Automation of Energy Systems

(Modelling and Control of Energy Systems)

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Exam call of 17 February 2022

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, ← DIO CANE !
- 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 "generator control" we mean

THIS! (Teacher) →

a. coordinating the pool of generators that feed a particular utiliser, or set of utilisers.
b. operating the generator as near as possible to its optimal efficiency condition, compatibly with the constraints in force.
c. switching the generator on and off timely with respect to the power generation plan.

2 For "generator mix control" we mean

a. distributing generation so as to be maximally efficient while properly fulfilling the demand.
b. blending the power from the active generation without provoking congestion.
c. activating generators according to an optimal sequence determined via some cost function minimisation.

3 A typical use of cascade controls in thermal energy systems is

a. to prevent pressure drops in a thermovector fluid supply from affecting utilisers in the short run.
b. to reduce control efforts in multivariable cases with significant loop interaction.
c. to compensate for slow environmental disturbances on centralised heaters/chillers.

4 An aspect to consider for the installation and maintenance of a cascade control structure is

OK!

a. the presence of an additional sensor with respect to a single loop.
b. the increased computational load for the host computing architecture.
c. the necessity of autotuning capability for the inner loop.

5 A frequent goal of control with decoupling in thermal systems is ?

a. to stabilise the system.
b. to prevent energy waste due to thermal zone interaction.
c. to equalise the energy expenditure of all the controllers.

6 The scheme in which several actuators are used in sequence, each one starting to act when the previous one has reached its limit, is called

a. daisy chain.
b. split range.
c. cascade.

7 The scheme in which a single control signal activates one out of a set of actuators depending on its value, is called

a. split range.
b. time division output.
c. decoupling.

8 In classical approaches to the management of AC grids

a. control is exerted by generators and loads are viewed as disturbances.
b. control is exerted by loads while generators provide a base level of power.
c. loads and generators continuously exchange information to adapt the control policy.

9 In an electric generator, the presence of a rotating mass

a inherently couples frequency and power.
b. makes it impossible to have any storage, even minimum.
c. requires kinetic energy level control.

10 A major impact of distributed generation in AC grids is

a. to question the assumption of few "large" generators versus many "small" loads.
b. to increase the variability of loads over time.
c. to produce generation optimisation problem of larger dimension.

11 In AC grids, for "energy quality" we essentially mean ?

a the distance of all generators from their optimal operating point.
b. the required voltage and frequency.
c. the correct generation/demand balance.

12 In electric AC networks, the secondary control is

a integral.
b. proportional.
c. derivative.

13 A primary plus secondary control system for an AC grid can be viewed as

a a PI controller with centralised I and decentralised P.
b. a PI controller with centralised P and decentralised I.
c. a totally decentrialsed PI controller with an offset from a central network manager.

14 Concerning the load flow problem, a network is organised into generator busses, load busses and

a. as many slack busses as there are external connections.
b. control busses.
c. one slack bus.

15 In a load flow problem, a generator bus prescribes

a. reactive power and voltage amplitude.
b. active power and voltage amplitude.
c. active and reactive power.

16 The network admittance matrix

a. comes from applying voltage balances at busses.
b. comes from applying current balances at busses.
c. is determined once the admissible load is known.

17 A typical use of cascade controls in thermal energy systems is

a. to allow a flow control loop to respond more promptly when required.
b. to increase stability and robustness in general.
c. to quench the difficulties posed by valve nonlinearities via inner flow loops.

18 To help ambient condition control systems use less energy, set points are in general

?

a. kept constant whenever possible so as to minimise transients.
b. adapted on line so that no control signal hits the maximum-power saturation limit too often.
c. scheduled based on a periodic (e.g., daily) estimate/forecast of thermal loads.

19 When operating two actuators with opposite or complementary action, a major advantage of a two-loop saturation-based scheme over a mere split range structure is

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

20 As for sizing, a major advantage of a twin pipe heat network over a ring one is

a. that pumps can be smaller as there is practically no total hydraulic impedance variation.
b. that the heater outlet temperature can be made lower as there is virtually no drop on the forward line.
c. that the two pipes are smaller than a single one.

