IOT BASED ENERGY MANAGEMENT SYSTEM

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ABSTRACT: Energy Management System (EMS) is the recent emerging technology for automated and efficient use of generated energy. EMS operates on the use of real-time information of energy usage making it more accurate and precise. This requires continuous monitoring, assessment and visualization of energy usage, in the targeted sector. Use of EMS not only smooths the operations but also helps reducing the financial cost. Reducing the power consumption by centralized monitoring and control is the basic idea of EMS. In this paper, street lights are the targeted sector to implement EMS based on Internet of Things (IOT) technology. Basic idea is the use of LDR to sense the light intensity, which hence decides the necessity of street lights to be turned ON/OFF. Voltage, current and power are the electrical parameters to be monitored. The proposed system design includes use of Arduino microcontroller along with Node MCU to read these parameters and transmit them to server. Android App is developed to control and monitor the data anytime, from any location via google sheet. LCD are used to display the respective parameters and internet date and time. Provision of charging station for electric vehicles is also included in the design. Implementation results thus obtained, validate the system to accurately manage the street light operations, thus reducing the wastage of energy.

KEYWORDS: Android Application, Arduino microcontroller, Energy Management System (EMS), Internet of Things (IOT), LDR, Node MCU.

INTRODUCTION

In urban areas, street lights are a part of compulsorily included infrastructure. Illuminating city streets when it’s dark for proper and safe traffic flow, avoiding accidents, helping pedestrians to safely walk by illuminating the society premises and also making the city appearance stylish and fashionable are the major uses of street lights. Making visible the presence of ups and downs, open potholes, speed breakers or any other obstacles on the streets as well as footpaths are some of the important advantages of street lights, making them an important element of infrastructure worldwide. However, considering the daytime hours, street lights enlighten the streets/roads for almost 12-13 hours per day. Also, surveying various reports across various major cities, it is observed that street lights are the largest consumers of electricity and about 40% of the total energy consumed by a city is utilized to empower the street lights. Also with an increase in residential and office areas, and hence the increase in streets and roads for them, there is a substantial increase in installing the street light infrastructure, thus increasing the consumption of electrical energy and cost of utilities. Street lights being one of the largest energy consumers, optimization of consumed energy is a matter of concern to reduce the energy wastage. Hence, a well-designed and energy-efficient smart street light system is highly interesting area for research and implementation.

Traditionally used street lighting systems include manual ON/OFF of street lights. Few newly designed conventional automated techniques simply embed few sensors for automatically controlling the ON/OFF of street lights. These systems are based on the use of Light dependent Resistor (LDR) to sense the amount of light intensity present at particular time instants such as clear daytime, high intensity brightness, or lower brightness intensity due to presence of clouds, rainfall etc. Designing smart street lighting systems using micro-controllers and IOT can definitely prove as a promising solution to overcome the drawbacks of traditional and conventionally used street lighting systems. This paper presents a sophisticated IOT based smart street lighting system using LDR along with Arduino and Node MCU to sense, read and transmit data to server to maintain an online google sheet data log. LCD is used to display the monitored parameters. Relays are used to control the ON/OFF of lamps. When LDR is subjected to no/low light, relays are turned on, thus switching ON the street lights. When LDR is subjected to bright light, relays are turned off, hence switching off the street lights. The main focus is to reduce the energy consumption with the help of intelligent electronic devices and control mechanisms, thus reducing the overall system cost.

Major contributions through this research are:

1. IOT based Power monitoring system
2. IOT based automated ON/OFF switching of street lights including a provision of charging station for electric vehicles.
3. Interfacing multiple sensors with Arduino and establishing communication between two different micro-controllers.
4. Implementing an innovative concept of data logging for voltage, current and power monitoring with respect to accessing date and time using Google sheet.
5. Use of online data logger and android application, which makes the system user friendly whereas theS google sheet can be easily accessed by multiple users at the same time.

