Tutorial - 3

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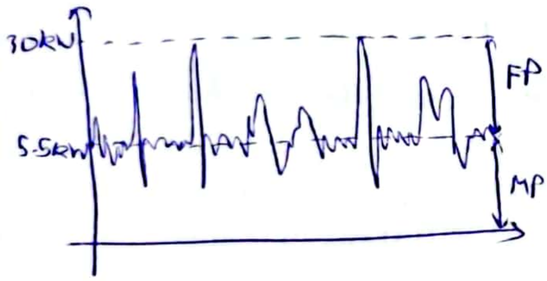
* Data for the Design of the hybridized RAT

- Power Profiles

Fluctuating Consumers

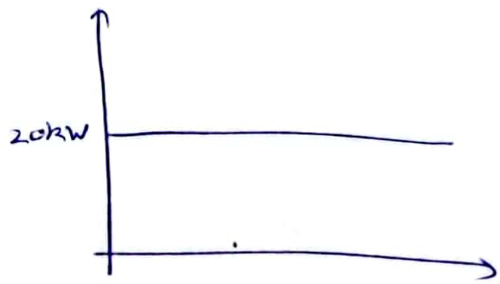


Mean power = 5.5kW

Peak power = 30kW

∴ Fluctuating power = 24.5kW

Constant Consumers



Constant Power = 20kW

Total average constant power to be provided

$$= 5.5 + 20 = 25.5\ kW$$

(to be provided by the turbine)

Fluctuating power = 24.5 kW (to be provided by the storage system)

* Structure and Strategy of hybridization and associated power requirements

1) The design margin is added to the sizing of the turbine.

$$\text{Total power} = FP + \underbrace{MP + DM}_{\text{Turbine}}$$

$$= 24.5 + 25.5 + 6.5 = 56.5\,kW$$

$$\cong 57\,kW$$

2) A conventional RAT will need to provide the total power $= 57\,kW$. This means, it will be accordingly sized to be heavier and larger than a h-RAT.

An h-RAT will be sized only for the constant power requirement $= 25.5 + 6.5 = 32\,kW$ which will result in a smaller RAT.

* Pre-sizing of the Turbine

1) $P_{elec} = \eta P_T$

$$= \eta \frac{1}{2} \rho (\pi R_T^2) V_T^3 C_p$$

$$\boxed{R_T = \sqrt{\frac{2 P_{elec}}{\eta \rho \pi V_T^3 C_p}}}$$

* We can see that

$$P_{elec} \propto R_T^2$$

$$\therefore \frac{P_c}{P_h} = \frac{R_{T_c}^2}{R_{T_h}^2}$$

$$R_{T_h} = R_{T_c} \left(\frac{P_h}{P_c}\right)^{1/2} = \frac{749.3}{2} \sqrt{\frac{32}{57}}$$

$$\boxed{R_{T_h} = 280\,mm}$$

Scanné avec CamScanner

2) $V = \omega R$

$$\alpha_R = \frac{R_h}{R_c} = 0.747$$

$$\therefore \omega = \frac{V}{R}$$

$$\frac{\omega_h}{\omega_c} = \frac{V_h}{V_c} \cdot \frac{R_c}{R_h} = \frac{1}{\alpha_R}$$

$$\omega_h = \frac{\omega_c}{\alpha_R} = [6425.7, 8835.34] \text{ rpm}$$

$$P = T\omega$$

$$T = \frac{P}{\omega}$$

$$\frac{T_h}{T_c} = \frac{P_h}{P_c} \cdot \frac{\omega_c}{\omega_h} = \alpha_R^2 \cdot \alpha_R$$

$$\boxed{T_h = \alpha_R^3 T_c}$$

- Mass Calculations

$$M = \rho S t$$

$$M_h = M_c \frac{S_h}{S_c} = M_c \alpha_R^2$$

$$M_h = 81.65 \times (0.747)^2$$

$$= 45.56 \text{kg}$$

* Pre-sizing of the Storage System

- First Configuration

1) $E = \frac{1}{2} C V^2$

2) DoD = 50%

$$\therefore V_{min} = \frac{1}{2} V_{max}$$

Energy stored in the Supercapacitor that is provided:

$$\Delta E = \frac{1}{2} C (V_{max}^2 - V_{min}^2)$$

$$= \frac{1}{2} C V_{max}^2 \left(1 - \frac{1}{4}\right)$$

$$\boxed{\Delta E = \frac{3}{8} C V_{max}^2}$$

3) Since $V_{max} = 250V$

$$C_{eq} = \frac{8}{3}\frac{(\Delta E)}{V_{max}^2}$$

$$= \frac{8}{3} \times \frac{62226}{(250)^2} = 2.65F = C_{min}$$

Capacitors need to connected in series to increase voltage. ~~and~~ The minimum equivalent capacitance = 2.65F has to be maintained.

