Exam 2021

# Question 1 – Battery pack

1. Generation (33%) => Transmission (94%) => Plug-to-wheel (76%)

Generation => wheel = 23 %

1. SiC has a lower thermal conductivity
2. V\_batt = 800 V

V\_bemf = 230 V

R = 3 ohm

Find I

V\_motor = V\_batt – V\_bemf = 800 – 230 = 570 V

I = V\_motor / R = 570 / 3 = 190 A

Find P

P = I \* V\_batt = 190 \* 800 = 152 kW

1. Nernst equation:

OCV = K\_0 + K\_2 \* SOC + K\_3 \* ln(SOC) + K\_4 \* ln(1-SOC)

K\_0 determines the constant component of the function

K\_2 determines the linear component of the function

K\_3 and K\_4 determine the logarithmic component of the function

1. Pack requirements:

Pack energy = 50 kWh

Voltage range = 320 – 550 V

Pk power = 75 kW

Cell properties:

Capacity = 200 Wh

Voltage range = 2.5 – 4.2 V

Max Current = 80 A

Pack design:

Min cells = pack energy / cell capacity = 50 kWh / 200 Wh = 250 cells

N\_s = min voltage / min cell voltage = 320 V / 2.5 V = 128 cells

Peak current = peak power / min voltage = 75 kW / 320 V = 235

N\_p = peak current / max cell current = 235 A / 80 A = 2.9 => 3 cells

# Question 2 – Thermal

1. T\_s = 30s

dU\_r0 = 0.65 V

dU\_tot = 0.85 V

dI = 50 A

R\_0 = dU\_r0 / dI = 0.65 V / 50 A = 0.013 ohm

R\_1 = (dU\_tot / dI) – R\_0 = 0.85 V / 50 A = 0.004 ohm

C\_1 = T\_s / (4 \* R\_1) = 30 s / (4 \* 0.004 ohm) = 1875 kF

1. The Dual Polarization model has a second RC component to improve accuracy
2. Discharge rate = 1C

Capacity = 2.6 Ah

R\_int = 0.05 ohm

h = 15 W/m2

T\_a = 25 C

I = 2.6 Ah \* 1 /h = 2.6 A

A = 2 \* pi \* r \* L = 2 \* pi \* 0.018/2 \* 0.065 = 3.68e-3 m2

T\_batt = I^2 \* R / (h \* A) + T\_a = 2.6^2 \* 0.05 / (15 \* 3.68e-3) + 25 = 31.1 deg C

1. T\_batt = 30

I = sqrt(h \* A \* (T\_batt – T\_a) / R) = sqrt(15 \* 3.68e-3 \* (30 – 25) / 0.05 = 2.35 A

Crate = I / capacity = 2.35 A / 2.6 Ah = 0.9

1. Thermal runaway is the occurrence of a rapid (exponential) increase in temperature due to a high temperature allowing exothermal chemical reactions to occur, thus increasing the temperature further.

# Question 3 - Motors

1. A changing current through a wire induces a magnetic field around that wire according to the right-hand rule. If said current is sinusoidal, the magnetic field will also be sinusoidal. If the wire is wound into a coil, the sinusoidal magnetic field will oscillate along the axis of the coil. If the coil is wound such that its axis is perpendicular to the axis of a rotor, the sinusoidal magnetic field will be perpendicular to both the rotor and coil axes – i.e. withing the motor air gap.
2. If two (or more, usually three) of the coils described in part a) are placed around a motor, the sinusoidal magnetic fields will combine. If the currents in the coils are evenely out of phase (i.e. for thee phase, 120 deg out of phase) the resultant magnetic field from the coils will rotate.
3. Both synchronous machines and induction machines rely on a rotating magnetic field generated by out of phase stator coils.

The rotor of a synchronous machine has a permanent magnet which is attracted to the rotating magnetic field from the stator. The rotor will rotate at the same speed of the rotating magnetic field from the stator.

The rotor of an induction machine is a squirrel cage. The rotating magnetic field from the stator cuts the bars of the squirrel cage and induces a current. Each current carrying squirrel cage bar experiences a force perpendicular to both the current and the magnetic field directions according to Flemming’s left hand law which causes the rotor to rotate. This squirrel cage must be rotating at a slower speed than the magnetic field from the stator to ensure a current is induced. The difference in speed is the ‘slip’.

An induction machine is self-starting as any difference in speed between the magnetic field and the rotor induces a force which rotates it.

A synchronous machine is not self-starting as the rotating magnetic field is not strong enough to overcome the inertia of the rotor.

