CEL – Power Electronics and Electromechanical Systems

T100

Thursday, 12/11/2015

08:30 – 11:30

WORKFORCE DEVELOPMENT AUTHORITY

P.O. BOX 2707 Kigali, Rwanda Tel: (+250) 255113365

ADVANCED LEVEL NATIONAL EXAMINATIONS, 2015, TECHNICAL AND PROFESSIONAL TRADES

EXAM TITLE: Power Electronics and Electromechanical Systems

OPTION: Computer Electronics (CEL)

DURATION: 3hours

INSTRUCTIONS:

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

Section **I**: Fourteen **(14)** questions, all **Compulsory**. **55marks**

Section **II**: Five (5) questions, **Choose Three (3) only.** **30marks**

Section **III**: Three (3) questions, **Choose only One (1).** **15marks**

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

Section I. Fourteen (14) Compulsory questions. **55marks**

01. What are types of power Diodes? **3marks**

02. Classify the main power electronics converters. **4marks**

03. Why is necessary to use fast-recovery diodes for high-speed switching? **2marks**

04. What is the effect of forward and reverse biasing of pn junction diode on the depletion region? **4marks**

05. Define the freewheeling diode and give its purpose as well. **4marks**

06. How is the Thyristor turn ON and OFF? **4marks**

07. Explain the following terms:

a. Natural commutation of thyristor.

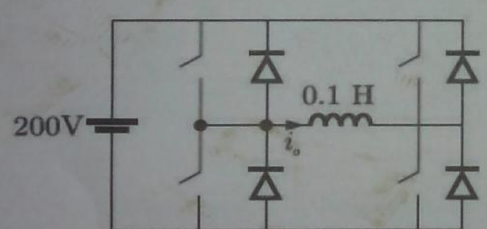
b. Forced commutation of thyristor. **4marks**

08. What is the purpose of connecting diodes in:

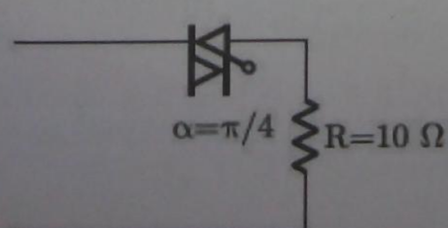
a. Series?

b. Parallel? **4marks**

09. The figure below shows a single phase source inverter which feeds a purely inductive load; the inverter is operated at 50 Hz in 180^0 square wave mode. Assume that the load current does not have any dc component, Compute the peak value of the inductor current i_O. **4marks**



10. The diagram below shows the triac circuit which controls the ac output power to the resistive load. Calculate the peak power dissipation in the load if the Vrms value is 230Volts. **4marks**



11. Mention at least five applications of controlled rectifier. **5marks**

12. What are the different types of chopper with respect to commutation process? **3marks**

13. A three phase fully controlled bridge converter is feeding a load drawing a constant and ripple free load current of 10 A at a firing angle of 30°. Calculate:

    a. The rms value of fundamental component of input;

    b. The approximate Total harmonic Distortion (%THD). **5marks**

14. Suppose that you are requested to buy a UPS (Uninterruptible Power Supply), what are important steps through which you may go before you go for purchasing that equipment. **5marks**

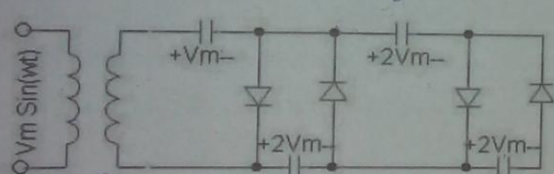
Section II. Answer any three (3) questions of your choice

(Do not choose more than <u>three questions</u>). 30marks

15. Why do we need filters in a power supply and explain briefly under which condition capacitor filter is preferred? **10marks**

16. Draw and briefly explain the simple block diagram of Variable frequency converter for motor control. **10marks**

17. Explain the functioning of the following circuit: **10marks**



18. With a neat sketch of a four-quadrant ac voltage controller, explain how it can control a pump drives with induction motors. **10marks**

19. An SCR is used to convert AC to DC signal. The anode supply is 220volts with the frequency of 50Hz and the firing angle (α) is adjusted to 60°. Find out the output voltage. **10marks**

