Development of an improved Automatic Water Level Controller

P.B. Mogaji
Email: pbmogaji@futa.edu.ng

Department of Industrial and Production Engineering, Federal University of Technology, Akure, Ondo State, Nigeria.

Abstract:

This report contains the analysis and description of the design as well as the performance improvement of an autonomous water level control system. The system is aimed at providing an appropriate control for delivering water to an overhead tank when empty and an automatic means by which the pump can be stopped as soon as the tank is full. The autonomous control system would consist of contactors, overload relay, circuit breaker, two indicator lamps and two float switches, which acts as the feedback element. A float switch is used to monitor the level of the water in the tank and controls the “ON and OFF” state of the machine using Archimedes principle of floatation. This report covers several grounds starting from introduction and literature review, design and method through results, discussion and conclusion are all summarized in the pages of this report.

Keywords: Archimedes principle of floatation, float switch, design and improvement

1. Introduction

An autonomous water level controller is a self-governing system that is is designed to monitor and regulate the volumetric flow rate of water as well as the water level in a tank. When the level of water is below the minimum threshold that is preset on the main controller, the pump is automatically activated transfer water into the tank. On the other hand, when the water level in the tank is the same or has exceeded the threshold, the pump is automatically deactivated. Several circuits are put together to ensure proper working and usage of this design. The water level control system is connected to various electrical components such as relays which help to cut off supply of AC to the pumping machine. The system employs an automatic pumping system for refilling the tank when the water level goes below the minimum while deactivating the pump as soon as the maximum threshold is reached. The need for efficient water resources distribution and management in many part of the world is now a prevailing issue due to the quest for sustainability. The development of an autonomous water level control system stems from the need to sufficiently address some challenges that relates to inefficient water distribution, and use as well as lack of independent and integrated water management system. Since, the use of water for agricultural, industrial, and domestic purposes can be overemphasized, therefore, water conservative and management measures will guarantee its optimal use. The only limitation being the availability of the water control and monitoring systems which are potential constraint for industrial, office, domestic and agricultural management system. Moreover, the water level control for many domestic appliances is grossly inefficient involving the feeding of the pump from a lower to a higher level in the water tank. The autonomous water level controller, has the capacity to monitor and maintain the level of water in the overhead tank. This will ensure uninterrupted flow of water without the need for the manual ON or OFF switching of the pump. Hence, it can operate independently, thus, saving energy, time and water resources. In addition, the automatic control allows the pump to rest intermittently thereby preventing the pump from excessive work or loading conditions. Many pumping machines are not adequately equipped with intelligent control systems to enable real time control of the volume of liquid it pumps. As such, this can increase the chances of overflow when the pump is left running for a long period of time thereby constituting environmental nuisance or hazards in the form of flooding. In addition, the continuous operation of the pumping system without intermittent rest can promote the wear rate of the pump's component resulting in the reduction of useful life or catastrophic failure.

Seng et al (1998) have proposed a neuro-fuzzy controller to a coupled-tank liquid-level laboratory process based on the use of Generic Algorithm (GA) to iteratively and automatically tune the radial basis function neural network. The work employs a linear mapping for encoding the chromosome of the GA, having the width and center of the membership functions, as well as the weights of the controller. In order to enhance faster convergence rates of the GA evolution, the dynamic crossover and mutation probabilistic rates are also applied to network. Compared to a manually tuned conventional fuzzy logic controller and a Proportional-Integral-Derivative (PID) controller which are applied to the same process, the proposed controller shows considerable robustness and advantages. Human expert intelligence in framing the rule base of fuzzy logic controller is a major limitation.

Naman et al (2000) have proposed the use of an adaptive model reference fuzzy control (AMRFC) for regulating the water level in a tank. The performance of the control system was compared with the conventional methods of Proportional and Integral (PI) control as well as the Model Reference Adaptive Control (MRAC). Unlike some of the literature reviewed which use the error and error change as inputs to the fuzzy system, this method uses the theoretical background developed for MRAC in choosing these inputs. Although the control system employs many inference rules (441 rules), the results obtained indicated that the required mathematical calculations are trivial, which makes its implementation on a low-end microcontroller highly feasible. The control algorithms are implemented in simulation and real-time on an 8-bit microcontroller. It was found that the MRAC proved to be better compared to the PI controller. Limitation is the similarity in performance due to the linearity of the plant.

