EEE4117F QUIZ 3 **TOTAL MARKS: 30**
DATE: 12 JUNE 2020 **TIME: 1 HOUR (X2)**

PART A: MACHINES **Marks: 15**

QUESTION 1 **[5 MARKS]**

Draw a **detailed** circuit diagram of an induction motor drive with a diode bridge rectifier on the front-end, which is fed from a 3-phase supply. Explain which modes of operation can be achieved with this drive and why? Show how your circuit can be modified to achieve **dynamic braking** of the motor.

QUESTION 2 [10 MARKS]

A Y-connected induction motor has the following ratings and parameters:

$$400\ V,\ 50\ Hz,\ 4-poles,\ 1370\ rpm,\ R_s = 2\ \Omega,\ R_r' = 3\ \Omega,\ X_s = X_r' = 3.5\ \Omega$$

The induction motor is fed by a voltage source inverter at a constant V/f ratio. The voltage source inverter allows frequency variation from $10\ Hz$ to $50\ Hz$. Answer the following:

2.1. Calculate the operating speed of the motor when the supply frequency is reduced to $30\ Hz$ and the motor delivers 80% of the full-load torque. **[3]**

2.2. Calculate the supply frequency when the motor operates at $1000\ rpm$ and delivers the full-load torque. **[2]**

2.3. If the supply frequency of the motor is regulated to $40\ Hz$, and the motor operates at a speed of $1100\ rpm$. Determine the percentage of the full-load torque delivered. [**3**]

2.4. Calculate the operating speed of the motor when the supply frequency is reduced to $30\ Hz$ and the motor delivers 80% of the full-load torque, when the inverter-fed induction motor is operating in the **regenerative braking mode**. **[2]**

PART B: POWER ELECTRONICS **Marks: 15**

QUESTION 1 **[7 MARKS]**

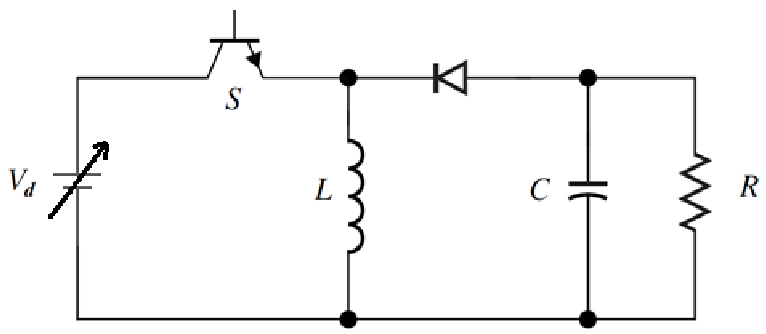


Fig. 1

A variable dc voltage source (V_d) is connected to the buck-boost converter as shown in Fig.1. The output voltage across the resistive load R is maintained at -12 V by varying the duty cycle (D) of the converter between 0.46 and 0.545. The power rating of the resistor (R) is 15 W. The inductance of L is 1.25 times the value of the inductance required to ensure the converter's continuous conduction. The switching frequency of the converter is 50 kHz. The output voltage ripple (ΔV_o) must be less than 1 percent of the output voltage. Answer the following questions:

1.1. Determine the voltage range of the variable dc voltage source (V_d) **[1]**

1.2. Determine all the possible values of inductors and propose the best inductor for the buck-boost converter. **[3]**

1.3. Determine the possible values of capacitors and propose the best capacitor for the buck-boost converter. **[2]**

1.4. Name one similarity between the buck-boost converter and the Cuk converter. **[1]**

QUESTION 2 [8 MARKS]

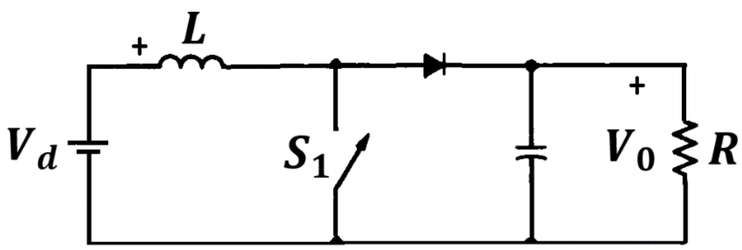


Fig. 2

The boost converter in **Fig. 2** is required to have an output voltage of 8V and supply a load current of 1A through the R. The switching frequency of the converter is 100 kHz. The input voltage varies from 2.7 to 4.2 V. A control circuit adjusts the duty ratio (**D**) to keep the output voltage constant.

