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First Name : ______________________________________

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Renewable Energy: Exam Part Van herle

Date: June 30, 2017; 16:15-19:15; CO1

Duration: total 3 hours (with Prof. Haussener's part)

Allowed material: Calculator, personal summary (10 single pages A4), formula memento (Van herle).

3 exercises – 50% of total points

Exercice question 1 (15% of total points) (15 pts)

Forest exploitation with a wood plant

We wish to exploit 300 hectare (1 hectare: 10'000 m^2) of a forest for a pilot demonstration plant for wood-to-electricity generation.
The growth/replantation cycle is assumed to be 10 years. The wood growth rate is 3 kg/m^2 (on a weight basis of 15% humidity).
Wood is represented by the approximated chemical formula $C_6H_{10}O_5$.
(C : 12 g/mole, H : 1 g/mole; O : 16 g/mole).
Energy is consumed in chopping the trees, drying the wood and their mechanical pelletizing, but this energy is supplied from other sources, hence not accounted for here. The stored wood product has 15% final humidity.
The pellets are gasified and the gas converted in a gas engine, for pellet energy-to-final electrical efficiency of 25%.

<u>Calculation Questions:</u> (8 pts)

a) Estimate the (lower) heating value of the stored wood (ash-free). (2 pts)

LHV formula : wt% C * 43.6 – 0.31 MJ/kg
C = 6 x 12 = 72 g
Wood = 72 g C + 10 g H + 5x16 g O = 162 g/mol
C-wt%= 72/162 = 44.44% => LHV = 19.07 MJ/kg (0% humidity) (1 pt)
Since final humidity = 15%, and with LHV_wet = LHV_dry * (1-1.14*H_2O%),
we obtain LHV_wet = 15.81 MJ/kg (1 pt)

b) What is the power size (in $MW_{electrical}$) of this potential pilot demonstration plant, if it operates 8000h per year ? (5 pts)

300 ha, 10 year cycle, hence 30 ha are exploited each year.
3 kg/m^2 (15% humidity) growth rate
=> thus 30 kg wood /m^2 after 10 years
=> energy content = 30 kg/m^2 * 15.81 MJ/kg = 474.3 MJ/m^2.
473.33 MJ/m^2 for 30 ha gives 142.3 TJ. (2 pt)

Conversion is 25% electricity, yielding 142.3 TJ*0.25= 35.57 TJ electricity = 9.88 GWh_{el}
The wood plant operates 8000 h/ yr.
Its power size is therefore 9.88 GWh/8000h = **1.235 MW_{el}** (3 pt)

c) Assume the forest receives a solar input of 1800 kWh/m^2/year. Derive from this information, and the wood growth rate of 3 kg/m^2 (weight basis: 15% humidity), the photosynthetic storage efficiency of sunlight into wood biomass (1 pt)

3 kg => 3 * 15.81 = 47.43 MJ wood output per m^2
1800 kWh = 6480 MJ solar input per m^2
=> 47.43/6480 = 0.732% solar to wood storage efficiency (1 pt)

<u>Side questions</u>: (7 pts)

d) What special care has to be taken for the gas engine ?
cleaning of the wood gas (particles, impurities, tar cracking) (2 pt)

e) Which gasifier type do you take ?
Updraft gasifier, for lowest particulate matter (gas engine) and highest cold gas efficiency. The size is compatible with updraft gasifiers (<20 MW). (2 pt)

f) What are the essential differences between coal-fired power stations and wood-fired power stations and why? (3 pt)

Size (MW vs GW) (1 pt)
Only simple small Rankine cycle with wood => lower efficiency (0.5 pt)
Less availability of the wood fuel (smaller supply area); humidity (0.5 / 0.5 pt)

