DEVELOPMENT AND CONSTRUCTION OF 220-VOLT, 2.5-HORSEPOWER LIQUID PUMP CONTROLLER

A. I. Popoola* and I. I. Ogunlade

*Department of Physics, Federal University of Technology, P. M. B. 704 Akure, Ondo State. Nigeria.

*E-mail: Wumag_2000@yahoo.com

Abstract

A controller, capable of monitoring and controlling the activities of 220V, 2.5horsepower liquid pump was developed and constructed. It contains a pair of wire, a comparator (LM311), two transistors (BC109 & TIP41), four NAND logic gates (4011), LM35 and two 6V/600mA relays. The wire pair served as liquid level sensor, while the LM35 served as thermal sensor to monitor the temperature of the pump winding. The controller was designed such that whenever it is connected to a liquid pump, the pump will be "ON" only if the liquid level is below the liquid level sensor and the winding temperature of the pump is 10% below its rated upper limit. If the winding temperature attempts to rise above the 10% margin, while the liquid level is still below the liquid level sensor, the controller stops the pump temporarily to allow the coil to cool down. The pumping action is resumed as soon as the temperature falls below the 10% set margin. This process is carried out several times until the liquid level rises to the level of the liquid sensor, at which time the controller finally disengages the pump.

Keywords: *Closed-loop, monolithic, offset nulling, combinational logic, darlington pair.*

Introduction

In recent years the importance of automatic control systems have been increasing rapidly in all fields of science and engineering. Control systems act as catalyst in promoting progress and development. It has enhanced rapid production and improved the quality of manufactured goods, which has influenced our way of life. Control systems can be defined as devices that regulate the flow of energy, matter or other resources. Their arrangement, complexity and appearance vary with their purpose and function. In general, control systems can be categorized as being either *open loop* or *closed loop*. The distinguishing feature between these two types of control systems is the use of feed back comparison for closed loop system operation (Shinners, 1992).

---

*corresponding author

The importance and use of liquid pumps in many terrains especially in agriculture, construction sites, laboratories and in the domestic domain can never be over-emphasized. Liquid pumps are available in various sizes and power ratings. These pumps, especially those meant for domestic use are available at affordable cost. Despite the availability of this much-needed device, the utility being derived by its users have not been encouraging. The problem is twofold, manual operation of the pumps and the absence of temperature control circuitry.

For example in Nigeria or developing countries generally, there have been many occasions that the pump will be switched "**ON**", and during the pumping process, there could be power failure due to erratic power supply in the country. Many times due to oversight, the pump may be left without been disconnected. When power is restored (in many cases at odd hours), the pump could have worked for several hours before being noticed, by this time, the pump may have over-worked. It is usual for electrical equipment to generate heat when operated for a long period of time; several cases of this nature have led to water wastage and destruction of many pumps. If the pumps have been equipped with facility for automatic operation, temperature monitoring and control, then the problems cited above would not have arisen.
It is therefore the aim of this paper to present the development and construction of a circuitry that is capable of achieving automatic operation with any manually operated 220V, 2.5horsepower liquid pump while at the same time ensuring temperature monitoring and control of the pump winding to prevent damage to the pump.

Design Structure

Figure 1 is a flowchart showing signal routes and all decision-making level in the controller. Figure 2 shows the block diagram of all the various stages involved in the realization of the controller.
There are two sensors in fig. 2, **S1** and **S2**. S1 is a pair of wire that operates like a switch. Whenever the water level rises to the level of S1, the two wires are shorted (closed) together. When S1 is closed, a voltage corresponding to this closed/on position is generated by the water level sensing circuitry. S2 (LM35) is a high precision monolithic temperature sensor. It is bonded with the chamber where the coil of the pump is housed. The thermal voltage generated by S2 is fed into a comparator. The comparator compares this voltage with a variable reference voltage that is 10% below the voltage that correspond to the upper temperature limit of the pump. The output voltage from the comparator that has been made digitally compatible and the voltage generated by the water level sensing circuitry are both fed to a set of combinational logic circuits (decoding logic). This is where the appropriate voltage is generated, depending upon the conditions of S1 and S2.

