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AUTOMATIC PRIMING OF CENTRIFUGAL PUMP

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Abstract- *Priming is the precondition to start a centrifugal pump. This process is difficult that makes complexity to start the pump. Most centrifugal pumps use manual priming, which is laborious and lengthy process. The centrifugal pump has one gate valve and two ports to operate the pump effectively. The pump casing must be filled with liquid through the delivery pipe to suction pipe before the pump is started, otherwise the pump will not be able to function. If the pump casing becomes filled with vapors or gases, the pump impeller becomes gas-bound and incapable of pumping. The conventional method of priming is to set a secondary pump (i.e. DC pump) for the priming of the centrifugal pump. However, this is not economical and user friendly method. It requires manual effort to start and stop the secondary pump. The problem can be overcome by using automatic priming. In this system, a priming reservoir is used to store necessary water that requires for priming action, and a solenoid valve is placed between the reservoir and the subjected pump to control the water flow. Microcontroller is used in this system to control all the devices attached to the system and the solenoid valve works as an actuator. A water level sensor is used to check the water level of priming reservoir. If the level is not sufficient for starting the pump, then alarming system activates to detect the problem. If there is sufficient water in the reservoir, then priming is occurred automatically.*

Keywords *Priming, Microcontroller, Automatic Control*

1. INTRODUCTION

Water is an essential resource for all lives on the planet. Of the water resources on earth only three per cent of it is drinkable and two-thirds of the freshwater is locked up in ice caps and glaciers. Of the remaining one per cent, a fifth is in remote, inaccessible areas and much seasonal rainfall in monsoonal deluges and floods cannot easily be used. At present only about 0.08 per cent of the entire world's fresh water is exploited by mankind in ever increasing demand for sanitation, drinking, manufacturing, leisure and agriculture [1]. Centrifugal pump is widely used to lift water. From domestic to industrial purposes it has huge applications. Without proper priming of centrifugal pump it would not be able to work properly and it will consume energy without any work. Traditional methods of water pump priming have involved the use of liquid ring vacuum pump technology. However, the days of rusty, leaking, slow and costly priming of water pumps with associated high maintenance costs is over. For automation in centrifugal pump, automatic priming is a precondition. This project is concerned about automatic priming of centrifugal pump to achieve automation in centrifugal pump. For automatically priming a reservoir is placed over the centrifugal pump named priming reservoir which is operated by a solenoid valve and microcontroller unit. There is an alarming system in this system to detect the fault of the operation. To sense the water level inside the priming reservoir water level sensor is developed and to produce different sound from alarm motor speed is controlled. This method is unique than others because this is easy to build, less complicated in design and highly sensitive than mechanical sensor.

This is fast water pump priming at the touch of a button and the unique feature is that it has a provision to increase or decrease number of sensing unit (probe and transistor) to sense the water level so that one can easily manipulate this device according to his requirements. Moreover, this method has energy saving feature which consumes comparatively low energy than traditional one.

2. DESIGN OF WATER LEVEL SENSOR

2.1 Electrical Conductivity Property of Water

Pure water without ions is an excellent insulator, but not even "deionized" water is not completely free of ions. Water undergoes auto-ionization in the liquid state. Further, because water is such a good solvent, it almost always has some solute dissolved in it, most frequently a salt. If water has even a tiny amount of such an impurity, then it can conduct electricity readily, as impurities such as salt separate into free ions in aqueous solution by which an electric current can flow. It is known that the theoretical maximum electrical resistivity for water is approximately 182 kΩ•m at 25 °C. This figure agrees well with what is typically seen on reverse osmosis, ultra-filtered and deionized ultra-pure water systems used, for instance, in semiconductor manufacturing plants. A salt or acid contaminant level exceeding even 100 parts per trillion (ppt) in ultra-pure water begins to noticeably lower its resistivity level by up to several kΩ•m or hundreds of nanosiemens per meter. The low electrical conductivity of water increases significantly upon solvation of a small amount of ionic material, such as hydrogen chloride or any salt. Any electrical conductivity observable in water is the result of ions of mineral salts and carbon dioxide dissolved in it. Carbon dioxide forms carbonate ions in water. Water self-ionizes, where two water molecules form one hydroxide anion and one hydronium cation, but not enough to carry enough electric current to do any work or harm for most operations. In pure water, sensitive equipment can detect a very slight electrical conductivity of 0.055 µS/cm at 25 °C. Water can also be electrolyzed into oxygen and hydrogen gases, but in the absence of dissolved ions this is a very slow process, as very little current is conducted. While electrons are the primary charge carriers in water (and metals), in ice the primary charge carriers are protons [2].

