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Design and Implementation of Efficient Energy Management System for Federal Polytechnic Nekede, Owerri.

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Abstract: *Federal Polytechnic Nekede, Owerri (FPNO) being one of the foremost Polytechnic and currently rated as the best and most sort after Polytechnic in the country requires an efficient and reliable power supply for its numerous activities. The polytechnic runs on two major sources of supply namely utility supply and local power generators but has in recent times depended solely on her local power sources due to the erratic nature of the utility supply. In other to conserve energy, optimize the use of these generators and to prevent frequent power wastage, as well as reducing cost on fuel, a microcontroller-based facility energy management system is developed. In Federal Polytechnic Nekede, Owerri, Imo state, there are critical and non- critical loads depending on functionalities required. Critical loads should never be turned off or lose supply while non-critical loads may be turned on or off depending on the power consumption and supply pattern. In practice, various combinations of load management and conservation measures are targeted at energy efficiency and rescheduling. The functionalities implemented for electrical load management which include timing of loads and smart switching off street lights are discussed. Besides, there is an algorithm for the determination of power restoration from the national grid to avoid wasting energy, particularly when there is an alternative source. A zoning arrangement is finally recommended which will reduce the number of active generators running simultaneously on the campus.*

Keywords: *Arduino, Microcontroller, Energy, Load, Schedule, Proteus, Relay, keypad, Timer, Simulation. Generation.*

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I. Introduction

Many critical shutdowns occur in power networks in many industrial sectors. The education and health sectors are no exception, but the impact of power outages on critical infrastructures like databases and research processes is somewhat ill-understood. Greater understanding is indispensable so that adverse impacts of a power failure and system collapse due to unplanned outages can be prevented and or mitigated. Some educational institutions with Federal Polytechnic Nekede as an example are currently operating on two major modes of power supply namely utility and local generators. The frequent failures and unavailability of supply from the utility source has made the institution depend mostly on local generators for electricity supply to most of its facilities. This development has led to the institution running different generators for different facilities and as a result, there are over 27 different generating sets with varying capacities running simultaneously almost daily. The high cost of fuelling and maintenance of these generators can be imagined. This paper, therefore, proposes an efficient energy management system for the polytechnic to reduce the running and maintenance cost of providing electricity.

An Energy Management System (EMS) is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation or transmission system. Also, it can be used in small scale systems like micro-grids (Emeis, 2011)**.**

Many countries in the world are currently facing an overwhelming energy crisis (Javid M. A et al, 2011) which disturbs not only the daily life of people but also has a severe impact on the social and economic growth of countries. According to the United Nation energies commission report released in December 2003, 1.3 billion people in the world are living without electricity. World electricity demand is projected to be double between 2000 and 2030, growing at an annual rate of 2.4% (IEA Report, 2014). The difference in demand and supply requires short term and long term policies by the Governments of different countries to solve this problem (Masood MT et al, 2012). The generation of electricity through different sources, effective monitoring of electricity and Corporate Social Responsibility practices can reduce the gap between demand and supply.

Electricity losses are also one of the main causes of the electricity crisis. Software systems can be used to identify the loss and theft of electricity. Electricity management systems are the applications for the management and optimization of electricity to reduce unstable power crisis. Software systems for energy management can be very important to overcome the problem of unstable electricity supply. In recent years, this area of research has attracted much attention from researchers throughout the globe. Developing interest in the field of energy management systems is evidence that there is a need to advance energy management systems that can be used globally. Most research in this field is limited primarily because researchers just have different suggestions, but they did not provide appropriate solutions that may be used on real problems. A small number of people who conduct research presented software solutions for electricity management but these solutions are confined in scope.

Hence, to conserve and prevent the power outages due to overload or extra-load on the system during peak time, microcontroller-based energy management is designed to solve this problem which is the main objective of this work. This involves the monitoring and control of activities of energy flow such as lighting, heating, ventilation, and air condition, electrical appliances using an automatic transfer system (ATS) and or setting time schedules for its operation. With a microcontroller-based energy management system in place, decision-makers can have peace of mind that their systems will be able to function in the event of an emergency.

Beyond convenience, this technology will be effective for managing electricity consumption. Leaving our security lights ON during the day or having the air condition ON even while we are away is not a good power management practice. However, a microcontroller-based energy management system helps to predetermine when you want these appliances turned ON/OFF –saving a great deal of energy.

