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A LabView Monitored Smart Solar Lighting System for the Streets and Highways in Oman

Manaf Zghaibeh [a,*], Omer F. Khan [b], Amina Kashoobv [c], Zainab Albalushi [d] and Noof Albalushi [e]

Department of Electrical and Computer Engineering, Dhofar University, P.O.Box: 2509 Postal Code: 211, Oman.

**Corresponding Author*

Abstract

This paper discusses the design and implementation of an ad-hoc smart solar powered street lighting system. The system is intended to be used as lighting system for highways and streets of Oman as a replacement of the expensive grid-powered lighting systems. This system is a network of nodes and a central control and monitoring unit. Nodes communicate over wireless channel and Xbee communication protocol. Each unit in the system is composed of: a solar panel, battery, led with daylight sensors, radio interface (Xbee), and a microcontroller. System operations are centralized and managed at the microcontroller. Battery level and intensity of light is continuously monitored to manage battery charging during daylight using **incremental charging procedure**. This charging mechanism eliminates the need of extra power components in contrast to traditional charging systems. The microcontroller also manages switching the LED panel and controlling its light intensity. Finally, each node in the system communicates its status to a central monitoring and controlling station that runs a LabVIEW interface.

Keywords: Renewable energy, Photovoltaic, Microcontroller, 8-Bit CMOS Microcontroller, XBee, LabVIEW, Incre- mental Charging.

INTRODUCTION

Renewable energy can be derived from variety of resources such as sunlight (solar), wind, geothermal heat, waves, and rain. This energy is being harvested and transformed into electricity for decades. With the advancement of technology in this century, renewable energy sources are being exploited on large scale implementations in order to generate electricity with low cost and low carbon impact on this earth.

Today, multiple enterprises are established globally to benefit from non- exhaustible energy sources. Wind farms and solar farms began contributing towards the generation of electricity along with diesel-operated plants, nuclear-powered plants, and coal plants. With the hope to replace expensive methods of generating electricity, renewable energy with its infinite sustainability comes to many nations as clean, carbon-free, and affordable.

The work in our paper is performed at Oman, a Gulf country with one of the highest levels of sunlight exposure during the year. The maximum temperature recorded was 48 Celsius degrees in summer with plenty of sunshine, therefore a potential to be one of the leading countries in the Gulf and the Middle East in increased research and implementation of solar energy harvesting technology.

Our paper aims to make use of solar energy to power up the streets and the highways of the Sultanate. For this purpose, we introduce a smart solar-powered lighting system that is remotely administered by LabVIEW [4]. The system comprises of nodes that are placed alongside of streets and highways. Each node is a standalone system with photovoltaic panel, battery cells, LED array, sensors, wireless interface, and a microcontroller as a central processing unit. Microcontroller's role is similar to that of a brain in central nervous system, where it operates the node, controls the charging process and powers up the light emitting diode (LED) array. Furthermore, each node communicates, via XBee module with microcontroller and LabVIEW interface. The status of each node is displayed and updated to a LabVIEW interface, where data is saved and analyzed for performance of the system under operation.

RENEWABLE ENERGY

There are certain advantages and disadvantages associated with the use of renewable energy for the application of solar street lighting. In this section we discuss the pros and cons.

Advantages

Installation cost: When comparing solar power to that of establishing grid power coming from gas-turbine power plant, the cost of installing a wind farm or a solar farm within the same capacity is much cheaper as the technology involved in the solar farm is much simpler, i.e., photovoltaic panels, cables, charge controller, and batteries.

Operating cost: This is one of the major advantages of renewable energy plants comparing to other choices. Once the farm is being installed, it is considered as a standalone entity that requires minimum personnel to run. Whereas, a diesel-powered electricity plant requires large number of on-the-clock engineers and staff to ensure its continuous operation.

