# AN AUTOMATIC SAFETY CONTROL FOR IMMERSION WATER HEATER

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## ABSTRACT
*The heating of liquids, especially water, is carried out in the homes and industries for various reasons. The domestic water heater has become a near- ubiquitous appliance in the Nigerian homes. An important source of concern with this appliance is the frequent possibility of outbreak of fire due to negligence on the part of the user. This paper describes an immersion water heater that is free from such hazards. The safety condition is achieved by incorporating a device, which automatically switches off power from the heating element when the water level drops below a certain mark.*

**KEYWORDS:** Electronic heating, control

## 1.0 INTRODUCTION.
A common water-heating appliance in Nigerian homes is the portable coiled immersion water heater. Through mostly human error, the use of this appliance has resulted in fire outbreaks many of which were destructive to lives and property. The misuse of the appliance consists mostly of negligence on the part of the user to switch off the heater at the appropriate time.

Forgetfulness on the part of the user to disconnect the heater from the mains during power outage is another major source of misuse. This negligence generally leads to the boiling away of the total water content of the container, or a critical volume of it, such that the container is exposed to greater levels of heat generated by the heater thereby leading to the deformation or origination of the container. Fire from such ignited containers can spread to nearby objects and the process has been known to have developed into full blown fire disasters.

Developments on water heater control elsewhere [5],[6],[7] have tended to ensure a near-constant temperature of the liquid rather than achieving a complete disconnection from the power supply that this work addresses. This work achieves an electronic safety control unit that is capable of switching off an immersion water heater when the level water in the container reduces below a certain mark on the heater. The control circuitry form an integral part of the appliance.

## 2.0 SYSTEM BLOCK DIAGRAM
The most widely used immersion water heater in the Nigerian market in its current form is depicted in the diagram of figure 1. It has been constructed without adequate attention being paid to the safety of the user and the environment when the situation described in section 1.0 arises.

The block diagram of the proposed control unit is depicted in figure 2 while the corresponding schematic diagram is given in figure 3.

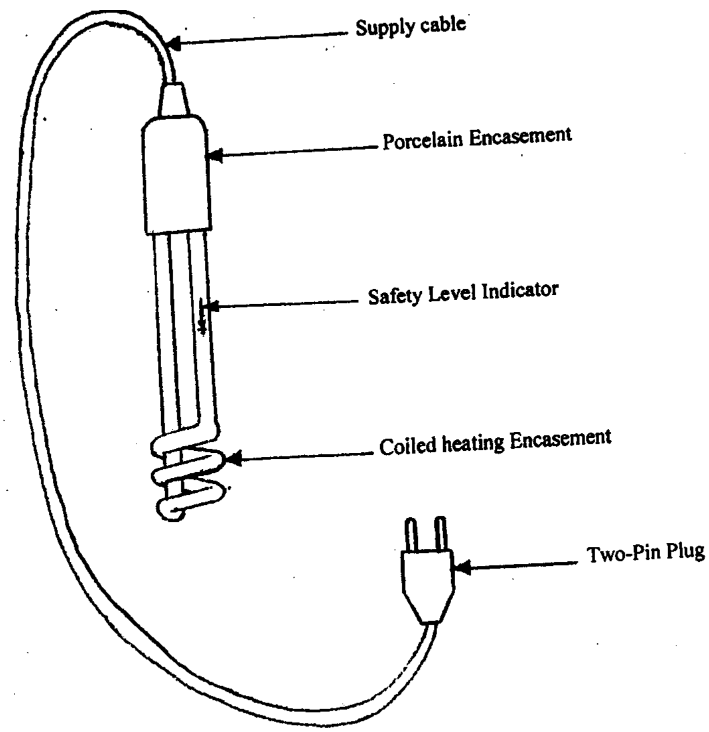


*Fig.1: Heater without control Unit*

## 2.1 The probes.

The probes play an important role in the realization of the control unit. The probes constitute the sensor that detects the absence or the presence of water and causes the rest of the circuit to take the appropriate action. An appropriate type of probes must be selected for the circuit to perform well.

