# MONITORING SYSTEM FOR MAINTENANCE AND FAULT DETECTION ON BOOSTER PUMPS

Joshua Darry D. Buenaobra | Alfonso R. Enriquez
Adviser: Engr. Melanie Asuncion

**Keynotes:** *Covid-19*, *V&A law center*, *maintenance and fault detection*

**Abstract of the study**

Due to the effects of the COVID19 pandemic, the V&A Law Center faced problems due to government restrictions therefore limiting employees. This faced the risk of neglecting pump maintenance. Especially because of the pandemic, sanitary facilities need to be operable throughout the day to meet government requirements. In light of this, the proponents designed a pump monitoring system capable of maintenance and fault detection for their client at the V&A Law Center for one of their booster pumps. This system allows a thorough investigation and specific output of the equipment's status, which can detect irregularities, leading to a more automated response and reduced costs. The system also increases productivity and lessens the possibility of an unplanned system shutdown, ultimately saving costs for the establishment. To determine the practicality and functionality of the system, the proponents tested the device using an observation sheet, through a test of its accuracy of information and reliability. The results showed a 100% success rate, giving accurate alerts to the user for any abnormalities while in operation around the clock. The client's acceptability of the device was evaluated on a test-case sheet by invited technical experts. The data from test-case provided dichotomous data, which underwent statistical analysis from frequency tool and percentage calculation for further analyzation.

**Introduction**

During the ongoing COVID-19 pandemic, the V&A Law Center faced challenges due to government restrictions and staff shortages, leading to issues with the maintenance of crucial water pumps in the building. Regular maintenance of these pumps is essential to prevent costly repairs and ensure uninterrupted water circulation for sanitation purposes. To address this challenge, a pump monitoring system was implemented on two centrifugal pumps, known as booster pumps, located on the top floor of the building.

The pump monitoring system continuously tracks the condition of the equipment, alerts maintenance staff of any abnormalities, and can implement temporary troubleshooting measures in the absence of personnel. This system has proven to be a valuable tool in increasing maintenance efficiency, as it allows for easy detection and addressing of pump faults, reducing the risk of pump failure. Moreover, it provides real-time information on the pumps' status and can automatically switch pump activation if one of the pumps fails during operation. Overall, the implementation of the monitoring system has been effective in maintaining optimal pump conditions and ensuring their efficiency and longevity over time.

*Review of related Literature*

This section contains the necessary information researched by the researchers to be able to design the pump monitoring system for the submersible pumps at the V&A Law Center building along with the pump operation and the electronics required for the implementation of the system.

A. Automated Water Pump Systems

automating water pumps can reduce manual operations alongside maintenance. They are designed to operate without manual intervention and are equipped with various technologies to achieve this. One such technology is a pump timer, which allows the pump to run for specific periods of time and then stop. This feature is useful for circulating applications where the fluid needs to be pumped for a set amount of time to prevent settling. Another useful feature of automated water pumps is a batch meter, which ensures that the pump stops once a specific volume of fluid has been transferred. This technology is ideal for container filling applications and for adding a set amount of fluid/ingredient into a mixture. In addition to the batch meter, some pumps are equipped with a stroke counter, which counts the number of times air is ejected by the pump and can turn it off once a specific number has been reached. This feature is useful for batching and ensures that the amount transferred is accurate and repeatable. Castlepumps.com (n.d.)

Automated water pumps can have level/float switches that turn the pump on/off based on fluid level, dry run protection that turns off the pump when no fluid is passing through it, and leak sensors that turn off the pump when it detects fluid leaking from the pump, which is useful for pumps handling hazardous fluids or chemicals.

Automated water pumps can have variable speed drives to match the actual demand, remote monitoring systems to detect issues, and radio operated control pads for easy operation without manual intervention.

Automated water pump systems not only reduce manual operations but also improve pump system performance and efficiency. According to Olivieri, V., (2013) Advanced automation technology like programmable logic controllers (PLCs) can streamline electrical control, allowing for the monitoring of various metrics such as liquid level, pressure, temperature, flow, and pH. PLCs can communicate on multiple platforms and gather and report system operating data and performance information, displayed through human machine interfaces (HMI) or operator terminal interfaces (OTI).

By allowing precise control of the speed of AC electric motors and the speed of the pumps connected to those motors, variable frequency drives (VFDs) enable the pumping industry to meet hydraulic performance curve requirements without the need for bulky and cumbersome sheave/V-belt mechanical power transmission systems nor the need on trimming impellers. The PLC and VFD technologies have been combined to create intelligent drive systems that enable the VFD to monitor and manage applications involving one or more pumps. Previously restricted to machine tool and industrial manufacturing applications, electric motors are now used in a variety of settings. For instance, aeration systems for municipal sewage treatment plants use permanent magnet motors. When compared to more established technologies like treatment lagoon circulation/aeration pumps, turbine air pumps run at high operating speeds with high efficiency, creating great potential for electrical energy savings. The development of new water and wastewater technologies, such as pressure boosters, rainwater harvesting, reverse osmosis, membrane bioreactor, moving-bed bioreactor, and ceramic filtration systems, makes the marriage of these technological advances a necessity. (Hillsirrigation.com.au, n.d.)

