



Design and Construction of an Automatic Water Level Control (AWLC) System.

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ABSTRACT

The use of water pumps to collect water in tanks has become common, but the challenge of controlling the pump (switching on and off) has been a problem. Most often, turning on/off the pump is done manually. Manually carrying out this task can cause a lot of inconveniences due to human error, time wastages etc, since there is a tendency to allow the water in the tank to completely dry up or to get filled to the brim causing wastage. The task could also be tedious and an attempt to check the water level in an overhead tank could be hazardous. This project presents an automated water level controller (AWLC) and its aim is to ensure that the water in the tank does not fall below or go above certain levels. To accomplish this task, float sensors are attached inside the tank to detect the upper and lower levels of water and send signals to the control unit which automatically switches on/off the water pump of rating 0.5 Hp. It also puts into consideration the fact that the water being pumped from the reservoir to the overhead tank (60 l) could also be exhausted. Therefore in order to prevent a dry run of the motor, this system is designed such that the motor remains off at that instance. This project is flexible, limits the level of water wastage to the barest minimum and it does not need a manual operator for it to operate.

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1.0 Introduction

A water level controller is a device that manages water levels on a variety of systems such as water tanks, swimming pools, factories, steam engines, power plants etc [1]. This water level controller system is an electronic equipment which when electrically connected to the starter of any given pump set will automatically trigger **ON** or **OFF** the water pump depending on the water level in the storage tank [2, 3]. The basic function of a water level controller is to regulate water flow and optimize system performance. This flexible system automatically maintains steady water supply by detecting the upper and lower thresholds in a water tank and then switching on/off a pump set as the case may be [2].

The concept of water storage implies storage in tanks which can either be overhead or underground [5]. This approach is mostly used for domestic applications, in the factories and large industrial plants where large quantity of water is needed constantly and as such, constant water level has to be maintained. The need for this project is borne out of the fact that human error is ever present when operating a device manually. These human error factors can result in extensive damage to both property and personnel.

Since the beginning of the industrial revolution, a lot of efforts have been made in order to increase the mean time between failure of systems and to achieve the maximum uptime of equipment and machines and that is where the design of the automatic water level control finds intensive use [4]. This device helps in the control of the water level to avoid wastages and lack of water in storage tanks for domestic, agricultural and industrial applications, with minimal manual labour [1-3].

2.0 Materials and Methods

2.1 System Architecture

The block diagram of the automatic water level control system (AWLC) is shown in Figure 1 below. The power supply unit supplies power to the entire system. The entire control circuitry is supplied with the DC voltage taken from the regulated DC output, while the water pump takes in AC voltage via relay contacts. The dc power supply consists of the transformer, rectifier, filter and voltage regulator unit. In this system, a step down transformer 220/12V is used to step down 220V to 12V. A bridge rectifier is used which is a capacitor to filter and remove the pulsations (ripple) present in the output voltage and a Voltage regulator to maintain the rectified DC

output voltage at a constant value (12V) even when the AC input voltage to the transformer varies or the load varies [4].

From the input unit (level detection), Bipolar Junction Transistors (BJTs) are used as switches to send high or low output to the control unit. As a switch, the transistor acts in saturation and cut off modes [6]. In the cut off mode, the base current $I_B = 0$ and thus $I_C = \beta I_B = 0$. Therefore there is no voltage drop at the collector and the output voltage is equal to V_{CC} . In saturation mode, the transistor acts as a closed switch of negligible resistance. Therefore, the output voltage is very low (almost zero).

The 555 timer is used together with a switching transistor and relay to perform the control function. The 555 which operates as a flip-flop in bistable mode, is utilized for the control [6]. A relay is also used here as an electromechanically operated switch that consists of a coil of wire wrapped around a soft iron core, the coil is energized with direct current. The components that make the output unit are the light emitting diode (LED) and Electric Pump. The light emitting diode is used as an indicator lamp in this project while the electric Pump (AC) is a pump that uses electrical power to pump water from a reservoir to an overhead tank.

