بسم الله الرحمن الرحيم

**Sudan University of Science and Technology**

**Collage of Post Graduate Studies**

كلية الدراسات العليا

# Designing a Model of Control System for F-800 Mud Pump Unit

# تصميم نموذج نظام تحكم لوحدة مضخة الطين F-800

A Dissertation Submitted for Partial Fulfillment for the Requirement of the of M.Sc. Degree of Mechatronic Engineering

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# Dedication

To my parents who taught me life's essentials, to my wife who put up with me during research period and my little girl whom I hope to continue what I've started.

To all people who paid great effort to introduce the mechatronic engineering program into collage of graduate studies Sudan University of Science and Technology.

# Acknowledgment

It is pleasure to express my deep gratitude to all people who helped with advice and direction, and without whose help the completion of this research would have never been possible.

I am deeply indebted to the supervisor of this research Dr. Mohammed Elnour for his continuous support, advice and encouragement.

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# Abstract

Increasing the productivity of any unit required a continuous improvement for that unit. For that purpose the study is concentrated on improvement the control system of mud pump unit which is the main oil transfer pump in Hadida FPF located in Block-6 in Sudan by designing a control system model based on programmable logic controller and human machine interface method. The study in its first part discussed the theory of operation of mud pump unit and identified the operation parameters which are effecting on the unit performance. Later parts discussed the concepts of using programmable logic controllers as method of controlling the systems and its advantages over other control methods. In later part the study presents the contents, steps, and layout of designing a model to control mud pump unit according to the parameters identified earlier in this study. Then the study presents the results of experiments that are carried on the designed model which showed that the research objectives are obtained. Finally the study recommends installing the designed model in mud pump unit working in Hadida FPF.

# التجريدة

زيادة الإنتاجية لأي وحدة تتطلب تطوير مستمر لأداء هذه الوحدة. لهذا الغرض تركز هذه الدراسة على تطوير الأداء لنظام التحكم لوحدة مضخة الطين F-800 والتي تعتبر مضخة الخام الرئيسية العاملة في محطة معالجة الخام في حقل حديدة الواقعة في مربع 6 في السودان، وذلك عن طريق استخدام نظام تحكم يعتمد على طرائق المتحكمات المنطقية القابلة للبرمجة. هذه الدراسة تناقش في جزئها الأول طريقة عمل المضخة والعوامل المؤثرة على أداء الوحدة، في الجزء اللاحق تناقش الدراسة مفهوم استخدام المتحكمات المنطقية القابلة للبرمجة كطريقة للتحكم في النظم ومميزاتها عن باقي الطرق الأخرى، لاحقاً توضح الدراسة المكونات والخطوات ونظام التخطيط لتصميم نموذج للتحكم في وحدة المضخة وذلك بالإعتماد على العوامل التي تم تحديدها سابقاً في هذه الدراسة. بعد ذلك تعرض الدراسة نتائج التجارب التي نفذت على النموذج المصمم والتي توضح أن النموذج يحقق أهداف البحث المرجوة. في الختام توصي الدراسة بتركيب النموذج المصمم على وحدة مضخة الطين العاملة في حقل حديدة.

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# List of Abbreviations

| | |
|---|---|
| **ANSI** | American National Standard Institute |
| **ASCII** | American Standard Code for Information Interchange |
| **COM** | COMmunication |
| **CPF** | Central Process Facility |
| **CPU** | Central Processing Unit |
| **DC** | Direct Current |
| **FBD** | Functional Block Diagram |
| **FPF** | Field Process Facility |
| **HMI** | Human Machine Interface |
| **HSE** | Health Safety Environment |
| **IEEE** | Institute for Electrical and Electronic Engineers |
| **IL** | Instruction List |
| **IP** | International Protection |
| **I/O** | Input/output |
| **LCD** | Liquid Crystal Display |

| | |
|---|---|
| **LD** | LoaD |
| **LDN** | input LoaD Not |
| **LED** | Light Emitting Diode |
| **LSB** | Least Significant Bit |
| **MEM** | Ministry of Energy and Mining |
| **OGM** | Oil Gathering Manifold |
| **PC** | Personal Computer |
| **PID** | Proportional Integral Derivative |
| **PLC** | Programmable Logic Controller |
| **PSA** | Production Sharing Agreement |
| **QRV** | Quick Release Valve |
| **RS** | Recommended Standard for IEEE |
| **RTD** | Resistive Temperature Device |
| **RTU** | Remote Terminal Unit |
| **SFC** | Sequential Function Charts |
| **ST** | Structured Text |
| **STL** | Statement List |
| **TFT** | Thin Film Transistor |
| **USB** | Universal Serial Bus |

# Chapter one

# Introduction

## 1.1 Background

Petro-energy E&P is oil and gas operating company with the main objective is to explore, develop, and produce oil and gas in Block 6 in Sudan.

The company officially established by signing of production sharing agreement (PSA) between the ministry of energy and mining (MEM) of Sudan and the company's shareholders.

It consists of one CPF (Central Process Facility) which is purifying and processing the oil to be transmitted through pipeline to Khartoum Refinery Company or for export, and seven FPFs (Field Process Facility) "Keye, jake, FNE, Moga, sufyan, Shoka and Hadida" which the oil from the wells being processed at nearest FPF and pumped to CPF for more processing.

Each FPF consists of oil gathering Manifold (OGM) which gathers the oil coming from wells, separator to separate water and gas from crude oil, heater treater for more separation of water and gas from crude oil and finally to storage tanks and then to main transmission pumps to be pumped to CPF.(Petroenergy-EP.Co.Ltd)

The research is focusing on HADIDA oil transmission pump (Mud Pump) which is multi pistons pump driven by diesel engine.

The operation of mud pump is totally manual and there is no protection system to shut down the pump in case of malfunction or emergency.

In addition to that the pump is difficult to operate by one person and also it takes much time to startup and shut down.

The case of No protection system in mud pump makes the company suffers of losing the whole unit and thus put the station out of production.

For the reasons above the company recruits more than one technician to operate the mud pump and monitor its operation and make the routine maintenance in close periods to ensure that the pump could work safely.

The main objective of research is to improve the system that controls the unit by designing a model of control system so when installed it allows one operator to operate the pump by pressing one button.

Also the operator monitors the pump operation, view the history of errors in case of break down and view the maintenance schedule.

Also the model includes a protection system to alert the operator or shut down the unit in case of unsafe operation or emergency.

## 1.2 Problem statement

The pump consists of manual control system and on-field analog monitor, this make the operation of the unit consumes much time which effect in unit productivity, rather than the time taken to detect and response with malfunctions occur during unit's operation due to no protection system for the unit which leads to increase the risk of losing the unit likelihood.

## 1.3 Research objectives

1. To reduce the time of operation and faults detection by improving the control system of F-800 mud pump unit.

2. Design a model of control system using sensors or potentiometers, actuators, PLC modules and HMI.

## 1.4 Methodology

The objectives of the research could be achieve by studying the system firstly and identify the parameters that have major effect on the unit's operation and then design a model by selecting preferred PLC, HMI, sensors (or potentiometers) and actuators and then design a PLC program that operates the PLC to control the unit and also design HMI program to interact with the user and finally test the model and investigate the results.

## 1.5 Research layout

**Chapter one:** introduction, brief description to field process facility systems. Description for mud pump's system defines problem statement, proposed solution, methodology and research outlines.

**Chapter two:** literature review about control systems already exists in mud pump unit and technical and environmental parameters for operating mud pump unit then describes its components features.

**Chapter three:** describes programmable logic controller definition, its components, types, theory of operation, its programming languages and application. Also describes the Human machine interface (HMI).

**Chapter four:** describes in detail the component used in designing the model, their feature and operating conditions. And also describes the wiring of designed model and its theory of operation.

**Chapter five:** test the system and showing the results and discussion.

**Chapter six:** conclusion and recommendations.

## Chapter two

# Mud pump unit structure and components

# Chapter two

# Mud pump unit structure and components

## 2.1 Unit Overview

The mud pump as shown in figure2-1 and figure 2-2 is specially designed for oil transmission pipeline from FULA oil field to Khartoum oil refinery in Sudan. Oil transmission pump unit's suction inlet is 12" Class 300 ANSI B16.5 flange, and its discharge outlet is 12" Class 600 ANSI B16.5 flange. Inlet and outlet is equipped with high pressure rubber hose which correspond to flange class.

F-800 pump unitization assembled with power transfer assembly, F-800 mud pump, belt protection guard, belt, big belt sheave assembly, big case, and air system. The power transfer system includes G12V190PZL-1 diesel engine, BHJ385F-350 ball cage cardan shaft, drive shaft, small belt sheave, 20CB500 dual air tube clutch, friction hub of air control system, power transfer base and so on. The G12V190PZL-1 diesel engine has used the desert air filter, muffler with fire –proof cover. Between the F-800 mud pump and the G12V190PZL-1 diesel engine has installed the partition wall, which enhance the security of pump station. The F-800 mud pump relief valve outlet has the reduction tube run into dirty collection holder in the station yard. That ensures the discharge in station yard 6 confirm to the HSE requirement. The diesel engine start adopts air start, hand operated to adjust speed.(Baoji, 2005)

The oil transmission pump station includes two sets of F-800 mud pump unitization (BC180121-00), suction and discharge manifold assembly, awning and so on. Two sets of F-800 mud pump unitization are connected together by main suction pipeline 12” and main discharge line 12”. The distance from main suction pipeline to main discharge pipeline is 800mm. in order to meet the oil transfer requirement, the hydraulic cylinder of fluids end and the valve spring is specially designed as shown in figure 2-19. The F-800 mud pump suction inlet and discharge outlet are equipped with pulsation dampers and corresponding class valve. The pump station and the main pipe line are connected with the high-pressure oil transfer rubber tube. Each F-800 mud pump unitization of the pump station has awning. On the top of the diesel engine, and on the top of the pump installed explosion-proof lighting lamps.

Pump unitization equipped with air system to supply air for diesel engine and air clutch.

The F-800 mud pump as shown in figure 2-18 consists of drive end assembly and fluid end assembly. The power end assembly consists of driven pulley, gearbox and crankshaft which convert the rotary motion of the driven pulley to reciprocating motion to the pistons for pumping the fluid.

The fluid end assembly as shown in figure 2-19 and figure 2-20 consists of 3 pumping champers which contain pistons, suction and discharge valves and suction and discharge lines equipped with pulsation dampers to absorb the shocks due to pump operation (Baoji, 2005).

Figure 2-1: mud pump compartment.(Baoji, 2005)

Figure 2-2: mud pump compartment other view.(Baoji, 2005)

Figure 2-3: fluid end assembly.(Baoji, 2005)

## 2.2 Unit's Parameters and type

The table 2-1 shows the environmental and technical parameters of F-800 mud pump unit. The environmental parameters are special for block 6 in Sudan.(Baoji, 2005)

Table 2-1: environmental and technical parameters:(Baoji, 2005)

| **Parameter** | **Unit** | **Values** |
|---|---|---|
| **Environmental Parameters** | | |
| Rainy Season | --- | June to October |
| Average rainfall per year | mm | 318 |
| Environment temperature | $^{o}C$ | 10/85 |

| | | |
|---|---|---|
| (max/min) under sunshine | | |
| Environment temperature (max/min) under awning | $^{o}C$ | 58 |
| Min/Max relative humidity | % | 20/80 |
| Designing humidity | % | 100 |
| Maximum wind speed | m/s | 40.5 |
| Height above sea level (min/max) | m | 366/686 |
| Transmission medium temperature (Crude oil temperature) | $^{o}C$ | 40 |
| **Technical Parameters** | | |
| Maximum flow rate | L/s | 36.8 |
| Suction inlet pressure | MPa | 0~5 |
| Discharge outlet pressure | MPa | 10 |
| Weight | Kg | 79799 |
| Rated power | KW (HP) | 596 (800) |
| Rated strokes | r/min | 150 |
| Stroke length | Mm | 229 |
| Gearwheel ratio | ------ | 4.185:1 |
| Maximum working pressure | MPa | 34.5 |

| | | |
|---|---|---|
| Maximum liner diameter | mm | 170 |
| Diesel engine Type | ---- | G12V190PZL-1 |
| Diesel Engine Rated rotation | r/min | 1200 |
| Diesel Engine Rated power | KW | 740 |
| Transmission belt type | ----- | 4X4ZV25J-8000 |
| Air clutch type | ----- | 20CB500 daul air clutch |

## 2.3 Effective operation parameters

The parameters listed below are effect directly on unit operation, safety and lifetime. These parameters are:

1. **Engine coolant temperature:** the operation range of cooling temperature between 75°C to 85 °C, if an internal combustion engine is run at an overheated state, problems such as piston seizure may take place and damage the engine. Especially in an engine continuously running at a constant speed.(Tobinaga and Nasuda, 1984)
2. **Engine oil temperature:** when the oil temperature rise above 90 oC the oil viscosity will decrease cause the direct contact between moving parts and thus increases the wear between them and decrease engine lifetime.(Jack, 2005b)
3. **Engine oil pressure:** the lubrication system must be delivered in suitable and recommended pressure and flow rate to perform the following duties:

a. Generating the lifting capacity in journal bearings (crankshaft, connecting rod, camshaft, etc.).
b. Counterbalancing centrifugal forces within the crankshaft.
c. Operating auxiliary devices.(Mancò et al., 2004)

The range of oil pressure should not be less than 5 Bar. (Jinan, 2005)

4. **Engine speed:** diesel engine cannot be operated at speeds which exceed a certain value. Such value is determined by the structural characteristics of a particular engine. If the engine operates at a maximum permissible speed and its cylinders continue to receive fuel, the speed can increase beyond the permissible value but with the attendant danger of substantial damage.(Eheim, 1972)
5. **Pneumatic air pressure:** the pneumatic air is mandatory to operate the unit. It is responsible of operating startup oil pump which is pneumatic motor connected to an oil pump and starter motor which is also pneumatic motor to start the engine. Also the clutch that connects between the pump and drive engine is an air clutch. The air pressure of the system should not be less than 588 KPa (Jinan, 2005)
6. **Suction and discharge pulsation dampener pressure:** the pulsation dampeners consist of a vessel contains a nitrogen bag to absorb the shock that happens when the crude oil is pumped by F-800 mud pump. The high pumping shock leads to high vibration in suction and discharge lines and thus to damage them. The pressure of nitrogen of pulsation dampener should not be less than 1.7 Bar and not exceed 2 Bar.(BAOJI, 2004)

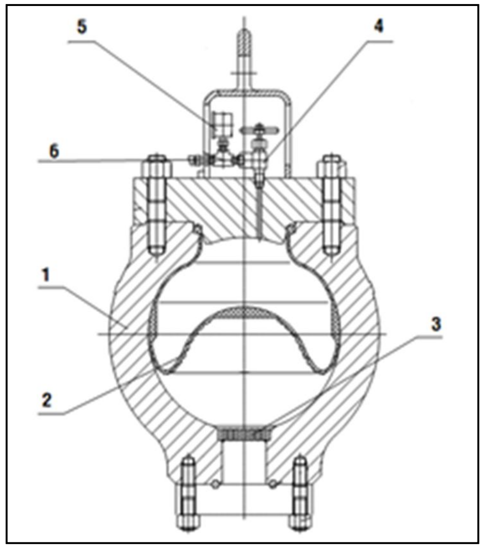



Figure 2-4: Pulsation Damper. 1. Damper case. 2. Nitrogen bag. 3. Fluid chamber. 4. Charging valve. 5. Pressure gauge. 6. Charging nipple.(BAOJI, 2004)

7. **Main discharge pressure:** if the main discharge pressure of mud pump unit exceed 10 Bar it damages the pump and lines.(Baoji, 2005)
8. **Crude oil tank level:** it is an indicator and help the operator making a decision whether the unit runs or not.

## 2.4 Items to be controlled

The items shown below are the suggested items to be controlled and operated automatically by control system according to the effective parameters discussed earlier in this chapter. By controlling these items the control system achieve full control to the unit:

1. **Main air valve:** the pneumatic system supplied to the unit to operate startup oil pump, starter motor and air clutch is supplied from air vessel near the unit and through a ball valve shown in figure 2-5. When the operator desires to operate the unit he opens the main air valve as first step to allow the air to be supplied to pneumatic components.

2. **Startup oil pump:** it is a pneumatic motor connected to oil pump as shown in figure 2-5 and operated manually by pneumatic bush button. The main job of startup oil pump is to rise the engine oil pressure up to recommended before starting the engine to make an oil layer between crankshaft and camshaft and their journal bearings before starting the engine to prevent them running in dry surfaces.

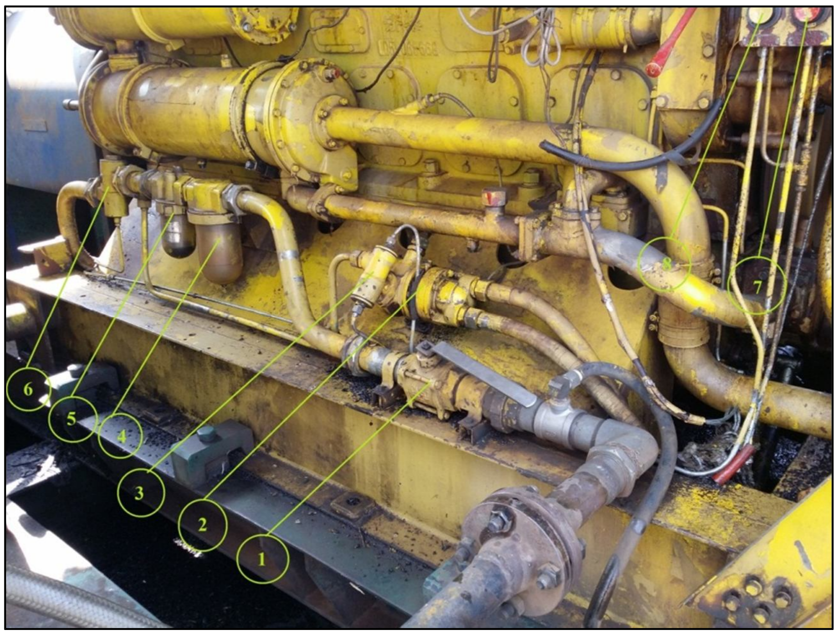



Figure 2-5: pneumatic starting system with pneumatic prime pump 1. King valve. 2. Pneumatic oil prime pump. 3. Control valve. 4. Air filter. 5. Oil sprayer. 6. Relay. 7. Oil prime pump bush button. 8. Starter bush button.(Jinan, 2005)

3. **Starter motor:** it is pneumatic motor as shown in figure 2-6. in front of this motor there is a pinion gear mounted on the motor shaft and connected to power fly wheel gear to transmit the starting power to engine to start it as shown in figure.

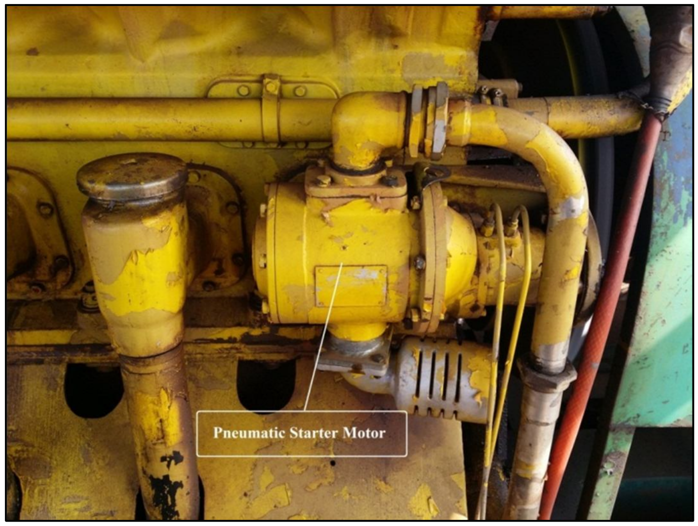



Figure 2-6: pneumatic starter motor.(Jinan, 2005)

4. **Fuel control device (throttle/ accelerator):** it is manually controlled by operator to increase/ decrease engine speed to desired limit as shown in figure 2-7.

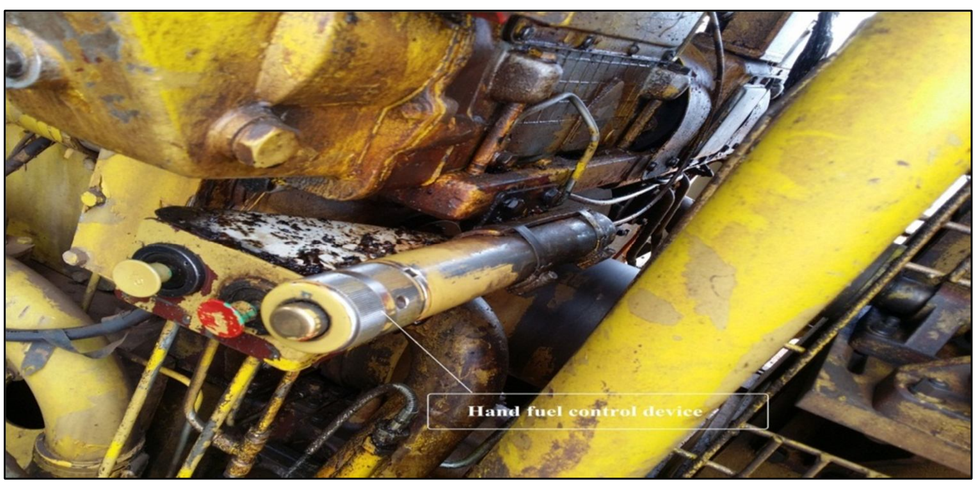



Figure 2-7: hand fuel control device (Jinan, 2005)

5. **Suction and discharge valves:** they are a 12” class 1500 ball valve operated manually by operator. It should be opened before the pump running.