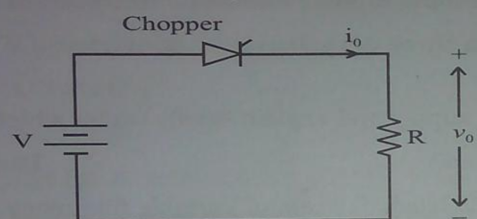
Section III. Answer any one (1) question of your choice

(Do not choose more than <u>one question</u>). 15marks

20. Draw and briefly explain the working Principle of Step-up Chopper. **15marks**

21. The dc chopper in the following figure has a resistive load of R=10 Ohm and the input voltage of Vs=220V. When the chopper switch remains ON, its voltage drop is V_{ch} =2V and the chopping frequency is f=1kHz. If the duty cycle is 50%, determine:

a. The average output voltage, V_a
b. The rms output voltage V_o
c. The chopper efficiency
d. The effective input resistance R_i of the chopper

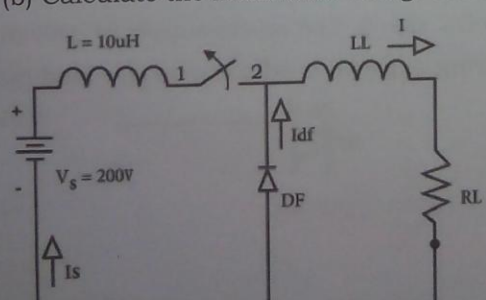


15marks

22. The figure below shows a simple switch mode power supply. The switch (1-2) is closed at t = 0 s. When the switch is open, a freewheeling current IF =20A flows through the load (RL), freewheeling diode (DF), and the large load circuit inductance (LL). The diode reverse recovery current is 20A and it then decays to zero at the rate of 10 A/µs. The load is rated at 10Ω and the forward on-state voltage drop is neglected.

(a) Draw the current waveform during the reverse recovery (Irr) and find its time (trr).

(b) Calculate the maximum voltage across the diode during this process.



A simple switch mode power supply with freewheeling diode. **15marks**

Section I. Fourteen (14) Compulsory questions. 55marks

01. What are types of power Diodes? **3marks**

Answer:

Diodes are classified into three types:

1. General purpose diodes 1mark
2. Fast-recovery Diodes 1mark
3. Schottky Diodes 1mark

02. Classify the main power electronics converters. **4marks**

Answer:

The main classes of power electronics converters are:

- AC/DC converters called also rectifiers that convert input AC voltage to DC voltage. 1mark
- DC/AC converters called inverter that produce output AC voltage of controllable magnitude and frequency from input DC voltage. 1mark
- AC/C converters or frequency converters and changers that establish AC frequency. 1mark
- DC/DC converters called also choppers that change DC voltage and current levels using the switching mode of semiconductor devices. 1mark

03. Why is necessary to use fast-recovery diodes for high-speed switching? **2marks**

Answer:

It is because the Fast-recovery Diodes have low recovery time, let's say 5μ seconds, therefore, they are used where the speed of recovery is of critical importance.

04. What is the effect of forward and reverse biasing of pn junction diode on the depletion region? **4marks**

Answer:

The thickness of depletion region is the order of few microns. Where, 1micron=10^{-4}cm.

Forward bias: In forward bias, the thickness of depletion layer is very thin because p-type is connected to positive terminal and the n-type is connected to the negative terminal. This causes the holes and electrons to move freely across the junction, hence resulting in a large current. 1mark

Reverse bias: As the p-type is connected to the negative terminal and n-type is connected to the positive terminal, the force of attraction takes place, so the holes from p-side and the electrons from n-side moves away from the junction, thus increasing the width of depletion region. This results in a very little current, almost equal to zero. Therefore, in reverse bias the thickness of the depletion region is large. 2marks

05. Define the freewheeling diode and give its purpose as well. **4marks**

Answer:

The freewheeling diode Called also flyback diode is a diode used to avoid the sudden voltage spike seen across an inductive load when its supply voltage is suddenly reduced or removed. 2marks
This antiparallel diode must be connected across the load to provide a path for the inductive current to flow in order to protect the switching device from being damaged by the reverse current of an inductive load. 2marks

06. How is the Thyristor turn ON and OFF? **4marks**

Answer:

The thyristor is turned ON by increasing the anode current while when the thyristor is ON, It can be turned OFF by reducing the forward current to a level below the holding current.

07. Explain the following terms:

a. Natural commutation of thyristor.
b. Forced commutation of thyristor. **4marks**

Answer:

Natural commutation of thyristor.