$2.5V \times (\text{no. of capacitors}) = 250V$ $\therefore$

$$n = \frac{250}{2.5} = \underline{100 \text{ capacitors}}.$$

$$C_{eq} = \frac{C}{n} = \frac{350}{100} = \underline{3.5F}$$

Since $C_{eq} > C_{min}$, this configuration works.

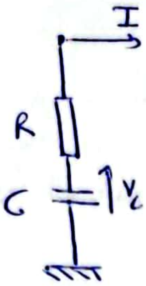
Total mass $m = \frac{8.4 \times 100}{1000} = \underline{8.4 kg}$

4) $C_{min} = 2.65F$ (above)

• Converter and Current Calculations

1) $P_{in} = \frac{P_{fluctuating}}{\eta} \cong \frac{25}{0.95} = 26.3 kW$

2)



$R = 110\,m\Omega$

Power balance:

$$P_{in} = V_c I - R I^2$$

$$R I^2 - V_c I + P_{in} = 0$$

$$\boxed{I = \frac{V_c - \sqrt{V_c^2 - 4 R P_{in}}}{2R}}$$

3) $$I = \frac{250 - \sqrt{(250)^2 - 4 \times 0.11 \times 26.3 \times 10^3}}{2 \times 0.11}$$

$$I = 110.58\,A$$

We take the minimum current to reduce losses due to resistance & heating.

• Sizing of the Inductance

$\Delta I \rightarrow$ current ripple $= 10\%$ of current max

$$\therefore L = \frac{V_{bus}}{4 f \Delta I} = \frac{270}{4(20 \times 10^3) \times (0.1 \times 110.58)} = \underline{305.2\,\mu H}$$

• Mass Balance

Mass = Supercapacitor + Converter + Inductor + Turbine

~~= 8.4 + 10 + 5 = 23.4 kg~~

$= 8.4 + 10 + 5 + 45.56 = \underline{68.96\,kg}$

• Second Configuration

1) The change in voltage is a result of energy discharge which is:

$$\Delta E = \frac{1}{2} C (V_{max}^2 - V_{min}^2)$$

$$C = \frac{2 \times 62226}{(306)^2 - (234)^2} = 3.2F \text{ (minimum capacitance required)}$$

2) $C_{min} = 3.2F$ $V_{min} = 306V$

1 Capacitor specifications

15V/58F/19.2mΩ/0.5kg

$\frac{306}{15} = 20.4 \Rightarrow 21$ capacitor blocks needed in series to reach a minimum voltage

Each capacitor block would have a parallel arrangement of n capacitors.

If we calculate for n=1 (simply 21 capacitors in series)

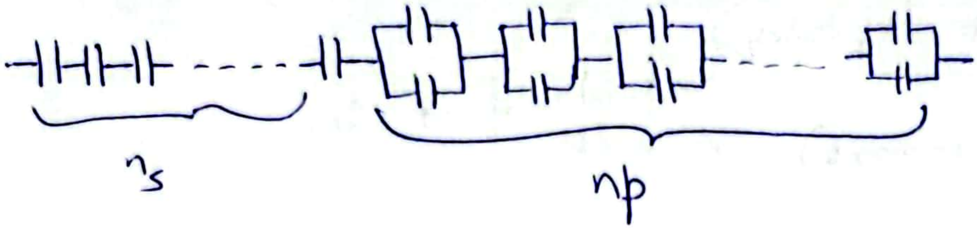
n=1

$$C_{eq} = \frac{C}{21} = 2.76F < 3.2F \Rightarrow \text{This configuration is not possible}$$

n=2

$$C_{eq} = \frac{2C}{21} = 5.52F > 3.2F$$

This means that the ideal configuration is a combination of n_s capacitors in series & n_p parallel arrangements of 2 capacitors each.