The voltage from the decoding logic circuit is used to drive two relays, via two transistor buffers, connected as a darlington pair. The two relays are connected in parallel to meet the power consumption requirement of the pump. An ac voltage of 220V is maintained across the pump for a period of time determined by S1, which monitors when the tank is filled to its installed capacity and S2, which monitors when the temperature of the pump winding is 10% below its maximum rated value.

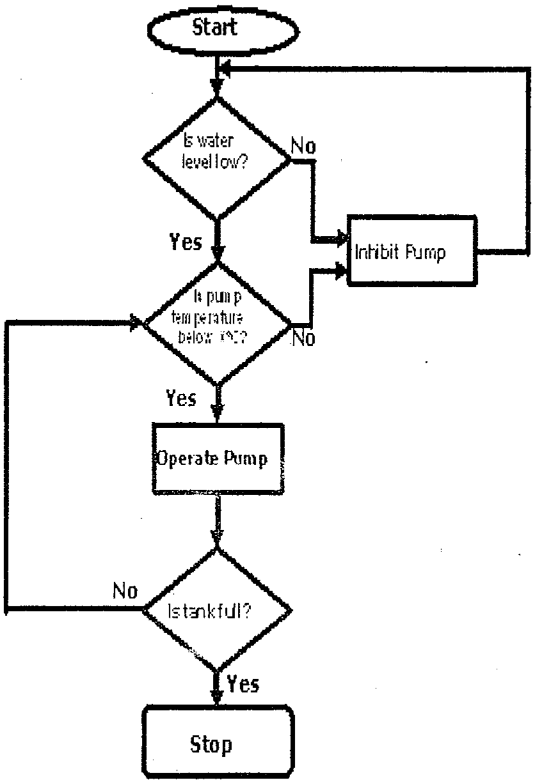

Fig.1: Flowchart for the operation of the controller

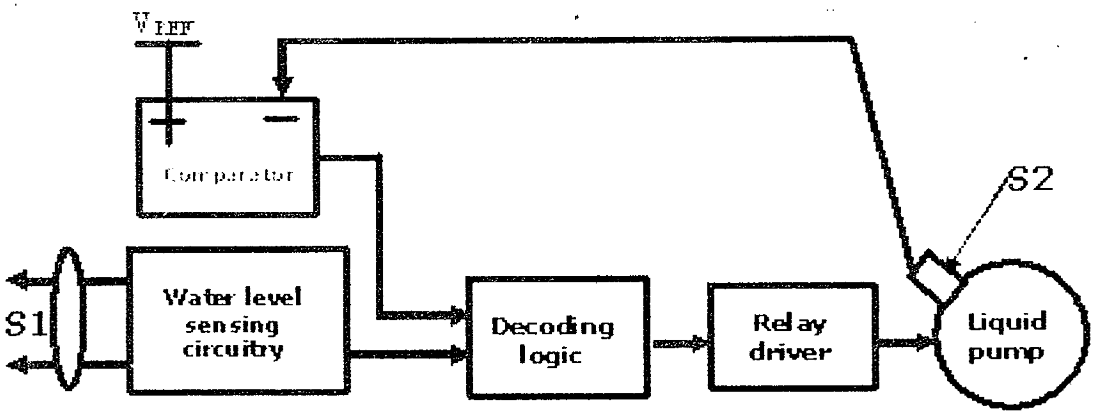

Fig. 2: Block diagram of the controller

Circuit Description

The complete circuit diagram of the controller is shown in fig. 3. When the liquid level is below S1, point P1 will be at 9V. This is because S1 is being used as a switch, and with the liquid level below S1, it is open. With point P1 at 9V, point P2 will be at 0V and point P3 will be at 9V. Supposing that while S1 is open, if the temperature recorded by S2 is below the 10% margin set via VR1, then point P5 will be at higher voltage than point P4. Due to this condition, point P6 will be at 9V. With points P3 and P6 at 9V, point P7 will go to 0V. This will subsequently put point P8 at 9V and the two relays will be switched "**ON**".