B. Centrifugal pump and fault detection

Figure 1

*Pump system curve*

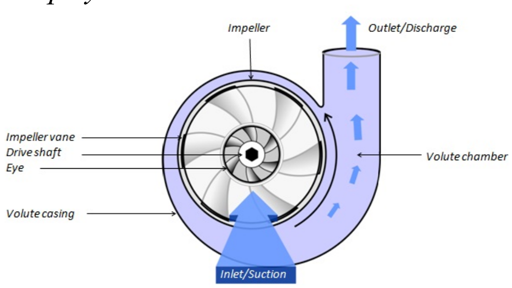



*Figure 2. Volute case design*

According to Michael Smith engineers (n.d.), it's a mechanical device that moves liquid using the key part called impellers as shown on figure 1, this series of curved vanes help to create a low-pressure area located inside the volute chamber driven by a shaft to extract water from the source.

Centrifugal pumps are commonly used in various industries and can pump not only water but also other liquids such as solvents, oils, organics, bases, and acids. After priming, the pump's shaft is driven by the rotor to rotate the impeller, which typically spins at 500-5000 rpm. The liquid then rotates inside the volute chamber and is discharged. When the liquid hits the volute chamber, kinetic energy is transformed into potential energy or pressure, and low pressure at the impeller's eye pulls more liquid in through the suction/inlet to increase the flow rate due to the conversion of water inflow to pressure. (Evans, E., 2020).

A monitoring system is valuable in pump maintenance as it can identify faults before they occur through collecting specific data from the pumps and using algorithms to provide feedback to the operator. It is important to identify where the cause of a potential fault might happen in the long run. Important data points for monitoring include tank pressure, water running time, water level, and motor amp readings.

With these readings, activation failure or tank condition can be observed and monitored in order to identify faults in the system before it occurs. There are also other faults that could be detected such as vibration fluctuation caused through cavitation. It is interesting to note that there are specific vibrations that can be recorded and recognized if there is a problem with the internal working of the pumps itself. This could prove beneficial as some of these faults require the entire operation to be shut down, enabling inspection through partial disassembly. Having to know there is a fault without disassembly inspection maintains run-time operation, decreasing inconvenience and expenses from the company as well as increasing equipment efficiency and productivity (Long, 2021).

C. Pump Switching Mechanism with Alternating Relay

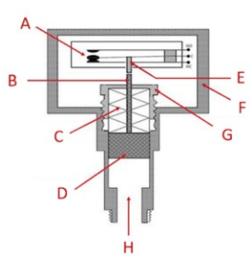
According to Evans (2021), the reason to duplicate equipment being installed in high-rise residential, industrial plants, commercial buildings, and utility infrastructures is to create a stand-by if the other fails to take over. As mentioned earlier, relays are electromechanical switches, and among the other relays that the proponent would be using is an alternating relay. This would be used to switch operations between the two (2) centrifugal pumps, to be specific the model Schneider Electric Control Relay - 2NO + 2NC, 10 A F.L.C were used to alternate between the two pumps.

D. Pressure Switch for Automatic Water Pump Activation

The proponents made use of a pressure switch to do the automatic operation. According to the product article of Tameson (n.d.), pressure switches are devices that make use of electric contact in the condition that the preset pressure level has been met. It's generally used in HVAC (Heating, Ventilation, and Air conditioning) systems, well pumps, furnaces, and more. It works when an inlet pressure pushes the piston inside with known spring resistant force which then triggers the microswitch between the NC and NO position through an insulated trip button and operating pin.

Figure 3

*"The components of a pressure switch include"*




*micro-switch (A), operating pin (B), range spring (C), operating piston (D), insulated trip button (E), switch case (F), trip setting nut (G), inlet pressure (H)."*

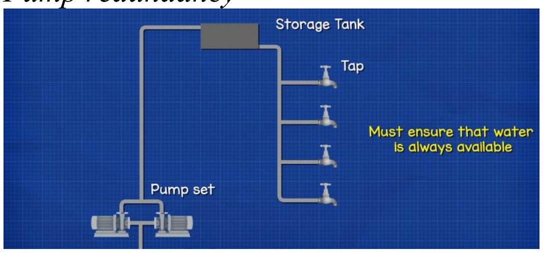
For mechanical pressure switches like figure 3, the switch points on how high or low the pressure is adjusted by troubleshooting the trip setting nut, while electronic types have keypads for adjustments. It's important for this pump monitoring system since the design of the proposed control system has an automatic operation. Using the pressure switch in detecting pressure levels the device shall be able to use the two (2) booster pumps selected by the alternator relay, it operated in response to the current flowing whenever the pressure switch NO contactor is high. Additionally, this keeps the water tank supply sufficient and avoids flooding on floors or halting its operation due to an empty tank.

