POLITECNICO
MILANO 1863

Automation of Energy Systems

(Modelling and Control of Energy Systems)

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Academic year 2020/2021
Exam call of 31 August 2021

Family name ______________________

Given name(s) ______________________

Reg. code ______________________

Signature ______________________

- This booklet contains a total of **12 pages**, including this cover and the last page with the phase ruler to detach. **Check that the booklet is complete** and if this is not the case signal the problem immediately.
- **Fill in the space above with your personal data and signature; do this now, and in ink**. For the rest of the exam you can use a pencil.
- Answer the questions in the spaces provided, **following the instructions precisely** and writing legibly; **order and clarity are part of the evaluation**.
- During the exam **you are not allowed to consult books, notes or any other material**.
- **Hand in only this booklet**: nothing else will be accepted.
- The sections of the exam report **indicative** scores, so as to give an idea of their relative weights. Keep in mind that these are just indications, of course reliable but **not to be taken as rigid constraints**. Scoring is done considering the exam as a whole.

Foreword — read carefully

If you are taking Automation of Energy Systems (hereinafter AES) as a standalone exam, you must answer all the questions in the booklet.

If you are taking this test as part of the Modelling and Control of Energy Systems (hereinafter MCES) exam, you must **NOT** answer the questions marked with **"AES only"**.

If taking MCES, do not answer "AES only" questions in an attempt to compensate for other possibly missing answers: **no marks will be awarded** for that.

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1 Multiple choice questions

This section is made of 30 questions for AES, 20 for MCES; only one of the proposed answers is correct. The total value of the section is **15 points**:

- each correct answer adds 0.5 points for AES, 0.75 for MCES,
- each incorrect answer subtracts 0.25 points for AES, 0.375 for MCES,
- answers not given have no effect.

Warning: answers must be provided by ticking the boxes on page 6, **not in the body of the questions**.

1 For" secondary" energy we mean in general

a. energy not in the form found in nature but somehow "transformed".
b. energy devoted to non critical uses.
c. energy used as reserve in electric networks.

2 In general, the utilisation of renewable energy

a. is completely cost free.
b. does not entail the release of pollutants.
c. requires no consumables except the energy source itself.

3 For "energy intensity" we mean

a. the amount of energy per unit of intended result.
b. the energy spent for the intended result in the unit of time.
c. the average rate at which energy is released for the intended purpose.

4 A major reason for possible realisability problems with feedforward compensation in thermal systems is the frequent presence of

a. process dynamics with high relative degree.
b. unstable dynamics.
c. PI controllers.

5 The control quality achieved with a cascade control could not be obtained – in the same control problem – with a single-loop one

a. if the bandwidth separation between the two loops is not sufficient.
b. if there are relevant disturbances affecting the inner loop.
c. if there are relevant disturbances affecting the outer loop.

6 In a 2×2 decoupler-controller structure, if antiwindup is applied upstream the decoupler and one of the physical control variables hits a saturation limit,

a. the affected loop slows down.
b. both loops can undergo highly undesired behaviour.
c. the effect is unpredictable, but for sure stability is preserved.

7 A Smith predictor will most likely not function correctly

a. if there are significant unmeasured disturbances on the process to corrupt the used prediction.
b. if the delay is too large for the prediction block to react timely, as in that case rational dynamics prevails.
c. if the process rational dynamics is not asymptotically stable, because the predictor block is in parallel to it.

8 When using split range actuation, to avoid too fast actuator cycling one typically

a. chooses the sampling period based on the actuator limitations instead of the continuous-time loop characteristics.
b. avoids the use of integral action as possible windup phenomena would exacerbate the problem.
c. introduces a dead zone around the switching point.

9 The two main control loops aboard a thermoelectric generator, from a system-centric viewpoint, concern

a. mechanical power and energy (pressure) level.
b. primary and secondary control.
c. primary and tertiary control (the secondary one is centralised).