LITERATURE SURVEY

Developments in designing smart and intelligent control mechanism for switching ON/OFF of street lights is an area of interest for researchers, engineers in electrical as well as finance department. Because this not only helps reduce the energy consumption but also reduces the system cost. A survey on various energy management systems implemented in India is presented in [1]. A case study of JK Lakshmi Cement plant is considered for discussion. An efficient energy management system using LDR and piezoelectric transducer (PZT) is presented in [2]. Few piezo electric materials are capable of generating electric charge when pressure/strain is applied on them. This feature is used in this paper. An intelligent EMS based on Multi-Agent Systems (MAS) is presented in [3]. The system considers various types of energy producers/sources and different types of consumers i.e., loads. Every type of source/load is modeled as a separate micro-grid entity capable of taking decisions independently depending on the situations raised. Lighting system using LED lamps based on sensor networks is discussed in [4]. Brightness sensor, motion sensor along with micro controller and Zigbee module form the sensor network to be implemented. EMS implemented using Raspberry Pi and GSM module is developed in [5]. Image of presence of vehicle/person under particular street light is captured using camera. With the help of image processing and controller, ON/OFF of street lights is controlled. Additional sensors to detect malfunctioning of street lights and texting the concerned authority via SMS using GSM technique is also implemented in this design.

An IOT based lighting control and EMS using Bluetooth sensor, DHT-11 sensor, distance sensor and Arduino Uno is developed in [6]. Vehicle/person approaching a particular street light is sensed from a particular distance, immediately turning on the light. Once it passes the lamp pole, the lights are turned off. IOT based smart lighting system using Arduino Mega 2560 microcontroller is designed in [7]. IR and voltage sensors are used to monitor the system parameters. Various case studies on weekdays and weekends are observed for system validation. Lighting system based on PIC microcontroller, GSM and WSN is presented in [8]. System also includes an anti-theft design to detect power theft if any. The operation of street lights is controlled via a single computer obtained the real-time parameters via WSN. A novel approach to control organization of street and outdoor lightings in residential complexes, based on EN-15,232 standard guidelines is presented in [9]. A smart street lighting system using renewable energy based on IOT is developed in [10]. A hybrid combination of solar and wind energy generating units along with mobile radiation receiver is used to empower the street lights.

PROPOSED SYSTEM ARCHITECTURE

Block Diagram

The Fig. 1 illustrates the block diagram of proposed street lighting system. The system is IOT based. It consists of two micro-controllers, one being Arduino Uno and the other one being Node MCU. Voltage, current and power are the three parameters monitored for the street lights (represented by fluorescent lamps) using current and voltage sensors. Arduino controller is used to read these values for all connected lamps and display them on LCD. Two 16 x 2 LCD are used, one for displaying the electrical parameters read by Arduino and other LCD displays the internet date and time at that particular instant. This data is sent serially to server using Node MCU controller. An android application is designed to monitor and control the street light/designed system operation. Data logger technique is used to collect, monitor and save all the data of electrical parameters measured for each lamp which is further transmitted continuously via serial communication through Node MCU. Thus, preparing a real-time google sheet for the data collection. Both the used controllers require 5V for operation hence a 5V power supply is designed using step-down transformer and 7805 regulator IC along with MOSFET for heat dissipation. Four lamps are considered resembling four street-light systems. ON/OFF of each lamp is controlled via relays. Hence, we say four small micro-grids, namely G1, G2, G3, and G4 are designed to drive the four loads (i.e., the lamps L1, L2, L3, and L4). Two separate relay circuits are included wherein one relay circuit is used for selecting day/night operating mode and other relay which is also connected to battery is used to provide charging station for electric vehicles (EV). Operation of relay (turning it ON/OFF) and charging of EV is controlled via an ON/OFF button. This button is operated with the help of android application. As the project is IOT based, connection of all the sensors, elements and the monitored real-time data is stored on server which can be accessed by anyone using the designed android application anytime anywhere. Google sheet is prepared to serve this purpose. LDR is used to detect the intensity of light brightness present in the environment at regular intervals. When LDR is subjected to no or low light intensity relay is turned on, hence switching ON the lamp at dark hours such as evening and night or cloudy/rainy weather conditions. When LDR is subjected to brighter light intensity relays are turned off, switching OFF the lamp during daytime. This automatic ON/OFF of street-light only according to the requirement, helps reduce the energy consumption and specially the wastage of energy in urban areas. Fig. 2 illustrates the pictorial representation of designed system implementation. Android kit consisting of all the shown sensors and circuitry, will monitor the street lights, the data will be transmitted to server serially via Node MCU. The system operator will be able to access the developed android app from any location, at any time.

