EEE4117F QUIZ 2 **TOTAL MARKS: 30**
DATE: 29 MAY 2020 **TIME: 1 HOUR (X2)**

PART A: MACHINES Marks: 15

QUESTION 1 [5 MARKS]

In **Fig. 1** below, a block diagram showing the various components of a DC motor drive used for the propulsion of an electric vehicle is provided. This electric vehicle is designed to provide both forward motoring and reverse braking operation. The DC-DC converter is a type of DC chopper, the DC motor (shown as DC machine in Fig. 1) operates at rated speed of 5000 rpm and the fixed gear (FG) is incorporated to step-down the speed to 1000 rpm for driving the vehicle wheels.

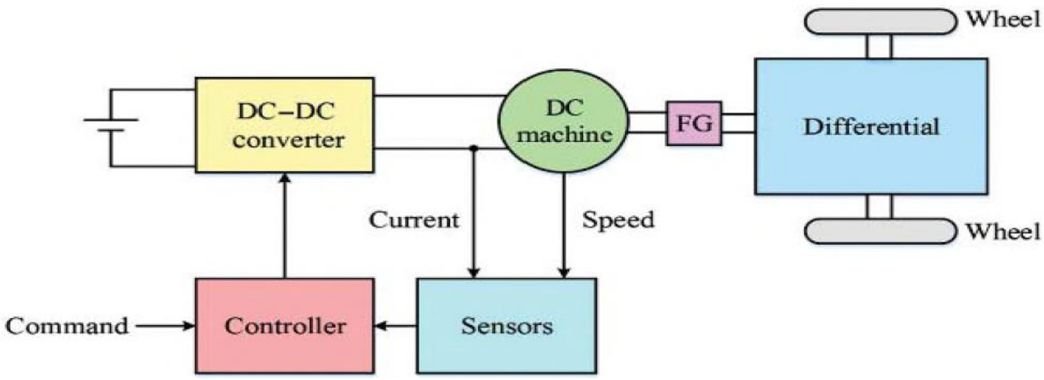


Fig. 1: Configuration of DC Motor Drive for Electric Vehicle Propulsion

Answer the following:

1.1. State the class of DC motor that is ideal for the above application (hint: consider the rated speed of the DC motor) and explain the reason for your choice. **[2]**

1.2. State two advantages of using a DC chopper for the above application and also state the type of chopper required for the application. **[2]**

1.3. Draw a well-labelled diagram to illustrate the quadrants of operation for the above application; show the polarity of the armature voltage, and armature current in each quadrant. **[1]**

QUESTION 2 [10 MARKS]

A 220 V, 960 rpm, 80 A, separately excited dc motor has an armature resistance of 0.06Ω. Under rated conditions, the motor is driving a load whose torque is constant below base speed. The speed of the motor is controlled below rated speed by means of armature voltage control. Furthermore, its speed above rated speed is controlled by means of field control (with rated armature voltage). Determine the following:

2.1. The terminal voltage of the motor when the speed is adjusted to 620 rpm. **[2]**

2.2. The value of flux as a percentage of rated flux if the motor speed is 1200 rpm. (Neglect the motor’s rotational losses). **[1]**

2.3. The developed torque of the motor at 1200 rpm. **[1]**

2.4. If the motor is also considered for a low-speed application under rated conditions, which requires rated torque with a peak-to-peak ripple of less than 2% at 960 rpm. Determine the peak-to-peak ripple torque requirement for this application. **[1]**

2.5. If the separately excited DC motor is brought to rest from 300 rpm, by switching off the supply and placing a resistor across the armature terminal of the motor. Calculate the braking resistance value to limit the armature current to twice the rated value while neglecting the effect of the inductance. **[2]**

2.6. If a Class-A chopper is connected to the separately excited DC motor for effective speed control. The armature inductance of the motor is given as 5mH. The chopper is operated at a switching frequency of 1 kHz with a duty cycle of 50%, while the rotor of the DC motor is locked at standstill. Calculate the value of the on-time of the switching device in the chopper and determine the load time constant. **[2]**

