# Design and Construction of a Microcontroller Based Circuit to Control Load Consumption Using Prepaid Energy Meter and Gsm Module

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**Abstract**
This circuit aims to save funds spent on electricity bills and to enables electricity consumers to be cautious of their utilization of electricity. The circuit is controlled by a microcontroller which is interfaced to an electricity prepaid meter. The relay is connected to the microcontroller that cuts off power supply to their building once the amount of kilowatt programmed in the microcontroller is surpassed. A GSM module is also interfaced to the microcontroller that is responsible for receiving signals and transmitting responses that enables consumers to reset the circuit, receive warning notifications and recharge their prepaid meters. An LCD is also connected to display the number of kilowatts.

**Keywords**: microcontroller, prepaid meter (electric energy meter), GSM module

## 1. Introduction

meters are energy meters found in buildings where payment must be done before they supply energy [6]. In 2006, the prepaid meter was introduced in Nigeria by the Power Holding Company of Nigeria (PHCN) and the meter reading and estimated billing methods were abolished. This was done in order to aid revenue collection and generation and ever since then the use of prepaid meter in Nigeria has been on the steady increase. According to the most recent power sector report released by the National Bureau of Statistics, the numbers of persons using the prepaid meter rose by 1% in the last quarter of 2018 to 1.67millon people from 1.65millon in the second quarter [9].

As advantageous as the usage of prepaid meters is, one of which includes enabling users to control their electricity supply and how often they pay, there are also several shortcomings which include inconvenience of going to the local pay point, sudden cut off of power supply at inconvenient times amongst others [6]. Two profound challenges encountered by clients of the prepaid meter and they are sudden cut off of power supply at inconvenient times and negligence of consumers to turn off unnecessary and/or not in use electrical and electronic appliances causing their energy units to drain faster and costing consumers more for electricity supply to their buildings.

This microcontroller based circuit answers to these shortcomings experienced by consumers using the prepaid meter. By automation, it ensures that consumers stay within their budget by sustaining a certain amount of kilowatt (per day). In like manner automation, the circuit is also interfaced with a GSM module that sends out warning notifications when energy units are almost exhausted and can also be used for recharge of the prepaid meter.

Here electricity coming in from the mains passes the prepaid meter which goes on to the distribution box (load). The energy units paid for by the user are stored in the prepaid meter and once the user starts to turn on appliance(s) the units start counting per the kilowatt of each appliance turned on. The more appliance(s) are used, the faster the units are exhausted. The microcontroller is programmed with a set amount for load so as the consumer turns on more appliance(s), the value is read and compared with that in the microcontroller so once the value set is surpassed power supply to the building is cut off using the relay. The GSM module receives signals and allows responses for reset and recharge.

## 2. Materials and Methodology

The circuit is used in connection with electricity prepaid meters. It helps users to save cost of providing electricity by cutting off power supply once the user surpasses the set value for load consumption. The circuit by automation ensures that consumers make use of a certain amount of kilowatt for load that uses only a small/average amount of energy units to avoid draining the total amount of energy at a faster rate causing consumers to spend less on electricity.

The prepaid meter functions by supplying a building the number of energy units bought by the consumer. It uses up these units by counting load consumption by kilowatt-hours. The microcontroller circuit is programmed with a set value for load and a switching unit (relay) that cuts off power supply once the set load value is surpassed. The GSM module further enhances the automation of this circuit by alerting consumers when the energy units is almost exhausted and enables consumers top up their units [2]. The GSM module also allows consumers to send SMS that allows them reset and restore the power supply that was cut off.

The microcontroller counts the load build up alongside the energy meter where it shows overtime as loss of energy units. The value of the load unit in the building is measured and compared with the set load value in the microcontroller. Once the load in the building measured exceeds that of the set load value, the relay goes on to cut off the power supply to the building. The consumer then sends SMS to the GSM module that closes the relay to allow power supply once again to the building.