2.1. Determine a value for the inductor indicating reasons for your selection to ensure the variation in inductor current is no more than 45 percent of the average inductor current for all operating conditions. Assume continuous conduction mode of operation. **[6]**

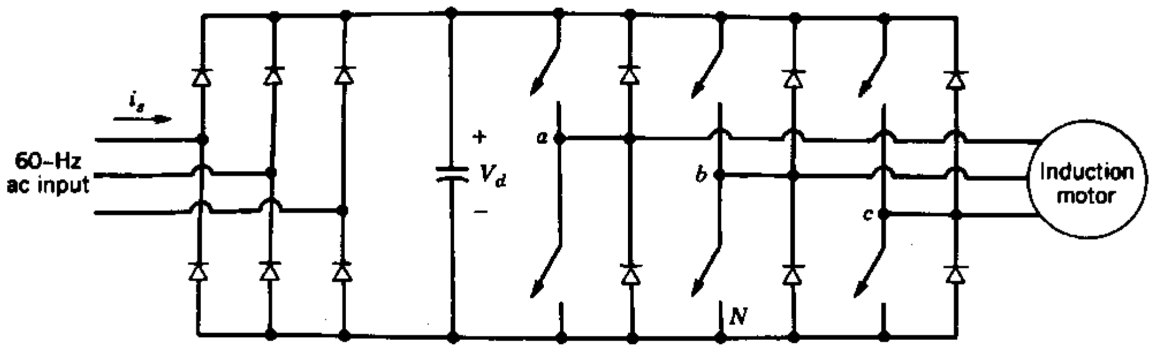
2.2. Determine a value for an ideal capacitor such that the output voltage ripple is no more than 1 percent. **[2]**

SOLUTIONS

QUESTION 1 [5 MARKS]

Draw a **detailed** circuit diagram of an induction motor drive with a diode bridge rectifier on the front-end, which is fed from a 3-phase supply. Explain which modes of operation can be achieved with this drive and why? Show how your circuit can be modified to achieve **dynamic braking** of the motor.

Ans:



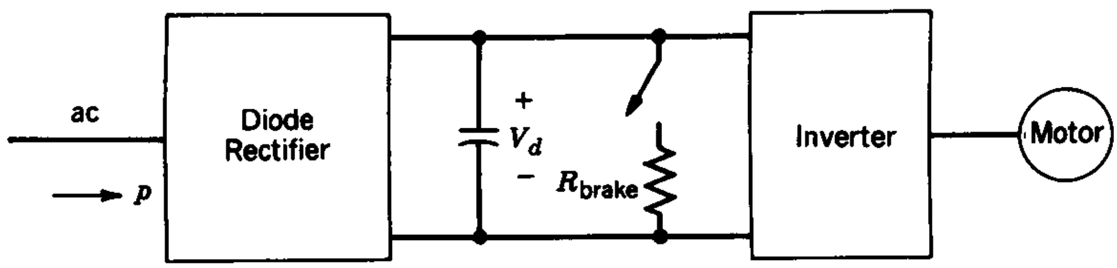
[3]

Q: Explain which modes of operation can be achieved with this drive and why?

Ans: Modes of operation: Motor mode only in a forward or reverse direction. Reason is because energy cannot be returned to supply through front-end rectifier. [1]

Q: Show how your circuit can be modified to achieve dynamic braking of the motor.

Ans: Dynamic braking can be achieved by adding braking resistor across the DC-link. This should be illustrated as in circuit below or by adding resistor across DC-link in circuit above. [1]



QUESTION 2 [10 MARKS]

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The induction motor is fed by a voltage source inverter at a constant V/f ratio. The voltage source inverter allows frequency variation from 10 Hz to 50 Hz. Answer the following:

2.1. Calculate the operating speed of the motor when the supply frequency is reduced to 30 Hz and the motor delivers 80% of the full-load torque. **[3]**

Ans:

At 50 Hz,

$Synchronous\ speed(N_s) = \frac{120f}{P} = \frac{120\times 50}{4} = 1500\ rpm$

The motor's slip speed at full-load torque is: $1500 - 1370 = 130\ rpm$ [1]

The motor's slip speed at 80% of full-load torque is: $130 \times 0.8 = 104\ rpm$ [1]

At 30 Hz, and constant load torque at 80% of rated torque, slip speed constant at 104*rpm*

$Synchronous\ speed(N_s) = \frac{120f}{P} = \frac{120\times 30}{4} = 900\ rpm$

Motor speed= $900\ rpm - 104\ rpm = 796\ rpm$ [1]

2.2. Calculate the supply frequency when the motor operates at 1000 rpm and delivers the full-load torque. **[2]**

Ans:

Under rated load torque conditions, slip speed remains constant at ***130rpm***, which was calculated under rated supply frequency of *50Hz*.

