ETL – Power Electronics
T099
Thursday, 12/11/2015
08:30 – 11:30

WORKFORCE DEVELOPMENT AUTHORITY
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ADVANCED LEVEL NATIONAL EXAMINATIONS, 2015, TECHNICAL AND PROFESSIONAL TRADES

EXAM TITLE: **Power Electronics**

OPTION: **Electronics and Telecommunication (ETL)**

DURATION: **3hours**

INSTRUCTIONS:

The paper is composed of **three (3) main Sections** as follows:

Section **I**: Sixteen **(16)** questions, all **Compulsory**.	**55marks**
Section **II**: Five (5) questions, **Choose any Three (3)**.	**30marks**
Section **III**: Two (2) questions, **Choose any One (1)**.	**15marks**

Every candidate is required to strictly obey to the above instructions. Punishment measures will be applied to anyone who ignores these instructions.

Marking Guides

Section I. Sixteen (16) Compulsory questions. **55marks**

01. Explain why BJT is a current controlled device while IGBT is a voltage controlled device. **3marks**

Answer:

The output current I_C of BJT is a direct function of the level of input current I_B. (1mark) That is for the BJT transistor increasing levels of input current result in increasing levels of output current. (1mark) For the IGBT the output current will be a function of the voltage V_{GE} applied to the input circuit. (1mark)

02. At a fixed anode-to-cathode voltage less than the forward blocking $V_{(BR)F}$ What is the effect on the firing of the SCR as the gate current is reduced from its maximum level to zero level? **2marks**

Answer:

The SCR will not fire once the gate current is reduced to a level that will cause the forward blocking region to extend beyond the chosen anode-to-cathode voltage (1mark). In general, as I_G decreases, the blocking voltage required for conduction increases. (1mark)

03. What is a DIAC? Differentiate the structure of a DIAC from that of a Bi-polar Junction Transistor. **5marks**

Answer:

A DIAC is a two terminal five layer semi-conductor bi-directional switching device (1mark). It can conduct in both directions. The device consists of two p-n-p-n sections in anti-parallel (1mark).

A Bi-Polar Junction Transistor is a 3 layer, 3 terminals device. The 3 terminals are base, emitter and collector (1mark). It has 2 junctions' collector-base junction (CB) and emitter-base junction (EB) (1mark). Transistors are of 2 types, NPN and PNP transistors (1mark).

04. State two (2) cases in which a TRIAC is widely used. **4marks**

Answer:

- The TRIAC is widely used to control the speed of single phase induction motors. 2marks
- It is also used in domestic lamp dimmers and heat control circuits, and full wave AC voltage controllers. 2marks

05. What are different types of power transistors? **2marks**

Answer:

- Depletion MOSFETs and Enhancement MOSFETs.

06. Differentiate latching current from holding current in case of a thyristor. **3marks**

Answer:

Latching current I_L is the minimum anode current required to maintain the thyristor in the on-state immediately after a thyristor has been turned on and the gate signal has been removed (1.5mark).

Holding current I_H is the minimum anode current to maintain the thyristor in the on-state. The holding current is less than the latching current. If the anode current is reduced below this critical value, the thyristor will turn off. The lowest value of current, just before the thyristor turns off (1.5mark).

07. Which type of output voltage obtained from the cyclo converters compared to the input signal? **2marks**

Answer:

The cyclo converters generally produce output AC voltage at a lower output frequency. That is output frequency of the AC output is less than input AC supply frequency.

08. A chopper supplied by a 200V dc has ON time of 30 ms and OFF time of 10 ms. Determine the value of the averaged output voltage. **3marks**

Resolutions:

$T_{ON}=30 \times 10^{-3}s$, $T_{OFF}=10 \times 10^{-3}s$. $T=T_{ON}+T_{OFF}=40 \times 10^{-3}s$ 1mark

Duty cycle of the chopper$=30 \times 10^{-3}s/40 \times 10^{-3}s=0.75$ 1mark

VL=Vdc x duty cycle

$=200 \times 0.75=150V$ 1mark

09. What are the different ways of turning off a SCR? **3marks**

Answer:

a) Diverting the anode current to an alternating path; 0.5mark

b) Shorting the SCR from anode to cathode; 0.5mark

c) Applying a reverse voltage (by making the cathode positive with respect to the anode) across the SCR; 0.5mark

d) Forcing the anode current to zero for a brief period; 0.5mark

e) Opening the external path from its anode supply voltage; 0.5mark

f) Momentarily reducing the supply voltage to zero. 0.5mark

10. Explain the classifications of choppers according to their circuit operation? **3marks**

Answer:

According to their circuit operation choppers can be classified into:

- First-quadrant chopper: the output voltage and both current must be positive (class A) 1mark
- Two-quadrant chopper: the output voltage is positive and current can be positive or negative (class-C) or the output current is positive and the voltage can be positive or negative (class-D) 1mark
- Four- quadrant chopper: the output voltage and current both can be positive or negative (class-E) 1mark

11. Outline the main functions of DC to DC converters. **6marks**

Answer:

The functions of dc-dc converters are:

- to convert a dc input voltage VS into a dc output voltage VO; 1mark
- to regulate the dc output voltage against load and line variations; 1mark
- to reduce the ac voltage ripple on the dc output voltage below the required level; 1mark
- to provide isolation between the input source and the load (isolation is not always required); 1mark
- to protect the supplied system and the input source from 1mark
- Electromagnetic interference (EMI); and to satisfy various international and national safety standards. 1mark

12. What are the advantages of GTO over SCR? **4marks**

Answer:

The advantages of GTO over SCR are:

a. Elimination of commutation of commutating components in forced commutation, resulting in reduction in cost, weight and volume. 1mark

b. Reduction in acoustic noise and electromagnetic noise due to elimination of commutation chokes. 1mark

c. Faster turn-off, permitting high switching frequencies. 1mark

d. Improved efficiency of the converters. 1mark

13. What is meant by PWM control in dc chopper? **2marks**

Answer:

In the control method, the on time Ton is varied but chopping frequency is kept constant. The width of the pulse is varied and hence this type of control is known as Pulse Width Modulation (PWM).

14. What is a Unijunction transistor? Compare it with an ordinary diode. **3marks**

Answer:

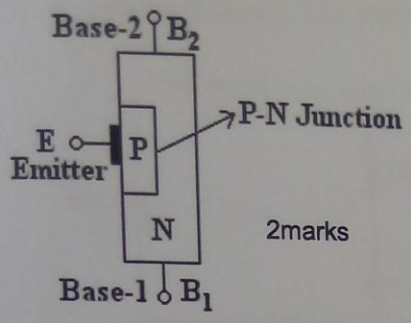
Unijunction transistor is also called the double base diode is a two layer, three terminal solid state switching device. 1mark

The device has unique characteristic that when it is triggered, its emitter current increases regeneratively until it is restricted by emitter power supply. 1mark

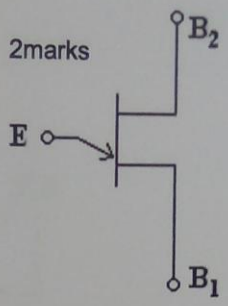
The device, because of one PN junction, is quite similar to a diode but it differs from an ordinary diode that it has three terminals. 1mark

15. Draw the Unijunction transistor circuit symbol with equivalent circuit and briefly describe its construction. **6marks**

Resolutions:



2marks



Construction-

The basic structure of a Unijunction transistor is shown in the above fig. It essentially consists of a lightly doped N-type silicon bar with a small piece of heavily doped P-type material alloyed to its one side to produce single P-N junction. The single P-N junction accounts for the terminology Unijunction.————2marks

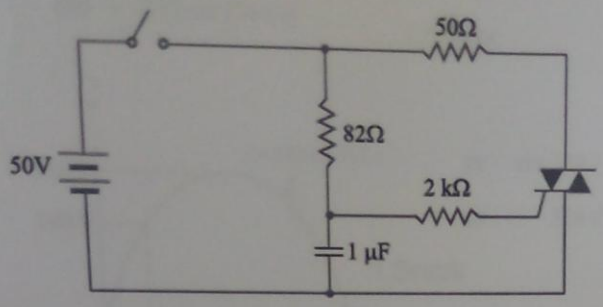
16. What are the advantages of single phase bridge converter over single phase mid-point converter? **4marks**

Answer:

1. SCRs are subjected to a peak-inverse voltage of 2Vm in a fully controlled bridge rectifier. (1mark) Hence for same voltage and current ratings of SCRs, power handled by mid-point configuration is about. (1mark)
2. In mid-point converter, each secondary winding should be able to supply the load power. (1mark) As such, the transformer rating in mid-point converter is double the load rating. (1mark)

Section II. Answer any three (3) among the following questions on your own choice (do not go beyond the three questions in this section). **30marks**

17. In following figure, the switch is closed.



If the triac has fired, what is the current through 50Ω resistor when:

(i) Triac is ideal.