Water used in daily life has a conductivity property that is why shock is observed when electric line is grounded to water in pond. However, in case of low voltage this shock does not observe in human body. This small voltage can be used as signal transformer. Based on this property of water, water level sensor is developed.

2.2 Water Level Sensor

Water level sensor is such kind of a device which produces a certain voltage due to change of water level. This sensor consists of two parts. They are water level sensor bar and water level sensor circuit.

2.2.1 Water Level Sensor Bar

Figure 1 shows a typical water level sensor. Water level sensor bar consists of a long tube having some extended probes for sensing water level. The height of the water level sensor bar is determined from the design of the water reservoir.

Each probe is placed at equal distance apart of the total height. If the total number of probes is *n* and the height is *l* meter, then the distance between each probe will be

$$X = \frac{l}{n+1} \quad (1)$$

Here 1 is added to provide an extra probe for negative voltage. The probe is made of aluminum, iron or carbon alloy. However, it is recommended to use carbon alloy to withstand against rust for long period of time. Otherwise, maintenance is required to get optimum performance from this bar. Positive voltage has higher tendency of electrolysis and the rate of deposition of dissolved

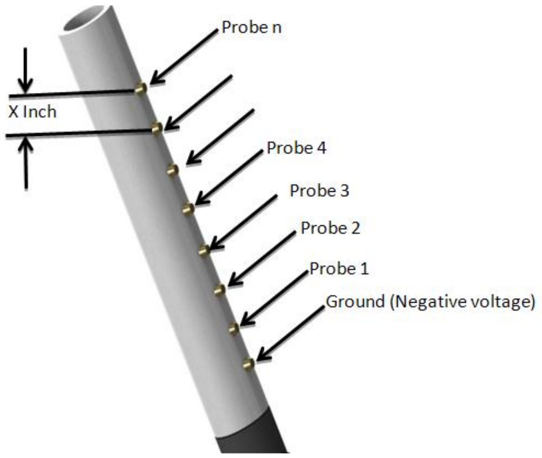

Fig.1: Computer aided design of water level sensor bar

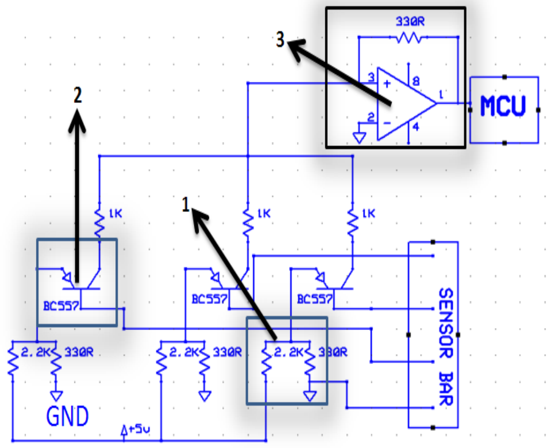

Fig.2: Water level sensor circuit

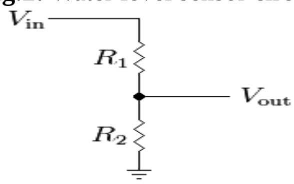

Fig.3: Voltage divider circuit

materials in water on to the surface of probe is greater. Negative voltage is used to keep clean the probe surface, as the rate of dissolving tendency of probe material into solution is too low for low voltage, it can withstand for long period of time.

