Design and Development of an Electronic Voltage Indicator for Public Utility

Folorunso C. O.*, Folorunso A. M**, and Ogunlewe A. O***.
Department of Electronic and Computer Engineering,
Lagos State University, Lagos Nigeria

Abstract

This paper discusses a simple, reliable and cheap means of detecting the availability of public utility for domestic and industrial use. The system made use of a 555 timer in the monostable- multivibrator mode and two-transistor astable multivibrator. The multivibrator is used as the sensor to detect the availability of mains by using the negative falling edge of the Alternating Current waveform (mains). Once the monostable multivibrator is triggered, it sends a one shot waveform output to the astable multivibrator which in turn triggers an alarm for a predetermined period of time that the monostable remains ON. The duration for the alarm system can be varied using a resistor-capacitor (RC) combination of the monostable multivibrator. The output impedance of the system is 600Ω with 0.24W power dissipation. It was shown from the results obtained that at a constant capacitance of 100μF and when the resistance is varied from 90Ω to 500Ω the alarm sounded between 10 seconds and 1 minutes respectively in the ON state.

Keywords: Alarm System, Monostable multivibrator, Astable multivibrator, 555 Timer, Darlington pair transistor.

1. Introduction

It is certain that lack of electricity is one of the main problems of our Country Nigeria. This has been a recurrent issue as the present administration is trying to address it wholly. As a result of this, nearly every home in Nigeria has one type of generator or the other to serve as the main supply of electricity while the public supply now serves as the stand by. When the public utility comes on, there is need for the consumer to be alerted of this so that one can change over to the public supply while switching off the alternative power supply. Various methods have been devised for achieving this.

In big establishments, automatic change over switch is usually used which automatically changes over to the public supply. In private establishments and homes, indicator bulbs also known as pilot lamps are used. However, more recently, alarm systems have been introduced. These systems are connected in such a way as to alert the consumer of the availability of the public supply. This type of alarm system which is mechanical in nature costs =N=5,000.00 upwards for both the sensor and the alarm system. However, this amount may not be affordable by an average Nigerian. It is for this reason that the simple and relatively inexpensive electronic system presented in this paper was explored. It uses components that are readily available locally. The work presented in this paper is a development of an electronic voltage indicator.

The functionality is implemented as a monitoring and notification system. The 555 timer is used as a monostable multivibrator which monitors the presence of the mains voltage and then produces an output by sounding an alarm for a predetermined period of time.

The approach used in this work is the modular one where the overall design was first broken into functional block diagrams, each block in the diagram represents a section of the circuit that carries out a specific function. It comprises power supply unit, triggering network, timing network, Comparator unit and the Output unit as shown in figure 1.

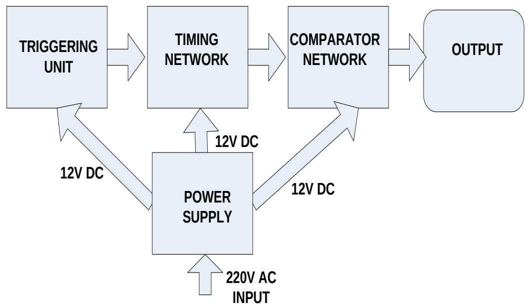

Figure 1. Block Diagram of the System

In this paper, the methodology is presented in Section 2, while section 3 discusses the result and analysis, and section 4 concludes the research work.

2. Methodology

The system made use of a 555 timer in the monostable- multivibrator mode and two transistor astable multivibrator. The multivibrator is used as the sensor to detect the availability of mains by using the negative falling edge of the Alternating Current waveform (mains). Once the monostable multivibrator is triggered, it sends one shot waveform output to the astable multivibrator which in turn triggers an alarm for a predetermined period of time that the monostable remains ON. The duration for the alarm system can be varied using a resistor-capacitor (RC) combination of the monostable multivibrator. The current at the output of the system was calculated using Kirchoff's Current Law.