Han (2006) have developed an adaptive neural network control system with a fuzzy self-tuning ability to regulate the tank water level of a coal fired power plant. The Fuzzy Inference Engine (FIE) was employed to iteratively train the neural network online. The control system has a feed forward compensation ability for the steam flow disturbance which is obtained by introducing the signal from the steam flow into the neural network controller. The robust control system is developed to guarantee a good control performance with the dynamic behavior of the controlled system. When compared to the conventional cascade PID control system, the results obtained from the simulation, show improved performance and efficiency of the proposed strategy.

Yazdizadeh et al (2009) used two novel adaptive PID-like controllers (the neural network PID and neural network PID having internal dynamic feedbacks for controlling multivariable, nonlinear Multiple-Input Multiple-Output (MIMO) systems. The developed novel adaptive controllers were tested with the conventional methods and the comparative analyses of the results confirm that the algorithm demonstrated excellent control performance. It has been applied to regulate the level of water in tanks during the water refinement process, which is highly nonlinear and good performance and stability was achieved. The only limitation is the fact that the learning rate and the system disturbances are not considered during the design. Hasan et al (2011) have investigated and found a solution by designing the intelligent controller such as the neural network for regulating the water level in a system. The control system can also be specifically run under the same circumstance of the system disturbances. In order to achieve these objectives, a prototype of the water level controller was developed and implemented using both the PID and neural network control algorithms. For the PID control, the Ziegler Nichols tuning rule was employed for the system's control while the neural network control, uses the Model Reference Adaptive Neural Network (MRANN) control which is based on the back propagation algorithm that is used for training the system. The two control algorithms are developed and incorporated into a standalone DSP-based micro-controller and their performances are compared. The only limitation is the fact that the nonlinear process characteristics are not preserved.

Jun et al (2011) developed a Modified Particle Swarm Optimization (MPSO) for tuning the PID control parameters for regulating a boiler drum water level. When compared with the Basic Particle Swarm Optimization (BPSO), it was observed that the MPSO shows greater searching ability and prevents the particles from falling into the local minimum. This is makes the searching of global optimal solution more efficient by adopting the principles of solution and searching range sharing.

A new error criterion was proposed to validate the performance of a PID control system that is based on MPSO (MPSO-PID). The experimental results indicate that the MPSOPID achieves better response time than the PID controller based on the BPSO (BPSO-PID). A major limitation is the increase in execution time.

From the literature surveyed, it is obvious that there is a need to incorporate an automatic control alongside with a water level detector to check water overflow and continuous overrunning of water pumping machines. In view of the foregoing, this work considers the development of a highly efficient and autonomous water pump control with high level sensing and adequate overload protection to cut-off supply to the pump in case of any event of overload or short circuiting faults. There are two counter weight placed on a beam that would be incorporated into the tank and the deviation of both weights depends on the water level which alters the switch.