2.7. If the switching frequency of the chopper is increased four times to 4 kHz and the value of the armature inductance is increased to 20mH, explain the impact of this increase on the armature current ripple and losses in the dc motor drive. **[1]**

PART B: POWER ELECTRONICS Marks: 15

QUESTION 1 [8 MARKS]

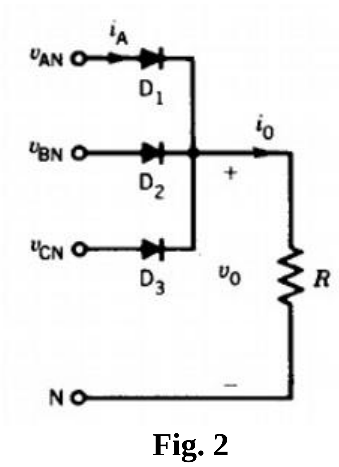


Fig. 2

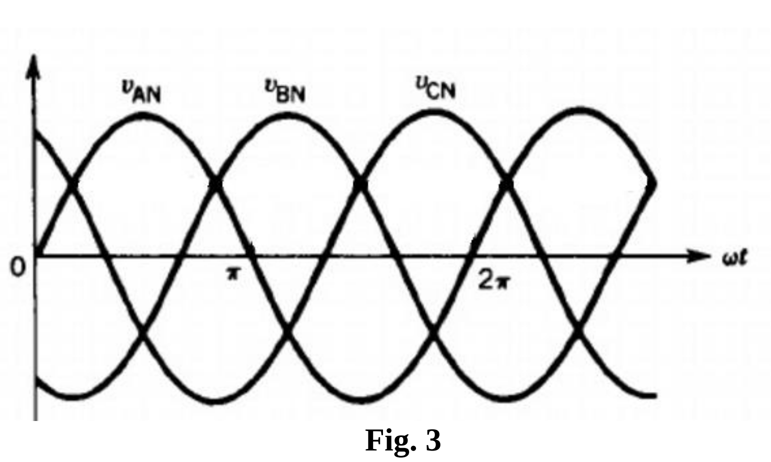


Fig. 3

Fig. 2 shows an uncontrolled rectifier connected to a three-phase voltage source. The phase voltages are $v_{AN}(t)$, $v_{BN}(t)$ and $v_{CN}(t)$ respectively. The waveform of the three-phase voltage source connected to the uncontrolled rectifier is shown in **Fig. 3**

If $v_{AN}(t) = V_p \sin(\omega t)$, where V_p is the peak voltage of phase A.

1.1. Write the equations for phase voltages $v_{BN}(t)$ and $v_{CN}(t)$ [1]

1.2. Draw the output waveform $v_0(t)$ and phase C current $i_c(t)$ on the same graph by using **Fig.3** as the reference waveform. [2]

1.3. Determine the relationship between the average output voltage of the rectifier (V_0) and the rms voltage of phase A (V_r). [2]

1.4. **Fig. 4** shows a voltage multiplier circuit with input voltage source $V_{in} = 100\sqrt{2}\sin(\omega t)$.

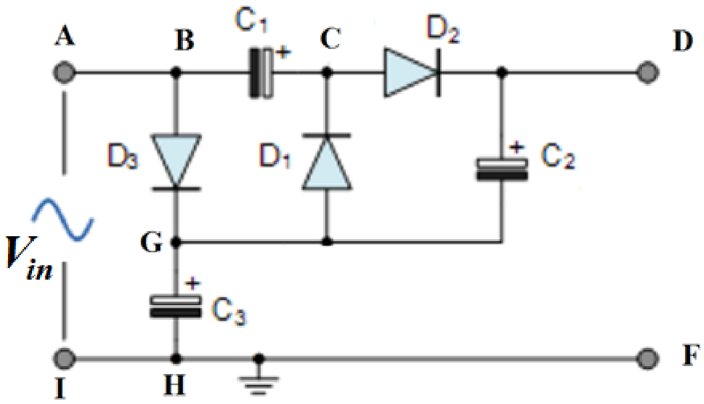


Fig. 4

a) Determine the voltage across the terminals G and H [0.5]
b) Determine the voltage across the terminals B and C [1]
c) Determine the voltage across the terminals D and G [1]
d) Determine the voltage across the terminals D and F [0.5]

