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Efficient Energy Management and Utilization Using IoT Enabled Intelligent System

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Abstract

Energy is essential for economic development, and the demand for electricity is rising at an extraordinary pace. Currently, fossil fuels remain the main source of global power generation, but these resources are limited and detrimental to the environment. Therefore, there is an urgent need to broaden energy sources and transition towards cleaner, sustainable, and renewable options. This study examines the potential of multi-source power generation and usage as a viable solution. Incorporating Internet of Things (IoT) technologies into multi-source power systems offers a revolutionary method to enhance energy efficiency, reliability, and sustainability. This study concentrates on how IoT can be used to monitor, control, and enhance a variety of renewable energy sources, including solar, wind, and hydroelectric power. By utilizing IoT devices and sensors, real-time data can be gathered and analyzed to ensure smooth operation and flexible adjustments of energy sources according to demand and availability. The study aims to tackle the limitations of single-source power systems by developing a smart, interconnected network that fully utilizes renewable energy potential. Anticipated results indicate considerable advancements in energy management, decreased dependency on non-renewable resources, and a thorough framework for future smart grid developments. This research adds to the renewable energy sector by offering insights into the practical uses of IoT in building resilient and effective power generation systems.

Keywords: Arduino UNO R3, GSM modem and LCD display, internet of things (IOT), smart grid renewable energy integration, IOT, hybrid power generation, energy optimization

INTRODUCTION

Energy is crucial for driving economic development, and the need for electricity is rising rapidly. Currently, fossil fuels remain the dominant source of power generation globally, but they are limited in supply and detrimental to the environment. It is therefore essential to diversify energy sources and transition toward cleaner, sustainable, and renewable alternatives. This study investigates the potential of multi-source power generation and its use as a viable sustainable solution. The Internet of Things (IoT) has revolutionized energy management by enabling real-time tracking and regulation of energy consumption across various industries. In smart buildings, IoT-powered systems optimize lighting, heating, and cooling by adapting to occupancy and environmental factors, leading to significant energy efficiency [1]. The research seeks to overcome the limitations of single-source energy systems by developing a smart, interconnected network that enhances the use of renewable energy. Anticipated outcomes include notable advancements in energy management, decreased dependence on non-renewable resources, and a thorough framework for future smart grid projects. This study adds to the renewable energy sector by offering insights into the practical use of IoT in designing resilient and efficient power generation systems (Figure 1).

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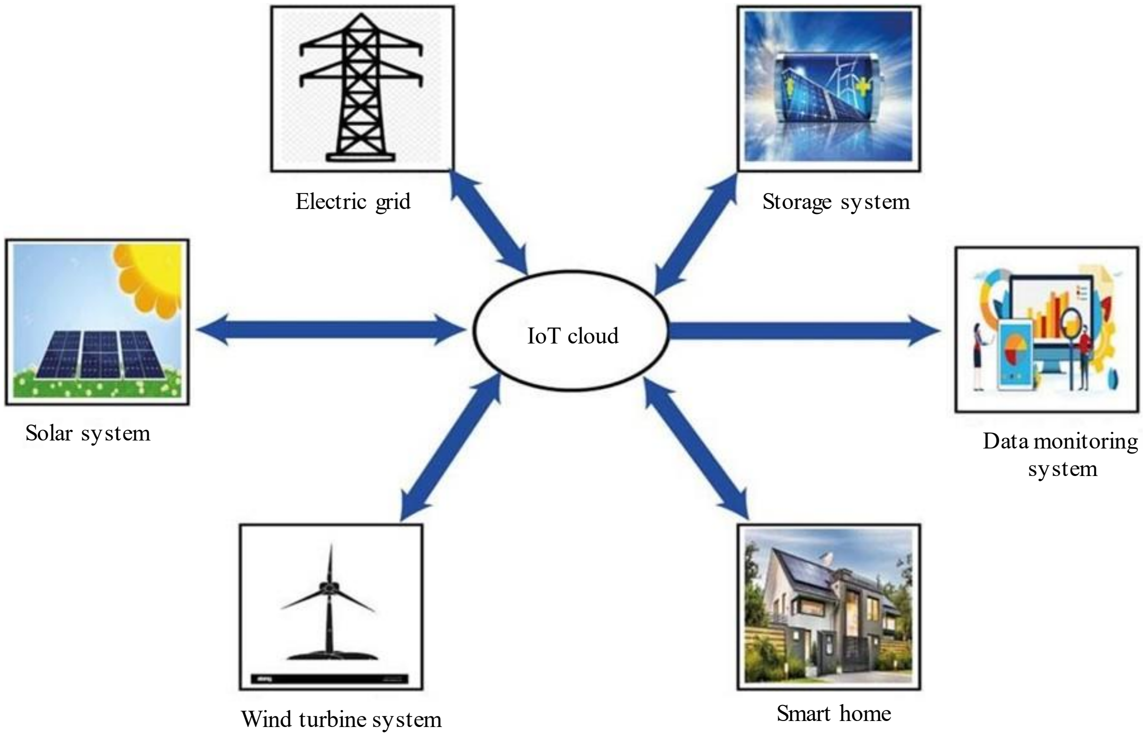

