DES Notes for the final in week 12

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Contents

Introduction

1. Energy source
   - Sun
2. Solar Panel
   - Parameters
   - Sizing
3. Solar Charge Controller
4. Battery
   - Parameters
   - Type
   - Sizing
5. LED
   - Load

1 Week 6

1.1 Solar Radiation Spectrum

The sun emits EM radiation across most of the electromagnetic spectrum.

- **Spectral irradiance** is the irradiance of a *surface* at a given wavelength.
- **Irradiance** is the power received per unit area

Irradiance is a measure of solar power per unit area at any moment in time. Measured in W/m^2 Irradiation (Wh/m^2) is the total amount of solar energy per unit are received over a given period. Peak sun hour is equivalent to the total irradiation received at the site during the day. 1 peak sun hour is equivalent to $1kWh/m^2$

1.2 Solar Irradiance Variation

Solar irradiation variation depends on location on globe and the position of sun throughout. Here are some considerations for the Energy/Power available for collection:

1. Weather and climate
2. Tilt angle and orientation
3. Shadowing due to surrounding buildings, vegetation

1.3 Solar Module

Solar irradiation proveds energy in the form of a photon. The solar module (photvoltaic panel, solar panel) absorbed the photon to produce electron hole pair that conduct electricity.

1.3.1 Formation of Electron-Hole Pairs with Solar Energy

Semiconductors (p and n) have a bandgap $< 5eV$.
Attaching a piece of silicon to a circuit will not make current flow however, because the electrons in the conduction band will move in to occupy vacant sites in the valance band. We have to create a driving force. A driving force has to be present to move the electrons created out of the semiconductor.

1.3.2 Putting p-n doped semicon together

	p-doped	n-doped
Major charge carrier	holes	electrons
Minor charge carrier	electrons	holes
Overall charge	Neutral	Neutral

1.3.3 Formation of + and − Terminals (Driving Force)

So when put together, the electrons will move from n to p leaving behind the + ion and creating − ion. So when there is photon with energy > the bandgap. The electron will move from $p \to n$ junction. Resulting in current. This current is called **photocurrent** I_{sc}.

2 Week 8

2.0.1 Current in a p-n junction

Electric field goes from $n \to p$. I_D or **drift current** goes in the opposite direction to the electric field. and can be modelled as

$$I_D = I_o(e^{\frac{qV}{k_B T}} - 1) \tag{1}$$

Where:

- I_o: Reverse saturation current
- q: charge of an electron
- k_B: Boltzmann constant
- T: Temperature in Kelvin

Name	Symbol	Description
Photocurrent	I_{sc}	Current during a short circuit when the resistance is zero. Maximum current output of the PV cell.
Open-circuit voltage	V_{oc}	Voltage during an open circuit when resistance is at maximum. Maximum voltage output of the PV cell.
Maximum power	P_{max}	Maximum power output of the PV cell.
Maximum power point	MPP	The point on the I-V curve at which the PV cell will generate the most power
Voltage at MPP	V_{mp}	The PV cell voltage at MPP
Current at MPP	I_{mp}	The PV cell current at MPP

2.0.2 Photocurrent

The effect of the illumination of light is the development of photogenerated carriers(electron-hole) pair. The electric field causes the photegenerated carries to flow

- Electrons to the n
- Holes to the p

The photocurrent produced is in the opposite direction of I_D.
Well then the ouput current is simply

$$I = I_D - I_{sc} \tag{2}$$

$$\Rightarrow I = I_o(e^{\frac{qV}{k_BT}} - 1) - I_{sc} \tag{3}$$

When the solar cell is in operation, $I_{sc} > I_o(e^{\frac{qV}{k_BT}} - 1)$ and current flows from the p terminal.
The equation for the IV plot can be written as follows

$$I_r = I_{sc} - I_o(e^{\frac{qV}{k_BT}} - 1) \tag{4}$$

2.0.3 Open Circuit Voltage

If the terminals of the solar cells are not connected, no current flows. The voltage that develops across the device is called the open circuit voltage $V = V_{oc}$

$$V_{oc} = \frac{k_BT}{q} ln(\frac{I_{sc}}{I_o} + 1) \tag{5}$$

2.0.4 Output Power

Output power is determined experimentally. Use graph to determine P_{max}. Geometrically, it can be found by maximizing the area of the green rectangle that can fit within the I-V plot of the solar cell.

$$P_{max} = I_{max}V_{max} = FFI_{sc}V_{oc} \tag{6}$$

$$FF = fillfactor = \frac{P_{max}}{I_{sc}V_{oc}} \tag{7}$$

2.0.5 Efficiency

$$\eta = FF\frac{I_{sc}V_{oc}}{P_{in}} \tag{8}$$

3 Week 9

3.1 Capacity of Battery

Energy stored in a battery is in Wh but batteries are rated in terms of capacity Ah. Capacity (Ah) measures the amount of charge in a fully charged battery that can be delivered under specified or nominal discharge current and temperature. It is simply the product of the current drawn from a battery, multiplied by the number of hours this current flows.