2.1 Power Supply Unit

A regulated power supply of 12V output voltage was used. This power supply was rectified using a full wave bridge rectifier; this was then regulated as well as filtered to remove all sort of ripple voltage.

The maximum ripple voltage present for a Full Wave Rectifier circuit is not only determined by the value of the smoothing capacitor but by the frequency and load current, and is calculated as:

$$V_{RIPPLE} = \frac{I_{LOAD}}{2fc} volts \qquad (1)$$

Where: I is the DC load current in amps, f is the frequency of the ripple or twice the input frequency in Hertz, and C is the capacitance in Farads.

The power of the transformer and the current rating can be calculated using the formula below:

$$P = IV \qquad (2)$$

The power drawn from the power supply is calculated as follows:

$$I_T = I_{TRIGGER} + I_{TIMER} + I_{COMPARATOR} \qquad (3)$$

$$Power = 12(I_{TRIGGER}+I_{TIMER}+ I_{COMPARATOR}) \qquad (4)$$

The minimum voltage required for the circuit is

$$\sqrt{3}.V_{dc}. \qquad (5)$$

The ripple frequency is equal to the alternating current line frequency for a half wave rectifier, and twice the alternating current frequency in a full wave rectifier. That is for a full-wave rectifier on 50 Hz mains, frequency is 100 Hz. A ripple voltage of 5% of the dc output voltage is a reasonable value. The ripple formula can be modified as follows:

From equation (1),

$$C = I_{dc}/(2fVripple) \qquad (6)$$

$$C \times V_{dc} = I_{dc}/\{2f(V_{ripple}/V_{dc})\} \ (7)$$

If I_{dc} =1 A and $V_{ripple}/V_{dc} = 0.05$, (= 5%)

$$C \times V_{dc} = 10/f\ , \qquad (8)$$

$$C = 10/fV_{dc}$$

$$C = 1/10V_{dc}, \qquad (9)$$

2.2 Triggering Unit

It's an electronic circuit that generates or modifies an existing waveform to produce a pulse of short time duration with a fast-rising leading edge. This waveform or triggering circuit is normally used to initiate a change of state of some relaxation devices such as a multivibrator. The most important characteristic of the waveform generated by a triggering circuit is usually the fast leading edge. The exact shape of the falling portion of the waveform is of secondary importance, although it is important that the total duration time is not too great. A pulse generator such as a blocking oscillator may also be used and identified as a triggering circuit if it generates sufficiently short pulses.

Peaking circuits which make use of higher-frequency components of a pulse waveform, cause sharp leading and trailing edges and are therefore used as triggering circuits. The simplest form of peaking circuits are the simple RC and RL networks shown in the figure 2. If a steep waveform of amplitude V is applied to either of these circuits, the output will be a sudden rise followed by an exponential decay. These circuits are often called differentiating circuits because the outputs are rough approximations of the derivative of the input waveforms, if the RC or R/L time constant is sufficiently small.

A transistor triggering circuit is used to trigger the circuit as shown in figure 2 below.

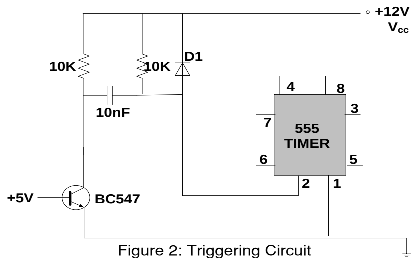

Figure 2: Triggering Circuit

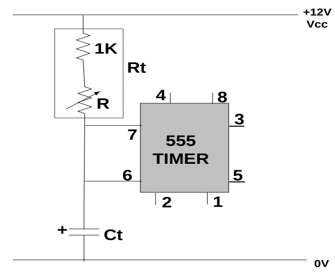

Figure 3: Timing Circuit

2.3 Timing Network

The timing network of a monostable multivibrator consists of a combination of resistor and capacitor in series which is connected to pin 6 and 7 of the 555 Timer as shown in figure 3. However, the time period can be adjusted, by using a linear variable resistor and 1KΩ fixed resistor value for R.

