IMPERIAL COLLEGE LONDON

E4.38
C3.3

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2003

MSc and EEE PART IV: M.Eng. and ACGI

10am

Q4 b. IN instead of 13.

MODELLING AND CONTROL IN POWER ENGINEERING

Friday, 9 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

Corrected Copy

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : T.C. Green, B.C. Pal

Second Marker(s) : B.C. Pal, T.C. Green

1.

(a) Describe the principle of state-space averaged models and explain why they are useful in designing control systems for power electronic systems. [4]

(b) Consider a circuit which has two conduction modes: mode "On" with a duty-cycle of δ and mode "Off" with a duty-cycle of $(1-\delta)$.

(i) Give the equations for the state-space averaged model in terms of the steady-state and perturbation components of the signals (input vector, state vector, output vector and duty-cycle respectively) defined as: $\mathbf{u} = \mathbf{U} + \tilde{\mathbf{u}} \quad \mathbf{x} = \mathbf{X} + \tilde{\mathbf{x}} \quad \mathbf{y} = \mathbf{Y} + \tilde{\mathbf{y}} \quad \delta = \Delta + \tilde{\delta}$ [2]

(iii) Separate the model into its steady-state and small-signal portions for the case where the circuit input, $\mathbf{u}$, is constant. [7]

(c) Figure 1.1 shows the circuit diagram of the flyback switch-mode power supply. The state-space models for the On and Off modes, using the state vector $\mathbf{x} = [i_L \quad v_C]^T$, have been established for the two modes as:

On Mode

$$\mathbf{A}_{\mathrm{On}} = \begin{bmatrix} -\frac{R_L}{L} & 0 \\ 0 & -\frac{1}{C(R_O + R_C)} \end{bmatrix}, \quad \mathbf{B}_{\mathrm{On}} = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}, \quad \mathbf{C}_{\mathrm{On}} = \begin{bmatrix} 0 & \frac{R_O}{R_O + R_C} \end{bmatrix}, \quad \mathbf{D}_{\mathrm{On}} = [0]$$

Off Mode

$$\mathbf{A}_{\mathrm{Off}} = \begin{bmatrix} -\frac{R_L + R_C}{L} + \frac{R_C^{\,2}}{L(R_O + R_C)} & \frac{1}{L} - \frac{R_C}{L(R_O + R_C)} \\ -\frac{1}{C} + \frac{R_C}{C(R_O + R_C)} & -\frac{1}{C(R_O + R_C)} \end{bmatrix},$$

$$\mathbf{B}_{\mathrm{Off}} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad \mathbf{C}_{\mathrm{Off}} = \begin{bmatrix} -\frac{R_O R_C}{R_O + R_C} & \frac{R_O}{R_O + R_C} \end{bmatrix}, \quad \mathbf{D}_{\mathrm{Off}} = [0]$$

Show that the solution to the steady-state portion of the model yields the relationship $\frac{V_O}{V_I} = \frac{-\Delta}{1-\Delta}$ when the parasitic resistances R_C and R_L are ignored. [7]

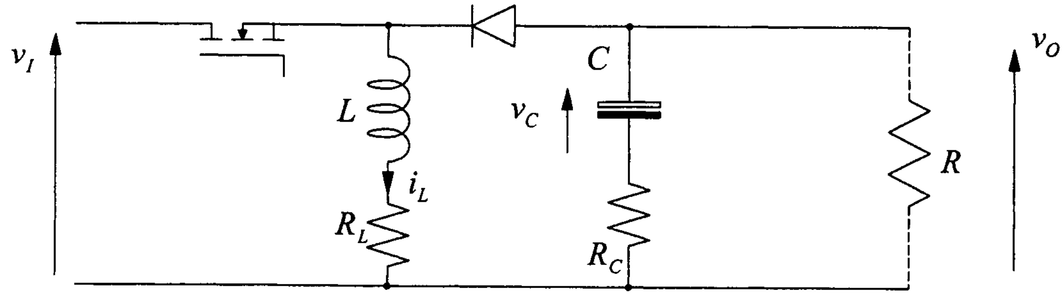

Figure 1.1 A Flyback switch-mode power supply

2.

(a) Explain why it is important that the three-phase *abc* to $\alpha\beta\gamma$ transformation matrix T has the property $T^T T = I$. [4]

(b) Show that an inductive voltage drop in *abc* quantities, $L\frac{di_{abc}}{dt}$ transforms to two terms in $dq\gamma$ quantities when transformed by the transformation matrices:

$$[T] = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \qquad [T_R] = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) & 0 \\ -\sin(\omega t) & \cos(\omega t) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and explain the physical interpretation of the two terms. [6]

(c) Figure 2.1 shows a three-phase circuit. The circuit is balanced, *i.e.*, the circuit parameters for the three phases are the same. Write the circuit equations for this circuit and transform them into $dq\gamma$ terms (using T and T_R as defined in part (b)) and draw a circuit diagram to represent the transformed system. [10]