(ii) Triac has a drop of 1V? **10marks**

Resolutions:

(i) Since the triac is ideal and it is fired into conduction, the voltage across triac is 0V (2marks).

Therefore, the entire supply voltage of 50V appears across 50Ω resistor (2marks).

$\therefore$ Current in 50Ω $= \frac{50V}{50\Omega} = 1\,A$ (2marks)

(ii) When triac is fired into conduction, voltage across 50Ω resistor = 50V – 1V = 49V. (2marks)

$\therefore$ Current in 50Ω $= \frac{49V}{50\Omega} = 0.98\,A$ (2marks)

18. A. A unijunction transistor has 10 V between the bases. If the intrinsic standoff ratio is 0.65, find the value of standoff voltage. What will be the peak-point voltage if the forward voltage drop in the pn junction is 0.7 V?

B. An a.c. voltage v = 240 sin314 t is applied to an SCR half-wave rectifier. If the SCR has a forward breakdown voltage of 180 V, find the time during which SCR remains off. **10marks**

Resolutions:

$V_{BB} = 10\,V$; $\eta = 0.65$; $V_D = 0.7\,V$ (1.5mark)

Stand off voltage $= \eta V_{BB} = 0.65 \times 10 = 6.5\,V$ (1mark)

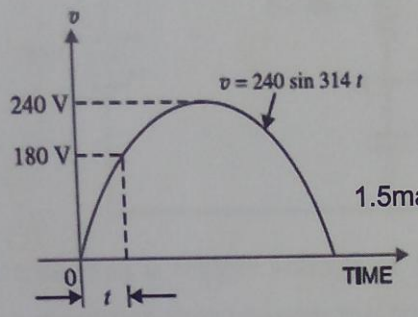
A. Peak-point voltage, $V_P = \eta V_{BB} + V_D = 6.5 + 0.7 = 7.2\,V$ (1.5mark)

B. The SCR will remain off till the voltage across it reaches 180 V. This is shown in figure below. Clearly, SCR will remain off for t second. 1.5mark

Now $v = V_m \sin 314\,t$

Here $v = 180$ V; $V_m = 240$ V

$\therefore \quad 180 = 240 \sin (314\,t)$ 1.5mark



1.5mark

or $\sin 314\,t = \dfrac{180}{240} = 0.75$

or $314\,t = \sin^{-1}(0.75)$

$= 48.6° = 0.848$ radian

$\therefore \quad t = \dfrac{0.848}{314} = 0.0027$ sec

$= 2.7$ millisecond 1.5mark

19. Write fully and correctly the answer's sentence. Fill in the following statements. **10marks**

a) A triac has three terminals viz ..... (*i*) drain, source, gate, (*ii*) two main terminal and a gate terminal, (*iii*) cathode, anode, gate.

b) A triac is equivalent to two SCRs..... (*i*) in parallel, (*ii*) in series, (*iii*) in inverse-parallel.

c) A diac has ..... terminals. (*i*) two (*ii*) three, (*iii*) four.

d) A *UJT* has..... (*i*) two *pn* junctions, (*ii*) one *pn* junction, (*iii*) three *pn* junctions.

e) A diac is simply..... (*i*) a single junction device, (*ii*) a three junction device, (*iii*) a triac without gate terminal.

Answer:

a) A triac has three terminals viz, two main terminal and a gate terminal. (2marks)

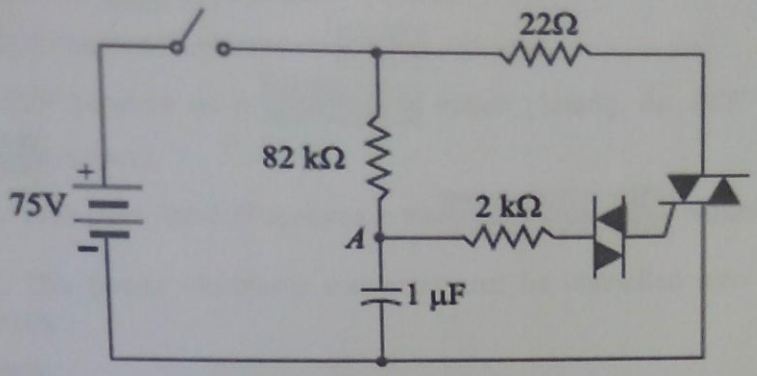
b) A triac is equivalent to two SCRs in inverse-parallel. (2marks)

c) A diac has two terminals (2marks)

d) A *UJT* has one *pn* junction. (2marks)

e) A diac is simply a triac without gate terminal. (2marks)