Maintenance cost: Maintenance of Renewable energy plants is more cost effective as the components of such systems are more basic comparing to other alternatives. The batteries being the most maintenance costly components of the solar system are by far less costly than the turbine components.

Sources: As mentioned before, the sources for renewable energy are non-exhaustive i.e. there will always be sunlight and wind. However, many sources of gas, diesel, oil, and coal are about to deplete.

Disadvantages

Seasonal: Some of the renewable energy sources are seasonal in the sense that they do not provide a constant and continuous level of exposure during the year, i.e., wind farms could be futile for some period of time. Furthermore, solar farms can only generate power during sunlight although most implementation of such systems adopt sun-following tracking devices. Moreover, intensity of sunlight differs during the year in many geographical areas and therefore unpredictable solar panel's efficiency. Same goes for the battery operation as the electrical charge consumed and withheld within the chemical composition of battery gets affected by the sudden changes in the weather. The consistency of operations is affected therefore performance of the system varies.

Area: Wind farms and solar farms requires large areas. This is a major obstacle in the implementation of such farms. However, with the advancements in the design of wind turbines and solar panels, reduction in size with innovative new designs of solar systems. E.g. Flexible solar panels or staked arrangements.

Geographical Areas: Finally, not all places are suitable to install systems operated by solar power. The major key in determining the efficiency of an area is the continuity of exposure and the consistency in intensity. Moreover, some geographic areas are suitable for one type of renewable energy, while another area is suitable for another type.

SOLAR PV POWER GENERATION

Electrical power system running on Photovoltaic (PV) cells is designed to capture and converts solar energy to electrical energy for powering up electrical appliances. On the generating side, PV system intrinsically produces Direct Current (DC) sufficient enough to charge a lead acid or any other type of battery using a specialized Charge Controllers (CC) for respective type of battery. The rating and load capacity of the battery is crucial for supplying enough current to the Power Inverters which convert the stored energy of battery to AC. Battery can be tapped by the Inverter as well as DC-DC buck boost converters. Inverters are used to power up the AC devices while DC-DC buck boost converters supply the power to the PV System's accessories as well as other DC appliances such as direct USB chargers for mobile phones or data acquisition port e.g. interfacing cable for Lab View for our paper.

In Principle, the light energy excites the electrons in the atoms of a semi-conducting material that constructs the PV cell. Then, the energized electrons generate the electrical current which is either consumed directly, or captured and saved in battery cells. While extracting the current generated in the cells we have to make sure that current travels out of the array towards the charge controller, not the other way around (by using specialize diodes), otherwise the PV cells perform inefficiently leading to breakdown of cells.

A PV cell is usually quite small. Thus, to make an efficient device we need to put together many cells in order to form a PV panel [8]. These panels can then be grouped together into solar PV arrays [6]. Photovoltaic systems have now been used for fifty years in specialized applications. Moreover, they have been used for power generation for more than twenty years.

The capacity of PV systems ranges from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts. The amount of electricity a solar PV system generates de- pends on the intensity of the sunlight it is exposed to. PVs are able to generate electricity on overcast days, however, with less amount comparing to sunny days.

Worldwide Solar PV Capacity

For two decades, the worldwide growth of PV use has been fitting an exponential curve. These days, PV has evolved to become a mainstream electricity source around the world. The reliance on PV electricity has drastically increased in North America, Europe, and China. Recognizing PV systems to be a promising source of power for many countries, we should expect that implementation of such systems to even grow more especially with the dramatic decline in their cost and the advancement in their technology. The solar PV capacity from 2004 to 2014 is shown in figure 1 [1].