6. **Pump's clutch:** is type 20CB500 dual air clutch as shown in figure 2-8. And operated by leaver that allow the air inters to clutch's air pocket to push the friction shoes which lock the clutch to drum and transmit the power from the engine to F-800 mud pump.

Figure 2-8: Air clutch installed in the unit.(Baoji, 2005)

7. **Engine stop arm (shutdown device):** when the operator desires to stop the engine after disengage the clutch and disconnects the pump he pulls the stop leaver as shown in figure 2-9 where is attached to mechanical fuel governor to cut the fuel supplied to the engine and stop the engine immediately.

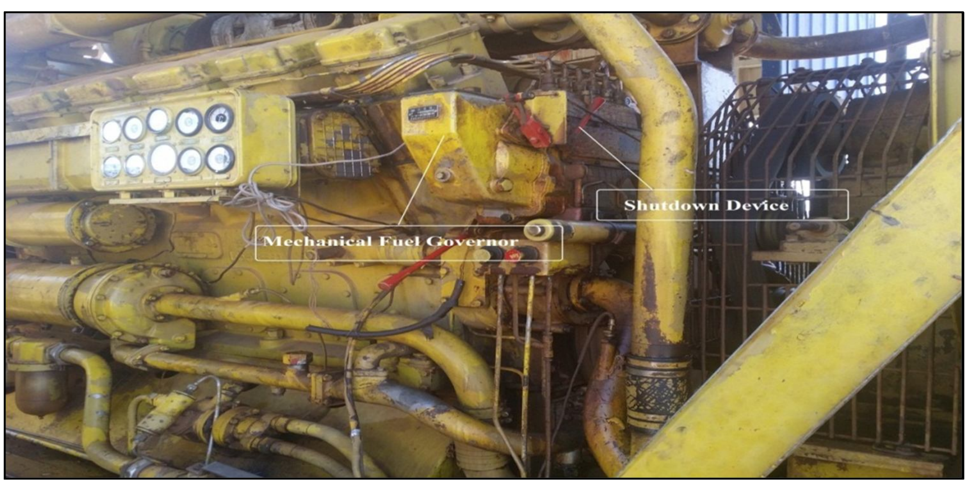



Figure 2-9: Mechanical fuel governor 1.Mechanical governor. 2. Shutdown device.(Jinan, 2005)

# Chapter three

# Theory of Programmable logic controllers (PLCs)

# Chapter Three

# Theory of Programmable Logic Controllers (PLCs)

## 3.1 Introduction

Control engineering has evolved over time. In the past human was the main method for controlling a system. More recently electricity has been used for control and early electrical control was based on relays. These relays allow power to be switched on and off without a mechanical switch. It is common to use relays to make simple logical control decisions. The development of low cost computer has brought the most recent revolution, the Programmable Logic Controller (PLC). The advent of the PLC began in the 1970s, and has become the most common choice for manufacturing controls.(jack, 2005a, Yusufjai et al., 2017)

## 3.2 Definition of PLCs

Programmable logic controllers also called programmable controllers or PLCs are solid-state members of the computer family(Saleh et al., 2017), using integrated Circuits instead of electromechanical devices to implement control functions. They are capable of storing instructions, such as sequencing, timing, Counting, arithmetic, data manipulation, and communication, to control Industrial machines and processes. Also the Programmable logic controllers can be defined as industrial computers with especially designed architecture in both their central units (the PLC itself) and their interfacing circuitry to field devices (input/output connections to the real world).(Brayan and Brayan, 1997, Segovia and Theorin, 2012)

## 3.3 The advantages of PLC control

Any control system goes through four stages from conception to a working plant. A PLC system brings advantages at each stage. The first stage is design; the required plant is studied and the control strategies decided. With conventional systems design must be complete before construction can start. With a PLC system all that is needed is a possibly vague idea of the size of the machine and the I/O requirements (how many inputs and outputs). The input and output cards are cheap at this stage, so a healthy spare capacity can be built in to allow for the inevitable omissions and future developments. Next comes construction. With conventional schemes, every job is a 'one-off' with inevitable delays and costs. A PLC system is simply bolted together from standard parts. During this time the writing of the PLC program is started (or at least the detailed program specification is written).

The next stage is installation, a tedious and expensive business as sensors, actuators, limit switches and operator controls are cabled. A distributed PLC system using serial links and pre-built and tested desks can simplify installation and bring huge cost benefits. The majority of the PLC program is written at this stage. Finally comes commissioning, and this is where the real advantages are found. No plant ever works first time. Human nature being what it is, there will be some oversights. Changes to conventional systems are time consuming and expensive. Provided the designer of the PLC system has built in spare memory capacity, spare I/O and a few spare cores in multicore cables, most changes can be made quickly and relatively cheaply. An added bonus is that all changes are recorded in the PLC's program and commissioning modifications do not go unrecorded, as is often the case in conventional systems. There is an additional fifth stage, maintenance, which starts once the plant is working and is handed over to production. All plants have faults, and most tend to spend the majority of their time in some form of failure mode. A PLC system provides a very powerful tool for assisting with fault diagnosis.(Hackworth and Frederick D. Hackworth, 2004)

## 3.4 PLCs Principle of operation

A programmable controller, as illustrated in Figure 3-1, consists of two basic Sections:

- The central processing unit.
- The input/output interface system.

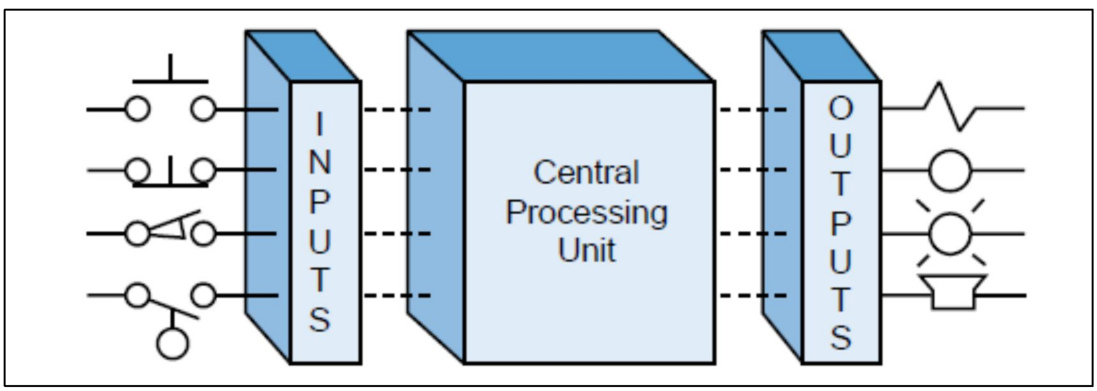



Figure 3-1: Programmable controller Block diagram.(Brayan and Brayan, 1997)

The central processing unit (CPU) governs all PLC activities. The following three components, shown in Figure 3-2, form the CPU:

- The processor.
- The memory system.
- The system power supply.(Gupta et al., 2017)

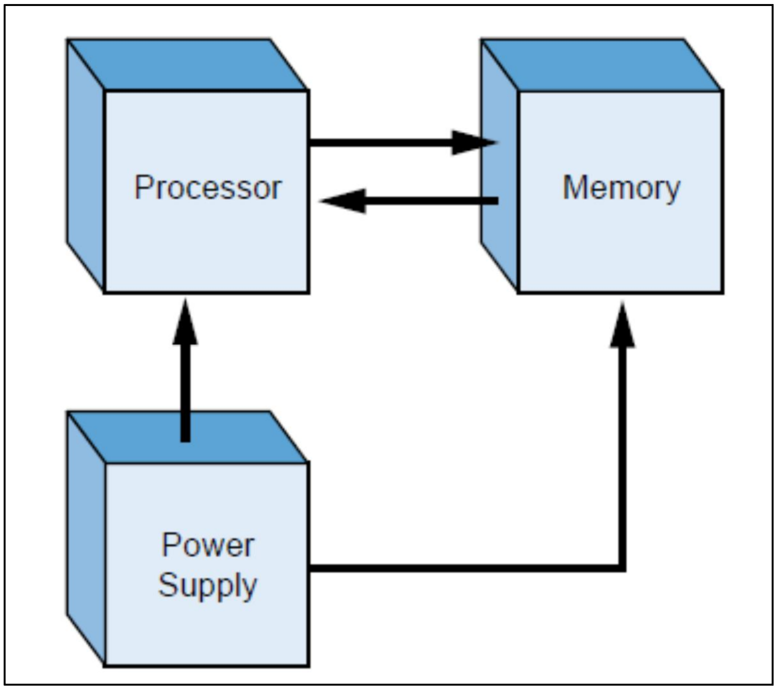



Figure 3-2: Block Diagram of CPU components.(Brayan and Brayan, 1997, Gupta et al., 2017)

The operation of a programmable controller is relatively simple. The input/output (I/O) system is physically connected to the field devices that are encountered in the machine or that are used in the control of a process. These field devices may be discrete or analog input/output devices, such as limit switches, pressure transducers, push buttons, motor starters, solenoids, etc. The I/O interfaces provide the connection between the CPU and the information providers (inputs) and controllable devices (outputs). During its operation, the CPU completes three processes: (1) it reads, or accepts, the input data from the field devices via the input interfaces, (2) it executes, or performs, the control program stored in the memory system, and (3) it writes, or updates, the output devices via the output interfaces. This process of sequentially reading the inputs, executing the program in memory, and updating the outputs is known as scanning. Figure 3-3 illustrates a graphic representation of a scan(Tiwary et al., 2017, Brayan and Brayan, 1997).

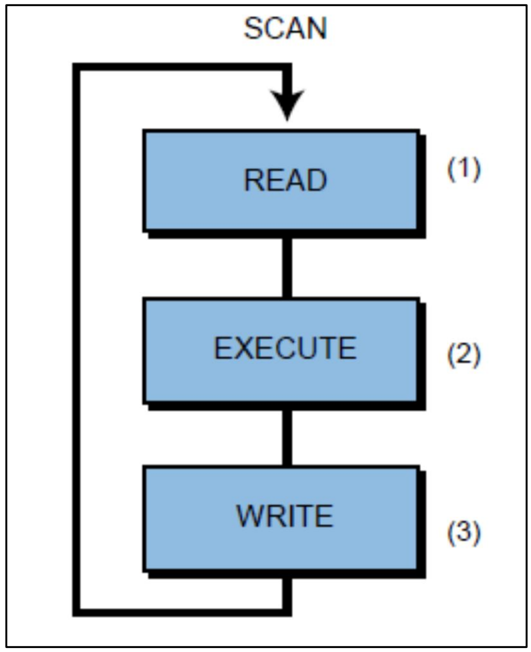



Figure 3-3: illustration of a Scan.(Brayan and Brayan, 1997, Tiwary et al., 2017)

The input/output system forms the interface by which field devices are connected to the controller (see Figure 3-4). The main purpose of the interface is to condition the various signals received from or sent to external field devices. Incoming signals from sensors (e.g., push buttons, limit switches, analog sensors, selector switches, and thumbwheel switches) are wired to terminals on the input interfaces. Devices that will be controlled, like motor starters, solenoid valves, pilot lights, and position valves, are connected to the terminals of the output interfaces. The system power supply provides all the voltages required for the proper operation of the various central processing unit sections.

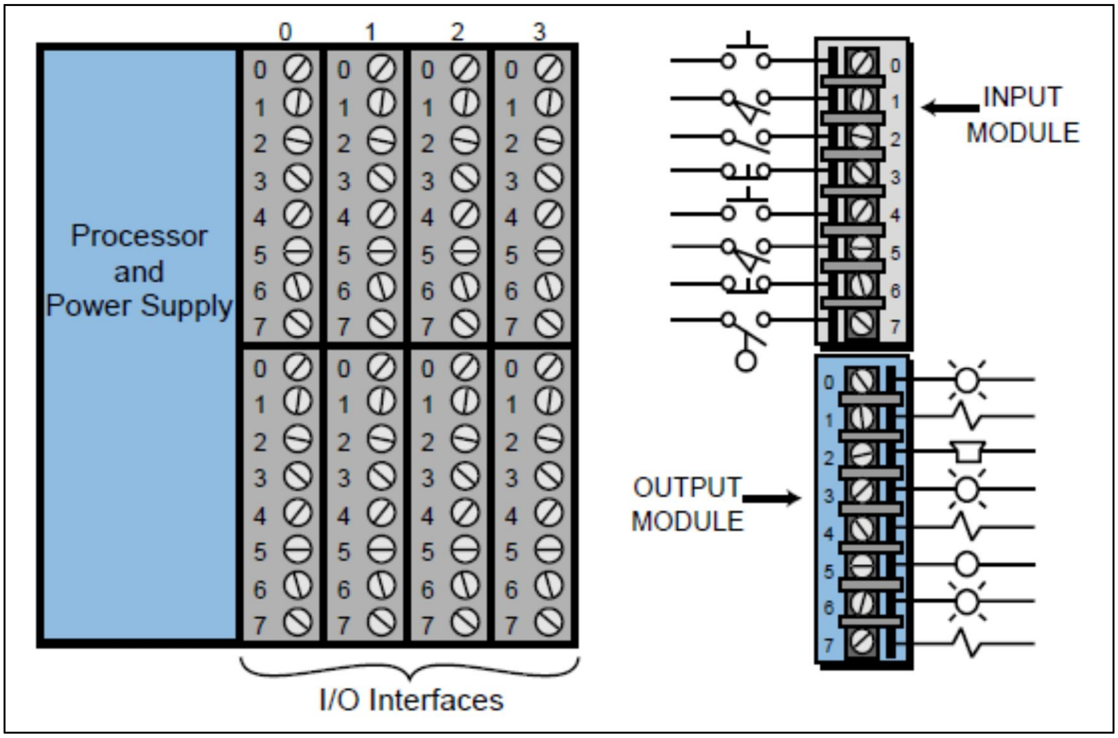
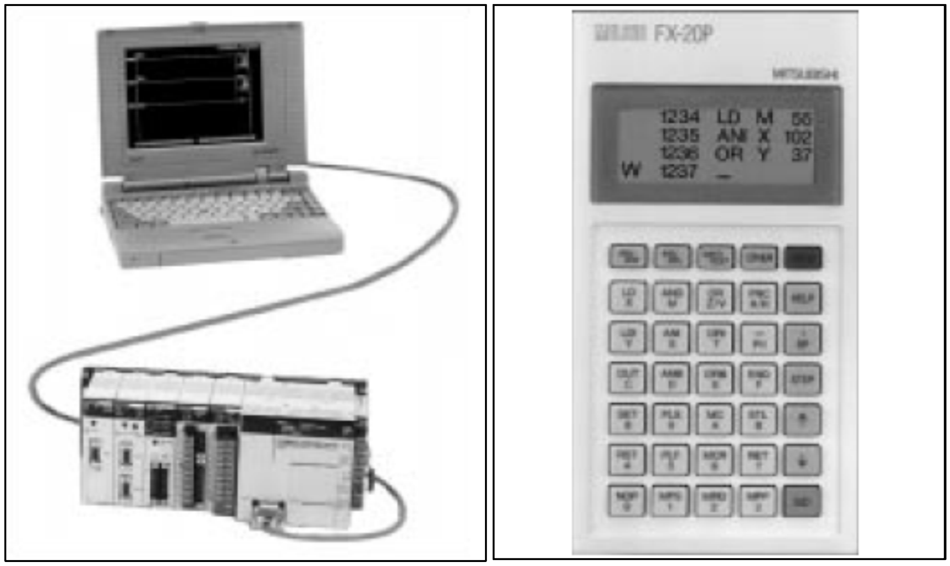



Figure 3-4: Input/output interface.(Brayan and Brayan, 1997)

Although not generally considered a part of the controller, the programming device, usually a personal computer or a manufacturer's mini-programmer unit is required to enter the control program into memory (see Figure 3-5). The programming device must be connected to the controller when entering or monitoring the control program.(Brayan and Brayan, 1997)




(a) (b)

Figure 3-5:Programming devices (a) personal computer used as programming device and (b) a mini-programmer unit.(Brayan and Brayan, 1997)

# 3.5 PLC programming

The first PLCs were programmed with a technique that was based on relay logic wiring schematics. This eliminated the need to teach the electricians, technicians and engineers how to program a computer - but, this method has stuck and it is the most common technique for programming PLCs today.(Segovia and Theorin, 2012)

## 3.5.1 Ladder Logic

Ladder logic can be seen in Figure 3-6. To interpret this diagram, imagine that the power is on the vertical line on the left hand side, we call this the hot rail. On the right hand side is the neutral rail. In the figure there are two rungs, and on each rung there are combinations of inputs (two vertical lines) and outputs (circles). If the inputs are opened or closed in the right combination the power can flow from the hot rail, through the inputs, to power the outputs, and finally to the neutral rail. An input can come from a sensor, switch, or any other type of sensor. An output will be some device outside the PLC that is switched on or off, such as lights or motors. In the top rung the contacts are normally open and normally closed. This means if input A is on and input B is off, then power will flow through the output and activate it. Any other combination of input values will result in the output X being off.

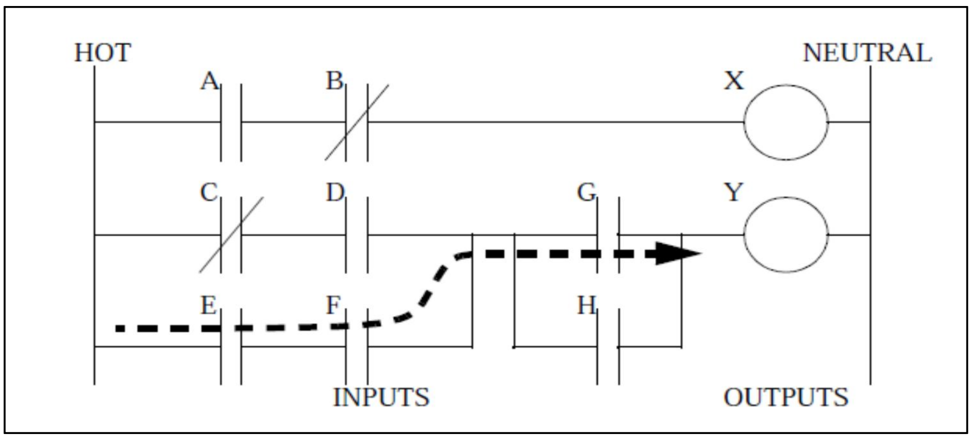



Figure 3-6 Ladder Logic Diagram and program flow.(jack, 2005a)

The second rung of Figure 6 is more complex, there are actually multiple combinations of inputs that will result in the output Y turning on. On the left most part of the rung, power could flow through the top if C is off and D is on. Power could also (and simultaneously) flow through the bottom if both E and F are true. This would get power half way across the rung, and then if G or H is true the power will be delivered to output Y. (jack, 2005a, Sasidhar et al., 2017)

## 3.5.2 Statement list diagram

There are other methods for programming PLCs. One of the earliest techniques involved mnemonic instructions (Statement list) abbreviated as

(STL). These instructions can be derived directly from the ladder logic diagrams and entered into the PLC through a simple programming terminal. An example of mnemonics is shown in Figure 3-7. In this example the instructions are read one line at a time from top to bottom. The first line 00000 has the instruction LD (input load) for input 00001. This will examine the input to the PLC and if it is off it will remember a 1 (or true), if it is on it will remember a 0 (or false). The next line uses an LDN (input load not) statement to look at the input. If the input is off it remembers a 0, if the input is on it remembers a 1 (note: this is the reverse of the LD). The AND statement recalls the last two numbers remembered and if they are both true the result is a 1, otherwise the result is a 0. This result now replaces the two numbers that were recalled, and there is only one number remembered. The process is repeated for lines 00003 and 00004, but when these are done there are now three numbers remembered. The oldest number is from the AND, the newer numbers are from the two LD instructions. The AND in line 00005 combines the results from the last LD instructions and now there are two numbers remembered. The OR instruction takes the two numbers now remaining and if either one is a 1 the result is a 1, otherwise the result is a 0. This result replaces the two numbers, and there is now a single number there. The last instruction is the ST (store output) that will look at the last value stored and if it is 1, the output will be turned on, if it is 0 the output will be turned off. (jack, 2005a)

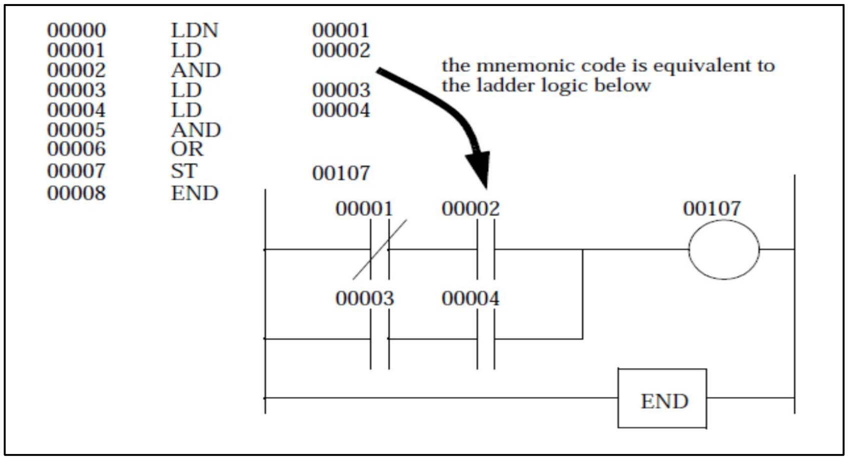



Figure 3-7: An example of mnemonic program (STL) and equivalent ladder logic.(jack, 2005a)