2. Methodology

2.1 Design concept

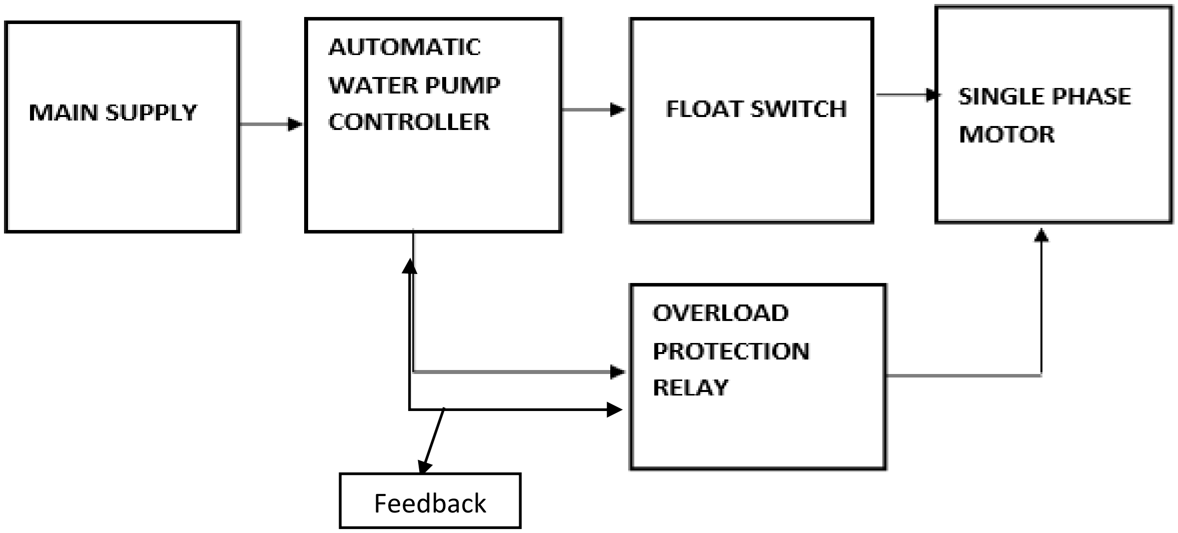

Figure 1: *Block Diagram of the control system*

The first design consideration involves the detailed calculations of the component values and their specifications. This is followed by the individual design stages as well as their operational principle. The design stages consists of the following;

a. Main supply stage
b. Automatic water pump controller stage
c. Float switch
d. Overload protection relay
e. Single phase motor pump

The system uses a 240V single phase mains supply which is fed to the automatic water pump controller. The flow switch and the single-phase motor are connected to the controller with the aid of the control circuit arrangement. An overload protection relay is incorporated whose function is to provide a feedback path between the controller and the motor. In any event of excessive application of current to the motor, the overload protection relay will sense it and cut-off the power supply to the motor. The component employed for the control system also include like the miniature circuit breaker and the contactors, which are assembled to enable simultaneous supply of power to both the float switch and the overload protection relay. While the overload protection relay, monitors the magnitude of current supplied to the motor, the float switch, on the other hand monitors the water level in the water tank. The single-phase water pump motor which pumps water to the overhead tank is activated by the float switch actuates when the water level drops below the minimum threshold.

2.2 Description of machine

The automatic water level control system consist of the contactors, overload relay, circuit breaker, two indicator lamps and two float switches, which acts as the feedback element. The working principle of the internal circuitry would be based on the movement of the float switches in the water tanks. The float, being counter weighed, would move downward with the water level towards the float stopper. At a preset level, the floater's weight would be enough to pull the float switch ON position. The contact of the float switch would be pulled down. Once the contacts are established, electric current would flow through the circuit and energize the coil of the contactor. The contactor coil would in turn close the contactor contact and the pump would start to pump water in order to maintain its level. At another preset level, the float would become lighter and the counter weight would pull the switch to OFF position which would de-energize the contactor coil and put OFF the electric pump and in the process regulates the water level which has been preset. A float switch is a device used to detect the level of liquid within a tank, the most commonly used float switch is simple float which raises a rod that actuates the micro-switch. They are often adjustable and can include substantial hysteresis (In other words, the point of the switch "turn on" may be much higher than that of its the "shut off"). This minimizes the on/off cycles of the associated pump.

The block diagram of the controller shows the logical connection between each stages of the design.

2.3. Determination of the Pump HP and Efficiency

The electrical pump is assumed to pass forward a flow of 8.7843 m^3/hr to its receiving tank while the operating pressure of the pumped system is calculated in the SI unit of meters (m). To maintain dimensional consistency, any pressure values used within the calculations are therefore converted from kilopascal (kPa) into meter (m) using the following conversion; 1 kPa = 0.102 m (as measured by a water filled U tube manometer) (Mathew Milnes)

The total system head (operating pressure), H_{Total}, is defined as Equation 1.