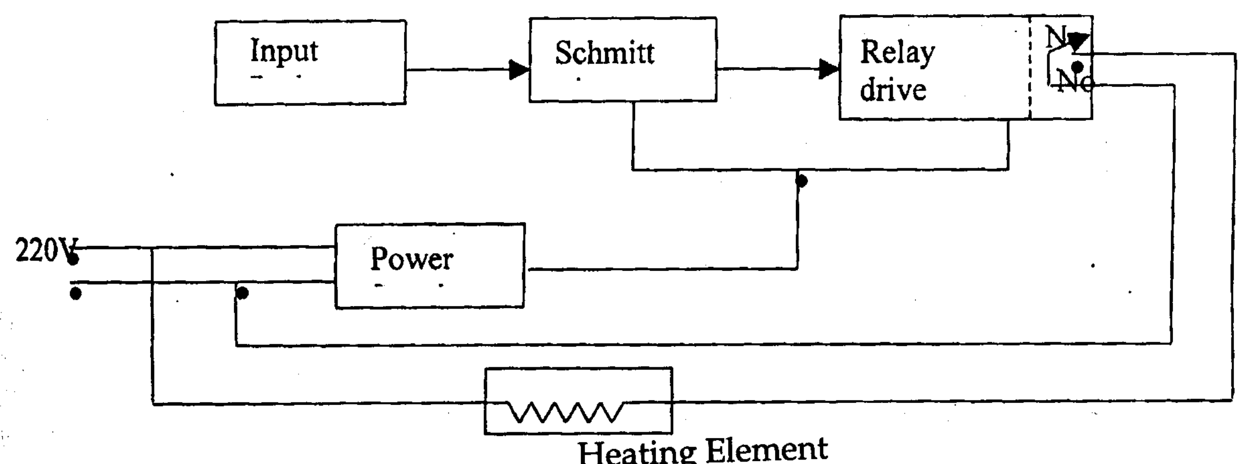


***Fig. 2*** *Block diagram of the Control unit.*

The probes to be used should be inert electrodes [1]. This refers to electrical conductors which remain passive or chemically stable when electricity passes through them into another substance or vice-Versa. Inert electrodes are commonly used in food processing and in the manufacturing of in chemicals. The platinum material is used probe for this work.