### 3.5.3 Sequential function charts (SFCs)

Sequential Function Charts (SFCs) have been developed to accommodate the programming of more advanced systems. These are similar to flowcharts, but much more powerful. The example seen in Figure 3-8 is doing two different things. To read the chart, start at the top where is says start. Below this there is the double horizontal line that says follow both paths. As a result the PLC will start to follow the branch on the left and right hand sides separately and simultaneously. On the left there are two functions the first one is the power up function. This function will run until it decides it is done, and the power down function will come after. On the right hand side is the flash function, this will run until it is done. These functions look unexplained, but each function, such as power up will be a small ladder logic program. This method is much different from flowcharts because it does not have to follow a single path through the flowchart.(jack, 2005a)

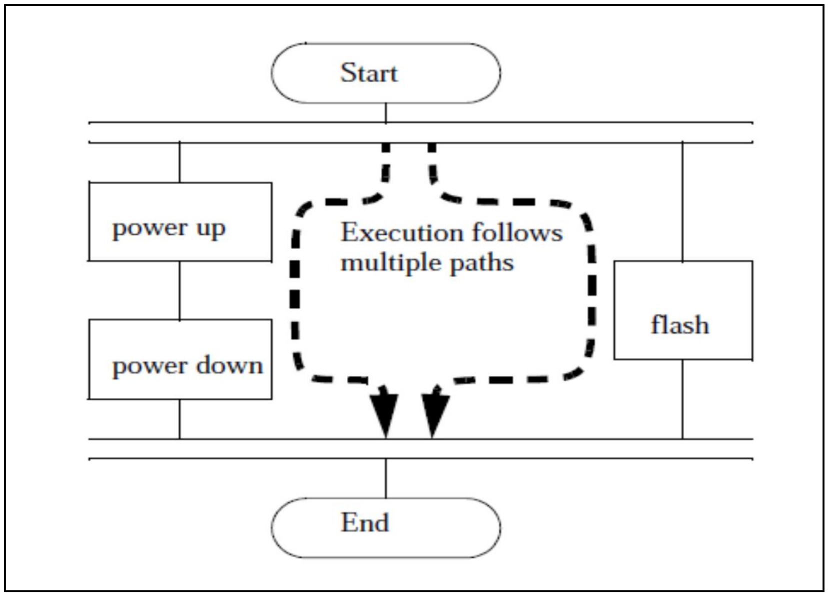



Figure 3-8: An example of Sequential function chart.(jack, 2005a)

### 3.5.4 Structured text programming

Structured Text programming has been developed as a more modern programming language. It is quite similar to languages such as BASIC. A simple example is shown in Figure 3-9. This example uses a PLC memory location N7:0. This memory location is for an integer. The first line of the program sets the value to 0. The next line begins a loop, and will be where the loop returns to. The next line recalls the value in location N7:0, adds 1 to it and returns it to the same location. The next line checks to see if the loop should quit. If N7:0 is greater than or equal to 10, then the loop will quit, otherwise the computer will go back up to the REPEAT statement continue from there. Each time the program goes through this loop N7:0 will increase by 1 until the value reaches 10.(jack, 2005a)

```
N7:0 := 0;
REPEAT
N7:0 := N7:0 + 1;
UNTIL N7:0 >= 10
END_REPEAT;
```

Figure 3-9: An example of structured text programing.(jack, 2005a)

## 3.5.5 Function Block Diagram

Functional Block Diagrams (FBD) provides another view of a set of instructions. Each function has a name to designate its specific task. Functions are indicated by a rectangle. Inputs are shown on the left-hand side of the rectangle and outputs are shown on the right-hand side. The function block diagram shown in figure 3-10 performs the same function as shown by the ladder diagram and statement list (STL).(Nasr, 2003)

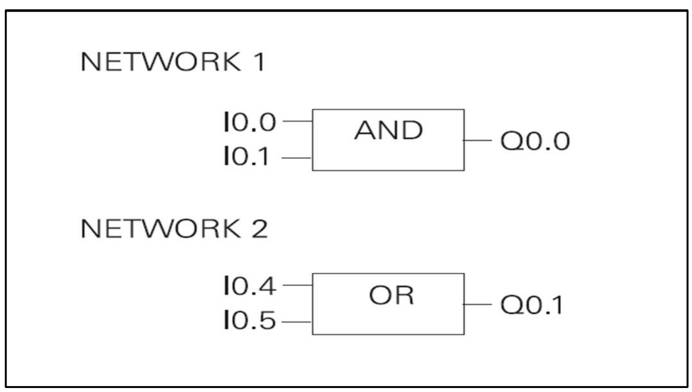



Figure 3-10: An example of Function Block Diagram.(Nasr, 2003)

# Chapter four

# Design a model to control mud pump unit

## Chapter four

# Design a model to control mud pump unit

## 4.1 Design Parameters

The necessary mud pump unit's operation parameters are shown in table 4-1.

Table 4-1: engine operation conditions:(Jinan, 2005, Eaton, 2005, Baoji, 2005)

| Parameter | Rated Value | Alarm Value | Shutdown Value |
|---|---|---|---|
| **Engine's Operation parameters** | | | |
| **Water outlet temperature ($^oC$)** | 0 – 85 $^oC$ | ≥ 90 $^oC$ | ≥ 95 $^oC$ |
| **Oil Temperature ($^oC$)** | 0 – 85 $^oC$ | ≥ 87 $^oC$ | ≥ 100 $^oC$ |
| **Low oil Pressure (MPa)** | 0.5 – 0.8 MPa | 0.25 MPa | 0.25 MPa |
| **Engine speed (rpm)** | 1200 rpm | 115% | 118% |
| **Air pressure for starter and startup oil pump (MPa)** | 0.882 | 0.6 | ≤ 0.588 |
| **Air Clutch Operation parameters** | | | |

| | | | |
|---|---|---|---|
| **Maximum Speed (rpm)** | 1300 | None | None |
| **Maximum Pressure for control valves and hoses(MPa)** | 1 | None | None |
| **Minimum operation pressure (MPa)** | 0.52 | None | None |
| **Pump's operation parameters** | | | |
| **Suction line pressure (MPa)** | 0-5 | None | None |
| **Discharge line pressure (MPa)** | 10 | None | None |
| **Minimum suction and discharge dampers pressure (MPa)** | 2.5 | None | None |

## 4.2 Control system components

The control system is divided into four sections: input devices, output devices, control modules and accessories.

The input devices used to design the control system model are devices to covert the physical operational parameters to electrical signals to by controlled by control unit. The devices used in the model are: temperature sensors, potentiometers, level sensor, electrical switches, emergency push button and speed sensor.

The output devices used in the model are working either to interface the control signals coming from PLC with components that need current higher than supplied from PLC such as relays or representing some components in the mud pump unit such as engine, starter motor, oil prime pump and throttle. Or used as indication for operator such as indicator lamps.

The control modules are: main PLC attached with digital extension and analog extension modules, temperature control modules, power supply module and HMI unit.

The accessories are components used for communication between PLC and other modules or peripherals such as RS-232 cable and programming cable.

### 4.2.1 Temperature sensors

The temperature sensors used in the model are representing engine coolant temperature and oil temperature sensors. A thermocouple type K is used in the model which has characteristics shown in table 4-4.(Webster, 1999)

Table 4-4: thermocouple's characteristics:(Webster, 1999)

| **Thermocouple characteristics** | |
|---|---|
| Color code | Brawn |
| Recommended range ($^oC$) | -200 to 1260 |
| Emf at 400 $^oC$ (mV) | 16.397 |

| | |
|---|---|
| Normal tolerance $^{o}C$ (%) | 1.1 (0.40) |
| Resistance (μΩ-cm) | 112 |

### 4.2.2 Potentiometers

The potentiometers in this model represent the pressure sensors (air vessel pressure sensor, engine oil pressure sensor and pump's discharge pressure sensor). The potentiometers are made by Jameco electronics Co. the type and criteria of potentiometers are shown in table 4-5 and figure 4-1.

Table 4-5: potentiometers characteristics:

| **Characteristic** | **Value** |
|---|---|
| Potentiometer type | RV 16A-20 rotary potentiometer |
| Rotation angle | $300^{o}$ |
| Maximum resistance | 5KΩ at $300^{o}$ |
| Type of terminals | Horizontal |

Figure 4-1: potentiometer used in the model.

### 4.2.3 Level sensor

The level sensor converts the level of liquid into analog signal to be read by controller. The level sensor using in the model is representing crude tank level sensor and made by funduino. Co. and is type of: SR073 level sensor which is illustrated in figure 4-2. The characteristic of the sensor is shown in the table 4-6.

Table 4-6: characteristics of level sensor used in the model:

| | |
|---|---|
| Working voltage (VDC) | 3 to 5 |
| Working current (mA) | <20 |
| Detection area (mm) | 40 x 16 |
| Working temperature ($^{o}$C) | 10 to 30 |
| Working humidity (%) | 10 to 90 without condensation |
| Size (mm) | 65x20x8 |

Figure 4-2: level sensor.

### 4.2.4 Switches

The switches installed in the model are 2 toggle switches represent the suction and discharge dampers pressure switches the type of switches is: 1321 toggle switch which has two contacts as shown in figure 4-3 .Its specification is shown in table 4-7.

Table 4-7: toggle switch characteristics:

| **Characteristic** | **Value** |
|---|---|
| Type | E-SG 1321 |
| Rated current and voltage (A at Vac) | 15 at 250 to 20 at 125 |
| Contact resistance (mΩ) | ≤50 |
| Temperature ($^{o}$C) | -55 to 85 |
| Working life (Cycle) | ≥ 10000 |


Figure 4-3: toggle switch.

### 4.2.5 Emergency push button

The emergency push button used in the model is type: DB2- BS542 normally close switch mushroom as shown in figure 4-4. The specification of emergency push button is shown in table 4-8.

Table 4-8: specification of emergency push button:

| **Specifications** | |
|---|---|
| Type | emergency stop mushroom |
| Model number | DB2-BS542 |
| Contact type | 1 N/C (one normal close) |
| Manufacture name | XIDER ELECTRIC |
| Position number | 2 |
| Mushroom size (mm) | 40 |
| Maximum voltage (V) | 660 |
| Rated current (A) | 6 to 10 |
| Working AC frequency (Hz) | 50/60 |
| Protection grade | IP 65 |

Figure 4-4: emergency push button.

### 4.2.6 Proximity sensor

The proximity sensor installed in the model is to measure the motor rotational speed as a model of engine speed sensor. And is made by Autonics .Co type: PSN17-8DN as shown in figure 4-5. Its specifications shown in table 4-9.

Table 4-9: proximity sensor specifications:

| **Specification** | **Value** |
|---|---|
| Type | Rectangular (PS/PSN series) |
| Sensing distance (mm) | 8 |
| Header dimension ($mm^2$) | 17 |
| Voltage (VDC) | 12 – 24 |
| Wire type | DC 3-wire |
| Output type | NPN |

| | |
|---|---|
| Frequency (Hz) | 200 |
| Housing size (mm) | 17 x 17 x 36 |

Figure 4-5: proximity sensor.

### 4.2.7 Relays

It is used as interface between the signal coming from PLC and the actuators. And in case of this model the relays used as a replacement of air solenoids that should be used to control the mud pump unit. The replacement is done to simplify model test.

The relays used in the model as shown in figure 4-6 are type: P14-FPC-24VDC-S which have specifications shown in table 4-10.

Table 4-10: relays specifications:

| **characteristic** | **Value** |
|---|---|
| No. of terminals | 14 |
| Materials standard for contacts | AgNi |
| Max switching current (A) | 7 |

| | |
|---|---|
| Max. peak inrush current (Amps at 20 ms) | 15 |
| Max. switching voltage (V) | 250 |
| Max. AC load (KVA) | 2.5 |
| Nominal coil power (W) | 1 |
| Operate time (ms) | 10 |
| Release time (ms) | 6 |

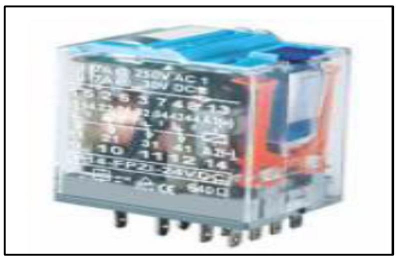


Figure 4-6: P14 relay used in the model.

### 4.2.8 DC motors

The DC motors used in the model as simulation for engine, fuel control device, starter motor and oil prime pump motor.

The type of engine motor and fuel control device is: RK-370CC-14230 made by Mabuchi motors co. ltd. As shown in figure 4-7: the specification of motor is shown in table 4-11.

Table 4-11: specification of engine and fuel control device motors:

| Item | Value |
|---|---|

| Model | | RK-370CC-14230 |
|---|---|---|
| Voltage (V) | Operating range | 12- 30 |
| | Nominal | 30 |
| Speed (rpm) | No load | 20700 |
| | Maximum efficiency | 17460 |
| Current (A) | No load | 0.11 |
| | Maximum efficiency | 0.59 |
| | Stall | 3.2 |
| Torque (mN.m) | Maximum efficiency | 6.13 |
| | Stall | 39.2 |
| Output power (W) | | 11.2 |

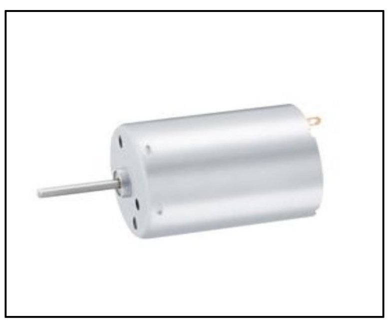


Figure 4-7: RK-370CC-14230 motor used as model of engine.

The motors used as a model for oil prime pump and starter are type: JFA-130RA-2270 as shown in figure 4-8. The specification of the motor is shown in table 4-12.

Table 4-12: specification of 5V motor used in the model:

| Item | | Value |
|---|---|---|
| Model | | JFA-130RA-2270 |
| Nominal operation | Operation range voltage (V) | 1.5 to 3 |
| | Speed (rpm) | 9100 to 16400 |
| | Current (A) | 0.2 to 0.23 |
| At maximum efficiency | Speed (rpm) | 6990 to 13200 |
| | Current (A) | 0.66 to 0.84 |
| | Torque (mN.m) | 0.59 to 0.84 |
| | Output power (W) | 0.43 to 1.16 |
| Stall | Current (A) | 2.20 to 3.92 |
| | Torque (mN.m) | 2.55 to 4.32 |

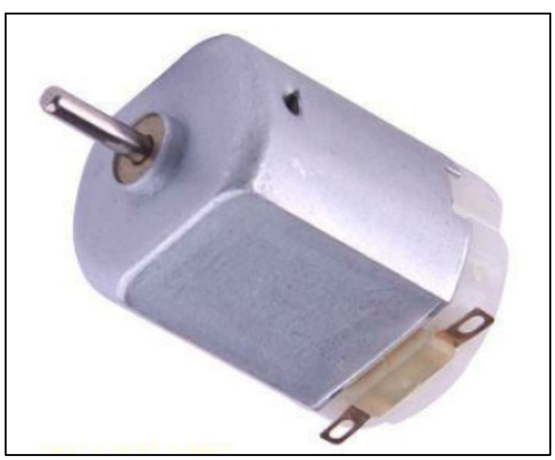


Figure 4-8: DC motor used in the model for startup oil pump and starter.

### 4.2.9 Indicator lamps

The indicator lamps used in the model as shown in figure 4-9 is made by APT Co. Ltd type: AD16-22DS the specification of the indicator lamps is shown in table 4-13.

Table 4-13: specification of indicator lamps used in the model:

| **Item** | **Value** |
|---|---|
| Model | AD16-22DS |
| Mounting size (mm) | 22 |
| Color used | Red and Yellow |
| Operational voltage | 6VDC/12VDC/24VDC/220VAC/380VAC |
| Operational temperature ($^oC$) | -25 to +55 |
| Operational humidity (%) | 45 to 90 |
| Protection grade | IP22 |

Figure 4-9: indicator lamps used in the model.

### 4.2.10 Main PLC

The main PLC used in the model is type DVP-12 SA2 made by Delta Co. Ltd. Shown in figure 4-10. It communicates with all other modules in the model receiving their data process them and send them back to output devices via other modules or its own output channels. It also receives the digital signals from speed sensor, emergency push button and toggle switches which represent the suction and discharge damper pressure switches for processing. The main PLC has the following specifications:

- MPU points: 12 (8DI + 4DO)
- Max I/O points: 492 (12+480)
- Program capacity: 16K step
- COM port: built-in RS-232 &2 RS-485 ports, compatible with Modbus ASCII/RTU protocol.
- Can be master or slave.

- High-speed pulse output: supports 2 points (Y0, Y2) of 100kHz and 2 points (Y1, Y3) of 10kHz
- Extendable to Max. 8 Modules: DVP-SA2 is extendable to analog I/O. temperature measurement, input DIP switch, PROFIBUS/DeviceNet communication modules and single-axis motion control functions.
- Built-in High-Speed counters.

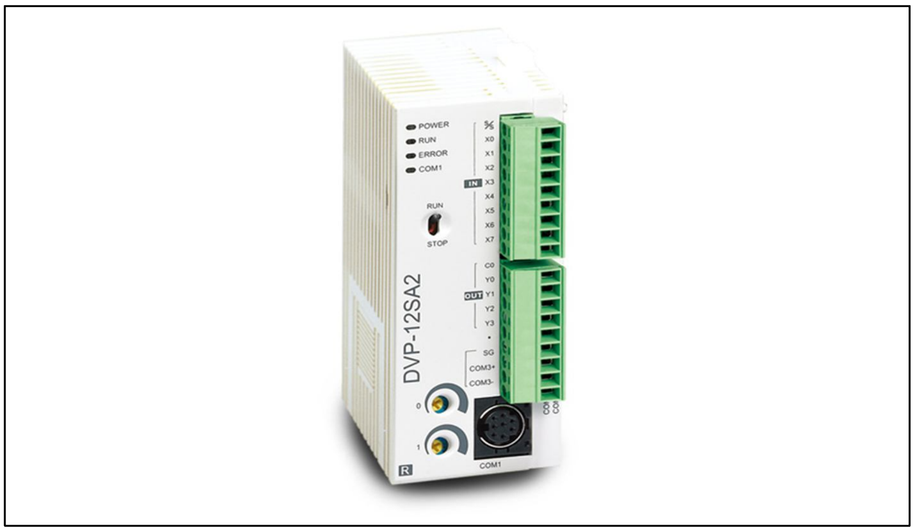



Figure 4-10: PLC type Delta DVP-12SA2 used in the model.

### 4.2.11 Digital extension module

The digital module is an extension I/O for PLC which receives the data from PLC and sends them to output devices (relays) via output channels. Its type is DVP – 16 SP 11R and has 16 I/Os (8 inputs and 8 outputs relay type) the module shown in figure 4-11.


Figure 4-11: digital extension module used in the model.

### 4.2.12 Analog module

The analog module as shown in figure 4-12 used to convert the analog signal coming from potentiometers and level sensor into digital signal and store them in registers, the PLC read the data from the analog module's registers and then store them into its own registers for more processing. The type of analog module is DVP – 06 XA has 4 input channels which can read either volt or current, and 2 analog output channels. Its specifications of analog module are discussed below:

- Analog input channel : 4 channels per module
- Analog input range: ± 10V or ±20mA
- Digital data range: ±2000
- Resolution: 12 bits ($1_{LSB}$= 5mV)

- Response time : 3ms/channel
- Analog output channels: 2 channel
- Analog output range: 0 to 10 V or 0 to 20 mA
- Digital Data range: 0 to 4000
- Resolution: 12 bits ($1_{LSB}$=2.5mV).


Figure 4-12: DVP-06XA analog module.

### 4.2.13 Temperature controller module

The temperature controller modules used to read the signals of temperature sensors (engine's coolant temperature sensor and oil temperature sensor) and interpret them into digital form to be stored in registers. The PLC read the data from controller registers and then stores them into its own register for more processing.

The types of temperature controllers used in the model are DTC 1000 and DTC 2000 as shown in figure 4-13. Their specifications discussed below: (21)

- PID/on-off/ manual input/ programmable control modes.
- 2 groups of outputs for auto-tuning 2 groups of PID parameters
- Able to connect to various thermocouples (B, E, J, K, L, N, R, S, T,M U, TXK), platinum RTD (PT100, JPT100), Analog linear current (0 to 20mA) and linear voltage (0 to 5V, 0 to 10V)
- Maximum 2 groups of alarm switched are available, with 12 alarm modes each.
- LED status display
- Celsius or Fahrenheit temperature display.
- Built-in RS-485 communication interface (Modbus, ASCII, RTU, baud rate: 2400 to 38400)
- Sampling time of thermocouple/platinum RTD: 0.4 second/time; sampling time of analog input: 0.15 second/time.
- Programmable logic controller is able to set up 64 sets of temperature and control time.
- 3 levels of password protection; wire saving, synchronous communication protocol setting; ID auto setting.


Figure 4-13: DTC 1000 and DTC 2000 temperature controllers.

### 4.2.14 Power supply module

The power supply module as illustrated in figure 4-14 supplies the power to all controllers with desired voltage and current. The module used in the model is type DVP-PS02. Its specifications are shown below: (22)

- Power input: 100 to 240 VAC, 50 to 60 Hz
- Output power: 24 VDC (±3%).
- Maximum output current: 2A
- Efficiency : 78% to 87% typical on full load
- Overcurrent/ short circuit protection: Auto Recovery.


Figure 4-14: DVP-PS02 power supply module.

### 4.2.15 Human Machine Interface (HMI)

The DOP Series Human machine interface (HMI) provides various touch screens with multiple dimensions and colors. It is connected with PLC to displays its data and sends operator’s commands to PLC. The HMI used in the model is type DOP-B03S211 illustrated in figure 4-15.

Its specifications are shown below:

- 4.3-inch (480x272 pixels) TFT LCD 65536 colors
- 2 sets of COM ports, supports RS-232/ RS-485/ RS-422.
- For data transfer/download: RS-232, USB
- Complies with IP65 standard.
- Support horizontal/ vertical display.
- PC editing software, DOPSoft is compatible with operating systems: Windows XP, Windows Vista, and Windows 7.