The circuit makes use components such as microcontroller (ATmega32), GSM module (SIM900A), Relay, Optocoupler (4N26), LCD, LED, Step down Transformer (220V/12V), Crystal, Transistor, Lamp (Load), Rectifier, Capacitors, Resistors, Energy Meter and Voltage Regulator (7805). Several units make up the circuitry and are represented by the block diagram below;

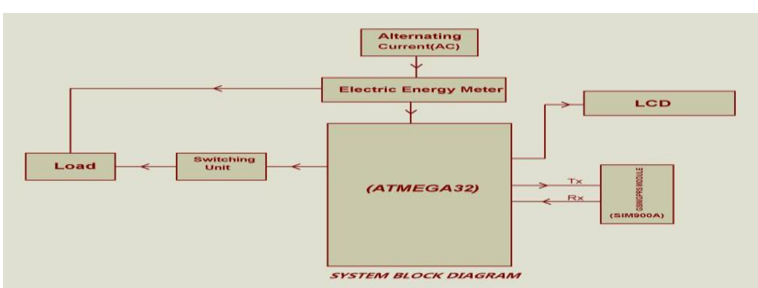


Figure 1: Block Diagram of the Microcontroller Circuit

The block diagram above shows several sections and they are described below;

1. POWER UNIT

The schematic diagram of the power circuit is as shown below.

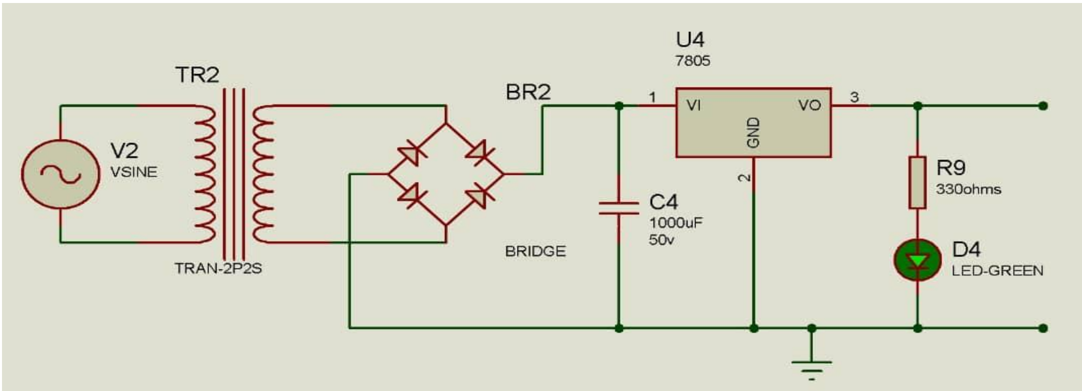


Figure 2: Power Unit

The power unit comprises of the step down transformer labeled in the diagram as TR2 that steps down the incoming 220V to 12V providing enough current for the requirement the circuit. It moves on to the bridge rectifier consisting of four diodes labeled as BR2in the diagram above. The diodes chosen must have a peak inverse voltage (PIV) that must be able to withstand twice the peak voltage ($V_p$) of the transformers output and a forward current ($D_{c)}$) of 1.5 times the output current of the transformer. The rectified current then moves on to the filter capacitor labeled as C4 in the diagram with a rating of 1000µF and 50V. The voltage then passes into the voltage regulator (7805) labeled as U4 and finally through a resistor, R9 of rating 330Ω. A LED is also connected to indicate power in the circuit when it lights up.

$$V_P = \sqrt{2}\ Vrms$$

Where $V_P$ is the peak voltage of the transformer output

$V_{rms}$ is the actual output voltage from the transformer = 12Vac

$$V_P = \sqrt{2} x 12$$

$$V_P = 1.414x12$$

$$V_P = 16.97Vac$$

$$D_{(piv) =} 2 \text{ x } V_P$$

Where $D_{(piv)}$ is the PIV of the rectifier diode

$$D_{(piv)} = 2x16.97$$

$$D_{(piv)} = 33.94.$$

$$Dc = 1.5 \text{ x } 300 \text{ x } 10^{-3}$$

$$Dc = 0.45A$$

$$D_{(piv)} = 33.94, Dc = 0.45A$$

Therefore the required diode must have a:

$$PIV \geq 33.94V$$

$$Dc \geq 0.45A$$

From diode catalogue, the IN4007 has the following characteristics:

$$PIV = 50V$$

$$D_C = 1A$$

Consequently, the diode chosen is the IN4007.

$$D_1\text{-}D_4 = IN4007$$

C4: This is the filters capacitor. Electrolytic capacitors come with a capacitance and a voltage rating.