Because the resistance of a variable resistor goes down to around 0Ω at one end of its range, a 1kΩ resistor is placed in series with it so that the value of R will never fall below 1kΩ. As the shaft of the variable resistor is turned from its lowest setting to its highest, t will become longer.

The timing equation is given as:

$$t = 1.1\, R_t C_t \qquad (10)$$

The capacitor C has to charge through resistance R_t. The larger the time constant R_tC_t, the longer it takes for the capacitor voltage to reach $+2/3V_{CC}$.

In other words, the RC time constant controls the width of the output pulse. The time during which the timer output remains high is given as

$$t_p = 1.0986\, R_t\, C_t \;= 1.1\, R_t\, C_t$$

Where R_t is in ohms and C_t is in farads. The above relation is derived as follows. Voltage across the capacitor at any instant during charging period is given as

$$v_c = V_{CC}\,(1 - e^{-t/RtCt}) \qquad (11)$$

Substituting $v_c = 2/3\ V_{CC}$ in above equation we get the time taken by the capacitor to charge from 0 to $+2/3V_{CC}$.

So,

$$+2/3V_{CC}. = V_{CC}.\,(1 - e^{-t/RtCt}) \quad \text{or}$$

$$t - R_tC_t \log_e 3 = 1.0986\, R_tC_t$$

So pulse width,

$$t_P = 1.0986\, R_t\, C_t \ \text{s} \ = 1.1\, R_tC_t \qquad (12)$$

The pulse width of the circuit may range from micro-seconds to many seconds.

2.4 Comparator Network

The 555 Timer is a monolithic timing circuit that can produce accurate and highly stable time delays or oscillations. The timer basically operates in one of the three modes—monostable (one-shot) multivibrator, astable (free-running) multivibrator or as a bistable multivibrator.

In the monostable mode, it can produce accurate time delays from microseconds to hours. In the astable mode, it can produce rectangular waves with a variable duty cycle. Frequently, the 555 is used in astable mode to generate a continuous series of pulses, but the 555 can be used to make a one-shot or monostable circuit.

The 555 can source or sink 200 mA of output current, and is capable of driving wide range of output devices. The output can drive TTL (Transistor-Transistor Logic) and has a temperature stability of 50 parts per million (ppm) per degree Celsius change in temperature, or equivalently 0.005 %/°C.

The 555 timer consists of a voltage divider arrangement, two comparators (both lower and upper comparator), an RS flip-flop, an n-p-n transistor Q1 and a p-n-p transistor Q2. Since the voltage divider has equal resistors, the upper comparator has a trip point of-

$$\text{UTP} = 2/3\text{Vcc}. \qquad (13)$$

The lower comparator has a trip point of

$$\text{LTP} = 1/3\text{Vcc}. \qquad (14)$$

2.4.1 Monostable Multivibrator

A monostable multivibrator is a pulse-generating circuit having one stable and one quasi-stable state. Since there is only one stable state, the circuit is known as ‘monostable multivibrator’. The duration of the output pulse is determined by the RC network connected externally to the 555 timer. The stable state output is approximately zero or at logic-low level. An external triggering pulse forces the output to become high or approximately. After a predetermined length of time, the output automatically switches back to the stable state and remains low until a triggering pulse is again applied. The cycle then repeats. That is, each time a trigger pulse is applied, the circuit produces a single pulse. Hence, it is also called 'one-shot multivibrator'.

A 555 timer connected for monostable operation is shown in Figure 4. Pin 1 is grounded. Triggering input is applied to pin 2. In quiescent condition of output, this input is kept at $+V_{cc}$. To obtain transition of output from stable state to quasi-stable state, a negative-going pulse of narrow width (a width smaller than expected pulse width of output waveform) and amplitude of less than $+1/3V_{cc}$ is applied to pin 2. Output is taken from pin 3. Pin 4 is usually connected to $+V_{cc}$ to avoid accidental reset. Pin 5 is grounded through a 0.01µF capacitor to avoid noise problem. Pin 6 (threshold) is shorted to pin 7. A resistor R_A is connected between pins 6 and 8. At pins 7 a discharge capacitor is connected while pin 8 is connected to supply V_{CC}.

