CG1111 Week 2 Studio 2

Energy is the ability to do work

Energy can be converted from one form to another

eg chemical → heat → mechanical → electricity

Energy can be transmitted within a system

e.g Transmission lines for electricity

Gears for mechanical energy

Instantaneous power p is the rate of change of transmitted / converted energy

$$\boxed{p = \frac{dW(t)}{dt}}$$

Efficiency $$\boxed{\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{loss}}}$$

* energy will be loss during conversion / transmission

Energy Balance Equation $$\Sigma E_{in} = \Sigma E_{out} + \Sigma E_{stored} + \Sigma E_{lost}$$

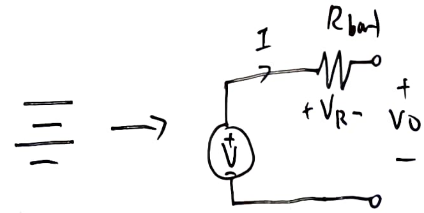
* basically conservation of energy

energy usually lost in the form of heat

Power is the rate of energy flow $$\boxed{P = \frac{dE}{dt}}$$

Batteries

voltage source derived from an internal chemical reaction



important specifications

↳ nominal voltage V_{bat} [V]

↳ total store of energy / capacity [mA-h, A-h, W-h]

↳ internal resistance [Ω]

* thevenin equivalent?

KVL

$V - V_O - V_R = 0$

$V_O = V - V_R = V - IR_{bat}$

Activity 1

Customer	priority 1	priority 2	priority 3	priority 4
Business Executive	battery	weight	processor	graphic
Student	weight	battery	processor	graphic
Gamer	graphic	processor	battery	weight
programmer	processor	graphic	battery	weight

* The above priority table stems from understanding the requirements of the 4 customers.

for example, the gamer prioritizes good graphics and performance over other concerns
he probably games while at home, plugged into a power source, at his desk
so battery and weight are not an issue

customer	processor	Graphics Card	Total power consumed / w	Battery life
Business Executive	Intel Core i3 10110Y	GeForce GTX 1650	5.5 + 75 + 15 = 95.5	6 - 8 hours
student	Intel core i5 10110Y	GeForce GTX 1650	5.5 + 75 + 15 = 95.5	6 - 8 hours
Gamer	AMD Ryzen 9 4900HS	GeForce GTX 2080	35 + 215 + 15 = 265	4 hours
Programmer	Intel Core i5 10600K	GeForce GTX 2070	125 + 160 + 15 = 300	4 hours.

* Based on the rules, power consumption and battery life are negatively correlated
power consumption and weight are positively correlated

As such, the business executive and students should get components with lowest power consumption
while the gamer and programmer are not restricted by constraints and can have the higher performing components

Battery Capacity

Instantaneous power delivered by battery given by $p(t) = v(t)i(t)$ [watts]

Total energy delivered over an interval of time $E(t) = \int_{t_1}^{t_2} v(t)\, i(t)\, dt$ [joules]

Battery delivers 1W when $V = 1V$ and $I = 1A$

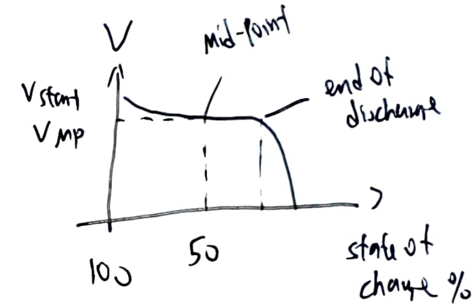
If power delivered is constant throughout period T $E = pT$

Battery Discharge Characteristics

① Mid-Point Voltage — * more of the time, battery supplies this voltage

↳ approximate operational voltage / nominal voltage

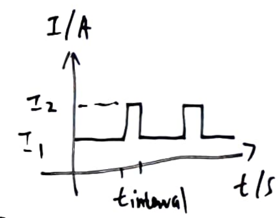
↳ when battery has discharged 50% of total energy



② Cycling — e.g. flickering lights vs constantly on

↳ non-constant current discharged

↳ different current required at certain stages



$$I_{discharge} = \begin{cases} I_1 + (I_2 - I_1)\dfrac{t_{interval}}{T} & \text{if } \dfrac{t_{interval}}{T} < 0.05 \\ I_2 & \text{if } \dfrac{t_{interval}}{T} > 0.05 \end{cases}$$

