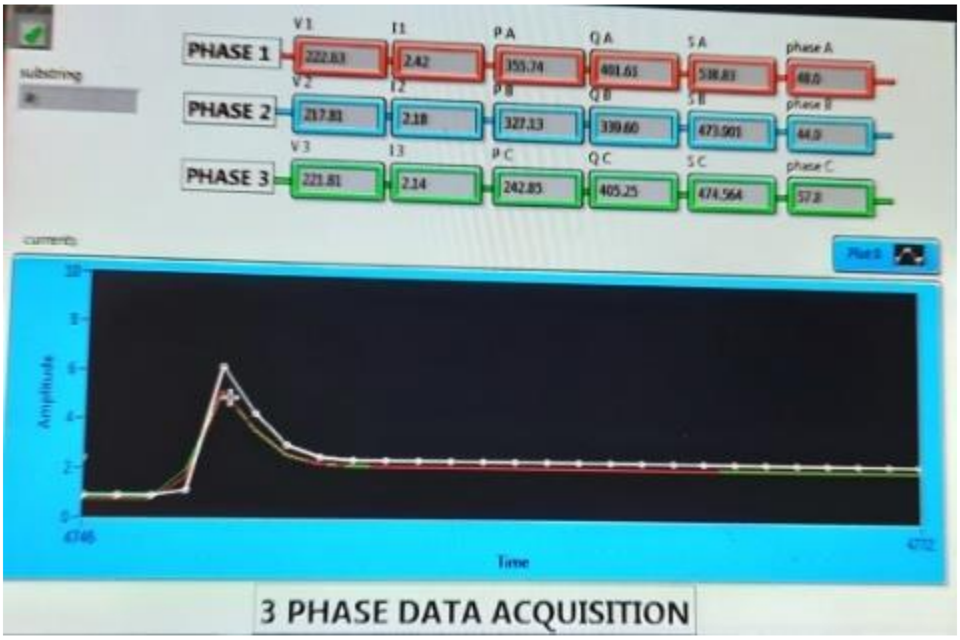


Figure 3-9. Three phase delta current graph.

The current values for star method

9/28/2021	6:04:40 AM	i1: 6.395157	,i2: 6.828939	,i3: 7.746486	
9/28/2021	6:04:40 AM	i1: 10.687920	,i2: 10.230429	,i3: 10.272338	Peak starting current
9/28/2021	6:04:40 AM	i1: 6.554457	,i2: 6.140343	,i3: 6.062289	
9/28/2021	6:04:40 AM	i1: 3.371814	,i2: 3.126354	,i3: 3.092925	
9/28/2021	6:04:40 AM	i1: 1.772144	,i2: 1.598210	,i3: 1.631500	
9/28/2021	6:04:41 AM	i1: 1.150798	,i2: 0.984607	,i3: 1.079955	
9/28/2021	6:04:41 AM	i1: 0.977960	,i2: 0.812882	,i3: 0.924049	
9/28/2021	6:04:41 AM	i1: 0.939526	,i2: 0.785484	,i3: 0.886660	
9/28/2021	6:04:41 AM	i1: 0.928941	,i2: 0.780664	,i3: 0.876379	
9/28/2021	6:04:41 AM	i1: 0.926896	,i2: 0.779125	,i3: 0.873613	
9/28/2021	6:04:41 AM	i1: 0.925179	,i2: 0.775477	,i3: 0.871816	
9/28/2021	6:04:41 AM	i1: 0.923362	,i2: 0.771854	,i3: 0.868409	
9/28/2021	6:04:41 AM	i1: 0.920583	,i2: 0.771960	,i3: 0.868131	
9/28/2021	6:04:42 AM	i1: 0.919132	,i2: 0.772116	,i3: 0.867439	
9/28/2021	6:04:42 AM	i1: 0.917420	,i2: 0.773018	,i3: 0.866461	
9/28/2021	6:04:42 AM	i1: 0.915598	,i2: 0.773613	,i3: 0.865204	
9/28/2021	6:04:42 AM	i1: 0.912224	,i2: 0.770496	,i3: 0.861847	
9/28/2021	6:04:42 AM	i1: 0.909606	,i2: 0.767435	,i3: 0.859983	
9/28/2021	6:04:42 AM	i1: 0.908530	,i2: 0.766617	,i3: 0.858861	
9/28/2021	6:04:42 AM	i1: 0.908598	,i2: 0.768603	,i3: 0.858963	

Figure 3-10. Star current values.