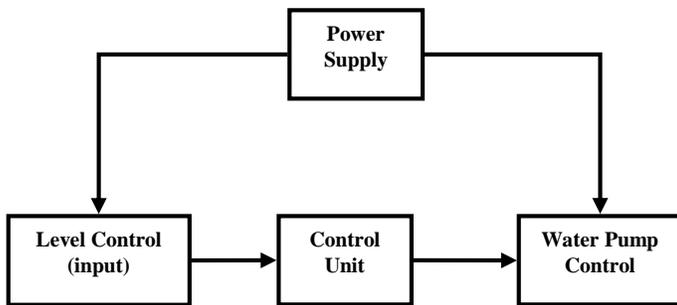


Figure 1. Block diagram of Automatic water level control system.

2.2 Working Principle of the Designed Circuit.

The 555 timer, which is in bistable mode, is used for the control. In this mode, the output of the timer goes high (near V_{CC}) when the trigger pin is grounded (i.e. when a low voltage is sent to trigger pin). The output remains high even when the trigger pin is brought high until the input to the reset pin is grounded. This resets the timer and the output goes low. V_{CC} is supplied to the base of the tank. The base of transistors Q_1 and Q_3 are also brought into the tank via resistors and are set at the low and high levels respectively.

At the initial instance, the voltage into the trigger and the reset pin should be high so that a low input to the trigger pin can start the timing. Assuming the water level to be half way in the tank, Q_1 is conducting and is in saturation while Q_3 is in cut off. Therefore, LED_2 comes on while LED_1 is off. The output of Q_1 is low and this serves as input to Q_2 which now operates in cut off mode and sends

a high output to the trigger pin. Also since Q_3 is cut off, it sends a high into the reset pin, thus both pins are high.

When the water level falls below L, Q_1 is cut off, LED_2 goes off. The output of Q_1 which is now high is sent as input into Q_2 and drives it to saturation. Q_2 therefore gives out a low output to the trigger pin and the timer is set, giving out a high output. This output drives Q_4 to saturation and the current causes the relay contacts to close. The motor comes on and water is pumped from the reservoir into the overhead tank. As the water level rises above L, transistor Q_1 conducts, LED_2 comes on. The output of Q_1 is now low and Q_2 high. But the output of the timer is still high, so the motor keeps pumping water until the water level rises to H. At this point, Q_3 conducts and its output is low which goes to the reset pin and resets the timer. The output of the timer goes low and the pump is switched off. LED_1 comes on.

In order to monitor the level in the reservoir, so that the motor does not start when the water level in the reservoir goes low, the base of transistor Q_5 is dropped into the reservoir via resistor R_9 . V_{CC} is also taken into the reservoir and connected to one terminal of the relay. When there is water in the tank, the transistor Q_5 turns on resulting in the closure of the relay contact and V_{CC} is sent to the circuit. When the water level falls below the lower threshold, the Q_5 transistor goes off and V_{CC} is cut from the entire circuit. Figure 2 below shows the complete circuit diagram of the system.

2.3 Design Equations

The following equations are used in the design of Automatic water level control system across the various units of the entire system. A 220/12 V transformer with the following rating: frequency = 50 Hz, I = 500 mA. The peak value is given as

$$V_p = \sqrt{2} V_{rms} \quad (1)$$

The capacitance of the capacitor is given by equation 2 [7].

$$C = \frac{1}{4\sqrt{3}V_p V F} \quad (2)$$

For safe design, 40% of the rated current is assumed and a ripple factor of 2%.

The transistors Q_1-Q_3 is a typical bipolar junction transistor switch, where $Q_1 = Q_2 = Q_3$ (2N222 npn transistor) while at the output stage, the BJT Q_4 is SL100. Biasing the transistor Q_1 and Q_3 into saturation mode as shown in Figure 3 below [6]. Taking KVL at the collector – emitter loop, $V_{CC} - I_C R_C - V_D - V_{CE(sat)} = 0$ or

$$R_C = \frac{V_{CC} - V_D - V_{CE(sat)}}{I_C} \quad (3)$$

The relationship between the collector current I_C and the base current I_B is given as shown in equation 4 [6].