If the input voltage to thyristor is alternating current (AC), the thyristor current goes a natural zero and the reverse voltage appears across the thyristor. Therefore the device is automatically turned off due to the natural behavior of the AC voltage. 2marks

Forced commutation of thyristor.

This is the commutation technique used to force the thyristor current goes to zero when the input is direct current (dc). This is done by additional circuit called forced commutational circuit to turn OFF thyristor. 2marks

08. What is the purpose of connecting diodes in:

a. Series?

b. Parallel? **4marks**

Answer:

Series?

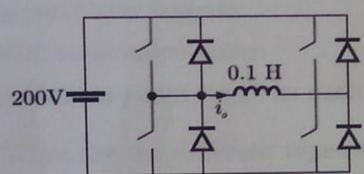
In many high voltage applications, diodes are connected in series to increase the reverse blocking capabilities when a single dingle diode cannot meet the required voltage rating. 2marks

Parallel?

The purpose of connecting diodes in Parallel is to increase the current carrying capacity to meet the desired current requirement in also high power application. 2marks

09. The figure below shows a single phase source inverter which feeds a purely inductive load; the inverter is operated at 50 Hz in 180^0 square wave mode. Assume that the load current does not have any dc component. **4marks**

Compute the peak value of the inductor current i_o.



Solution:

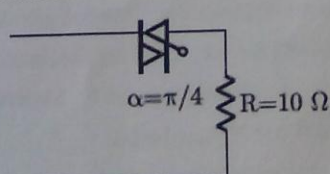
Data:

f=50 Hz t=20ms, Vs=200V, L=0.1H

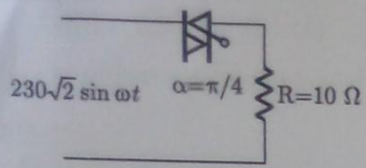
I_{peak} = (Vs/L)*(t/4) 2marks

I_{peak} = (200/0.1)*(20*10(-3)/4 =10 amps 2marks

10. The diagram below shows the triac circuit which controls the ac output power to the resistive load. Calculate the peak power dissipation in the load if the Vrms value is 230Volts. **4marks**



Solution



V (t) s=230*√2 sin wt with R=10 Ω 1mark

Peak instantaneous voltage Vpeak =230*√2 1mark

Peak power = (Vm peak)^2 / R =10580 watts 2marks

11. Mention at least five applications of controlled rectifier. **5marks**

Answer:

Diverse applications of controlled rectifier:

- Steel rolling mills, printing press, textile mills and paper mills employing dc motor drives.
- DC traction
- Electro chemical and electro-metallurgical process
- Portable hand tool drives
- Magnet power supplies
- HVDC transmission system

Candidates may earn 1mark for each correct application, retain five for the 5marks.

12. What are the different types of chopper with respect to commutation process? **3marks**

Answer:

- Voltage commutated chopper. 1mark
- Load commutated chopper. 1mark
- Current commutated chopper. 1mark

13. A three phase fully controlled bridge converter is feeding a load drawing a constant and ripple free load current of 10 A at a firing angle of 300. Calculate:

a. The rms value of fundamental component of input;

b. The approximate Total harmonic Distortion (%THD). **5marks**

Solution:

Total rms current I_A=√2/3*10=8.16 A 1mark

Fundamental current $IA1$=0.78*10=7.8 A 1mark

Where THD = √ (1/DF^2) −1 1mark

$DF= I_{a1}/I_a$= 7. 8/8.16=0.955 1mark

THD = √ (1/0.955^2) −1 = 31% 1mark

14. Suppose that you are requested to buy a UPS (uninterruptible power system), what are important steps through which you may go before you go for purchasing that equipment. **5marks**

Answer:

1. Making a list of all the equipments which will be protected by that UPS; 1mark
2. Determine how many volts and amps every device on the list draws; 1mark
3. For each device, multiply volts by amps to arrive at a VA figure; 1mark
4. Summing up all the VA figures together; 1mark
5. Multiply that sum by 1.2, to build in room for growth. (This is because The UPS should have a rating equal to or greater than the final number you arrived at in step, unless you have more precise load data for the equipment you are protecting.) 1mark

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

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15. Why do we need filters in a power supply and explain briefly under what condition capacitor filter is to be preferred? **10marks**

Answer:

The filter is any circuit that can be used to minimize the undesirable Alternating Circuit (A.C) in the output of a rectifier and letting only the DC component to appear at the output (2marks). Thus, in power supplies, the output of rectifier contains both AC and DC components (1mark). Therefore, filters are used to remove unwanted ripple contents from this pulsating DC to get pure DC voltage (1).