$H_{Total} = H_{1s} + H_{2\,s} + H_{1\,D} + H_{2\,D} + (P_{tank} - P_{well})$ and for the well system, is: (1)

where;

H_s *is the Static head (m)*

H_D *is the Dynamic head (m)*

P_{tank} *is the Pressure on the surface of the water in the receiving tank (m)*

P_{well} *is the Pressure on the surface of the water in the well (m)*

Even though the atmospheric pressure changes with the pumping height, the difference in pressure that occurs over the pumping height is often so small that it can be considered negligible.

In this project, the difference in pressure (that is pressure change) over the elevation from the well to the receiving tank is not that significant and hence is negligible, i.e.,

$$P_{tank} - P_{well} \approx 0$$

Therefore, Equation (1) becomes:

$$H_{Total} = H_s + H_D \qquad (2)$$

The static head, Hs is the physical change in elevation between the surface of the well and the point of entry into the overhead tank. As the water level in the well and receiving tank vary, the static head for the system will vary between a maximum and a minimum value respectively:

$H_{S_{min}}$ $is\ the\ discharge\ level\ at\ receiving\ tank - well\ TWL$

and

$H_{S_{max}}$ $is\ the\ discharge\ level\ at\ receiving\ tank - well\ BWL$

Where,

$TWL\ is\ the\ Top\ Water\ level\ (well)$

$BWL\ is\ the\ Bottom\ Water\ level\ (well)$

For the purpose of this project $H_{S_{max}}$ only is considered to calculate the maximum pump power needed.

The discharge point is at a level of 13.05m high (at overhead tank) is assumed and the well level minimum level of 0.10m is also assumed, then

$$H_{S_{max}}\ is\ 13.05 - 0.10 = 12.95m$$

The dynamic head is generated as a result of friction within the system. The dynamic head is calculated using the basic Darcy Weisbach Equation expressed by Equation 3.

$$H_D = \frac{KV^2}{2g} \tag{3}$$

where;

k is the loss coefficient

g is the acceleration due to gravity (m/sec^2*)*

v is the velocity in the pipe (m/sec) expressed by Equation 4.

$$v = \frac{Q}{A} \tag{4}$$

where;

Q is the flow rate through the pipe (m^3 */sec)*

A is the pipe cross sectional area (CSA) (m^2*)*

Note: All the parameters used in this modelling were assumed.

Q is 8.7843 m^3/hr and the flow is pumped through a 0.043 m diameter pipe then:

$$A = \frac{\pi D^2}{4} = \frac{\pi \times 0.043^2}{4} = 0.00145m^2$$

Hence, using Equation 4,

$$v = \frac{8.7843}{3600} \times \frac{1}{0.00145} = 1.6828m/sec$$

The loss coefficient K consists of two components expressed as Equation 5.

$$K = K_{fittings} + K_{pipe} \tag{5}$$

$K_{fittings}$ is associated with the fittings used in the pipe works of the system to pump the water from the well to the reservoir and from the reservoir to the storage tanks. There values can be obtained from standard tables and a total $K_{fittings}$ value can be calculated by adding all the $K_{fittings}$ values for each individual fitting within the system. Hence, the total $K_{fittings}$ for the system under consideration is 7.3. K_{pipe} is associated with the straight lengths of pipe used within the system and is defined as:

$$K_{pipe} = \frac{fL}{D} \tag{6}$$

where;

f is the friction coefficient

L is the pipe length (m)

D is the pipe diameter (m)

The friction coefficient can be obtained using the modified version of the Colebrook Equation (Equation 7).

$$f = \frac{0.25}{\left[log\left\{\frac{k}{3.7\times D}+\frac{5.74}{{R_e}^{0.9}}\right\}\right]^2} \tag{7}$$

where:

k is the Roughness factor (m)

Re is the Reynolds number

The pipe roughness factor k for the overhead system, is a constant value obtained from standard tables and is based upon the material of the pipe, including any internal coatings, and the internal condition of the pipeline i.e. good, normal or poor.