The current values for delta method

9/28/2021	6:04:44 AM	i1: 0.900037	,i2: 0.764082	,i3: 0.857267	
9/28/2021	6:04:45 AM	i1: 0.898654	,i2: 0.764268	,i3: 0.858853	
9/28/2021	6:04:45 AM	i1: 0.900071	,i2: 0.764917	,i3: 0.859798	
9/28/2021	6:04:45 AM	i1: 0.900332	,i2: 0.765718	,i3: 0.861459	
9/28/2021	6:04:45 AM	i1: 5.953285	,i2: 5.492092	,i3: 6.545095	Peak value at the transient state
9/28/2021	6:04:45 AM	i1: 5.447736	,i2: 4.903516	,i3: 5.324500	
9/28/2021	6:04:45 AM	i1: 3.586982	,i2: 3.259019	,i3: 3.402038	
9/28/2021	6:04:45 AM	i1: 2.688329	,i2: 2.499453	,i3: 2.506184	
9/28/2021	6:04:45 AM	i1: 2.416368	,i2: 2.279203	,i3: 2.236990	
9/28/2021	6:04:46 AM	i1: 2.351644	,i2: 2.226114	,i3: 2.178238	
9/28/2021	6:04:46 AM	i1: 2.338200	,i2: 2.218810	,i3: 2.163098	
9/28/2021	6:04:46 AM	i1: 2.334489	,i2: 2.209102	,i3: 2.164085	
9/28/2021	6:04:46 AM	i1: 2.334628	,i2: 2.206353	,i3: 2.165384	
9/28/2021	6:04:46 AM	i1: 2.336104	,i2: 2.207783	,i3: 2.168083	
9/28/2021	6:04:46 AM	i1: 2.339706	,i2: 2.212480	,i3: 2.171423	
9/28/2021	6:04:46 AM	i1: 2.342101	,i2: 2.215036	,i3: 2.174467	
9/28/2021	6:04:46 AM	i1: 2.346284	,i2: 2.217225	,i3: 2.177622	
9/28/2021	6:04:46 AM	i1: 2.349987	,i2: 2.219190	,i3: 2.180439	
9/28/2021	6:04:47 AM	i1: 2.352281	,i2: 2.219881	,i3: 2.183888	
9/28/2021	6:04:47 AM	i1: 2.352631	,i2: 2.218055	,i3: 2.186731	
9/28/2021	6:04:47 AM	i1: 2.345542	,i2: 2.219084	,i3: 2.185719	
9/28/2021	6:04:47 AM	i1: 2.349148	,i2: 2.219831	,i3: 2.186149	
9/28/2021	6:04:47 AM	i1: 2.350577	,i2: 2.220286	,i3: 2.185137	
9/28/2021	6:04:47 AM	i1: 2.348043	,i2: 2.220236	,i3: 2.183526	

Figure 3-11. Delta current values.

Discussion

The value of peak stating current is not reduced because the starting method at the first 5 seconds is the same as DOL starters, then the same effects are noticed. The remarkable is the increasing value of current at steady state from star case to delta one by about three times, thus there were an increasing at speed of the motor as an improvement of power factor (about 50%). This leads to that the star delta starter is used to increase the current gradually, because if the motor is connected directly in delta configurations there will be an excess of current that causes a damage of windings unlike the star delta connection.

3.3 VFD starter

VFD starter implemented using“fullingDZB280 inverter” that fed by 220VAC power supply and the terminals U, V and Ware connected directly to the motor. Programming the inverter was done using “DZB200_DZB300 Inverter manual”. The frequency was set in range of 10Hz to 50Hz thus the starting speed was low and increased accordingly with frequency. The figure below shows front of the inverter.