Even though, the output of a filter is not exactly a constant DC level. Thus, the output of a filter must be fed to a regulator which gives steady DC output. 1mark

The reason why the capacitor filter is to be preferred is that, the capacitive filter is an inexpensive filter for light loads which is connected directly across the load. 1mark

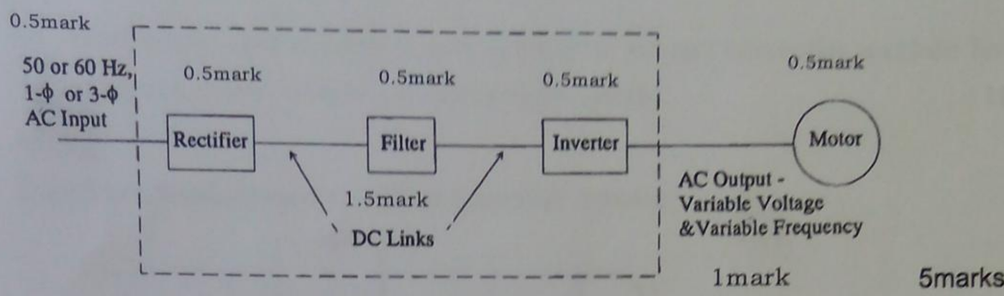
It is also a simple circuit to obtain pure DC voltage, but it has to be used where the higher (<90%) efficiency is not highly required 1mark due to the following reasons:

- the ripple factor is dependent on the load resistance, RL. 1mark
- the output obtained using capacitor filter is not smooth as desired. 1mark
- the values of capacitor or load resistance must be fairly large to obtain a ripple voltage. 1mark

16. Draw and briefly explain the simple block diagram of Variable frequency converter for motor control. **10marks**

Answer:

Block diagram of Variable frequency converter for motor control

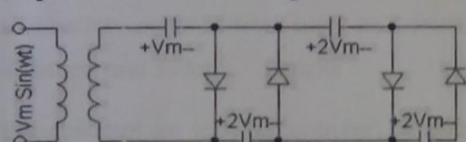


In this block diagram, electronic components such as thyristors are used to construct the first stage of an electric motor drive in order to vary the amplitude of the voltage waveform across the windings of the electrical motor 2marks

An electronic component controller controls the gate current of these thyristors. 1mark

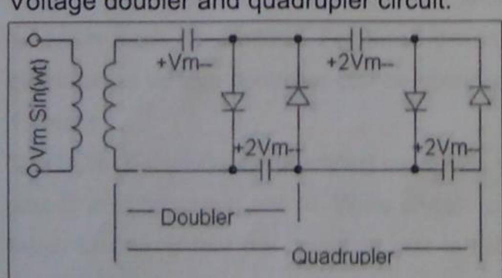
The rectifier and inverter sections can be thyristor circuits whereby a controlled rectifier is used in conjunction with a square wave or pulse-width modulated (PWM) voltage source inverter (VSI) to create the speed-torque controller system. 2marks

17. Explain the functioning of the following circuit: **10marks**



Solution

Voltage doubler and quadrupler circuit. 4marks

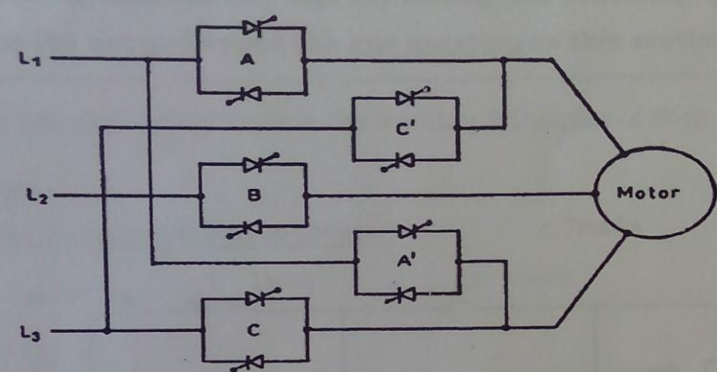


The foreshowed circuit represents the Voltage Multiplier and by connecting diodes in a predetermined manner, an ac signal can be doubled, tripled, and even quadrupled (**3marks**). This circuit will yield a dc voltage equal to 2 V_{Peak} whereby the capacitors are alternately charged to the maximum value of the input voltage (**3marks**). **6marks**