E. Load Alternator Relay for Duplex Pump Systems

In various types of buildings like commercial, high-rise residential, industrial plants and utilities infrastructure, we commonly find duplicate mechanical items such as fans, compressors, and pumps. As shown figure 4 buildings such as commercial, high-rise residential, industrial plants, and utilities infrastructure, it's common to have duplicate mechanical items like pumps for added safety in case of malfunction or failure. A duty and standby pump set is used to ensure a constant water supply where two pumps are connected to the same pipe but only one operates at a time, and the standby pump takes over if the duty pump fails. Additional standby pumps may also be available depending on the criticality of the pumping system. Alternating relays manage the pumps and switch between the duty and standby pumps. (Evans, P., 2021)

Figure 4

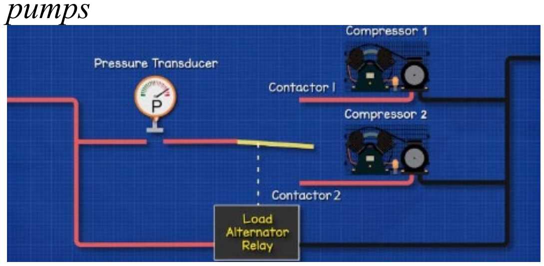
*Pump redundancy*




However, According to Broyce Control (2021), Alternating relays are used to control and distribute the workload between pumps, compressors, and other machines. They require only one input to control two connected loads or outputs. The input control, which is usually an open voltage-free contact, starts and stops the first pump. The second pump starts running when the input contact closes the second output relay contact. Each time the input contact opens and closes, the operation of both pumps alternates. If the demand from the application is too high for one pump to handle, a second contact can be connected to the inputs to start both pumps simultaneously.

Figure 5

*Load Alternator relay to control the pumps*




Because of this, a load alternator relay is necessary for a duplex pump system as shown on figure 5. Duplex pumps are commonly used in both single and dual acting designs, and they are often preferred over other reciprocating pumps because of their simpler design and advantages over simplex pumps. (Powerzone.com, n.d.) Therefore, a load alternator relay is necessary for duplex pumps because it allows for the efficient and effective control of the two pumps. With duplex pumps, it is important to alternate between the duty and standby pumps to ensure that both pumps wear evenly and remain operational in case of a failure. The load alternator relay provides a simple and reliable method for switching between the pumps, ensuring that the workload is evenly distributed and the system runs smoothly. Without this type of relay, the operation of the duplex pumps would be more complex and less reliable, leading to potential issues with system performance and maintenance.

F. GSM over Wi-Fi Network

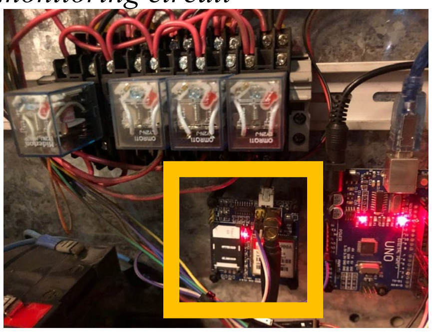
According to PUSR IOT (2020), Wi-Fi modules are devices used for wireless communication in IoT applications, allowing serial or TTL-level data to be converted into WiFi-compatible data that can be transmitted over a wireless network. It is equipped with a built-in IEEE802.11 B.G.N protocol stack and TCP/IP protocol stack, making it compatible with standard WiFi networks. WiFi modules are essential components for enabling wireless connectivity in IoT applications, especially for smart homes, M2M communication, and other IoT applications.

GSM Modules on the other hand are chips or circuits used to establish communication between a mobile device or a computing machine and a GSM system. It is composed of a GSM or

GPRS modem, powered by a power supply circuit, and communication interfaces (like RS-232, USB 2.0, and others) for computers. (Electronicsforu.com, 2021)

Figure 6

*Sim module, coil Relays, Arduino within the monitoring circuit*



GSM as shown on figure 6 is a widely used standard in cellular communication networks. Wireless data transfer is made possible by GSM modules, which are lightweight, simple to use, and consume little power relative to the work they can accomplish. These modules can be applied in a variety of applications, such as tracking communication projects, connecting remote site monitoring systems with LANs, and more. A GSM module is a specialized gadget that utilizes a SIM card and runs on a mobile operator subscription, much like a cell phone or pager. A GSM modem resembles a phone from the standpoint of a mobile operator. The versatility of applications is what separates a module from a cell phone. Since cellular connections don't require a particular membership to a different service provider, they can be a quick and effective approach to begin using SMS notifications in network monitoring solutions. In most parts of the world, GSM modules are a cost-effective solution for sending and receiving alarm notifications since they utilize existing networks instead of requiring expansion of infrastructure to include hardware that allows direct connections with remote sites. (DPSTelecom, n.d.)