QUESTION 2 [7 MARKS]

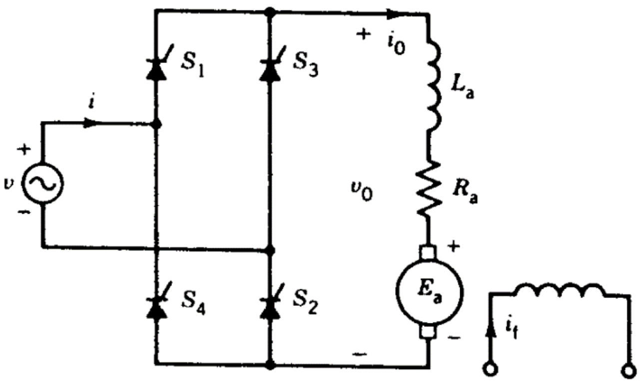


Fig. 5

The speed of a dc motor is controlled by a single-phase ac-dc thyristor converter, as shown in **Fig. 5.** The ac supply is single phase 240 V (rms value), 50 Hz. The armature resistance is $R_a = 1\Omega$ and armature circuit inductance is $L_a = 50\ mH$. The motor voltage constant is 0.055

V/rpm. The field current of the motor is adjusted such that the armature voltage E_a is negative. The thyristors are fired at an angle $\alpha = 60^0$ and the speed of the dc machine is 200 rpm. Assume that the dc machine current is **continuous and ripple-free**

2.1. Determine the average value (I_0) for the dc machine current. **[2]**

2.2. Is the ac supply receiving power or delivering power? Determine this power (P_{ac}). **[1]**

2.3. Is the dc machine delivering power or receiving power? Determine this power (P_a). **[1]**

2.4. Where is all the power being lost or dissipated? Determine this power (P_x). **[1]**

2.5. Determine the supply power factor. **[2]**

SOLUTIONS

QUESTION 1 [5 MARKS]

In Figure 1 below, a block diagram showing the various components of a DC motor drive used for the propulsion of an electric vehicle is provided. This electric vehicle is designed to provide both forward motoring and reverse braking operation. The DC-DC converter is a type of DC chopper, the DC motor (shown as DC machine in Fig. 1) operates at rated speed of 5000 rpm and the fixed gear (FG) is incorporated to step-down the speed to 1000 rpm for driving the vehicle wheels.

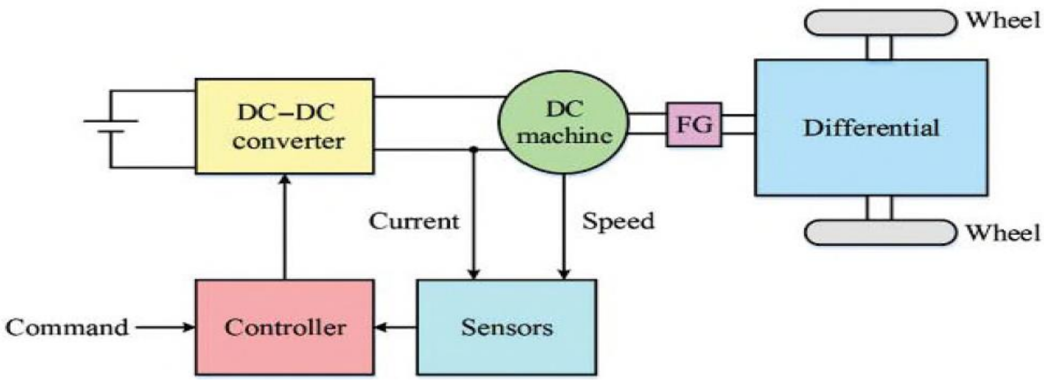


Figure 1: Configuration of DC Motor Drive for Electric Vehicle Propulsion

Answer the following:

1.1. State the class of DC motor that is ideal for the above application (hint: consider the rated speed of the DC motor) and explain the reason for your choice. **[2]**

Ans:

Brush-Less DC Motor (BLDC) is ideal for the propulsion of electric vehicle. **[1]**

The DC motor is required to operate at about 5000 rpm; at this speed the physical size of the motor is reduced considerably, making it possible for the motor to fit into the limited space of the electric vehicle. The speed of conventional brushed DC motors such as, field-winding DC motors and permanent magnet DC motors are limited to about 1000 rpm due to the commutator-brush assembly.