How long can a 2Ah battery discharge a current at 1A? 2 hours.

3.2 Depth of Discharge (DOD)

Percentage of the battery that has been discharge relative to the overall capacity of the battery.

$$DOD = \frac{\text{capacity that is discharged from a fully charged battery}}{\text{battery capacity}} \tag{9}$$

DOD affects the cycle service life of the battery. For some batteries, there are maximum depth of discharge recommendations.

3.3 Nominal Voltage

Nominal voltage or mid-point voltage is the voltage when 50% of the available capacity is discharged.

3.4 Cut-off Voltage

Minimum allowable voltage to prevent damage to the battery.

3.4.1 Discharge Current Effect on Voltage and Capacity

Voltage of the battery is different with different discharge current. The **higher** the discharge current, the **lower** the voltage. Capacity changes with the value of the discharge current. The **lower** the discharge current, the **longer** the discharge time.

3.5 Specific Energy/Energy Density

Specific energy ($\frac{Wh}{kg}$) is the energy stored per unit mass. Energy density ($\frac{Wh}{L}$) is the energy stored per unit volume Energy content (Wh) of a battery determines its run time; related to the specific energy or energy density. The theoretical limit of specific energy is determined by standard reduction potential (voltage of the battery), the number of electrons involved, and mass of th eactive materials.

$$\text{Theoretical specific energy of battery}[\frac{Wh}{kg}] = \frac{V[V] \times (\text{number of electrons} \times q)[Ah]}{\text{mass of active materials}[kg]} \tag{10}$$

3.6 Power Density and Specific Power

Power density ($\frac{W}{L}$) is the maximum amount of power per unit volume. Specific power ($\frac{W}{kg}$) is the maximum amount of power per unit mass. Which is a characteristic of the battery chemistry and packaging.

3.7 Self Discharge Rate

Loss of capacity through reactions during the battery storage and when battery is not connected to a load. Self-discharge is usually reversible when a battery is recharged (the capacity is restored). For lead-acid batteries the product of discharge reaction is lead sulfate which maya build and grow irreversibly if the recharge doesn't occur within a certain amount of time.

3.8 End of Life (EOL)

Batteries that have reached the end of their usefulness and/or lifespan and no longer operate at sufficient capacity. Use graph find curve.

3.9 Days of Autonomy

Days of autonomy is the duration the battery can supply the site's loads without any support from generation sources. (eg, cloudy days). System design requirement that takes the following into consideration,

- System application - critical load applications require more autonomy than non-critical appliactions
- System availability - minimum percentage of the time that the PV system should be able to satisfy the system's specified design loads. Standalone PV system requires some battery reserve to ensure reliability of service and to provide time for intervention in the event of an unanticipated occurence.

3.10 Designing a Standalone PV System

3.10.1 Determine the load energy requirement

1. Assume total system losses
2. Determine peak sun hours
3. Decide on Array:Load ratio (More means less chance for standalone system to not work)
4. Choose a PV module
5. Daily photovoltaic Ah needed: load requirement x A:L ratio
6. Convert total system losses to percentage and subtract from 1
7. Daily photovoltaic ampere-hours per chosen solar panel: system loss percentage x peak sun hours x current at P_{max}
8. Number of panels required: Daily photovoltaic ampere-hours needed / daily photovoltaic ampere-hours per chosen solar panel
9. Actual number of panels required: Round number of panel required up
10. Go to sg.rs-online.com

3.10.2 Sizing of the battery

1. Nominal system voltage: Refer to Load
2. Days of autonomy: Determine by use-case
3. Total daily load: Load current [A] x hour of operations per day [h] $\rightarrow$ [Ah]
4. Unadjusted battery capacity: Days of autonomy x total daily load [Ah]
5. Maximum allowable depth of discharge: based on battery, 80% for lead acid so it won't die
6. Capacity adjusted for MDOD: Unadjusted battery capacity / MDOD [Ah]
7. Maximum daily depth of discharge: Based on EOL then look at graph

8. Capacity adjusted MDDOD: Total daily load / MDDOD
9. Percent of capacity at EOL: set by how you want to sell the battery
10. Capacity adjusted for EOL: Capacity adjusted for MDOD / Percent of capacity at EOL
11. Capacity adjusted for DODs or EOL: Greatest capacity adjusted value
12. Design margin factor: anything ≥ 1
13. Capacity adjusted for design margin: greatest value x design margin factor
14. Find battery on sg.rs-online.com