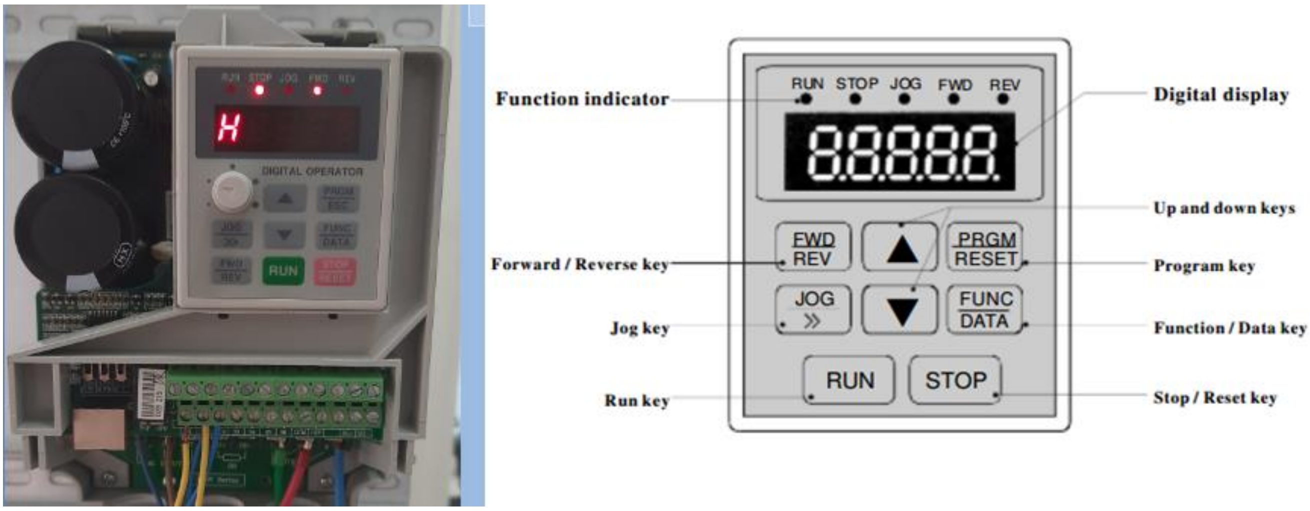


Figure 3-12. Operation panel schematic diagram.

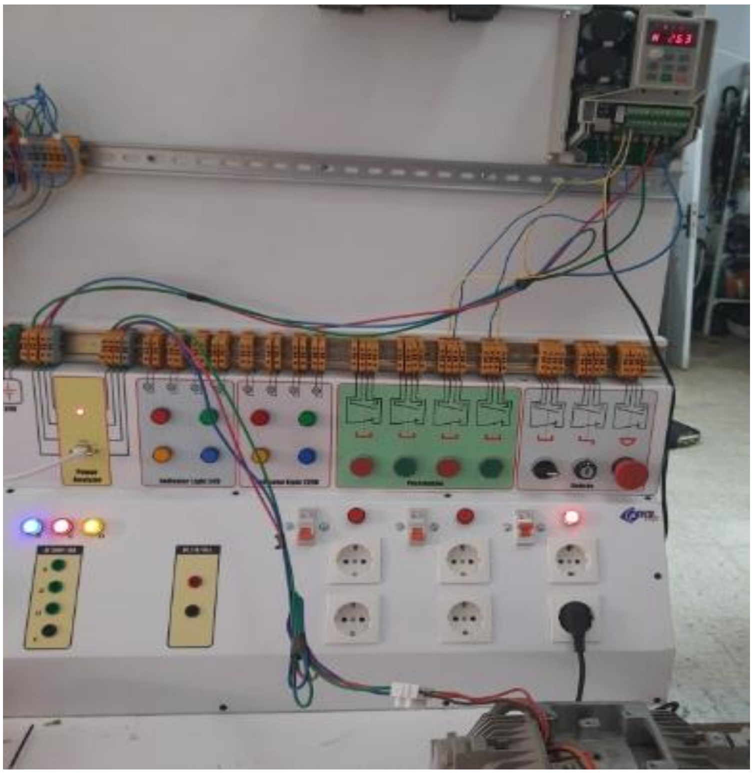


Figure 3-13. VFD implementation circuit.

After connecting the circuit and programming the VFD and setting the starting frequency at 10 Hz, the RUN button is pressed and starts varying the frequency. The figure below reveals the currents graph.

