Automation of Energy Systems

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Reg. No. ______________________________

Last name ______________________________

Given name(s) ______________________________

Signature ______________________________

- Answer the questions in the spaces provided.
- If you run out of room for an answer, continue on the back of the page.
- Hand in *only* this booklet. No additional sheets will be accepted.
- Scoring also depends on clarity and order.

1. Consider an islanded electric generator, and let the its transfer function – having as input the command $\theta \in [0, 1]$ and as output the variation ΔP_g of the generated power expressed in MW – be

$$G(s) = \frac{10}{1 + 2s}.$$

(a) Assuming a network inertia of $10kJ/(r/s)^2$, determine the network equivalent time constant T_A.

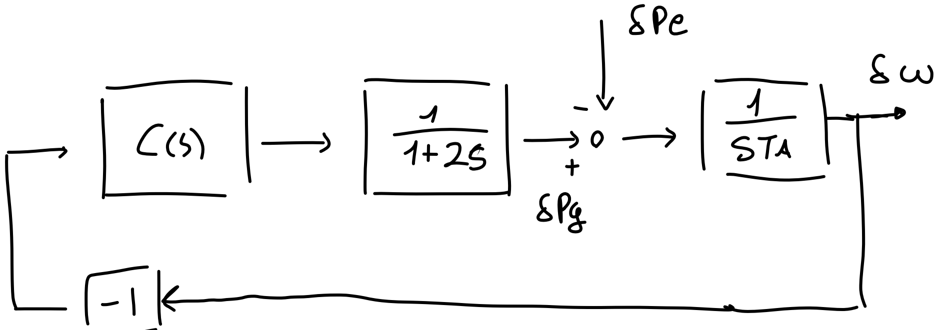
Considering $\omega_0 = 2\pi f_0$ with usually $f_0 = 50Hz$, $\omega_0 = 314{,}16\ rad/s$

$$T_A = \frac{J\omega_0^2}{P_m} \quad \text{with } P_m = 10\,MW \text{ as we can see from } G(s)$$

$$= 98.7\ sec$$

(b) Draw the block diagram representing the generator, the network and a primary plus secondary frequency controller in PI form.

In PI form $C(s) = \frac{K_s}{s} + K_p = K\frac{1+sT_i}{sT_i}$



(c) Tune the controller for a settling time of 20s and determine the corresponding phase margin.

IF we wanna obtain $t_{SET} = 20s$, we want

$$\omega_c = \frac{1}{\frac{20}{5}} = 0.25 \text{ rad/s}$$

We have the generator pole in $0.5 = \omega_p$

We can place PI ZERO to obtain $\varphi_m = 50°$

by placing properly:

$T = 1/0.06 = 16.7$ to guarantee $\varphi_m = 50°$

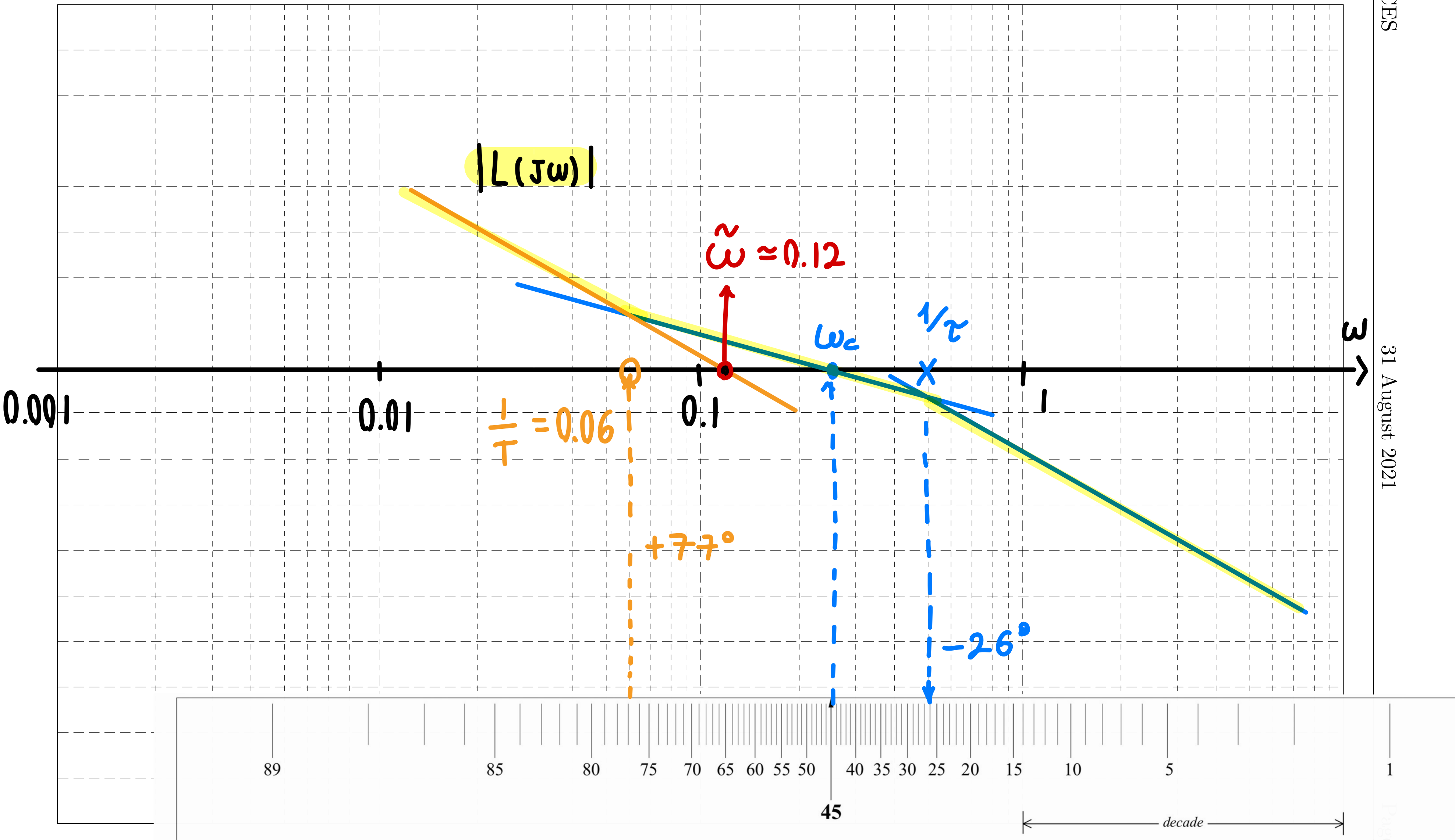
$\mu = \tilde{\omega}^2 = 0.0144 \rightarrow$

$$\mu \frac{\cancel{1+sT}}{\cancel{s^2}\cancel{(1+s\tau)}} = \frac{\cancel{1+sT}}{\cancel{s}} K \frac{1}{\cancel{1+s\tau}} \frac{1}{\cancel{s}T_A}$$

$$\Rightarrow K = \mu T_A = 1.42$$

$$K \frac{1+sT}{s} = k_i \frac{1+sT_i}{sT_i} \Rightarrow \begin{cases} \frac{k_i}{T_i} = K \rightarrow k_i = 23.73 \\ T_i = T = 16.7 \end{cases}$$

PI controller parameters


|L(jω)|
$\tilde{\omega} \simeq 0.12$
ω_c
$1/\tau$
ω
0.001
0.01
0.1
1
$\frac{1}{T} = 0.06$
+77°
−26°
89
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
1
decade

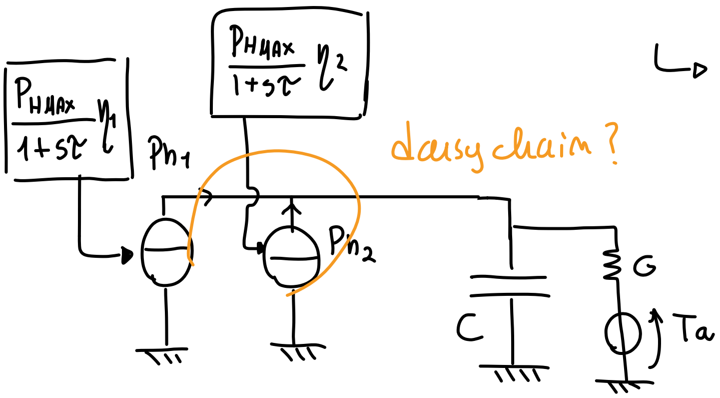
2. Consider a thermal system in which a body of capacity $C = 20$ kJ/°C is connected to two daisy-chained heaters (hereinafter H1 and H2). Both can be described by a first-order system with a $[0, 1]$ command input, a gain of $2kW$ and a time constant of $5s$, however the efficiencies of H1 and H2 (defined as power released to the body over consumed power) are respectively 0.5 and 0.8. The body disperses heat through a thermal conductance $G = 80W/°C$ toward an exogenous temperature T_e,

   (a) Draw an electric equivalent of the system.