2.2.2 Water Level Sensor Circuit

Water level sensor circuit consists of voltage divider circuit, transistor circuit, and op-amp circuit. Figure 2 shows the diagram for water level sensor circuit.

Voltage Divider

Microcontroller ADC operates 0v to 2.56v. It is necessary to maintain voltage level within this level for sensing purpose. For operating microcontroller 5v dc supply is required. So to operate sensor with this volt voltage dividing rule is applied in sensor design [3] as shown in figure 3.

The output voltage can be written as

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in} \qquad (2)$$

In this experiment,
For probe 1

$$\therefore V_1 = 0.652 \ volts$$

Voltage dividing circuit for probe 2 is same as probe 1

$$V_2 = 0.652 \ v$$

For probe 3

$$\therefore V_3 = 0.349 \ volts$$

Transistor

A transistor is a semiconductor device used to amplify and switch electronic signals. Transistors are commonly used as electronic switches, both for high-power applications such as switched-mode power supplies and for low-power applications such as logic gates.

In a grounded-emitter transistor circuit, such as the light-switch circuit shown in figure 4, as the base voltage raises the base and collector current rise exponentially, and the collector voltage drops because of the collector load resistor. The relevant equations:

$V_{RC} = I_{CE} \times R_C$, the voltage across the load (the lamp with resistance R_C)

$V_{RC} + V_{CE} = V_{CC}$, the supply voltage shown as 6V

If V_{CE} could fall to 0 (perfect closed switch) then Ic could go no higher than V_{CC} / R_C, even with higher base voltage and current. The transistor is then said to be saturated. Hence, values of input voltage can be chosen such that the output is either completely off, or completely on. The transistor is acting as a switch, and this type of operation is common in digital circuits where only "on" and "off" values are relevant [3].

A negative portion of 5 volt DC source is placed inside the reservoir lower portion. When the level of water is raised it contains the negative voltage of DC source. This voltage is used to switch the transistors attached to the different probes of the sensor bar. Three PNP transistors are used in this experiment where base is connected to the probes of sensor bar. Switching circuit of PNP transistor is shown in figure 5.

Op-Amp

An operational amplifier ("Op-Amp") is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. An op-amp produces an output voltage that is typically hundreds of thousands times larger than the voltage difference between its input terminals [4]. Using op-amp as Summing amplifier in water level sensor is showed in figure 6.

Equation for above diagram:

$$V_{out} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_n}{R_n} \right) \qquad (3)$$

In this experiment three voltage sources are used to calibrate the water level. Voltages are v_1 and v_2 are 0.652 v, and v_3 is 0.349v. The value of resistance used here is 330 ohm and the values of all the resistance are same.

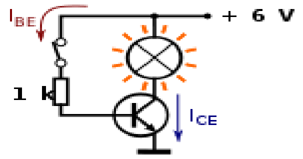

Fig.4: BJT used as an electronic switch, in grounded-emitter configuration.

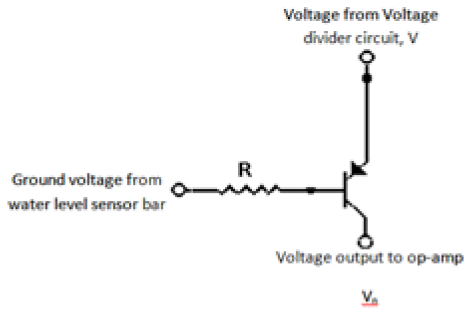

Fig.5: Switching circuit of PNP transistor

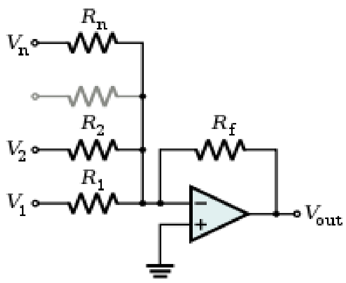

Fig.6: Op-Amp act as summing amplifier in water level sensor

Voltage is getting from transistor where transistor acts as switch.

