Tutorial 2: A Review of Power Conditioning Circuits and Control Systems

Problem 1 A balanced three-phase source is supplying an unbalanced load via a three-phase three-winding transformer as shown in Figure 1. The turns ratio of the windings of all phases are equal. The ground impedance Z_g is indicated.
If the leakage in the windings is assumed to be negligible, then show that the ground current (i_g) is zero and also indicate the *current* distributions on all the windings.
Hint: consider MMF balance for each phase.

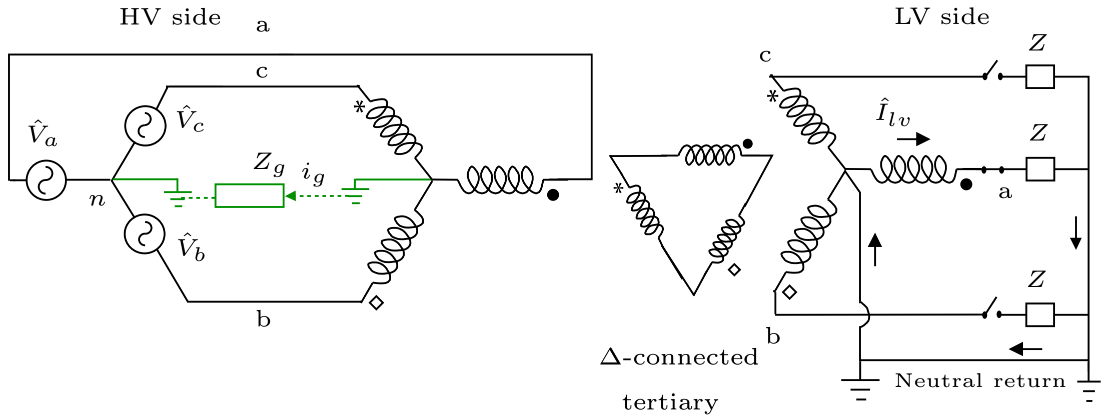


Figure 1: Diagram for Problem 1

Problem 2 A Thyristor Controlled Reactor (TCR) is connected to a sinusoidal voltage source (230 V rms) as shown in Figure 2. If the fundamental component of the current is 1 A (rms), then compute the firing angle α. The inductance L is 500 mH. Assume thyristors to be ideal.
Hint: First compute the expression for the fundamental component of the *current* as a function of α and then solve the equation thereafter numerically.

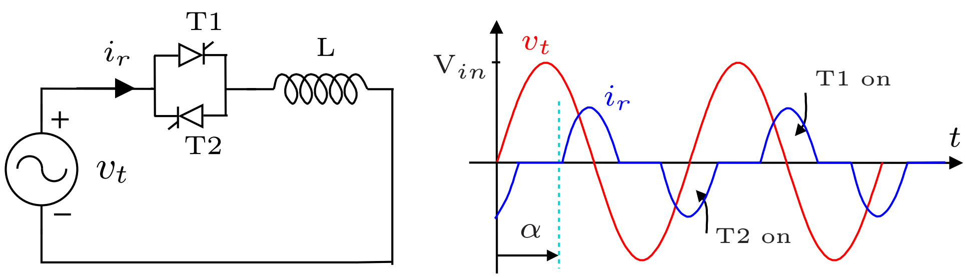
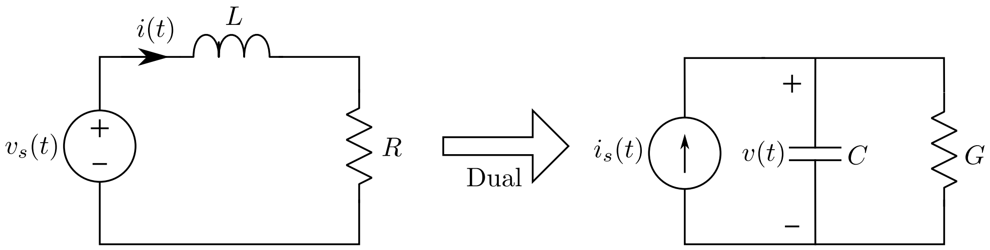


