

CITY UNIVERSITY OF HONG KONG

Module code & title : EE2921 Power Electronics and Drive Systems

Session : Semester B 1996-97

Time Allowed : Two hours and 30 minutes

This paper has **NINE** pages (including this page)

Instructions to candidates:

1. The paper consists of **SIX** questions in two sections.
 2. Attempt a total of **FOUR** questions and not more than TWO questions from each section.
 3. All questions carry equal marks.
 4. Use a separate answer book for each section.
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Materials, aids & instruments permitted to be used during examination:

Approved portable battery operated calculator

Special materials (other than standard materials e.g. answer book or supplementary sheets) to be supplied to students.

1 graph paper

SECTION A

Q1(a). A 50 Hz three-phase bridge converter supply up to 450 d.c. has three thyristors in parallel in each arm. Details of thyristors (with their associated fuses) are as follows:

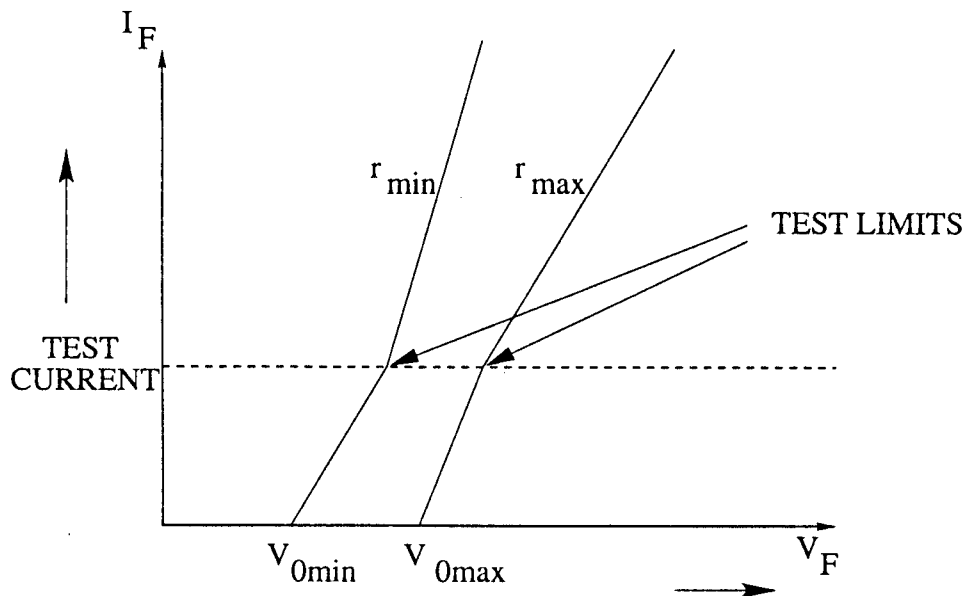


Figure 1: Possible spread of forward conducting characteristics in thyristors matched for voltage drop at one current

$V_{0max} = 1.21V$, $a_V = 0.1$ (the range of voltage variation) ($V_{0min} = 1.1V$)
 $r_{max} = 1.76 \text{ m}\Omega$, $a_R = 0.2$ (the range of resistance variation) ($r_{min} = 1.47 \text{ m}\Omega$).

What current-sharing inductors are required to ensure that no thyristor current is to exceed one-third of the total current by more than 10% ($\Delta_I = 0.1$). The inductor tolerance is -0.1, +0.5% ($a_L = 0.05$).

[10 marks]

Q1(b). The circuit in Figure 2 shows a power pulse output stage in which flux resetting of the transformer magnetic circuit is accomplished between pulses by means of the dissipative clamp circuit consisting of components C_1 , R_1 and D_1 . The stage is fed from a 360 V d.c. supply and produces current pulses of duration $5 \mu\text{s}$ and repetition frequency 50 kHz in the 1.5Ω load resistor R_L . The pulse transformer has a turn ratio 12:1, a magnetizing inductance of 20 mH and a primary-side leakage inductance of $120 \mu\text{H}$.

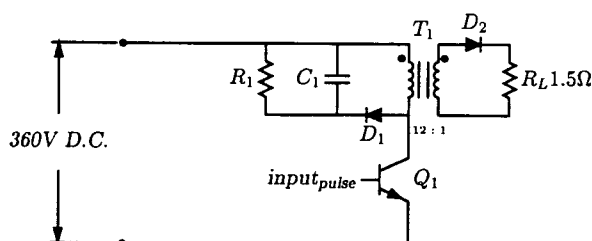


Figure 2: Power Pulse Output Stage

If the peak collector-emitter voltage of the switching transistor is not to exceed 500V and the transformer core is to be completely reset between pulses, determine

- suitable values for the clamp circuit resistor R_1 and capacitor C_1 , and
- the power dissipation of resistor R_1 .

