Math and Science for Sub-Saharan Africa (MS4SSA)

Project-Based Learning: Introduction to Photovoltaics

M.G. Zebaze Kana
Visiting Scholar, Worcester Polytechnic Institute
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: \[ V = I \times R \]

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.

- 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)
Quiz

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

![Diagram showing a simple electrical connection between a panel, battery, and load]

- PANEL
- BATTERY
- LOAD

+     -
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