Figure 2: Diagram for Problem 2

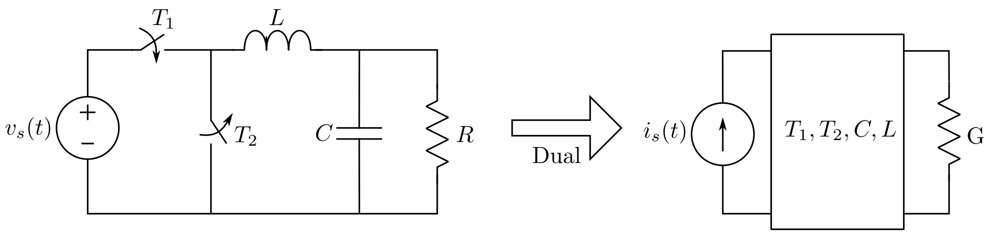
Problem 3 The dual of a circuit has the same equations with the voltages replaced by currents, inductors replaced by capacitors, resistances replaced by conductances and loops replaced by nodes. For example, a particular circuit and its dual circuit are shown in Figure 3a. Draw the dual of the circuit shown in Figure 3b where T_1 and T_2 are switched complementarily.



$$L\frac{di(t)}{dt} = -Ri(t) + v_s(t)$$

$$C\frac{dv(t)}{dt} = -Gv(t) + i_s(t)$$

(a) Circuit and its Dual



(b) Circuit for Problem 3

Figure 3: Circuits for Problem 3

Problem 4 The dual circuit of a TCR is shown in Figure 4.

Obtain an expression of the fundamental component of the voltage, as a function of σ.

For the switches (T1 and T2), can thyristors be used or do we require switches with turn-off capability?

Assume the switches to be ideal.

Note: the source here is an alternating *current* source.

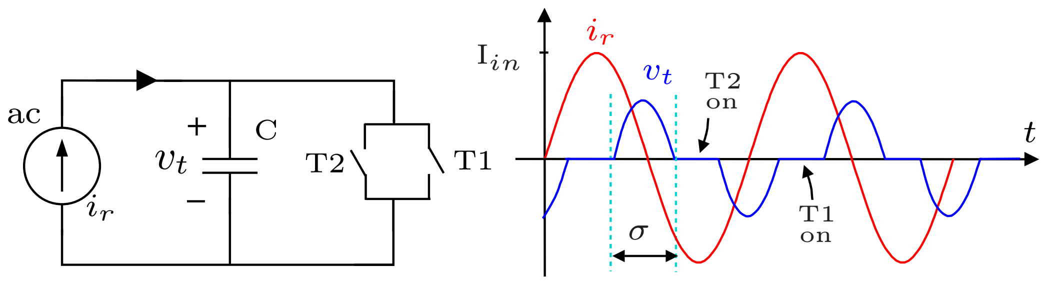


Figure 4: Diagram for Problem 4

Problem 5 Figure 5 shows the schematic of a line-commutated thyristor bridge based HVdc link with power being transferred from 1 to 2. If the active power flow direction is to be reversed without change of the connections, indicate the polarities/directions of the voltages, currents and reactive power flows on the Figure 6.

Note: The variables considered here are positive.

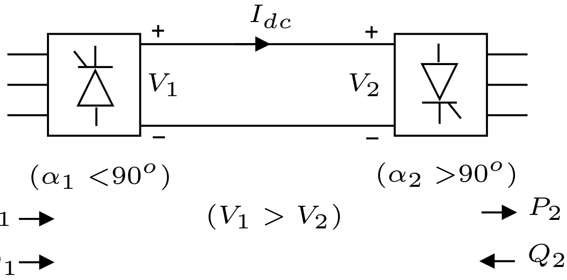


Figure 5: Diagram for Problem 5

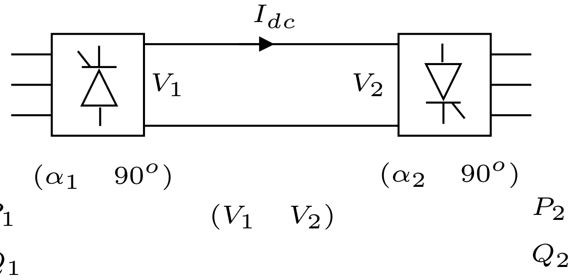


Figure 6: Diagram for Problem 5

Problem 6 Consider a 12 pulse bipolar HVdc system as shown in Figure 7. For a converter transformer what is the approximate turns ratio between the primary (ac grid side) star winding and the corresponding star winding on the converter side?