$$I_C = \beta I_B \quad (4)$$

Taking KVL at the base emitter junction to find R_B ,

$$V_{in} - I_B R_B - V_{BE(sat)} = 0 \text{ or}$$

$$R_B = \frac{V_{in} - V_{BE(sat)}}{I_B} \quad (5)$$

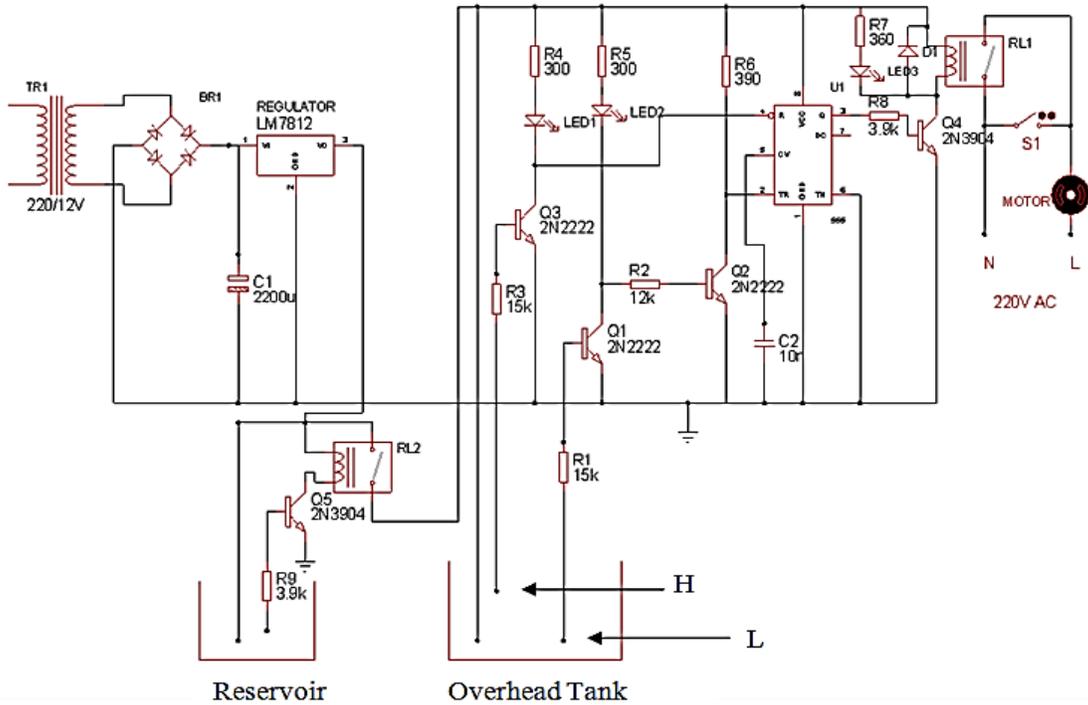


Figure 2. Complete Circuit Diagram of Automatic Water Level Control System.

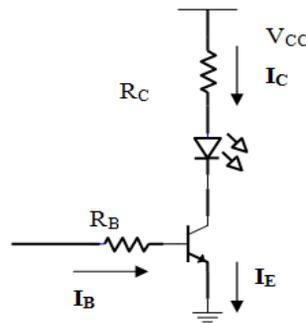


Figure 3. A Bipolar Junction Transistor Switch

At the instance that the probe is connected to the base of the transistor, there is a voltage at the base of the transistor and the transistor is driven to saturation mode. Thus, the output V_0 is given as:

$$V_0 = V_{CC} - I_C R_C - V_D \quad (6)$$

On the other hand, when the water level falls below the probe, no current flows into the base of the transistor. Therefore from

equation 4, the collector current $I_C = 0$. The output voltage from equation 6 becomes

$$V_D = V_{CC} - V_D \quad (7)$$

For Q_2 , taking KVL at the collector emitter loop, $V_{CC} - I_C R_C - V_{CE(sat)} = 0$, or

$$R_C = \frac{V_{CC} - V_{CE(sat)}}{I_C} \quad (8)$$

Taking KVL at the base emitter junction to find R_B , the same as in equation 5 and here $V_{in} = V_o$ of Q_1 . In saturation mode, the output of Q_2 is given as

$$V_o = V_{CC} - I_C R_C \quad (9)$$

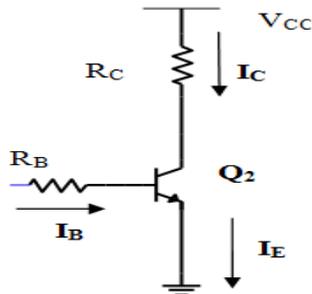


Figure 4. A Bipolar Junction Transistor Switch For Q_2 .