Effective Energy Management Systems help to establish sustainable processes to improve energy performance. Proper implementation can reduce the user's artificial shutdown, energy costs, and minimize risks.

Hence, constant electrical power is needed in places like Rector's office to provide a better work environment and thereby improve performances of staff members whose jobs need the power to be executed. The system can automatically and efficiently transfer loads to the available power without the need of a human being.

Problem Statement

In most tertiary institutions in Nigeria, it was discovered that loads are not properly distributed to the various offices, lecture halls, and other important places. With FPNO as a case study, several generators are running simultaneously per working day thereby stressing the available financial resources on fuelling and maintenance. It was also observed that the generators are manually operated and require human efforts for switching.

Objective

The main objective of this paper is to design and develop a microcontroller-based energy management system (EMS). Which will drastically reduce the number of active generators running by redistributing and zoning the generators with higher capacity to pick up the loads previously carried by the smaller units.

Specific Objectives are:

1. To critically review the current power supply structure in the Polytechnic.
2. Develop a mechanism to automatically switch over to the available power source at any point in time.
3. Develop a smart switch for the street lights.
4. Build a prototype EMS module for the school for the accurate timing of every load.

Energy and its Social benefits

Firms and industries that implement energy efficiency cost-effectively improve productivity; an increase in productivity is the main factor responsible for both industrial and economic growth. As such, an improvement in productivity translates into higher profit margins that can be redistributed as increased wages and also invested to expand output, benefiting both supplier and consumer (UNIDO, 2011). Improving productivity (as a consequence of increased industrial energy efficiency) can lead to the development of innovations that can create new jobs and also expand employment. The implementation of energy efficiency can also improve the working environment of firms and the quality of life of society.

Energy Management

According to market Research by Rockwell Automation (2012), it would be difficult for companies to be uninformed of energy use in their facilities nowadays. Energy consumes an increasingly large share of operating costs, and extracting, producing or doing anything. Energy is very important for the creation of wealth and improvement of social ware fare. This means that energy is needed mostly to ensure sustainable development.

Energy Management Strategies

Conduct an energy survey

The first step to an effective energy management program is to learn how and when each piece of equipment uses energy. Calculate the demand and monthly energy consumption for the largest equipment. The rate at which energy is consumed will vary throughout the day, depending upon factors such as demand from the distribution system and time of the day. Note the largest equipment which can be operated off-peak. Examine all available rate schedules to determine which can provide the lowest cost in conjunction with appropriate operational changes.

Improve power factor

The low power factor is not only inefficient but can also be expensive over the life of an electrical system. This is frequently caused by motors that run less than fully loaded thereby wasting energy due to a drop in the motor efficiency below full load.

Improved power factor will increase the distribution system's efficiency and reduce energy loss associated with power factor penalties.

Types of Electrical Loads

An electrical load is a device or an electrical component that consumes electrical energy and converts it into another form of energy. Electric lamps, air conditioners, motors, resistors, etc. are some of the examples of electrical loads. They can be classified according to various factors. Electrical loads can be classified according to their nature as Resistive, Capacitive, Inductive and combinations of these.

Resistive Load

i. Two common examples of resistive loads are incandescent lamps and electric heaters.
ii. Resistive loads consume electrical power in such a manner that the current wave remains in phase with the voltage wave. That means the power factor for a resistive load is unity.

Capacitive Load

i. A capacitive load causes the current wave to lead the voltage wave. Thus, the power factor of a capacitive load is leading.
ii. Examples of capacitive loads are capacitor banks, buried cables, capacitors used in various circuits such as motor starters, etc.

Inductive Load

i. An inductive load causes the current wave to lag the voltage wave. Thus, the power factor of an inductive load is lagging.
ii. Examples of inductive load include transformers, motors, coils, etc.

Combination Loads

i. Most of the loads are not purely resistive or purely capacitive or purely inductive. Many practical loads make use of various combinations of resistors, capacitors, and inductors. The power factor of such loads is less than unity and either lagging or leading.
ii. Examples: Single-phase motors often use capacitors to aid the motor during starting and running, tuning circuits or filter circuits, etc. Figure 1 shows some of the key interconnectivity in EMS.

Fig 1 Energy Management System

Critical and Non-Critical Loads

Critical loads are those loads that need a constant supply of energy regardless of circumstances. The energy supply to these loads should not ever be interrupted.