By eliminating the brush from the DC motor in the case of a BLDC, the associated drawbacks of the commutator-brush assembly is mitigated. **[1/2+1/2]**

1.2. State two advantages of using a DC chopper for the above application and also state the type of chopper required for the application. **[2]**

Ans:

Two Advantages of Chopper Fed DC Motor: **[1/2 + 1/2]**

- Control flexibility.

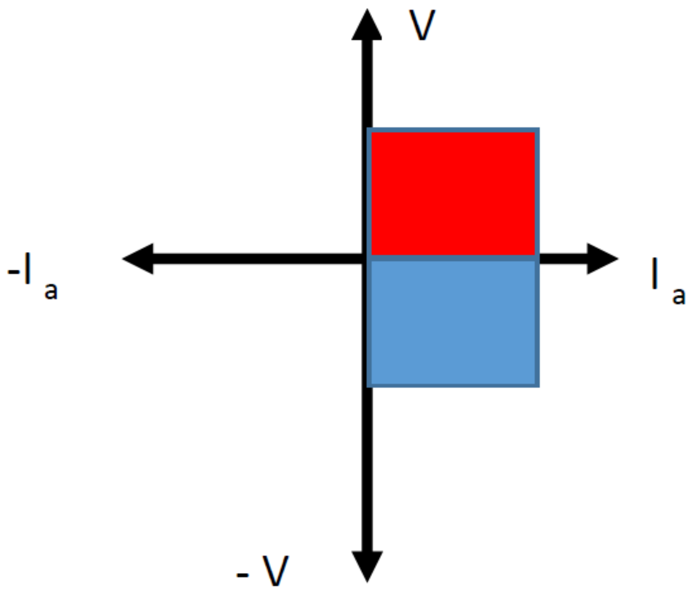
- Lightweight.

- Regenerative braking down to low speed.

- High efficiency.

The Class-D (two-quadrant) chopper is required for the application. **[1]**

1.3. Draw a well-labelled diagram to illustrate the quadrants of operation for the above application; show the polarity of the armature voltage, and armature current in each quadrant. **[1]**



QUESTION 2 [10 MARKS]

A 220 V, 960 rpm, 80 A, separately excited dc motor has an armature resistance of 0.06Ω. Under rated conditions, the motor is driving a load whose torque is constant below base speed. The speed of the motor is controlled below rated speed by means of armature voltage control. Furthermore, its speed above rated speed is controlled by means of field control (with rated armature voltage). Determine the following:

2.1. The terminal voltage of the motor when the speed is adjusted to 620 rpm. [2]

Ans:

The back-emf at 960 rpm,

$V_t = E_a + I_a R_a$

$E_a = V_t - I_a R_a$

$E_a = 220 - (80 \times 0.06) = 215.2\ V$ [1]

$Back\ emf\ at\ 620\ rpm\ is;$

$\frac{E_{a1}}{E_a} = \frac{620}{960}$

$E_{a1} = \frac{620}{960} \times 215.2 = 138.98\ V$

$motor\ terminal\ voltage\ V_t = E_{a1} + I_a R_a$

$V_t = 138.98 + (80 \times 0.06) = 143.78\ V$ [1]

2.2. The value of flux as a percentage of rated flux if the motor speed is 1200 rpm. (Neglect the motor's rotational losses). [1]

Ans:

In field weakening above the base speed; $E_a, V_t, \&\ I_a$ *are all constant.*

$\therefore, \quad E_{a2} = E_{a1}$

$\therefore, k_e \emptyset_2 \omega_2 = k_e \emptyset_1 \omega_1$

$\emptyset_2 = \frac{\omega_1}{\omega_2} \cdot \emptyset_1$

$\emptyset_2 = \frac{960}{1200} \cdot \emptyset_1$

$\emptyset_2 = 80\ \%\ (\emptyset_1)$ [1]

