

IMPERIAL COLLEGE LONDON

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  $\delta$  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:  $\mathbf{u} = \mathbf{U} + \tilde{\mathbf{u}}$   $\mathbf{x} = \mathbf{X} + \tilde{\mathbf{x}}$   $\mathbf{y} = \mathbf{Y} + \tilde{\mathbf{y}}$   $\delta = \Delta + \tilde{\delta}$  [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  $\mathbf{x} = [i_L \ v_C]^T$ , have been established for the two modes as:

On Mode

$$\mathbf{A}_{\text{on}} = \begin{bmatrix} -\frac{R_L}{L} & 0 \\ 0 & -\frac{1}{C(R_o + R_c)} \end{bmatrix}, \quad \mathbf{B}_{\text{on}} = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}, \quad \mathbf{C}_{\text{on}} = \begin{bmatrix} 0 & \frac{R_o}{R_o + R_c} \end{bmatrix}, \quad \mathbf{D}_{\text{on}} = [0]$$

Off Mode

$$\mathbf{A}_{\text{off}} = \begin{bmatrix} -\frac{R_L + R_c}{L} + \frac{R_c^2}{L(R_o + R_c)} & \frac{1}{L} - \frac{R_c}{L(R_o + R_c)} \\ -\frac{1}{C} + \frac{R_c}{C(R_o + R_c)} & -\frac{1}{C(R_o + R_c)} \end{bmatrix},$$

$$\mathbf{B}_{\text{off}} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad \mathbf{C}_{\text{off}} = \begin{bmatrix} -\frac{R_o R_c}{R_o + R_c} & \frac{R_o}{R_o + R_c} \end{bmatrix}, \quad \mathbf{D}_{\text{off}} = [0]$$

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]

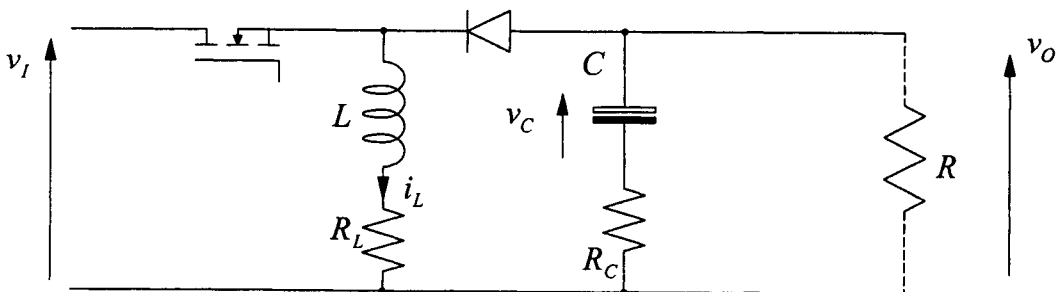


Figure 1.1 A Flyback switch-mode power supply

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:

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

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]

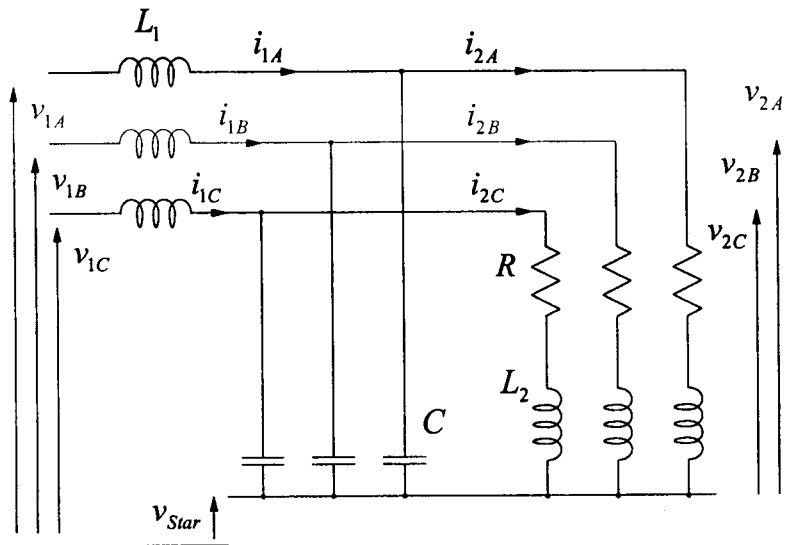


Figure 2.1

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 torque 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 in power systems? [5]

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

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

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

Using  $P_{mech}$  as input and  $\omega$  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]

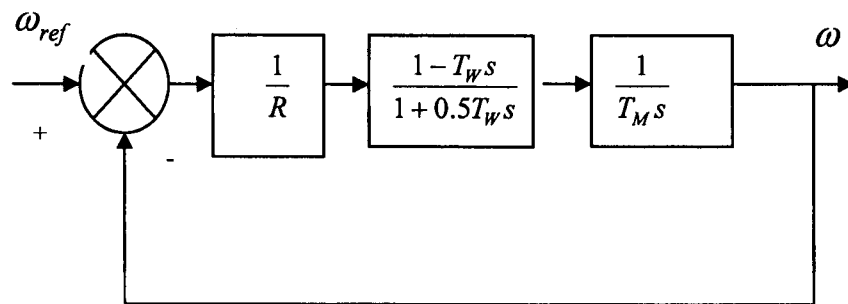


Figure 6.1