Usually critical loads are present in plants, hospitals, financial and educational institutions, etc where certain processes cannot be stopped. The equipment is so critical that there is a greater demand for steady electric energy. Hence an auxiliary power supply is needed for times when the public supply goes down or when the power exceeds or below certain rated value.

Non –Critical loads are those which do not form part of a production or process plants and its disconnection is only minimal or nuisance value. These loads are automatically disconnected when maximum energy is needed for the operation of essential loads. For instance, leaving an outside light on in the day time when the surgical operation is going on in a hospital might cause a shortage of energy at that time, hence it should be switched off.

II. Materials and Methods

The following session gives the technical details of some of the components adopted in the development of this concept:

Hardware development

Many electronic components will be used for the development of the Energy Management and Control System with Mobile Application Interface. Each component plays an important role(s) and interoperates with one another to give a complete circuit design. They are as follows:

MICROCONTROLLER (ARDUINO UNO, NANO AND ARDUINO MEGA 2560)

Microcontrollers are often described as single-chip computers. They contain a microprocessor core, some memory and various "peripheral" devices such as parallel I/O ports, serial I/O ports, timers, analog to digital converters (ADC) and various other special functions subsystems.

The Arduino microcontroller is a powerful single-board computer that has gained considerable adoption by hobbyists and professionals alike because of its ease of use. Arduino is open-source, hence hardware is reasonably priced and the development software is free. There are many types of Arduino microcontroller but for this design purpose, the Arduino Nano and Mega2560 microcontrollers are used (Leo Louis, 2016).

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x) or ATmega168 (Arduino Nano 2.x). It has more or less the same functionality of the Arduino Duemilanove but in a different package. It lacks only a DC power jack and works with a Mini-B USB cable instead of a standard one. The Nano was designed and is being produced by Gravitech.

Specifications:

Microcontroller	Atmel ATmega328
Operating Voltage (logic level)	5 V
Input Voltage (recommended)	7-12 V
Input Voltage (limits)	6-20 V

Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	8
DC Current per I/O Pin	40 mA
Flash Memory	32 KB (ATmega328)
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Figure 2 below shows the Arduino Microprocessor board and pin-out layout

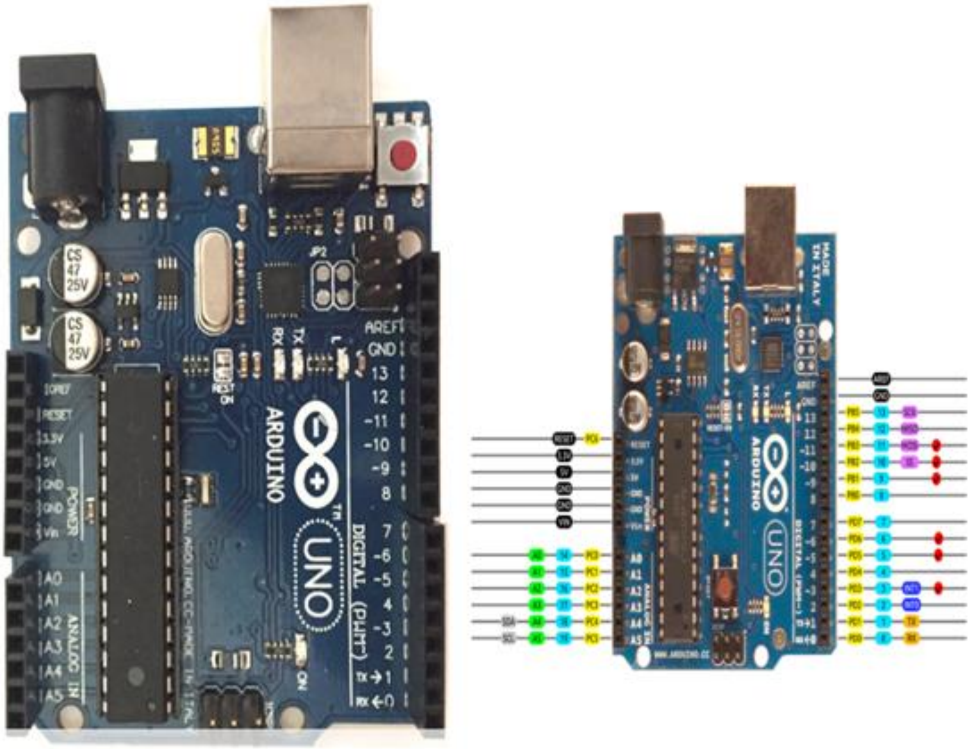


Figure 2: Arduino Microprocessor board and pin-out layout (source: Arduino UNO 2018)