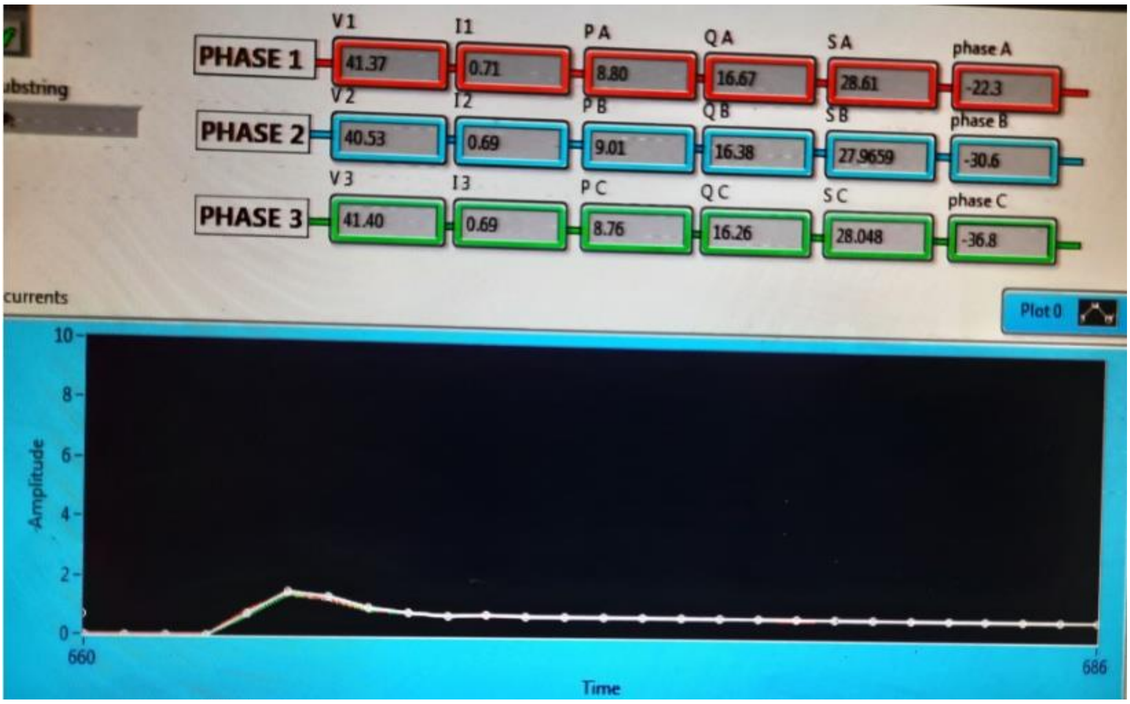


Figure 3-14. VFD current graph.

The values of current are shown in the figure below.

```
9/28/2021    5:17:52 AM    i1: 0.003209 ,i2: 0.003340  ,i3: 0.008063
9/28/2021    5:17:52 AM    i1: 0.132800 ,i2: 0.477961  ,i3: 0.307165
9/28/2021    5:17:52 AM    i1: 1.309386 ,i2: 1.440942  ,i3: 1.171070
9/28/2021    5:17:52 AM    i1: 1.475645 ,i2: 1.406223  ,i3: 1.349596  Peak starting
9/28/2021    5:17:53 AM    i1: 1.095482 ,i2: 1.041221  ,i3: 1.016640  current
9/28/2021    5:17:53 AM    i1: 0.827950 ,i2: 0.792877  ,i3: 0.792257
9/28/2021    5:17:53 AM    i1: 0.734010 ,i2: 0.728229  ,i3: 0.714325
9/28/2021    5:17:53 AM    i1: 0.704225 ,i2: 0.686846  ,i3: 0.688811
9/28/2021    5:17:53 AM    i1: 0.704006 ,i2: 0.696883  ,i3: 0.691789
9/28/2021    5:17:53 AM    i1: 0.693256 ,i2: 0.693324  ,i3: 0.680090
9/28/2021    5:17:53 AM    i1: 0.704912 ,i2: 0.687846  ,i3: 0.691401
9/28/2021    5:17:53 AM    i1: 0.695529 ,i2: 0.697359  ,i3: 0.686475
9/28/2021    5:17:54 AM    i1: 0.702799 ,i2: 0.692261  ,i3: 0.685615
9/28/2021    5:17:54 AM    i1: 0.705629 ,i2: 0.691873  ,i3: 0.694445
9/28/2021    5:17:54 AM    i1: 0.693809 ,i2: 0.695614  ,i3: 0.679306
9/28/2021    5:17:54 AM    i1: 0.707253 ,i2: 0.690857  ,i3: 0.692050
9/28/2021    5:17:54 AM    i1: 0.695609 ,i2: 0.690486  ,i3: 0.685977
9/28/2021    5:17:54 AM    i1: 0.699944 ,i2: 0.696697  ,i3: 0.684485
9/28/2021    5:17:54 AM    i1: 0.704149 ,i2: 0.686859  ,i3: 0.691460
9/28/2021    5:17:54 AM    i1: 0.696575 ,i2: 0.697402  ,i3: 0.684400
9/28/2021    5:17:54 AM    i1: 0.703390 ,i2: 0.693007  ,i3: 0.687774
9/28/2021    5:17:55 AM    i1: 0.701948 ,i2: 0.688832  ,i3: 0.690355
9/28/2021    5:17:55 AM    i1: 0.697739 ,i2: 0.698907  ,i3: 0.682933
9/28/2021    5:17:55 AM    i1: 0.704647 ,i2: 0.686298  ,i3: 0.689410
```

Figure 3-15. VFD current values at 10Hz.