Voltage Rating: The voltage of the capacitor ($V_C$) must be able to withstand 150% of the output voltage from the diode.

The voltage of the capacitor $V_{C\,=}$ 150% of $V_{DP}$

Where $V_{DP}$ is the peak output voltage from the diodes

But $V_{DP}$ is given as

$$V_{DP} = V_P - V_D$$

Where $V_P$ is the peak voltage of the transformer (16.97)

$V_D$ is the voltage drop of the diodes ($0.7 \times 2=1.4$)

$$V_{DP} = 16.97 - 1.4$$

$$V_{DP} = 15.57V$$

$$\therefore Vc = 1.5 x V_{DP}$$

Where $V_C$ is the voltage rating of the capacitor

$$V_C = 1.5 \text{ x } 15.57$$

$$V_C = 23.6V$$

Capacitance Rating: The capacitance of the capacitor must be such that it could reduce the ripple voltage ($V_R$) to about 30% of the output peak voltage from the diodes.

$$V_R = 30\% \text{ of } V_{DP}$$

But $V_{DP} = 15.57$

$$V_R = \frac{30}{100} \text{ x } 15.57$$

$$\therefore V_R = 4.67V$$

From the ripple voltage equation, we could get the capacitance

$$V_R = \frac{Imax}{2 \text{ x } f \text{ x } C1}$$

Where $V_R$ is the ripple voltage

$I_{max}$ is the maximum current from the diodes/ transformers (300mA)

f is the frequency of supply (50Hz)

C is the capacitance of the capacitor in Farads.

$V_R = 4.67V$

$$\therefore V_R\,(2FC) = I_{max}$$

$$C_4 = \frac{Imax}{V_R \times 2 \times f}$$

Substituting,

$$C_4 = \frac{300 \text{ x } 10^{-3}}{4.67 \text{ x } 2 \text{ x } 50}$$

$$C_4 = \frac{0.3}{467}$$

$$C_4 = 6.42 \text{ x } 10^{-4} \text{ F}$$

Converting to µF

$$C_4 = \frac{6.42 \text{ x } 10-4}{10-6}$$

$$C_4 = 642.4\ \mu F$$

Therefore the capacitance chosen is:

$$C_4 = 1000\mu F\ @50V$$

U4: This is the voltage regulator. Regulator specifications include

- Maximum input voltage = 30V
- Maximum output voltage = 5.5V
- Operating temperature = 0%- 150%

For effective Voltage regulation, the minimum input voltage should be:

$$V_{min} = V_{out} + V_{ref}$$

Where $V_{min}$ – Minimum input voltage

$V_{out}$ – required output voltage: 5V

$V_{ref}$ – Datasheet Stipulated reference voltage; 3V

$$V_{min} = 5 + 3$$

$$V_{min} = 8V$$

The output voltage after the capacitor is 15.57 volts. This is enough to supply the minimum input voltage (8 volts) Therefore, the voltage regulator could be comfortably used. The regulator chosen is $U_4$ = 7805.

Resistor Rating:

R9 = 300Ω

This value of resistor is not in the market, so the appropriate value to use is:

R9= 330Ω

Light emitting diode characteristics:

Forward current of…..$10\times10^{-3}$A to $10\times10^{-3}$A

Voltage drop of…….2V.

## 2. MICROCONTROLLER UNIT

The schematic diagram of the microcontroller unit is as shown below.