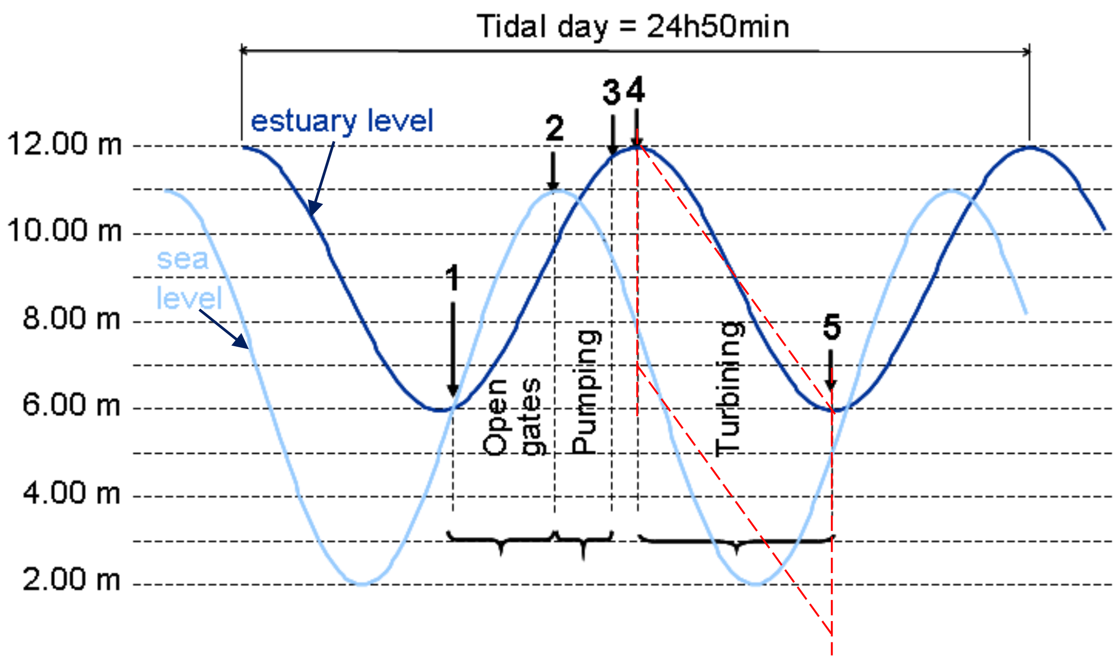
Exercice question 2 (10% of total points) **(10 pts)**

Tidal hydropower scheme

A tidal hydropower scheme with storage basin is considered. Its technical characteristics are described, including a sketch of the periodic water level change between the basin ('estuary') and the sea coming in and out with the rising and receding tide. The principal question is to compute the installed turbine power and the yearly produced electricity. As indicated on the sketch, a tidal day equals 24 hours and 50 minutes.

<u>Technical characteristics</u>:

- Area of the storage basin (or estuary), A_b = 35 km^2
- Average level of stored water in basin following high tide: 9 m
- Fraction of stored water that can be effectively used for turbining: 85%
- Turbining efficiency, ε_T = 88% (water-to-electricity)
- Operating scheme: evaluate the average water head H (=water drop) during turbining, from the sketch below (=see dashed parallellogramme below, from point 4 to point 5 (=1/4th of a tidal day), indicated for illustration and evaluation)



Calculation Questions: (8 pts)

a) Estimate the

(i) average power (MW_{elec}) (6 pts)
(ii) annual electricity production (GWh_{elec}) (2 pts)

from this tidal scheme, assuming the above characteristics.

power = 517 MWe
annual electricity = 2.265 TWh
any partial answer gives corresponding fraction of points

Turbining global efficiency	ε_T	88	%
Storage basin area	A_B	35	km²
Average water level following high tide	H_{Bav}	9	m
Fraction of basin water that can be used	f_w	85	%

Physical constants

Tidal day = 24h50min	t_d	89 400	s
Specific mass of water	ρ	1000	kg/m³
Terrestrial acceleration	g	9.81	m/s²

Scheme power and electricity production

Turbining duration per cycle	$t_c=t_d/4$	22 350	s
Number of cycles per year	$N_c=2$ * (365d×24h/d×3600s/h)/td	706	cycles
Volume of stored water	$V_w=A_B \cdot H_{Bav}$	3.15E+08	m³/cycle
Mass of usable stored water	$M_w=\rho \cdot V_w \cdot f_w$	2.68E+11	kg/cycle
Average head during a turbining cycle	H_{Tav}	5	m
Turbinable energy	$E_T=\varepsilon_T \cdot M_w \cdot g \cdot H_{Tav}$	1.16E+13	J/cycle
Tidal average scheme power	$P_s=E_T/t_c$	**517**	**MWe**
Electric energy produced per year	$El_a=P_s \cdot t_c * N_c=E_T \cdot N_c$	**2 265**	**GWh/yr**