Figure 4-15: DOP –B03S211 HMI.

### 4.2.16 RS-323 communication cable

The RS-232 communication cable is connected between the PLC and HMI in order to transfer the data from PLC to HMI and vice versa. It is connected to PLC programming cable RS-232 also which has a different terminal. The RS-232 cable is shown in figure 4-16.

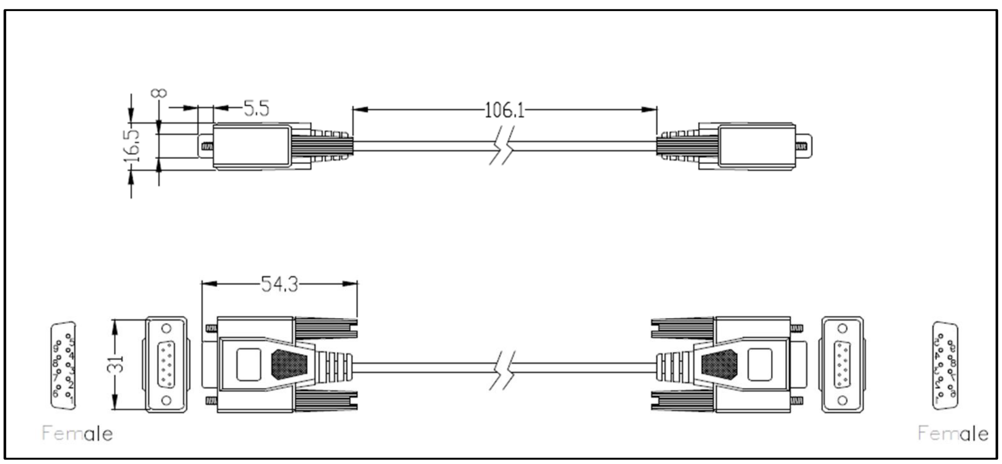



Figure 4-16: RS-232 cable used between PLC and HMI.

## 4.2.17 PLC programming cable

The programming cable as shown in figure 4-17 is type RS-232. The cable connects between PLC programming terminal and PC in order to program the PLC and monitor the program from PC.

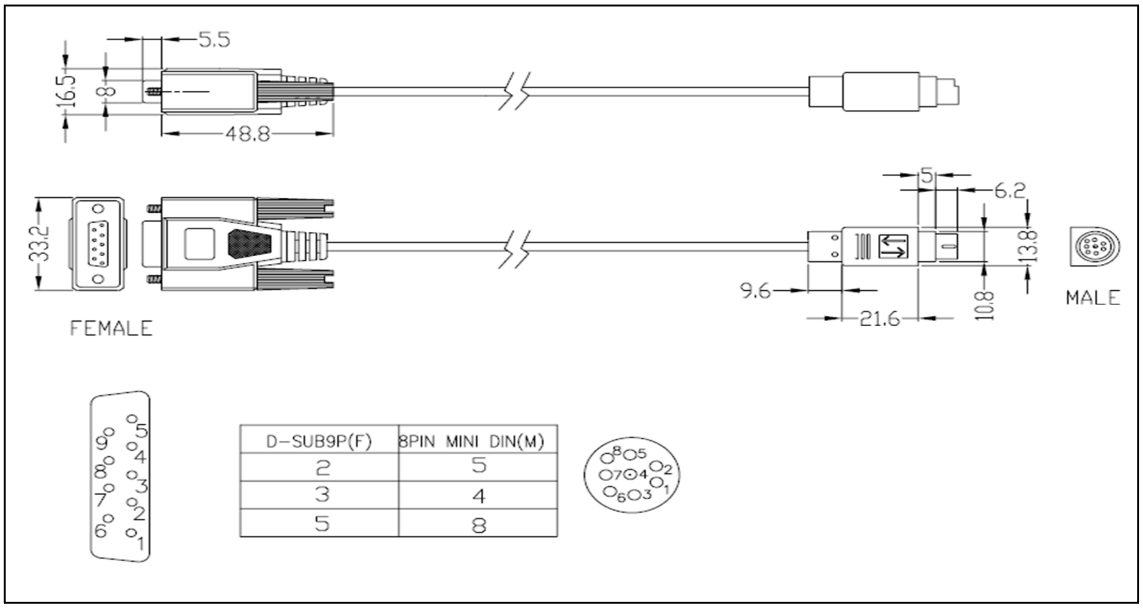



Figure 4-17: PLC programming cable.

## 4.2.18 PLC programming software

ISPSoft is a highly accessible programming software application for Delta's programmable logic controllers (PLC). With its modular editing interface, ISPSoft integrates hardware configuration, network configuration, and motion control programming into the same editing platform. The user-friendly ISPSoft provides graphical interfaces and convenient wizards to enhance software accessibility as well as editing flexibility. ISPSoft offers up to 5 programming tools*, including: Ladder Diagram (LD), Function Block Diagram (FBD), Sequential Function Chart (SFC), Instruction List (IL), and Structured Text (ST), allowing users to choose proficient tools for better editing efficiency. Delta's ISPSoft adopts the IEC 61131-3 standard and supports PLCopen® function blocks for quick configuration of motion control programs that helps you save on project development time and achieve more intelligent and powerful industrial control solutions.

Figure 4-18: ISPSoft program.

## 4.3 Control system layout

The control system as illustrated in figure 4-19 consists of three groups, the first group is input devices which includes all sensors that measure the effective operational parameters, the second group is control devices which includes all control modules (PLC with analog and digital extension modules, HMI and temperature controller modules), the third group is output devices which consists of relays that interface between the output channel of control devices and real actuators.

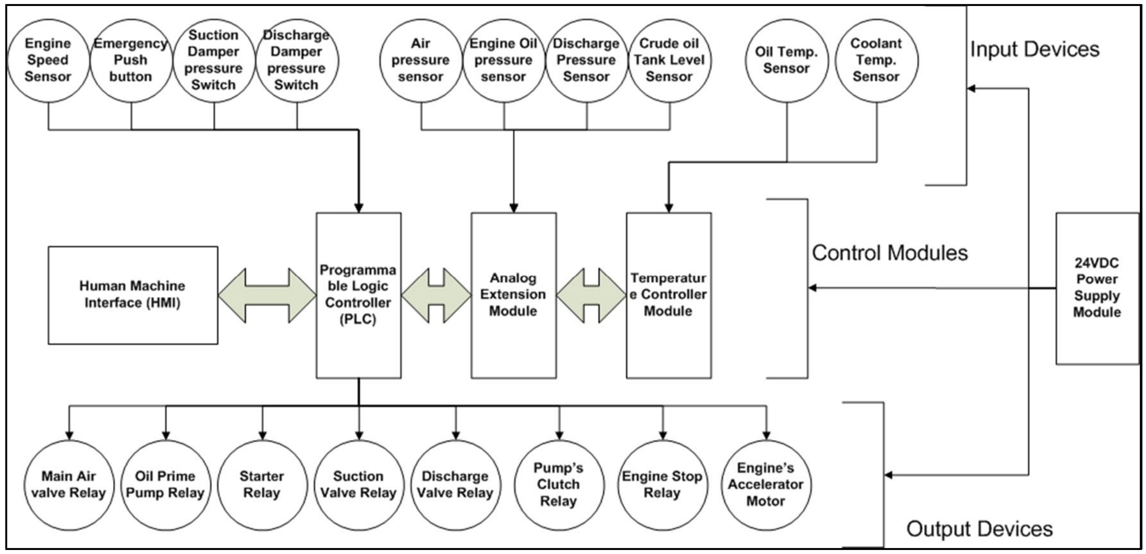



Figure 4-19: control system layout

## 4.4 Control system schematic

The model's schematic describes the connection between each modules and sensors and actuators to control them by installed programs in both PLC and HMI. It is divided into control diagram which illustrates the control units and all components connected directly to them, and power diagram which illustrates the other components that is not connected directly to control unit. Both schematics are shown in figure 4-20 and figure 4-21.

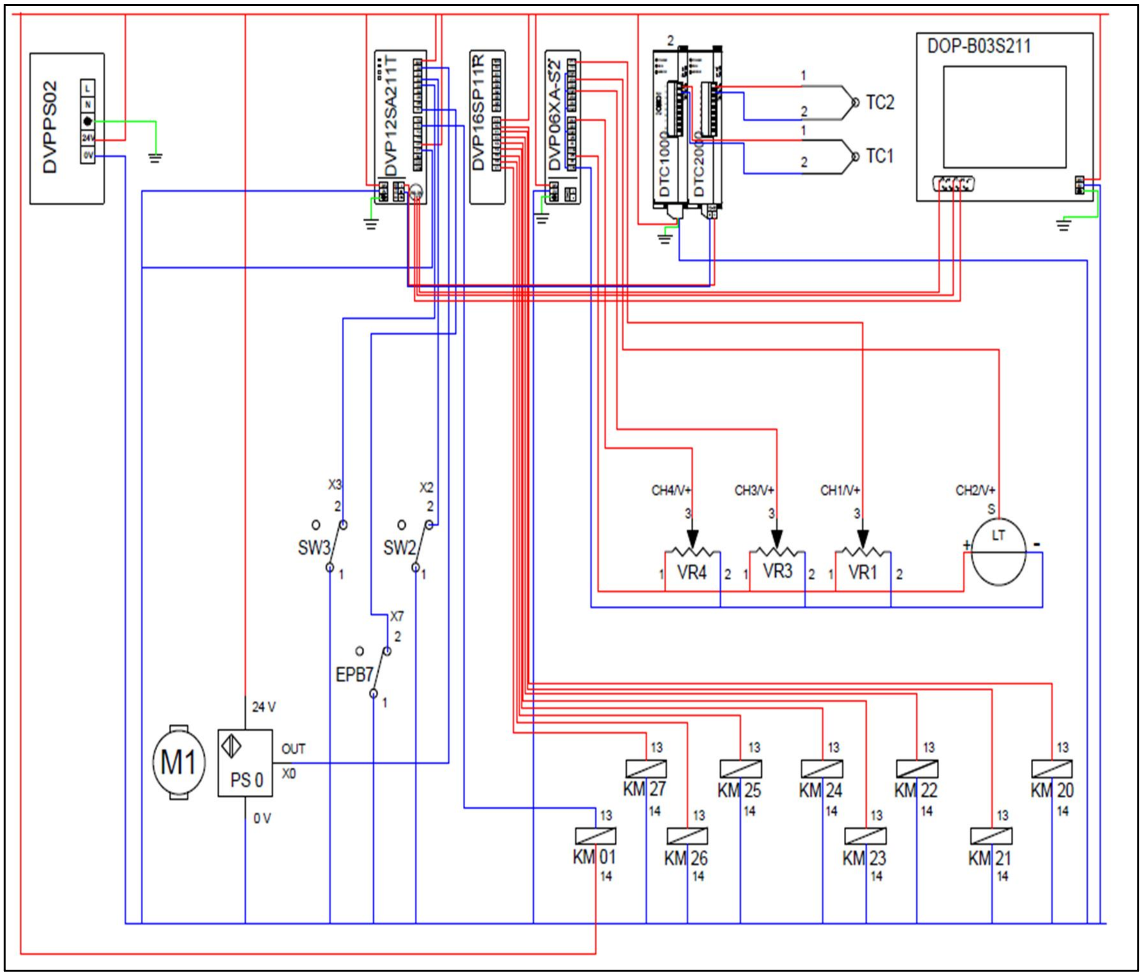



Figure 4-20: control system schematic (control diagram)

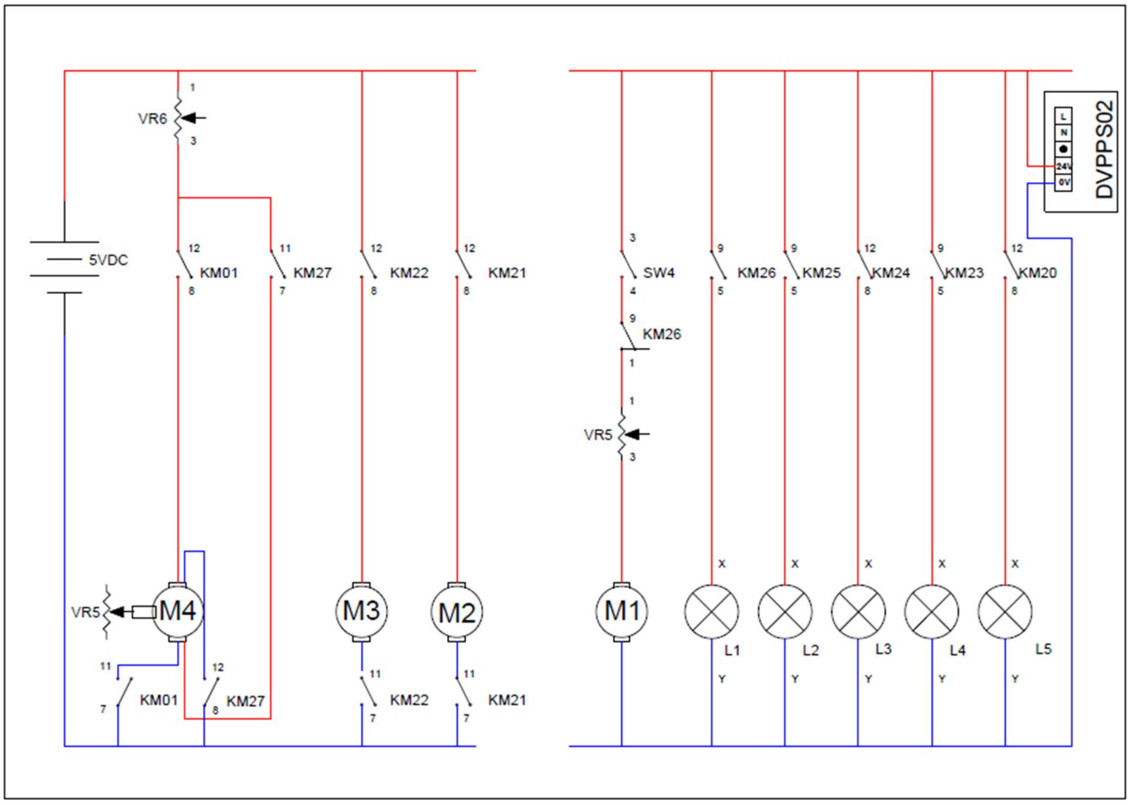



Figure 4-21: control system schematic (power diagram)

In figure 4-20 which illustrate control system schematic (control diagram) the DVPPS02 is representing power supply which supply the electrical 24 V DC current to all components in model, DVP12SA211T is PLC module, DVP16SP11R is digital extension module, DVP06XA-S2 is analog extension module connected with PLC, DTC 1000 and DTC 2000 are temperature controllers connected with PLC via RS-485 cable DOP-B032S211 is HMI module connected to PLC by RS-232 cable via programming port.

The input devices shown in figure 4-20 are: SW2, SW3, EPB7, PS0, VR1, VR2,VR3, VR4, TC1 and TC2 which representing respectively: suction damper pressure switch, discharge damper pressure switch, emergency stop, speed sensor, engine oil pressure sensor, tank level transmitter, main discharge pressure sensor, Air vessel sensor, coolant temperature sensor and engine oil temperature sensor.

The engine is representing in figure 4-20 and figure 4-21 by M1

The relays connected to PLC are number by output channels they are connected to. These relays are: KM20, KM21, KM22, KM23, KM24, KM25, KM26, KM27and KM01 which representing respectively: main air solenoid, oil prime pump solenoid, starter solenoid, pump's clutch solenoid, suction valve solenoid, discharge valve solenoid, and engine stop device solenoid, fuel control device motor lowering and fuel control device motor rising.

In figure 4-21 the motors illustrated are: M1, M2, M3, M4 which representing respectively: Engine, oil prime pump, starter motor, and fuel control device motor. Each motor is connected to corresponding relays, oil prime pump to KM21, starter motor to KM22, fuel control device motor to KM27 and KM01. The engine is connected to normally close contact of engine stop device relay KM26.

The indicator lamps in figure 4-19 are marked as follow: L1, L2, L3, L4, L5 which representing respectively main air valve, pump's clutch, suction valve, discharge valve and engine stop device. They are connected respectively to (KM26, KM25, KM24, KM23 and KM20)

Other components in figure 4-19 are SW4, VR6 and VR5 which representing manual engine start stop, fuel control device motor (throttle motor) adjusting potentiometer and VR5 representing fuel control device potentiometer which controls engine speed and connected to fuel control device motor.

## 4.5 Model’s construction

At the beginning a wood plate with size of 60 cm * 60 cm has been brought and white poster paper is fixed on it and green poster paper has been fixed at the back side of the plate to make the model at good looking. Then two rows of 35mm × 7.5 mm wide rail has been installed on the front side of wooden plate to mount controllers at upper row and the button one for mounting 2.5 mm DIN terminal blocks as shown in figure 4-20.

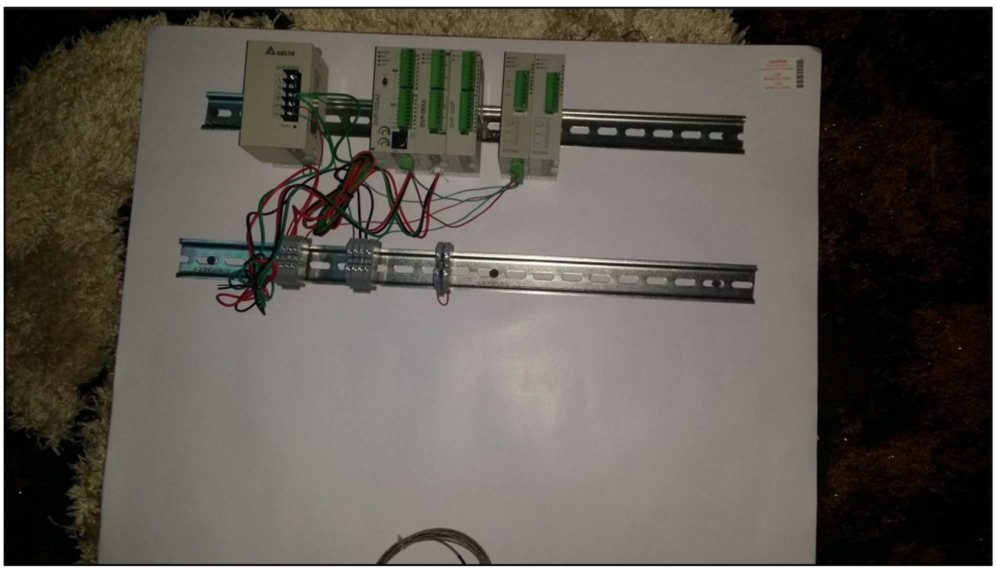


Figure 4-22: the plate after installing wide rails and mounting controller modules and 2.5mm terminal blocks.

At the lower suction of plate installed DC motor (M1) that represents diesel engine with its switch (SW4) and speed sensor (PS0) as shown in figure 4-21.

After installing motor M1 the relays have been mounted in the rail and switches SW1 and SW2, potentiometers VR1, VR3, VR4 and level sensor LT have been installed, then fuel control motor M4 with external power source 5V have been installed at the model as shown in figure 4-22 and 4-23.

Figure 4-23: the model after installing DC motor and its switch and speed sensor.

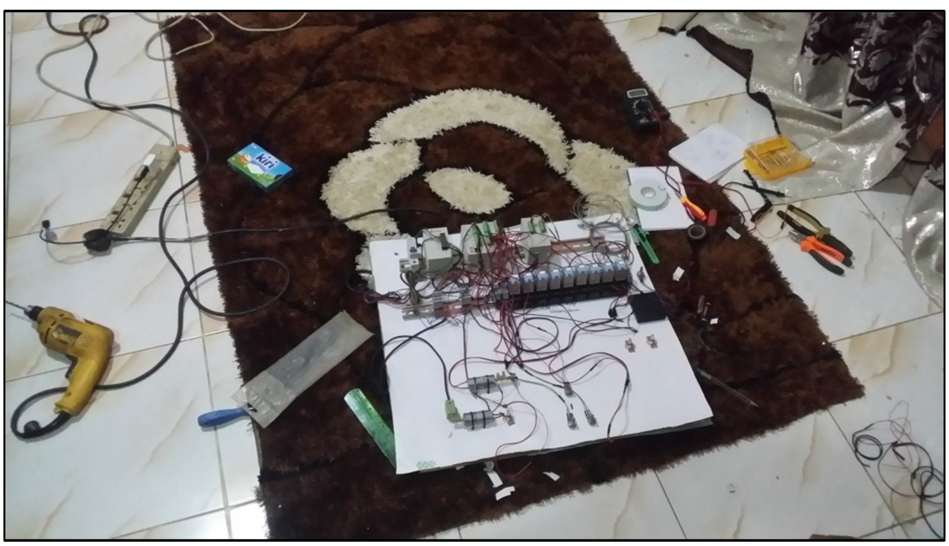


Figure 4-24: installing sensor and motors at the model.