20. A. In figure bellow, the switch is closed. A diac with breakover voltage V_{BO} = 30V is connected in the circuit.



If the triac has a trigger voltage of 1V and a trigger current of 10mA, what is the capacitor voltage that triggers the triac?

Answer:

When switch is closed, the capacitor starts charging and voltage at point *A* increases (1.5mark). When voltage V_A at point A becomes equal to V_{BO} of diac plus gate triggering voltage V_{GT} of the triac, the triac is fired into conduction (1.5mark).

$V_A = V_{BO} + V_{GT} = 30V + 1V = 31V$ (1mark). This is the minimum capacitor voltage that will trigger the triac (1mark).

B. Write fully and correctly the answer's sentence. Fill in the following statements.

a) An SCR has ..... pn junctions. (i) two (ii) three, (iii) four.

b) An *SCR* has three terminals *viz.* ..... (*i*) cathode, anode, gate, (*ii*) anode, cathode, grid, (*iii*) anode, cathode, drain.

c) An *SCR* behaves as a ..... switch. (*i*) unidirectional, (*ii*) bidirectional, (*iii*) mechanical.

d) An *SCR* is sometimes called ..... (*i*) triac, (*ii*) diac, (*iii*) unijunction transistor, (*iv*) thyristor.

e) After peak point, the *UJT* operates in the..... region. (*i*) cut-off, (*ii*) saturation, (*iii*) negative resistance.

Answers:

a) An *SCR* has three *pn* junctions. (1mark)

b) An *SCR* has three terminals *viz* cathode. (1mark)

c) An *SCR* behaves as a unidirectional switch (1mark). An *SCR* is sometimes called thyristor (1mark).

d) After peak point, the *UJT* operates in the negative resistance region (1mark).

21. A. The power electronic converter can be classified into six types, list out them.

Answers:

19. The power semiconductor devices or power electronic converter fall generally into the following categories: /6

(i) AC to DC Converter (0.5mark) (Controlled Rectifier) (0.5mark)

(ii) DC to DC Converter (0.5mark) (DC Chopper) (0.5mark)

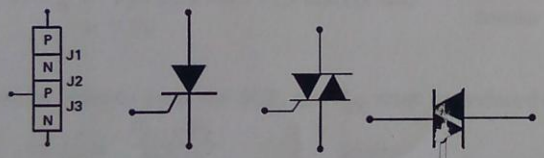
(iii) AC to AC Converter (0.5mark) (AC voltage regulator) (0.5mark)

(iv) DC to AC Converter (0.5mark) (Inverter) (0.5mark)

(v) Diode Rectifier (1mark)

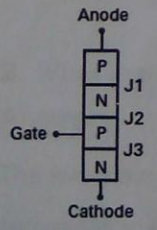
(vi) Static Switches (1mark)

B. From the symbols of the figure below, write the terminal for each.

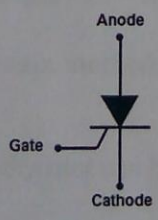


10marks

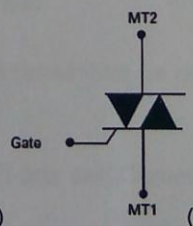
Answer:



(1mark)



(1mark)



(1mark)

(1mark)

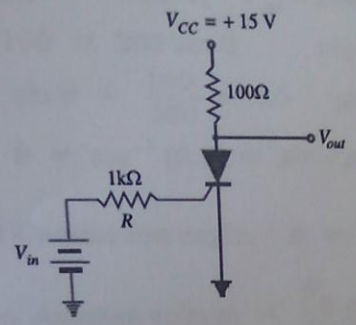
Section III. Answer any one (1) among the following questions on your own choice (do not go beyond the one question in this section). 15marks

22. A. The SCR of figure below has gate trigger voltage V_T = 0.7V, gate trigger current I_T = 7mA and holding current I_H = 6mA.

