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Design and Simulation of a Multi Tank Water Level Controller

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ABSTRACT:
In this study, a multi-tank water level controller was developed using the Arduino Nano microcontroller board as the PLC of the system. The use of this PLC allowed for flexibility of control, display and reduction of human inference in operating the system. A hydrostatic pressure based approach was adopted in measuring the volume of liquid in each of the six tanks. Six MPX4115 pressure sensors were used in obtaining the pressure in the tanks. The outputs of these sensors are fed to the analog input of the Arduino Nano (PLC). These inputs are calibrated to a scale of 100% to give the volume of liquid in the tanks. The volume of liquid in each individual tank is used in controlling the supply valve of that tank when filling. When the volume of liquid in a tank is less than 80%, the valve is opened to allow for filling, and closed at 80% full. The volume of each of the six tanks is summed to give the volume of liquid in the entire system. This volume controls the borehole pumping machine.
Keywords: Programmable Logic Controller (PLC), Arduino Nano, Multi tank, Water level controller, MPX 4115.

1. INTRODUCTION:

Basic tank water level control utilizes 2 control circuit switches; one low water level switches that makes to ON the filling borehole pump and one high water level switch that breaks contact to shut OFF the borehole pump power source. With this control, the level and volume of water in the tank between these two control points is not known. This simple design is ideal for a one-water Tank system, consequently, this water tank must be sufficiently big to meet the estate or building's water demand.Because conventional storage water level control assumes that the storage unit is ONE tank, most estate now resort to manual operation in refilling of the water in a multi-tank utility system.

This project aims to control the water inflow and storage in 2-8 tanks using one Arduino Nano programmable logic controller.The level in each tank is calculated by sensing the pressure due to the height of water column, that is, the hydrostatic pressure head of the water column. Each tank will have a 0 -3psig MPX4115 pressure sensor attached to it at the base to sense the hydrostatic pressure due to the water height within the tank.With the pressure sensed and inputted as a voltage signal into the analogue input of the Programmable Logic Controller (PLC), the height of water in that particular tank and hence its volume is calculated and displayed as a percentage.

Several attempts have been made by previous researchers in developing tank water level control systems.

Anyanwu (2012) in his work used MC14066 integrated circuit to realize automatic regulator suitable for water level sensing and control. This water level sensor was tested in real time application by using it to control the level of water in a tank fed by a single phase 0.5 HP AC pump. This system recorded inaccurate volume calculation and display due to limited sensor capabilities.Again, it is still limited to one tank per sensor per Arduino.

In the works of Asaad et al. (2013), Arduino was used in automating the process of water pumping into a tank by detecting the level of water in the tank per time using a floating water level sensor. This sensor was designed out of a floating material attached to the arm of a potentiometer. The system had the ability to detect the level of water in a tank, switch on or off the pump accordingly and display the status on an LCD screen.This system was limited to 12v pumps therefore making it unsuitable for industrial or domestic application.

Erua & Anyasi (2014), developed a closed loop automatic water level controller using a mercury float sensor. Their system incorporates two mains contactors which are energized to provide a direct online start of the motor. An over load relay which senses the presence of excess current and disconnect the supply and a mercury flood switch which uses the Archimedes principle of floatation to provide the electrical contact to switch ON or OFF supply to the motor when the tank is empty or full respectively. This was capable of providing a seamless utilization of water at domestic and industrial level without causing spillage. This controller is not feasible for application in residential homes as the mercury float sensor used is expensive and not readily available.

Yuriy et al. (2015) designed a PLC based system to control liquid level by using Radar sensor remotely. This system measures the liquid level, volume, temperature, and pressure and controls these measurements remotely. The system consists of the Radar sensor, temperature sensors, discrete level sensors and a programmable logic controller.

Alam (2016), developed an Automated Water Pump Controller (AWPC). This system used three water level sensors to monitor the water level of both the ground-level water reservoir and the rooftop residential water tank. Once the supply of water decreases down to a point of concern, roughly 10% of the tank capacity, the controller turns off the water pump. This prevented the water pump from siphoning air which can result in the water pump's malfunction or complete breakdown. Similarly, the controller turned off the water pump when the rooftop tank reached a water level of greater than or equal to 95%. This prevented the tank from overflowing and wasting water.