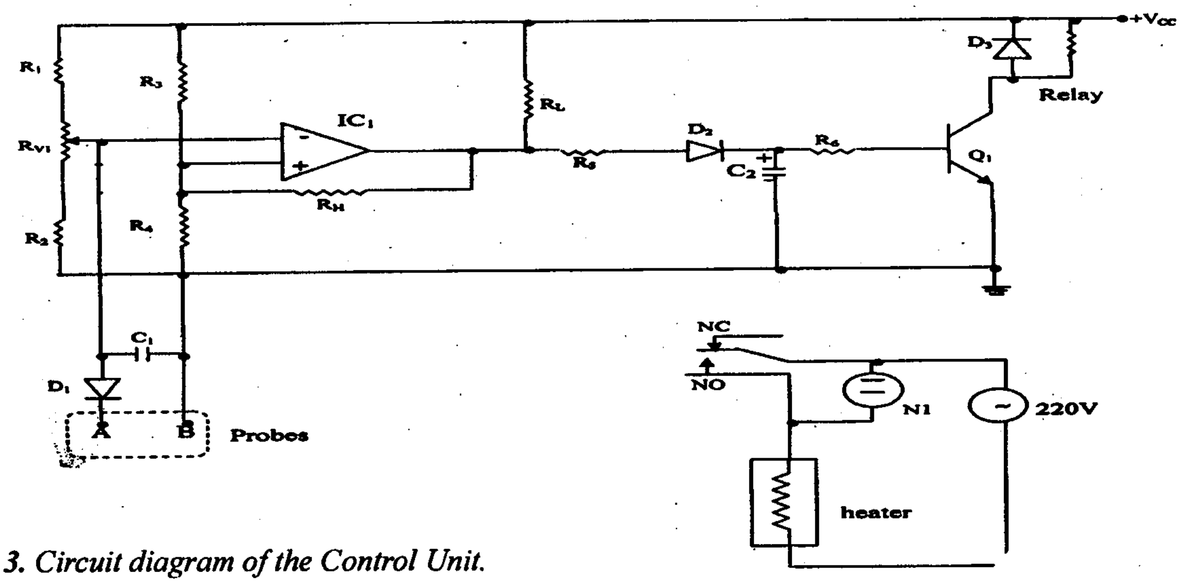


*Fig. 3. Circuit diagram of the Control Unit.*

The platinum wire is embedded in a plastic material and this arrangement is attached to the body of the appliance (fig.8).

The probe is in physical contact with water. The presence or absence of the water is detected by the probes. The conductance of the water needs to be obtained in order to set an appropriate reference point for the Schmitt trigger comparator [2]. The arrangement shown in figure 4 is used for this measurement. The results are displayed in tables 1 to 4. The tables show clearly that the conductance of the water increases (i.e. The resistance decreases) as the temperature is increased as well as when the water contains more impurities.

Due to the proximity of the probe wires to the ac supply lines it was observed during measurement that ac noise became super imposed on the probe signals. The diode $D_1$ was thus added to rectify any ac signals thereby preventing ac electrolysis which can destroy the platinum electrodes. The capacity $C_1$ was used to filter out any ripple voltage that may appear at the comparator inputs.

**2.2 The Schmitt trigger**

The Schmitt trigger, which is a comparator with hysteresis, is built around ICI (LM39) The hysteresis [3] is necessary as it reduces sensitivity of the circuit to noise and also help in reducing multiple transitions at the output when changing states. The circuit representing the comparator stage is depicted in figure 5. It should be noted that the pull-up resistor $R_L$ is necessary because the comparator used is an open collector type. It is instructive to take a close look at the operation of the Schmitt trigger. The equivalent operational circuit of the comparator is depicted in figure 6 [8]. The transistor Q is the internal output transistor of the comparator.

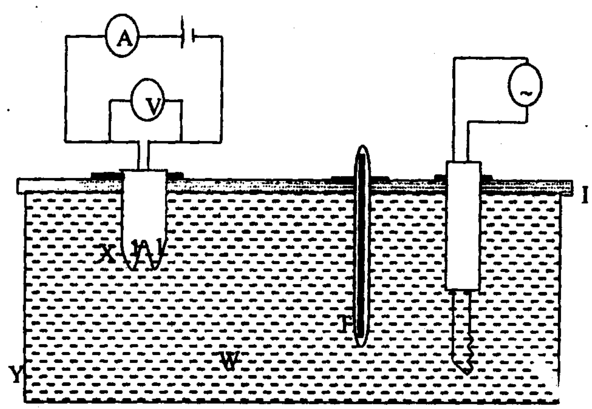


***Fig.4*** *Scheme for measurement of Conductance of water*

Key: T (thermometer), H (immersion heater), Y (plastic vessel), I (insulating material), W (water), X (platinum electrodes),A(ammeter), V (voltmeter).

**Table 1**: Soft water at 26. 4°C

| V (V) | I (mA) |
|---|---|
| 8.41 | 0.69 |
| 8.40 | 0.71 |
| 8.38 | 0.70 |
| 8.37 | 0.73 |
| 8.38 | 0.67 |
| 8.38 | 0.63 |
| 8.38 | 0.77 |
| 8.39 | 0.69 |
| 8.39 | 0.72 |
| 8.37 | 0.67 |
| V (average) =8.38V | I (average) =0.70mA |
| $R(average) = \frac{8.38}{0.0007} = 11971\Omega$ | |

**Table 2**: Soft water at 96.2°C

| V (V) | I(mA) |
|---|---|
| 8.37 | 0.96 |
| 8.37 | 0.99 |
| 8.37 | 1.06 |
| 8.37 | 1.05 |
| 8.37 | 1.03 |
| 8.38 | 1.08 |
| 8.37 | 1.07 |
| 8.37 | 1.01 |
| 8.37 | 0.96 |
| 8.38 | 1.00 |
| V (average) = 8.37V | I (average) =1.02mA |
| $R\ (average) = \frac{8.37}{0.00102} = 8205\Omega$ | |