So, when the single transistor is in switch on condition the nominal equation is

$$V_{out} = \frac{R_f}{R} \times V_1 \qquad (4)$$

In this case the value if reference resistance is 1Kohm and the value of second resistance is 330 ohm, however in practical case output voltage is 1.946V.

So, percentage of error of Op-amp is 1.49%.

Figure 7 shows the voltage versus water level graph.

Table-1: Voltage versus Number of water level graph

LEVEL	VOLTAGE
0	1.859
1	1.946
2	1.9845
3	2.035

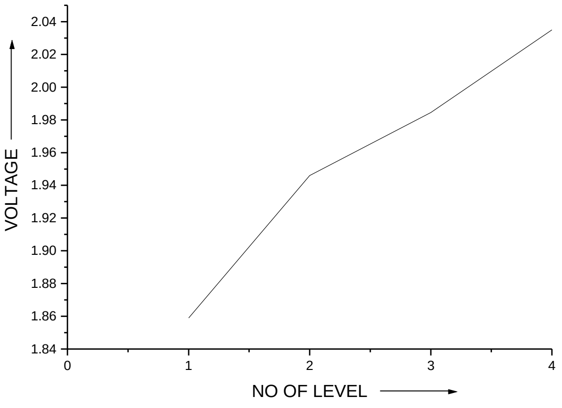

Fig.7: Voltage versus Number of water level graph

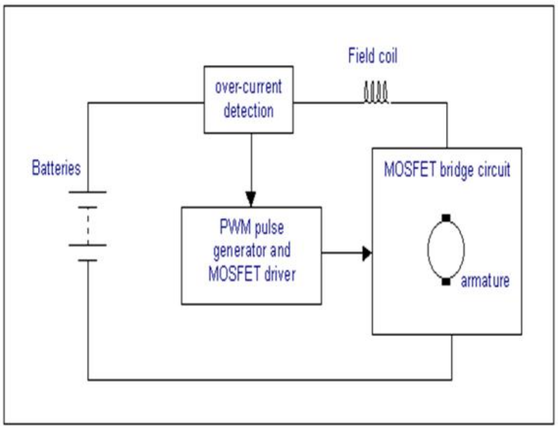

Fig.8: Block diagram of motor speed control

3. DC MOTOR CONTROL DEVICE FOR ALARMING PURPOSE

There are different types of alarming device in market. To produce different sounds from a single alarming device dc motor alarming device is used in this project where different sound is produced by controlling speed of the dc motor.

3.1 Speed Controllers

The purpose of a motor speed controller is to take a signal representing the demanded speed, and to drive a motor at that speed. The controller may or may not actually measure the speed of the motor. If it does, it is called a Feedback Speed Controller or Closed Loop Speed Controller, if not it is called an Open Loop Speed Controller. Feedback speed control is better, but more complicated, and may not be required for a simple alarming system.

Motors come in a variety of forms, and the speed controller's motor drive output will be different dependent on these forms. These motors are generally series wound, which means to reverse them. Figure 8 shows the block diagram of motor speed control.

Motor speed is regulated by pulse width modulation system using microcontroller. Pulse width diagram is shown in figure 9. Microcontroller produces different pulse width for different conditions and manipulated the speed of the alarming motor. Figure 10 shows the variation in duty cycle for changing speed.