Figure 1. Interconnected hybrid generation and data monitoring.

RESEARCH METHODOLOGY

Hardware Components

Multi-source power generation solar power, wind power hydroelectric power IoT devices, sensors data collection, communication network, Arduino UNO, R3 GSM modem, LCD display, Energy Management System (EMS), battery storage grid interface, power grid, IoT, smart grid, renewable energy integration, data processing and analysis, cloud servers, edge devices, control system, control interfaces [2].

Solar Power Components

- Solar panels, solar inverters, charge controllers.
  Function: Converts sunlight into electrical energy.
- *Wind power components*: Wind turbines, wind inverters, anemometers.
  Function: Converts kinetic energy from wind into electrical energy.
- *Hydroelectric power components*: Hydroelectric generators, inverters, water flow sensors.
  Function: Converts the energy from flowing water into electrical energy.
- *Grid system*: An electrical grid is a networked system that transmits electricity from producers to consumers. It consists of interconnected power suppliers and users, linked through transmission and distribution lines, and is overseen by one or more control centers to ensure synchronization and efficiency. The term "grid", when discussed by the majority of people, usually denotes the electricity transmission system. This project entails that when solar and wind sources are not available, the grid will switch out to ensure a continuous power supply to the load [3].
- *Battery*: A solar battery is a valuable component of a solar power system that stores excess energy generated by solar panels. This stored electricity can be utilized when solar panels produce less power, such as during night time, cloudy weather, or power outages.
- *Power inverter*: In a hybrid system, one of the key components is an inverter. It is a device that converts the DC electricity generated by solar panels into AC electricity, which is used by the power grid.

- *Arduino (UNOR3):* For beginners in electronics and coding, the Arduino UNO is the ideal board. The Arduino Uno R3 is an ideal choice for beginners exploring the platform, known for its durability and widespread use. As the most documented and commonly utilized board in the Arduino family, it features a microcontroller board equipped with a removable ATmega328 AVR microcontroller in a dual-inline-package (DIP) format [4]. It offers 20 digital I/O pins, including six pins that function as PWM outputs and another six pins that serve as analog inputs. Additionally, programs can be easily uploaded onto the board to-utilize Arduino software. Due to its large support community, the Arduino provides a very accessible entry point for working with embedded electronics. The R3 is the most recent and third version of the Arduino Uno.
- *GSM modem:* The SIM900 GSM/GPRS shield serves as a GSM modem and can be utilized in various IoT projects. This shield allows you to perform nearly all the functions of a regular mobile phone, including sending text messages, initiating voice calls, using GPRS for Internet access, and many other tasks. A GSM modem is a dedicated device that operates with a SIM card and a mobile network subscription, functioning much like a mobile phone. For a mobile operator, a GSM modem appears to be the same as a mobile phone [5]. A GSM modem can either be a specialized modem device connected via serial, USB, or Bluetooth, or it can be a mobile phone that offers GSM modem functionalities. A GSM modem can be a standalone device connected via serial, USB, or Bluetooth, or it can function as a mobile device.
- *LCD display*: The Liquid Crystal Display (LCD) is a type of flat-panel display that functions using liquid crystals. In this process, serial input from the computer is received and transferred to the Arduino, allowing the LCD to display characters. LEDs are widely used in smartphones, televisions, computer monitors, and instrument panels, resulting in a large and diverse array of applications for both consumers and businesses.