10 Major problems in controlling solar generators of "traditional" type (e.g., mirror field plus receiving tower) come from

a. the particularly fast dynamics of the steam generator, that require very prompt actions.
b. the thermal inertia of the generator, that slows down the system.
c. the variability of the primary source and the difficulty of introducing storage if not in the steam generator.

11 A relevant advantage of modern solar generators with tube captors is

a. the higher working temperatures.
b. the possibility of introducing significant energy storage thanks to the circulating fluid.
c. the faster dynamics of the captor.

12 The main policies for the control of a thermoelectric generator are called

a. primary, secondary and tertiary control.
b. boiler follows, turbine follows, and sliding pressure.
c. prime mover, turbine and alternator control.

13 The main factors to decide a control policy for a given generator in an electric network are

a. size, type, role (e.g., base load vs. dispatching) and cost of transients.
b forecast electric power at the network level and position of the generator.
c. age of the generator.

14 A network admittance matrix is always

a. real.
b. diagonalisable.
c. symmetric.

15 The active and reactive generator-network power transfer are jointly governed by

a. machine angle and voltage phase.
b. machine angle and voltage amplitude.
c. power and frequency control.

16 Thermal systems composed of controlled volumes and containment elements (e.g., walls) typically exhibit

(tube walls even!)

a. dynamics with multiple time scales, often widely separated.
b. oscillatory dynamics, though in general quite well damped.
c. highly nonlinear dynamics.

17 When confronted with multiple dynamic time scales, the most proper use of thermal energy is normally achieved by

a. focusing the control design on the slowest time scale, as this is the dominant dynamics.
b. determining the time scale on which control needs centring based on the objective (e.g., comfort).
c. considering all scales, for example by means of nested loops.

18 If a thermal controller is tuned so as to exhibit zeroes at too low frequency with respect to the loop cutoff, a typically expected result is

a. poor robustness.
b. a sluggish load disturbance response.
c. oscillations when the set point is modified.

19 The main control loops in a heat network substation heat exchanger are

a. secondary and primary side outlet temperatures.
b. secondary side outlet temperature, possibly with primary side flow as inner cascade loop.
c. secondary side outlet temperature and primary side flowrate.

20 In a generic heat network, a larger working fluid flowrate

?

a. allows for a smaller temperature drop.
b. requires a larger temperature drop.
c. uselessly increases the power spent for moving the fluid.

21 **AES only.** In a cascade control structure having a temperature as the outer value, the inner one quite typically is

a. pressure.
b. level.
c. flowrate.

22 **AES only.** In energy systems, a typical phenomenon the presence of which may suggest a Smith predictor is

a. fluid transport in long pipelines.
b. large electric storages that are slow at reacting.
c. high sampling times, resulting in an equivalently high computation delay.

23 **AES only.** In time division actuation, the base period

a. must be small with respect to the actuator dynamics so that the system is hardly affected by the switching.
b. must be small with respect to the process dynamics yet tolerable for cycling the actuator.
c. needs not choosing with particular care.

24 **AES only.** From the control viewpoint, a nice peculiarity of hydeoelectric generators is

- **a.** that the pressure upstream the turbine is not affected by how much power is taken.
- **b.** that no component heats up too much.
- **c.** that there is no secondary control required.

25 **AES only.** In an islanded generator case, a means to overcome or at least mitigate response speed imitations is

- **a.** to introduce derivative action.
- **b.** to decrease the integral time.
- **c.** to increase the integral time.

26 **AES only.** The control policy for a generator

- **a.** is never changed once decided.
- **b.** can vary over time depending e.g. on the present load.
- **c.** is changed only when maintenance is in order.

?