For the above diagram,

$$Duty\ Cycle = \frac{T_H}{T_t}$$

$$Frequency = \frac{1}{T_t}$$

In this study ATMEGA32 microcontroller (µc) is used and the frequency of pulse width modulator is determined by the following equation

$$f = \frac{F_c}{2 \times P \times 2^B} \times 100\% \qquad (5)$$

Where,

F_C= Crystal frequency

P= Prescaler Value

B= 8, 9 or 10 (Constant)

f= Required frequency

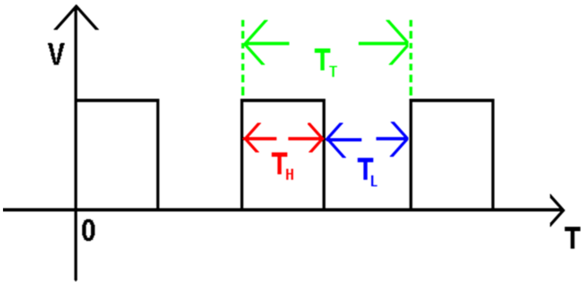

Fig 9: Pulse Width diagram

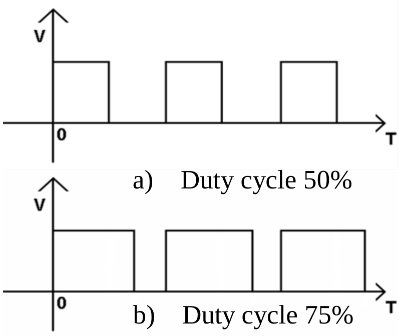

Fig.10: Variation in duty cycle for changing speed

Duty cycle for pulse width modulation is determined by the following equation

$$Duty\ cycle = \frac{Pwm1a}{2^B - 1} \times 100\% \qquad (6)$$

Where,

Pwm1a= Values of Pwm1a register

B= 8, 9 or 10 (Constant)

4. SCHEMATIC DESIGN OF CENTRIFUGAL PUMP AUTOMATION

Centrifugal pump is the most common mechanical device found in every house in modern age. It is used for lifting water from underground house tank to overhead house tank in domestic buildings. Moreover, it has huge application in industry and agriculture purpose. Agriculture is the biggest consume of water and about 70% of water is consumed by agriculture [5]. Centrifugal pump needs priming for starting. This process is critical and laborious process. Moreover, it is recommended to operate centrifugal pump for optimum period of time as it consumes high electric power and to reduce the loss of valuable purified water. The automation of centrifugal pump is divided in two parts i.e. automatic starting system for centrifugal pump, and overhead tank control The apparatus used for Centrifugal pump automation i.e. A reservoir for priming action of centrifugal pump, solenoid valves, water level sensor, DC motor alarming system, microcontroller unit.

4.1 Reservoir for priming action of centrifugal pump

A reservoir is required for automatic priming of centrifugal pump. For automatic priming foot valve of centrifugal pump is trimmed. Required volume of water is stored in this reservoir and there is gate for discharging water from this reservoir to pump. This pump is located to over the centrifugal pump so that water can flow under the action of gravity force. When pump will start water comes through this gate and fills up this reservoir.
Figure 11 and figure 12 show the schematic and circuit diagram of automation of pump respectively.

4.2 Solenoid valves

Solenoid valve is required for controlling flow of water. There are two solenoid valves in this system to control flow of water from reservoir to pump and pump to overhead tank. One valve is attached to the below of priming reservoir which open the gate when water comes from reservoir to pump and close the gate after filling up the reservoir. Another valve is attached to the pump and overhead tank line. This valve is normally closed during filling up the priming reservoir and opens when water directly flows to overhead tank. This valve is helpful to determine the discharge rate of pump.

4.3 Water level sensor

Water level sensor is the most important device among all the devices. This device senses the water level in priming reservoir and send data to microcontroller. Based on these data microcontroller decided to operate solenoid valves and pump switches.

4.4 DC motor alarming system

DC motor alarming system is the most suitable alarming device in this system because of it can produce more intensive sound than other alarming device. However, by regulating motor speed of this device we can produce different types of sound for different cases. In this system, for performing different steps different sounds are produced so that if a device is failed, we can easily figure out that device.

4.5 Microcontroller Unit

Microcontroller is programmable device which can operate according to a program written for it. By writing program we can provide the brain in this device so that it will capable for making a decision. Logic is set according to the demand of the project and sequential operation is repeated by this device. In this project Microcontroller takes all the decision and operates solenoid valves according to sense the water level of priming reservoir.

