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Residential Electricity Management and Protection System

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ABSTRACT

The Residential Electricity Monitoring System is an electricity meter connected to the Internet to provide real time data on the power system in your home. The REMS is designed to replace the distribution board allowing it to conduct a series of tests on the quality of the electricity supply to your home/facility and, within your home detect basic wiring faults and allow owners and service providers to identify potential problems with the electrical systems.

The electrical monitoring system finally puts proper electrical control into the hands of the home owner by providing him with the ability to control power distribution within the home from anywhere in the world via sms, and to view analytical data over the web.

The R.E.M.S is capable of metering individual room power consumption, detecting voltage surges and tripping off voltage supply to the home, detecting high temperatures on distribution lines within the home, even detecting high temperatures at socket points, while tripping off affected lines or even the entire home.

The R.E.M.S is also capable of detecting electrical smoke and tripping off the entire system and contacting emergency services via call and text messaging.

It is GPRS enabled giving it internet and sms functionalities, meaning it can receive commands via sms like "Switch off the kitchen", send out emergency SOS alerts and warnings etc. Also, it can be monitored and controlled with an app over the internet. The E.M.S can detect simple electrical wiring faults, short circuiting, use of low current rated wires on high current distribution lines etc.

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INTRODUCTION

Electricity is wonderful, but under certain conditions it can be very dangerous, destructive and deadly. Within Nigeria and throughout the whole world, electrical hazards have been responsible for the loss of life and property of many. These may come as electrical surges- damaging every single plugged device in the home, electric shock- leading to the serious injury or even death of the victim, or electrical fires, which may lead to the total loss of the home including its residents. These electrical hazards are mainly caused by voltage surges, overloading, and electrical wiring faults like poor ARC wiring, short circuiting, poor distribution board wiring. Other electrical wiring faults include; use of wrong wire diameter for certain load lines- this causes over heating of the wire and melting of the insulation.

As for electrical fires, you need to understand and respect the power of electricity and the role it can play in home fires. It can start in an instant and consume your home in just minutes. It takes lives, injures victims, destroys homes, and steals precious possessions.

How Electrical Fires Burn

According to a report done by Eng. H. E. Orovwode (2007) on “Electrical fire outbreaks in homes”, fire requires three elements, both to ignite and to continue burning: They are:

a) Heat: this could be a hot stove burner, a spark from a worn electrical wire. Overloaded wires, sockets and extensions that gets very hot and could melt the rubber insulations.

b) Fuel: clothing, food, furniture, paper, plastics and more. But in the case of electrical fires, rubber wire insulations would serve as a good first fuel that could lead to the fire.

c) Oxygen: The oxygen in the air around us also fuels a fire. As a fire burns, the heat it creates warms nearby items, making it even easier for them to start burning, too.

Consider these startling statistics: In the United States of America, there is a home-fire injury every twenty-three minute. A home-fire death happens every 130 minutes. In 2000 alone, 3,420 people died in home fires one of the highest fire death rates among industrialized nations.

According to a Siemens industry Inc. (2011) report on the "Causes of electrical fires", two reports – one from the National Fire Protection Agency (NFPA) and one from the National Association of State Fire Marshals (NASFM) (Campbell, 2019) – estimate that 50 to 75 percent of all home fires in the United States are caused by electrical wiring faults. Data from the National Fire Incident Reporting System and the NFPA, meanwhile, indicate that between 1994 and in 1998, electrical arcing caused approximately 48,800 fires within the USA annually in one- and two-family dwellings (Siemens, 2011). These wiring faults clearly is an issue and needs to be curtailed. Hence this project aims to detect these faults, and if it can't detect faults, it will still detect the parameters and conditions that cause these electrical hazards in a residential building.

Electricity within Nigeria has over time proven to be unstable and unreliable. Millions of naira worth of property is lost yearly due to this fact and although special electrical protection like fuses, relays, circuit breakers are usually already in place, old, outdated and analog and are not sufficient for proper electrical protection. With the current advancement in technology, more computerized systems are more reliable. Furthermore, proper electrical protection equipment acquired within Nigeria are imported and usually very expensive, adding to the already high cost of electricity in the country. Energy wastage in the country is also a big problem that needs to be curbed. These compounds the economic side of electricity consumption even more, making electricity tracking and metering very vital to every home to save money and electricity.