The Arduino Mega is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button (Thomas E. Murphy & Hien Dao 2012). It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

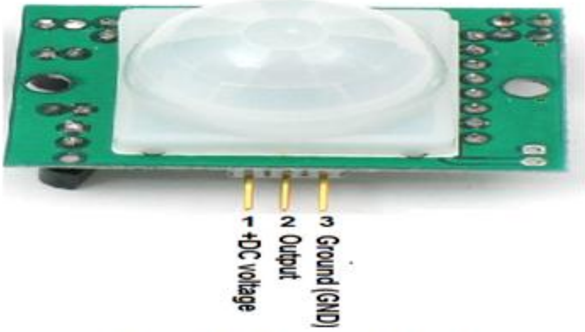
Specifications:

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	128 kB of which 4 KB used by the boot loader
SRAM	8 kB
EEPROM	4 kB
Clock Speed	16 MHz

The Arduino Mega can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the power connector Thomas E. Murphy & Hien Dao (2012).

Passive Infra-Red (PIR) SENSOR

Passive Infra-Red sensor is a device used to detect motion by receiving infrared radiation. When a person walks past the sensor, it detects a rapid change of infrared energy and sends a signal. PIR sensors are used for applications such as automatically turning on lights when someone enters a room or causing a video camera to begin operating. PIR sensors are low power, low cost, have a wide lens range, easy to interface.



Fixed Resistors

Figure 3: PIR sensor and fixed resistors.

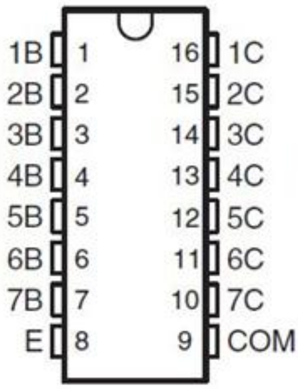
RESISTORS (FIXED)

Resistors restrict or limit the flow of current in a circuit. The ability of a material or component to resist current flow is called its resistance and it is measured in ohms. A resistor can be either fixed or variable. The fixed types are used when the resistance required is intended to be steady regardless of the circuit operation (see fig 3).

ULN2003 (DARLINGTON PAIR)

The ULN2003A is an array of seven NPN Darlington transistors capable of 500mA, 50V output. It features common-cathode flyback diodes for switching inductive loads. The Darlington transistor (also known as Darlington pair) achieves very high current amplification by connecting two bipolar transistors in direct DC coupling so the current amplified by the first transistor is amplified further by the second one.

It can come in PDIP, SOIC, SOP or TSSOP packaging. In the same family are ULN2002A, ULN2004A, as well as ULQ2003A and ULQ2004A, designed for different logic input levels.



The Liquid Crystal Display

Fig 4. The ULN2003A Pinout, 12V Relay and LCD (source: futurelec.com)

RELAYS

A relay is an electromechanical device. A relay can be of two types; AC (can supply AC load from its terminals) or DC relay (can supply only DC from its terminals). It is an automatic switch for controlling a high current circuit with a low current signal safely. It has a coil and poles of normally open and normally closed terminals with a common terminal (Kumar, S. A. I. P., & Rao, B. S. A. I. V. 2015). The coil provides the control on which contact/terminal is to make the common terminal. It controls a high load current with a rated voltage and current of 240V and 10A, respectively. A DPDT AC relay (which we used in this project) has two sets of normally open contact and a normally closed contact with the control coil.

BATTERIES

A rechargeable battery, storage battery, secondary cell, or accumulator is a type of electrical battery which can be charged, discharged into a load, and recharged many times, while a non-rechargeable or primary battery is supplied fully charged, and discarded once discharged. It is composed of one or more electrochemical cells. Rechargeable batteries are produced in many different shapes and sizes, ranging from button cells to megawatt systems connected to stabilize an electrical distribution network. In this project, we used a 12V rechargeable battery and a 9Vdisposable battery (Borkar & Karande, 2017).

LCD LM321

The Liquid Crystal Display (LCD) is a flat panel display, an electronic visual display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content that can be displayed or hidden, such as preset words, digits, and 7-segment displays as in a digital clock. They use the same basic technology, except that arbitrary images are made up of a large number of small pixels, while other displays have larger elements (Ahmed, 2017). LCDs are used in a wide range of applications including computer monitors, television, instrument panels (as used in this project), aircraft cockpit displays, and signage. They are common in consumer devices such as DVD players, gaming devices, clocks, watches, calculators, and telephones. The LCD which we used in this project is LM321 which comes in 2 rows and 16 columns.

