① 1) → e)
2) → a)
3) → d)
4) → c)
5) → b)

② a) Momentbalanse

b) $J\dot{\omega} = -k\omega + Md$

$\dot{\omega} = -\frac{k}{J}\omega + \frac{Md}{J}$

$T = -\frac{1}{a} = -\frac{1}{-\frac{k}{J}} = \underline{\underline{\frac{J}{k}}}$

c) $\dot{\omega} = -\frac{k}{J_2}\omega + \frac{Md}{J_2}$

$T = \frac{J_2}{k} = \frac{J + J_{LP}}{k}$

siden J er stor vil ikke J_{LP} endre mye på systemet

så $\frac{J + J_{LP}}{k} \approx \underline{\underline{\frac{J}{k}}}$

d) Likespenningsmotor

e) $L_a \frac{d}{dt} i_a = -R_a i_a - K_E \omega + u$ (1)

$J\dot{\omega} = K_m i_a - k\omega$ (2)

integrerer (2)

$J\ddot{\omega} = K_m \frac{d}{dt} i_a - k\dot{\omega}$

(1) $\frac{d}{dt} i_a = \frac{1}{L_a}(-R_a i_a - K_E \omega + u)$

② $J\ddot{\omega} = -\frac{K_m R_a i_a}{L_a} - \frac{K_m K_e \omega}{L_a} + \frac{K_m}{L_a} u - k\dot{\omega}$

$\ddot{\omega} = -\frac{k}{J}\dot{\omega} - \frac{K_m K_e}{J L_a}\omega - \frac{K_m}{J L_a}(R_a i_a - u)$

$\ddot{\omega} + \frac{k}{J}\dot{\omega} + \frac{K_m K_e}{J L_a}\omega + \frac{K_m}{J L_a}(R_a i_a - u)$

f) 33 rpm → $\frac{rad}{s} = \frac{2\pi \cdot n_{rpm}}{60}$ → $\frac{33 \cdot 2\pi}{60} = \underline{\underline{\frac{11}{10}\pi}}$

$\omega_r = \underline{\underline{\frac{11}{10}\pi}}$,

g) $\ddot{\omega} + \frac{k}{J}\dot{\omega} + \frac{K_m K_e}{J L_a}\omega + \cancel{\frac{K_m}{J L_a} R_a i_a} - \cancel{\frac{K_m}{J L_a} R_a i_a} - \frac{K_m}{J L_a} K_p \omega_r + \frac{K_m}{J L_a} K_p \omega + \cancel{\frac{K_m}{J L_a} K_d \dot{\omega}_r} - \frac{K_m}{J L_a} K_d \dot{\omega}$

$\ddot{\omega} + \left(\frac{k}{J} - \frac{K_m K_d}{J L_a}\right)\dot{\omega} + \left(\frac{K_m K_e}{J L_a} + \frac{K_m}{J L_a} K_p\right)\omega - \frac{K_m}{J L_a} K_p \omega_r = 0$

$\omega_0^2 = \frac{K_m(K_e + K_p)}{J L_a}$ $\quad 2\omega\zeta = \frac{k}{J} - \frac{K_m K_d}{J L_a}$

$\omega_0 = \sqrt{\frac{K_m(K_e + K_p)}{J L_a}}$ $\quad \zeta = \frac{1}{2}\left(\frac{k}{J} - \frac{K_m K_d}{J L_a}\right)\sqrt{\frac{J L_a}{K_m(K_e + K_p)}}$

h) $\frac{k}{J} - \frac{K_m K_d}{J L_a} > 0$ $\quad \frac{K_m(K_e + K_p)}{J L_a} > 0$

$K_d < \frac{k L_a}{K_m}$ $\quad \underline{K_p > -K_e}$

i) $\left(\frac{K_m K_e}{J L_a} + \frac{K_m}{J L_a} K_p\right)\omega - \frac{K_m}{J L_a} K_p \omega_r = 0$

$\underline{\underline{\omega = \frac{(K_e + K_p)}{K_p}\omega_r}}$

j) I-ledd i regulatoren

k) $f_s \geq 2 f_{max}$

$f_{max} = \frac{f_s}{2} = \frac{44{,}1\,kHz}{2} = \underline{\underline{22{,}05\,kHz}}$

③ $\dot{x} = ax + bu$

$T = 2$ $\quad T = -\frac{1}{a} \Rightarrow a = -\frac{1}{T} = \frac{1}{0{,}5} = -2$

$k = \frac{b}{a} \Rightarrow b = ak = 2$

$\dot{x} = -2x + 2u(t-2)$

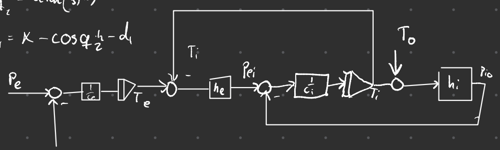
④ a) $x = \cos q_2 \cdot l_2 + d_1 + q_1$

$y = \sin q_2 \cdot l_2$

b) $q_2 = \text{atan}(y, x)$

$q_1 = x - \cos q_2 \cdot l_2 - d_1$

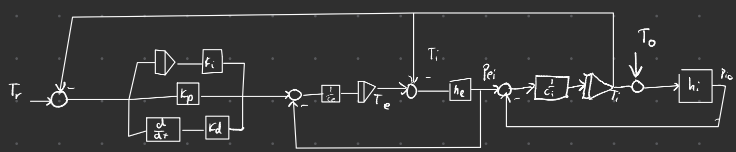
⑤ a)



b) $T_e(n) = T_e(n-1) + h \cdot \left(\frac{1}{C_e} \cdot \left(P_e - h_e\left(T_e(n-1) - T_i(n-1)\right)\right)\right)$

$T_i(n) = T_i(n-1) + h \cdot \left(\frac{1}{C_i}\left(h_e\left(T_e(n-1) - T_i(n-1)\right) - h_i\left(T_i(n-1) - T_o\right)\right)\right)$

c) $P_e = u = k_i \int e\,dt + k_p e + k_d \dot{e}$



d) $K_{PK} = 506$ $\quad T_k \approx 12$

$K_p = 0{,}6 \cdot 506 = \underline{304}$

$T_i = 0{,}5 \cdot 12 = 6$

$T_d = 0{,}125 \cdot 12 = 1{,}5$

$k_i = \frac{304}{6} = \underline{50{,}6}$

$k_d = 304 \cdot 1{,}5 = \underline{456}$

e) $\underline{1s}$