Principle of LCD Display

As part of the process, the data (which is to be shown on the LCD screen) is entered into the data registers. The instruction register stores the commands from the Register Select. The Liquid Crystal Library simplifies the process of displaying characters on an LCD. The LCD can be operated in either 4-bit or 8-bit modes, necessitating 7 and 11 Input/Output pins from the specific Arduino board, respectively.

CONNECTION DIAGRAM OF LCD 16×2 WITH ARDUINO

In LCD 16×2, the term LCD refers to Liquid Crystal Display, which employs a flat panel display technology found in the screens of computer monitors and TVs, smartphones, tablets, mobile devices, and more. Although LCDs and CRTs look alike, they function differently. A liquid crystal display relies on a backlight for illumination instead of utilizing electron diffraction on a glass screen every pixel that is organized in a rectangular grid. Each pixel comprises a green, red, and blue sub-pixel that can be activated/deactivated [6].

Once all these pixels are turned off, it will look black; conversely, when all the sub-pixels are turned on, it will look white. By adjusting the intensity of each light, different color combinations can be produced. This study offers an insight into the LCD 16×2 and its role in diverse applications. To control the display, you need to load the data that constitutes the image you wish to show into the data registers, and then enter commands into the instruction register (Figure 2). You do not have to be familiar with the low-level instructions, as the Liquid Crystal Library makes this easier for you.

The initial step in interfacing an LCD 16×2 with an Arduino is to link its data pins to the designated digital pins.

- *Step-1:* Connect the RS pin of the LCD to pin 13 of the Arduino board.
- *Step-2:* Connect the Enable pin of LCD to pin 12 of the Arduino board.
- *Step-3:* Connect the D4pin of LCD to pin6 of the Arduino board.
- *Step-4*: Connect the D5 pin of LCD to pin4 of the Arduino board.

- *Step-5:* Connect the D6 pin of LCD to pin3 of the Arduino board.
- *Step-6:* Connect D7 pin of LCD to pin2 of the Arduino board.
- *Step-7*: Connect the middle terminal of the potentiometer to the VEE (contrast pin).
- *Step-8*: Connect the two ends soft to the potentiometer to the Ground and 5 V.
- *Final Step-9:* Connect one end of a resistor to the A and K of the LCD and another end to 5 V.

FLOWCHART AND ALGORITHM

An IoT-enabled energy management system typically follows a structured flow to optimize energy consumption. Here is a simplified flowchart:

1. *Data collection:* IoT sensors and smart meters gather real-time data on energy usage from various sources, including appliances, machinery, and renewable energy systems.
2. *Data transmission:* Collected data is transmitted securely to a centralized platform via communication networks.
3. *Data processing and analysis:* Advanced analytics and algorithms process the data to identify consumption patterns, inefficiencies, and potential areas for optimization.
4. *Decision-making*: Based on the analysis, the system generates actionable insights and recommendations for energy optimization.
5. *Control actions:* Automated or manual interventions adjust energy usage, such as controlling lighting, HVAC systems, or machinery, to align with optimal consumption strategies.
6. *Feedback loop:* Continuous monitoring and feedback ensure that the implemented actions are effective, allowing for ongoing adjustments and improvements.

This iterative process enables efficient energy management and utilization through IoT-enabled intelligent systems.