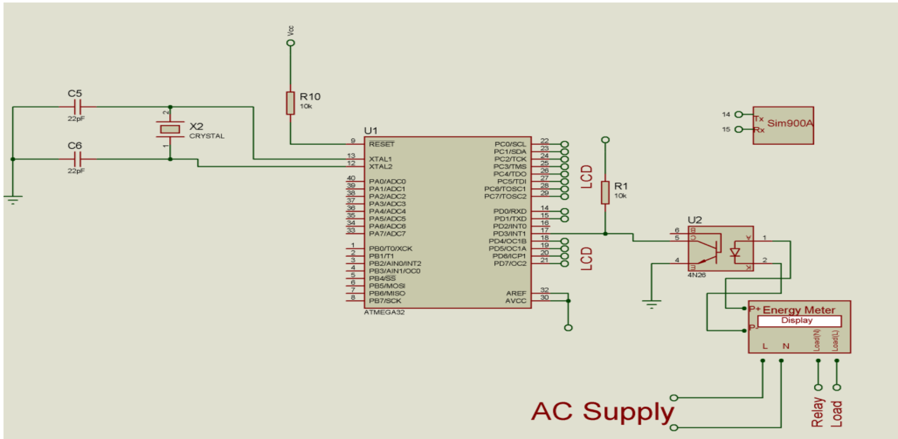


Figure 3: Microcontroller Unit

A microcontroller is an integrated circuit that carries out instructions, under the guidance of a program. The program is written in an acceptable program code, in this case, assembly language and burned into its ROM. The working of the microcontroller is then carried out through its input-output ports. The microcontroller used in this project is the ATmega32 belonging to the Atmel's AVR series microcontroller family. It has 40 pins in which two are for power

(Pin10(+5V)and11(ground)), two are for oscillator (Pin12and13), one for reset (Pin9), three for providing necessary power and reference voltage to its internal ADC and 32(4×8) I/O pins. No pin can perform two functions at the same time. Furthermore, the ATmega32 has three inbuilt timer/counter, two 8 bit (timer 0 and 2) and one 16 bit (timer1); three data transfer modules (Two wire Interface), USART and Serial Peripheral Interface) and a memory of 32 kilobytes of In-System Self-Programmable Flash Programmable memory, 1024bytes EEPROM, 2kilobytes internal SRAM. ATmega32 can run at a frequency from 1-16MHz using an external source (crystal oscillator) and has one successive approximation type ADC [8].

The microcontroller unit is the heart of the circuit. It is interfaced to the energy meter through an optocoupler on Pin 17(PD3/INT1). It also interfaced to the GSM module. The microcontroller is programmed to energize the relay once the kilowatt measure of the load in the building is met. The microcontroller send information through coding to the GSM module inform the consumer that the energy unit in the prepaid energy meter is almost exhausted or is completely exhausted. The crystal oscillator is also connected to the microcontroller on Pins 12 (XTAL2) and 13 (XTAL1) to enhance communication and for better processing.

## 3. GSM MODULE UNIT

The schematic diagram of the GSM module in the circuit is as shown below.