The Reynolds number can be calculated using the Equation 8, for any type of flow,

$$Re = \frac{vD}{V} \tag{8}$$

Where, V= Kinematic viscosity (m^2 /s)

The total pipe length is 24.46 m, the pipe has an absolute roughness factor of 0.0875 mm and a relative roughness factor of 2.0349, the kinematic viscosity of water is 1. 31 x10^{-6} m^2 /sec, then from Equation 8,

$$Re = \frac{1.6828 \times 0.043}{1.31 \times 10^{-6}} = 55236.95$$

Where, relative roughness $= \frac{\text{absolute roughness}}{D}$

Using this value in Equation 7,

$$f = \frac{0.25}{\left[log\left\{\frac{2.0349}{3.7\times0.043}+\frac{5.74}{55236.95^{0.9}}\right\}\right]^2}$$

=0.2040

Using this value in Equation 6,

$$K_{pipe} = \frac{0.204 \times 24.46}{0.043}$$

=116.07

Finally, using Equation5, the total K value for the system is:

K= 116.07 + 7.3

=123.37

The dynamic head of the pump is calculated using Equation 4 as follows;

$$H_D = \frac{123.37 \times 1.6828^2}{2 \times 9.81}$$

=17.80 m

The dynamic head is the same in magnitude for both the maximum and minimum static head conditions as the dynamic head is independent of the system elevation. Hence, the maximum total head values for the system at a flow of 8.7843 m^3/hr can now be calculated using equation (3):

$$H_{Total} = 12.95 + 17.8$$

=30.76m

Therefore, in order to pump 8.7843 m^3/hr from the bottom level in the well, the pump will need to overcome a system pressure of 30.76m. The power requirement for the pump can be calculated by:

$$P = \frac{QxHxgx\rho}{3960Pump\ Efficiency} \tag{9}$$

Where,

P = Power (W)

ρ = *Density (Kg/m^3) = 1000 kg/m^3 for water*

For this pump, at the maximum head of 30.76m and a flow of 8.7843 m^3/hr. The pump efficiency is 75%. Therefore, using equation (9), the power requirement is:

$$P = \frac{8.7843x30.76x9.81x1000}{3960\times Pump\ Efficiency}$$

P = 892.50W

=1.2hp

Hence, to overcome the required head of 30.76m, a speed pump with 1.2 hp is needed. The closest standard pump size to 1.2 hp is 1.5 hp (therefore ≤ 1.5 hp).

2.4. Determination of Overload Relay Trip Current

Considering, a single phase, 1.5hp (horse power) pump motor was chosen. The lowest operating voltage of the motor is 180V (the lowest voltage was chosen because the lower the voltage the higher the current). The current capacity of the motor was calculated with the formula:

P = VI

Where; P = Power rating of the Induction motor =1.5hp= 746x1.5 watts=1119 watts

V = lowest Operating voltage = 180v

I = Current rating

Calculating for I, we obtained I = 6.2167A~ 7A

The circuit breaker was connected directly to the main A.C. source. The rating of the current of the circuit breaker was 1.45 x the design current (current drawn by motor). Icb = 1.45 x 7 = 10.15A Therefore, preferred value of the circuit breaker was 10A. This means that the protection relay will trip at any current value ≥ 10Amps.

3. Assembling Principle

The autonomous water pump control system consists of a miniature circuit breaker, contactor, overload protection relay, three indicating lights, a switch for the pump and two float switches (Overhead tank float switch and Well) and. The working principle of the internal circuitry is based on the movement of the float switches, in the water tanks, the float, being counter weighed, move downward with the water level towards the float stopper (a notch). At a preset level as determined by the lower notch position, the weight of the floater is sufficient to pull the float switch to **'ON'** position. The contact of the float switch is pulled down. Mercury is the medium used to close the contacts to avoid arcing between contacts terminals. Once the contacts are established, there is flow of electric current through the circuit and energize the coil of the contactor. The contactor coil in turn closes the contactor contacts and the water pump starts to pump water in to the tank. At another preset level as the float moves towards the float stopper (notch) at the top, float becomes lighter and the counter weights pull the switch to '**OFF**' position. The mercury fluid flows backward thereby breaking contact. The action de-energizes the contactor coil which put '**OFF**' the electric pump. The overload relay protects the water pump from overload faults. When an overload fault occurs the normally closed of the relay opens, thereby de-energizing the coil and putting '**OFF**' the electric pump. The second float switch is responsible for putting OFF the pump as soon as the water level in the well is lower than the pre-set level.