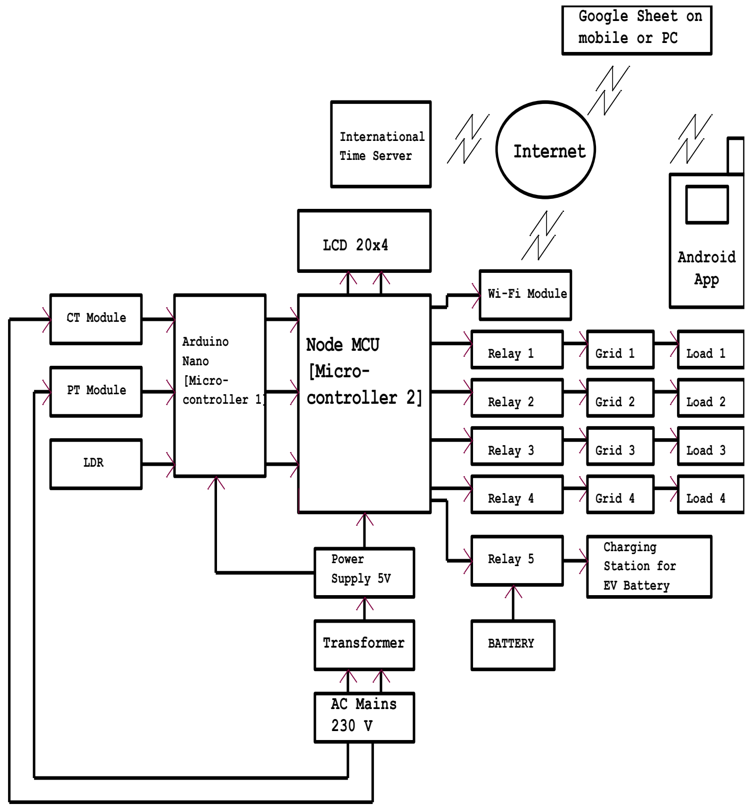

Fig 1: Block diagram of proposed system

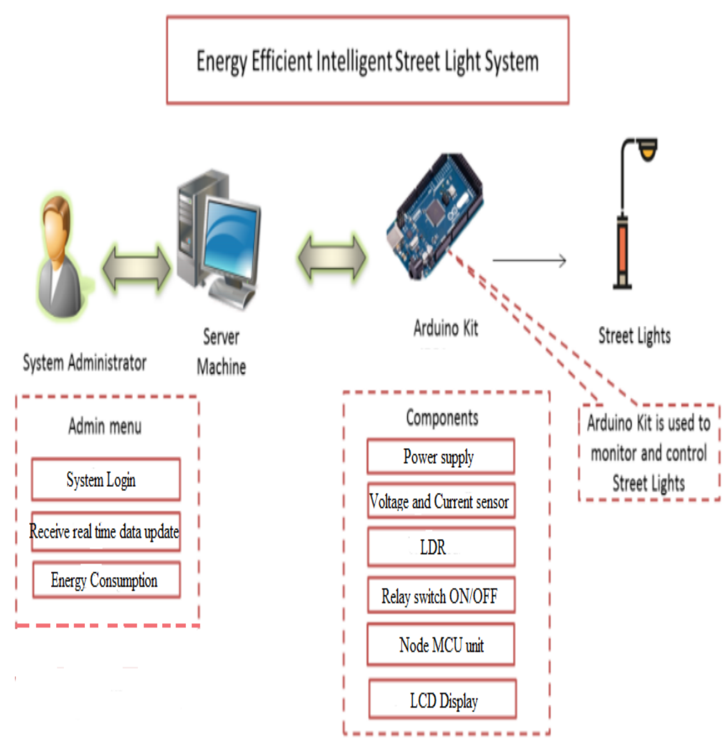

Fig 2: Pictorial Representation

Hardware Requirements

There are 7 components are required to successfully implement the design which are summarized in table I followed by their brief description.

Hardware Specifications

Table I illustrates the list of various components and their specifications used to implement the proposed design.

Table I: Hardware specifications

Sr. No.	Component	Specification
1	Micro - Controller	Arduino Uno development board, AT mega 328P microchip, 5V operating voltage, 14 digital I/O pins
2	Node MCU	ESP8266 Wi-Fi Module chip having ESP-12 SMD footprint, 16 digital I/O pins, in-built codes to enable USB to serial chip upload
3	Current Sensor	ACS 712 fully integrated sensor based on hall effect offering lower offset and precise readings.
4	Voltage Sensor	ZMPT101B high precision voltage sensor, max upto 250V
5	LDR	Light sensor, 5mm photocell
6	LCD	Two 16 x 2 LCD displays
7	Relay	One 5V isolated relay module

Component details

Following is a brief description of all the components used in implementation.