Although both Wi-Fi and GSM modules have their own advantages and disadvantages. Wi-Fi modules are easy to use, have strong signals, and support all Wi-Fi-enabled devices. (Mustafa, A., 2022) However, they require maintenance, need to be charged, and can be damaged easily. On the other hand, GSM modules are cost-effective, require less maintenance, and have good signal strength in both rural and urban areas. They accept a SIM card and can be used for tracking communication projects and linking remote site monitoring systems with your LAN. However, they only support smartphones and a limited number of SIM-compatible tablets and laptops. Considering the scope of the project, which involves sending and receiving alarm notifications, GSM modules would be a more preferred choice as they do not require a special subscription to a separate service provider and can utilize existing networks. This makes them a quick and efficient way to get started with SMS notifications in network monitoring solutions. Moreover, GSM modules are more cost-effective than expanding infrastructure to include hardware that allows direct connections with remote sites.

H. C and Arduino Programming

As the monitoring system that the proponents are making requires the use of a multitude of electrical components, it would come hand in hand that the monitoring system along with the control circuit provided that the use of a microprocessor would be necessary. The programming language that would be registered into these microprocessors and microcontrollers make use of the C language. Because of the nature of the system, the C language gives for excellent use of memory capacity and is executed in stages. It is also the preferred language with which the proponents are familiar, thus executing the program with great familiarity and precision. (Programiz, n.d.)

Arduino integrated development environment (IDE) also known as Arduino software contains a text console used in editing or writing a code, auxiliary toolbar with buttons for common functions and a series of menus. It connects the hardware and the software for communication so a user can upload the program into the microcontroller exclusively to arduino. (Arduino, n.d.) A related study by Howedli et al. (2016) proposed a design in implementing a prototype of a smart house system using an Arduino IDE, at the end of their study the implementation successfully integrated the hardware composed of controlling and monitoring module and software of the system by using it. Arduino IDE Coding was needed to have the microprocessor and microcontrollers communicate with the rest of the electrical components as most of the programming only involve fault detection, control over the switching and activation of the pumps, and the alert protocol to notify the operator in light of system malfunction or a system data report for maintenance. LiquidCrystal_I2C by Frank de brabander was used due to the proponent's familiarity with the library. (Arduino.cc, n.d.) while Emon Library by OpenEnergyMonitor is needed in order to properly use the sensor and was used due to familiarity of the proponents (Arduinolibraries.info, 2016)
This information can prove vital to the longevity of not only the motor current of the pumps but the entirety of the pump's operation. Having the ability to identify said faults, especially within the motor, can improve the performance of the pumps and can quickly adjust to the specifications of the standard regulations for pump operations given to the building.

I. Pump Monitoring System

Failure to maintain the water pump's working condition can wear out the equipment in the long run which could eventually lead to total failure. Not only would this be very costly to replace, but it can also bring disaster to the rest of the floors of a building. A pump monitoring system gives a plethora of advantages and benefits to the entire pump's working operations. Although installing a monitoring system to a pump can be quite costly, having to spend quite a hefty amount, it did the company good installing one in the long run as it monitoring systems are placed in order to control pump operations temporarily so as to switch to an automatic solution and alert operators in order to properly assess the problem and attend to. With a pump monitoring system in place, it is able to detect faults in the pump's operation, giving data reports to the operator in order to accurately pinpoint the cause of the problem. With a monitoring system in place, it can help increase the productivity of the equipment and extend its lifespan. (Pumps & Systems, 2019)

Figure 7
*Monitoring system monitoring factors*


Pump monitoring system does not have a standard installation method as there are different types of pumps and every establishment has a different system put in place in order to manage pump operations. In order to achieve its purpose, several sensors are put into place on the specific pumps. Some of the factors that are to be monitored are presented at figure 7. Although the image provided is not the actual pump that the proponents would be working with, it gives a good representation of what usually tends to fail for finding faults in the system.

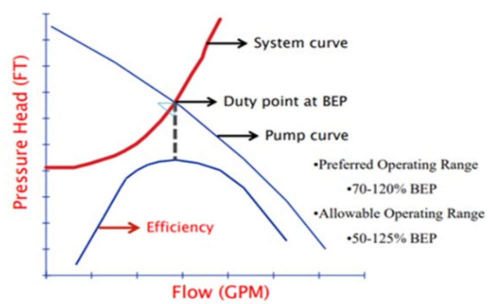
J. Maintenance for Centrifugal Pumps

Maintenance is an important part of maintaining pump operations. As there are many different types of pumps, there are also different types of maintenance procedures for each of these. To set up a monitoring system for the client's building pumps, it is important to know the equipment's specific maintenance as well as the building's maintenance protocol.

According to Syan et al., (2020) there are two (2) major types of maintenance done on centrifugal pumps. The first type of maintenance is corrective maintenance is used when an unexpected breakdown occurs. The latter preventive maintenance which uses Condition-based maintenance (CBM) techniques applied in monitoring pump operations like lubrication analysis, infrared thermography, and motor current signature analysis.

To Ensure the pump's working condition, it is important to check the system's reading such as motor current or amp readings, motor winding resistance, leakage, motor winding problems through resistance checks, Motor insulation, megger readings to determine insulation degradation, impeller condition, etc. These are some of the factors that determine the system curve in contrast with its duty point. (Kernan, n.d.)