Considering the works of previous researchers reviewed in this chapter, the automatic water level controller and pump controllers developed thus far fail to address the issues of presenting a graphic indication or display of the volumetric amount of water present in the tank being studied or controlled per time. They also failed to develop water level controller systems which could be applied in a multi-tank system where the pump and filling of the different tanks is dependent on the collective average volume of water in all tanks and independent of the level of water in another tank respectively.

This project looks at automating the water filling and availability aspect. It provides a system that can measure, to reasonable accuracy, the quantity of water used by a small community.The system designed in this work is one which intends to solve the afore mentioned challenges by developing a multi-tank water level controller, which can effectively control the pump (supply) of water to six tanks. This is to be based on the cumulative average volume of water in all six tanks. Also, in this system, filling of each tank is independent of another tank as separate valves are to be used in controlling the supply of water into each tank. This work intends to achieve this using an Arduino Nano, six MPA4115 pressure sensors, a pump, and six/eight valves. This work is to be designed and simulated on the Proteus professional Suite environment, with the program governing the system developed on the Arduino IDE.

2. MATERIALS AND METHODS:

The volume of liquid in a vessel of measure level depends solely on the shape of the vessel. For the proposed study, cylindrical water Tank is assumed to be used. A typical tank used for water storage in Nigeria is cylindrical in shape and has height of up to 8 feet.

Considering a typical tank as shown in Fig 1, Mathematically, therefore, the volume of water V in the tank will be

$V = h * \pi * \mathrm{R}^2$ (1)

Where h is the height/level of water in tank, π is 3.142 and R is the Radius of the cylindrical tank.

Since R, radius of tank and π are constants, the volume therefore varies directly with the height/level.

Putting $h = p/\rho g$ in equation 3.3 will give

$V = p * \pi * \mathrm{R}^2/g$ (2)

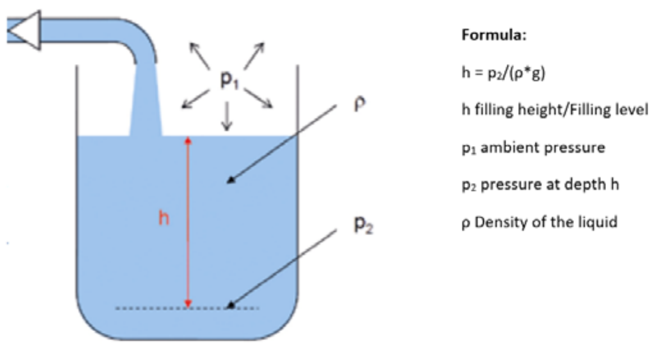

Fig 1: Pressure Exacted at the Base of a Container with Liquid Level h.

2.1 Mathematical Model for Tank water inflow/outflow.

Modeling of a real time cylindrical tank which exhibit non linearity property will be considered in this research work.

This mathematical model of a cylindrical tank is gotten by considering two variables namely; the control variable and the manipulated variable. While our desired level will be the control variable, the manipulated level is the inflow to the tank. We can get this by controlling the input flows to the tank.

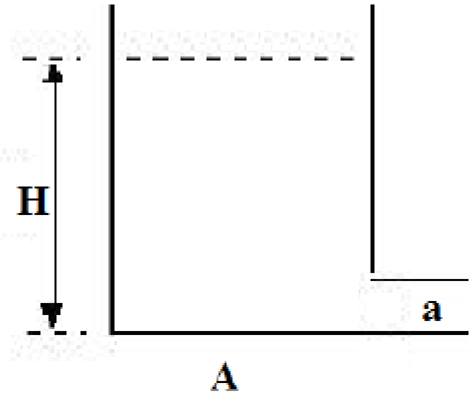

Fig 2: Pressure due to liquid column of height H

Given;

$A = \pi r^2$ = cross sectional area of our cylindrical tank

$V = \pi r^2 h$ = volume f the tank

Q_1 =Input flow rate

Q_2 = outlet flow rate.