State clearly any assumption made.

[15 marks]

Q2(a). A fully-controlled three-phase bridge converter supplies a current of 100 A d.c. (assumed smooth). The thyristor voltage drop at 100A is 1.89V, can be represented by a threshold voltage of 1.1V and a slope resistance of 0.0079Ω , the junction-to-core thermal resistance is $0.45 ^\circ\text{C}/\text{W}$ and this mounting thermal resistance is $0.1^\circ\text{C}/\text{W}$. The transient thermal impedance can be represented with sufficient accuracy over the range in question by the empirical relationship $Z_{th}(t) = 0.535t^{0.42^\circ}\text{C}/\text{W}$ (t in seconds), or at 50 Hz, $Z_{th}(t) = 0.00815(wt)^{0.427} ^\circ\text{C}/\text{W}$. Estimate the junction-to-cooler temperature rise at the beginning and the end of each 120° conduction period at 50 Hz.

[7 marks]

Q2(b). A BJT is operated as chopper switch at a frequency of $f_s = 60\text{kHz}$. The circuit arrangement is shown below. The d.c. input voltage of the chopper is $V_s = 45\text{V}$ and the load current is $i_L = 60\text{A}$. The switching times are $t_r = 50\text{ns}$ and $t_f = 20\text{ns}$. (See Figures 3 and 4)

Determine the value of

- (i) L_s ,
- (ii) C_s ,
- (iii) R_s for critically damped condition,
- (iv) R_s if the discharge time is limited to one-third of switching period,
- (v) R_s if peak discharge current is limited to 5% of load current,
- (vi) power loss due to RC snubber, P_s neglecting the effect of inductor L_s on the voltage of snubber capacitor C_s . Assume $V_{CE(sat)} = 0$.

[18 marks]

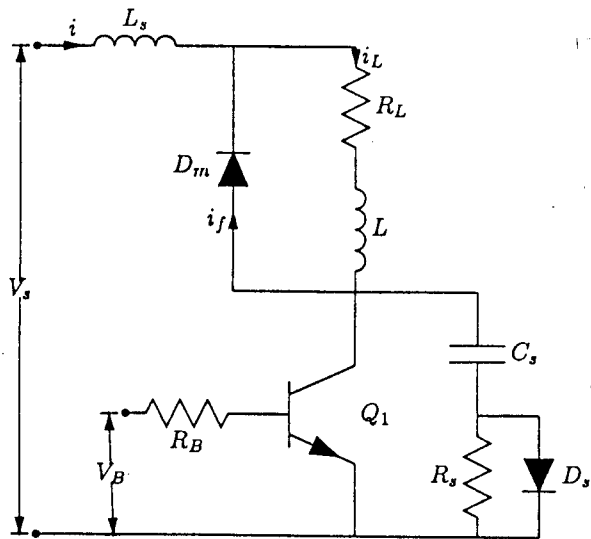


Figure 3: BJT Chopper Switch Circuit

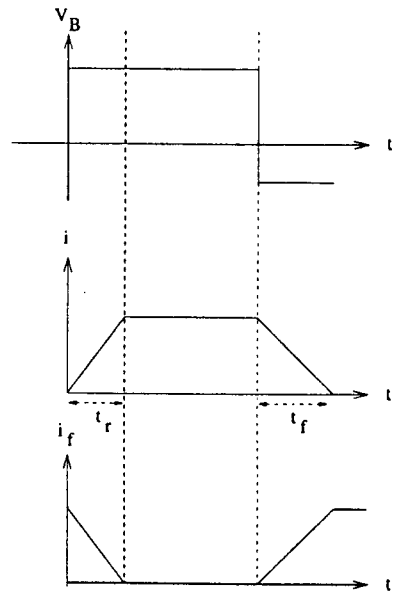


Figure 4: Voltage and Current Diagrams

Q3(a). With the aid of a diagram, define the following diode's parameters:-

(i) software factor

[1 mark]

(ii) reverse recovery time

[1 mark]

(iii) peak reverse current

[1 mark]

(iv) storage charge

[2 mark]

Q3(b) The peak input voltage of a single-phase half-wave diode rectifier is $V_m=180V$ at 50 Hz and the load resistance is $R_L=1.2\Omega$. The reverse recovery time is $t_{rr} = 5\mu s$.

If the softness factor $SF = 0$, determine

(i) peak reverse current, I_{RR} and

[4 marks]

(ii) storage charge, Q_{RR} .

[4 marks]

Q3(c) The buck-boost regulator has an input voltage of $V_s=12V$. The duty cycle, $K = 0.25$ and the switching frequency is 25 kHz. The inductance $L = 150 \mu H$ and filter capacitor $C = 220\mu F$. The average load current $I_o = 1.25$ A.