Figure 8
*Pump system curve*




*Note*. For the pump system to remain in optimal condition, it is important to maintain the pump's duty point to be near its best efficiency point as shown for example in figure 8.

When these things are checked, it becomes easier to pinpoint the faults of the system which is why these points are some of the points of focus for installing a monitoring system. Having connected sensors and other electronics to the pumps, it is also important to connect them to a singular point at a control circuit where they would feed the monitoring circuit the specified data it needs to alert the operator and temporarily correct the problem to prevent further damage from occurring in the system.

The Tendency of Pressure Switch Failure and Water Run Time Implications

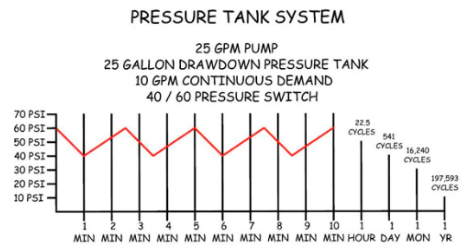
As operations for a functional booster pump require automation, the booster pumps that are the subject of this project have their automatic mode for switching and activation rely mostly on the pump's pressure switch. According to Waqar (n.d.), Booster pumps increase water pressure and flow in low-pressure areas such as tall buildings, but relying on pressure switches for automation may lead to problems and implications for water running time.

` The automation mechanism in booster pumps is controlled by the pressure switch, which is set to a specific range (20-40 psi) by the management in accordance with water pump regulations. If the pressure falls below or exceeds this range, the mechanism will activate the pump until the pressure is restored to the designated range. But in accordance with what was observed along with an article from Advanced Pump & Well (2018), pressure read from the pressure switch may lead to complications to the pumps that could potentially prevent the pumps from shutting down. According to Advanced Pump & Well (2018), Complications such as foreign material or rusted components can cause a malfunction in the pressure switch, while weak water pressure can bring the pressure switch into a state of balance in water flow, resulting in continuous water running time. (Inspectapedia.com. n.d.).

If the pressure switch were to fail in alerting the system to shut down and continue water run time, it could potentially wear and damage the pumps which would prove costly upon repair or replacement.

Figure 9

*Pressure Tank System Cycle*




As shown in Figure 9 above is an example of a water cycle but at 40/60 pressure, water running time in pumps usually comes in cycles as the water pressure is expected to increase and decrease as time goes by leaving regular intervals as to when are the optimal times for pump operations to resume. But with a 20/40 pressure switch, the chart is easily scalable as with a 50/70 depending on the tank and capacity of the pumps, with a pressure of 40 psi, water running time is to start until water pressure decreases until it reaches below or within the set pressure range. (Cyclestopvalves.com, n.d.)

As the proponents would be implementing a monitoring system for the booster pumps, it is important to take into consideration the implications of water running time and how to include this fault within fault detection parameters and automate a temporary solution as part of the design. In doing so would be a part of the proponent's objectives, therefore satisfying the client and the management.

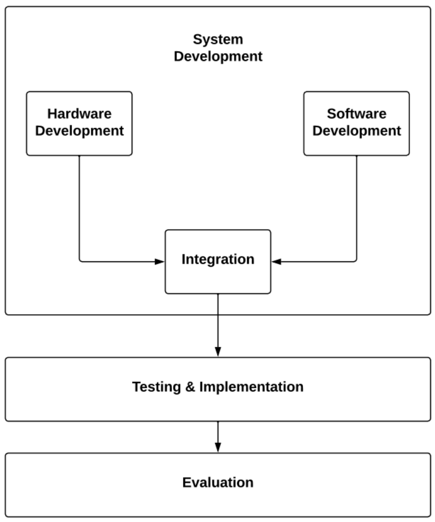
**Methods**

In this study the proponents used developmental research to meet the objectives set by the beneficiary of this study at the V&A Law Center Building.

Specifically, a 3-phased block diagram as shown in figure 10 was used by the proponents to show the development of the device. Each described below:

Figure 10

*Block diagram of the study*




*System Development.* whereas the proponent includes the prototyping process separately assemble the monitoring and the control circuit and lastly the Arduino program for the microcontrollers, they're then integrated to create a pump monitoring system.

*Testing and Implementation.* In this stage the proponents started with the integration of the device to the two booster pumps on the locale. During also this experimental phase the proponent's gathered data using an observation sheet.

*Evaluation.* In this phase the acceptability and functionality were tested through the selected technical experts or respondents.

*Objectives*

1. To construct the circuitry and hardware of the device in terms of.
   a. Monitoring Circuit
      a.1 Arduino UNO
      a.2 AC Voltage Sensor
      a.3 Coil Relays
      a.4 SIM900A GSM Mini Module
      a.5 20x4 I2C LCD
      a.6 Generic SMPS Power Supply
      a.7 SLA Backup Battery
      a.8 PC Cabinet Fan
   b. Control Circuit
      b.1 Magnetic Contactor
      b.2 Alternating Relay
      b.3 Overload Relay
      b.4 Auxiliary Contact
      b.5 Pressure Switch
      b.6 Selector Switch
      b.7 LED Indicator
2. To develop a program for the monitoring circuit connected to the control circuit and integrate it to the hardware.