Side questions: (2 pts)

b) Why is the pumping phase (from point 2 to point 3 in the figure) especially advantageous in this hydropower scheme? (1 pt)

Pumping occurs with a small head (1 m) while turbining at a bigger head (5 m), hence a much more important gain as with classical pumping-turbining schemes which occur over constant head in both directions.

c) How could you further increase the electricity production from this scheme? (1 pt)

Double effect scheme, i.e. turbining upon water inflow from the sea to the estuary.

Exercice question 3 (25% of total points) (25 pts)

Wind Turbine Dimensioning

Parameters	**Values**
Rated Power:	2.5 MW_{elec}
Number of blades:	N=3
Operation :	Variable speed, pitch control
Power coefficient C_P:	0.335
Lift coefficient K_L :	0.8
Rated wind speed:	45 km/h
Generator :	50 Hz, 4 poles (grid frequency : 50 Hz)
Gearbox :	1 : 50 step-up
Air density ρ_{air}	1.2 [kg/m^3]

<u>Calculation Questions</u>: (18 pts)

Dimension this wind turbine, giving:

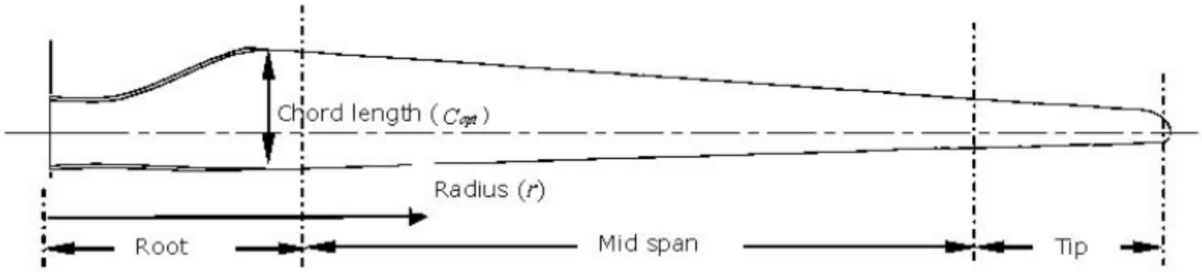
a) the blade length (turbine radius R) (2 pt)
45 m

b) the rated angular velocity ω (in rad / s) (2 pt)
ω=3.142 rad/s

c) the tip speed ratio λ (1 pt)
λ=11.32

d) the pitch angle β (for an angle of attack α = 5°)
- at the minimum chord length (=at the blade tip, r = R) (3 pt)
- at the maximum chord length (3 pt)

(= assumed to be at a radius r, equal to 1/5th of the blade length R – see the drawing on next page)



γ (r=1/5R) = 0.2865 rad or 16.4°, β = 11.4°
γ (r=R) = 0.05885 rad or 3.4°, β = -1.6°
partial points given if correct formulas are used

e) the minimum and maximum optimal cord length c(r) (2 x 2 pt)
C (r=1/5R) = 3.9 m
C (r=R) = 0.8 m
partial points given if correct formulas are used

what will be the tip speed at rated angular velocity for the above turbine?
141 m/s (1 pt)

f) assuming a constant C_P for this turbine's wind speed operating range situated between 5 and 12.5 m/s, what will be the power extracted by the turbine at a windspeed of 20 km/h ? And at a windspeed of 10 km/h?
219.5 kW at 20 km/h
0 at 10 km/h, as this is below the cut-in speed (2 pt)

Side questions: **(7 pts)**

g) explain what 'variable speed' means and what is its specific advantage to fixed speed operation (2 pt)
adapt ω to follow the v^3 power curve below v_{rated}; this extracts more energy than fixed speed

h) explain what 'pitch control' means (3 pt)
changing the pitch angle (the angle between the blade chord line and the plane of rotation of the blades) to regulate lift and hence power

i) how is the angle of attack α defined (geometrically)? (2 pt)
the angle between the blade chord line and the relative wind velocity vector, the latter constructed by the absolute wind speed and angular rotation speed vectors