27 **AES only.** Denoting by Q_i the reactive power injected/drawn at bus i of a network with n_B busses, by $G_{ij} - jB_{ij}$ the (i, j) element of the admittance matrix and by V_i,V_j the voltage amplitudes at busses i and j, the reactive power balance at bus i reads

- **a.** $Q_i = \sum_{j=1}^{n_B} V_i V_j \, (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij})$.
- **b.** $Q_i = \sum_{j=1}^{n_B} V_i V_j \, (G_{ij} \cos \delta_{ij} - B_{ij} \sin \delta_{ij})$.
- **c.** $Q_i = \sum_{j=1}^{n_B} V_i V_j \, (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij})$.

28 **AES only.** When acting on a thermal system via two actuators (e.g., heater and cooler) the most energy-efficient strategy is

- **a.** to employ two loops, one per actuator, thanks to saturation.
- **b.** to set up a cascade control to equalise the actuator dynamics.
- **c.** to use the two in a split range configuration with a wide dead zone.

29 **AES only.** When operating two actuators with opposite action, a major advantage of a two-loop scheme over a split range one is

- **a.** that the two controllers are led to always use actuators at the minimum possible level.
- **b.** that the tuning of the two controllers can be made equal (i.e., only one in fact needs tuning).
- **c.** that setting two extremal set points governs the controlled variable swings better than a control dead zone.

30 **AES only.** In heat network control, a primary role of optimisation is

- **a.** to determine the most energy-efficient flowrate/temperature combination for the working fluid.
- **b.** to determine the optimum number of loads to serve at any given time.
- **c.** to distribute the load among the utilisers in the most efficient manner.

Answers to the multiple choice questions

responce here!

	a	b	c		a	b	c	AES only	a	b	c
1				11				21			
2				12				22			
3				13				23			
4				14				24			
5				15				25			
6				16				26			
7				17				27			
8				18				28			
9				19				29			
10				20				30			

2 Open questions

The total **indicative** value of this section is **6 points**; partial values – indicative as well – are shown question by question.

Question 1 (AES 2 points, MCES 3 points)

Explain how a primary/secondary control structure for an AC grid can be made to encompass a centralised integral control and overall result in a PID-like control law.

If we want to obtain overall a PID structure, we have to

↳ [add $\frac{\text{pole}}{\text{zero}}$ on primary controller → PID
if just Kp primary is a PI]

mantain the centralized integral action, (necessary to avoid controllability issues) ⇒ and include a derivative action on the decentralized proportional part, introducing an additional pole, so the overall scheme is the usual one but instead of proportional K_p we use $K_p \frac{(1+sT_z)}{(1+s\tau)}$

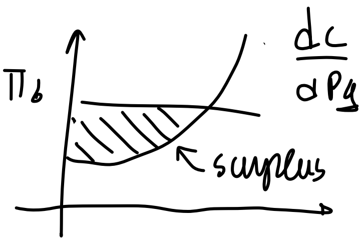
Question 2 (AES 2 points, MCES 3 points)

Illustrate how a price-taking generator can determine its optimum production level with a completely selfish approach.

In the pov of the producer, it will have to determine its optimum amount of power to generate P_g, considering a fixed price of power sell (price-taking) Π_b [€/kWh] and a generation cost $C(P_g)$, and it has to optimize

$$\max\{\Pi_b P_g - C(P_g)\} \rightarrow \frac{d}{dP_g}(//) = 0 \Rightarrow \frac{dC(P_g)}{dP_g} = \Pi_b$$

So we find optimal condition P_g^* where the two curves encounter



Question 3 (2 points) — AES only

all others are cons!