3. To test the performance of the device according to:
   a. Accuracy of data displayed on LCD and message sent through SMS.
      a.1. Main Breaker status indicated by voltage status
      a.2. Individual pump activation status
      a.3. Individual pump fault detection
   b. Reliability of fault detection on:
      b.1. Voltage drop or spike
      b.2. Water running time
      b.3. Water pump motor trip
4. To determine the technical expert and the client's acceptance of the

device via test-case sheet and evaluation to the following:

a. Control Circuit
b. Monitoring Circuit

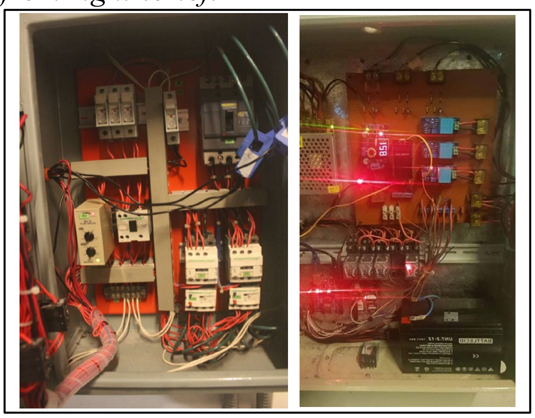
**Results**

Below are the results made following the objectives stated in the first chapter of the study.

*1. Construction of the circuitry and hardware of the device.*

Figure 11

*Control Circuit and Monitoring circuit from right-to-left*



The device consists of two separate systems: the monitoring circuit and the control circuit. The monitoring circuit collects data on parameters such as voltage, temperature, and operation length using an Arduino Uno microcontroller, AC voltage sensors, 24V coil relays, and a 20x4 LCD display for easy monitoring. The data can also be sent remotely via an SMS module to a pre-programmed phone number. The monitoring circuit is powered by a 12VDC 5A power supply connected to a circuit breaker and a backup 12V 7.2Ah SLA battery, with a step buck converter regulating the voltage supplied to the SMS module. Fans are added for system cooling.

As shown in figure 11, the control circuit is responsible for controlling the operation of the pumps in the device. It uses magnetic contactors to control the flow of electrical power to the pumps, overload relays to protect against overheating or overloading, and alternating relays to alternate the operation of the pumps to ensure equal wear and tear. A pressure switch is used to detect the pump level for automatic operation based on tank pressure. Selector switches allow for manual, automatic, and off operation modes, with LED indicators providing visual feedback on the status of each pump.

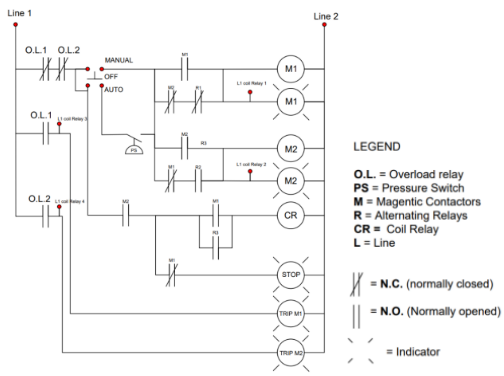
*2. Connecting the monitoring and control circuit into one pump monitoring system, integrating the hardware and the software.*

The pump monitoring system integrates both the hardware and software components, specifically the monitoring circuit and control circuit, to ensure smooth operation of the pumps. The control circuit regulates the pump's operation and condition, while the monitoring circuit uses sensors to detect any faults or abnormalities through the control circuit. This allows for automated response measures such as reporting status and temporary troubleshooting methods.

The hardware components of the system include a microcontroller, four relays, a SIM module, a 20x4 LCD, and an AC voltage sensor. The relays are connected to specific parts of the control circuit based on their functions related to sensing Pump 1, Pump 2, Pump 1 Fault, and Pump 2 Fault. The SIM module is connected to digital pins 2 and 3 for communication, and its configuration in the code includes setting the phone number and message to be sent for different triggers. The 20x4 LCD is connected to the SDA pin for display, and the AC voltage sensor is connected to an auxiliary pin for detecting voltage.

Figure 12

*Control Circuit diagram*




The connection between the components is strategically made to respond to system faults and abnormalities. The relay connections are shown in Figure 12, indicating the normal operations of the pumps, as well as the paths for different states of the selector switch (Manual, Off, Auto). In case of a fault detected by the overload relay, the pump with the fault will be tripped and its function will cease, while the other pump will take over the operation if the selector switch is set to auto.

Overall, the pump monitoring system integrates the hardware and software components to ensure smooth and efficient operation of the pumps, while also providing temporary troubleshooting measures in case of pump failure.

