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.

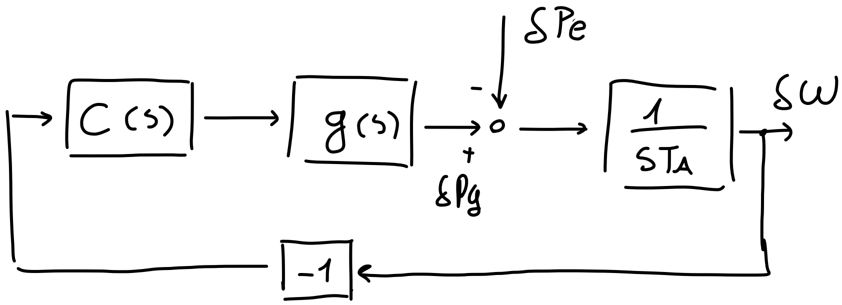
1. An islanded electric generator in an AC network with nominal frequency $f_o = 50Hz$ is described by the transfer function

$$G(s) = \frac{P_n}{1 + sT}$$

from the command θ, in the range 0–1, to the variation ΔP_g of the generated power, where $P_n = 40MW$ and $T = 4s$.

   (a) Draw the block diagram representing the generator connected to a local network of inertia J, and determine the said inertia so that the equivalent time constant T_A be $8\,s$.

$$\frac{1}{T_A} = \frac{P_m}{J\omega_0^2} \Rightarrow J = \frac{P_m T_A}{\omega_0^2} = 3{,}242\ KJ/(r/s)^2$$



$$g(s) = \frac{1}{1 + 4s}$$

(b) Tune a PID power/frequency controller for a closed-loop settling time of 10s and a phase margin of 60°; report the obtained frequency response, together with the phase margin computations, on the logarithmic sheet following this page.

$t_{set} = 10s \rightsquigarrow \omega_L \simeq \frac{1}{10/5} = 0,5$ rad/s

$\varphi_m \simeq 60°$

by loop shaping: $\tilde{\omega} = 0,31$

$T_1 = 4$

$T_2 = 5$

$\tau_p = 0,2$

$$L(s) = \frac{\cancel{(1+T_2 s)}}{s^{\cancel{2}}\cancel{(1+\tau_p s)}}(\tilde{\omega})^2 = \frac{1}{1+\cancel{s}T_1} \quad K \frac{(1+\cancel{sT_1})\cancel{(1+sT_2)}}{\cancel{s}\cancel{(1+s\tau_p)}} \frac{1}{\cancel{s}T_A}$$

$$\Rightarrow K = (\tilde{\omega})^2 T_A = 0,7688$$

(c) Quantify – also approximately – the maximum closed-loop settling time compatible with the phase margin requirement above, in the absence of derivative action.

Without derivative action, so just using a PI we have huge limitations on tuning, if we still want $\varphi_m = 60°$ ...

but the generator pole in $1/\tau = 0,25$ rad/s

we should have for sure $\omega_c < 1/\tau$ and place the controller zero using phase reuler before ω_c

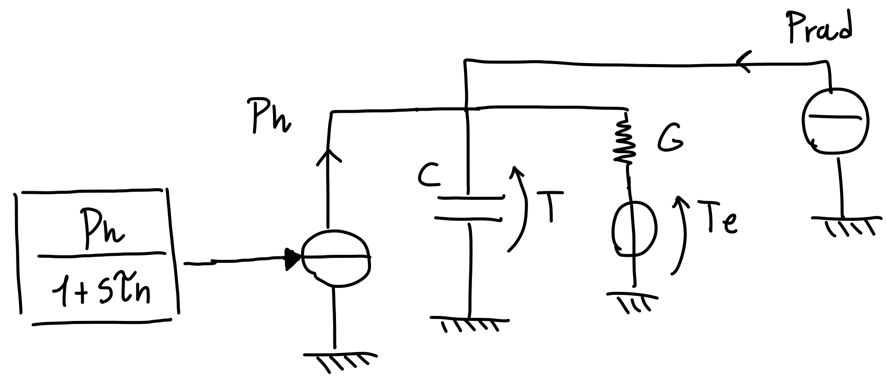
so $\frac{1}{\frac{t_{set}}{5}} < \frac{1}{\tau}$ $\quad t_{set} > 5\tau = 20$ sec