Arduino Uno

Arduino Uno is an open-source development board consisting of an AT mega 328P microchip designed by Arduino.cc. Like any other controller chip, this too has various interfacing pins, such as six analog and fourteen digital I/O pins, six PWM compatible I/O pins etc. Generally, requires 5V supply to turn ON and programed using Arduino IDE via USB cable. The operation of proposed design is wholly monitored and controlled using Arduino Uno. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable. It can be powered by the USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts.

Node MCU

Node MCU is widely used for implementing IoT in projects. It is a combined micro-controller and Wi-fi platform built using ESP8266 Wi-Fi module chip, having ESP-12 SMD footprint. All the required provisions for programming and uploading the code are readily embedded on the chip. In this project, Node MCU is used to upload all the sensor data and project status serially to google sheet and Android App.

Current Sensor

ACS712 is used as current sensor. It is a fully integrated sensor mainly based on Hall effect principle, capable of sensing AC as well as DC currents. Low offset and higher precision are its major advantages. The module is easily compatible with all micro-controllers as well as micro-processors such as Arduino, PIC, AVR, ARM. In this project, the sensor is used to measure and read the current value for the grid and lamp.

Voltage Sensor

ZMPT101B module is preferred as voltage sensor. This module having higher precision is based on voltage transformer principle. It is mainly capable of measuring upto 250V AC mains supply and is easily compatible with controllers like Arduino and Raspberry Pi. The only thing is this module only supports analog signals. We need to use external ADC provision for conversion into digital equivalents. The module has a built-in multi-turn trim pot, which can be varied to adjust the analog output.

LDR

LDR i.e., Light Dependent Resistor, also named as photo-resistor, is widely used as light sensor in projects that are dependent on light intensity. The length of the sensor being 5mm, its resistance changes with respect to the intensity of incident light falling on its surface. The intensity of incident light is inversely proportional to the device resistance. Resistance increases when subjected to low/no light and decreases when subjected to bright light. The device is widely used in light sensing application projects, aiming automatically switching the lights ON/OFF. As this project, too, contains the similar application, the design contains the use of LDR.

LCD

Two 16 x 2 LCD displays are used to display the output parameters such as voltage, current, obtained power along with current date and time.

Relay

Relay circuits are used to control the ON/OFF of external devices, which are operated by the interfaced micro-controller. The relay module preferred here has in-built optocoupler used for isolation which will hence protect the main operating components in case of short-circuit issues. BC547 transistor drives the relay circuit triggered by the optocoupler IC used for isolation. The relay module is capable of driving both analog as well as digital appliances, such as motors, lamps, solenoids, batteries etc. A total of five relay circuits are used here, wherein four are used for operating the four grids and the fifth one is used for enable/disable of EV charge station.

Software Requirements

Four software's are required to successfully implement the design which are summarized in table II followed by their brief description.

Table II: Software requirements

Sr. No	Software	Purpose
1	Arduino IDE	Programming Arduino Uno
2	Blynk Android App	Hardware agnostic IoT platform compatible with iOS and Android devices

Arduino IDE

To perform a particular task using Arduino controllers, we need to execute the developed program and upload it to the controller. For this purpose, we need Arduino IDE (Integrated Development Environment). It is generally a text editor containing provisions for writing the code, menu series, toolbar for common functions, message area and text console. To upload the respective code, we first need to choose the micro-processor type. The process for selection is – Tools > Board menu> Arduino Uno w/AT mega 328. The boot loader is pre-burned on the selected processor, which helps user to upload their new code without external hardware programmer.

Capture and PCB designer software.

Screenshot of running simulation window of designed power supply is presented in fig 3 below.