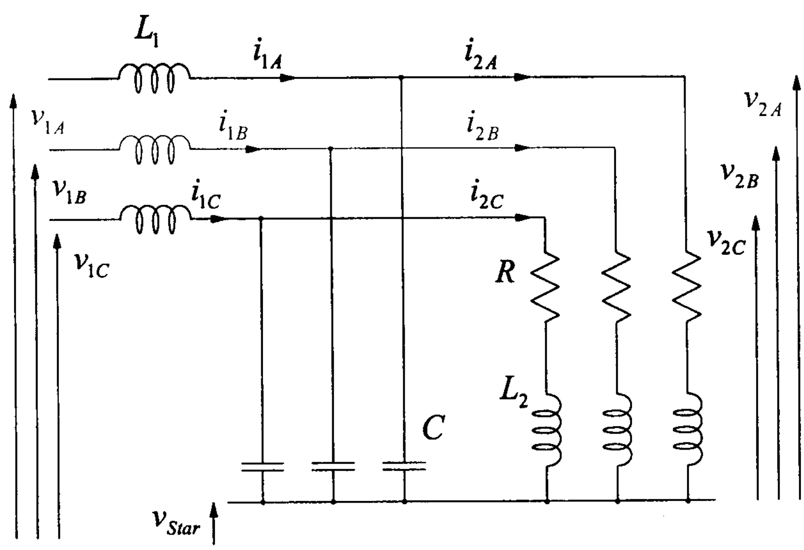

Figure 2.1

3.

(a) Starting from the voltage equation for the referred model of an induction machine,

$$[v'_{DQ}] = [R'_{DQ}][i'_{DQ}] + [X'_{DQ}][i'_{DQ}] + [L'_{DQ}]\frac{d}{dt}[i'_{DQ}]$$

show that the torque produced by the machine is related to the product of stator current and rotor current. The rotational voltage matrix, X'_{DQ} is:

$$[X'_{DQ}] = \begin{bmatrix} 0 & -\omega L_S & 0 & -\omega M' \\ \omega L_S & 0 & \omega M' & 0 \\ 0 & -P\omega_{slip} M' & 0 & -P\omega_{slip} L'_R \\ P\omega_{slip} M' & 0 & P\omega_{slip} L'_R & 0 \end{bmatrix}$$

[10]

(b) Within the context of a field orientation controller of an induction machine, explain why it is desirable to orientate the d-axis to the rotor flux linkage. [4]

(c) Give a reason why, in a field orientation controller, the flux linkage magnitude is controlled to be constant and the torque is set via the q-axis current (rather than adopting the opposite approach). [2]

(c) An induction machine is normally supplied from a voltage source inverter whereas the toque equation from (a) is a function of current. Explain what steps are taken to enable field orientation control to be achieved with a voltage source rather than a current source. [4]

4.

(a) What are the basic differences between angle and voltage stability? [5]

(b) Describe briefly various types of oscillatory stability in the context of small signal stability ~~is~~ in power systems? [5]

(c) The model of a single machine and infinite bus (SMIB) is given by:

$$\frac{d\delta}{dt} = (\omega - \omega_s) \qquad (4.1)$$

$$M\frac{d\omega}{dt} = P_{mech} - P_{\max}\sin\delta - K_D(\omega - \omega_s) \qquad (4.2)$$

Using P_{mech} as input and ω as output, obtain a linear state-space model in the standard form $\dot{X} = AX + Bu$ and $y = CX + Du$. Write down the expression for A, B, C and D [10]

5. Write short notes on any four of the following:

(i)	Damper winding	[5]
(ii)	Inter-area oscillations	[5]
(iii)	Eigen-value sensitivities in small signal stability	[5]
(iv)	FACTS controllers	[5]
(v)	Effect of Automatic Voltage Regulator (AVR) on power system stability	[5]
(vi)	Midterm and long term stability	[5]

6.

(a) Describe the importance of power system stabilizers (PSSs) in the small signal stability performance of a power system. What are the commonly used input signals to a PSS? [8]

(b) What is "*governor droop*" in a turbine speed control? Why is it so important to have a large droop setting for governor in hydraulic turbine?. [5]

(c) Figure 6.1 shows the block diagram of a turbine speed control system. The values of T_W and T_M are 2.0, 10.0 respectively. Write down the closed-loop transfer function and identify the range of R that ensures closed-loop stability. [7]

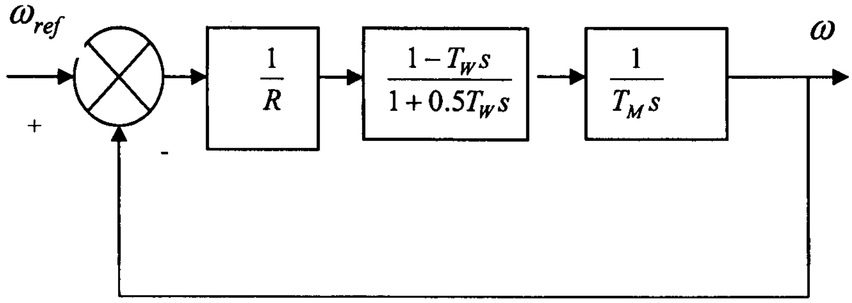

Figure 6.1