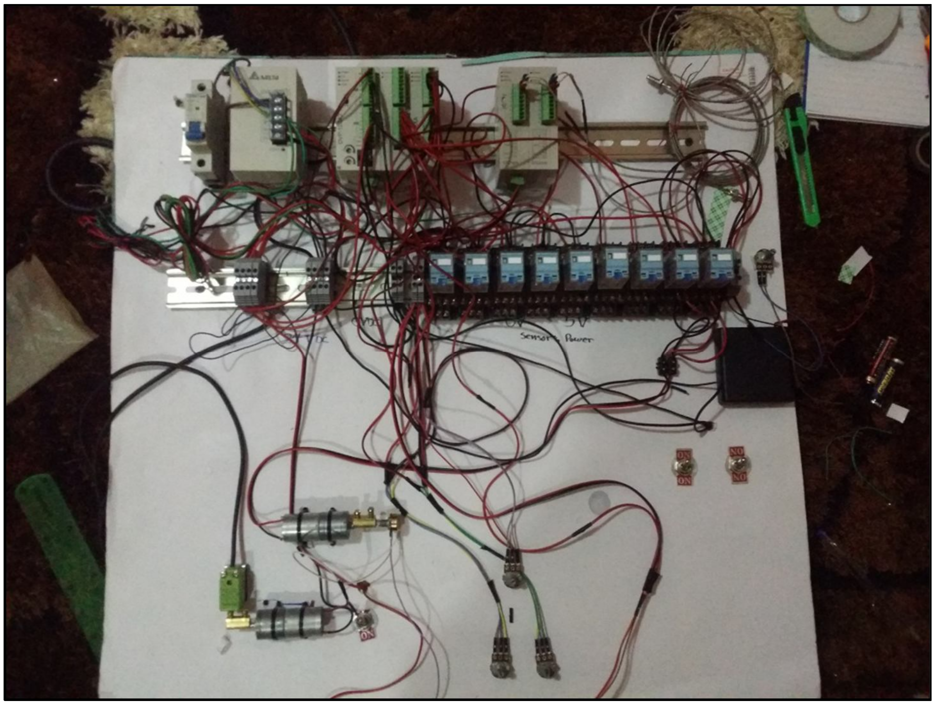


Figure 4-25: the model after installing sensors and switches.

Then the indicator lamps L1, L2, L3, L4, L5, emergency push button EPB7, the rest of motors M2, M3, HMI unit and safety decals and labels have been fixed to the model as shown in figure 4-24.

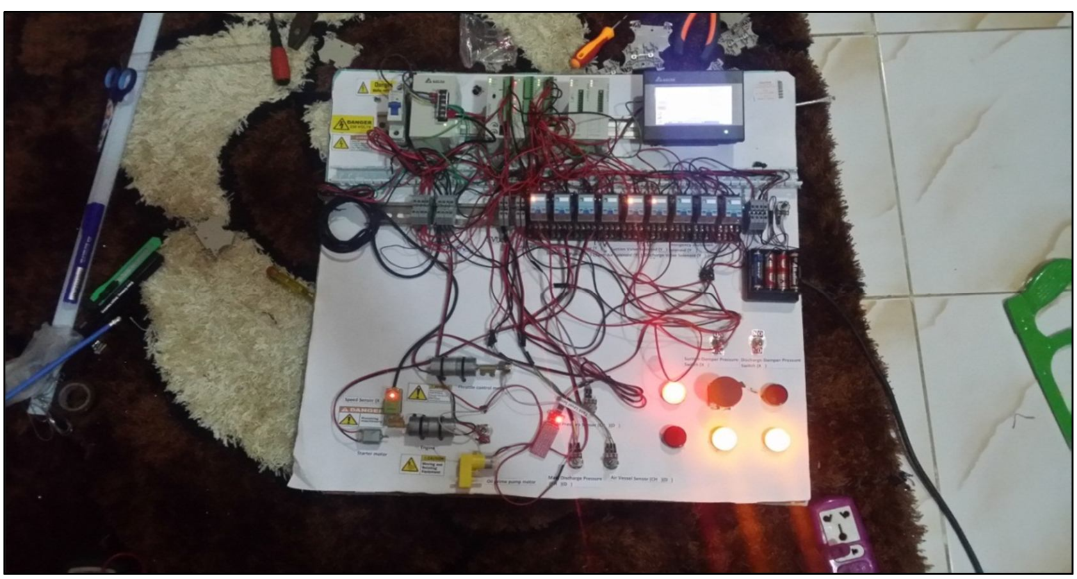


Figure 4-26: model after installing lamps, motors and HMI unit.

Generally the model is wired by using 2.5mm wires with three colors, the red wire represents positive voltage wire (24V or 5V), the black one represents 0 voltage wire and green one used for earthing purpose.

Finally after installing all components and wiring them a PVC cable trunk has been installed to arrange the distribution of wire in all model As shown in figure 4-25.

The PLC program and HMI program has been uploaded to PLC module and HMI module to control the whole model. The programs are shown in appendices.

The final model appearance is shown in figure 4-26.

Figure 4-27: trunking cables in the model.

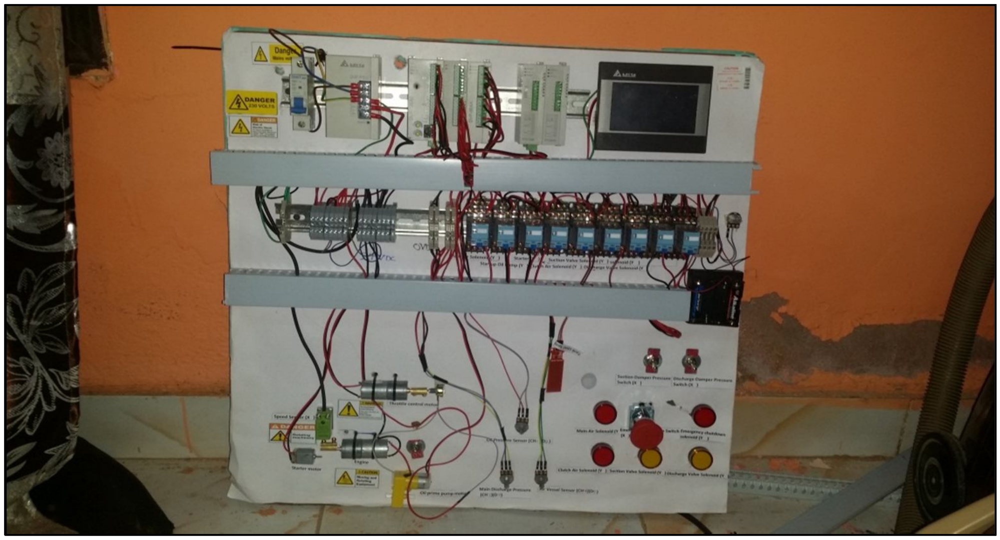


Figure 4-28: complete designed model.

The tools used to design the model are: steal saw, electrical drilling machine, electrical tape, 2 side adhesive tape, screw drivers, digital multimeter, cutter, ruler, note and pen, pencil, and marker pen, cable welding pen and cable cutter. They are shown in figure 4-27.

Figure 4-29: tools used to design the model.

## 4.6 Model's theory of operation

When turn on the power for model the main PLC establishes communication with other modules (temperature modules, analog module and HMI module) and fetches the operation parameters from the sensors through these modules, these parameters are: air vessel pressure from sensor VR4, coolant temperature TC2 , oil pressure VR1 , oil temperature TC1, tank level LT and main discharge pressure VR3. Then the PLC stores these parameters in its own registers then the control unit compares the stored parameters with preset values which are stored in control unit's registers by the operator.

The control unit also checks the status of digital input units (suction damper pressure switch SW1, discharge damper pressure switch SW2, emergency bush button EPB7 and engine's speed PS0) and shows the results in HMI.

The HMI installed in the model gives the operator the choice of selection between manual operation mode and automatic operation mode.

When the operator selects the automatic operation mode the HMI jumps immediately to automatic operation screen which allows the operator to only start/stop the unit and monitor the operation parameters.

When the operator presses start button the control unit starts by checking the air vessel pressure read from sensor CH4 with preset values if it is O.K then the control unit activates the main air solenoid relay KM20 and then activates the oil prime pump relay coil KM21to run the oil prime pump motor M2 for 10 seconds, then checks the oil pressure read from CH1with preset value if it is below the preset value the control unit immediately shutdown the system and activate alarm on HMI, otherwise it energizes the starter relay coil KM22 which activates the starter motor M3 for 7 seconds and deactivate the shutdown relay KM26 to start the engine M1.

When the engine is running the control unit activates the suction and discharge relays KM24 and KM25 respectively to open the suction and discharge solenoids in order to prepare for pump operation (the mud pump is positive displacement pump so it is mandatory to open suction and discharge valves before operating the pump) then the control unit wait for 1 minute to warm up the engine and then activates the clutch solenoid's relay coil KM23 which engages the clutch that transfer the engine's power to mud pump.

When the mud pump is running the control unit monitors the operation parameters and compares them with preset values and takes the action when they are changed.

In case the control unit detects one or more of the operation parameters change from set point it reacts with the change in different ways, the table 4-14 shows the reaction taken by control unit when the parameters are changed.

Table 4-14: consequences of parameters change

| Parameter | Set point | Change to take an action | Consequence |
|---|---|---|---|
| Engine oil temperature | Set by operator | Above set point | Activate alarm only |
| | | Reach maximum set point | Activate alarm and cold shutdown for the unit |
| Engine | Set by | Above high set | Activate alarm only |

| | | | |
|---|---|---|---|
| Coolant temperature | operator | point | |
| | | Reach maximum set point | Activate alarm and cold shutdown for the unit |
| Engine oil pressure | Set by operator | Fall below set point | Activate alarm and hot shutdown for the unit |
| Tank level | No set point | None | No Action |
| Air vessel pressure | Set by operator | Falls below set point | Activate alarm and cold shutdown for the unit |
| Main discharge pressure | Set by operator | Rise above set point | Activate alarm only |
| Suction damper pressure | Set by manufacture | Falls below set point | Disengage clutch and activate alarm |
| Discharge damper pressure | Set by manufacture | Falls below set point | Disengage clutch and activate alarm |
| Engine speed | Set by operator | Rise above set point | Activate alarm only |

When the system activate cold shutdown for the unit it disengage pump's clutch KM23 and then allow the engine to cool down for 1 minute, then activate stop solenoid relay KM26 to stop the engine M1, after 3 seconds the system closes suction and discharge valves by deactivating their corresponding relays KM24 and KM25 together and waits 20 seconds before activating the start button to allow the operator to start the unit again.

At hot shutdown state the system disengages pump's clutch by deactivating its relay KM23 and activates the stop solenoid relay KM26 at the same time to stop the engine M1, after 3 seconds the system closes suction and discharge valves by deactivating their corresponding relays KM24 and KM25.

When the unit is running the operator is allowed to control the engine speed M1 controlling the throttle motor M4.The starting sequence chart is shown in figure 4-20.

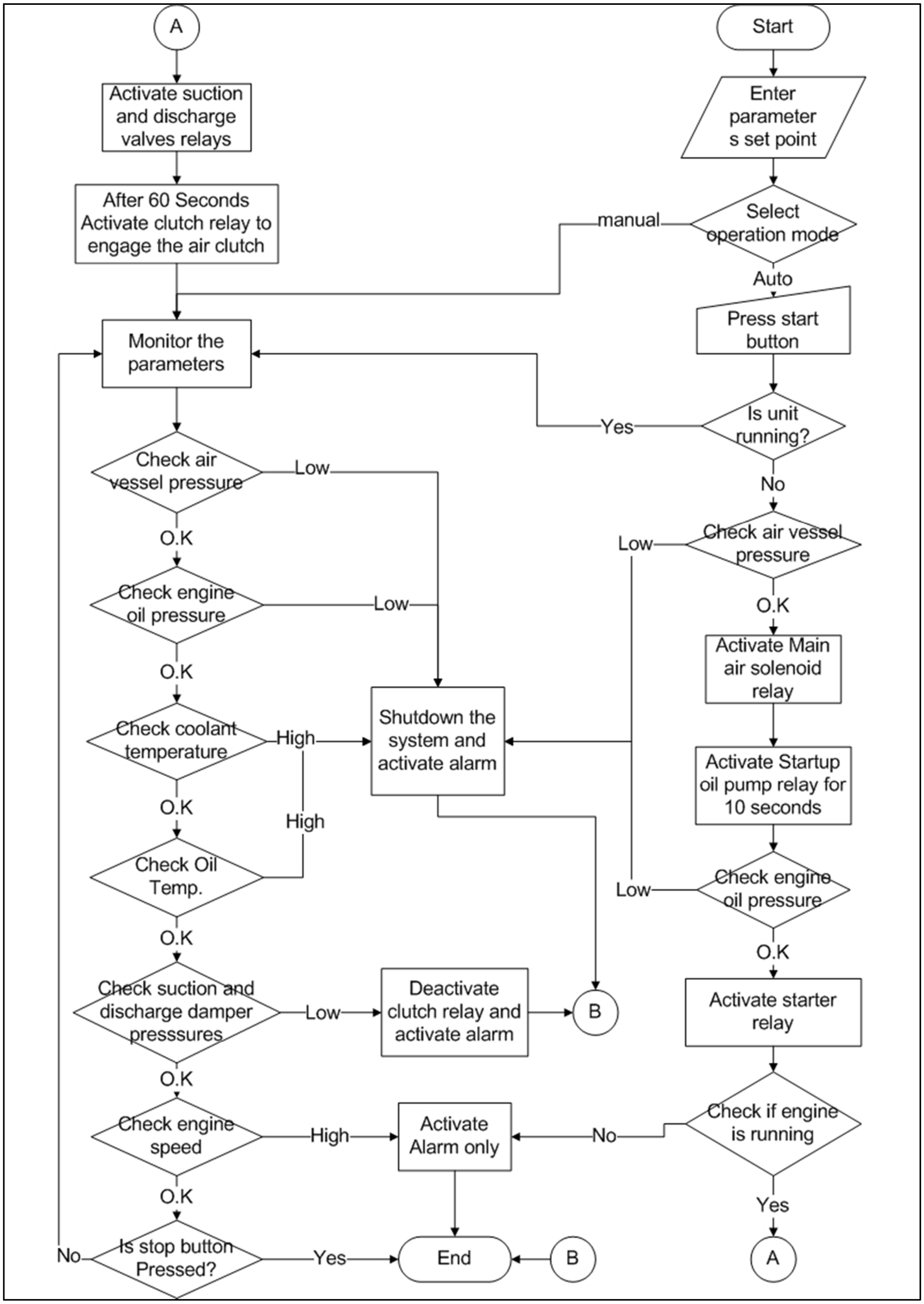



Figure 4-30: control system theory of operation flowchart (starting the unit).

When the operator desires to shut down the system he presses the stop button appear in the operation screen, the control unit immediately disengages the clutch by deactivating the clutch solenoid relay coil KM23, and waits for one minute to cool down the engine before activating the shutdown device relay KM26 to shut down the engine M1, after 3 seconds the control unit deactivates suction and discharge valves solenoids relays KM24 and KM25 to close them. And finally the control unit reset the operation relay which is internally relay to allow the operator to restart the engine if needed.

The main air solenoid KM20 is kept open at all time as long as the air vessel pressure is above the low set point.

The stopping sequence chart is shown in figure 4-21.

In manual operation mode the control system allows the activation of any component in the unit individually by the operator and monitors the parameters. This mode is helpful for inspection and maintenance purposes.

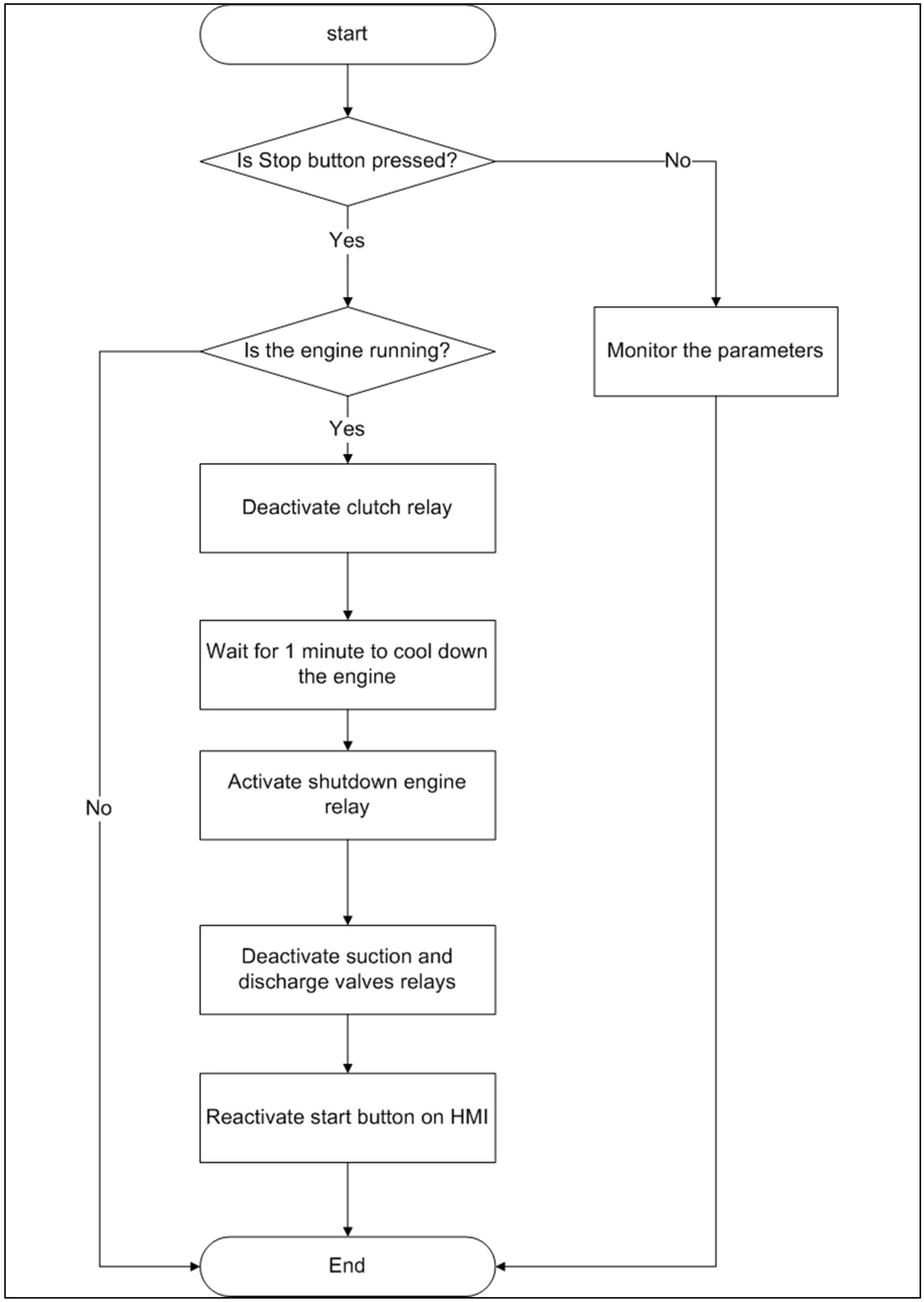



Figure 4-31: control system theory of operation flowchart (stopping the unit).

# Chapter five

# Results and Discussion

# Chapter Five

# Results and Discussion

## 5.1 Results

After defining the problem, the research goes through solving the problem by designing a model, the next step is testing the model to check if it is meet the expected results or not. In this chapter the prescribed model will be tested through the procedure detailed later in this chapter and the result will be documented and discussed.

### 5.1.1 Objectives

Testing the model to ensure that the system can carry out:

1. Rapid startup and shutdown for unit.
2. Monitoring for all parameters.
3. Taking an action when one or more parameters deviate from set point.

### 5.1.2 Apparatus

The apparatus used in the experiment are:

1. The designed control system's model.
2. Heat source (cigarette igniter or any other heat source).
3. Water container (for testing the level transmitter).
4. Electrical power source (AC power socket).

### 5.1.3 Procedure

After supply the model with power and turn on the control system then we press start button on screen and monitor the operation of the system. After the system operation's state is maintained we press stop button to stop the system and monitor the time and procedure of starting and stopping the system.

When the system is in operation mode we monitor the parameters and make some changes to them individually to monitor the expected reaction of the system in each change.

After experiment is accomplished the results are checked and documented and compared with old control system.

### 5.1.4 Experiment results

#### 5.1.4.1 Ordinary operation of the system:

Normal operation of the system is described as starting and stopping the system in ordinary circumstances the table 5-1 and figure 5-1 show the time of normal operation of the system.

Table 5-1: time ordinary operation of the system

| Parameter | time when using old control system (sec) | Time when using the designed model (sec) | Time saved (Sec) | Time saving percent (%) |
|---|---|---|---|---|
| Starting the unit | 306 | 77 | 229 | 74.8 |

| | | | | |
|---|---|---|---|---|
| Stopping the unit | 271 | 63 | 208 | 76.7 |

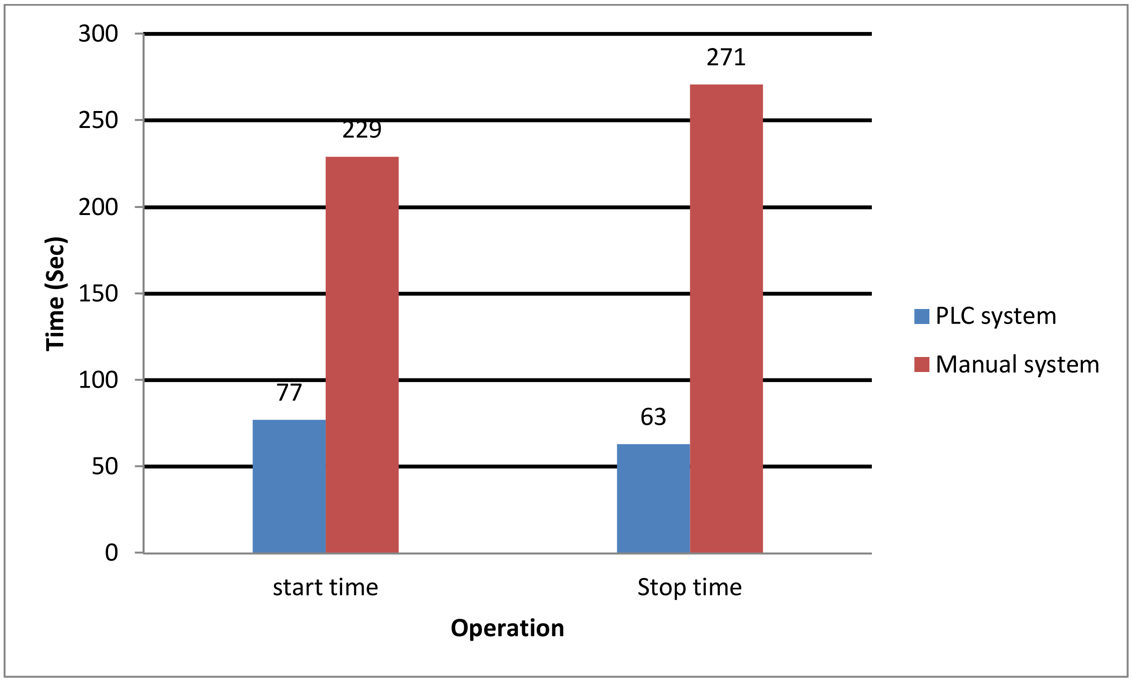



Figure 5-1: starting stopping time.