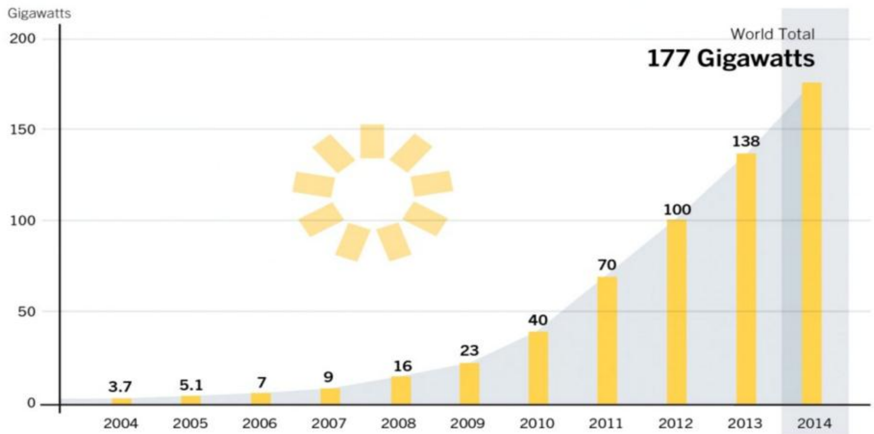

Figure 1: Solar PV capacity worldwide from 2004 till 2014. Source: REN21 Renewables 2015 Global

Oman took major steps towards investing in renewable energy. The Public Authority for Electricity and Water **PAEW** has joined the International Renewable Energy Agency **IRENA** [8]. In 2012 a strategic research and development (R&D) program for renewable energy was established with objectives that focus on enhancing the competency in this sector [7].

Some of the renewable energy projects in Oman are listed here [6]:

1. 100 kW PV solar project in Hiji;
2. 292 kW solar project in Al Mazyonah;
3. 28 kW solar project in Al Mathfa incorporating battery storage capability;
4. 500 kW wind project in Masirah Island; and
5. 4200 kW wind project in Saih Al Khairat, Wilyiat of Thumrait.

Solar PV Lights for Streets and Highways

Installing lights on streets and highways is essential to cities and municipalities. This task is simple in some areas where the electricity grid is already established. In this case it only requires installing the lights on the electricity poles. In this case the cost of per kilometer commissioning of cable pulling, poles installation, fixtures, light bulbs etc. Cost of maintenance and electricity generation for powering up these light is a significant additional recurring cost.

On the other hand, in some rural areas and along highways, it may not be economically viable and efficient to extend the electricity network to those areas, due to much higher project's cost.

In Oman, intercity streets and highways of Muscat and Salalah are provided with grid based lighting system. The infrastructure is available and the street lights are conveniently operational utilizing national grid electricity.

However, in case of branches of roadways and local streets extending to rural and mountainous areas, there is a crucial need to provide lighting for better road traffic visibility. Our paper introduces a practical, cost effective, and sustainable solution to provide lighting to those areas and highways. Furthermore, our measurements for the PV output in Salalah are very encouraging

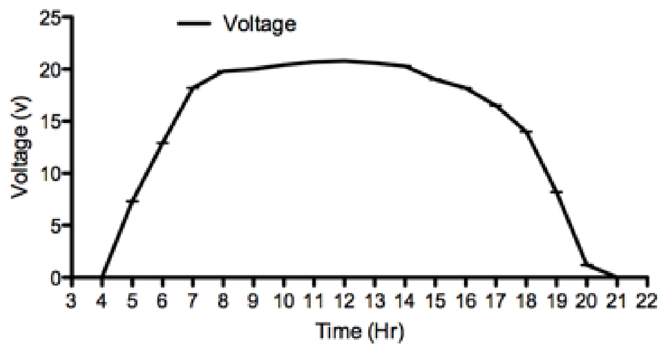

Figure 2: Fig. 2: Average PV panel output in volts from March 2016 until April 2016

Those measurement were performed during an extensive period of time from the 1st of March 2016 until the 12th of April 2016. Figure 2 shows the average output in volts of a standard PV panel at DU campus. The system we propose is simple and easy to implement. It eliminates the cost of cables and most importantly the electricity bill associated with powering up the lights.