**Table 3**: Hard water at 26.4°C

| V (V) | I (mA) |
|---|---|
| 8.27 | 2.30 |
| 8.28 | 2.10 |
| 8.29 | 2.06 |
| 8.28 | 2.12 |
| 8.27 | 2.21 |
| 8.26· | 2.41 |
| 8.37 | 1.93 |
| 8.30 | 1.96 |
| 8.27 | 2.39 |
| 8.28 | 2.22 |
| V (average) = 8.28V | I (average) = 2.17mA |
| $R\ (average) = \frac{8.28}{0.00217} = 3815\Omega$ | |

**Table 4**: Hard water at *98.2°C*

| | |
|---|---|
| 8.08 | 5.10 |
| 7.84 | 5.30 |
| 7.94 | 5.00 |
| 7.85 | 5.43 |
| 7.97 | 5.31 |
| 8.10 | 5.23 |
| 8.09 | 5.43 |
| 8.09 | 5.43 |
| 8.08 | 5.55 |
| 8.08 | 5.45 |
| V (average) = 8.01V | I (average) = 5.32mA |
| $R\ (average) = \frac{8.01}{0.00532} = 1503\Omega$ | |

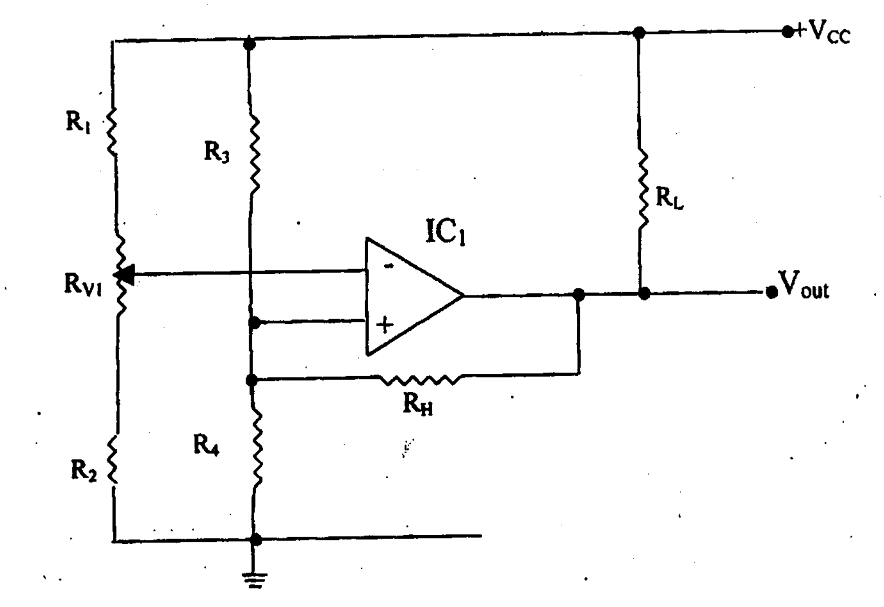


***Fig.5: The Schmitt trigger***

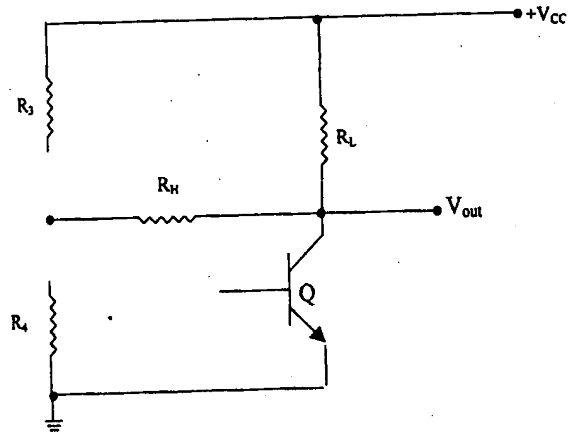


*Fig.6: Equivalent circuit of the Schmitt trigger*

The comparator is required to switch between + $V_{cc}$ and ground. If $V_{out}$ must switch close to + $V_{cc}$ then $R_L << R_H$ ----- (1)