The synchronous speed associated with the operation of the motor at rated load and at this unknown supply frequency can be determined by simply adding the rated slip speed to the operating shaft speed: $N_s = 1000 + 130 = 1130\ rpm$ [1]

$f = \frac{N_s \cdot p}{120} = \frac{1130\times 4}{120} = 37.67\ Hz$ [1]

2.3. If the supply frequency of the motor is regulated to 40 Hz, and the motor operates at a speed of 1100 rpm. Determine the percentage of the full-load torque delivered. [**3**]

Ans:

At 40 Hz,

$Synchronous\ speed(N_s) = \frac{120f}{P} = \frac{120\times 40}{4} = 1200\ rpm$ [0.5]

The slip speed at this unknown load torque is: $1200 - 1100 = 100 rpm$ [0.5]

The ratio of the unknown load torque to rated load torque is equal to the ratio of the operating slip speed of 100rpm (with the unknown load torque) to the rated operating slip speed of 130rpm (with rated load torque).

$\therefore\ Torque\ delivered\ at\ 1100\ rpm = \frac{100}{130} \cdot T_F$ [1]

$\therefore\ Torque\ delivered\ at\ 1100\ rpm$ is at: **76.9%** of the full-load torque. [1]

2.4. Calculate the operating speed of the motor when the supply frequency is reduced to 30 Hz and the motor delivers 80% of the full-load torque, when the inverter-fed induction motor is operating in the **regenerative braking mode**. **[2]**

Ans:

At 50 Hz,

The motor's slip speed at 80% of full-load torque is as calculated above: ***104rpm*** [0.5]

At 30 Hz, the synchronous speed is as calculated above: ***900rpm*** [0.5]

In regenerative braking mode of operation, the shaft speed is greater that synchronous speed, therefore, the motor speed is: $900\ rpm + 104\ rpm = 1004\ rpm$ [1]

PART B: POWER ELECTRONICS Marks: 15

QUESTION 1 **[7 MARKS]**

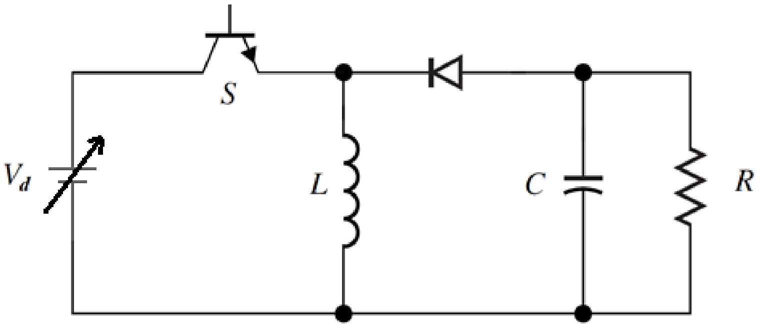

Fig. 1

A variable dc voltage source (V_d) is connected to the buck-boost converter as shown in Fig.1. The output voltage across the resistive load R is maintained at -12 V by varying the duty cycle (D) of the converter between 0.46 and 0.545. The power rating of the resistor (R) is 15 W. The inductance of L is 1.25 times the value of the inductance required to ensure the converter's continuous conduction. The switching frequency of the converter is 50 kHz. The output voltage ripple (ΔV_o) must be less than 1 percent of the output voltage. Answer the following questions:

1.1. Determine the voltage range of the variable dc voltage source (V_d) **[1]**

Ans:

$$D = \frac{|V_0|}{V_d+|V_0|}$$

$$0.545 = \frac{12}{V_d+12} \qquad [0.5]$$

$$V_d = 10\ V$$

$$0.46 = \frac{|V_0|}{V_d+|V_0|} = \frac{12}{V_d+12} \qquad [0.5]$$

$$V_d = 14\ V$$

$$10 \leq V_d \leq 14$$

1.2. Determine all the possible values of inductors and propose the best inductor for the buck-boost converter. **[3]**

Ans:

$$R = \frac{V^2}{P} = \frac{(-12)^2}{15} = 9.6\ \Omega \qquad [0.5]$$

$$(\mathrm{L})_{\mathrm{D_1 min}} = \frac{(1-\mathrm{D})^2\mathrm{R}}{2\mathrm{f}} = \frac{(1-0.545)^2 9.6}{2(50000)} = 19.87\ \mu\mathrm{H} \qquad [0.5]$$

$$(\mathrm{L})_{\mathrm{D_1}} = 1.25(\mathrm{L})_{\mathrm{D_1 min}} = 24.84\ \mu\mathrm{H} \qquad [0.5]$$

$$(\mathrm{L})_{\mathrm{D_2 min}} = \frac{(1-\mathrm{D})^2\mathrm{R}}{2\mathrm{f}} = \frac{(1-0.46)^2 9.6}{2(50000)} = 27.99\ \mu\mathrm{H} \qquad [0.5]$$

$$(\mathrm{L})_{\mathrm{D_2}} = 1.25(\mathrm{L})_{\mathrm{D_2 min}} = 34.99\ \mu\mathrm{H} \qquad [0.5]$$