DESIGN & IMPLEMENTATION

Figure 3 illustrates the block diagram of a node in our proposed system. In this section we discuss some of its major components.

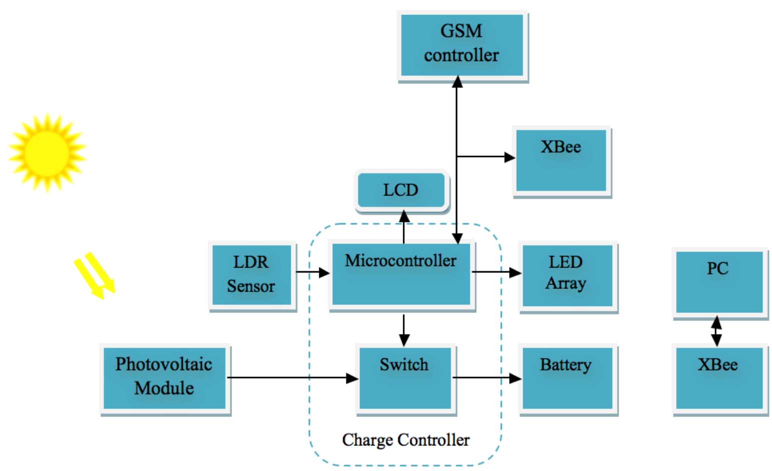

Figure 3: Block diagram of a typical node in the system

CMOS FLASH-based 8-bit microcontroller

The heart of the node is an 8-bit microcontroller having **PIC16F877A** microcontroller [5]. It emulates the role of the typical charge-controller that is implemented in many Uninterruptable Power Supply (UPS) units. However, our implementation eliminates the use of power components, i.e., metal–oxide–semiconductor field-effect transistor **(MOSFETs)**. The microcontroller will manage the process of charging the battery cell through an *incremental charging procedure* during daylight. At night, the microcontroller will turn off the charger and turn on the Light Emitting Diode (LED) array unit.

The PIC16F877A is an affordable, reliable, and easy to use microcontroller. It is suitable for many applications and able to work under industrial and commercial temperature ranges [5]. It is a 40 pin low power consumption device with 33 pins are for input and output. The operating voltage as the specification state is between 2 and 5.5 VDC. It is equipped with an analog to digital converter **ADC**,

3 timers, FLASH memory, and a USART terminal. The latter is essential in our application as we intend to connect a wireless device to the microcontroller, **XBee** module [2].

Charge Controller: From its name, the role of the charge controller is to “control the charging process of the battery “[10, 13, 12, 11, 9]. Once the battery is fully charged, the current must be cut off from the source in order not to overcharge the battery. Therefore, this task is a very essential part in the design of such systems. Using power electronic components that manage the flow of the current into the battery typically does this. However, in our implementation, we eliminate the use of such components. Instead, we follow an incremental charging process that is managed by the microcontroller.

In general, the microcontroller continuously monitors the level of the battery. During daylight, the microcontroller repeatedly switches the relay that controls the flow of the current to the battery on and off until it is fully charged. The microcontroller divides the charging process into several overlapping stages with each stage has specific period of charging time.

Incremental Charging: Since the microcontroller requires constant 5 VDC to operate, we do not allow the battery to discharge to less than 5.5 VDC on the input terminal of the voltage regulator. Therefore, the incremental charging process initiates from 5.5 VDC as a minimum bound. On the other hand, the maximum value of charge that we allow is 11.8 VDC. The algorithm of incremental charging checks the level of the battery and matches it up to a charging range.