*3. Testing the performance of the device.*

The performance of the device was tested based on two critical parameters: accuracy of data displayed on LCD and messages sent through SMS, and reliability in detecting faults. Accuracy is important to ensure that the data displayed and messages sent are reliable and precise, as any discrepancies can lead to incorrect results. Fault detection is crucial for the device's function as a pump monitoring system, especially in critical applications where minor errors can have significant consequences.

Table 1

*Accuracy of the alerts from SMS and LCD*

| *Accuracy Test* | Frequency | | Percent |
|---|---|---|---|
| | Pass | Fail | |
| *Voltage* | 3 | 0 | 100.00% |
| *Water running Time* | 3 | 0 | 100.00% |
| *Pump Trips* | 3 | 0 | 100.00% |
| ***Total*** | n = 3 | | 100.00% |

Table 1 shows that the device passed all three trials for accuracy of data displayed on LCD and messages sent through SMS for various fault detection scenarios, including voltage status, individual pump activation status, and individual pump fault detection. This indicates that the device provided accurate reports for both the LCD display and SMS, reaching satisfactory results.

Table 2

*Quick reference on observation test of the device reliability*

| Faults | SMS | Pump Switch | Pump Shutdown |
|---|---|---|---|
| None | None | N | N |
| Voltage Drop / Spike | Sent | N | Y |
| Tripped | Sent | Y | N |
| Pump 1 and 2 tripped | Sent | Y | Y |
| Water running for 300 s | Sent | N | N |

Table 3

Results of reliability of the Fault detection from Observation sheet

| Day | Pump no. | status | Pump Condition | Fault Detected | Time | SMS Alert | Pump switched | Pump Shutdown | Result |
|---|---|---|---|---|---|---|---|---|---|
| Day 1 12/18 | 1 | Normal | - | - | - | - | N | N | Pass |
| | 2 | Normal | - | - | - | - | N | N | |
| Day 2 12/19 | 1 | Normal | - | - | - | - | N | N | Pass |
| | 2 | Normal | - | - | - | - | N | N | |
| Day 3 12/20 | 1 | Normal | - | - | - | - | N | N | Pass |
| | 2 | Normal | - | - | - | - | N | N | |
| Day 4 12/21 | 1 | Fault | Voltage Dropped | Main breaker Fault | 14:07 | Sent | N | Y | Pass |
| | 2 | Fault | Voltage Dropped | Main breaker Fault | 14:07 | Sent | N | Y | |
| Day 5 12/22 | 1 | Normal | - | | - | - | N | N | Pass |
| | 2 | Fault | Tripped | Tripped | 16:05 | Sent | Y | N | |
| Day 6 12/23 | 1 | Normal | - | - | - | - | N | N | Pass |
| | 2 | Normal | - | - | - | - | N | N | |
| Day 7 12/24 | 1 | Normal | - | - | - | - | N | N | Pass |
| | 2 | Normal | - | - | - | - | N | N | |

Reliability of fault detection was tested over a span of seven days for observation and evaluation. The device should be able to respond to abnormalities of the pumps by sending alerts to the user, displaying faults, and performing temporary troubleshooting methods. Table 3 shows the activity of the device over the seven-day testing period, indicating whether the device is fit to operate for a long period of time while performing its intended function with the programmed protocols.

Table 3 shows that a fault occurred on the 4th and 5th day of testing, including a voltage drop and pump trip. However, the device detected these faults accurately and executed proper protocols according to Table 2, resulting in successful operation and passing the test. The remaining days continued with normal pump operations, achieving satisfactory results with 100% reliability of the system, able to send accurate and timely reports along with proper execution of protocols according to the detected faults.

Additionally, during ongoing operations of the pump monitoring system after testing, a fault was detected on February 3, 2023, related to power fluctuations in the building. The device was able to send alerts despite the power outage, indicating an unexpected function of alerting power failures not only for the pumps but also for the building itself, due to the backup battery of the monitoring system.

*4. Acceptance of the device from the client and technical experts via test-case sheet and evaluation.*

The acceptance of a device goes beyond just its proper functioning; ease of operation from the user's perspective is also crucial. A device that is difficult to use or requires extensive training may not be practical or useful, and may not be adopted by the user. To evaluate the ease of use, the device needs to be tested from the user's perspective, and the results of these tests determine the acceptability of the device from both technical experts and the client.

Figure 13

*Test-case sheet response in google forms*


Video: **Control Circuit (CT3 & CT4)**

Test-case sheet: **Control Circuit (CT3)**

| Test Case ID | Test Scenario | Test Step | Test Data | Expected Result | Actual Result | Pass/Fail |
|---|---|---|---|---|---|---|
| CT3 | Check if the customer can use the pump using automatic operation | Set Selector switch to automatic | Selector switch – “Auto” state Pressure switch = “1” | The user is expected to be able to use the pumps automatically because of the pressure switch | | |

☑ Pass
☐ Fail
☐ Other:

The test-case sheet via G-forms shown in figure 13 was used by the technical experts to evaluate the device is composed of two parts labeled CT and MT. CT evaluates the control circuit, while MT evaluates the monitoring circuit. The test results are recorded as acceptance rates, with 100% acceptance rate indicating maximum acceptability.