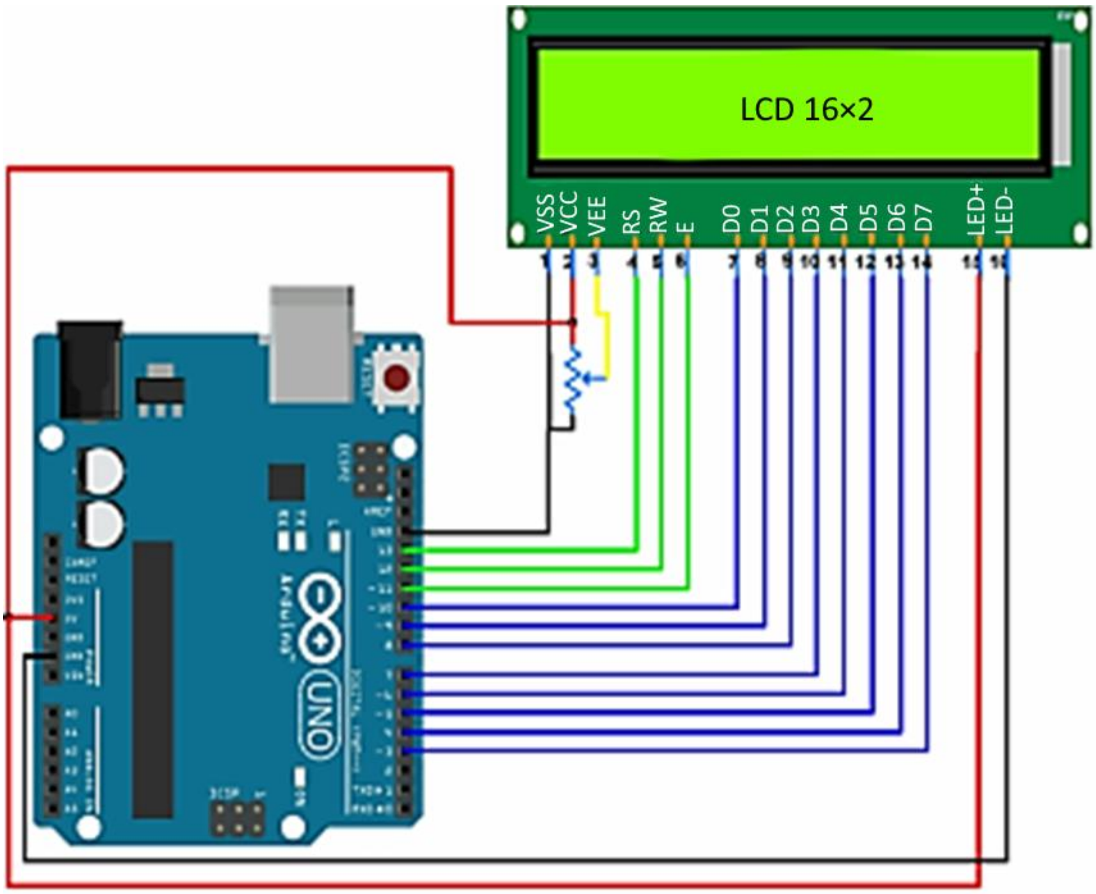

Figure 2. Connection diagram of LCD 16×2 with Arduino.

RESULT AND DISCUSSION

IoT-based hybrid power generation and monitoring using a GPRS network describes a system that integrates both renewable and non-renewable energy sources to produce electricity, while leveraging IoT and GPRS technologies for remote system oversight and management [7].

This setup usually includes multiple power sources, such as solar panels, wind turbines, and a backup generator, all connected to a centralized power management system. The power management unit features IoT sensors that gather real-time information about energy production and usage, along with the condition of the system's components.

IoT sensors collect data and transmit it via a GPRS network to a cloud platform, where it is processed and analyzed. This platform delivers real-time insights into system performance, enabling operators to enhance energy production and consumption, as well as identify and troubleshoot any potential problems. The GPRS network ensures secure and dependable communication between the IoT sensors and the cloud-based platform. As a wireless communication standard, GPRS facilitates data transmission over a cellular network, making it well-suited for the remote monitoring and management of IoT devices. In this project we have three different modes of operations such as one is solar switching, second one is wind switching and third one is grid switching. The hybrid power generation and monitoring system, utilizing the GPRS network, operates through three distinct switching modes:

Condition 1: Solar Power-Connected, Wind Turbine-Disconnected

We begin by setting a voltage threshold of 12 V, along with a decision-making algorithm designed for charging the battery from non-conventional energy sources. This algorithm first examines two energy sources: wind and solar. If the battery voltage is at 12 V, the solar power produced must exceed 12 V for the battery to begin charging.