Initially, if the output of the timer is low, that is, the circuit is in a stable state, (refer to figure 4 transistor Q1 is ON and the external capacitor C is shorted to ground. Upon application of a negative triggering pulse to pin 2, transistor Q1 is turned off, which releases the short circuit across the capacitor and as a result, the output becomes high. The capacitor now starts charging up towards V_{cc} through R_A. When the voltage across the capacitor equals $2/3V_{cc}$, the output of comparator 1 switches from low to high which in turn makes the output low via the output of the flip-flop. Also, the output of the flip-flop turns transistor Q1 on and hence the capacitor rapidly discharges through the transistor. The output of the monostable multivibrator remains low until a triggering pulse is again applied. The cycle then repeats. The pulse width of the triggering input must be smaller than the expected pulse width of the output waveform. Moreover, the trigger pulse must be a negative-going input signal with an amplitude larger than 1/3Vcc.

Once the circuit is triggered, the output will remain high for the time interval t_p. It will not change even if an input triggering pulse is applied during this time interval. In other words, the circuit is said to be non-retriggerable. However, the timing can be interrupted by the application of a negative signal at the reset input on pin 4. A voltage level going from $+V_{cc}$ to ground at the reset input will cause the timer to immediately switch back to its stable state with the output low.

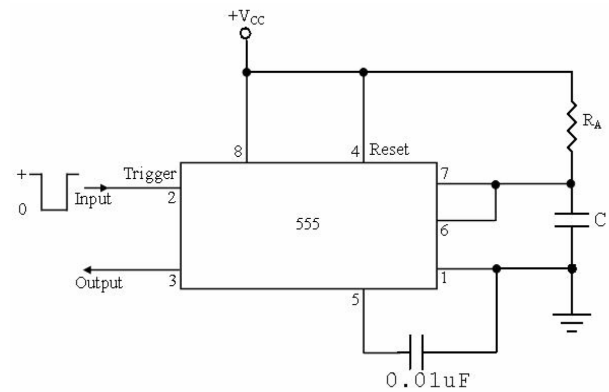

Figure 4. Monostable multivibrator

2.5 Output

The astable multivibrator was achieved using two transistors. The output of the astable was then amplified using the two transistor in Darlington pair configurations.

Transistorized Astable Multivibrator is a cross coupled transistor network capable of producing sharp continuous square wave. It is a free running oscillator or simply a regenerative switching circuit using positive feedback. Astable Multivibrator switches continuously between its two unstable states without the need for any external triggering circuit. Time period of Astable multivibrator can be controlled by changing the values of feedback components such as coupling capacitors and resistors.

The Darlington transistor also called a Darlington pair, is a compound structure consisting of two bipolar transistors connected in such a way that the current amplified by the first transistor is amplified further by the second one. This configuration gives a much higher current gain (called β or h_{FE}) than each transistor taken separately and in the case of integrated devices, can take less space than two individual transistors because they can use a shared collector.

A Darlington pair behaves like a single transistor with a high current gain (approximately the product of the gains of the two transistors)

A general relation between the global current gain and the individual gains is given by:

$$B_{Darlington} = \beta_{1.}\ \beta_2 + \beta_1 + \beta_{2,} \qquad (15)$$

Where β_1 is $beta_1$ while β_2 is $beta_2$. Equation (15) is approximately β_1 . β_2, The approximation is valid if $beta_1$ and $beta_2$ are high enough (hundreds). A typical modern device has current gain of 1000 or more, so that only a small base current is needed to make the pair switch on.