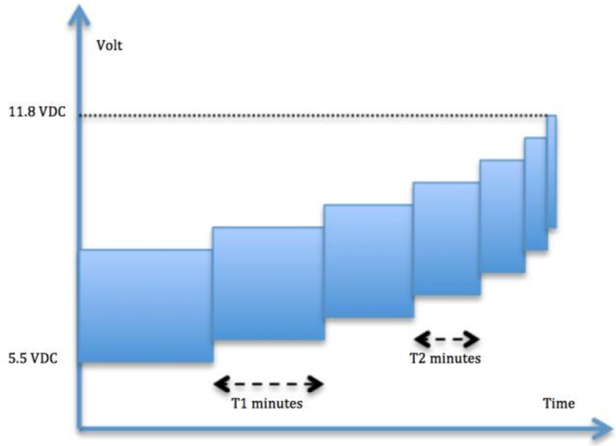

Figure 4: Illustration of incremental charging

Figure 4 illustrates an example of incremental charging that is implemented in our design.

For example, if the voltage of the battery is between 5.5 and 7.5 VDC, the microcontroller will energize the relay to charge the battery for $T1$ minutes. After that, the microcontroller will get a new voltage reading. If the new value of the voltage is between 6.5 and 7 VDC, the microcontroller will re-energize the relay to charge the battery, however, for $T2$ minutes, where $T1 > T2$.

Basically the charging process will be initiated during daylight and when the voltage of the battery is less than 11.8 VDC. Incremental charging is essential since the intensity of sunlight differs during the year. During some months the intensity is very high which accelerates the charging process. Whereas during winter in Muscat, or Khareef season in Salalah, it takes much more time to charge the battery.

Light Dependent Resistor (LDR).

The LDR has two major roles. The first one is to sense daylight, i.e., distinguish day from night in order to initiate the charging process if required. The second role is to manage the consumption of the voltage of the battery during dawn and dusk. This is accomplished by using an array of LEDs in a replacement to the traditional light bulbs. The microcontroller through its output ports will control the groups of LEDs to be switched on or off based on the voltage output of the LDR. The averages of output obtained by the LDR in Salalah are shown in Figure 5 and Figure 6.

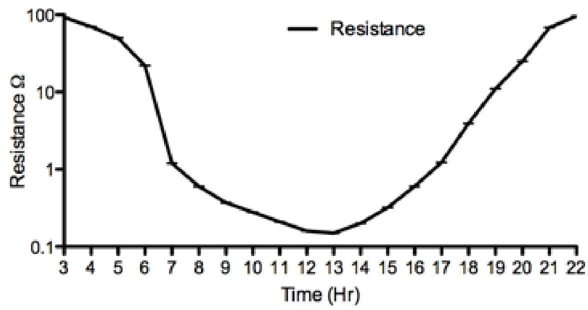

Figure 5: Average LDR values in Ohms from 1st of March 2016 until 12th of April 2016, DU campus, Salalah

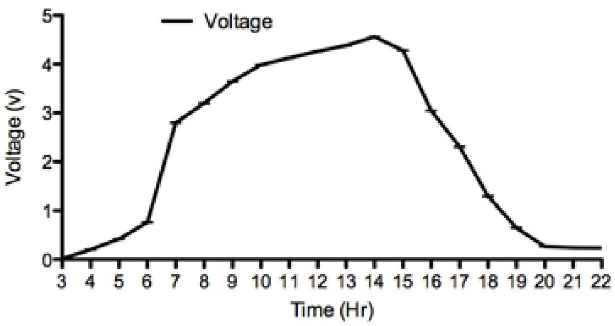

Figure 6: Average LDR values in volt from 1st of March 2016 until 12th of April 2016, DU campus, Salalah

XBee Module

The XBee interface allows the node to communicate with a central controlling and monitoring unit that observes the status of the system [2]. Each node reports to the central unit the voltage level of its battery, its LDR reading, and the status of its LEDs. The central monitoring unit deduces from this information any malfunction in the nodes. For example, an LDR reading that is not consistent with other adjacent values indicates a faulty sensor. Moreover, a faulty battery could be easily detected at the central station if its voltage dropped drastically comparing to other batteries.