When solar power generates more energy than wind, the relay connects to the battery, while the wind source is disabled. The system will utilize the Arduino Uno R3 to transmit data to a remote server or a cloud-based platform. This allows users to monitor and manage the system remotely via a GPRS network, with information displayed on a 16×2 LCD screen. A simulation diagram illustrates an IoT-enabled hybrid power generation and monitoring system that operates via a GPRS network when connected to solar energy (Figures 3 to 5) [8].

Condition 2: Wind Turbine Power-Connected, Solar Power-Disconnected

Initially, we set the threshold of 12 V. We have a decision-making algorithm that will decide for a non-conventional energy source to charge the battery. The decision-making algorithm will first consult these two sources, wind and solar. If the battery is 12 V, the wind-generated power must exceed 12 V for the battery to charge.

When wind produces more power than solar, the relay links to the battery and another wind source is cut off. The Arduino Uno R3 will transmit data to a remote server or cloud platform via the GPRS network, allowing users to monitor and control the system from any location. The information will be displayed on a 16×2 LCD screen [9].

Condition 3: Grid-Connected, Wind Turbine and Solar Power-Disconnected

Initially, we set the threshold of 12 V. We have a decision-making algorithm that will decide for a non-conventional energy source to charge the battery. The decision-making algorithm initially will check with these two sources such as wind and solar. The grid system activates when neither solar nor wind power is available, ensuring that both renewable sources remain disconnected. Utilizing ArduinounoR3, the system will send data to a remote server or cloud platform, enabling users to supervise via the GPRS network and control the system from any location through the GPRS network, with results shown on a 16×2 LCD [10].