### 5.1.4.2 Faults detecting and taking action time

The faults detecting time is the time that the system or the operator takes to detect the fault and response time is time for taking an action to illuminate or reduce the risk of this fault to the unit. The table 5-6 shows the fault detecting and response time for each parameter that effects on mud pump operation by using existed manual control system and PLC control system.

Table 5-2: fault detecting and response time

| **Parameter** | **Setting Value** | **Reaction** | **Time of reaction (Sec)** | | | **Time saving (%)** |
|---|---|---|---|---|---|---|
| | | | **Manual control system** | | **PLC control system** | |
| | | | **Detecting problem** | **Taking action** | | |
| Coolant temp. | High =90 °C | Alarm | 7200 | 20 | 0.5 | 99.9 |
| | Max = 95 °C | Cold shutdown | | | 0.000007 | 100 |
| Engine oil temp. | High = 90 °C | Alarm | 7200 | 10 | 0.5 | 99.9 |
| | Max = 95 °C | Cold shutdown | | | 0.000007 | ≈ 100 |
| Engine oil pressure | Low = 5 Bar | Hot shutdown and alarm | 7200 | 10 | 0.000007 | ≈ 100 |
| Air vessel pressure | Low = 5 Bar | Cold shutdown and alarm | 7200 | 30 | 0.000007 | ≈ 100 |
| Engine speed | High= 115% | Alarm | Undetectable | | 0.5 | 99.9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Suction damper pressure | Low = switch off | Disengage clutch and alarm | 7200 | 60 | 0.000007 | ≈ 100 |
| Discharge damper pressure | Low= switch off | Disengage clutch and alarm | 7200 | 60 | 0.000007 | ≈ 100 |
| Emergency stop button | Activate | Hot shutdown and alarm | N/A | N/A | 0.000007 | ≈ 100 |
| Main discharge pressure | High = 10 Bar | Alarm | 7200 | 0 | 0.5 | 99.9 |

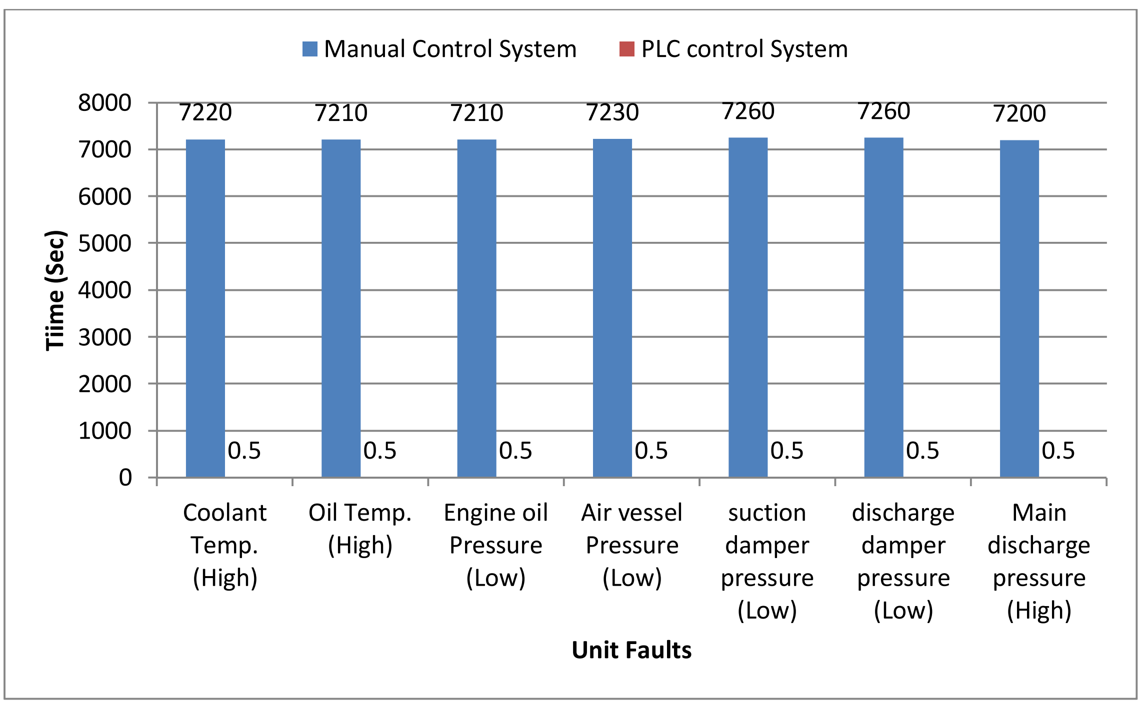



Figure 5-2: Faults detection time Using manual control system and PLC control system.

## 5.2 Discussion

According to table 5-1 which shows the operation time by using the existing manual control system and designed model, the time of manual operation is taken from observation of operation under normal circumstances, started at when the operator touches the handle of suction valve until the engine is loaded and pump is running.

The time is documented and shown in details in table 5-3.

Table 5-3: starting and shut down time when using the existing manual control system

| **Operation sequence** | **Time (sec)** |
|---|---|
| **Starting the unit** | |
| Opening suction and discharge valves | 165 |
| Time to reach the engine from valves | 30 |
| Starting the engine (opening main air valve and startup oil pump and starter) | 35 |
| Warming up the engine, adjust speed and engage pump's clutch | 181 |
| **Total** | 411 |
| **Shutdown the unit** | |

| | |
|---|---|
| Disengage clutch and cool down the engine and stop the engine by using stop arm | 181 |
| Time to reach valves from the engine to close them | 30 |
| Close suction and discharge valves | 165 |
| **Total** | 376 |

The time of operation of mud pump unit when using the design model is taken from starting point at when the operator presses start button at screen until the engine is loaded and pump is running.

The time described in details in table 5-4

Table 5-4: operation time when using designed model

| **Operation sequence** | **Time (sec)** |
|---|---|
| Starting oil prime pump | 10 |
| Starter motor operation | 7 |
| Warming up the engine | 60 |
| Opening suction and discharge valves | 0.000007 |
| Engage pump's clutch | 0.000007 |
| Total | 77 |

| | |
|---|---|
| Shutdown the unit | |
| Disengage pump's clutch, cool down the engine and stop the engine | 60 |
| Close suction and discharge valves | 3 |

At table 5-2 which shows the results of detecting faults and reaction time when using the existing manual control system compared with designed model, the time is taken from observation and starts when the operator detects the faults until taking an action.

The table 5- is describing the time of reaction when using manual control system which is based on operator experience and skills in detecting the faults and reaction needed to be carried out to eliminate or reduce the risk of certain fault for the unit.

The time of fault detection is based on routine check for all equipment in the facility that means if the operator checks the unit at certain time and finds no faults he continues checking all equipment and then come back to the mud pump unit for checking after completing the rotation. This single rotation takes two hours.

The faults detection time using the designed model as control system for mud pump unit is reduced to be 0.5 seconds. This is minimum scan time for HMI unit, but the PLC reacts with faults within 0.7 µs which is program scan time for this PLC module.

# Chapter six

# Conclusion and recommendations

# Chapter six

# Conclusion and Recommendations

## 6.1 Conclusion

The following conclusion can be drawn:

- It was found that using PLC control method to control mud pump unit reduces the operation of mud pump by 74.8 % for starting the unit and 76.7 % for shutdown the unit compared with manual control method which already exists.
- It was also found that using PLC control method to control mud pump reduce the fault detection time by approximately 100% compared with existing method and thus reduce the risk of losing whole unit due to major faults by 100 %.

## 6.2 Recommendations

- It is recommended that to install a designed model in the mud pump unit to reduce the operation and maintenance time and costs.
- It is recommended when installing the designed model to mud pump unit to replace the DC motor that works as fuel control device with servo motor to achieve accurate fuel control for engine.
- It is also recommended that when installing the designed model in the unit to fabricate a suitable panel to keep the control modules and relays away of dust, moisture direct sunlight and heat sources.

- It is also recommended to connect the designed model after installation to control room to allow only one operator to operate and monitor the mud pump unit from control room as well as controlling other equipment in Hadida FPF.
- Because the model depends on pneumatic system, it is recommended that the existing pneumatic system being modified to work as an actuator for designed control system. The pneumatic system schematic shown in figure 6-1.

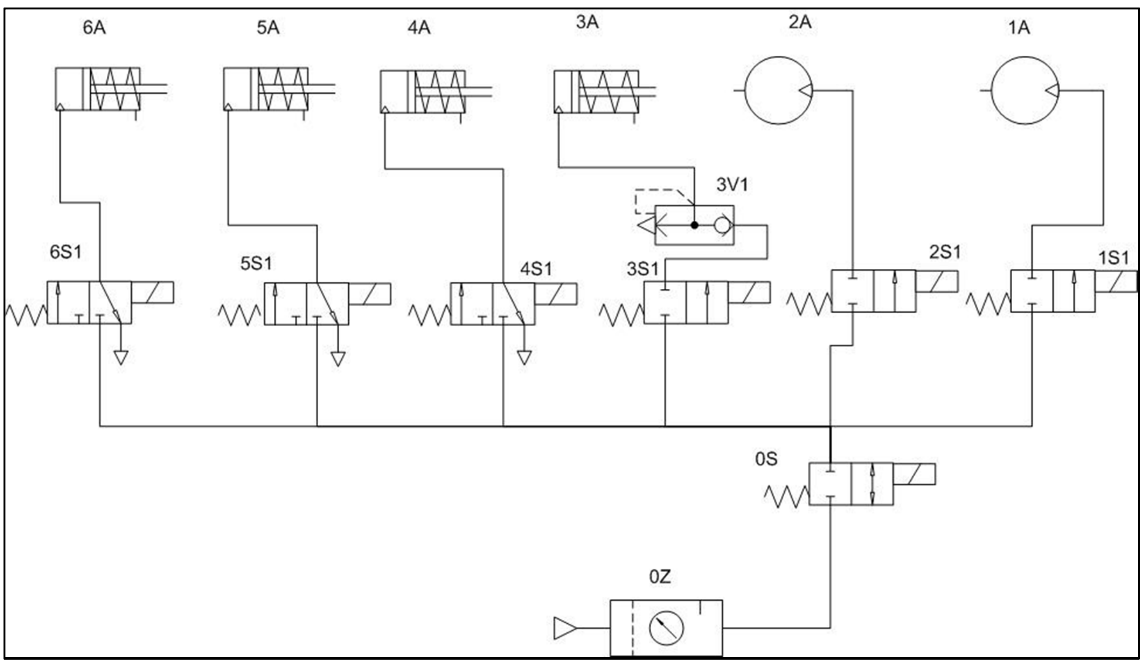



Figure 6-1: Recommended Pneumatic system for designed model.

The actuators (1A,2A,3A,4A,5A,6A) representing oil prime pump, starter motor, pump's clutch, suction valve, discharge valve and engine stop device respectively.

The valves (1S1,2S1,3S1,4S1,5S1 and 6S1) should be connected with (KM21,KM22,KM23,KM24,K25,KM26 and KM27) respectively and representing oil prime pump solenoid valve, starter solenoid valve, pump's clutch solenoid valve, suction valve solenoid valve, discharge valve solenoid valve and engine stop solenoid valve.

The valve 3V1 is quick release valve which is connected to pump clutch to release the clutch's air when the valve 3S1 becomes inactive.

The valve 0S is main air valve which should be connected with KM20 relay. And finally 0Z is air service unit which filters and lubricates the supplied air.

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# Appendices

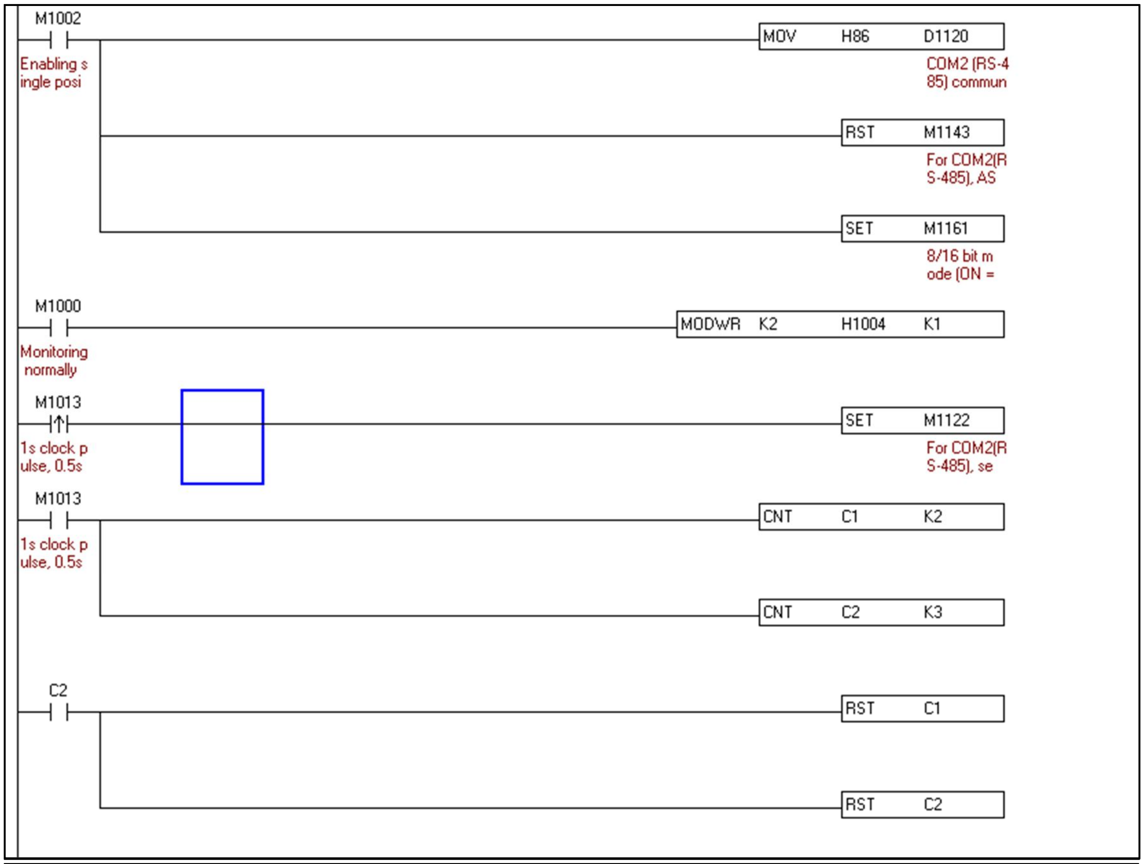
# Appendix A: Designed model's PLC program

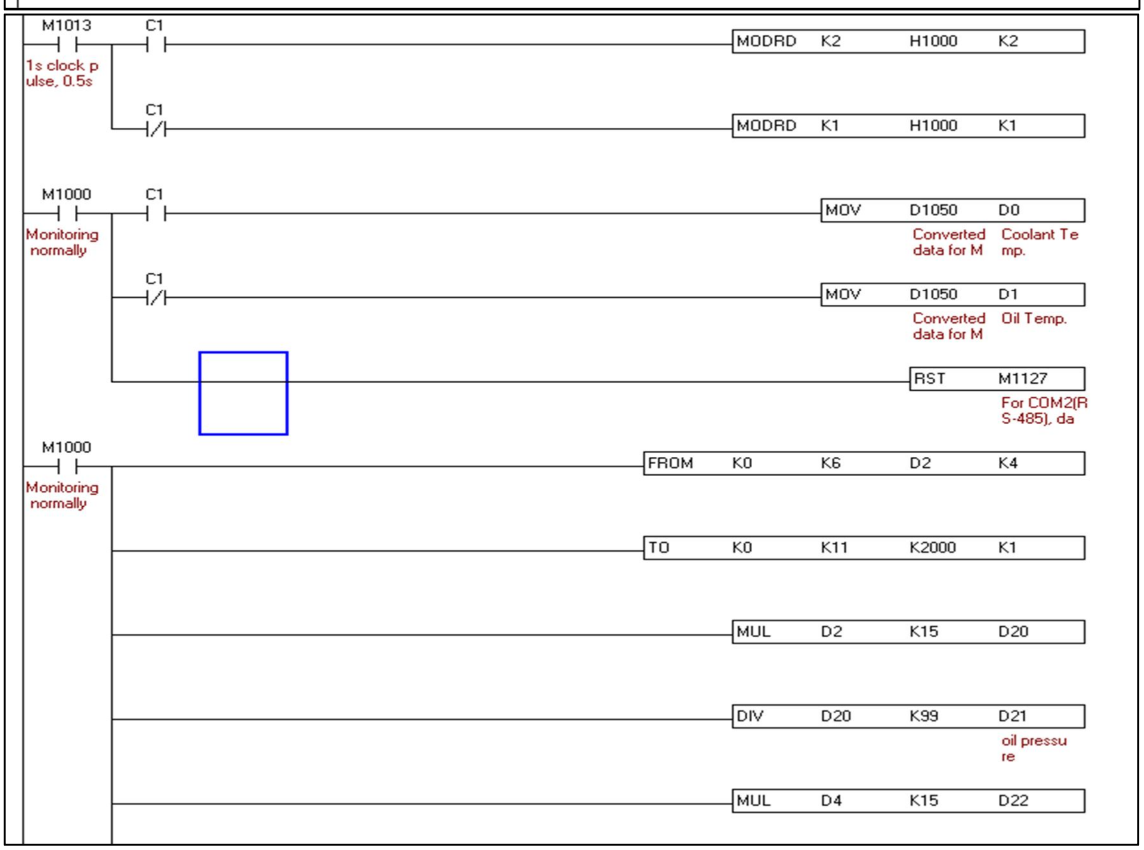
Program Title:Mud pump Operation Program

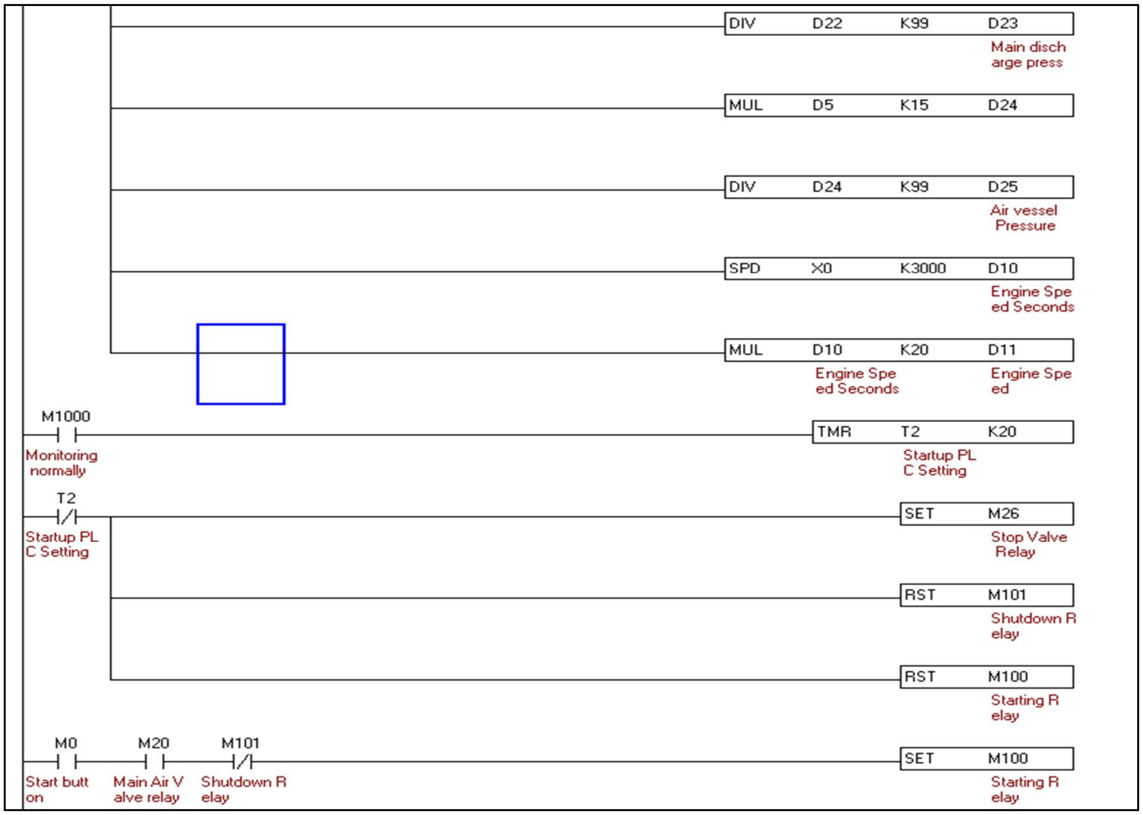
File Name:Mud pump Operation Program (revised April 2nd 2018)