1. PMSM torque equation:

T\_e = 3/2 \* n\_p \* (L\_d – L\_q) \* i\_d \* i\_q + 3/2 \* n\_p \* lamda\_f \* i\_q

First term is ‘reluctance torque’ – dependent on i\_q as well

Second term is ‘magnet torque’ – dependent on i\_q only

1. Values in the ABC frame rotate with time

Values in the DQ frame are constant as the frame itself rotates with the rotor. This makes modelling and control easier.

1. L\_d = 80 uH

L\_q = 200uH

R = 0

N\_p = 1

W\_max = 6000 rpm = 6000 \* 2\*pi/60 = 628.3 rad/s

P @ W\_max = 200 kW

K\_e = 0.036 V/rpm = 0.036 \* 60/2\*pi = 0.344 V/rad/s = lamda\_f

1. I\_d = 0

T\_e = P / W\_max = 200 kW / 268.3 = 318.3 Nm

I\_q = 2 \* T\_e / (3 \* n\_p \* lamda\_f) = 2 \* 318.3 / (3 \* 1 \* 0.344) = 616.9 A

I\_phase = i\_q / sqrt(2) = 616.9 / sqrt(2) = 436.2 A

V\_d = -W\_max \* L\_q \* i\_q = -628.3 \* 200e-6 \* 616.9 = -77.5 V

V\_q = W\_max \* lamda\_f = 628.3 \* 0.344 = 216.1 V

V\_phase(pk) = sqrt(V\_d^2 + V\_q^2) = 229.6 V

V\_phase(rms) = sqrt(3/2) \* V\_phase(pk) = 281.2 V

1. I\_phase = 400 A

I\_peak = 400 \* sqrt(3) = 565.7 A

K = lamda\_f / 4\*(L\_d – L\_q) = 0.344 / 4\*(80u – 200u) = -716.6

I\_d = -sqrt((I\_peak^2)/2 + K^2) – K = -sqrt((565.7^2)/2 + 716.6^2) + 716.6 = -104.1A

I\_q = sqrt(I\_peak^2 – I\_d^2) = sqrt(565.7^2 + 104.1^2) = 575.2 A

T\_e = 3/2 \* n\_p \* (L\_d – L\_q) \* i\_d \* i\_q + 3/2 \* n\_p \* lamda\_f \* i\_q

= 3/2 \* (80e-6 – 200e-6) \* -104.1 \* 575.2 + 3/2 \* 0.344 \* 575.2

= 304.1 Nm

MTPA maximises torque per ampere

1. V\_d = i\_d \* R – W\_max \* L\_q \* i\_q = - 628.3 \* 200u \* 575.2 = -72.3 V

V\_q = W\_max \* L\_d \* I\_d + W\_max \* lamda\_f

= 628.3 \* 80u \* 200u + 628.3 \* 0.344

= 216.1 V

V\_peak = sqrt(V\_d^2 + V\_q^2) = sqrt(72.3^2 + 216.1^2) = 227.9 V

V\_rms = sqrt(3/2) \* V\_peak = sqrt(3/2) \* 227.9 = 279.1 V

Effect of i\_q on voltage?

1. Reluctance torque is negative so extends motor operation range

# Question 4 – other shit

1. An SMPS is a type of power supply that uses switching devices to convert electrical power.

An SMPS is significantly more efficient than a linear power supply.

1. PWM is the ratio of on time to total time. It determines the average power delivered to the load.
2. Modulation index: ratio of the amplitude of the modulating signal to that of the carrier signal.

Frequency modulation ratio: ratio of the carrier frequency to the modulating frequency

1. Modulation index should be less than 1 as more than this causes over modulation (non-sinusoidal).
2. Voltage overshoot can cause a breakdown which creates a short circuit and damages the component – risk of explosion.
3. Dead time is a period of time between transistors in a SMPS switch state which is required to avoid direct shoot through.

It produces a square-wave voltage distortion with low-order odd harmonics.

1. Wide band-gap devices have a higher breakdown voltage which means they can be smaller and have lower resistance.

They also have higher switching speeds reducing the switching period where most losses occur.

i)

Electric motors have a high torque even from zero speed. This reduces the need to change gear ratio to provide the necessary torque at different speeds.

ii)

V\_dc = 400 V

V\_line(rms) = 254 V

M\_svm = sqrt(2) \* V\_line(rms) / V\_dc = 2 \* sqrt(2) \* 254 / 400 = 0.898

M\_spwm = 2\*sqrt(3)/3 \* M\_svm = 2 \* sqrt(30/3 \* 0.898 = 1.037

Tutorial Questions

# Battery Pack Design

Pack requirements:

Min pack energy = 50 kWh

Min voltage = 250 V

Max voltage = 500 V

Peak power = 100 kW

Cell properties:

Capacity = 100 Wh

Min voltage = 2.5 V

Max voltage = 4.2 V

Max current = 50 A

Find pack arrangement:

Min cells = pack energy / capacity = 50 kWh / 100 Wh = 500 cells