21 **AES only.** A Smith predictor is advisable

a. in the presence of a delay large enough to make response speed requirements not attainable.
b. every time the controlled dynamics exhibits a delay.
c. when the delay contained in the controlled process is significantly larger than the sampling time.

22 **AES only.** The main difference between daisy chain and split range actuation

a. is that in daisy chain the "preceding" actuator stays on when the "following" is activated, while in split range just one is active.
b. resides in fact not in the schemes themselves, but rather in the different way possible discrepancies in the actuator dynamics are addressed.
c. does not exist: the schemes are in fact the same, the only point is that split range just concerns two actuators while in daisy chain there can be any number.

23 **AES only.** The power response of a thermoelectric generator to a throttling valve step

a. is practically instantaneous but then decays unless energy (pressure) is restored.
b. is practically instantaneous and then sustained.
c. cannot be instantaneous owing to the boiler dynamics.

24 **AES only.** The power response of a thermoelectric generator to a combustion power step

a. is in general dominantly first- or second-order as the boiler dynamics need traversing.
b. is practically instantaneous but then decays unless the throttling valve intervenes.
c. is the slowest possible.

25 **AES only.** In electric AC networks, the reason why secondary control is centralised resides in

a. observability.
b. controllability.
c. stability.

26 **AES only.** Denoting by $\underline{y}_{ij}$ the line admittance between busses i and j, the i-th diagonal element of the admittance matrix for a network with n_B busses is

a. $\underline{Y}_{ij} = -\underline{y}_{ij}$
b. $\underline{Y}_{ii} = \underline{y}_{ii} + \sum_{j=1,j\neq i}^{n_B} \underline{y}_{ij}$.
c. $\underline{Y}_{ii} = \underline{y}_{ii} - \sum_{j=1,j\neq i}^{n_B} \underline{y}_{ij}$.

27 **AES only.** Thermal systems composed of controlled volumes and containments typically exhibit ?

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

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, exploiting controller 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.** In a generic heat network, the temperature of the working fluid ?

a. should be be as high as possible so as to reduce pumping power to the minimum.
b. should be as low as possible compatibly with load requirements and optimal flow, to minimise losses.
c. has no influence on efficiency, it is just a matter of desired temperatures to serve.

30 **AES only.** In a ring heat network, disturbances propagate to downstream utilisers as

a working fluid temperature variations.
b. working fluid flow variations.
c. shock waves.

Answers to the multiple choice questions

	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 the roles and interplay of primary, secondary and tertiary power/frequency control for an AC grid.

when tuning the control of an AC grid with multiple generators we need integral action to kill frequency error on long run (power error is already killed by the alternator integrator). The problem is that with parallel generators we could not use PI(D) parallel decentralized controllers (parallel integration leads to a loss of controllability). So our solution is to set up a primary decentralised control (proportional action taking care of initial behaviour) plus secondary centralized integral action (taking care of going well to regime), weighted properly for each gen. and on top a centralized tertiary control that take care of optimization of the gen. power respect some cost rate, acting as tertiary bias

Question 2 (AES 2 points, MCES 3 points)

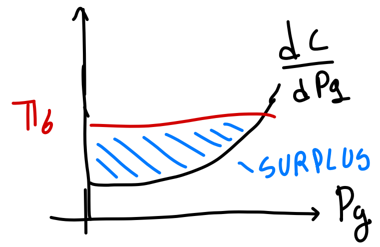
Illustrate how a price-taking energy producer can determine its optimum production level with a completely selfish approach.

In the producer P.O.V its selfish goal is to maximize its revenue, so if $C(P_g)$ is the [€/h] cost of energy and π_b is the €/MW price fixed:

his objective will be: $\max_{P_g} \{ \pi_b P_g - C(P_g) \}$

$\Downarrow$

derive and set to 0 $\rightarrow$ $\frac{dC(P_g)}{dP_g} = \pi_b$ so intersepting the two function we find optimal point of generation P_g



Question 3 (2 points) — AES only

List and briefly comment the major use(s) of cascade controls in thermal systems.