$\boxed{C = 58F}$

$n_s + n_p = 21$

$(C_{eq})_s = \dfrac{C}{n_s}$ $\qquad$ $(C_{eq})_p = \dfrac{2C}{n_p}$

$$\frac{1}{C_{eq}} = \frac{1}{(C_{eq})_s} + \frac{1}{(C_{eq})_p}$$

$$= \frac{n_s}{C} + \frac{n_p}{2C}$$

$$\frac{1}{C_{eq}} = \frac{1}{C}\left(\frac{2n_s + n_p}{2}\right) = \frac{1}{2C}(n_s + n_s + n_p)$$

$$= \frac{n_s + 21}{2C}$$

$$C_{eq} = \frac{2C}{n_s + 21} > C_{min} = 3.2F$$

$$n_s + 21 < \frac{2C}{C_{min}}$$

$$n_s < \frac{2C}{C_{min}} - 21 = \frac{2 \times 58}{3.2} - 21 = 15.25$$

$\cancel{\boxed{n_s > 15} \quad \& \quad n_s + n_p > 15 + n_p}$

$\cancel{n_p + 15 < 21}$

$\cancel{\boxed{n_p < 6}}$

$\therefore \boxed{n_s < 15.25}$ since, $n_s + n_p = 21$

$\boxed{n_p > 5.75}$

This concludes that $n_s = 15, n_p = 6$

$\therefore$ A configuration with 15 capacitor in series and 6 parallel arrangements of 2 capacitors each is ideal.

Achieved voltage $= 21 \times 15V$
$= 315V$

Equivalent Capacitance

$$C_{eq} = \frac{2C}{2n_s + n_p} = \frac{2 \times 58}{2 \times 15 + 6}$$

$$= 3.22F$$

3)

$$\text{Total mass} = 0.5\,kg \cdot (n_s + 2n_p)$$ total no. of capacitors

$$= 0.5(15 + 2\times 6)$$

$$= 13.5\,kg$$

4) II[nd] Configuration

Advantages

- Removing the storage converter reduces overall mass.
- It reduces design complexity.
- Removing the converter reduces tendency to generate harmonics in the supply system.

Disadvantages

- Overall decreased quality of voltage
- A converter reduces some power fluctuation.
- The converter also provides less thermal dissipation.

* Study of the implementation of the hybridized RAT in the aircraft

- Having 2 storage systems reduces risk in the event of failure.
- Since the storage systems are close to their respective power consumers, it eliminates the need for long wirings reducing weight.
- A single storage system operates at powers upto 30 kW. By splitting the supply into 2 storage systems, we reduce the maximum output power which increases safety.

- Replacement by a liquid hydrogen fuel cell

1) $P_{avg}(EMA) = 3.145\,kW$

$P_{constant}$ (with design margin) = 2076.5 = 26.5 kW

$P_{avg}(AFT) = 2.294\,kW$

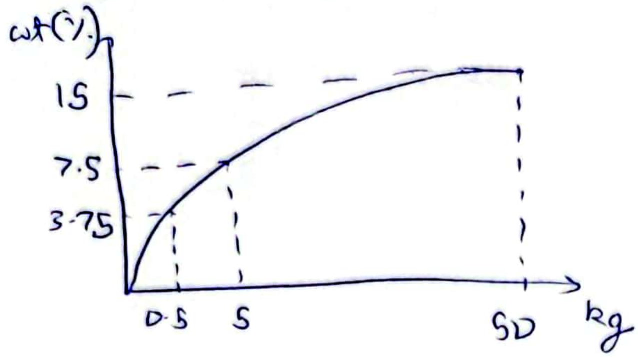
Total power required $= 26.5 + 3.145 + 2.294 \simeq 32\,kW$

Energy $= 32 \times 0.5 = 16\,kWh$

$\therefore$ Mass $(LH_2) = \dfrac{16}{33.29} = 0.48 \simeq \underline{0.5\,kg}$

Volume $(LH_2) = \dfrac{16}{2.36} = \underline{6.77\,L}$

2) Logarithmic Extrapolation



mass increases 10 fold $\longrightarrow$ wt(%) increase 2 fold.

$\therefore$ for $m = 0.5 kg \rightarrow wt(\%) = 3.75\%$

$$\text{Total mass } (H_2 + \text{tank}) = \frac{0.5}{0.0375} = \underline{13.3} \text{ kg}$$

• Replacement by a gas hydrogen fuel cell

1) Energy = 16 kWh

$$\text{Mass } (GH_2) = \frac{16}{33.29} \cong 0.5 \text{ kg}$$

$$\text{Volume } (GH_2) = \frac{16}{2.75 \times 10^{-3}} = \underline{5.81} \text{ kL}$$

2) Taking composite cylinders

For $P = 350 \text{ bar} \Rightarrow wt(\%) \cong 13\%$

$$\therefore \text{Total mass} = \frac{\text{mass}(GH_2)}{wt(\%)}$$

$$= \frac{0.5}{0.13} \cong \underline{3.84} \text{ kg}$$

As previously calculated, RAT mass = $\underline{45}.56$ kg

A system of gaseous H_2 tank weighs the least at 3.84 kg. However, the high volume of 5.81 kL will be a challege. Additionally, the weight of the fuel cell, depressurization systems will have to be considered as well.