Arduino UNO Microcontroller

Arduino Uno is a microcontroller board based on an 8-bit ATmega328P microcontroller. Along with ATmega328P, it consists of other components such as crystal oscillator, serial communication, voltage regulator, etc. to support the microcontroller. Arduino Uno has 14 digital input/output pins (out of which 6 can be used as PWM outputs), 6 analog input pins, a USB connection, A Power barrel jack, an ICSP header, and a reset button.

Relay drives

This is an electro-mechanical device for switching

Crystal Oscillator

A crystal oscillator is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a precise frequency. This frequency is often used to keep track of time to provide a stable clock signal for a digital integrated circuit.

KeyPad

A keypad is a set of buttons arranged in a block or "pad" which bear digits, symbols or alphabetical letters.

LED

A light-emitting diode (LED) is a semiconductor light source that emits light when current flows through it.

Signal Diode

This is used for switching and to detect signals.

Voltage regulator

A voltage regulator is a system designed to automatically maintain a constant voltage level.

Connector

Connectors are used to join subsections of circuits together

Liquid Crystal Display (LCD)

A liquid-crystal display (LCD) is a flat-panel for displaying information.

Step-down transformer

This brings down the voltage level from 220V to 12V.

Buzzer

This is an electronic component for generating sound. It is used in this work to indicate to us when their power restoration from the national grid.

And other discrete components.

The Arduino microcontroller monitors its timing pins to know when there is a change in any button as a result of pressing any of them by the users. This stage is called the initialization stage. Each button is dedicated to a function. Figure 5 below shows the block diagram of the entire system while figure 6 gives the system flow chart.