(a) 400:212

(b) 400:100

(c) 400:350

(d) 400:400.

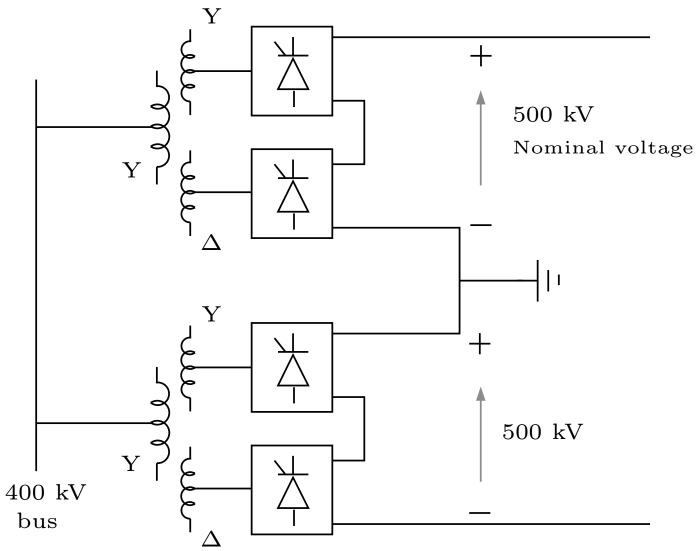
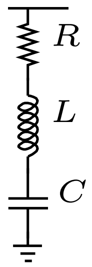


Figure 7: Diagram for Problem 6

Problem 7 A series R-L-C circuit is used as a shunt-connected filter as shown below. It is tuned at the 12^{th} harmonic (R = 0.75 Ω, L = 15.2 mH, C = 4.2 μF).
The filter will

(a) generate reactive power at the fundamental frequency
(b) absorb reactive power at the fundamental frequency
(c) not exchange reactive power with the system at fundamental frequency
(d) behave like a pure resistor at fundamental frequency.



Problem 8 A high frequency square wave (1 kHz) voltage is applied to an R-L circuit (R = 1 Ω) as shown in Figure 8. Sketch the steady-state waveform of the current $i(t)$ if the time constant of the circuit is (a) 1 s, (b) 1 μs.

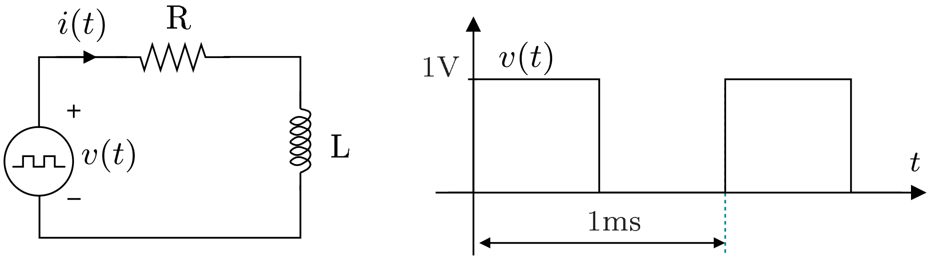


Figure 8: Diagram for Problem 8

Problem 9 In the circuit shown in Figure 9, the output of a single phase inverter is connected to an R-L load. The inverter switches are switched such that the inverter output voltage $v_{AB}(t)$ is as shown in Figure 10. Find the rms value of the fundamental component of the load current $i(t)$ in steady-state.
Note: A square wave $v(t)$ of zero mean and amplitude $\pm V$ with a period of T = $\frac{2\pi}{\omega}$, can be represented as