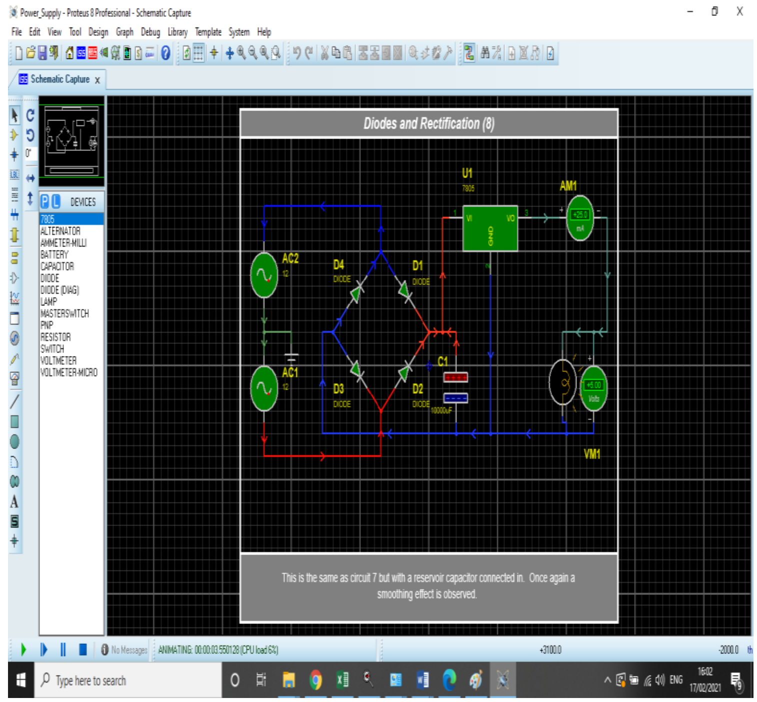

Fig 3: Power supply simulation

Blynk Application

Blynk is the application specially designed for implementing internet of things concept in hardware projects wherein the user interfaces can be easily monitored and controlled via any iOS or Android device. Once the app is downloaded, users get easy access to the app features where we can create new project dashboards by means of arranging various available graphs, sliders, buttons, widgets, etc. present on screen. It is an IoT platform supporting and offering private clouds, data analytics, device management, white-label mobile apps, machine learning. The developed hardware can be remotely controlled. User has an easy access to the sensor data which can be stored on Blynk cloud and displayed whenever commanded. The app has three major components, namely the app, the server and the libraries. The app is used to create the interfaces using widgets. The server helps to communicate with the smartphone, having the installed app with the project hardware, which can be achieved using companies Blynk cloud or by creating our private Blynk server. The libraries are responsible for communicating the server with the executing process using incoming/outgoing commands. The data privacy is well maintained using email ID and password system for authentication, which will generate a unique key after logging in to connect with the project micro-controller.

FLOWCHART

The following figure represents the flowchart for the proposed design. First step is to initialize the circuitry used in the design. Therefore, voltage sensor, current sensor, two LCD's, relay circuits, LDR, timer circuitry are initialized after switching on the power supply. As the design also includes use of android app and google sheet, one needs to open the desired downloaded android application as well as the google sheet to be monitored. On a welcoming note, the LCD after initialization displays the name of university, i.e., "Welcome to Sandip University, Nashik". Simultaneously, the second LCD displays the name of the respective project, i.e., "IoT based Energy Management System". These introductory displays are held for approximately 4 seconds. Beyond this, the LCD display is cleared. Next step is to read the required parameter values from the sensor circuits. Hence, voltage and current values are read from voltage sensor and current sensor respectively. Estimation of total power is also carried out at this stage using the basic formula "P = V x I". The read values of current, voltage and power are displayed on LCD. The respective values are also displayed on android application as well as google sheet. Next state of LDR is to be checked. LDR subjected to bright light (E.g. daytime), resistance decreases i.e., value of LDR will not be equal to 1, and the grid will remain to be in OFF state. The system will restart reading new current and voltage values at that particular time instant. LDR subjected to low or no light (consider night time), resistance increases making the value equal to 1 and the grid will turn ON switching on the lights. As the aim of the project is to design smart energy management system, lights of the required area only will be turned ON. Hence ON/OFF switching of every lamp is controlled using independent relay circuits. ON/OFF state of every grid connection is checked. In-case the button to switch ON grid 1 is pressed, relay 1 turns ON switching on lamp 1. Similarly, for pressing grid 2 switch ON button, relay 2 and correspondingly lamp 2 is turned ON. Same process if repeated for four grids as the project is prototyped considering four grids. While switching OFF the lamps, grid buttons for OFF state are monitored. Incase button for switching OFF grid button is pressed, relay 1 is turned OFF, turning OFF lamp 1. Button for switching OFF grid 2 is pressed, relay 2 and lamp 2 are turned OFF. Same procedure is repeated for grid 3 and grid 4. Similarly, condition for EV charging station is checked. In-case some electric vehicle is to be charged; the user can press the EV charging button. This will turn ON relay 5 which will enable the EV charging facility. When the button is released, relay 5 will be turned OFF, disabling the EV charging feature. After regular time intervals, the system will again get back to read voltage and current values from sensors and estimate the power, in order to constantly monitor the ON/OFF state of lamps and decrease the energy consumption.