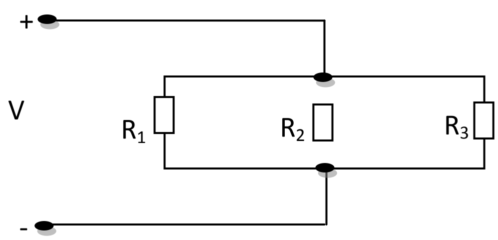

Figure 5. Simplified Block diagram of the system

To calculate the current drawn by each unit, the equivalent resistance was first calculated as follows:

Let $R_{TRIGGERING} = R_1$,

$R_{TIMER} = R_2$, and $R_{COMPARATOR} = R_3$

$1 / R_T$ =

$1 / R_{TRIGGERING} + 1 / R_{TIMER} + 1 / R_{COMPARATOR}$

i.e.

$$1 / R_T = R_1 + R_2 + R_3 \qquad (16)$$

Current in any unit is calculated using the current divider rule as follows:

$V = I_x R_x$

$IR_T = (R_T / R_x)$

$$I_X = (R_T / R_x) * I \qquad (17)$$

3. Results and Analysis

The entire circuit was tested. The circuit worked perfectly as planned and the following results were obtained:

Table 4.1. Test result for the system in the ON state

Variable Resistor (K&)	Input Current (I_T) (mA)	Triggering Unit Current (mA)	Timing Unit Current (μA)	Comparator Unit Current (mA)	Output Current (mA)	Time Constant (seconds)
90	20.0	0.96	17.1	19.03	19.88	10
180	20.0	0.96	9.14	1 9.03	19.88	20
270	20.0	0.96	6.23	19.03	19.88	30
360	20.0	0.96	4.71	19.03	19.88	40
450	20.0	0.96	3.71	19.03	19.88	50
500	20.0	0.96	3.43	19.03	19.88	60

The power supply gave the output of 12V DC at 20mA. The calculated current for the triggering unit was 1.2mA while the measured current ranges from 0.0 to 0.96mA which lie within 20% tolerance. The calculated current for the timing unit was 24μA while the measured current ranges from 3.43μA to 17μA although this current is negligible. The calculated current for the comparator unit was 18.8mA while the measured current ranges between 114.29μA and 19.03mA which lie within 5% tolerance. The current at the output was approximately equal to the input current which agrees coherently with the Kirchoff's current law.

Table 4.2. Test result for the system in the OFF state

Variable Resistor (K&)	Input Current (I_T) (μA)	Triggering Unit Current (mA)	Timing Unit Current (μA)	Comparator Unit Current (μA)	Output Current (mA)	Time Constant (seconds)
90	133.1	0.0	18.84	114.29	0.0	10
180	123.8	0.0	9.47	114.29	0.0	20
270	120.6	0.0	6.33	114.29	0.0	30
360	119.1	0.0	4.76	114.29	0.0	40
450	118.1	0.0	3.80	114.29	0.0	50
500	117.7	0.0	3.43	114.29	0.0	60

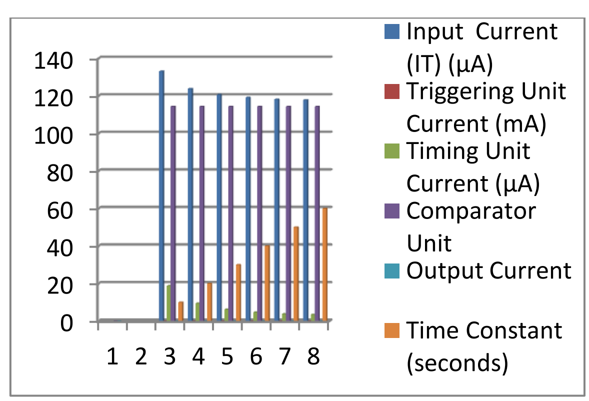

Figure 6. Graph showing the relationship between the results of each module of the system when in the ON state.

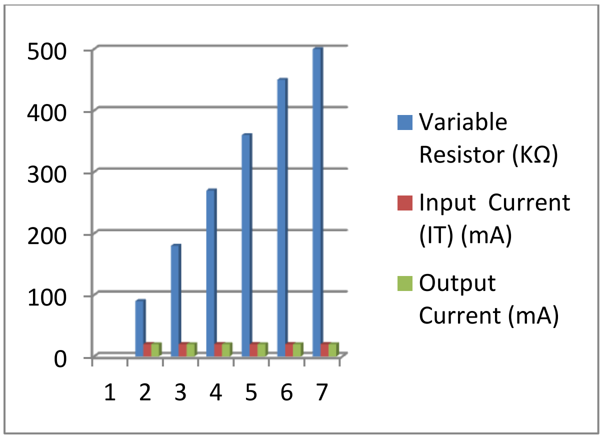

Figure 7. Graph showing the relationship between the input and the output current in the ON state.