2.3. The developed torque of the motor at 1200 rpm. [1]

Ans:

$T_{e1} = k_e \emptyset_1 I_{a1}$

$T_{e2} = k_e \emptyset_2 I_{a2}$

$but, I_{a1} = I_{a2}$

$\frac{T_{e1}}{T_{e2}} = \frac{k_e \emptyset_1}{k_e \emptyset_2} = \frac{\omega_2}{\omega_1}$

$\therefore, \frac{T_{e2}}{T_{e1}} = \frac{\omega_1}{\omega_2}$

$T_{e2} = \frac{\omega_1}{\omega_2} \cdot T_{e1}$

$T_{e2} = \frac{960}{1200} \cdot T_{e1}$

$T_{e1} = \frac{P}{\omega_1} = \frac{E_a \cdot I_a}{\omega_1} = \frac{215.2 \times 80}{\left(960 \times \frac{2\pi}{60}\right)} = 171.25\ Nm$ [0.5]

$T_{e2} = \frac{960}{1200} \cdot 171.25 = 137\ Nm$ [0.5]

2.4. If the motor is also considered for a low-speed application under rated conditions, which requires rated torque with a peak-to-peak ripple of less than 2% at 960 rpm. Determine the peak-to-peak ripple torque requirement for this application. [1]

Ans:

$T_e = \frac{P}{\omega_1} = \frac{E_a \cdot I_a}{\omega_1} = \frac{215.2 \times 80}{\left(960 \times \frac{2\pi}{60}\right)} = 171.25\ Nm$ [0.5]

$Peak - to - peak\ ripple\ torque = 0.02 \times 171.25 = 3.425\ Nm$ [0.5]

2.5. If the separately-excited DC motor is brought to rest from 300 rpm, by switching off the supply and placing a resistor across the armature terminal of the motor. Calculate the braking resistance value to limit the armature current to twice the rated value while neglecting the effect of the inductance. [2]

Ans:

$Rated\ Condition\ (960\ rpm)$

$E_b = 220 - (80) \times (0.06) = 215.2V$ [0.5]

$At\ 300\ rpm, the\ back\ emf\ is;$

$E_{b1} = \frac{300}{960} \times 215.2 = 67.3V$ [0.5]

$R_a + R_b = \frac{E_{b1}}{2 \times I_a} = \frac{67.3}{2 \times 80} = 0.420\ \Omega$ [0.5]

$R_b = 0.420 - 0.06 = 0.360\ \Omega$ [0.5]

2.6. If a Class-A chopper is connected to the separately excited DC motor for effective speed control. The armature inductance of the motor is given as 5mH. The chopper is operated at a switching frequency of 1 kHz with a duty cycle of 50%, while the rotor of the DC motor is locked at standstill. Calculate the value of the on-time of the switching device in the chopper and determine the load time constant. [2]

Ans:

The chopper period, $T_s = 1/1000 = 1ms$

Duty ratio, $\delta = t_{on}/T_s$

$\therefore, t_{on} = 0.5\ ms$ [1]

$Load\ time\ constant, \tau = L_a/R_a = 0.083s$ [1]

2.7. If the switching frequency of the chopper is increased four times to 4 kHz and the value of the armature inductance is increased to 20mH, explain the impact of this increase on the armature current ripple and losses in the dc motor drive. [1]

Ans:

By increasing the switching frequency and the inductance, the armature current ripple is reduced, but the switching losses is further increased due to higher switching frequency. [1]

PART B: POWER ELECTRONICS Marks: 15

QUESTION 1 [8 MARKS]