Company Name:Petro Energy E&P. Co.Ltd

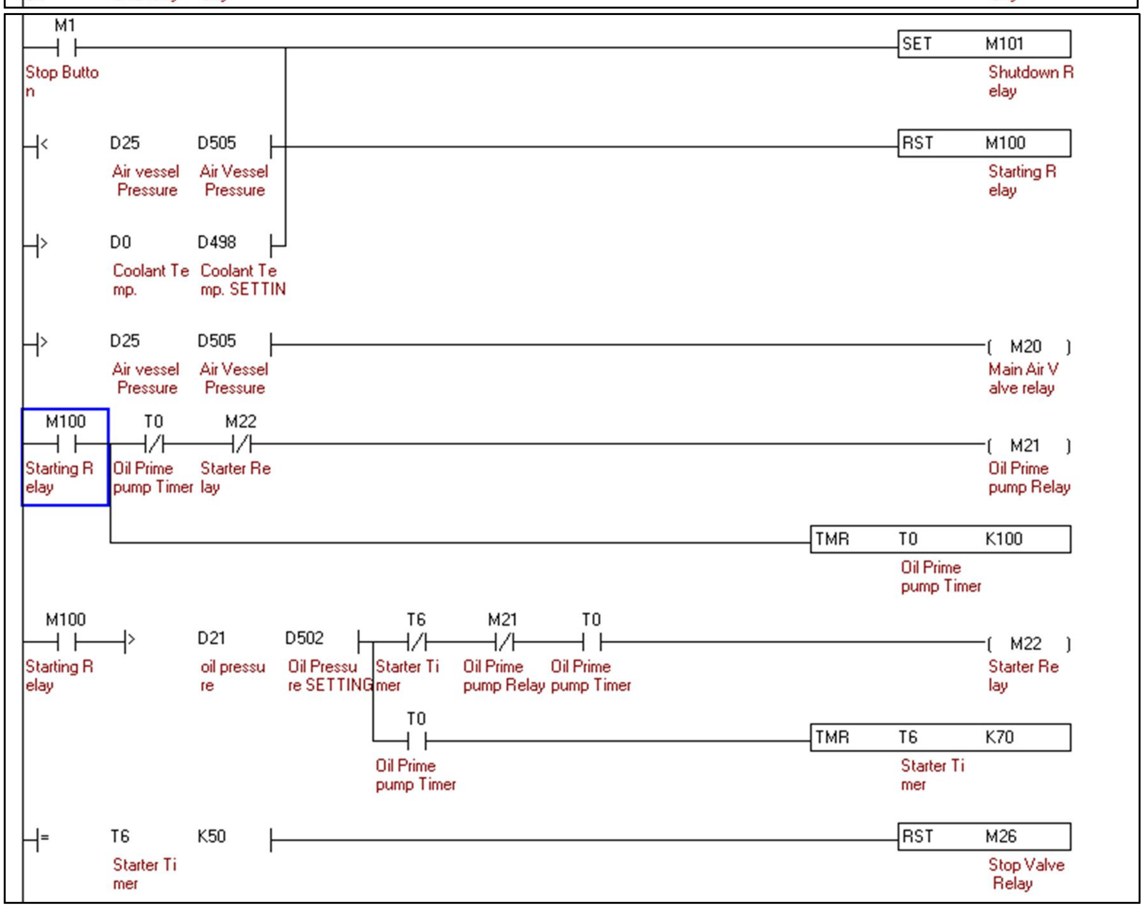
Designer:Ahmed Abdulmuttalib Osman Elzaki


M1002
Enabling s ingle posi
MOV H86 D1120
COM2 (RS-485) commun
RST M1143
For COM2(RS-485), AS
SET M1161
8/16 bit mode (ON =
M1000
Monitoring normally
MODWR K2 H1004 K1
M1013
1s clock pulse, 0.5s
SET M1122
For COM2(RS-485), se
M1013
1s clock pulse, 0.5s
CNT C1 K2
CNT C2 K3
C2
RST C1
RST C2

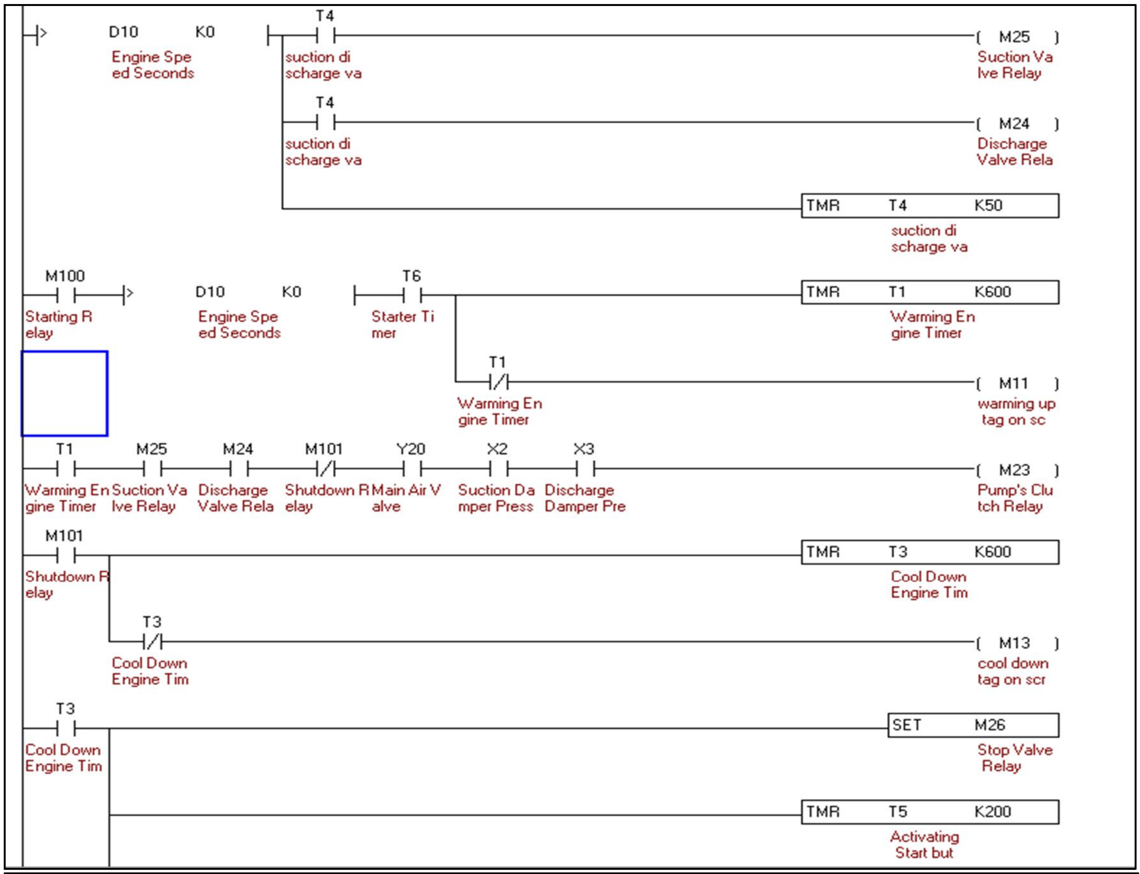

M1013
C1
1s clock pulse, 0.5s
MODRD K2 H1000 K2
C1
MODRD K1 H1000 K1
M1000
C1
Monitoring normally
MOV D1050 D0
Converted data for M
Coolant Temp.
C1
MOV D1050 D1
Converted data for M
Oil Temp.
RST M1127
For COM2(RS-485), da
M1000
Monitoring normally
FROM K0 K6 D2 K4
TO K0 K11 K2000 K1
MUL D2 K15 D20
DIV D20 K99 D21
oil pressure
MUL D4 K15 D22

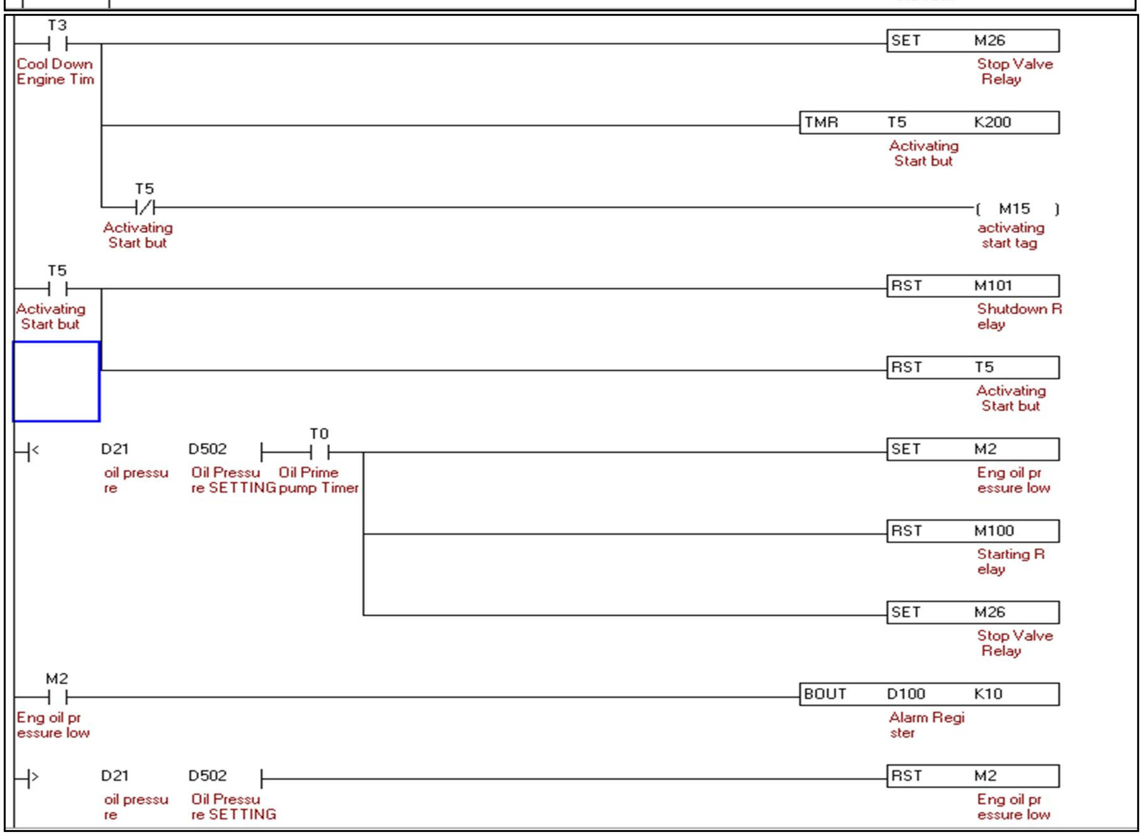


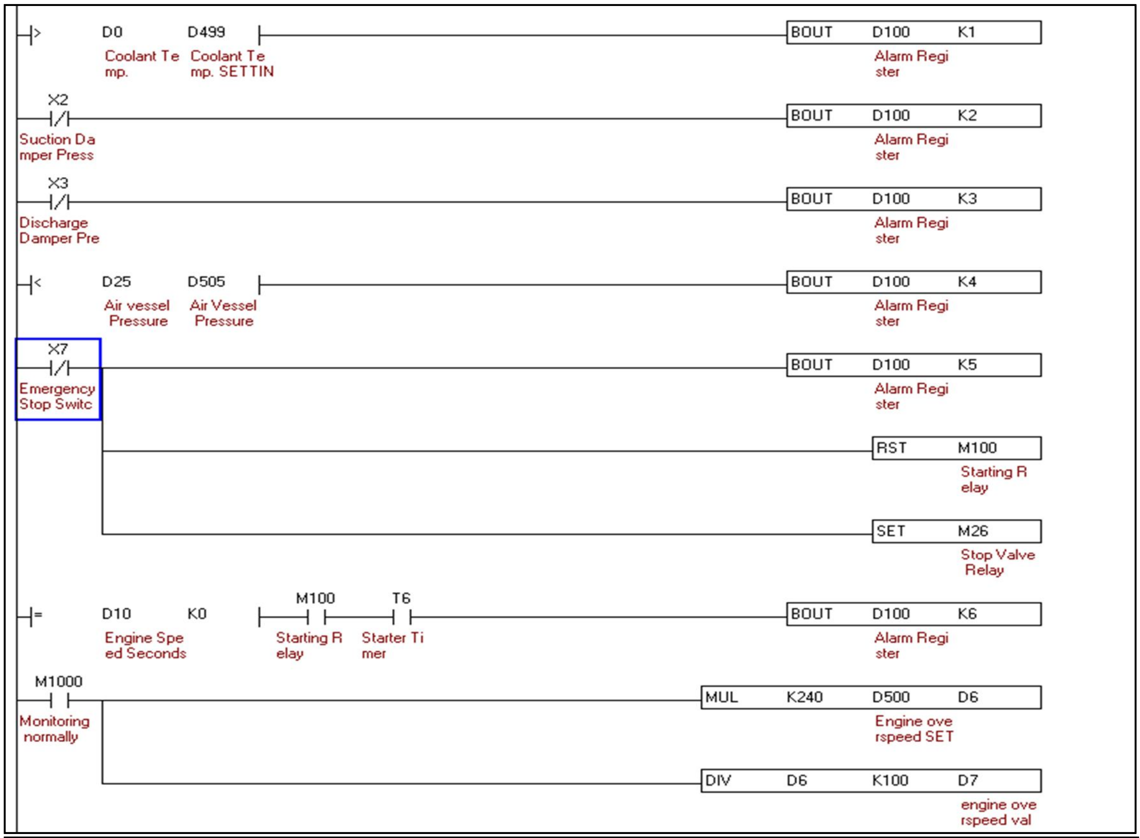
DIV D22 K99 D23
Main disch arge press
MUL D5 K15 D24
DIV D24 K99 D25
Air vessel Pressure
SPD X0 K3000 D10
Engine Spe ed Seconds
MUL D10 K20 D11
Engine Spe ed Seconds
Engine Spe ed
M1000
Monitoring normally
TMR T2 K20
Startup PL C Setting
T2
Startup PL C Setting
SET M26
Stop Valve Relay
RST M101
Shutdown R elay
RST M100
Starting R elay
M0
Start butt on
M20
Main Air V alve relay
M101
Shutdown R elay
SET M100
Starting R elay

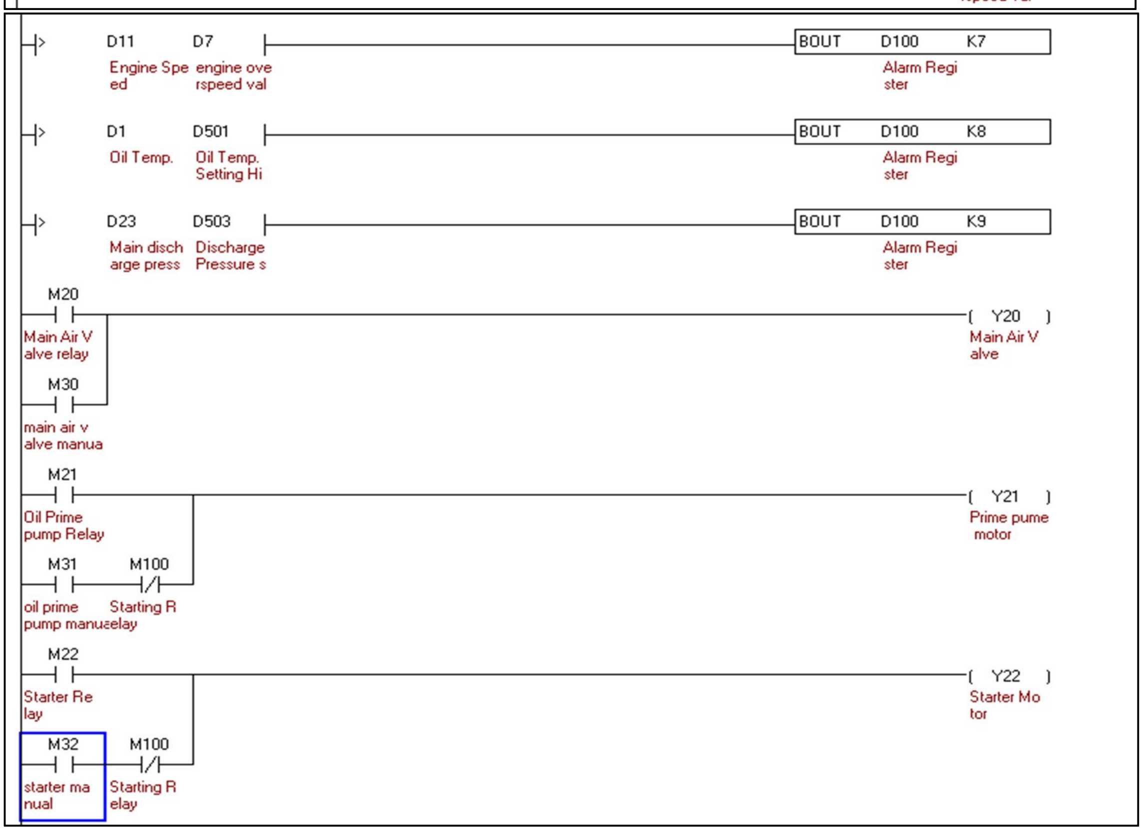
M1
Stop Butto n
SET M101
Shutdown R elay
< D25 D505
Air vessel Pressure
Air Vessel Pressure
RST M100
Starting R elay
> D0 D498
Coolant Te mp.
Coolant Te mp. SETTIN
> D25 D505
Air vessel Pressure
Air Vessel Pressure
M20
Main Air V alve relay
M100
Starting R elay
T0
Oil Prime pump Timer
M22
Starter Re lay
M21
Oil Prime pump Relay
TMR T0 K100
Oil Prime pump Timer
M100
Starting R elay
> D21 D502
oil pressu re
Oil Pressu re SETTING
T6
Starter Ti mer
M21
Oil Prime pump Relay
T0
Oil Prime pump Timer
M22
Starter Re lay
T0
Oil Prime pump Timer
TMR T6 K70
Starter Ti mer
= T6 K50
Starter Ti mer
RST M26
Stop Valve Relay


D10
K0
T4
Engine Speed Seconds
suction discharge va
M25
Suction Valve Relay
M24
Discharge Valve Rela
TMR T4 K50
M100
Starting Relay
T6
Starter Timer
TMR T1 K600
Warming Engine Timer
T1
M11
warming up tag on sc
M101
Y20
X2
X3
Shutdown Relay
Main Air Valve
Suction Damper Press
Discharge Damper Pre
M23
Pump's Clutch Relay
TMR T3 K600
Cool Down Engine Tim
T3
M13
cool down tag on scr
SET M26
Stop Valve Relay
TMR T5 K200
Activating Start but

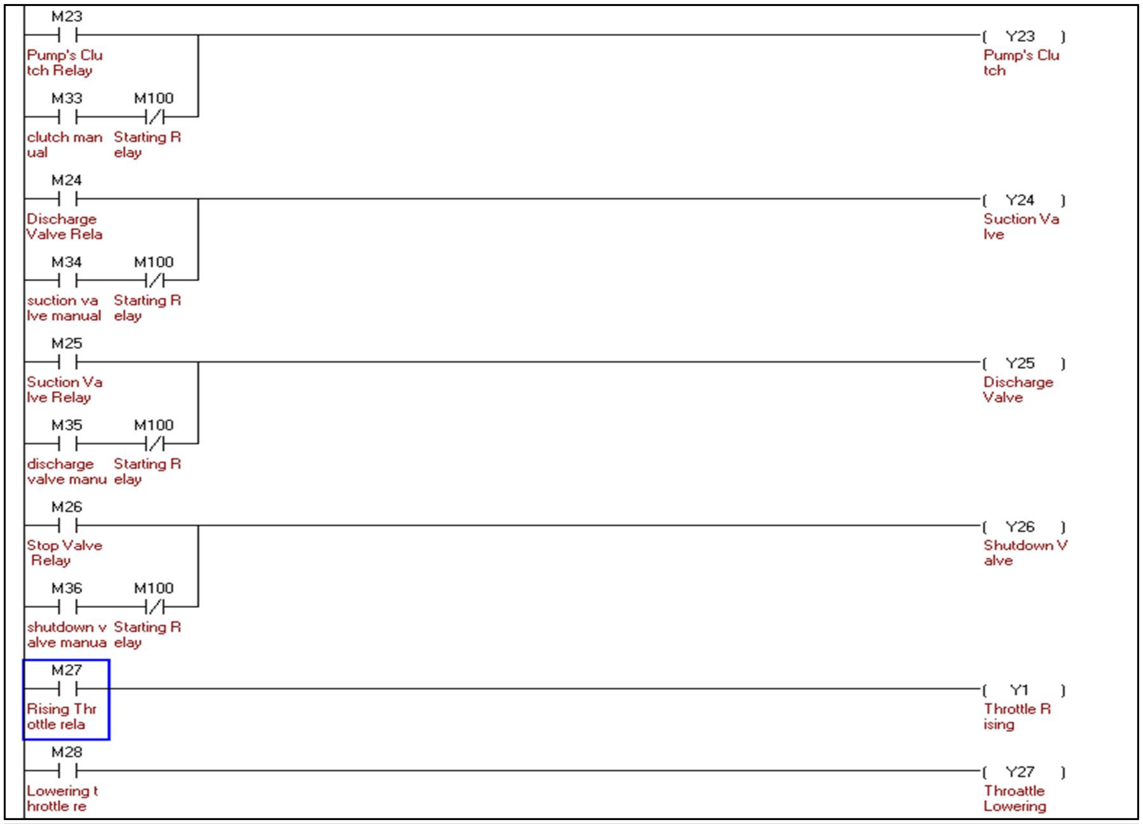

T3
Cool Down Engine Tim
SET M26
Stop Valve Relay
TMR T5 K200
Activating Start but
T5
M15
activating start tag
RST M101
Shutdown Relay
RST T5
D21
D502
T0
oil pressure
Oil Pressure SETTING
Oil Prime pump Timer
SET M2
Eng oil pressure low
RST M100
Starting Relay
SET M26
M2
BOUT D100 K10
Alarm Register
RST M2