The voltage at the inverting terminal of 1 $C_1$ is equal to

$$V- = \frac{V_{cc}R_2}{R_1+R_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

It should be observed that the effect of the wiper arm of the variable resistor $R_{VI}$ is included in equation (2). The effect of the insertion of the probes inside the water causes the voltage expressed by equation (2) to vary. This voltage is compared with a reference value *($V_{ref}$)* which is the voltage at the non- inverting terminal of the comparator. Let us consider the two situations when the comparator's output, $V_{out,}$ is either low or high.

(i) When V- > $V_{rer}$ the comparator's output is low i.e. the internal transistor Q is switched on. The voltage at the non-inverting terminal is given by

$$V_{+min} = V_{ref} = \frac{V_{cc}(R_4//R_H)}{R_3+R_4//R_H} \quad (3)$$

It should be note that equation (3) also gives the minimum value of the voltage at the non-inverting terminal of the comparator.

(ii) when V-< $V_{ref}$ the internal transistor of the comparator is turned off and $V_{out}$ = + $V_{cc}$. The voltage at the non-inverting input of the comparator is then maximum and is given by

$$V_{+max} = \frac{V_{cc}R_4}{R_4+R_3//(R_H+R_2)} \quad (4)$$

The hysteresis of the comparator is the difference between equation (4) and equation (3) and s expressed by

$$V_{+max} - V_{+min} = V = \frac{V_{cc}R_4}{R_4+R_3//(R_H+R_2)} - \frac{V_{cc}(R_4//R_H)}{R_3+R_4//R_H} \quad (5)$$

## 2.3 The Relay Driver

The relay-driving network is indicated in the circuit of figure 7.

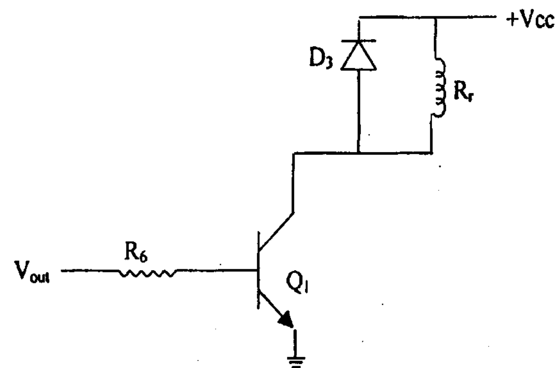


*Fig.7: Relay Driver network.*

The diode $D_3$ protects the transistor $Q_l$ from over voltage caused by the sudden seizure of the flow of current in the relay when $Q_1$ switches high. The relay has a dc resistance given by $R_r$ so that when the transistor $Q_1$ is switched on its collector current is given by

$$I_c = \frac{V_{cc}}{R_r} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

The base current of the transistor is expressed as

$$I_B = \frac{V_{out}-V_{BEsat}}{R_6} \quad \ldots\ldots.. (7)$$

The condition for the saturation of a bipolar junction transistor (BJT) is given by [2], [4]

$$\beta_F I_B > I_c \quad \ldots\ldots\ldots\ldots\ldots (8)$$

By substituting equations (6) and (7) into the inequality (8) we find that the range of resistor R, which will ensure the switching of $Q_1$ is given by

$$R_6 < \frac{B_F R_r(V_{out}-V_{BEsat})}{V_{cc}} \ldots\ldots\ldots (9)$$

## 3.0 MEASUREMENTS AND ADJUSTMENTS

The platinum electrodes used have already been characterized as the results displayed in tables 1-4. The variable resistor $Rv_1$ was adjusted under the following conditions:

### 3.1. Electrodes out of water

When the electrodes A, B are taken out of water, $Rv_1$ was adjusted until the voltage at the inverting terminal of the comparator $V_-$ became greater than the voltage at the comparator's non-inverting terminal, $V_+$. It was observed that latching, which is the failure of the comparator to return to its initial output state when a triggering input is removed, occurred for voltages of $V_-$, slightly higher than $V_+$. The adjustment of $Rv_1$ continued until the latching effect ceased.