H = Height of water in the tank.

h = Desired height of water in the tank.

g = Acceleration due to gravity.

C_1= Valve coefficient

$_{CA}$ = coefficient of desired height.

From the law of conservation of matter, we can say that;

Rate of accumulation of mass in the tank =mass inflow – mass outflow.

$\frac{dV}{dt} = Q_1 - Q_2$ (3)

$A\frac{dH}{dt} = Q_1 - Q_2$ (4)

The outlet flow rate of the cylindrical tank is given by the Torricelli's law which states that the speed or the outflow of a fluid through an edge hole at the bottom of a tank filled to a depth is the same as the speed that a body would acquire in falling freely from a height 'h'.

Hence

$Q = \sqrt{2gh}$ (5)

With respect to the size and shape of the valve, the outflow is given by

$Q_2 = C_2 * \sqrt{2gh}$ (6)

Putting equation 3.6 into 3.4 gives

$A\frac{dH}{dt} = Q_1 - C_2 * \sqrt{2gh}$ (7)

In steady state, we know that

$\frac{dH}{dt} = 0$ (8)

$Q_1 = Q_2$ (9)

That is that inlet flow = outlet flow

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To linearize equation 3.4, around the desired height, the out-flow equation can be linearized. And equation 3.6 is rewritten approximately as:

$$\frac{Q_2}{2\mathrm{gH}} \approx \frac{C_2 * a}{\sqrt{2gh}} = c_1 \qquad (10)$$

$$Q_2 = c_1 * 2gH \qquad (11)$$

$$A\frac{dH}{dt} = Q_1 - C_1 * 2gH \qquad (12)$$

Dividing through by A

$$\frac{dH}{dt} = \frac{Q_1}{A} - \frac{C_1 * 2gH}{A} \qquad (13)$$

Where

$$C_1 = \frac{C_1 * a}{\sqrt{2gh}} \qquad (14)$$

$$C_2 = \frac{I_{act}}{I_{max}} \qquad (15)$$

$$I_{act} = Actualcurrentonthevalve$$

$$I_{max} = maximumcurrentonvalve$$

Substituting C_1 and C_2 into equation 3.13

$$\frac{dH}{dt} = \frac{Q_1}{A} - \frac{\mathrm{a} * I_{act} * 2gH}{\sqrt{2gh} * A * I_{max}} \qquad (16)$$

2.2 Circuit Components and Design

The multi tank water level controller designed in this work consists of an Arduino Nano PLC board, a MA4115 pressure sensors, a 16 X 2 LCD screen, six 5V DC low trigger relays, 2N3904 NPN transistors, IN4007 diodes and a 5V DC power source. This design was executed on the Proteus 8 professional design suit.

i. Pressure Sensors/Transducers.

A Transducer is a device that converts variations in a physical quantity, such as pressure or brightness, into an electrical signal. This study is aim at measuring Tank volume by it liquid level/height and this height is calculated based on the pressure a known column height of liquid will exert at the tank base.

Consequently, the Transducer chosen for this project is a differential pressure transducer. Considering Fig 1 and relating to storage tank liquid (water) level measurement, Hydrostatic pressure p can be calculated as

$p = \rho\, g\, h$

Where

p = pressure in liquid (N/m^2, Pa, lb$_f$/ft^2, psi)

ρ = density of liquid (kg/m^3, slugs/ft^3)

g = acceleration of gravity (9.81 m/s^2, 32.17405 ft/s^2)

h = height of fluid column - or depth in the fluid where pressure is measured (m, ft).

For the purpose of this work, a MPX4115 pressure sensor is used.

MPX4115 pressure Sensor

This is an integrated Silicon Pressure Sensor designed to sense pressure in an altimeter or barometer (BAP) application. In interfacing the sensor to the Arduino Nano, only three pins are required. Pins 1, 2, and 3. Pin 1 is connected to an ADC pin of the Arduino Nano, pin 2 connected to the common GND and pin 3 to the +5V output of the Arduino Nano. In this work, six of this sensor are required to determine the pressure in all six tanks. The connection of the six sensors to the Arduino ADC pins is shown in Fig 3.