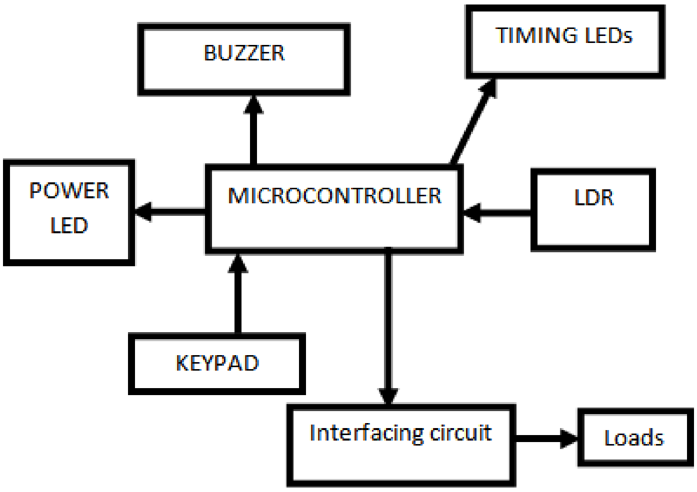


Fig. 5: System block diagram

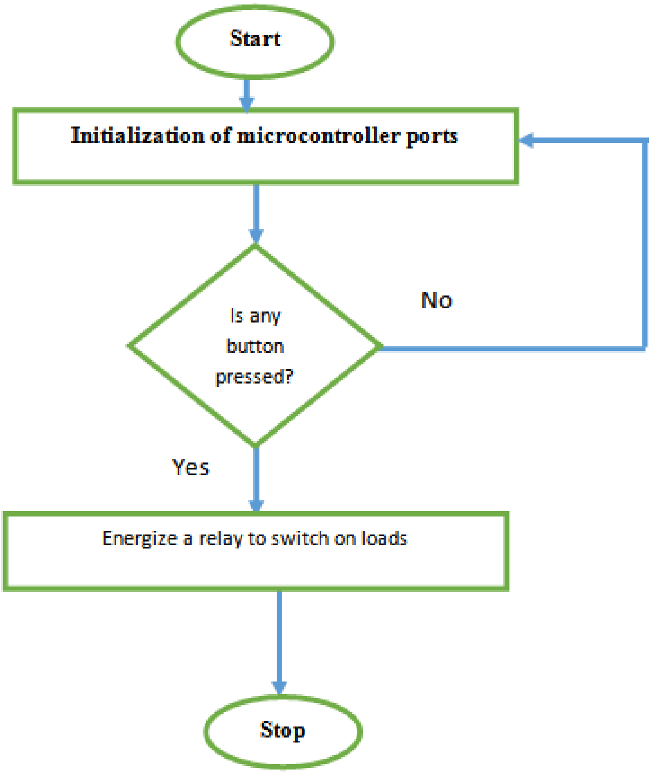


Fig.6: The system flowchart

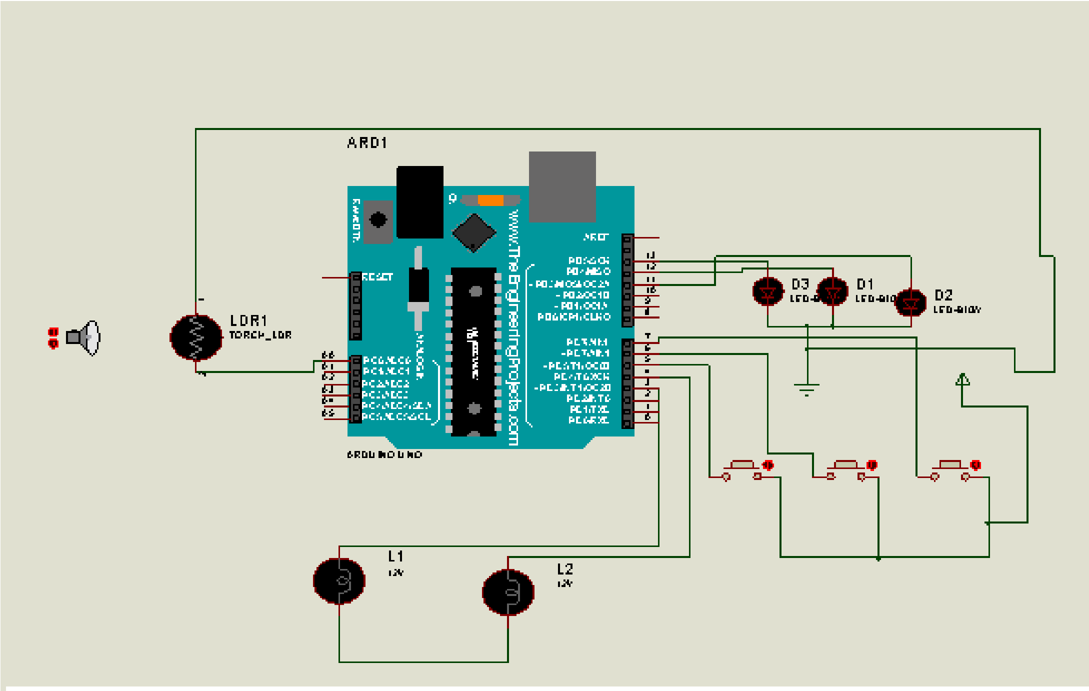


Fig.7: The circuit diagram of the system

Current Electricity Supply Structure in FPNO

Power is supplied to the Federal Polytechnic Nekede, Owerri from Egbu road Injection substation through FPNO switchyard within FPNO premises. The switchyard houses three 33/11kV, 5MVA step down transformers, metering equipment and oil circuit breakers that protect the transformers. One of the 33/11kV, 5MVA transformer supplies power to the FPNO medical Centre while the other two transformers supply power to the rest of the Polytechnic Community both residential and administrative buildings.

The various 33/0.415kV secondary substations are fed from the switch substations through Ring Main Units (RMU) and 95mm^2 underground armored Feeder Lines. Each feeder begins and ends at a switch substation through oil circuit breakers (OCB). That is each Feeder is connected on either side through OCB and power can be fed from any side, depending on the load distribution required. Each of these switch substations is equipped with South Wales Gear and uses a sectionalized busbar system with section switches (oil circuit breakers) and other switch ways for incoming and outgoing feeders.

Alternative source

Due to the unreliable and inefficient nature of the power supply from the Enugu Electricity Distribution Company (EEDC) the polytechnic management has resorted to powering its facilities from Local Generators. Details of the location, capacity, and condition of these generators are given in the table below.