List and briefly comment the major pros and cons of ring and twin-pipe heat networks.

comparing the two ways of implementing a heat network, if using a RING PIPE, we will use only one pipe which feed in series all the utilisers giving back flowrate to the Net, In this way the upstream thermal disturbance propagate through all the net (cons) and we have an overall thermal drop over all the Net (cons), in fact it is hardly used. While twin-pipe structure even if using a couple of pipes (hot line / cold return line) we can consider almost negligible T drop on the feed line (hot one). and the variation that spread on the Net is a flowrate error, that can be compensated using a Flow meter

3 Exercises

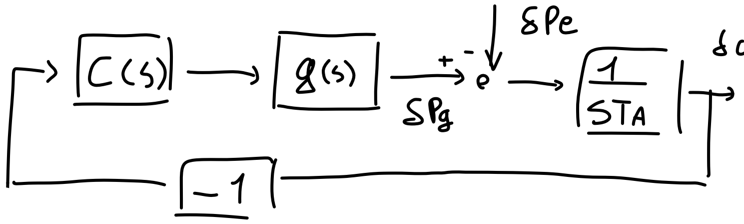
The total **indicative** value of this section is **12 points**; partial values – indicative as well – are shown exercise by exercise.

Exercise 1 (AES 5 points, MCES 12 points)

An islanded AC generator at frequency $f_o = 50Hz$, of nominal power $P_n = 10MW$ and characterised by a first-order dynamics with time constant $\tau = 20s$, feeds a load such that the equivalent time constant T_A equals $5s$.

1. Draw a block diagram representing the system with power and frequency control in PID form.
2. Tune the PID controller so that the dominant closed-loop time constant be $10s$, the corner frequency of the open-loop transfer function pole not in the origin be twice the cutoff frequency, and the phase margin be approximately $50°$; report the obtained open-loop frequency response magnitude, as well as the computations related to response speed and stability degree, on the semilogarithmic sheet of page 9.

1



$g(s) = \frac{1}{1+20s}$

$T_A = 5s$

with

$C(s) = K\frac{(1+sT_1)(1+sT_2)}{s(1+s\tau)}$ {PID controller}

2 $\tau_c = 10\,sec \rightarrow \omega_c = 0.1$ rad/s

$\tau = \tau_c/2 \rightarrow \omega_p = 0.2$ rad/s pole open loop

$= 5\,sec$

$\varphi_m \simeq 50°$

$\downarrow$

$\phi_z = 50 + 26° =$
$= 76°$

the obvious choice is to cancel the generator pole using the PID controller zero, so set $T_1 = 20$