In cut off mode (i.e. when the output received from Q_1 is low, $I_C = 0$. Therefore, $V_o = V_{CC}$. For the output stage, $Q_4 = SL100$. The relay used is rated 12V, 400 Ω . The BJT is shown below.

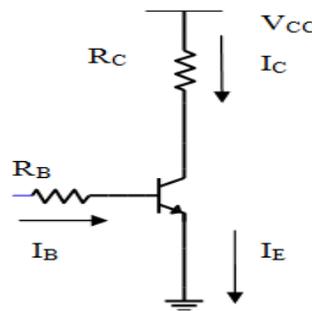


Figure 5. A Bipolar Junction Transistor Switch For Q_4 .

Taking KVL at the collector emitter loop,

$$V_{CC} - I_C R_C - V_{CE(sat)} = 0 \text{ or}$$

$$I_C = \frac{V_{CC} - V_{CE(sat)}}{R_C} \quad (10)$$

This is the current that flows through that energizes relay when the output of the timer goes high. I_B can be found using equation 4 and R_B using equation 5 respectively.

3.0 Results and Discussion

The preferred values (components with the closest values to those calculated) were used for components whose calculated values could not be found. Table 1 shows the calculated and measured values of components for resistors and capacitor.

Table 1. Calculated and Preferred Values of Resistors and Capacitor.

| Component | Calculated | Preferred |
|----------------|-------------------------------------|-------------------------------------|
| | Values (Ω), (μF) | Values (Ω), (μF) |
| R ₁ | 15060 | 15000 |
| R ₂ | 12400 | 12000 |
| R ₃ | 15060 | 15000 |
| R ₄ | 323.33 | 300 |
| R ₅ | 323.33 | 300 |
| R ₆ | 390 | 390 |
| R ₇ | 360 | 360 |
| R ₈ | 3960 | 3900 |
| R ₉ | 3960 | 3900 |
| C ₁ | 1856.43 | 2200 |

The design was then built on the bread board for testing and verification before being transferred to a vero board. The circuit was implemented block by block, first the power supply, then the reservoir sensing section, the overhead tank sensor and switches, the control unit and finally the output section.

At the completion of each block, the needed parameters which were previously calculated (I_C , V_{CE}) were measured. The output voltage of the power supply section was checked. The switching action of the transistors and relays was checked to ensure that the switches were active. The LEDs used as indicators were also checked to ascertain if they were turned on and off to indicate change in water level. The project was implemented and properly soldered on the vero board. Table 2 and 3 shows the calculated and measured values of some other needed parameters.

Table 2. Calculated and Measured Values of output voltage (V_o).

| Component | Cut-off mode | | Active mode | |
|----------------|-------------------|-----------------|-------------------|-----------------|
| | Calculated (V) | Measured (V) | Calculated (V) | Measured (V) |
| Q ₁ | 10 | 10.54 | 0.3 | 0.05 |
| Q ₂ | 12 | 11.88 | 0.3 | 0.7 |
| Q ₃ | 10 | 10.43 | 0.3 | 0.12 |
| Q ₄ | 12 | 11.53 | 0.6 | 0.45 |
| Q ₅ | 12 | 11.57 | 0.6 | 0.40 |
| 555 TIMER | 0 | 0 | 12 | 11.34 |

Table 3. Calculated and Measured Values of collector current (I_C).

| Component | Cut-off mode | | Active mode | |
|----------------|--------------------|------------------|--------------------|------------------|
| | Calculated (mA) | Measured (mA) | Calculated (mA) | Measured (mA) |
| Q ₄ | 30 | 35.7 | 0 | 0.13 |
| Q ₅ | 30 | 38.4 | 0 | 0.11 |



Conclusion

An automatic water level control system using transistor switches and 555 timer which takes into consideration the water level in both the overhead tank and reservoir was designed. For anyone willing to carry out further research on this project, we recommend that research be carried out on the control unit to develop alternative means that could effectively receive and process multiple inputs from sensors; and which can also give out multiple outputs to indicators and pumping units. This can be achieved with the use of microcontrollers. This will help in circumstances where the level of more than two tanks needs to be taken into consideration and also where water needs to be pumped to various tanks simultaneously.

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