Aims and Objectives of Study

The aim of this project is to detect potential and existing residential electrical faults, hazardous electrical conditions and take necessary actions to prevent, correct and contain the situation.

Objective of Study

The proposed objectives of study are to;

a) Design a computerized system which will serve as an easy-to-install upgrade to the basic electrical distribution board.

b) Detect electrical wiring faults by detecting short circuits, voltage fluctuations, frequency fluctuations and current overload on distribution lines, and take necessary actions which include; tripping off affected lines, and contacting the home administrator via text message.

c) Monitor temperature values of distribution lines and trip off over heated lines to prevent fire hazard.

d) Detect smoke and raise a fire alarm while tripping off the entire wiring system.

e) Measure and record energy usage and consumption while making it monitor-able over the internet.

Knowledge gap

Extensive research on electricity monitoring and protection are constantly being made in the field of Electrical electronics engineering. In fact, similar and even more sophisticated systems for smart electricity monitoring and protection have already been developed and in some cases mass produced. Companies like Schneider electric, Raycap and Eyedro are constantly releasing electrical monitoring and protection systems. All these are foreign companies (to Nigeria) located in Europe and the USA, and their products have been designed to fit their environment. But within Nigeria and even throughout Africa, little or no research or innovation in this field are being conducted. In Nigeria, all electronic equipment is imported and even electrical companies import everything including staff.

With the aim of being one of the first made-in-Nigeria electronic design and electrical protection device, the REMS takes a huge step in achieving that goal.

The rest of this paper will present:

1. Literature review
2. Methodology
3. Testing and evaluation
4. Summary and Conclusion
5. References

LITERATURE REVIEW

Introduction

In the design and construction of this project, a critical look at past similar designs and constructions that flow along the same lines as this project in order to get more ideas, pointers and knowledge while learning from their mistakes and identifying their flaws in order not to repeat them, and ultimately identifying their shortcomings and conclusions in order for me to continue from where they left off, and rather than “re-invent the wheel” I will be able to produce creative additions and solutions to make the world a better place.

Existing electricity protection systems

Distribution Board

A distribution board, commonly referred to as a breaker panel is an electricity supply component that redistributes electrical power from the mains to the different parts of a building, creating ‘sub-circuits’ that can easily be fused or protected by a

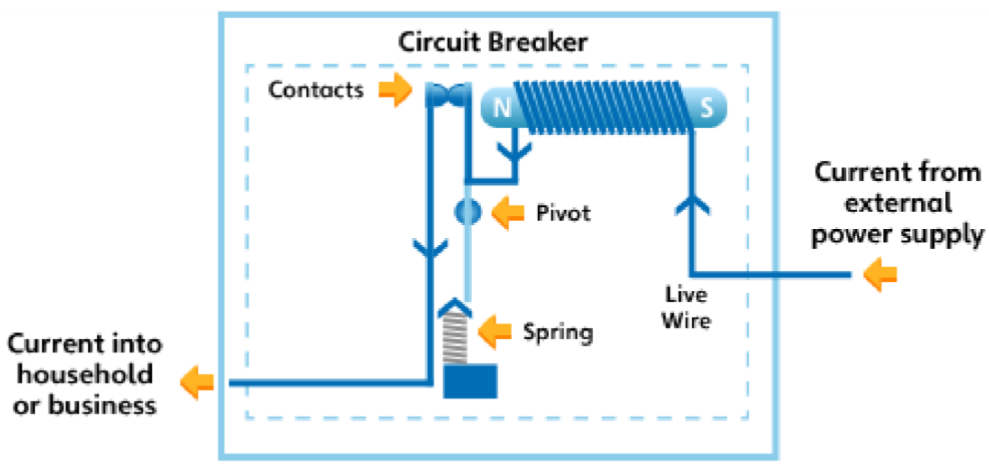
circuit breaker. It is referred as a breaker panel because it usually contains Circuit breakers attached to every current carrying cable that is distributed from the distribution board.
The distribution board is the most common form of residential electricity protection. It is particularly designed to protect against overloading and short circuiting. Using current rated electro-mechanical circuit breakers, it is capable of tripping off current carrying distribution lines in which the current being drawn have exceeded the specified limit. Below is a detailed explanation of how the circuit breaker works.