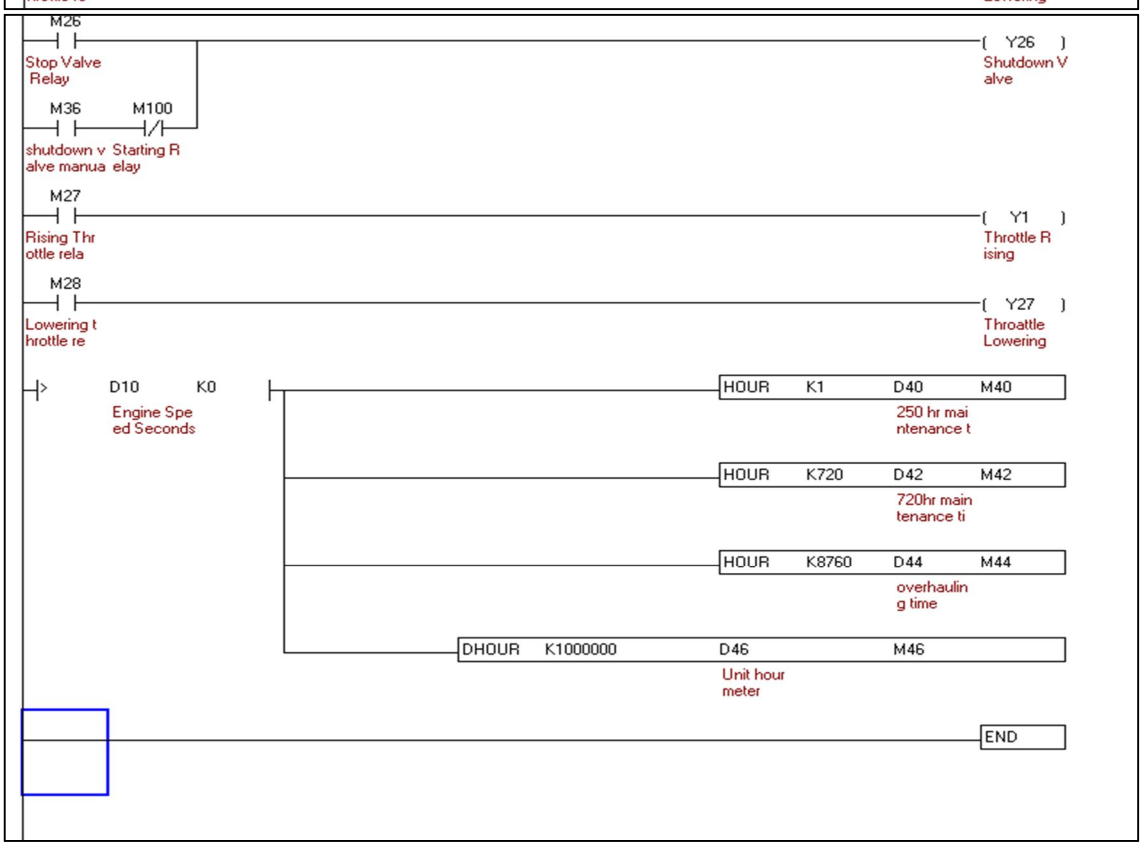


D0 D499
Coolant Temp.
Coolant Temp. SETTIN
BOUT D100 K1
Alarm Register
X2
Suction Damper Press
BOUT D100 K2
Alarm Register
X3
Discharge Damper Pre
BOUT D100 K3
Alarm Register
D25 D505
Air vessel Pressure
Air Vessel Pressure
BOUT D100 K4
Alarm Register
X7
Emergency Stop Switc
BOUT D100 K5
Alarm Register
RST M100
Starting Relay
SET M26
Stop Valve Relay
D10 K0
Engine Speed Seconds
M100 T6
Starting Relay
Starter Timer
BOUT D100 K6
Alarm Register
M1000
Monitoring normally
MUL K240 D500 D6
Engine overspeed SET
DIV D6 K100 D7
engine overspeed val

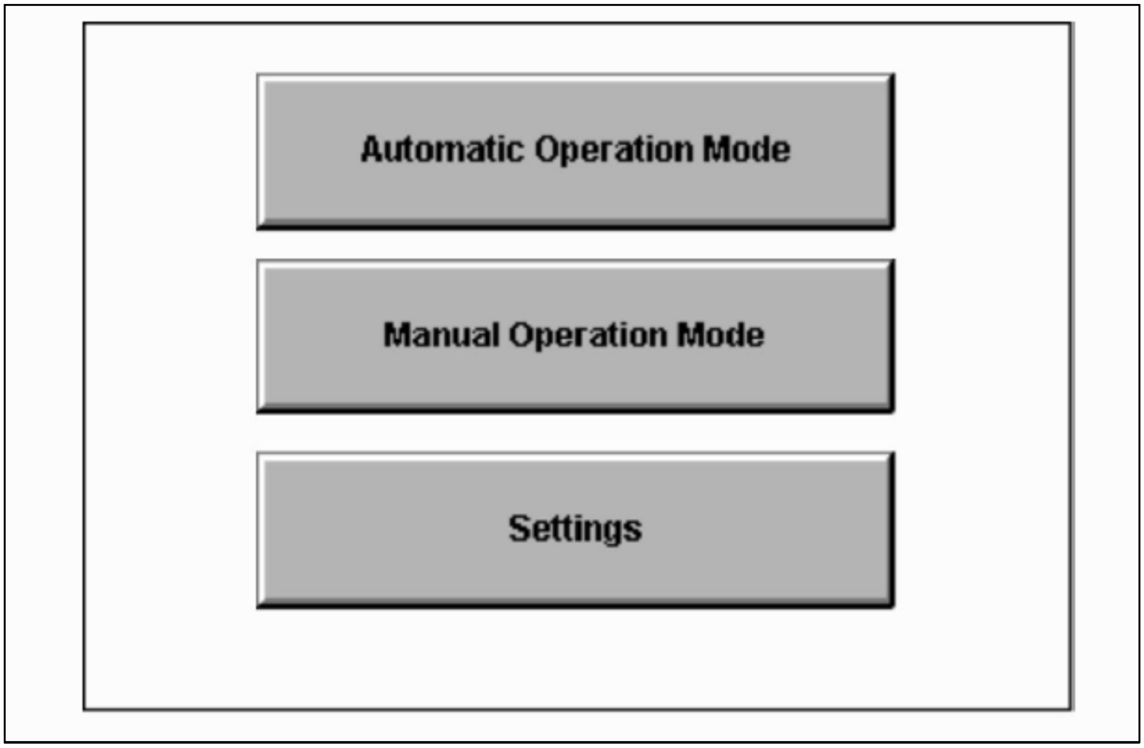



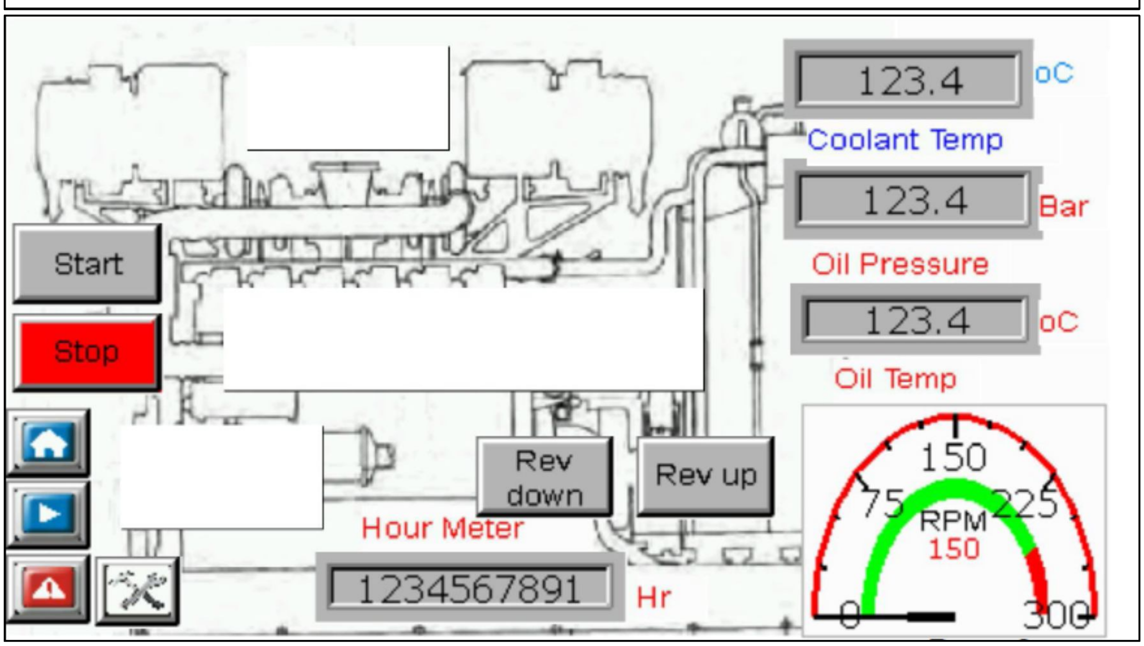
D11 D7
Engine Speed
engine overspeed val
BOUT D100 K7
Alarm Register
D1 D501
Oil Temp.
Oil Temp. Setting Hi
BOUT D100 K8
Alarm Register
D23 D503
Main discharge press
Discharge Pressure s
BOUT D100 K9
Alarm Register
M20
Main Air Valve relay
Y20
Main Air Valve
M30
main air valve manua
M21
Oil Prime pump Relay
Y21
Prime pume motor
M31 M100
oil prime pump manu
Starting Relay
M22
Starter Relay
Y22
Starter Motor
M32 M100
starter manual
Starting Relay

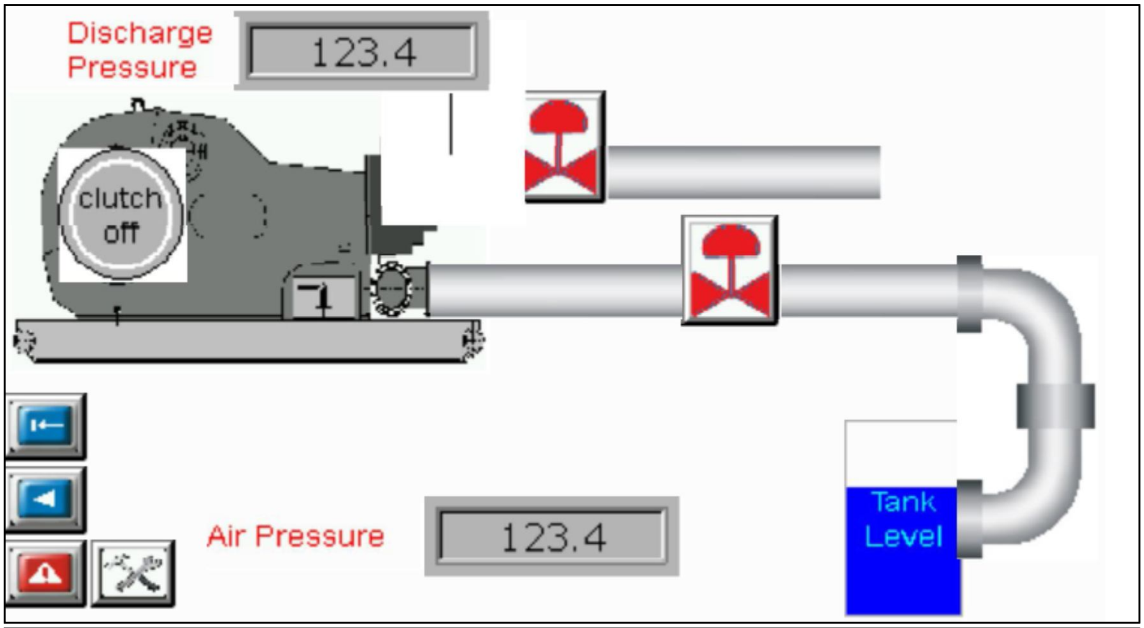

M23
Pump's Clu
tch Relay
Y23
Pump's Clu
tch
M33
M100
clutch man
ual
Starting R
elay
M24
Discharge
Valve Rela
Y24
Suction Va
lve
M34
M100
suction va
lve manual
Starting R
elay
M25
Suction Va
lve Relay
Y25
Discharge
Valve
M35
M100
discharge
valve manu
Starting R
elay
M26
Stop Valve
Relay
Y26
Shutdown V
alve
M36
M100
shutdown v
alve manua
Starting R
elay
M27
Rising Thr
ottle rela
Y1
Throttle R
ising
M28
Lowering t
hrottle re
Y27
Throattle
Lowering

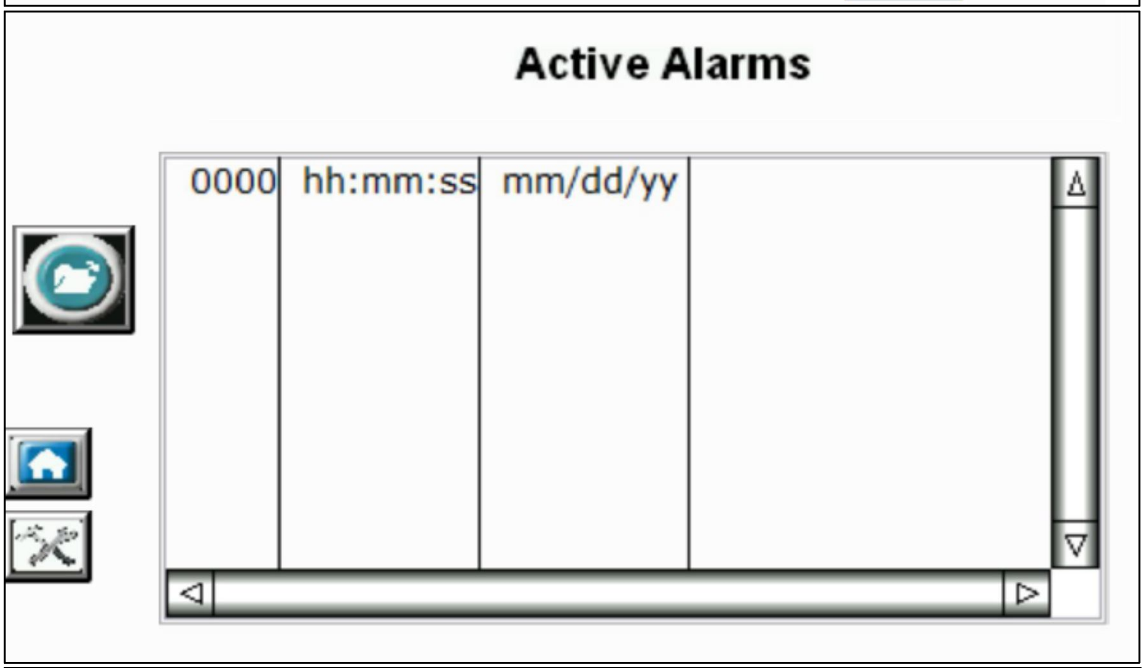

M26
Stop Valve
Relay
Y26
Shutdown V
alve
M36
M100
shutdown v
alve manua
Starting R
elay
M27
Rising Thr
ottle rela
Y1
Throttle R
ising
M28
Lowering t
hrottle re
Y27
Throattle
Lowering
D10
K0
Engine Spe
ed Seconds
HOUR
K1
D40
M40
250 hr mai
ntenance t
HOUR
K720
D42
M42
720hr main
tenance ti
HOUR
K8760
D44
M44
overhaulin
g time
DHOUR
K1000000
D46
M46
Unit hour
meter
END

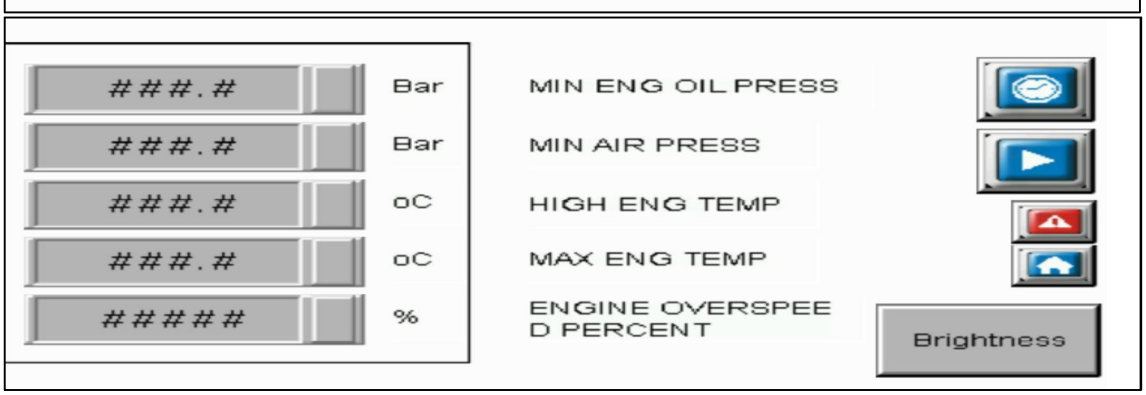
# Appendix B: Designed model's screen Program

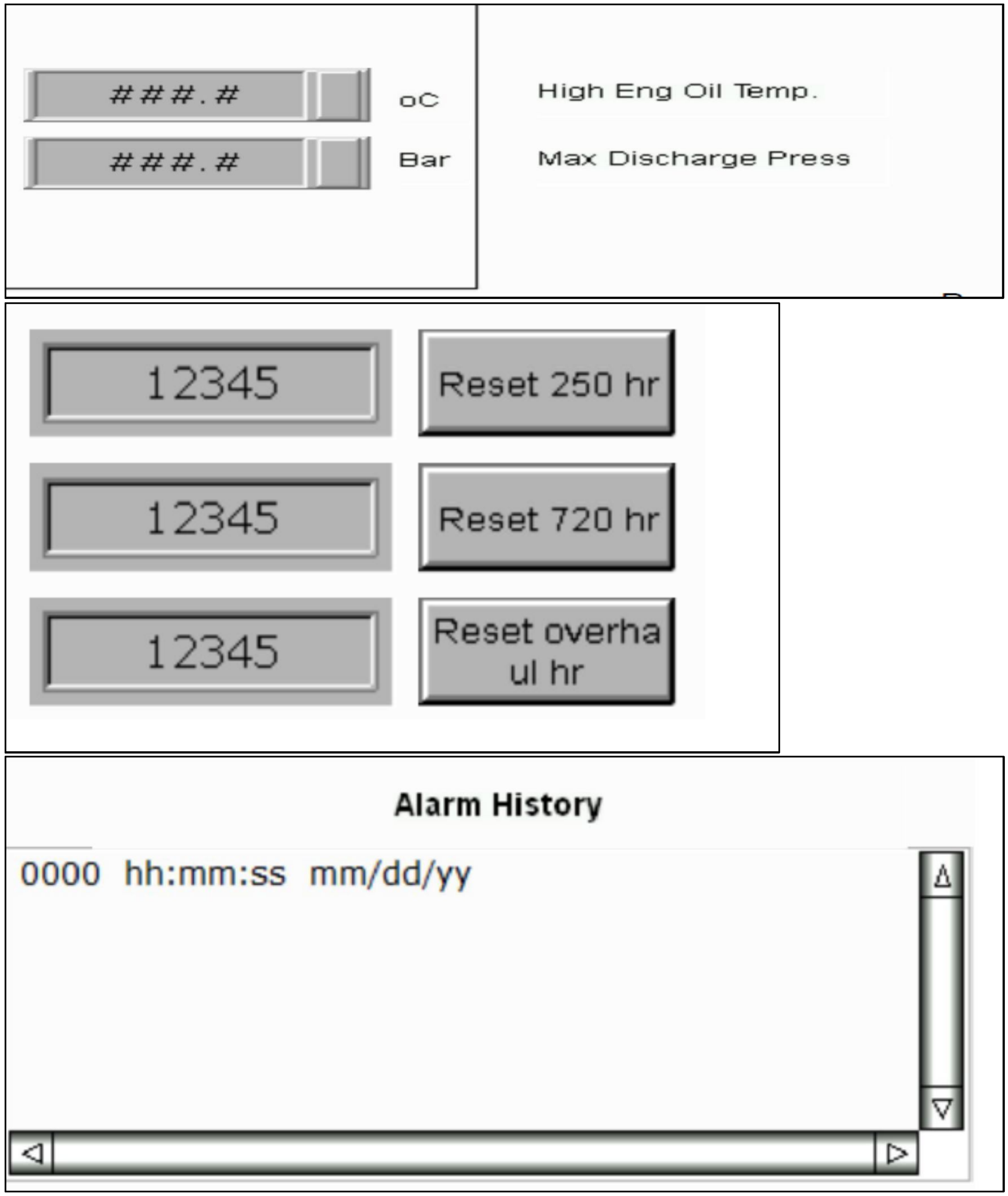



Discharge Pressure
123.4
clutch off
Air Pressure
123.4
Tank Level


Active Alarms
0000
hh:mm:ss
mm/dd/yy


###.#
Bar
###.#
Bar
###.#
oC
###.#
oC
#####
%
MIN ENG OIL PRESS
MIN AIR PRESS
HIGH ENG TEMP
MAX ENG TEMP
ENGINE OVERSPEE D PERCENT
Brightness


###.#
oC
###.#
Bar
High Eng Oil Temp.
Max Discharge Press
12345
Reset 250 hr
12345
Reset 720 hr
12345
Reset overha ul hr
Alarm History
0000 hh:mm:ss mm/dd/yy