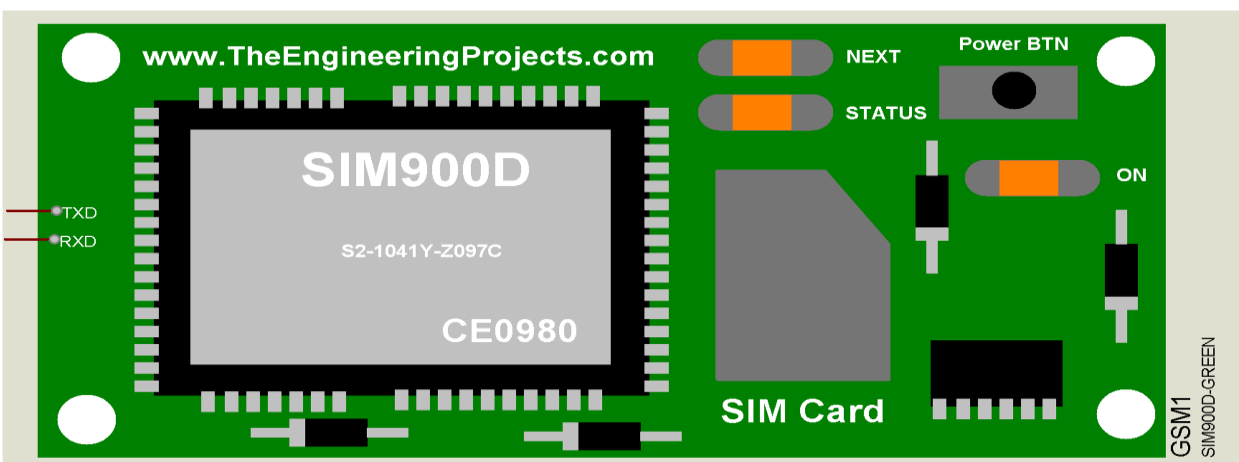


Figure 4: GSM module unit

SIM900A is a readily available GSM/GPRS module used in many mobile phones. It can also be used for developing Internet of Things (IoT) and embedded applications. It has sixty eight pins. It works on dual band frequencies 900/1800MHz [5] and can search these two bands automatically. Its communication is by using AT commands. It makes use of a single supply voltage (3.4V-

4.5V) and has a SLEEP power consumption of 1.5mA. It has an operating temperature of -30℃ to +80℃. It supports keypad interface, display interface, MIC and audio input, speaker input and a single SIM card [4].

The GSM module (SIM900A) is connected to the microcontroller on Pin 14(PD0/RXD) and 15(PD1/TXD). It receives information from the microcontroller that triggers the implementation of specific instructions (code) in the GSM module. These instructions include sending a SMS over cellular network to the consumer mobile phone. Through SMS the consumer can send instructions to recharge their electric energy meter and to reset the microcontroller unit to restore the power supply to the load (building).

## 4. SWITCHING UNIT

The schematic diagram showing the switching unit is as shown below.

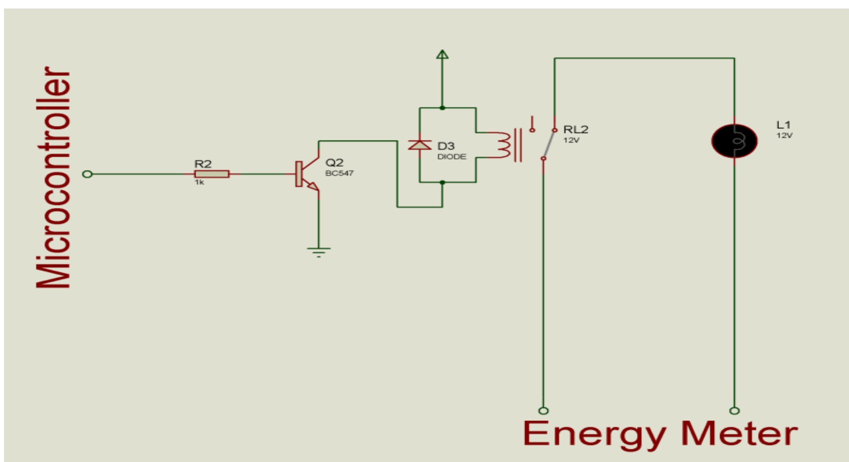


Figure 5: Switching Unit

It comprises of the relay that upon instructions received from the microcontroller, becomes energized and switches the relay open, power supply to the load is cut off and until the relay is closed following instructions from the microcontroller the power supply will not be restored. The relay is connected to the microcontroller on Pin 18(Pd4/OC1B). It is also interfaced to the output side of the electric energy meter.

## 5. DISPLAY UNIT

The diagram indicating the display unit is as shown below.