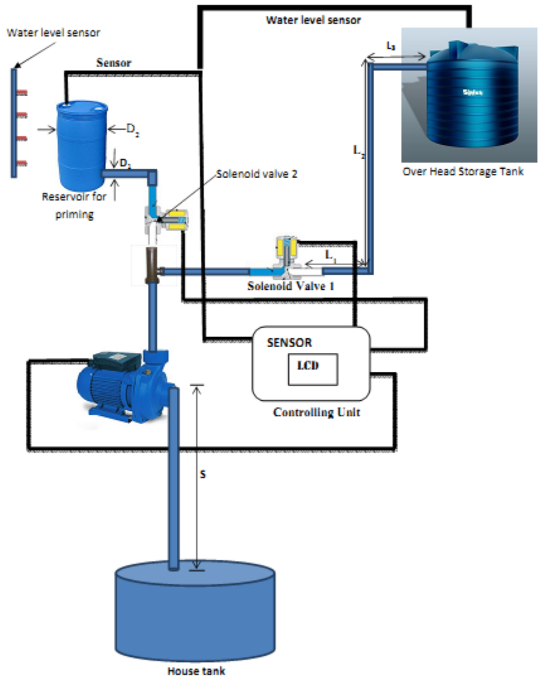

Fig.11: Schematic Diagram of Pump Automation

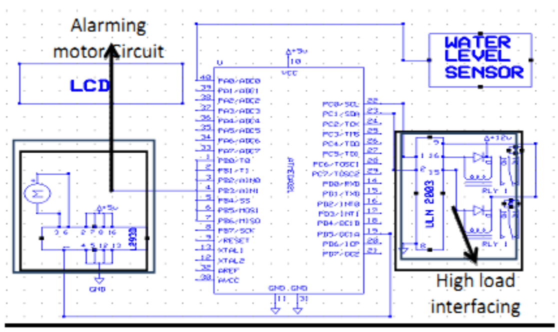

Fig.12: Circuit diagram of pump Automation

4.6 High load interfacing devices

Microcontroller operates low voltage circuit. However, to operate high voltage circuit or devices high load interfacing devices are required. In this project, L293D is used for interfacing alarming motor with microcontroller. ULN 2003 and relay are used to interfacing pump and solenoid valves with microcontroller. ULN2003 is used to operate to operate three relays with a single IC.

5. WORKING PROCEDURE

Working procedure for automation of pump consists of two parts, automatic starting system for centrifugal pump and overhead tank control. They are briefly discussed below.

5.1 Working procedures of Automatic starting system for centrifugal pump

Automatic starting system for centrifugal pump consists of a water level sensor, microcontroller unit, solenoids valves, LCD and alarming device. Figure 13 shows the flow chart for automatic priming.

a) First microcontroller read water level sensor which is immersed in priming reservoir.

b) If there is lack of available water for priming alarming device is activated automatically and produces a distinct sound.
c) After that, solenoid valve1 which is located under the priming reservoir is opened and water flows through it from reservoir to pump and complete the priming action.
d) Before starting the pump, solenoid valve 2 which is the gate of water flow towards overhead tank is closed.
e) When pump is open water flows directly to priming reservoir and fills the reservoir.
f) After filling, alarming device produce another type of sound to ensure filling status and after that solenoid valve1 is closed and solenoid valve 2 is opened.
g) Finally, the microcontroller calls the overhead tank control (OTC) function to complete rest of the part.

5.2 Working procedures of overhead tank control

Overhead tank control system consists of a Water level sensor, Microcontroller unit, LCD, and Alarming device. Figure 14 shows the flow chart for overhead tank control.

a) Via water level sensor it shows current level of water in percentage.
b) It produces different sounds in different level
c) After filling up overhead tank it automatically shut down the pump and produce a distinctive sound so that shutdown process can be understand.
d) When overhead tank is empty it automatically turn on the switch of the pump and produce a different sound so that we can understand that pump is in turn on condition.