The best inductor for the above circuit should have an inductance greater than $34.99\ \mu H$. [0.5]

1.3. Determine the possible values of capacitors and propose the best capacitor for the buck-boost converter. **[2]**

Ans:

$\Delta V_0 = 1\% * 12 = 0.12$ V [0.5]

$C_{D_1} = \frac{D}{R\left(\frac{\Delta V_0}{V_0}\right)f} = \frac{0.545}{9.6\left(\frac{0.12}{12}\right)50000} = 113.5\ \mu F$ [0.5]

$C_{D_1} = \frac{D}{R\left(\frac{\Delta V_0}{V_0}\right)f} = \frac{0.46}{9.6\left(\frac{0.12}{12}\right)50000} = 95.8\ \mu F$ [0.5]

The best capacitor for the above circuit should have a capacitance greater than 113.5 µF. [0.5]

1.4. Name one similarity between the buck-boost converter and the Cuk converter. **[1]**

Ans:

The output voltage is negative with respect to the input voltage. [1]

QUESTION 2 **[8 MARKS]**

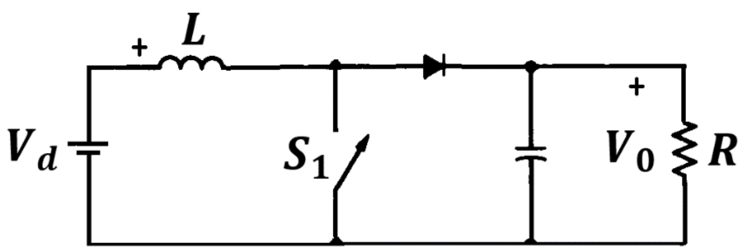

Fig. 2

The boost converter in **Fig. 2** is required to have an output voltage of 8V and supply a load current of 1A through the R. The switching frequency of the converter is 100 kHz. The input voltage varies from 2.7 to 4.2 V. A control circuit adjusts the duty ratio (**D**) to keep the output voltage constant.

2.1. Determine a value for the inductor indicating reasons for your selection to ensure the variation in inductor current is no more than 45 percent of the average inductor current for all operating conditions. Assume continuous conduction mode of operation. **[6]**

Ans:

For $V_s = 2.7$

$D = 1 - \frac{V_s}{V_0} = 1 - \frac{2.7}{8} = 0.663$ [0.5]

Average inductor current

$I_L = \frac{V_0 I_0}{V_s} = \frac{8(1)}{2.7} = 2.96\ A$ [0.5]

Variation of inductor current to meet 45% specification is
$\Delta i_L = 0.45(2.96) = 1.332\ A$ [0.5]
Determine the inductance
$L = \frac{V_S D}{\Delta i_L f} = \frac{2.7(0.663)}{1.332(100{,}000)} = 13.44\mu H$ [1]

Repeating the calculations for $V_s = 4.2$
$D = 1 - \frac{V_s}{V_0} = 1 - \frac{4.2}{8} = 0.475$ [0.5]
Average inductor current

$I_L = \frac{V_0 I_0}{V_s} = \frac{8(1)}{4.2} = 1.90\ A$ [0.5]

Variation of inductor current to meet 45% specification is
$\Delta i_L = 0.45(1.90) = 0.855\ A$ [0.5]
Determine the inductance
$L = \frac{V_S D}{\Delta i_L f} = \frac{4.2(0.475)}{0.855(100{,}000)} = 23.33\mu H$ [1]

Inductor must be at least $23.33\mu H$ to satisfy the specification for the total range of input voltages. [1]

2.2. Determine a value for an ideal capacitor such that the output voltage ripple is no more than 1 percent. **[2]**

The highest duty cycle must be selected! D=0.663 [1/2] mark

$$C = \frac{D}{R(\Delta V_0/V_0)f} = \frac{D}{(V_0/I_0)(\Delta V_0/V_0)f} = \frac{0.663}{(8/1)(0.01)100000} = 82.88\ \mu F$$

[1/2] mark for the calculation of R in the above equation and [1] mark for the value of C.