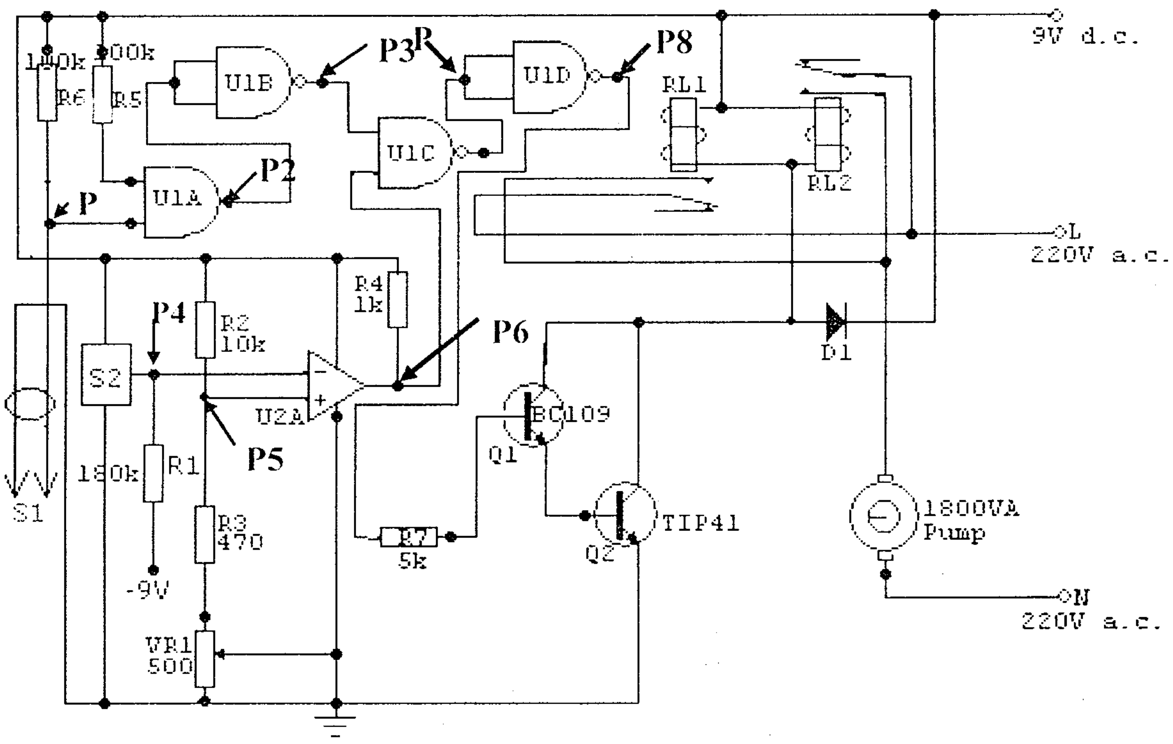

Fig. 3: Circuit diagram of the liquid pump controller

However, if the temperature recorded by S2 is a little above (in order of μV) the 10% level, while the liquid level is still below S1, then the voltage at point P4 will be higher than that at point P5. This will automatically make point P6 to drop to 0V. With this condition, point P8 will also drop to 0V and the relays will be "**OFF**". On the other hand, if the temperature of S2 is still below the 10% upper temperature limit of the pump when the liquid reaches the level of S1, point P1 will immediately attain 0V, while points P2, P6 and P7 will switch to 9V. Points P3 and P8 will attain 0V and with this condition, the relays will be "**OFF**".

Resistors R2 (10kΩ), R3 (470Ω) and VR1 (500Ω) are all voltage dividers, which permits the user to setup the voltage at point P5 (V_{REF}), which is the voltage corresponding to the 10% temperature value below the upper limit of the pump connected to the controller. The voltage from S2 was converted to a digital signal by a comparator. The comparator (LM311) used in the development of the controller exhibits high speed, low power consumption and it has open collector output configuration. The provision for offset nulling on its pins 5 and 6 was used to adjust its output to zero for zero input voltages using the manufacturers recommended network (Franco, 1988). The output of the comparator was pulled-up by R4 (1kΩ) resistor. NAND gates U1C and U1D were included to provide voltage level distinction and the required current needed to drive the relays through the buffer transistors Q1 and Q2 (BC109 & TIP41). Diode, D1, (1N4001) was included in the design to prevent Q1 and Q2 from the damage that could occur as a result of inductive kick from the relay coils.

Choice of thermal sensor S2

Nearly all-electrical properties of a device vary as a function of temperature and could in principle be employed as a temperature sensor (Worbschall, 1987). The requirements of operation over a wide temperature range with high *sensitivity*, *reproducibility* and *linearity* greatly limit the possibilities, especially if *cost*, *size* and *ease of use* are also considered.