6. CONCLUTION

A centrifugal pump has been developed with automatic priming option. The system does automatic priming successfully before starting the centrifugal pump. It is found that automatic priming reduces the laborious process of starting of a centrifugal pump. Microcontroller program gives the intelligence to the pump. By sensing water levels this system has ability to shut down the pump when desired water level is achieved. As a result this system reduces the energy consumption because of running motor for extended periods of time and the corresponding losses. This system can be implemented for the household purpose but the best use of this system is to control pump used in irrigation purpose. Moreover, this system also can be introduced to industry, where centrifugal pumps are used for processing works. Although this system is little expensive than traditional on-off method, the multiple functions of this system far outweigh of its disadvantages.

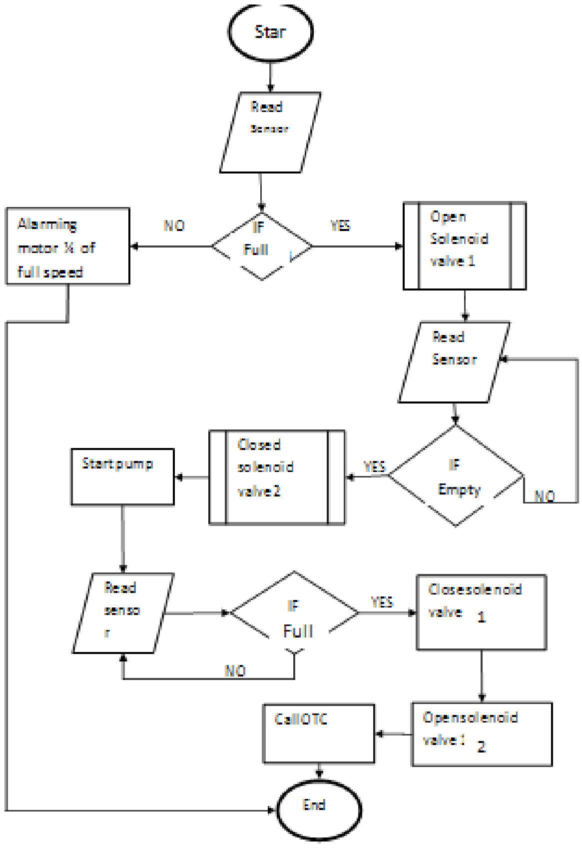

Fig.13: Flow chart for automatic priming

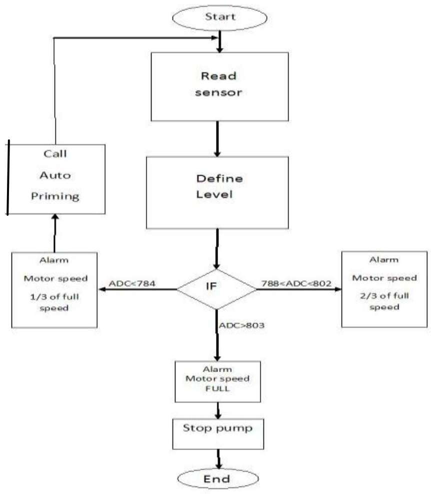

Fig.14: Flowchart for Overhead tank control

7. REFERENCES

[1] Fry, Carolyn the Impact of Climate Change: *The World's Greatest Challenge in the Twenty-first Century 2008*, New Holland Publishers Ltd.
[2] A. Crofts (1996), *Lecture 12: Proton Conduction, Stoichiometry*, University of Illinois at Urbana-Champaign.
[3] Robert L. Boylestad, *Electronics - Introductory Circuit Analysis*, 10th Edition Prentice Hall 2002
[4]Thomas G. Beckwith, *Mechanical measurements*, fifth edition
[5] Molden, D. (Ed). Water for food, Water for life: *A Comprehensive Assessment of Water Management in Agriculture*, Earthscan/IWMI, 2007.