2. Consider a body of thermal capacity $C = 20kJ/°C$ connected to a heater described by a first-order model, with maximum power $P_h = 2kW$, and time constant $\tau_h = 10s$. The body releases heat to a prescribed external temperature T_e through a thermal conductance $G = 200W/°C$, and is subjected to a radiative power disturbance P_{rad}.

   (a) Draw an electric equivalent of the system.

$$C\dot{T} = P_h - G(T - T_e) + P_{rad}$$

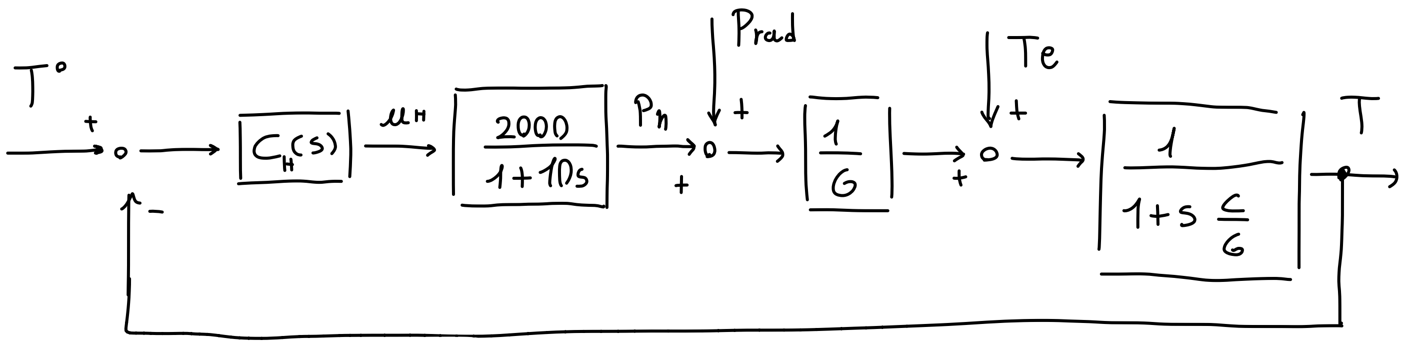
Electric equivalent



(b) Draw and tune a feedback temperature control scheme for a closed-loop dominant time constant of $50s$, guaranteeing asymptotic rejection of a step-like P_{rad}.

$\tau_c = 50s$ guarantee asymp. rejection.. for

$$T(s) = \frac{P_{rad}}{G\left(1+s\frac{C}{G}\right)} + \frac{P_h}{G\left(1+s\frac{C}{G}\right)} + \frac{T_e}{\left(1+s\frac{C}{G}\right)}$$



with a PI we can guarantee 0 steady state error

tuning $C_H(s)$ on $L(s) = \frac{1}{50s} = C_H \frac{2000}{1+10s} \cdot \frac{1}{G} \frac{1}{1+s(C/G)}$

$\frac{1}{10} > \frac{1}{50}$ negligible...

$$\Rightarrow C_H = \frac{1}{50s} \frac{(1+\cancel{10s})(1+s100)}{2000} G = \frac{1}{500s}(1+100s)$$

(c) Determine the obtained phase margin.

this guarantee more or less $\omega_c \sim 0{,}02$ rad/s >> 0,1 rad/s (neglected)

so $\varphi_m = 180 - \left|-90^\circ - \operatorname{atan}\left(\frac{\omega_c}{0{,}1}\right)\right| \simeq 78^\circ$

? NOT SURE !

3. Illustrate primary and secondary control in AC electric networks, evidencing their role, characteristics, typical time scales, and potential interplay.

4. Illustrate the “daisy chain” actuation scheme, explaining what are its most typical uses in thermal control systems.