The MT tests, which evaluate the monitoring circuit, showed a 100% acceptance rate, indicating that the device is intuitive and user-friendly in terms of visualizing the status of the pumps, receiving message alerts for status reports, and temporary troubleshooting protocols. Similarly, the CT tests, which evaluate the control circuit, also recorded a 100% acceptance rate, indicating that the device is easy to use in terms of shutting down the system, interacting with individual pumps in manual state, setting the system's state to automatic, operating the system automatically based on temperature changes, and sending message alerts for voltage abnormalities.

Overall, the device has passed the acceptability benchmark in terms of ease of operation, as all the tests recorded a 100% acceptance rate. This indicates that the device has been successful in achieving its intended purpose and is likely to be accepted by both technical experts and the client.

**Discussion**

Below are the summary of findings made following the objectives stated in the first chapter of the study.

1. The study focuses on the construction of the circuitry and hardware for a Monitoring System for Maintenance and Fault Detection on Booster Pumps. The design consists of two separate systems: the monitoring circuit and the control circuit. The monitoring circuit uses multiple sensors, including AC voltage sensors, to detect potential faults in the system. It is powered by an Arduino Uno microcontroller that processes incoming data and displays them on an LCD screen while sending alerts through SMS. To ensure continuous operation, a backup battery is installed. Fans are added to regulate the temperature of the components. The control circuit allows for manual and automatic operation of the pumps, with high-powered relays, auxiliary contacts, and overload relays coordinating the flow of energy and detecting abnormalities.

2. The study successfully integrated the monitoring and control circuit of a pump monitoring system using an Arduino Uno microcontroller as the central component of the monitoring circuit. The code was developed using the Arduino IDE and C language, with additional libraries added for operating additional modules such as an I2C LCD display and an Emon library for the AC voltage sensor. Coil relays were used to connect the monitoring circuit with the control circuit, including relays for each pump, overload relays, and AC voltage sensor. Additional relays were attached to the overload relays to connect pump 1 to pump 2, enabling power redirection in case of pump tripping to ensure continuous operation of the system.

3. The study tested the accuracy and reliability of the device by conducting trials in three categories: voltage status, individual pump activation status, and individual pump fault detection. The device achieved a 100% success rate in accurately detecting and assessing faults as per its programmed criteria and relaying information through the LCD and SMS. Additionally, the device was left to operate for 7 consecutive days to gather data in real emergency scenarios. During this period, the device successfully detected and alerted the user of two faults, including a voltage drop and a pump trip, and was able to continue pump operation through pump switching. The device also exhibited an unexpected function of detecting power fluctuations in the building, which was diagnosed as an issue with the main power supply rather than the pumps, resolving the problem promptly.

4. The study evaluated the acceptability of the device using a test-case sheet, which was assessed by technical experts and the client. The test-case sheet assessed the ease of operation

and functions of both the monitoring and control circuits of the device. The results showed a 100% total acceptance rate for both the monitoring circuit and control circuit, meeting the criteria within the average acceptable completion rate of 78% as per Sauro (2011).

**Conclusion**

Below are the conclusions made following the objectives stated in the first chapter of the study.

1. The study successfully designed and constructed the monitoring and control circuits for the Monitoring System for Maintenance and Fault Detection on Booster Pumps. The monitoring system was able to detect different faults in the system and display pump conditions through LCD and SMS. The control circuit was able to control pump operations manually and automatically, triggering relays and implementing temporary troubleshooting measures.

2. The connection of the monitoring circuit with the control circuit was successful, allowing the monitoring circuit to gather data from the control circuit through the relays and sensors. The software was integrated into the hardware effectively, enabling analysis of incoming data from the sensors and relays, visualizing assessed information, and prompting the programmed course of action for alerts and fault detection. This indicates that the integration of the hardware and software components of the pump monitoring system was successful, and the system is able to effectively monitor and control the pumps, detect faults, and initiate appropriate actions for alerts and troubleshooting.

3. Based on the testing results, the proponents concluded that the device displayed accurate information through SMS and the LCD, achieving a 100% success rate in detecting and assessing pump faults, individual pump activity duration, and voltage abnormalities. The device was also found to be reliable for long-term use in real emergency scenarios, as it was able to operate continuously for 7 days, detect faults, and initiate temporary troubleshooting procedures. The device's performance indicates its potential for effective monitoring and control of pumps in various scenarios, providing reliable and accurate information for prompt actions and ensuring smooth operation of the system.

4. Based on the evaluation by ten technical experts, including the client, through the test-case sheet, both the monitoring circuit and control circuit of the device were found to be acceptable, demonstrating ease of use and accomplishing their programmed tasks and functions. s. The device performed within the accepted standard based on the statistical treatment of acceptability benchmark to 70% minimum and 100% maximum. Regarding the proponent's monitoring system as a practical and efficient product.

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