$$v(t) = \sum_{k=1,3,5,\ldots}^{\infty} \frac{4V}{k\pi} \sin(k\omega t)$$

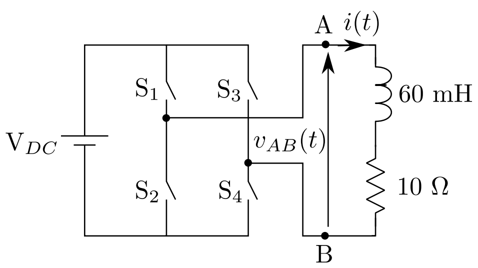


Figure 9: Circuit for Problem 9

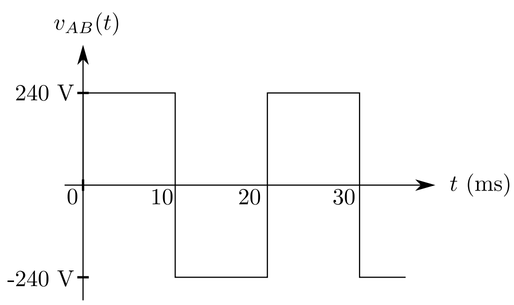


Figure 10: Waveform for Problem 9

Problem 10 A waveform is given as shown in Figure 11. Determine the magnitude of the 3rd harmonic component present in the waveform.

Note: the waveform shown is periodic with period T.

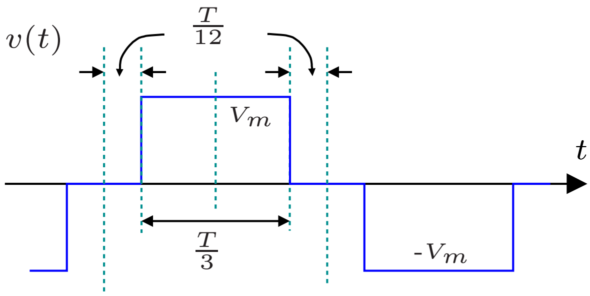


Figure 11: Waveform for Problem 10

Problem 11 If the control system shown in the Figure 12, and $K_p \neq 0$, $K_i \neq 0$,then the steady state value of y_1 is:

(a) 500 (b) Zero (c) $\dfrac{500}{K_p}$ (d) $500K_i$

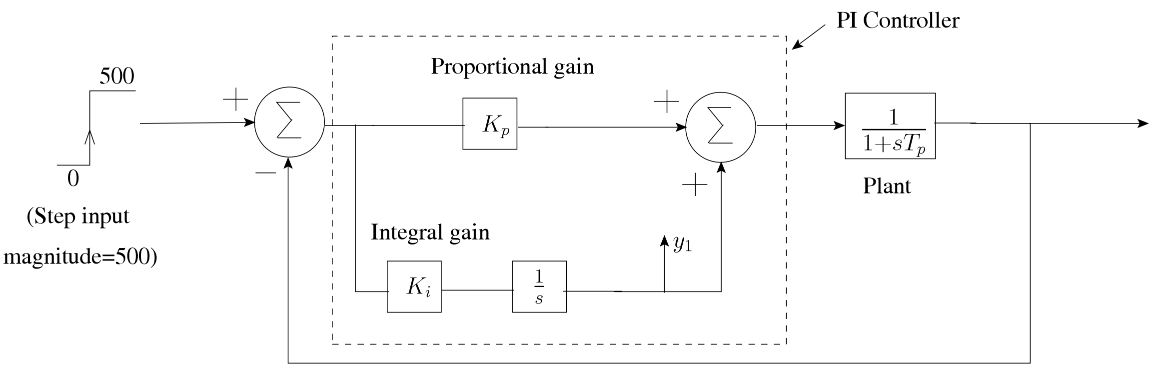
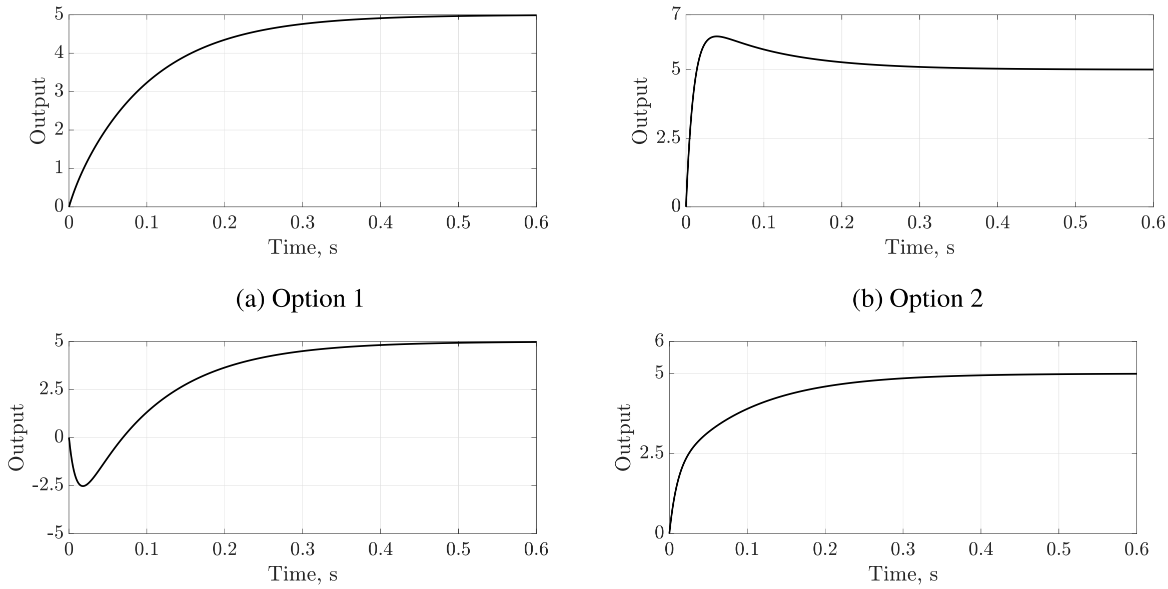