Algorithm 1 Incremental charging procedure

---

voltage.update() {Microcontroller reads battery voltage}

while True **do**

case: $v1 <= voltage <= v3$

charge for $T1$

case: $v2 <= voltage <= v4$

charge for $T2$

.

. $\{v1 < v2 < \ldots < vn\}$

. $\{T_x < T2 < \ldots < T1\}$

case: $v_{n-2} <= voltage <= v_n$

charge for T_x

voltage.update()

end while

The XBee module has a range up to 3.2 kilometer. It is compact, has low power consumption, and cheap which makes it a feasible choice for our application. The module works at 2.4GHz frequency and has a data rate of 250kbps in RF mode and 1 Mbps in serial mode. Finally, its operating temperature is suitable for our application: up to 85° degrees.

GSM Interface If the central unit is placed in a remote area where the XBee module cannot reach, a GSM module could be installed into one of the nodes in addition to its XBee module in order to communicate with the central unit. In this scenario nodes within range to this master node report directly to it.

Smart System: The use of a microcontroller in each node adds intelligence to the system and enhances its functionality [10, 13]. The microcontroller continuously calculates whether the voltage of the battery is sufficient to feed the LEDs through the night. Based on that, the microcontroller decides on the number of LEDs it has to power up. Transitioning from day to night and vice versa is achieved algorithmically as given in Algorithm 2, where a constant running system loop compares the current reading of light dependent resistor with that of set day and night thresholds. The value of LDR obtained by Analog to digital Converter (ADC) is in the range of 100 – 700. Upper threshold is 600 set for the day above this value, while the lower threshold is set at 500 where the value falls below it is considered night.

Algorithm 2 Efficient day-night transitioning algorithm for battery power utilization and charge

---

```
While (true)
  reading = analogRead(ldr_pin); // read the value from the
sensor on ldr_pin

  if ((reading > day_threshold_value) && (lightstatus == "ON"))
  {
     state = 0;
     lightstatus = "Off";
     Status Update: ("Sensor says: Day, initiate charge");
  }

  if ((reading < night_threshold_value) && (lightstatus ==
"OFF"))
  {
    state = 1; // turn on
    lightstatus = "ON";
    Status Update: ("Sensor says: Night, initiate charge utilization
mode");
  }
  else
  {
   state = -1; //  current state of no action
  }
End while
```