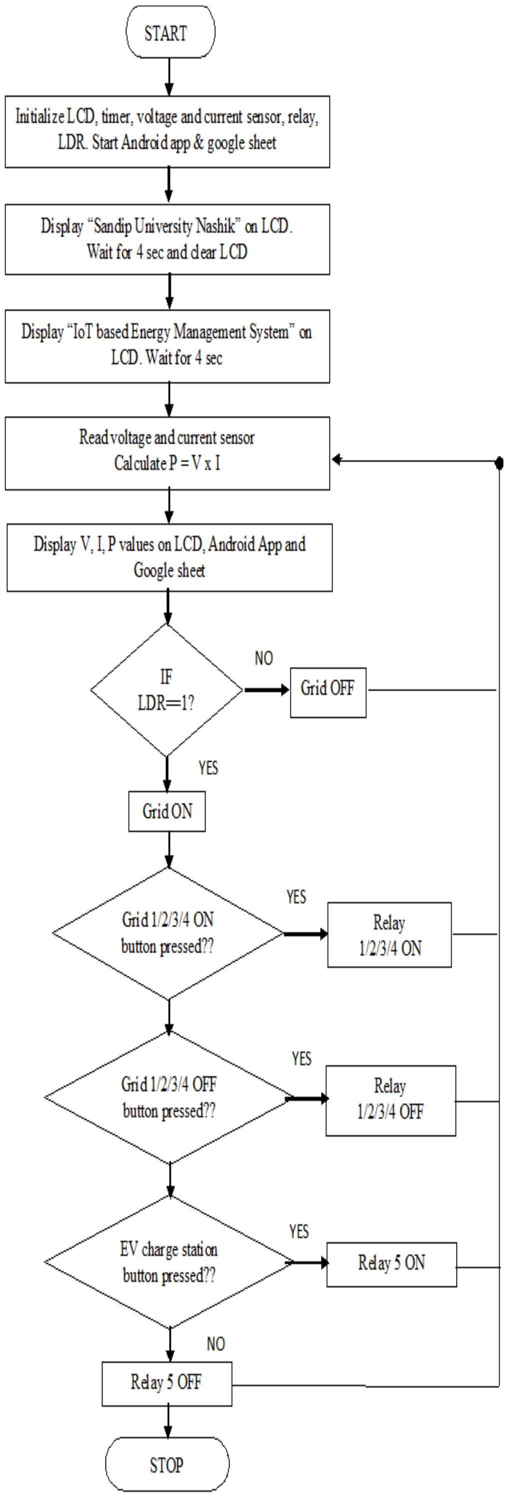

Fig 4: Flowchart

RESULTS AND DISCUSSION

Experimental Setup

As a demo prototype, street lighting system considering four lamps is implemented. Lamps can be any incandescent, LED etc. As the main aim is to make the design energy efficient, LED bulbs are preferred here. Accordingly, four micro-grids are designed one each for every lamp. Every grid further has LED indicator to represent its ON/OFF state. LED glows red when grids are in ON state and glows off when grids are turned OFF. Sensor data read from the two sensors i.e., current sensor and voltage sensor, is transmitted serially to Node MCU unit, which further transmits the data serially to IoT cloud in order to update the information in google sheet as well as developed android application. Total power estimation of the system can be easily evaluated from the voltage and current readings mentioned in sensor data. This estimation is carried out in Arduino Uno controller. Arduino Uno also plays a major role in system operation as all the sensor, monitoring, controlling circuitry along with display device are interfaced and operated alone by Arduino. Current date and time of the system operation is also updated on server. This helps keep a track of performance parameters, which can be easily referred sometime later too, in case of any emergency/technical fault. All the system components require 5V power for operation. Hence, a 5V power supply is designed using full wave bridge rectifier and IC 7805. 230V AC mains is stepped down to 12V using step-down transformer which is further rectified and regulated to 5V supply. Fig 5 represents the whole experimental setup of the proposed design. It consists of a 12V step-down transformer along with various circuits including 5V power supply, Arduino Uno, Node MCU, LDR, voltage and current sensor, relay circuits forming a small micro grid namely G1, G2, G3 and G4 and four lamps as a prototype of four street lights i.e., L1, L2, L3 and L4. Two 16 x 2 LCD are used as display device. One of each displays the monitored performance parameters current in Ampere, voltage in Volts and the corresponding estimated power rating in watts. The other LCD displays the live system monitoring status with respect to date and time when the system is accessed. Initially we check for no load condition i.e., when no lamp is connected to the system. Fig 6 represents the initial stage where no load i.e., no lamps are connected. Irrespective of the voltage being 255V at no load condition, the current rating is zero ampere. This makes the total power to be zero watt. Fig 6b represents the LCD-1 display for system performance at no load condition. Fig 6c represents LCD-2 display i.e., the date and time. The system was accessed on 16th April 2021 at 07:54pm as shown in fig 6c. Now considering system with one load/lamp connection. The current increases to 0.2A and voltage is 258V. Estimated power rating comes to 69W. Fig 6d represents LCD-1 display of performance parameters at one load connected scenario.