Main supply, through the circuit breaker provides the power to energize the contactor. At the same instance, supply gets to the float switch, and the red light comes on, indicating there is power in the circuit. If the supply from the contactor is not up to the tripping current of 10Amps (≤10 Amps) of the protection relay, supply gets to water pump motor, but if it exceeds 10Amps (≥10 Amps), the relay simply trips. And the white light indicates no water or low water (below the BWL) in the tank, at instance when there is enough water in the well or overhead tank, the float switch trips the pump, and the Green light comes up, which indicates that water is being pumped into the reservoir tank. As the float ball begins to move upwards with the water level in the tank until an upper limit is reached. At this limit, the float ball weight and the counter weight at same side is displaced in the liquid, thereby causing the switch to dangle to the side of the single counter weight which becomes heavier than the side with a counter weight and float ball. It works on Archimedes principle of floatation which states that “Any object, which is totally or partially immersed in a fluid, is buoyed up by a force that is equal to the weight of the fluid displaced by the object”. At this point, the mercury flows to disconnect the switch and supply is cut-off from the motor, and both the white light and green light trips off to indicate that the reservoir is filled to the TWL. If the pump is subjected to overload the pump will stop operation, and the orange light will be on. The reset button of the overload can be pushed to off the orange lamp.

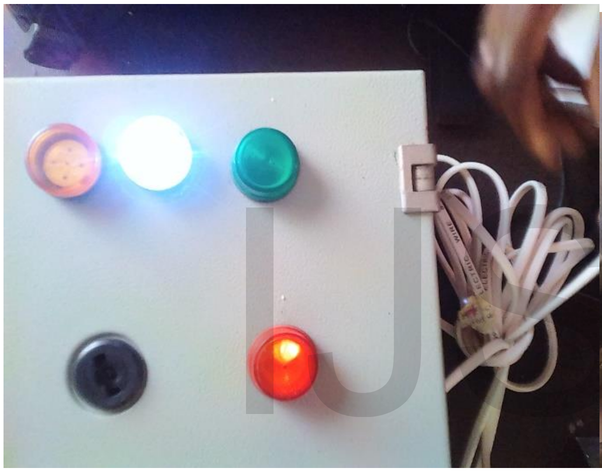

Figure 2*: ‘white light on’* *depicting no water in tank*

Figure 3*: ‘green light on’* *depicting water is pumping*

4. Performance Evaluation of the Machine and Construction of a Prototype.

Fabrication was carried out at the central Engineering workshop of the School of Engineering and Engineering Technology, FUTA. The actual performance evaluation was carried out prior to the laboratory demonstration. One float switch was installed on the top cover of the one 20 litre bucket (well), while the other one was installed on top of another 13 litre bucket (tank). The tank was emptied by allowing the water inside it to drain off. The electric pump was connected to the developed automatic water pump control system via the socket connected to the load terminal of the contactor via the overload. The control system was energized via a wall socket. Red indicating lamp was seen to come on as well as the neutral or white lamp that shows the emptiness of the tank. Also, the pumping machine started to pump water immediately and the green indicating lamp was on. After few minutes, the pumping machine stopped on its own when the level of water in the tank reached the preset upper level. At this juncture both the green and neutral or white lamp were off. The tank was emptied once again. It is observed that as the level dropped below the preset lower level, the pumping machine started automatically and resume its pumping operation while the green and neutral lamp were on. However, the pumping machine stopped operation before the water level reaches the upper preset level this time when the water in the well fell below the preset lower level. The well preset lower threshold level was chosen in such a manner as to prevent an inflow of air into the pump.

Moreover, the pump was subjected to overload to know the level of protection should this occur. The pump stopped operation as soon as overload was introduced and the orange lamp was on. The light was off when the reset button of the overload was pressed.