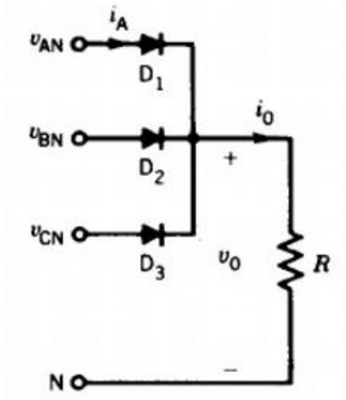


Fig. 2

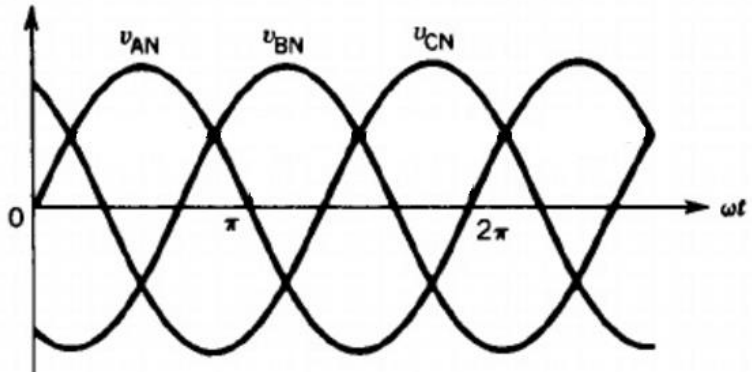


Fig. 3

Fig. 2 shows an uncontrolled rectifier connected to a three-phase voltage source. The phase voltages are $v_{AN}(t)$, $v_{BN}(t)$ and $v_{CN}(t)$ respectively. The waveform of the three-phase voltage source connected to the uncontrolled rectifier is shown in **Fig. 3**

If $v_{AN}(t) = V_p\ \sin(\omega t)$, where V_p is the peak voltage of phase A.

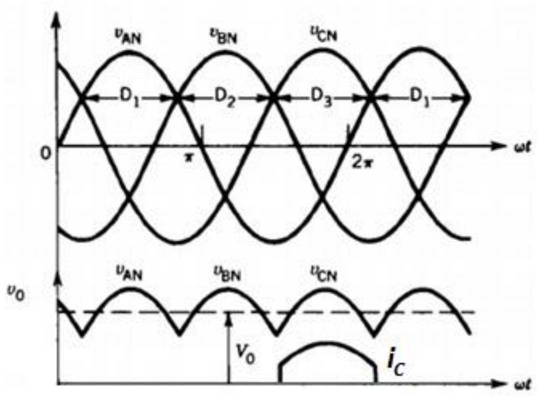
1.1. Write the equations for phase voltages $v_{BN}(t)$ and $v_{CN}(t)$ [1]

Ans:

$v_{BN}(t) = V_p\ \sin(\omega t - 120)$
$v_{CN}(t) = V_p\ \sin(\omega t + 120)$
[1/2] each

1.2. Draw the output waveform $v_0(t)$ and phase C current $i_c(t)$ on the same graph by using **Fig. 3** as the reference waveform. [2]

Ans:



[1] mark for the output voltage waveform and [1] mark for the current waveform.

1.3. Determine the relationship between the average output voltage of the rectifier (V_0) and the rms voltage of phase A (V_r). [2]

Ans:

$v_{AN}(t) = V_p \sin(\omega t)$ can be written as $v_{AN}(t) = \sqrt{2}V_r \sin(\omega t)$ [1/2]

$$V_0 = \frac{1}{\frac{2\pi}{3}} \int_{\frac{\pi}{6}}^{\frac{5\pi}{6}} \sqrt{2}V_r \sin(\omega t) d\,\omega t$$ [1]

(1/2 mark for the period and ½ for the limits)

$$V_0 = \frac{3\sqrt{6}}{2\pi} V_p = 1.17 V_r$$ [1/2]

1.4. **Fig. 4** shows a voltage multiplier circuit with input voltage source $V_{in} = 100\sqrt{2}\sin(\omega t)$.