Circuit Breaker

A circuit breaker is an automatically operated electrical switch which is designed to switch off and discontinue current flow through it when the current exceeds a predetermined limit (Hui et al., 2017). Much like a fuse, its main objective is to interrupt current flow in the event of a fault occurring, but unlike a fuse which gets damaged permanently after a single operation, a circuit breaker can be switched back on.

The circuit breaker can detect current overload using the electromagnetic or thermal properties of the current flowing through it. In the case of a magnetic or thermal magnetic circuit breakers, as current flows through the circuit breaker it energizes a solenoid coil whose pulling power increases with an increase in current. At a mechanically predetermined current, the pulling force of the solenoid will attain a magnitude capable releasing a loaded spring and separating the contacts in the breaker.

Figure 1.1: Operating principle of a Circuit breaker.



Although the circuit breaker serves as enough electricity protection, its weakness is in the fact that it cannot detect over voltage and therefore relies on the trust that the electricity supply voltage is 220 – 240V or (110 – 120V in some countries). As we know, electricity supply within Nigeria is not trust worthy, therefore homes are vulnerable to electrical hazards in the form of voltage surges.

Electricity Monitoring Systems

An electricity monitoring system is an electrical device which provide real time data on the power system in your home. The meters are connected to the distribution board (in an easy to-install manner) allowing it to conduct a series of tests on the quality of the electricity supply to your home/facility and within your home, detect basic wiring faults and allow owners and service providers to identify potential problems with the electrical systems.

Compliable historical data also helps end-users reduce the energy delivered to and consumed by electrical systems in their facilities.

Basics of Electricity Monitoring

Electricity monitoring includes constant measurement of the quality of the electricity supply to your home or residence. This includes measurement of voltage, current, load on the internal distribution lines and energy metering. In recent times, as the demand for electricity has increased, energy metering has become very common in homes. This involves the measurement of the voltage and the current consumed by the residency with time. In all this, there are three basic parameters required for electricity monitoring and energy metering; Voltage, Current and time.

Voltage

We define voltage as the amount of potential energy between two points on a circuit. One point has more charge than another. This difference in charge between the two points is called voltage (Sparkfun, 2013). It is measured in volts, which, technically, is the potential energy difference between two points that will impart one joule of energy per coulomb of charge that passes through it.

In Nigeria, the standard voltage of distribution lines is 220-240V. Electrical and electronic devices designed for 220 – 240V would not function properly if delivered less than that rating and would get damaged if delivered more. Therefore, it is imperative that only stable voltage within the required limits is allowed into homes and facilities.

Current

Current is the rate at which electrons flow past a point in a complete electrical circuit. An ampere or amp is the international unit used for measuring current (ElectronicsTutorials, 2018). It expresses the quantity of electrons or electric charge flowing past a point in a circuit over a given time (Sparkfun, 2013). A current of 1 ampere means that 1 coulomb of electrons which is 6.24×10^{18} electrons is moving past a specific point along the circuit. Accurate measurement of current is the foundation of electrical protection. From fuses to circuit breakers, current is the fundamental element of their operation because when current is closely monitored, it can reveal electrical faults.

In a small room with only one power outlet, a circuit breaker with a low current rating is to be installed. This is because the room has been designed not to supply a lot of equipment with power, so if there is a sudden spike in current draw, a potential fault like short circuiting or electrocution will be assumed and the distribution line is tripped off.

Component Review

This sub-topic discuses about the intricate specifics of every single component used in the construction of the project.

ACS712 Current Sensor

The ACS712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems. The device consists of a precise, low- offset, linear Hall sensor circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage (Allegro MicroSystems, 2006).

Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy after packaging.