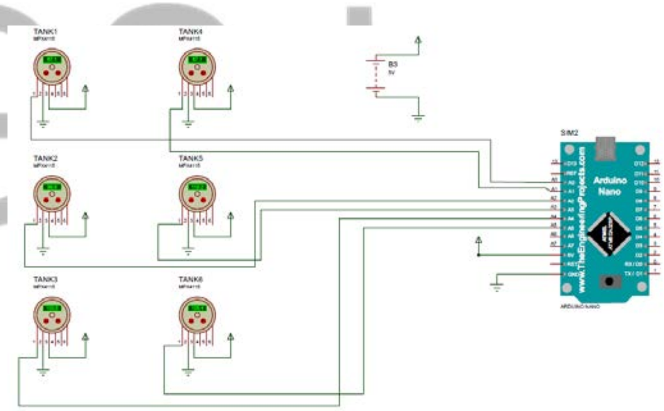

Fig 3: MPX 4115 Arduino Connection.

ii. Relay

In order to effectively control the filling of the six tanks, relays are used in cutting off voltage supply to the supply valves of the tanks and also in controlling the switching ON and OFF of the pump based on the average percentage water volume in all six tanks. A total of seven relays are used. Six for controlling the valves of the tanks and one for controlling the pump actuation. These relays require a driver circuit in order to operate thus, IN4007 diodes and 2N3904 NPN transistors are used in driving/controlling the relays from the

Arduino digital output pins. The relay/Valve driver circuit is shown in Fig 4.

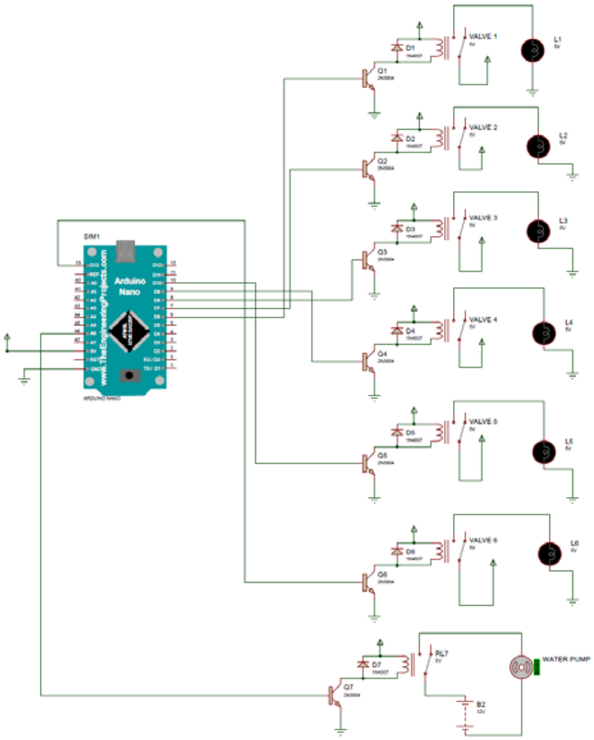

Fig 4: Valve Control Circuit

iii. 16 x 2 Liquid Crystal Display Screen

This is a Liquid Crystal Display (LCD) screen consisting of two rows and sixteen columns. The LCD is used in displaying combined average water level in all six tanks. The LCD has 16 pins and is connected to the Arduino Nano as shown in Fig 5.