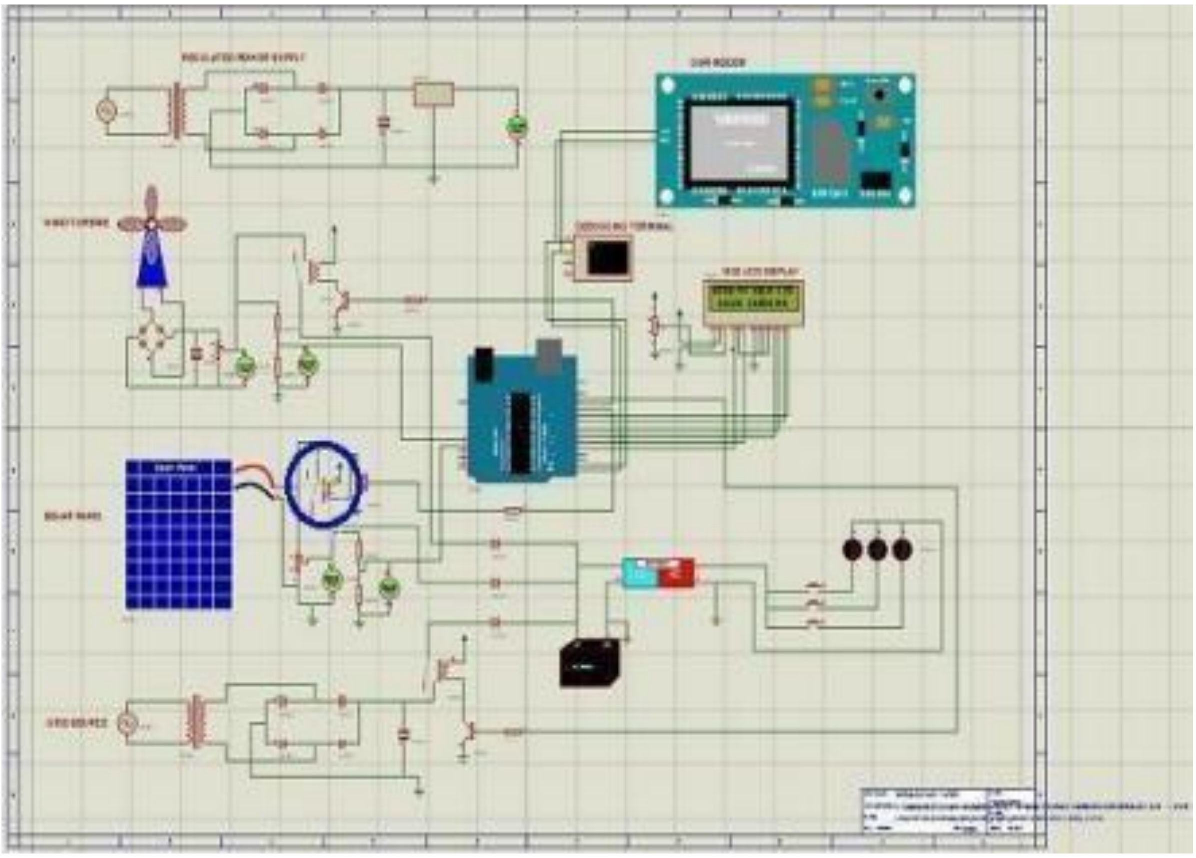

Figure 3. Solar power-connected, wind turbine-disconnected IoT enabled simulation diagram.

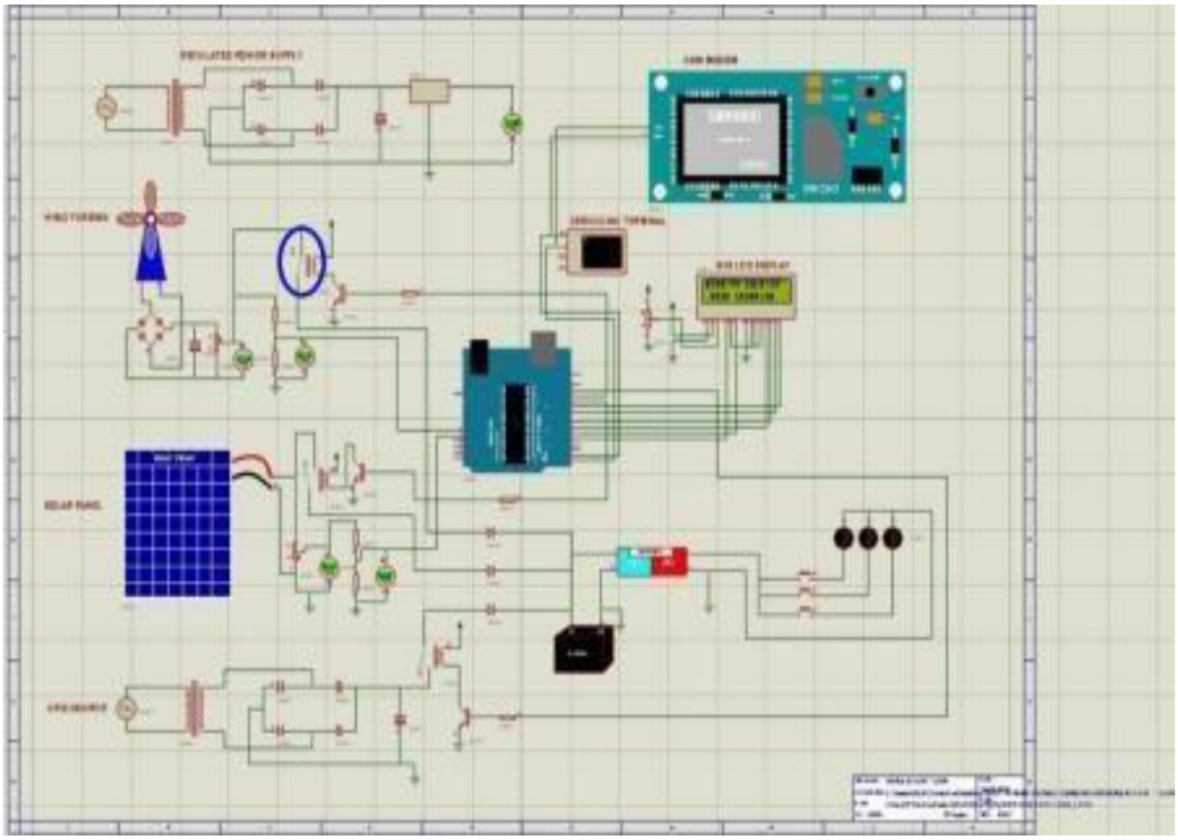

Figure 4. Wind power-connected, solar power-disconnected IoT enabled simulation diagram.