18. With a neat sketch of a four-quadrant ac voltage controller, explain how it can control a pump drives with induction motors. **10marks**

<u>Answer:</u>

Sketch of a four-quadrant ac voltage controller: 5marks



The AC voltage controllers are used either for control of the rms value of voltage or current in lighting control, domestic and industrial heating, speed control of fan, pump or hoist drives, etc, or as static ac switches (on /off control) in transformer tap changing, temperature control, speed stabilization of high inertia induction motor drives such as centrifuge, capacitor switching in static reactive power compensation, and so forth. 2marks

The four-quadrant ac voltage controller as drawn above controls the pump drives with induction motors as follows:

Normally, the torque varies as the square of the speed. Therefore, the speed control is required in a narrow range and an ac voltage controller is suitable for an induction motor with a full load slip of 0.1 to 0.2 in such applications. For these drives, both motoring and braking are needed and a four-quadrant ac voltage controller can be obtained by a modification of the ac voltage controller circuit..
1.5mark

The SCR (Silicon Control Rectifier) pairs A, B, and C provide operation in quadrants I and IV and A' B, and C' in quadrants II and III. While changing from one set of SCR pairs to another, care should be taken to ensure that the incoming pair is activated only after the outgoing pair is fully turned off.
1.5mark

19. An SCR is used to convert AC to DC signal. The anode supply is 220volts with the frequency of 50Hz and the firing angle (α) is adjusted to 60°. Find out the output voltage. **10marks**

Solution:

Data given: Vrms=220V, · =60o, f=50Hz

The maximum applied voltage to the anode (Vmax) = $\sqrt{2} * v_{rms} = \sqrt{2} * 220 = 311V$ 4marks

The output voltage will be:

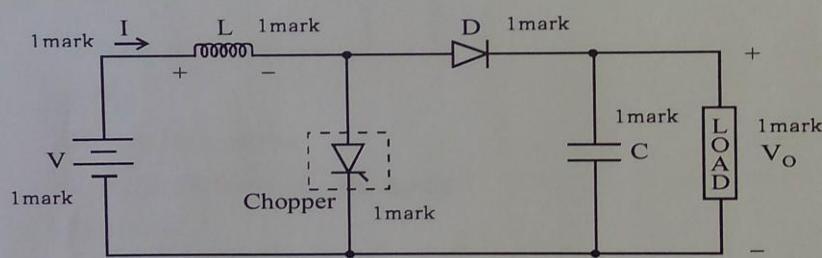
Vdc= $\frac{Vm}{2\pi}(1 + Cos\alpha) = \frac{311}{2\pi}(1 + \cos 60^0) = 74.2V$ 6marks

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**

20. Draw and briefly explain the working Principles of Step-up Chopper.

Answer:

The Circuit of a general Step-up Chopper 7marks



Principles of Step-up Chopper. 8marks

The Step-up chopper is used to obtain a load voltage higher than the input voltage *V*.

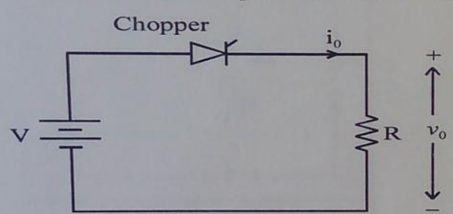
1. The values of *L* and *C* are chosen depending upon the requirement of output voltage and current. 1mark
2. When the chopper is *ON*, the inductor *L* is connected across the supply. 1mark
3. The inductor current *'I'* rises and the inductor stores energy during the *ON* time of the chopper, t_{ON}. 1mark
4. When the chopper is off, the inductor current *I* is forced to flow through the diode *D* and load for a period, t_{OFF}. 1mark
5. The current tends to decrease resulting in reversing the polarity of induced EMF in *L*. Therefore voltage across load is given by:

$$V_O = V + L\frac{dI}{dt} \quad i.e., \; V_O > V$$ 1mark

6. A large capacitor 'C' connected across the load will provide a continuous output voltage. 1mark
7. Diode *D* prevents any current flow from capacitor to the source. 1mark
8. Step up choppers are used for regenerative braking of dc motors. 1mark

21. The dc chopper in figure below has a resistive load of R=10 Ohm and the inpu voltage is Vs=220V. When the chopper switch remains ON, its voltage drop i V_{ch} =2V and the chopping frequency is f=1kHz. If the duty cycle is 50% determine:

a. The average output voltage, V_a
b. The rms output voltage V_o
c. The chopper efficiency
d. The effective input resistance R_i of the chopper