The thickness of the copper conductor allows survival of the device at up to 5 times overcurrent conditions. The terminals of the conductive path are electrically isolated from the sensor leads (pins 5 through 8). This allows the ACS712 current sensor to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques. The ACS712 is provided in a small, surface mount SOIC8 package. The lead frame is plated with 100% matte tin, which is compatible with standard lead (Pb) free printed circuit board assembly processes. Internally, the device is Pb-free, except for flip-chip high-temperature Pb-based solder balls, currently exempt from RoHS. The device is fully calibrated prior to shipment from the factory (ElectronicsTutorials, 2018).

LM35 Temperature sensors

The LM35 are precision integrated-circuit temperature devices with an output voltage linearly proportional to the Centigrade temperature (Texas Instruments, 1999). The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 device does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and +/- a quarter of a centigrade over a full −55°C to 150°C temperature range. As the LM35 device draws only 60 µA from the supply, it has very low self-heating of less than 0.1°C in still air (Texas Instruments, 1999).

GSM Module

A GSM module is a specialized type of modem which accepts a sim card and operates over a subscription to a mobile operator, just like a mobile phone. It is based on the “Global System for Mobile communications” technology and allows computers not necessarily designated for that technology make use of it. The GSM module allows the embedded system possess basic functionalities than any other mobile phone can perform. It gives it SMS, internet and call capabilities among many others. To perform these tasks, the GSM module must possess an extended AT command instruction set.

SIM800L

SIM800L is a GSM module which allows for GPRS transmission, sending and receiving SMS and making and receiving voice calls. After connecting power module boots up, searches for cellular network and login automatically. On board LED displays connection state (no network coverage - fast blinking, logged in - slow blinking) (Shanghai SIMCom Wireless Solutions, 2013).

Microcontroller

A microcontroller is an application specific integrated circuit (ASIC) that fetches and executes instructions based on input or an application program written to it. It does not have a fixed function but rather are controlled by a software. It possesses all the functional elements of a computer i.e. ROM, RAM, processor, input sub-system and output sub-system, all embedded into an integrated circuit. For this application, the Arduino nano was chosen as the microcontroller.

Microcontrollers are used in automatically controlled products such as automobile engine control systems, implantable medical devices, remote controls, home appliances like microwave ovens, air conditioners, toys, etc.

The Arduino nano was chosen for this application. Based on the 16MHz Atmega328 surface mount microcontroller, it is a small, affordable and breadboard friendly microcontroller with 32kb flash memory and 2kb SRAM. It operates with 5V level logic, 14 digital I/O pins and 8 analogue pins (2 of which are input only). Arduino is a user-friendly microcontroller with an active user-base and online support community that makes it the best for prototyping.

Relays

A Relay is a switch that can open and close circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing contacts in another circuit. As relay diagrams show, when a relay contact is normally open (NO), there is an open contact when the relay is not energized. When a relay contact is Normally Closed (NC), there is a closed contact when the relay is not energized. In either case, applying electrical current to the contacts will change their state.

Relays are generally used to switch smaller currents in a control circuit and do not usually control power consuming devices except for small motors and Solenoids that draw low amps. Nonetheless, relays can "control" larger voltages and amperes by having an amplifying effect because a small voltage applied to a relays coil can result in a large voltage being switched by the contacts.