Table 1. Existing Generators and location on campus

S/N	**LOCATION/Condition**	**kVA RATING**
1	Perkins new water scheme near Rectory (Undergoing repairs)	50
2	Perkins new water scheme near Plant house (Undergoing repairs)	50
3	Perkins new water scheme near Plant house (functional)	50
4	Medical center (Functional)	100
5	Staff school (Functional)	60
6	Rectory (Not functional)	**500**
7	Rectory Cummins (Functional)	500
8	Fabrication (Functional)	500
9	Plant house (Outdoor), Not functional	**500**
10	MIKANO Substationon (functional)	500
11	1000 capacity auditorium (not functional)	**200**
12	Hostel A (Functional)	200
13	SBMT (Functional)	200
14	SEDT (Functional)	200
15	Water factory (Functional)	100
16	Water factory (Functional)	60
17	Cummins hostel B and C (functional)	100
18	IPC (Functional, but not in use)	30

19	Cummins Humanities (Functional)	100
20	Cummings Food tech. (Functional)	100
21	FG Wilson Engineering /NDDC lab (Not functional)	**102**
22	Cummins Engineering Complex I and II (Not functional)	**100**
23	Perkins microfinance bank (Functional)	100
24	Perkins library (functional)	100
25	PTDF (Functional)	60
26	Perkins bookshop (functional)	9
27	Perkins stores (functional)	18.5
28	Perkins Weekend Program (undergoing repairs)	250
29	Perkins works (functional)	30
30	Perkins 1000 capacity auditorium (functional)	30
31	Perkins CBT (functional)	100
32	Perkins Skill G (functional)	60

The table shows that the Polytechnic has 32 generators with a total installed capacity of 5059.5kVA while the functional/available capacity is 3657.5kVA or 3.6575MVA. These generators run simultaneously to provide power to different facilities in the campus every working day. The average weekly fuel consumption of these generators is 7800 liters at ₦280 per liter. This translates to a total cost of ₦2,84,000.00 per week. This means that the Polytechnic is spending about ₦8,736,000.00 monthly on diesel. Furthermore, most of these generators especially those rated above 200kVA are not optimally loaded thereby making the Polytechnic spend more on their running and maintenance.

Proposed zoning arrangement

The following zoning arrangement was proposed to reduce the number of active generators running in the campus. This will greatly reduce the running and maintenance cost of these generators without affecting the efficiency, loading capacity and power supply to the campus.

Table 2. Proposed Zoning of Generators on campus

ZONE 1 500kVA	ZONE 2 500kVA	ZONE 3 500kVA	ZONE 4 250kVA	ZONE 5 100kVA
Rectory, Registry, Bursary, SIAS, SEDT, Hospitality, SHSS, IPC and Science Tech.	Set Auditorium, ASUP, SUG, Foundry, Engineering Labs and workshops, Ceremonial stand, TEDC, MIS, Skill-G labs.	Library, 1000 capacity Auditorium, SBMT (Classrooms and office), Old admin block, Fuel dump, Hostels A, B, C, Staff School.	Evening Programme, Weekend Programme, CBT Centre	Medical Centre, Works division, Security unit, Water Factory.

III. Results

After the design phase, the energy management and control system was tested unit by unit; subsystem by subsystem and finally the fully integrated system test before implementation. This was done to see if the desired objectives were met. The design was first simulated using the following software to determine the behavior of each subsystem before implementation.

a. Proteus 8.6 (by Lab center Electronics)
b. Arduino v1.5.8 (by Massimo Banzi et al, based on Processing by Casey Reas and Ben Fry)

The following are the plug-ins and drivers that we used;

a. Visual Micro Arduino plug-in for Visual studio
b. Proteus Arduino Library

Design Simulation

Below are the general procedure used in this phase of testing for each subsystem.

a. Install the required software.
b. Download and install plug-ins if required
c. Download and install libraries if required

IV. Discussions

It was observed that when the system was first powered, the alarm for power restoration triggered and lasted for five seconds and went off. At this point, the system was fully ready for testing the timing features

V. Conclusion

The need to have adequate, reliable and affordable power supply for Federal Polytechnic Nekede, Owerri has been stressed and effort by the school management to solve this problem has also been demonstrated. This paper has presented an energy management system that would time and allocate power to electrical loads and facilities based on priority. It also proposed a zoning arrangement that will greatly reduce the number of active Generators running on the campus. This arrangement is adopted will have only five generators running with a total installed capacity of 1850kVA. This will reduce the average weekly diesel consumption to 3945.3 liters and consequently reducing the weekly running cost to ₦1,104,688.00 and ₦4,418,755.98 per month. The environmental impact of running these no of generators will also be mitigated as well as the cost of maintenance.

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