Figure 12: Schematic for Problem 11

Problem 12 Which of the plots of Figure 13 depicts the unit step response of the following transfer function:

$$G(s) = 5\frac{(1+0.136s)}{(1+0.1s)(1+0.01s)}$$



(a) Option 1

(b) Option 2

(c) Option 3

(d) Option 4

Figure 13: Options for Problem 12

Problem 13 In a synchronous generator, the rms value of the open circuit voltage, denoted by V is related to its field voltage E_{fd} as follows

$$\frac{V(s)}{E_{fd}(s)} = \frac{1}{1 + s\,T'_{do}}$$

where $T'_{do} = \dfrac{L_{ff}}{R_f}$, and L_{ff} and R_f are the self inductance and resistance of the field winding. If $T'_{do} = 5$ s,

(a) sketch and appropriately label the open-circuit voltage V of the synchronous machine if a step input of 0.5 pu is applied to the field winding (E_{fd}),

(b) if the field voltage is regulated as shown in Figure 14, then evaluate the value of K_E such that the closed loop poles are complex conjugate with a damping ratio of 10%. The regulator time constant $T_E = 0.04$ s. For a step change in the reference voltage V_{ref}, sketch and appropriately label the open-circuit voltage V.

Note: For a complex conjugate pair of poles $s = \sigma + j\omega$, the damping ratio (ζ) is defined as

$$\zeta = -\frac{\sigma}{\sqrt{\sigma^2 + \omega^2}} \times 100\%$$

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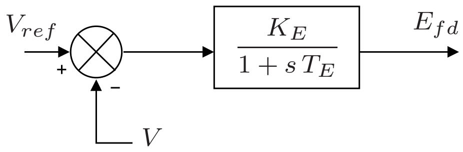


Figure 14: Schematic for Problem 13

Problem 14 The response (options are provided in Table 1) of the system ($T_1 < T_2$) shown below for a unit step input is

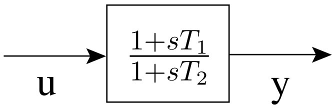
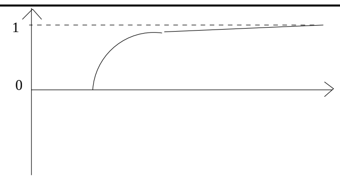
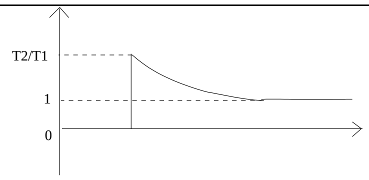
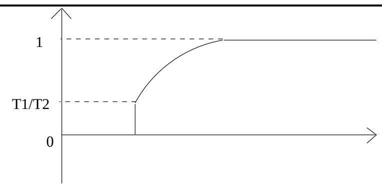


Table 1: Options for Problem 14

	Response
A)	
B)	
C)	
D)