In thermal systems where we have to deal with very heterogeneus timescales, cascade control is very usefull.

For example when we have to control T, the ideal control variable is power but in reality we use flow rate, so we can set up an internal flow loop that take care of possible pressure problem (that otherwise will propagate with delay on external power control loop) "decoupling" an external T control loop using power

another usage of cascade controls is when we have both centralized + small local energy source, where for each local enviromment we have a sort of inner loop while the central Global loop act overall.

NOT SURE ! ?

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 electric generator at frequency $f_o = 50Hz$ has nominal power $P_n = 10MW$ and a second-order dynamics, with time constants $\tau_1 = 10s$ and $\tau_2 = 2s$.The total inertia produces an equivalent time constant equal to the average of the said time constants.

1. Draw a block diagram representing the islanded AC systems with power and frequency control in primary plus secondary form, assuming the former and the latter to be purely proportional and integral, respectively.

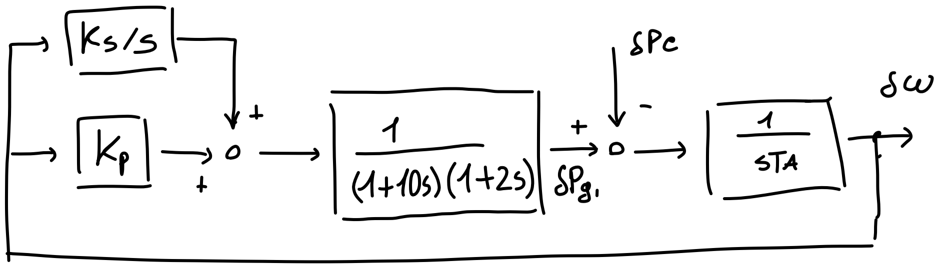
2. Determine the primary and the secondary gain for a the closed-loop step response settling time t_a of $150s$ and a phase margin φ_m as near as possible to $50°$; report the obtained open-loop frequency response magnitude, as well as the computations related to response speed and stability degree, on the semilogarithmic sheet of page 9.

$P_n = 10MW$

$\tau_1 = 10s$, $\tau_2 = 2s$

$T_A = \frac{10+2}{2} = 6s$

1 for an islanded Generator the control structure is easy:



2 $t_{set} = 150s \rightarrow \omega_c \simeq \frac{1}{\frac{t_{set}}{5}} = 0.0\bar{3} \simeq 0.035$

$\varphi_m \simeq 50°$

We proceed by loop shaping working on the semilog paper checking how much we loss from each pole.. We need

$\varphi_z \cong 50° + (21° + 3.5°) = 74.5°$ of gain!

$\simeq 75°$ placing the ZERO on $\frac{1}{T} = 0.01$

corresponding to a $\tilde{\omega} = 0.02$ (loop Gain) $\rightarrow \mu = \tilde{\omega}^2 = 0.0004$

so overall the control seen as a PI. to get our $L^\circ(s)$ desired

$T = 100$

$$K \frac{1+sT}{s} \cdot \frac{1}{(1+10s)(1+2s)} \frac{1}{sT_A} = 0.0004 \frac{(1+100s)}{(1+10s)(1+2s)\, s^2}$$

$$K = 0{,}0004 \cdot T_A = 0{,}0024$$

$$\begin{cases} K_s = 0{,}0024 \\ \frac{K_p}{K_s} = 100 \rightarrow K_p = 0{,}24 \end{cases}$$

$$C(s) = K_p + \frac{K_s}{s} = K_s \frac{1+(K_p/K_s)s}{s} = \frac{0{,}0024}{s}(1+100s)$$

Exercise 2 (7 points) — AES only

Consider a thermal system in which a mass $M = 100kg$ of specific heat $c = 1020J/kgK$ is connected to a heater with maximum power $P_{h,max} = 2500W$ and a cooler with maximum power $P_{h,max} = 1500W$ (*mind the signs*). Both actuators have a first-order dynamics, with time constant $\tau_h = 20s$ and $\tau_c = 100s$, respectively. The mass disperses heat toward an exogenous ambient temperature T_a through a thermal conductance $G = 200W/K$.