$\boxed{* \text{ Duty cycle} = \dfrac{t_{on}}{T} \times 100\%}$

③ C-rate

↳ rate at which battery is discharged relative to maximum capacity

1C means discharge current will discharge entire battery in 1 hour

1C for 1000 mAh → discharges 1A for 1 hour

1C for 5000 mAh → discharge 5A for 1 hour

5C for 5000 mAh → discharge 1A for 5 hour

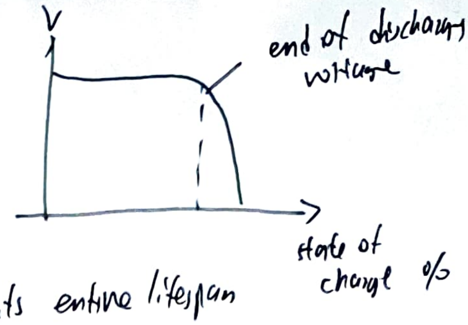
$\boxed{\text{current} = \dfrac{\text{capacity}}{\text{c-rate}}}$

* Higher C-rate means lower battery capacity (inverse relationship)

④ Depth of Discharge

↳ percentage of total capacity discharged

↳ complement to state of charge



* discharging battery completely reduces its life

* battery cannot sustain same operational voltage for its entire lifespan

Battery Design

batteries connected in <u>series</u> have <u>double</u> voltage but <u>same</u> capacity

batteries connected in <u>parallel</u> have <u>same</u> voltage but <u>double</u> capacity

current divider ⇒ current in each branch smaller

* derive from KVL, KCL

Framework

Mid-point voltage ⟶ # batteries in series ⟶ system energy requirements ⟶ load capacity ⟶ max Depth of discharge

⟶ C-rate ⟶ battery capacity ⟶ # parallel branches ⟶ Final Design

Mid-Point Voltage

↳ calculate MPV at given C-rate

↳ Assume 1C if not stated

Find MPV

Battery in Series

↳ $n_s = \dfrac{\text{operating voltage of load}}{\text{mid-point voltage}}$

↳ round up to integer

Find n_s

Find $V_{operating}$

System Requirements

↳ series $\quad P_{in} = \dfrac{P_{out}}{\eta_1 \eta_2 \eta_3}$

↳ parallel

$$P_{in} = P_{in1} + P_{in2} + P_{in3}$$
$$= \frac{P_{out1}}{\eta_1} + \frac{P_{out2}}{\eta_2} + \frac{P_{out3}}{\eta_3}$$

Find P_{in}

Load Capacity

↳ load energy = Pin * operating time

↳ load capacity = $\frac{\text{load energy [Wh]}}{\text{operating voltage [V]}}$ [mAh / Ah]

$\boxed{\text{Find load capacity in [Ah]}}$

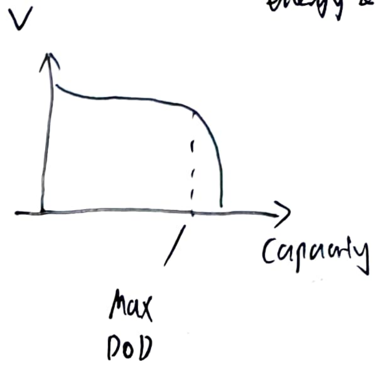
$\boxed{\begin{matrix} p = VI \\ p\text{-}h = V \cdot I\text{-}h \end{matrix}}$

energy & current-hour

Depth of discharge

↳ estimate battery capacity at corresponding C-rate

$\boxed{\text{Find max DoD}}$



Parallel Branches

↳ $n_p = \frac{\text{load capacity}}{\text{one battery capacity / DoD}}$

↳ round up to integer

Final Design

↳ operating voltage = $n_s \cdot$ MPV at C-rate

↳ load capacity = n_p branches of (n_s connected batteries) in parallel each with DoD

↳ total number of batteries = $n_s \cdot n_p$

Activity 2

average C-rate → 5hr ≡ 0.2C

instantaneous C-rate 0.5C

MPV = 3.5V (from graph)

$n_s = \frac{22V}{3.5V} = 6.286 = 7$ (integer value)

$$P_{in} = \frac{P_{out1}}{80\%} + \frac{P_{out2}}{95\%} + \frac{P_{out3}}{75\%}$$

$$= 146.32\ W$$

$$V_{DB} = 7 \times 3.5 = 24.5\ V$$

$$\text{load energy} = 146.32\ W \times 5\ \text{hours}$$

$$= 731.6\ Wh$$

$$\text{load capacity} = \frac{731.6\ Wh}{24.5\ V} = 29.861\ Ah$$

$$= 29861\ mAh$$

$$DoD = 3200\ mAh$$

$$n_p = \frac{29861\ mAh}{3200\ mAh} = 9.33 = 10 \text{ (integer value)}$$

operating voltage : 24.5V

↳ 7 batteries in series with MPV 3.5V at 0.5C

load capacity : 29861 mAh

↳ 10 branches of 7 series connected batteries in parallel with each battery capacity of 3200mAh

total # batteries = $10 \times 7 = 70$