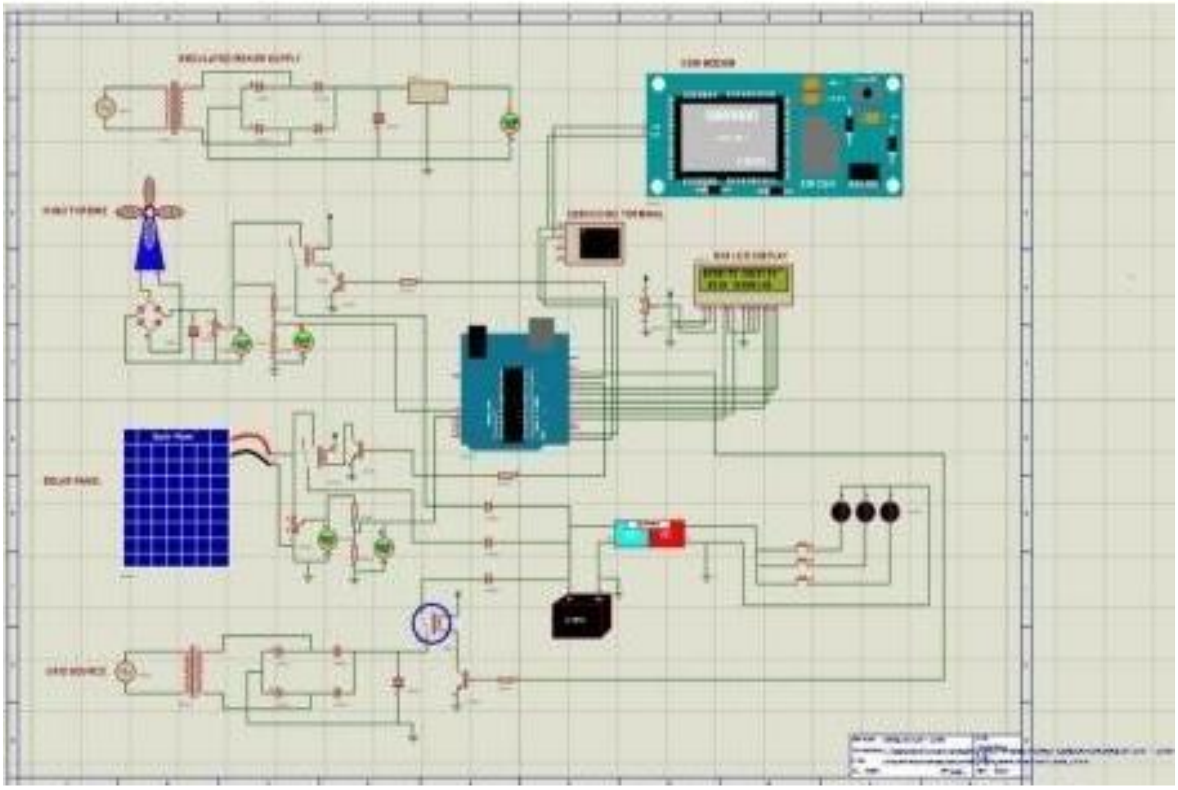

Figure 5. Grid feeding in absence of solar and wind generation IoT enabled simulation diagram.

CONCLUSION

In summary, hybrid power generation and monitoring based on IoT technology represent a cost-efficient and effective means of managing power systems in remote areas, with the potential to lower energy expenses and enhance energy efficiency. The proposed IoT-based framework for substation automation in a smart grid environment offers an efficient and reliable solution for modernizing power distribution. This system ensures sustainable energy generation by utilizing renewable sources such as solar, wind, and hydroelectric power. Real-time data collection and transmission are made possible using IoT devices and sensors, which improves grid performance and management. The Energy Management System (EMS) and control interfaces facilitate optimal power distribution and user-friendly monitoring. The integration of energy storage systems and smart grid infrastructure ensures efficient energy utilization and seamless integration of renewable energy sources. This framework provides a cost-effective and scalable solution, promoting the advancement of smart grid technology and the use of renewable energy. The successful implementation of the Arduino sensor hub prototype demonstrates the system's feasibility and practicality for future development.

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