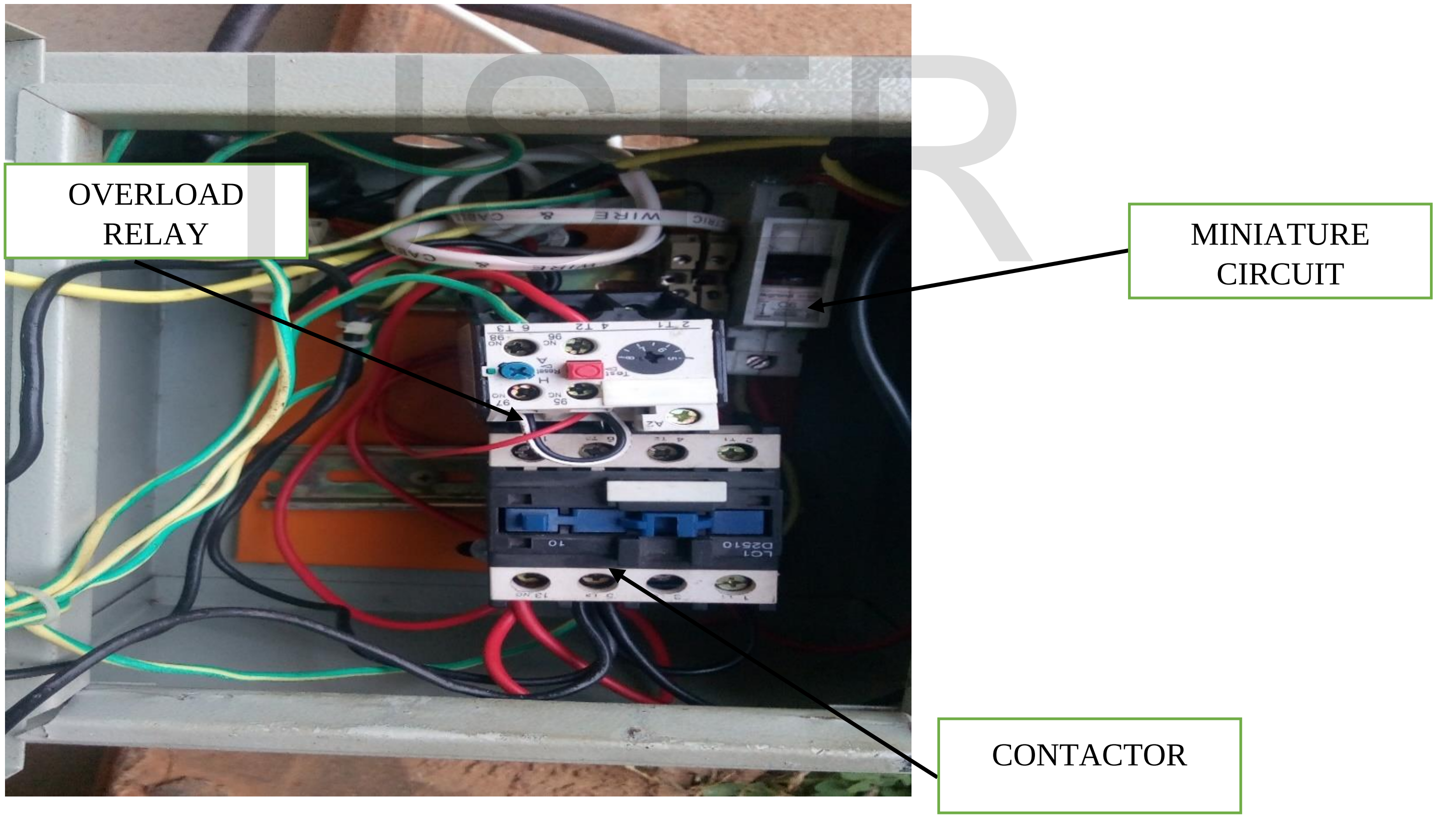

Figure 4: *interior view of the controller*

WATER INTAKE CHANNEL

WATER DISCHARGE CHANNEL

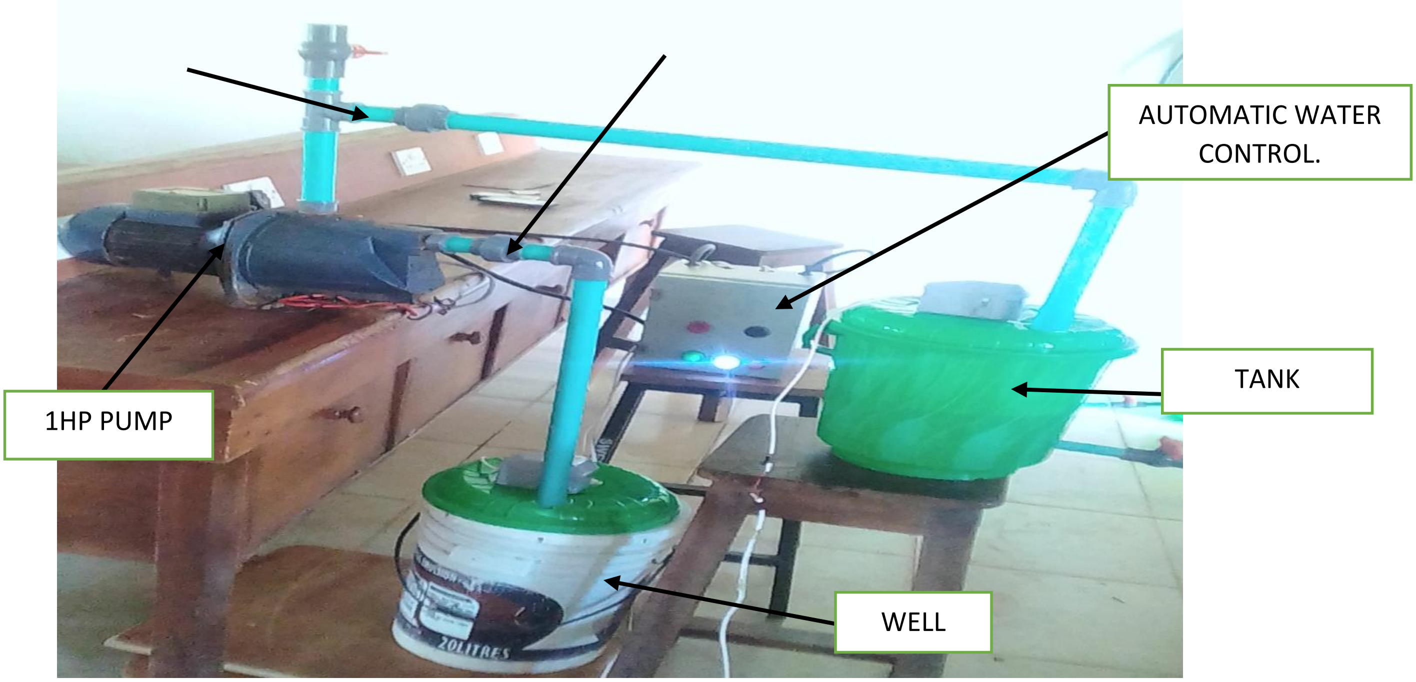

Figure 5: *The laboratory installation of the automatic water level control system*

5. Conclusion

An automatic water level control system was designed, constructed and tested, the system worked according to specification and proved quite satisfactory. It is relatively affordable, durable and efficient. Hence, give room for ease of operation and high level of reliability. It reduces stress associated with manual water pump controller, which require that somebody physically switching them on and off.

6. Recommendations

This project; an automatic water pump control system works perfectly and does not cost much compared to its benefits, it is therefore recommended for both domestic and industrial use; as well as private individuals, government and corporate organization most especially where there is a need for effective water resources management in a neat and hygienic environment that is free from water pollution.

Due to unstable power supply, solar power system is thereby recommended to power the control circuit as alternative power source to ensure consistent availability of water.

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