(i) What is the output voltage when the SCR is off?

(ii) What is the input voltage that triggers the SCR?

(iii) If VCC is decreased until the SCR opens, what is the value of V_{CC}



Resolutions:

(*i*) When the *SCR* is off (*i.e.* it is not conducting), there is no current through the 100Ω resistor.

$\therefore V_{out}$ = Supply voltage V_{CC} = 15V 3marks

(*ii*) The input voltage V_{in} must overcome V_T (=0.7V) and also cause 7 mA to flow through 1 kΩ resistor.

$\therefore V_{in} = V_T + I_T R = 0.7 + (7\text{ mA})(1\text{ k}\Omega)$
$= 7.7\text{V}$ 3marks

(*iii*) In order to open the *SCR*, the V_{CC} must be reduced so that anode current is equal to I_H.

$\therefore I_H = \dfrac{V_{CC} - V_T}{100\ \Omega}$ 3marks

or $V_{CC} = (100\Omega)(I_H) + V_T$
$= (100\Omega)(6\text{ mA}) + 0.7 = 1.3\text{V}$ 3marks

B. What are the two main methods the thyristor can be turn-off?

Answer:

The two main methods thyristor can be turn-off are: self Commutation (1.5mark) or external commutation (1.5mark).

23. **A.** A half-wave rectifier circuit employing an SCR is adjusted to have a gate current of 1mA. The forward breakdown voltage of SCR is 100 V for Ig = 1mA. If a sinusoidal voltage of 200 V peak is applied, find: (i) firing angle (ii) conduction angle (iii) average current. Assume load resistance = 100Ω and the holding current to be zero.

Resolutions:

(*i*) $v = V_m \sin\theta$ 1mark

Here, $v = 100$ V, $V_m = 200$ V 1mark

$\therefore 100 = 200 \sin\theta$ 1mark

or $\sin\theta = \frac{100}{200} = 0.5$ 1mark

$\therefore \theta = \sin^{-1}(0.5) = 30°$ *i.e.* Firing angle, $\alpha = \theta = 30°$ 2marks

(*ii*) Conduction angle, $\phi = 180° - \alpha = 180° - 30° = 150°$ 2marks

(*iii*) Average voltage $= \frac{V_m}{2\pi}(1+\cos\alpha) = \frac{200}{2\pi}(1+\cos 30°) = 59.25$ V 2marks

$\therefore$ Average current $= \frac{\text{Average voltage}}{R_L} = \frac{59.25}{100} = 0.5925$ A 2marks

B. What are the two most common phase controller configurations?

Answer:

i. Half wave control, (0.5mark) where the controlling device is a single thyristor (1mark).

ii. Full wave control, (0.5mark) where the controlling device is a triac or a pair of anti-parallel thyristors (1mark).

24. **A.** State the different thyristor turn-on methods.

B. DC/AC converters named inverters are employed to convert a dc supply to ac level of a definite frequency and value. Which controlled semiconductor devices used?

C. Determine the maximum and minimum peak-point voltage for a UJT with V_{BB} = 25 V. Given that UJT has a range of η = 0.74 to 0.86.

15marks

Answers:

A. The different thyristor turn-on methods are:

i. Turn-on by exceeding the breako ver voltage; 1.5mark

ii. Turn-on by leakage current 1.5mark

iii. Turn-on by dV/dt 1.5mark

iv. Turn-on by gate triggering 1.5mark

B. The controlled semiconductor devices used are:

Transistors (1mark), SCR (1mark), and GTO thyristors (1mark).

C. the maximum and minimum peak-point voltage:

$V_{BB} = 25\ V$; $\eta_{max} = 0.86$; $\eta_{min} = 0.74$

$$V_{P(max)} = \eta_{max} V_{BB} + V_D \quad \text{3marks}$$
$$= (0.86)(25V) + 0.7\ V = 22.2\ V$$
$$V_{P(min)} = \eta_{min} V_{BB} + V_D \quad \text{3marks}$$
$$= (0.74)(25\ V) + 0.7\ V = 19.2\ V$$

REFERENCES

1. Principles of Electronics
2. Digital Electronics, Principles, Devices and Applications,
   ISBN 978-0-470-03214-5 (HB), 2007 Ani K. Maini
   Defence Research and Development Organization (DRDO), India