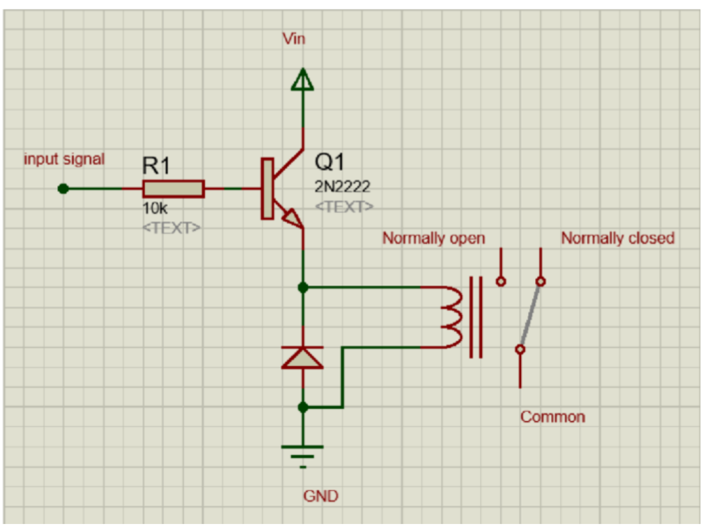


Figure 1.2: Internal circuitry of the Relay module

Relays involve two circuits: the energizing circuit and the contact circuit. The coil is on the energizing side; and the relays contacts are on the contact side. When a relays coil is energized, current flow through the coil creates a magnetic field. Whether in a DC unit where the polarity is fixed, or in an AC unit where the polarity changes 120 times per second, the basic function remains the same: the magnetic coil attracts a ferrous plate, which is part of the armature. One end of the armature is attached to the metal frame, which is formed so that the armature can pivot, while the other end opens and closes the contacts.

METHODOLOGY

2.1 Introduction

As a proof of concept and for the purposes of this research, a low budget prototype was designed and constructed. This prototype although not having all the functionality of the final desired product will share fundamental properties with the final product in its design methodology and should help further explain the concept.

2.2 Design Block Diagram

The block diagram of figure 3.1 depicts the sections of the R.E.M.S and how these sections are connected to the microcontroller.

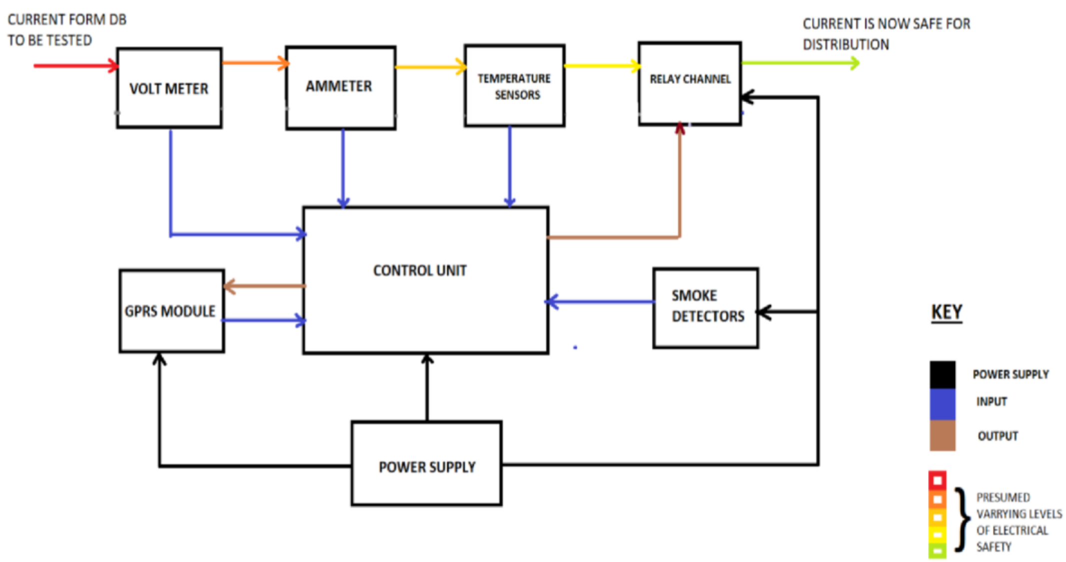


Figure 2.1: Block diagram of the residential electricity monitoring system

2.3 Overall Design

The REMS was designed to be as easy to setup and install as possible. It is mainly divided into the Input section, Output section and control section.

2.3.1 Input Section

The input section of this device is made up of all sensors that collect input into the control unit for processing. This includes; the voltage sensor, current sensor and temperature sensor. These input sensors collect voltage, current and the temperature of the individual distribution lines and deliver them to the control unit.

2.3.2 Output Section

The output section of the REMS is made up of all components which deliver feed back to the user of the device and carry out control instructions. This includes the LCD, Relay and SIM800L module.