Determine

(i) the average output voltage,

[4 marks]

(ii) peak-to-peak output voltage ripple, and

[4 marks]

(iii) peak-to-peak ripple current of the inductor.

[4 marks]

SECTION B

Q4.

(a) A schematic diagram of an armature-controlled d.c. motor is shown in Fig.Q4.

- i) Derive the transfer function of the motor, $\Theta(s) / E_a(s)$ and draw the block diagram. [10 marks]
- ii) Given that $e_a = 25$ V, $J = 1.8 \times 10^{-6}$ Nm/rad/s², $B = 2.1 \times 10^{-5}$ Nm/rad/s, $K_b/K_m = 1.2$, $T_s = 0.07$ Nm, $\omega_o = 500$ rad/s and assume negligible L_a , determine the transfer function, $\Theta(s) / E_a(s)$.

where T_s = stall torque ; ω_o = no load speed ;
 K_b = back emf constant ; K_m = motor constant.

[7 marks]

(b) Briefly discuss the factors in choosing motion transducers.

[8 marks]

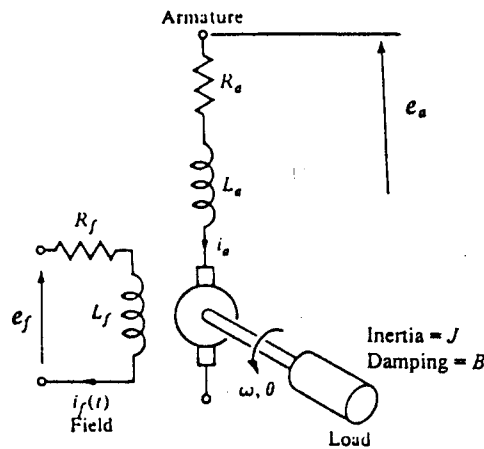


Fig.Q4

Q5.

- (a) With the aid of diagrams, briefly describe the principle of regenerative brake control of a d.c. chopper drive. [11 marks]
- (b) A chopper drive is operated in regenerative braking of a d.c. series motor. The d.c. supply voltage is 600 V. The armature resistance, $R_a = 0.02 \Omega$ and the field resistance $R_f = 0.06 \Omega$. The back emf motor constant, $K_v = 15 \text{ mV/A-rad/s}$. The average armature current is maintained at $I_a = 330 \text{ A}$. The armature current is assumed to be continuous and ripple free. If the duty cycle of the chopper is 40 %, determine the
- (i) average voltage across the chopper, V_{ch} ; [2 marks]
 - (ii) power regenerated to the d.c. supply, P_g ; [2 marks]
 - (iii) equivalent load resistance of the motor acting as a generator, R_{eq} ; [2 marks]
 - (iv) minimum permissible braking speed, ω_{min} ; [2 marks]
 - (v) maximum permissible braking speed, ω_{max} ; [2 marks]
 - (vi) motor speed, ω ; [4 marks]

Q6.

A three-phase 460 V, 60 Hz two-pole Y-connected induction motor has the following equivalent circuit parameters :

stator resistance, $R_s = 1 \Omega$;
rotor resistance, $R_r = 0.23 \Omega$;
stator reactance, $X_s = 0.7 \Omega$;
rotor leakage reactance, $X_r = 1.1 \Omega$;
motor reactance, $X_m = 15 \Omega$;

The no-load loss, $P_{\text{no load}} = 75 \text{ W}$ and the rotor speed is 3500 rpm. Use the approximate equivalent circuit shown in Fig.Q6 to determine the

- (a) synchronous speed, ω_s and slip, s ; [2 marks]
- (b) input current, I_i and input power, P_i ; [5 marks]
- (c) power factor of the supply, PF_s and gap power, P_g ; [4 marks]
- (d) rotor copper loss, P_{ru} and stator copper loss, P_{su} ; [2 marks]
- (e) developed torque, T_d and efficiency, η ; [2 marks]
- (f) starting rotor current, I_{rs} and the starting torque T_s ; [4 marks]
- (g) slip for maximum torque, s_m ; [2 marks]
- (h) breakdown torque, T_{mm} and maximum regenerative torque, T_{mr} . [4 marks]

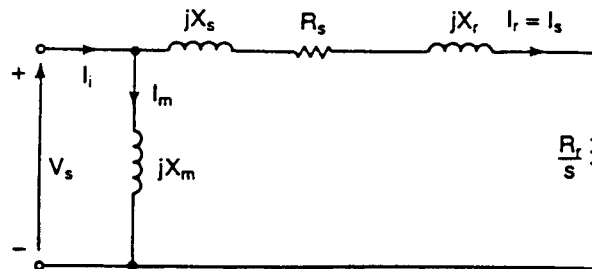


Fig.Q6