<u>**Solution:**</u>

Data: (see figure above)

V_s=220V, k=0.5, R=10 Ohm and V_{ch}=2V

We know that:

a. $V_a=\frac{1}{T}\int_0^{t1} V_o dt = \frac{t_1}{T}*V_s = ft_1V_s = kV_s$ =0.5*(220-2)=109Volt 3marks

b. With T is the chopping period

$V_o=\sqrt{(\frac{1}{T}\int_0^{kT} v_o^2 dt)} = \sqrt{k}*V_s = \sqrt{5}$ (220-2)=154.15V 3marks

c. The output power will be:

$P_o=\frac{1}{T}\int_0^{kT}\frac{v_o^2}{R}dt$ =k*(V_s-V_{cp})²/R=0.5(220-2)²/10=2376.2W 3marks

The input power to the copper is:

$P_i=\frac{1}{T}\int_0^{kT} V_s * i_s dt = k*\frac{V_s(V_s - v_{cp})}{R}$ = 0.5*220(220-2)/10=2398W, 3marks

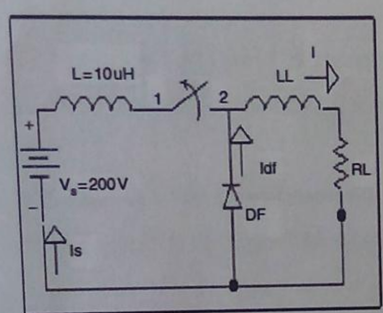
Therefore the chopper efficiency $\eta_{ch}=\frac{2376.2}{2398}$=99% 1mark

d. Ri=V_s/i_a=R/k=10/0.5=20Ω 2marks

22. The figure below shows a simple switch mode power supply. The switch (1-2) is closed at t = 0 s. When the switch is open, a freewheeling current IF =20A flows through the load (RL), freewheeling diode (DF), and the large load circuit inductance (LL). The diode reverse recovery current is 20A and it then decays to zero at the rate of 10 A/µs. The load is rated at 10Ω and the forward on-state voltage drop is neglected.

(a) Draw the current waveform during the reverse recovery (Irr) and find its time (trr).

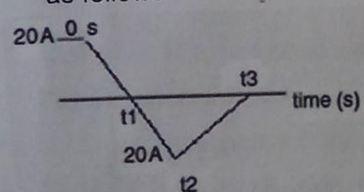
(b) Calculate the maximum voltage across the diode during this process (IRR).



A simple switch mode power supply with freewheeling diode.

SOLUTION.

(a) A typical current waveform during reverse recovery process for an ideal diode is drawn as follows:



3marks

When the switch is closed, the steady-state current is, I_S = 200 V/10Ω = 20 A, 1mark

since under steady-state condition, the inductor is shorted.

When the switch is open, the reverse recovery current flows in the right-hand side loop consisting of the LL, RL, and DF. The load inductance, LL is assumed to be shorted. Hence, when the switch is closed, the loop equation becomes:

V = L diS/dt from which:

di_S/dt= V/L= 200/10= 20 A/µs 2marks

At the moment the switch is open, the same current keeps flowing in the right-hand side loop.

Hence,

$Di_d/dt = -di_S/dt = -20$ A/μs from time zero t_o time t_1 the current will decay at a rate of 20 A/s and will be zero at $t_1 = 20/20 = 1$μs. Therefore, the reverse recovery current starts at this point and, according to the given condition, becomes 20A at t_2. **3marks**

From this point on, the rate of change remains unchanged at 20 A/μs. Period $t_2 - t_1$ is found as: $t2 - t1 = 20$ A/20 A/μs = 1μs **1mark**

From t_2 to t_3, the current decays to zero at the rate of 20 A/μs. Therefore, the required time: $t_3 - t_2 = 20$ A/10 A/μs = 2μs, Hence the actual reverse recovery time:

$t_{rr} = t_3 - t_1 = (1 + 1 + 2) - 1 = 3$μs. **3marks**

(b) The diode will get the maximum voltage only when the switch is open as both the source voltage 200V and the newly formed voltage due to the change in current through the inductor L.

Therefore, the voltage across the diode becomes:

$V_D = -V + Ldi_S/dt = -200 + (10\times10-6)(-20\times106) = -400V$ **2marks**

References

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