2.3.3 Control Section

This mainly refers to the microcontroller unit. This unit is responsible for managing the entire system, collecting input from the Input Section and providing appropriate output. The microcontroller was programmed in C++ using Arduino IDE to carry out its responsibility accordingly.

2.4 Construction of the Voltage Sensor

The Atmega 32p-pu microcontroller operates at a maximum voltage of 5v. That means its analogue input pins can accurately measure voltages less than 5v but any voltage greater than 5v would damage the microcontroller. To enable the Arduino microcontroller measure high AC voltages, the voltage needs to be reduced to a much smaller voltage which the Arduino Nano microcontroller can work with. This will become a measurable analogue signal but must stay directly proportional to the high AC voltage to be measured. By keeping the reduced voltage proportional to the AC voltage to be measured, the microcontroller can use the slight changes in the reduced voltage to predict the actual voltage.

Voltage regulators, DC choppers, etc. therefore cannot be used for this as they do not produce an output voltage proportional to the input.

The voltage sensor was built from scratch using voltage divider rule. The circuit divides the input voltage effectively by 80, allowing the device to be able to measure up to 400VAC.

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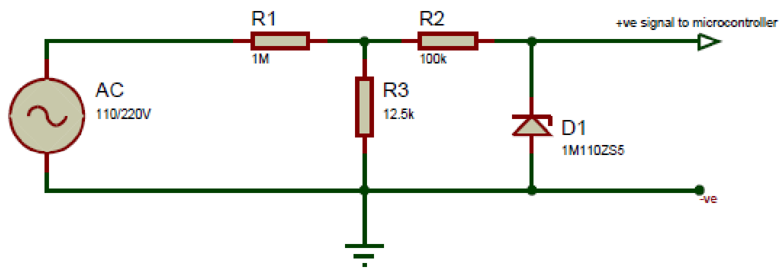

Figure 2.2: Voltage sensor

TESTING AND EVALUATION

The main purpose of this prototype was to serve as a proof of concept while also testing out basic functions that the final product should be able to implement. Although it would be unfair to judge the efficiency of the final desired product based on this mock up prototype, extensive tests were carried out of this; simulating 3 common faults: overloading (voltage and current), short circuiting, and temperature rise.

For safety purposes, test voltage was limited to 25V AC and a 15amp fuse was connected in series with the power line. These tests were conducted with the aid of a digital stop watch, clinical IR thermometer and an electricity multimeter.

For the test, the software on the ems was updated to see 25V AC as the maximum acceptable voltage and 5amps and the circuit breaker rating. A 60watt light bulb was used as the test load. This is because it would only draw 2.4amps at 25V (25v x 2.4a = 60w).

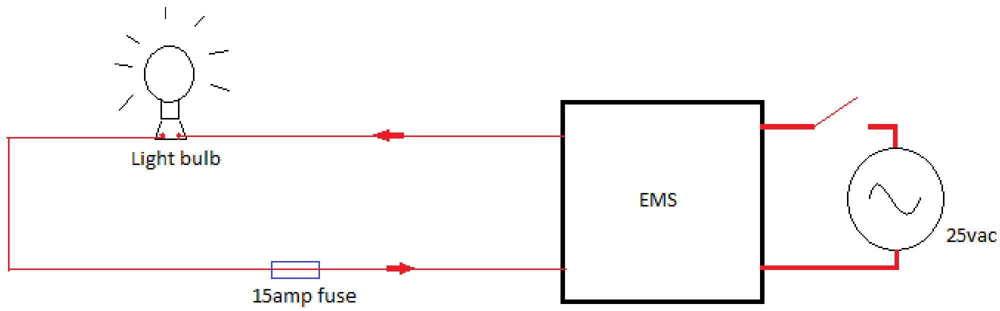

Figure 3.1: EMS test circuit

-Voltage surge test: from the illustration above, the switch was opened, the voltage source was then changed to 50v and then the switch was closed.

-Short circuiting: the switch was opened, then the phase and neutral wires were bridged with a wire after which the switch was closed.

-Current overloading: the switch was opened then the light bulb was changed to a 150watt bulb. This is because at 25v, the bulb will attempt to draw 6amps (25v x 6A = 150w) from the source when the EMS has been configured to cut off at 5amps.