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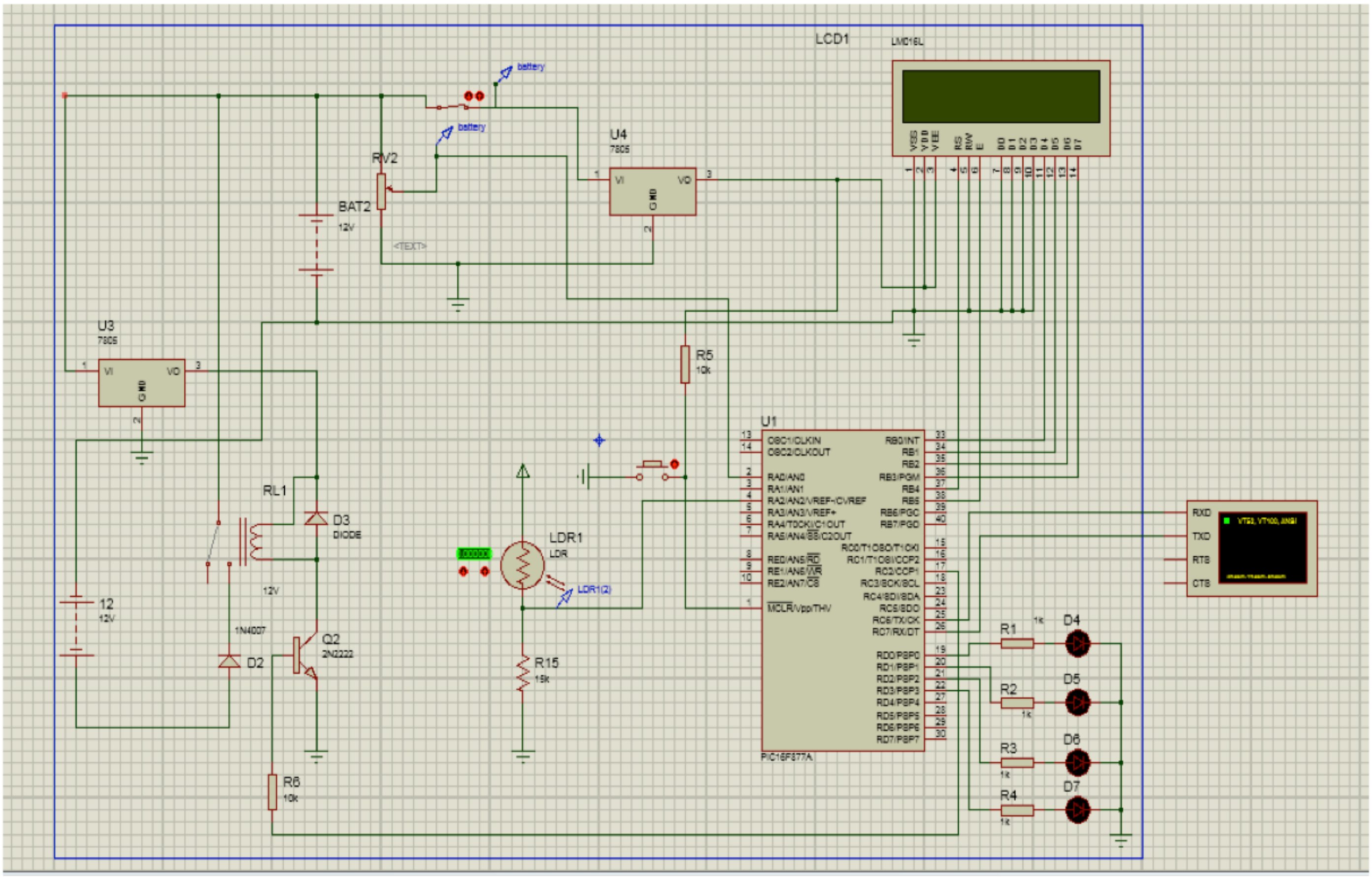

Figure 7 : Simulation of the circuit using Proteus software.

SIMULATION

The simulation circuit that we built using the Proteus software [3] is illustrated above in figure 7.

A voltage regulator stabilizes the battery's voltage (12-34V) down to 5V to power up the microcontroller. The PV panel is symbolized in Proteus by the 12V DC supply in the bottom left of the Figure 7. The microcontroller reads the value of the voltage from the voltage divider circuit (variable resistance) through its ADC pin labelled as RA0. It also reads the output from the LDR through an ADC pin labelled as RA2 of the microcontroller. The two pins RA0 and RA2 are part of a set of pins called as PORT. These pins are set in code as analog input so that they can read only the analog signals coming from the Voltage divider and the LDR respectively. The LED array and its accompanying actuator is minimalized (only for demonstration) by using the LEDs directly connected to the four digital output pins of Port D. The microcontroller controls a relay by outputting signal to a Bipolar Junction Transistor (BJT) through the digital pin RC2. When the microcontroller enables this port, the BJT will conduct to energize the relay and hence making or breaking the charging contacts. This allows the battery to be charged upon closing the contacts and stop charge by opening the contacts.

The XBee module is connected to the microcontroller via the Universal Asynchronous Receiver and Transmitter module on RX and TX pins respectively. It is depicted in Proteus by the monitor screen on the right side of the figure. The LCD screen in the figure is used to show the values of the LDR voltage and the battery voltage. However, the system is not dependent on the display, but it is useful for required status updates.