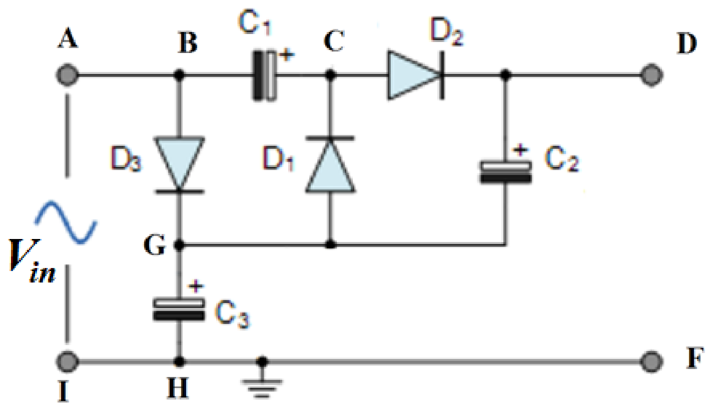


Fig. 4

e) Determine the voltage across the terminals G and H [0.5]

$100\sqrt{2}$V

f) Determine the voltage across the terminals B and C [1]

$200\sqrt{2}$

g) Determine the voltage across the terminals D and G [1]

$200\sqrt{2}$

h) Determine the voltage across the terminals D and F [0.5]

$300\sqrt{2}$

QUESTION 2 [7 MARKS]

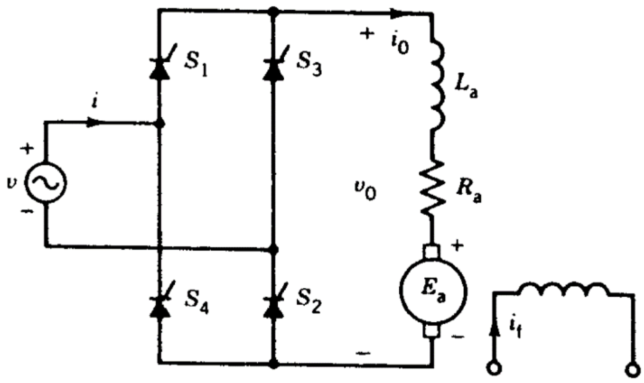


Fig. 5

The speed of a dc motor is controlled by a single-phase ac-dc thyristor converter, as shown in **Fig. 5.** The ac supply is single phase 240 V (rms value), 50 Hz. The armature resistance is $R_a = 1\Omega$ and armature circuit inductance is $L_a = 50\ mH$. The motor voltage constant is 0.055 V/rpm. The field current of the motor is adjusted such that the armature voltage E_a is negative. The thyristors are fired at an angle $\alpha = 60^0$ and the speed of the dc machine is 200 rpm. Assume that the dc machine current is **continuous and ripple-free**

2.1. Determine the average value (I_0) for the dc machine current. **[2]**

Ans:

$V_0 = \frac{2\sqrt{2}}{\pi} V_s\, cos\alpha = 0.9(240)(0.5) = 108\ V$ [0.5]

$E_a = 0.055x200 = 11\ V$ [0.5]

$V_0 = I_0 R + E_a$ [0.5]

Note armature voltage E_a is negative

$I_0 = \frac{V_0 - E_a}{R} = \frac{108-(-11)}{1} = 119\ A$ [0.5]

2.2. Is the ac supply receiving power or delivering power? Determine this power (P_{ac}). **[1]**

Ans:

ac supply is delivering power [0.5]

$P_{ac} = P_0 = V_0 I_0 = 108x119 = 12852\ W$ [0.5]

2.3. Is the dc machine delivering power or receiving power? Determine this power (P_a). **[1]**

Ans:

dc machine is delivering power [0.5]

$P_a = 11x119 = 1309\ W$ [0.5]

2.4. Where is all the power being lost or dissipated? Determine this power (P_x). **[1]**

Ans:

All the power lost in or going to the resistance

$P_R = I_0^2 R = 119^2(1) = 14161\ W$

Or

$P_R = P_a + P_{ac} = 1309\ + 12852\ W = 14161\ W$ [1]

2.5. Determine the supply power factor. **[2]**

Ans:

Supply volt ampere (S)

$S = 240\ x\ 119 = 28560\ VA$ [1]

$PF = \frac{P_{ac}}{S} = \frac{12852}{28560} = 0.45$ [1]