-Temperature spike: For this test, the setup above was rewired. A 24v 2A rated wire was used for the entire setup, then the 60watt bulb was replaced with a 100watt bulb. The EMS is configured to cut-off when the wire reaches 50℃. This is because by the time the wire has gotten to 50℃ at the EMS, the temperature would well be above 80℃ at the socket point. With the aid of an infrared thermometer, this took 6 minutes and 43 seconds for the wire to reach 50℃ due to the overloading of the wire. The EMS cut the circuit off after 7minutes and 29seconds; by then the temperature was at 56℃.

Each test was conducted 5 times each and their average reaction time was calculated.

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Presented here is a summary of the tests conducted.

s/n	Fault	Description	EMS action taken	Average Reaction time (milli seconds)	remarks
1	Voltage surge	Voltage supply was changed to 50V	Circuit was cut off and text was sent	800	The bulb was lit for 0.8 seconds before cut-off. Passed.
2	Short circuiting	The phase and neutral terminals were bridged	Circuit was cut off and text was sent	500	There was a spark and the 15amp fuse broke.
3	Current overloading	150w load was connected	Circuit was cut off and text was sent	1200	The overload lasted for 1.2s before cut-off.
4	Temperature spikes	Lower current rated wires were used and a 100watt load was connected	Circuit was cut off and text was sent	46000	Reaction to temperature change was too slow.