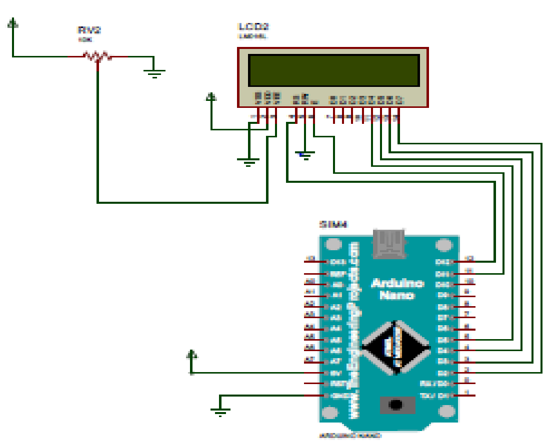

Fig 5 Display Circuit Connection

iv. Arduino Nano

The Arduino Nano is a Programmable logic controller with an onboard ATMega 328 microcontroller IC chip. The Arduino Nano serves as the main processor in this design. It is responsible for interpreting and calibrating analog inputs from the pressure sensors, performing the actuations on the valve and pump and also controlling the Display of the LCD.

v. Proteus 8.7 SP3 Professional

This is a version of the Proteus Design suite developed by Labcenter Electronics. It is widely used for electrical schematic design, PCB layout design and Virtual simulation. This software application is chosen for the purpose of this work due to its user friendly interface, vast Library of components, Virtual Terminal display and real time simulation. The entire circuit is designed on this platform. With each individual component picked form the component library. The complete circuit designed on Proteus can be seen in Fig. 6.

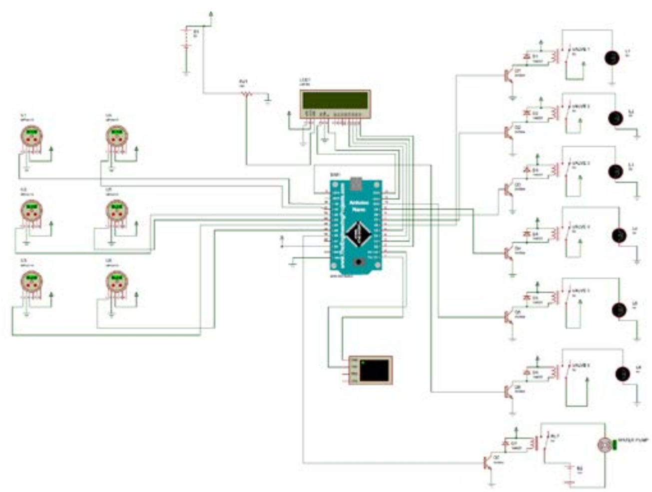

Fig 6. Multi-Tank Water Level Controller Circuit.

vi. Arduino IDE and Software Design

The program which governing the entire system is developed on the Arduino IDE (Integrated Development Environment) in the form of sketches written in C++ programming language. The complete Sketch is compiled using the AVRISP mkii programmer in the IDE. The compiled code which is then uploaded to the ATmega 328 through the Arduino Nano.

In developing the program, pins are first declared for the Pressure sensors with storage memory

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locations assigned to each pin these locations are used in storing the analog data from the pressure sensors. A maximum integer size is set at 1023 and a minimum set at 0, the LCD library is called in and pins assigned to the LCD. Other memory locations are assigned and the valve pins assigned. The valve pins are set on OUTPUT mode (pinMode, valvepin, OUTPUT) and serial communication is initiated at 9600Bps. The analog input from the pressure sensor is calibrated from 0-1023 to 0-100%. The flow structure is designed such that the for tank level less than 80%, the tank valves are left open otherwise they are closed. The water level in all six tanks are averaged and displayed on the LCD screen. If this average falls below 20%, the water pump is turned ON and pumped till the average is at 80%.

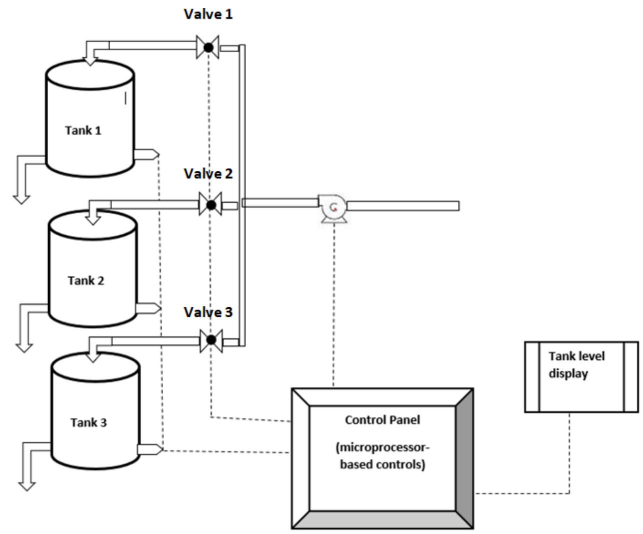

Fig 7: Block Diagram of Water Tank Level Control System.