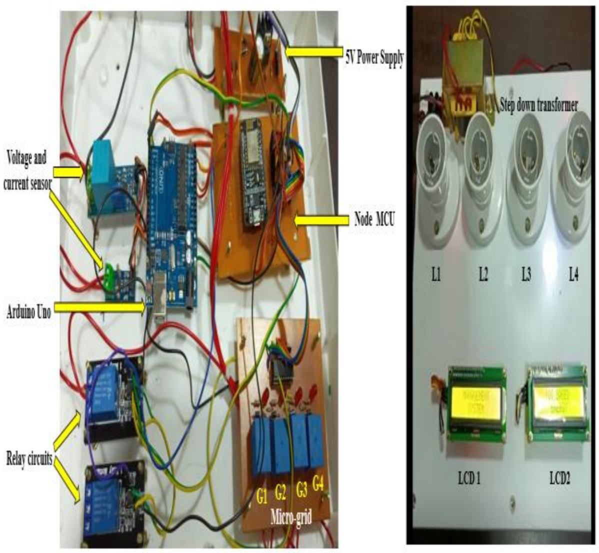

Fig 5: Experimental setup

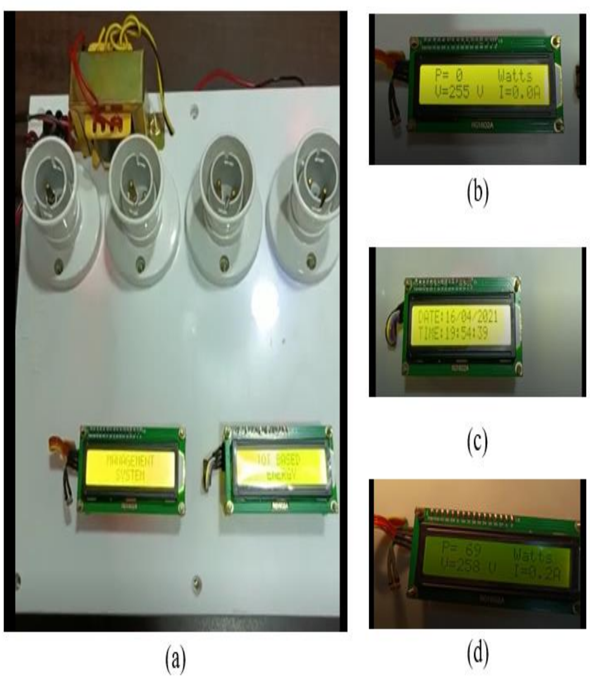

Fig 6: Prototype for street lamps. (a) Initial no load condition. (b) Initial voltage, current and power rating (c) Date and time (d) Voltage, current and power rating with one connected load.

Test Cases

Two test scenarios can be experimented, one for bright surrounding light (can be considered as daytime) and one for no or low light (considered as night time or cloudy environment). Fig 7 illustrates the results of two test cases.

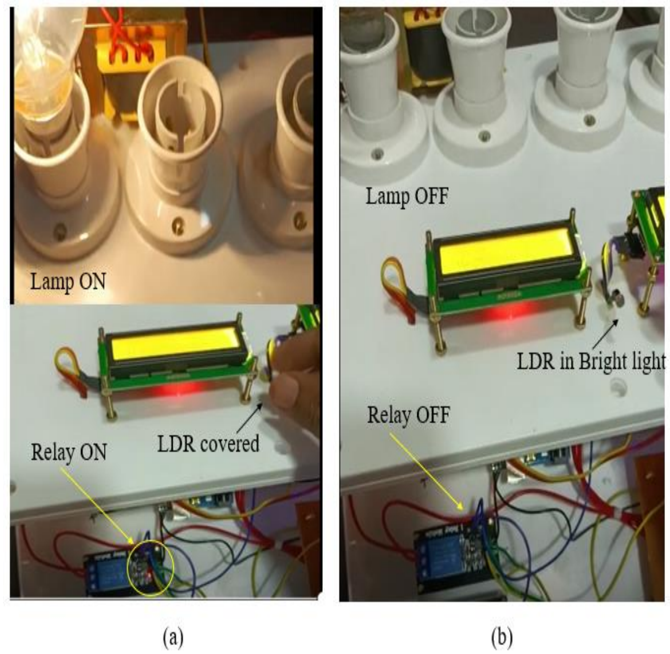

Fig 7: Test cases. (a) LDR in dark, relay and lamp ON. (b) LDR in bright light, relay and lamp OFF.

