Project-Based Learning: Introduction to Photovoltaics

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Introduction to Electricity and Photovoltaics

Section A: Background and introduction

Section B: Introduction to electricity

Section C: Introduction to photovoltaics

Section D: Summary and concluding remarks
Background and Introduction

• Electricity is generally considered by many people as a sign of development and modernization...
• Access to cheap and reliable electric power is also a requirement for improved quality of life and industrial development
• However, most people in Africa do not have adequate access to electricity
• This class presents the basic ideas behind electricity and an introduction to photovoltaics
Some Sources of Electricity

• Fossil Fuels
• Nuclear Power
• Renewable Energy (Solar, Biomass, Hydro, geothermal, wind, ...)
  • Solar cells – Generate electricity from the sun
  • Wind and hydro – Generate electricity from moving fluids (wind and water)
  • Dynamos and generators – Generate electricity from electromagnetic interactions, e.g., where coils (conductors) move in magnetic fields e.g., bicycle dynamo, generators etc.
• The energy generated can be stored temporally in batteries
Introduction to Electrical Circuits

- An electrical circuit comprises the source, electrical conductor, and a load.

- Electrons flow from the negative electrode of the battery towards the load and then to the positive electrode.

- Holes flow in the opposite direction, from the positive electrode to the load, and then to the negative electrode.

- By convention the electric current $I$ flows in the same direction with the holes.

- The battery is a 'reservoir' of charges.
Ohm’s Law

- If one applies a voltage (V) across a conductor, there will be a flow of current (I) through the conductor in such a way that I and V are proportional.
- This linear relationship between the Current (I) and the Voltage (V) is referred to as Ohm’s law: \[ V = I R \]

- The unit of voltage is Volt (V) while that of the current is Ampere (A).
- The unit of the resistance is Ohm (Ω).
- The reciprocal of the resistance is called **Conductance (G)** and its unit is **Siemens (S)**:
  \[ G = \frac{1}{R} \]
Units

• The potential difference (V) is measured in volts (V), whereas the current (I) is measured in Amperes (Amps)
• The unit of resistance is Ohms and is designated by
• Note that depending on the magnitudes of potential difference (p.d.), current or resistance, smaller or larger units that are multiples of the above units may be used, e.g., milli-volts (mV), kilo-volts (kV), milli-Amps (mA), mega-Ohms (MΩ) etc.
Resistances in Series

- Loads (or resistances) can be connected either in series or in parallel. Shown below is the series connection.

![Series Connection Diagram]

- The overall resistance or equivalent resistance \((R)\) is given by:

\[ R = R_1 + R_2 + R_3 \]

- Take note that the same current \(I\) flows through each Resistance, but the applied voltage \(V\) is shared proportionally among the 3 loads (resistances).

- The above equation can be generalized for a series of \(n\) resistances \(R_1, R_2, R_3, \ldots, R_n\) connected in series. The equivalent resistance \(R\) is

\[ R = R_1 + R_2 + R_3 + \ldots + R_n \]
Resistances in Parallel

• In the parallel connection shown below, the Equivalent resistance (R) is such that

\[ \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \]

• Notice same voltage across the loads, different currents flow through each load.
• Similarly for a set of \( n \) resistances \( R_1, R_2, R_3, \ldots, R_n \) connected in parallel, the equivalent resistance \( R \) is such that

\[ \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n} \]
Example 1

- Let us have a very simple circuit having 1Watt LED (lamp), A 6V battery and measure the current flowing through the load, the p.d. across the load and estimate the power.

- *If this system is ON for 1Hr, how much energy will be consumed?*
Light Emitting Diode (LED)

Used as white light-emitting alternatives to light-bulbs
Commonly used in electronics, devices such as cell phones, computers, TVs
Introduction to Photovoltaic

• A solar cell converts incident sunlight (photons) directly into electricity
• Materials suitable for converting sunlight into electricity are the semiconductors
• Solar cells can either be:
  – Inorganic (stable, high efficiency, but a bit expensive and relatively difficult to fabricate)
  – Organic (easy to fabricate, but unstable)
  – Hybrid Inorganic-organic
• Recall that an atom comprises the nucleus and electrons arranged in shells (allowed orbits) around the nucleus
Solar Cell Terms

• A set of cells assembled together constitute a Module
• Modules are connected together to form an Array

• $V_{oc}$ = Open circuit voltage
• $I_{sc}$ = Short circuit current
• $P_{max}$ = Maximum Power
• $\eta$ = Conversion efficiency

\[
\eta = \frac{P_{max}}{P_{in}}
\]

• $FF$ = Fill Factor

\[
FF = \frac{P_{max}}{I_{sc}V_{oc}} = \frac{I_{max}V_{max}}{I_{sc}V_{oc}}
\]
Practical Solar Cells

• We now have a rough understanding of the principles of a solar cell
• Remember that to minimize unnecessary recombination of the electron-hole pairs, materials of high purity are required
• Also to enhance absorption, antireflection coatings or thin films are recommended
• Sunlight is intermittent, hence the need for storage (batteries) of the charge generated
Problem 1

1. Let us use the solar panel to replace the battery in the previous example.
2. Measure current, voltage and estimate $P = I \times V$
3. What are some possible issues in this approach?
Energy Requirements

• The total energy requirements ($E$), can be determined as follows:

\[ E = \text{Total Watts of Loads} \times \text{Hrs in operation} \]
\[ = \text{Watt Hrs} \]

• Number & size of panels required can be determined

\[ \text{Watts Required (solar panels)} = \frac{\text{Total energy required}}{\text{system voltage}} \]
Introduction to Batteries

• Energy generated can be temporally stored in a batteries
• A battery is an electrochemical cell (or device) capable of generating energy from a chemical reaction
• A standard cell is one whose e.m.f. is almost time and temperature invariant
• The amount of electricity an accumulator can store is referred to as the capacity of the cell
• Cells can be connected either in Series to increase the Voltage or in Parallel to increase the Current
Battery Capacity

- The capacity of a cell may be considered as the amount of charge stored \( Q = It \).
- For example, if an accumulator can supply 4A for 20 hours (C20 rating), the capacity for this accumulator is 80 Amp-hours (80-AH).

Each cell is a voltage source with a source resistance.
This 12V, 4.5AH battery when fully charged can supply:

- A: A load of 54W for 20 hours
- B: A load of 20A for 4.5 hours
- C: A load of 12A for 4.5 hours
- D: 54WHR irrespective of the wattage
Problem 2

1. From the provided bulb, PV and battery, Design a small PV system and estimate its autonomy

2. Design a PV system to take care of your basic needs in a remote house
Practical Connection Modes

• **Case 1: One Battery: One Panel System**
  a) System without charge controller
Practical connection Modes

(b) System with charge controller
Summary and Concluding Remarks

• This class presents an introduction to electricity and photovoltaics
• Basic principles of Ohmic and non-Ohmic conduction were introduced
• Quantum mechanics fundamentals were then elucidated before using the band gap concept to distinguish between insulators, semi-conductors and holes
• It is our hope in our next hands-on session, we will be able to now construct simple systems to take care of our energy need