The next figure shows the values of current after increasing the frequency to 30Hz.

```
9/28/2021    5:18:50 AM    i1: 0.727655 ,i2: 0.719065  ,i3: 0.717176
9/28/2021    5:18:50 AM    i1: 0.725993 ,i2: 0.718571  ,i3: 0.717159
9/28/2021    5:18:50 AM    i1: 0.728650 ,i2: 0.717935  ,i3: 0.716003
9/28/2021    5:18:50 AM    i1: 0.731071 ,i2: 0.718078  ,i3: 0.715177
9/28/2021    5:18:50 AM    i1: 0.730881 ,i2: 0.718483  ,i3: 0.714654
9/28/2021    5:18:50 AM    i1: 0.731720 ,i2: 0.719862  ,i3: 0.716138
9/28/2021    5:18:51 AM    i1: 0.731109 ,i2: 0.719250  ,i3: 0.717167
9/28/2021    5:18:51 AM    i1: 0.730653 ,i2: 0.718770  ,i3: 0.718044
9/28/2021    5:18:51 AM    i1: 0.731809 ,i2: 0.720747  ,i3: 0.720321
9/28/2021    5:18:51 AM    i1: 0.732859 ,i2: 0.720667  ,i3: 0.720684
9/28/2021    5:18:51 AM    i1: 0.732391 ,i2: 0.719929  ,i3: 0.719664
9/28/2021    5:18:51 AM    i1: 0.732458 ,i2: 0.721485  ,i3: 0.718879
9/28/2021    5:18:51 AM    i1: 0.731425 ,i2: 0.720701  ,i3: 0.716636
9/28/2021    5:18:51 AM    i1: 0.734579 ,i2: 0.722721  ,i3: 0.718078
9/28/2021    5:18:52 AM    i1: 0.731682 ,i2: 0.719491  ,i3: 0.718432
9/28/2021    5:18:52 AM    i1: 0.729397 ,i2: 0.717197  ,i3: 0.718837
9/28/2021    5:18:52 AM    i1: 0.731058 ,i2: 0.717614  ,i3: 0.719368
9/28/2021    5:18:52 AM    i1: 0.731590 ,i2: 0.717386  ,i3: 0.718651
9/28/2021    5:18:52 AM    i1: 0.730303 ,i2: 0.719389  ,i3: 0.717184
9/28/2021    5:18:52 AM    i1: 0.729350 ,i2: 0.720735  ,i3: 0.716838
```

Figure 3-16. VFD current values at 30 Hz.

Discussion

Utilizing the VFD as a starter reduces the peak starting current to about two times instead of ten times that appeared in DOL and star delta starter. As it can be noticed that there is a notable improvement on power factor that increased up to 80%. For the situation of the motor, the thermal and mechanical stresses are mostly neglected.

3.4 Comparison of the motor starting methods

	DOL	Star delta	VFD
Peak starting current (A)	10.62 ~ 10.78	Y: 10.28 ~ 10.67 Δ: 5.49 ~ 6.54	1.34 ~ 1.47
Power factor	30%	50%	80%

Table 3.1: Comparison of the starters.

From the table the comparison clearly shows that the VFD has the lowest peak starting current and the highest power factor which means less reactive power thus fewer losses. In addition to its simple connection, VFD as a starter is the most suitable choice for the motor because it has less thermal and mechanical stresses.

4. Overall conclusion

To conclude this report, most of the time the power training station was operating perfectly. With its multiple power sources and protection the power training station provided a favorable working conditions therefore it can be used by students or researchers to realize any circuit at laboratories in universities or research centers. Using data acquisition to collect the different data from the circuits implemented saved more time and efforts than usual measurement methods as it is more accurate and precise. The data can be saved and used later which is the best advantage of using LABView data acquisition.

Using the station to implement the three starters was very helpful and safer especially since it is been dealt with three phase power sources. Realization of motor starters was done to verify the starting current and power factor because they are the most affecting factors on the motor. The investigation led to using VFD as a starter is the best method to start properly the motor according to its low starting current and high power factor.

For the future extensions, a web-based data acquisition is offered. It requires no software downloading; configuration is done by a web browser so that it is compatible with any device (smart phones, tablets, laptops or computers). Moreover, alarm outputs with email or text alerts could be applied and the data could be received, managed or retrieved and recorded in the internal memory or flash drive. Furthermore the station could be equipped with variable power source so it would be compatible with circuits that need a lower voltage. Finally the selectivity of circuit breakers could be ameliorated so that the station is well protected and isolated in case of any damages caused by short circuits and overload.

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