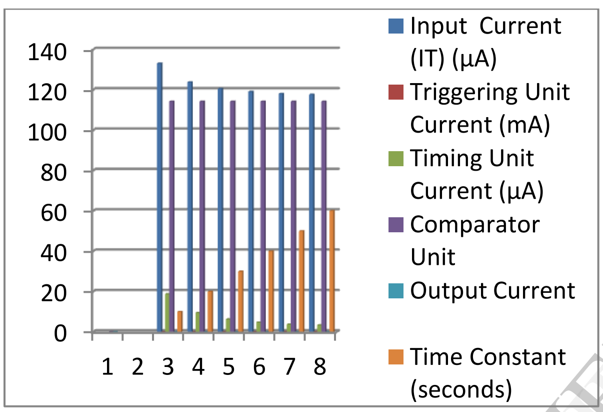

Figure 8. Graph showing the relationship between the results of each module of the system when in the OFF state.

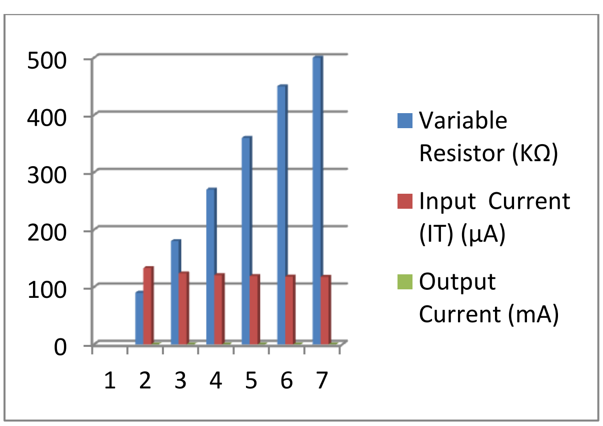

Figure 9. Graph showing the relationship between the input and the output current in the OFF state.

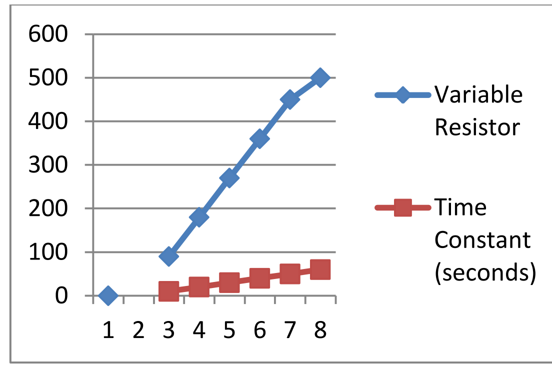

Figure 10. Graph of Time Constant versus Variable R esistance with the capacitance remaining constant at 100μF.

Figure 11. A picture of the prototype after it was packa ged.

Figure 12. The internal structure of the prototype.

4. Conclusion

In this paper, an electronic voltage indicator for mains supply was designed, constructed and tested, and impressive results were obtained. Furthermore, a prototype was built and tested at various stages for more than twenty times varying the resistance. A desired and expected timing was realized using a stopwatch. This design is suitable for homes, offices as well as industry. It serves as power conservation which reduces cost. This device is relatively cheap, affordable, reliable, easy to install, and dissipates lesser heat as the package provides enough ventilation for the transformer. More so, the 555

Timer used has a value of 600mW power dissipation which is indeed a very small amount.

The alarm system operates at 600Ω impedance and 0.24W power.

Finally, the current obtained at the output of the design was relatively and approximately equal to the current at the input which conforms to Kirchoff's current law.

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