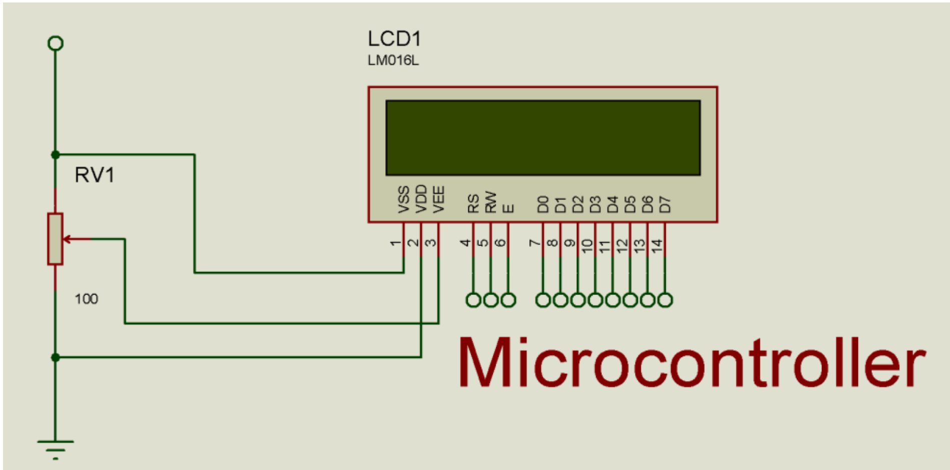


Figure 6: Display Unit

This comprises of the liquid crystal display (LCD) which is connected on Pins (19-29) on the microcontroller, ATmega32. It displays the amount of kilowatt used by the consumer.

## I. GENERAL CIRCUIT OPERATION

The circuit was designed using Proteus software. The schematic diagrammatic representation of the microcontroller based circuit is as shown below.

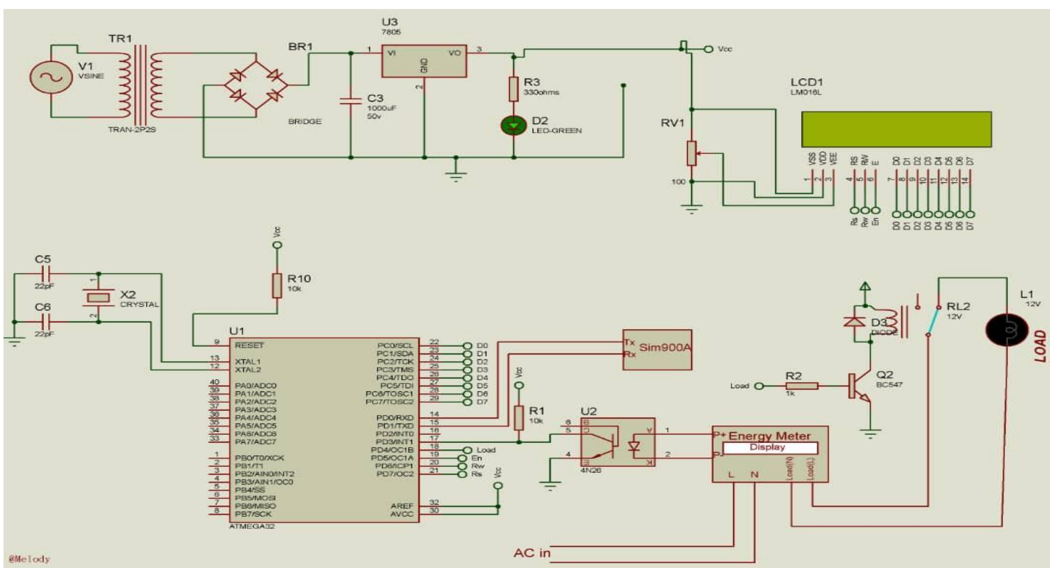


Figure 7: Schematic Diagram of the Microcontroller Circuit

The diagrammatic representation shows the different sections to the circuit design and construction. It shows the power unit, the microcontroller, the switching unit, the GSM module and the display unit.

The power unit comprises of the step-down transformer, bridge rectifier, filter capacitor, the voltage regulator that supplies the voltage that the circuit requires. The LED light turns on when there is power in the circuit. The microcontroller is embedded with a program to ensure that once the load kilowatt used by the consumer exceeds the programmed value in the microcontroller, it triggers the relay open that cuts off the power supply to the load. The GSM module (SIM900A) receives signals (text) and allows consumers to send responses (text) that enable recharge and reset when power supply is cut off. The display unit comprises of the LCD that displays the amount of kilowatt the consumer is using. The crystal oscillator is connected to the microcontroller to enhance communication and for better processing.

## 3. Conclusion

This microcontroller based circuit is a simple and practical circuit that allows consumers to use the same amount of funds for electricity bills for longer periods of time. Using the microcontroller (ATmega32), a circuit has been designed to control the amount of kilowatt for load that a consumer can use while using the electricity prepaid meter. Coupled with a GSM module, consumers can recharge their electricity prepaid meter from their mobile phone.

Other features can be embedded and programmed into the GSM module and the microcontroller. Further research can be done and modification made to the circuit for improvement.

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