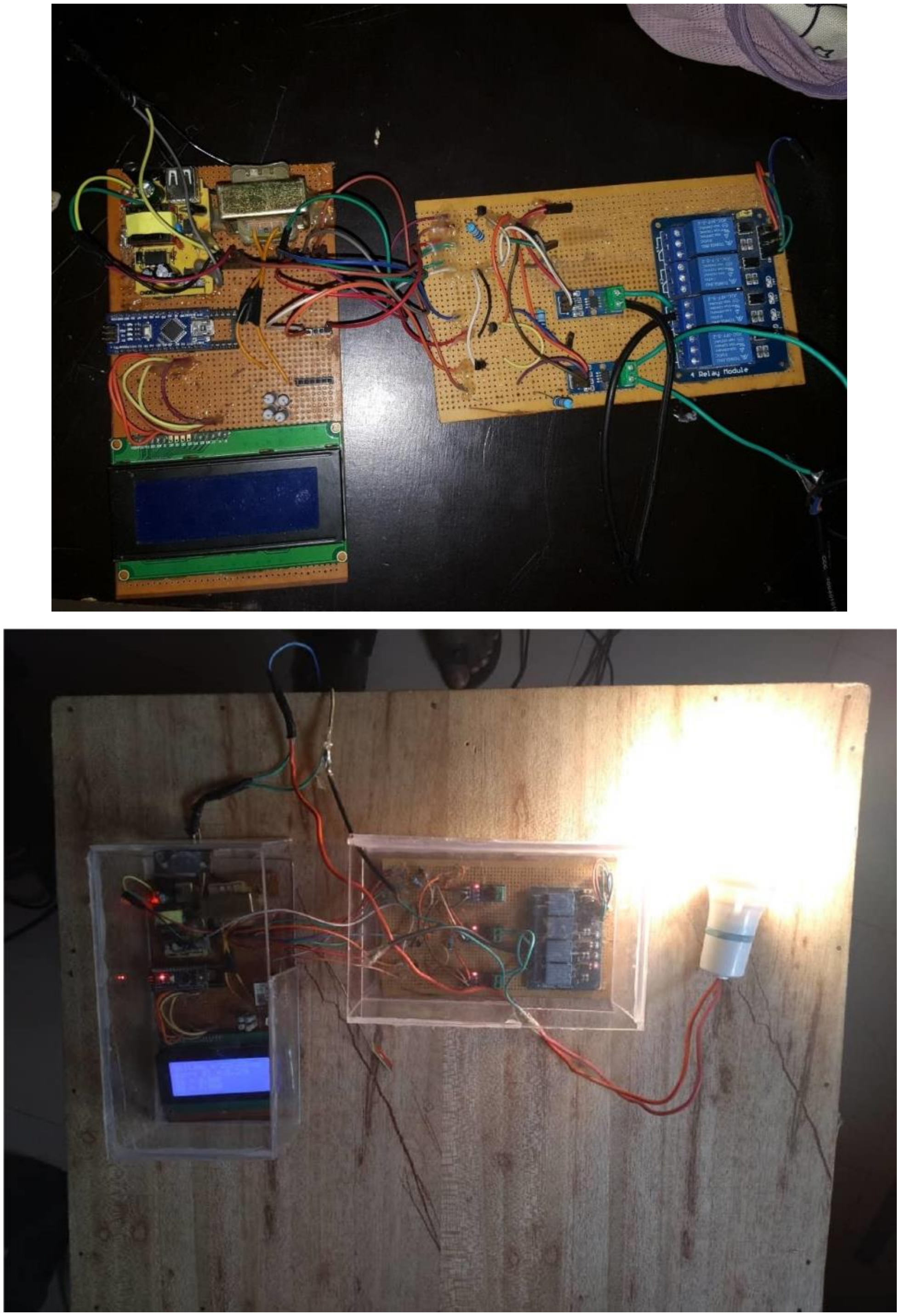

Figure 2.3: First prototype circuit

CONCLUSION AND RECOMMENDATION

Conclusion

The project has been motivated by the desire to optimize energy domestically in our homes and offices. During the course of the project through extensive research, it was concluded that one of the major factors that enables electrical fires and property damage due to electricity was lack of a robust protection system. With a system like this, consumers are given real time protection against electrical hazards, voltage surges, over loading, etc. From undergoing all these tasks, the following conclusions were drawn:

Positive conclusions:

i. At the end of the project, a Residential Electrical Monitoring system was developed.
ii. It allows for easy upgrades of protection protocols via software updates alone rather than the change of entire distribution board.
iii. A system which could be operated with-and communicates with the user via text messages was developed and tested.
iv. A system which could control house hold appliances through text messages and the sole utilization of relays was developed.
v. One of the first made-in-Nigeria mainstream electronic device was developed.
vi. Temperature monitoring of distribution lines is now possible.
vii. Voltage fluctuations are now detectable by a distribution board even when the fluctuation remains within standard voltage limits.
viii. Energy usage is measurable and optimizable by the same distribution board.

Negative observations:

i. Now, this system still struggles with long reaction time to critical changes in the state of electricity distribution. Between detection of a fault or occurring hazardous event, to measurement of the magnitude of the change in specified state, to processing what the best possible actions it can take to prevent a hazard, then reacting by taking those actions, all before sending texts and compiling comprehensive reports to be uploaded to the internet, almost 3 seconds would have passed. Although with faster processors, optimized software and a more efficient circuit design, this time can be reduced to under 100milli seconds. This is still not enough as it takes less than 100ms for major damage to occur. This makes it disadvantageous in comparison to electromechanical circuit breakers which do not utilize processors and can react to changes under 20milli seconds (C3Controls, 2018).

ii. Better design implementation process is required to improve reaction time and increase efficiency. Also, with a voltage measuring accuracy of +/- 2V, better designs are necessary to improve this accuracy.

iii. More funding is required as well.

iv. Proper mentorship is required. It is difficult to find seasoned electronics engineers in Nigeria to partner with for mentorship and this has been responsible for a slow development process.

Proposed contribution

With the high cost of electricity in Nigeria, its instability and unreliability, this project would go a long way in the protection of household appliances from potential damage due to electrical faults and would help save millions in electricity bills, electrical appliance repair and maintenance and damages including loss of life and property.

Another very important addition is the device's ability to contact emergency services via call and sms on detection of smoke so that even in your absence, your home is being secured from electrical fires. Most importantly, this project will help save thousands of lives lost annually due to electrical hazards, shock and electrical fires not just in Nigeria but all over the world.

This project will go a long way into pioneering engineering innovation in Nigeria and in Africa by initiating and encouraging electronics research in various fields and on the long run contribute to national economic growth.

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