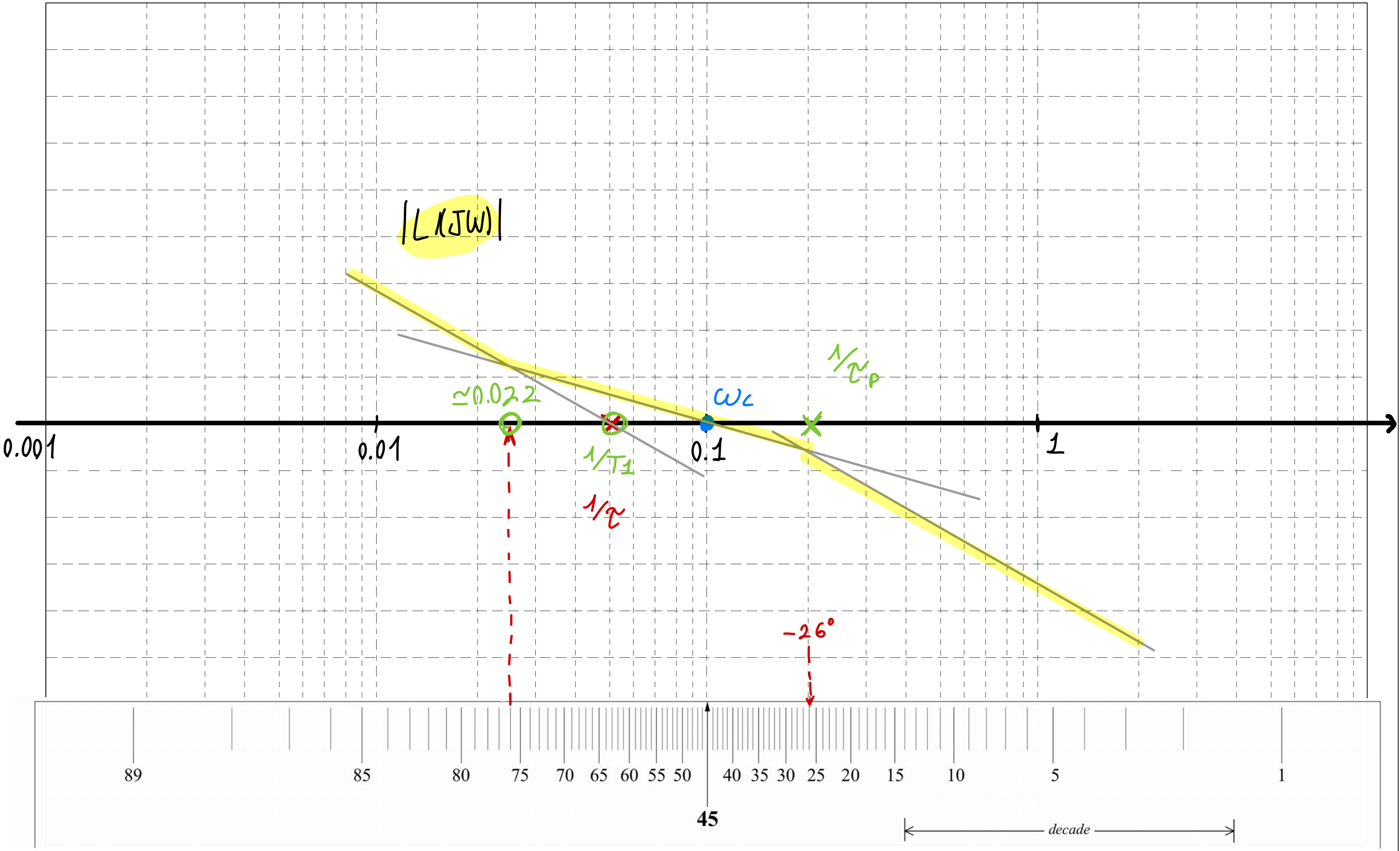
than study on semilog paper the loop $L(s)$ desired TF to place properly the ZERO!

this give us: $1/T_2 = 0{,}022 \rightarrow T_2 \cong 45{,}5$

than to find K, inverting the found $L(s)$ shape:

$\tilde{\omega} = 0.05 \rightarrow \mu = (0.05)^2 = 0.0025$

$$L^*(s) = 0.0025\,\frac{\cancel{(1+sT_2)}}{\cancel{s^2}\,\cancel{(1+s\tau_p)}} = \frac{1}{\cancel{s}T_A}\,K\,\frac{\cancel{(1+sT_1)}\cancel{(1+sT_2)}}{\cancel{s}\,\cancel{(1+s\tau_p)}}\,\frac{1}{\cancel{1+sT_1}} \rightarrow K = 0.0025\,T_A = $$
$$= 0.0125$$



|L(jw)|
0.001
0.01
0.1
1
≃0.022
1/T1
1/τ
ωc
1/τp
-26°
89
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
1
decade

Exercise 2 (7 points) — AES only

Consider a thermal system in which a mass $M = 40kg$ of specific heat $c = 250J/kgK$ is connected to a heater with maximum power $P_{h,max} = 800W$ and a first-order dynamics with time constant $\tau_h = 10s$; the mass disperses heat toward an exogenous ambient temperature T_a through a thermal conductance $G = 250W/K$.

1. Draw an electric equivalent for the system.
2. Draw and tune a control scheme with a PI controller to regulate the temperature T of the mass acting on the heater command, in the range $[0, 1]$ aiming for a dominant closed-loop time constant equalling 40% of the open-loop one.
3. Suppose that the heater be replaced with one ten times slower: would the controller choice still be adequate in your opinion? Why?