1. Draw an electric equivalent for the system.
2. Quantify the maximum achievable difference of the mass temperature T from the ambient one. in the heating and the cooling case.
3. Draw and tune a control scheme with two PI controllers, one per actuator, to keep T in a $[T_{lo}, T_{hi}]$ range acting on the heater and the cooler commands, both in the range $[0, 1]$. aiming for a dominant closed-loop time constant of half the dominant open-loop one for both the heating and the cooling case.

$C = Mc = 102 kJ/K$

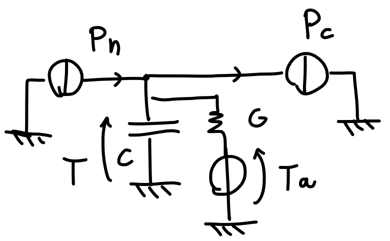
$c\dot{T} = P_h - P_c - G(T - T_a)$

$\Downarrow$

$$T = \frac{1}{G}\frac{P_h - P_c}{1+\frac{c}{G}s} + \frac{T_a}{1+\frac{c}{G}s}$$

sure ??

1



2 at regime for $\dot{T}=0$

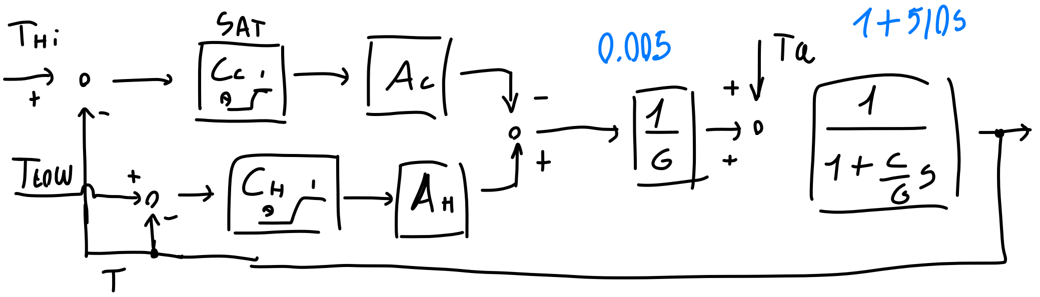
I can quantify with max conditions:

$(T-T_a) = \frac{P_{hMAX}}{G} \rightarrow \Delta T_{max} = 12.5K$

while $(T-T_a) = -\frac{P_{cMAX}}{G} = -7.5K$

?

3 with the following control scheme



$A_H = \frac{2500}{1+20s}$

$A_C = \frac{1500}{1+100s}$

$L_H = \frac{2500}{1+20s} 0.005 \cdot \frac{1}{1+510s}$ dominant τ_{OLH} is the slowest one, so $\frac{1}{510} \cong 0{,}002 \rightarrow \omega_c \simeq 0{,}004$ half dominant τ_c

so we want $L_H(s) = \frac{1}{255s} = C_H \frac{2500}{1+20s} 0{,}005 \frac{1}{1+510s} \rightarrow C_H = \frac{(1+510s)\cancel{(1+20s)}}{255s(0{,}005)2500}$ $\frac{1}{20} > \frac{1}{255}$ we can neglect

similarly

$L_C = \frac{1500}{1+100s} 0{,}005 \frac{1}{1+510s}$ again $\omega_c \simeq 0{,}004$, the process has the dominant dynamic

both PI

$L_C(s) = \frac{1}{255s} \Rightarrow C_C(s) = \frac{(1+510s)\cancel{(1+100s)}}{255s(1500)(0{,}005)}$ $\frac{1}{100} > \frac{1}{255}$ neglect