Semiconductor thermal sensors were considered for use in this design because their response to temperature is very linear and the sensors are extremely cheap. Semiconductor temperature sensors exist in two main types: these are *temperature sensitive voltage sources* and *temperature sensitive current sources*. An example of the first type is LM35 while an example in the other type is AD590J and AD592 (Hall, 1989; Usher and Keating, 1996). All the sensors have a working range between -55°C to 150°C, over which their accuracy is about ±1°C (National Semiconductor Corporation, 2000 and Intersil Americas Inc., 2002).

The advantage of the temperature sensitive current-source types over its temperature sensitive voltage source counterpart is that the former is more suitable for remote sensing because voltage drop in long connecting wires will not have any effect on its output value (Hall, 1989 and Intersil Corporation, 2002). However, current source sensors are more expensive to use, because of the need to convert their output current to proportional voltage in many applications. Also, the output of the sensor is not calibrated directly in degree Celsius. Therefore, the need for offsetting and calibration of its output voltage for thermometry use further increases its cost of usage. The voltage source temperature sensors, especially the National LM35 used in this design requires only a power source and a resistor to function as a full-range (-55°C to 150°C) Centigrade temperature sensor (National Semiconductor, 2000).

Calibration and testing

S2 does not need any calibration as the sensor had been trimmed and calibrated for an output voltage of 10mV/°C at wafer level (National Semiconductor, 2000). The only calibration required and which was carried out on the controller was done at the *comparator* stage, U2A (Fig. 3). The voltage at point P5 must be supplied by the user. This is done by adjusting VR1. To make this procedure easy for users, the controller was powered and the voltage corresponding to different temperature values was monitored on a voltmeter and the knob on VR1 was graduated in degree centigrade accordingly.

Hence, after installing the controller all that the user needs to do is to adjust VR1 knob to the marked point that match the specified maximum rated temperature of the pump connected to the controller. As an example, if a pump rated for safe operation at 50°C maximum coil temperature is connected to the controller, and then VR1 should be set to 50°C position. At 50°C, the voltage at S2 output will be 500mV. Therefore setting VR1 to 50°C marked position will internally put point P5 at 450mV (10% below 500mV). The controller has being in constant use since August 2005 and it has worked satisfactorily without any noticeable system or component failure.

Conclusion

This report has shown that any manual operated liquid pump can be upgraded to operate automatically, with facility for temperature monitoring and control. The beauty of the design offered in this study is that the lifespan of any liquid pump connected to the controller would be elongated, and at the same time, the controller together with the pump will ensure constant liquid supply without any manual interference.

All the materials used in the construction of the controller were locally sourced and the cost of achieving the entire construction was minimal (under $5). The controller demonstrated an excellent performance and was found to be thermally stable. Though the design reported here was targeted towards 220V, 2.5horsepower liquid pump. It can be easily modified to accommodate higher power liquid pumps. This can be achieved by adding more relays and changing the TIP41 transistor to a higher power one such as 2N3055. Also with a little modification to the controller and putting additional sensors such as soil moisture probe and sensor for sunlight intensity, the controller can be adapted to work as an integrated irrigation pump controller.

Reference

Shinners, M. S., (1992). Modern Control Systems: theory and design. John Wiley and sons Inc., New York, 1-5.

Franco, S., (1988). Designing with Op-amp and analogue IC's. McGraw-Hill Books, New York. U.S.A. 1-10, 295-300.

Darold, W., (1987). Circuit Design for Electronic Instrumentation. McGraw-Hill Inc., New York. USA, 59-75.

Hall, D. V., (1989) Digital Circuits and Systems. McGraw-Hill Publishing Company, New York. USA. 324.

Usher, M. J. and Keating, D. A., (1996). Sensors and Transducers; Characteristics, Applications, Instrumentation and Interfacing. Macmillan Press Limited, Hampshire, 89-90.

National Semiconductor Corporation, (2000) LM35 Precision Centigrade Temperature Sensors. Published by National Semiconductors Corporation Americas USA. (www.national.com), 1-5.

Intersil Americas Inc. (2002). 2-Wire, Current Output Temperature Transducer. Published by Intersil Corporation, California, USA. (www.intersil.com).1-10.