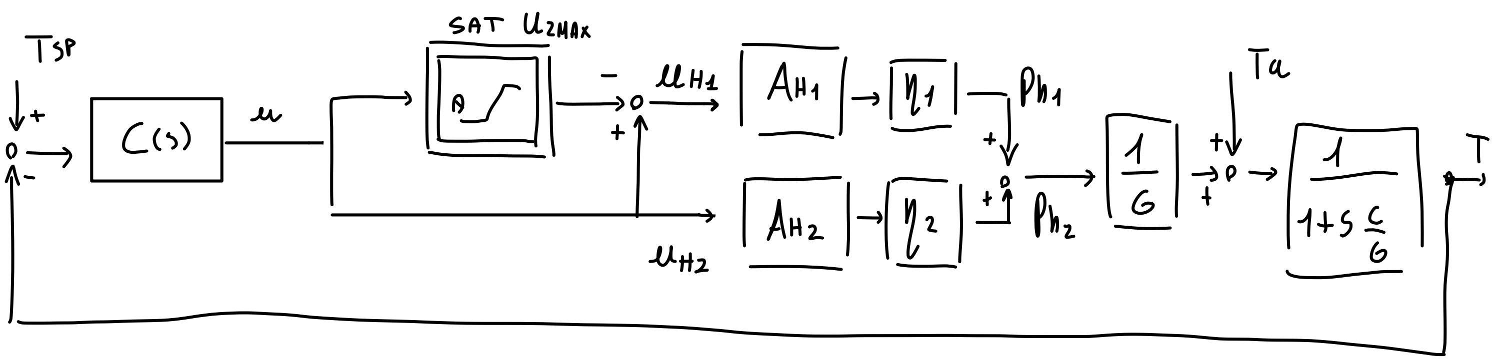
from the system equations

$$C\dot{T} = P_{H1}\eta_1 + P_{H2}\eta_2 - G(T - Ta)$$

$$\hookrightarrow T(s) = \frac{P_{H1}\eta + P_{H2}\eta}{G\left(1 + \frac{sC}{G}\right)} + \frac{Ta}{\left(1 + s\frac{C}{G}\right)}$$



   (b) Draw a scheme to control the body temperature T with a single regulator, daisy-chaining the heaters in the correct order



In this way first we use H2 which has an higher efficiency and than H1

(c) Tune the regulatore for a worst-case settling time of 30 minutes.

tune for $t_{SET} = 30\,min \rightarrow \omega_c \simeq \frac{1}{\frac{1800}{5}} = \frac{1}{360} \cong 0.0028$ rad/s

the actuators have a dynamic
in the order of $1/5 = 0.2$ rad/s almost 2 decades
after ω_c, so we can
neglect it when tuning
(bring a phase loss negligible!)

so we
tune $C(s)$
on

$$\frac{1}{G} \cdot \frac{1}{1+s\frac{C}{G}} = 0.0125 \frac{1}{1+s250} \Rightarrow$$

we want
$L(s) \simeq \frac{1}{360s}$

set up

$$C(s) = \frac{1}{360s} \cdot \frac{1+250s}{0.0125} = \frac{1}{4.5s}(1+250s)$$

PI
control

3. Illustrate the "turbine follows" control scheme for electric generators, indicating and briefly motivating its advantages and disadvantages.

looking to the internal control of the generator, so the specific control with input δ_f, δ_t value opening and output mech power and pressure energy P_m, e_m.
One possible control strategy to approach the simplified 2x2 generator control scheme, named "turbine follows" uses δ_t (throttling value opening, controlling the fluid energy inside turbine) to control e_m (pressure energy of fluid) and δ_f (fuel value) to control P_m (mech power).

This allow for a perfect pressure control, so no mechanical stress on the turbine, BUT slowdown the mechanical power "reactivity", because an input δ_f has to traverse through the slow thermal dynamic until having effect on P_m.
So its a good solution when dealing with slow load variation

4. Explain, with the need of convenient schemes if you deem it useful, what is meant for "time division output" actuation, with particular reference to its use in the control of thermal systems.

time division output is a particular type of actuation scheme on which we simulate a modulating actuator using an on/off dynamic.
this is often usefull for high power actuator hard to modulate or actuator more efficent IF used on full power.

Knowing the process timescale, we select a sampling time Ts enough smaller than it, on each actuation period Ts we mantain the actuation signal $u \in [0,1]$ on for a fraction of time that define the seen action as a modulating one for the process!

↓

This is very usefull for thermal systems, for example when we deal with huge pumps or other device that works better when on full range (?)