Case 1: LDR subjected to dark conditions.

No or comparatively lower bright conditions are observed practically during night time or cloudy/rainy atmosphere. Under such conditions, LDR will be subjected to no/low light. As the resistance of LDR is inversely proportional to light intensity, low light will increase the LDR resistance. This helps balance the overall circuit resistance of voltage divider loop, allowing flow of current through it. Correspondingly, the relay circuits are turned ON (highlighted by yellow circle in fig 7(a)), which will further turn on the respective micro-grids, hence switching ON the lamps (i.e., the street lights practically).

Case 2: LDR is subjected to bright light.

Bright light practically corresponds to daytime. Under this condition, bright light of higher intensity will be incident on LDR. Resistance being inversely proportional, will decrease with higher light intensity. This won't fulfill the required balance of voltage divider loop, which will hold back the conduction. Hence, the relay circuits will continue remaining in OFF state further switching OFF the lamps too. Hence, considering both test cases, an automated energy management system to switch ON/OFF the street lights as per the environment brightness is implemented.

Implementation for IOT

The whole system data is transmitted and stored on IoT cloud. This makes it user friendly and easily accessible using android app and google sheet from any remote place at any time. Blynk software is used for IoT implementation. The application window has various icon provisions to show the power rating, voltage as well as current rating. Also, it shows the status of EV charge station, whether it is enabled to charge any electric vehicle or disabled at that moment. The application also displays the status of four micro-grids whether they are in ON or OFF at that particular instant. The maximum range of parameters that can be measured and displayed is set between 0 – 100W for power, 0 – 1000A for current and 0 – 300V for voltage measurement.

Table III represents the parameter readings taken at various time instant as stated in table. The table has four columns depicting the date and time of system access along with sensor data reading for voltage, current and power. The readings are tabulated when system was accessed on April 15, 2021 03:02pm onwards. Initially at full load condition, there is a short high spike in the readings. Voltage at 333V, current at 269A and power at 88W. Later on, measurement readings stabilize with time. They are stable at normal values.

Table III: Parameter readings obtained at various time instant

Sr. No.	Date and Time	Voltage	Current	Power
1	April 15, 2021 at 3:02 pm	Initializing system		
2	April 15, 2021 at 3:19 pm	332	265	88
3	April 15, 2021 at 3:19 pm	332	265	88
4	April 15, 2021 at 3:19 pm	256	265	68
5	April 15, 2021 at 3:19 pm	252	265	67
6	April 15, 2021 at 3:19 pm	249	265	66
7	April 15, 2021 at 3:19 pm	249	265	66
8	April 15, 2021 at 3:19 pm	249	265	66
9	April 15, 2021 at 3:19 pm	249	265	66
10	April 15, 2021 at 3:20 pm	251	265	66
11	April 15, 2021 at 3:20 pm	252	265	67
12	April 15, 2021 at 3:20 pm	254	265	67
13	April 15, 2021 at 3:20 pm	253	265	67
14	April 15, 2021	250	45	11

	at 3:20 pm			
15	April 15, 2021 at 3:20 pm	250	45	11
16	April 15, 2021 at 3:20 pm	250	3463	868
17	April 15, 2021 at 3:20 pm	250	646	162
18	April 15, 2021 at 3:20 pm	250	280	70

CONCLUSION

Energy management system is a developing technology having the potential to change the energy consumption scenario worldwide. This technique is dependent on using the real time data collection of monitored electrical parameters. A smart and intelligent street lighting system based on IOT is proposed in this paper. LDR is used to detect the environmental light brightness. Relays are used to switch ON/OFF the street lights. The operation is controlled via Arduino Uno and parameters monitored are transmitted to server via Node MCU. A google sheet is also prepared to monitor the real time data transmitted by Node MCU which can be accessed using the developed Android Application. Voltage, Current and power are the monitored parameters whose values are displayed using LCD. Keeping in mind the increased use of electric vehicles today, EV charging station is also included in the proposed design. Relay and ON/OFF button are used to operate this provision which are accessed using the android application. The system uses less numbers of sensor circuits. Hardware results validate the system performance to accurately manage the energy consumption thus overcoming the drawback of conventional systems. Implementing fault or malfunctioning detection and location scheme can be taken as future scope for this research work.

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