### 3.2. ELECTRODES IN CONTACT WITH WATER

When the electrodes A, B are in contact with water, a weak current $I_w$, flows through the water. This gives rise to a shunt resistance $R_w$, which is connected between the wiper arm of $R_{v1}$ and ground. The behaviour of the circuit is modified by this effect. The potentiometer $R_{v1}$ is adjusted until the switching of the relay is observed.

### 3.3 Delay Effect

It was observed that the turbulent surface of boiling water produced a random making and-breaking of contact with the probes. This gave rise to chattering of the relay. This problem was solved by adding a snubber ($R_6C_2$) network to the circuit to produce suitable time delay between any two successive contacts. A delay time of about 1.5 seconds was found to be adequate.

A pictorial drawing of the water heater with the safety control unit incorporated is given in figure 8.

## 4.0 CONCLUSIONS, LIMITATION AND RECOMMENDATIONS

The safety control unit presented in this work successfully switched off an immersion water heater at a preset water level chosen as a safety water level. The controlled immersion water heater has the additional advantage of keeping the water heating element switched off when the appliance is not immersed in water even if the appliance is connected to the ac mains supply.

The use of the controlled immersion water heater in the heating of heavily chlorinated water may cause the degradation of the platinum probes as liberated chlorine gas molecules can attack the platinum metals. The power supply (ac to dc converter) of the control circuit is designed to supply 9V. This is to miniaturize the control circuit so that is takes a little space.

Given the huge safety benefits posed by the controlled immersion water heater we recommend that the scheme proposed in this work be improved upon so as to produce the best possible automatically controlled immersion water heater for use by the Nigerian public.

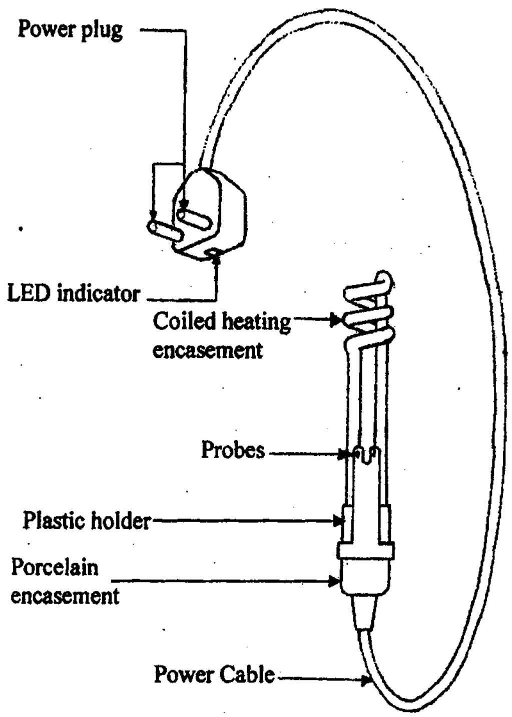


*Fig 8. Water heater with safety control unit.*

**REFERENCES**

1. Holderness and Lambert, "New Certificate Chemistry", H.E.B Publishers, 1976.
2. J.Millman and A.Grabel, Microelectronics, McGraw- Hill Book Company, New York, 1988.
3. Donald A.Neamen, Electronic Circuit Analysis and Design, McGraw- Hill Book Company, New York, 1996.
4. P.Horowitz and W.Hill, The Art of Electronics, CambridgeUniversity Press, Cambridge, 1981.
5. H.M. Talukder, A.V. Gholap, and S. Kanyemba, Design and construction of a water heater controller, African Journal of Science and Technology (AJST), Science and Engineering series Vo1.5, No.1, pp.15, June, 2004.
6. Tito Smailagich, Temperature Controller saves energy, Electronic Design News. EDN, (www.edn.com),February, 2005.
7. Water heating, Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/water heating, September, 2007.
8. LM393 Data Sheet, http://onsemi.com,March, 2006.