IMPLEMENTATION

Figure 8 shows a prototype of a node in our system in our projects lab at Dhofar University. As seen, the implementation is compact and practical. It may even become much smaller when printing the circuit on a PCB board. Thus, apart from the bulky items in our components, the PV panel, the battery, and the LEDs, the entire node size is no bigger than that of a human hand.

The LabVIEW interface that we designed is shown in Figure 9. The screen shot in the figure depicts a simple prototype of the system. The purpose of this interface is to remotely monitor and detect any malfunction in the system. In this prototype, the interface shows the status of the LEDs and the charge level of the battery for each node. Other indicators could also be added easily to the screen. Moreover, remotely controlling the node is also implementable using LabVIEW, i.e., rebooting the node.

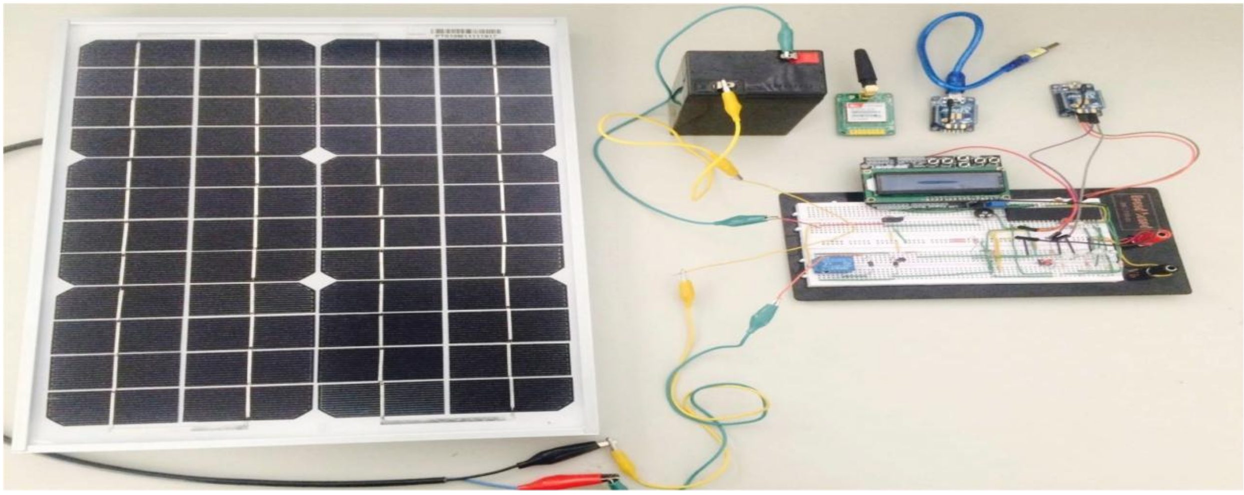

Figure 8: Prototype of a node

Figure 8: LabVIEW panel screenshot illustrates the status of multiple nodes.

CONCLUSION

Electricity generation using solar power is an affordable and economical choice. In this report we presented a solar powered lighting system that is smart, reliable, cost effective and simple. The system is intended to be used for streets and highways as a replacement to the current grid-powered expensive network. The system is composed of many nodes. Each node is run by an efficient and cost effective 8-bit CMOS microcontroller that is more than capable of charge management for the battery by incremental charging procedure. It's watchdog timers and external and internal interrupt functionality enables our system to be fully autonomous and self-recovering in case of any system failure. It is able to go to sleep mode and partially turn of its internal circuitry such as UART to conserve on power. Such functionality is useful to conserve backup battery when the system is not transmitting or receiving. In this way the system's control unit can operate utilizing very little power from the main battery. Each node is equipped with a wireless interface, XBee module that transmits its status to a central controlling and monitoring unit that utilizes the Graphical User Interface (GUI) of LabVIEW. The decision of choosing LabVIEW was made to accelerate the design process and hence other GUI's such as web based real-time view are also implementable with our design.

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