3. RESULTS AND DISCUSSION:

The result of the calculated hydrostatic pressure calculated for water up to 8meters is shown in table 4.1.

Table 1: Hydrostatic pressure for water column up to 8meters.

Height of Water Column	**Pressure**				
h(m)	**(ft)**	**(kPa)**	**(bar)**	**(atm)**	**(psi)**
1	3.28	9.81	0.098	0.097	1.42
2	6.56	19.6	0.196	0.194	2.85
3	9.84	29.4	0.294	0.29	4.27
4	13.1	39.2	0.392	0.387	5.69
5	16.4	49.1	0.491	0.484	7.11
6	19.7	58.9	0.589	0.581	8.54
7	23	68.7	0.687	0.678	10
8	26.2	78.5	0.785	0.775	11.4

Having designed the multi-tank water level circuit on Proteus and the program file uploaded to the Arduino Nano in the worksheet, the worksheet is run and the characteristics behaviour of the system

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observed. The results of this simulation are presented in Fig. 8,9,10, and 11

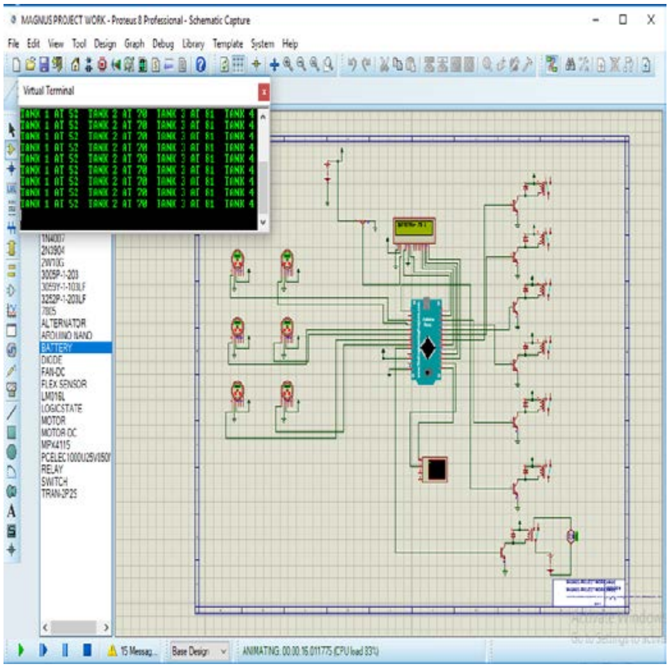

Fig 8: Simulation of Multi-Tank Water Level Controller

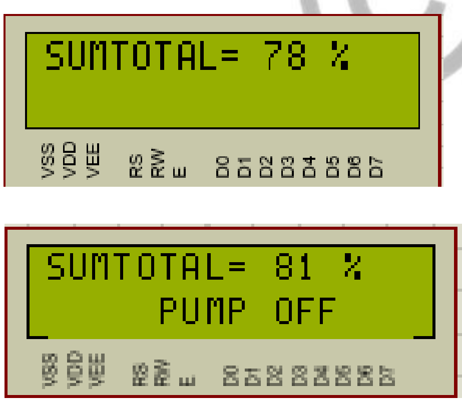

Fig 9: LCD showing Cumulative Average water level.

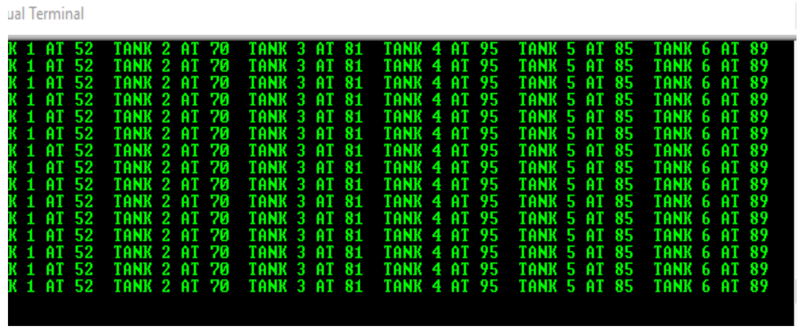

Fig 10: Virtual Terminal Display of Water Level in Each Tank.

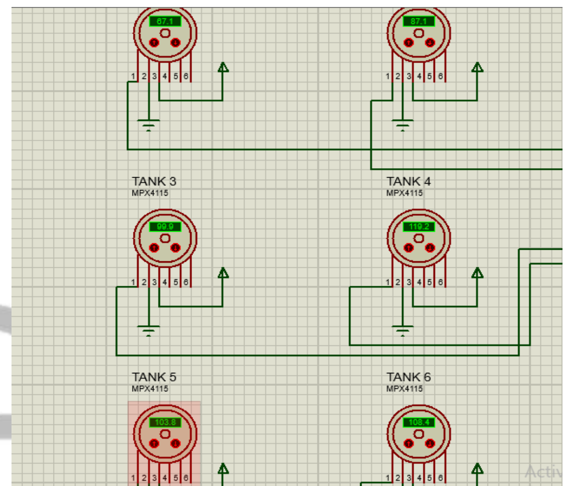

Fig 11: Pressure Sensor showing the Pressure (KPa) in each Tank

From the results obtained from the simulation of the multi-tank water level controller, it can be observed that the pressure measured in each tank by the pressure sensors is converted to a scale of 100%. When the pressure in Tank 1 is increased by clicking the arrow key pointing upwards in Fig 11, the percentage water level in tank 1 is increased as can be observed on the virtual terminal as shown in Fig 10. Thus, any change in the pressure in the tank results in an equivalent change in the tank water level on the virtual terminal. Thus, the pressure sensors are able to accurately measure and display the volume of water per time in the storage tanks.

In Fig 9, the LCD is observed to display “SUMTOTAL=78%”, and “SUMTOTAL=81%.

PUMP OFF". This percentage value is the cumulative average of the water levels in all six tanks. It is observed that, when the water level in any of the tanks is less than 80%, the valve controlling the supply of water to that tank is switched to the NO (Normally Open) configuration otherwise. When the cumulative pressure in all six tanks drop to or falls below 20%, the water pump is turned ON until the average is back to 80%. Thus, through the use of the Arduino Nano, analog inputs from the different pressure sensors on the different tanks are able to calculate the individual volume of each tank and sum the total cumulative average volume of all the tanks. This cumulative average is used in initiating a START and STOP signal to the borehole pumps.

4. CONCLUSION

Automatic water level controllers are devices that are used in controlling the volume of water of liquid in a tank. These devices make use of various methods in determining the volume of water or liquid in the tank. In this study, a multi-tank water level controller was developedusing the Arduino Nano microcontroller board as the PLC of the system. The use of this PLC allowed for flexibility of control, display and reduction of human inference in operating the system. A pressure based approach was adopted in measuring the volume of liquid in each of the six tanks. Six MPX4115 pressure sensors were used in obtaining the pressure in the tanks. The outputs of these sensors are fed to the analog input of the Arduino Nano (PLC). These inputs are calibrated to a scale of 100% to give the volume of liquid in the tanks. The volume of liquid in each individual tank is used in controlling the supply valve of that tank. When the volume of liquid in a tank is less than 80%, the valve is opened to allow for supply, and closed at 80% full. The volume of each of the six tanks is summed to give the volume of liquid in the entire system. This volume controls the borehole pumping machine.
The system was able to satisfy all of its intended aim and objectives as can be seen in the results obtained when the system is RUN.

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