UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: October 2019

Module Number: EE7202 **Module Name: Power Electronic Applications**

[Three Hours]

[Answer **all questions**, each question carries 12 marks]

Q1. a) The circuit diagram of a practical forward converter is shown in Figure Q1(a). All notations in the figure have their usual meanings. The output voltage of this forward converter is given by

$$V_o = \frac{N_s}{N_p} D\, V_d$$

where D is the duty ratio of the switch S, V_d is the input voltage, and N_s/N_p is the turns ratio of the transformer (secondary winding to primary winding).

i) For the practical forward converter shown in Figure Q1(a), derive an expression for the maximum duty ratio of the switch S.

ii) Derive an expression for the maximum voltage stress on the switch S.

(3.5 Marks)

b) You are given a switch with voltage rating of 400 V. You have to use this switch to design a forward converter, which gives 48 V dc output voltage for input voltage range of 100 V-120 V. Consider switching frequency of 20 kHz. The expected load current variation is 0.5 A – 5.0 A.

i) Find appropriate turns ratios for $N_p: N_T$ and $N_p: N_s$.

ii) In your design in part b)(i), calculate the maximum voltage stress on the switch S and the variation of the duty ratio for the given input voltage variation.

iii) Calculate the size of the filter inductor needed to maintain continuous conduction of inductor current at minimum load current of 0.5 A. Equations that may require to calculate the inductor size must be derived.

(8.5 Marks)

Q2. a) i) State two types of series connected FACTS controllers and draw their circuit diagrams.

ii) What power system parameters are controlled by each FACTS controller mentioned in part i) above?

iii) Draw the circuit diagram of a single-phase grid connected solar PV inverter with electrical isolation, which is used to transfer maximum possible power from PV panels to the grid.

(3.5 Marks)

b) i) Can a wind turbine be connected to the grid via a permanent magnet synchronous generator (PMSG) as shown in Figure Q2(b)? Explain your answer.

ii) Suppose you are asked to design a wind energy conversion system to extract maximum power from a wind turbine using an electrically excited synchronous generator (EESG). Draw the diagram of the proposed system and name all the components.

(3.0 Marks)

c) Figure Q2(c) shows a monopolar HVDC link which connects AC systems in two cities in Japan. The length of this HVDC link is 200 km, and it is operating at nominal voltage of 300 kV. The rated capacity of the line is 500 MW. The leakage reactance of the transformers in AC-1 side is 32 Ω and AC-2 side is 26 Ω.
At a certain loading condition, AC-1 system transfers 420 MW of power to AC-2 system. At this loading condition, the dc voltage at AC-1 side is 310 kV and the dc voltage at AC-2 side is 295 kV. The ac side line voltages at AC-1 side is 152 kV and at AC-2 side is 154 kV.

i) Calculate the current in the HVDC line.

ii) Calculate the power loss in the HVDC line.

iii) Calculate the firing angle of the rectifier side.
Hint: The dc voltage of a 6-pulse phase-controlled rectifier with usual notations is given by

$$V_{dc} = \frac{3\sqrt{2}}{\pi} V_{LL} cos\alpha - \frac{3X_S}{\pi} I_{dc}.$$

iv) Calculate the amount of reactive power absorbed by the converters at the rectifier side.

v) From where the rectifier gets the required reactive power?

vi) How can the reactive power consumption of the rectifier be reduced?

(5.5 Marks)

Q3. a) i) How does a load-proportional capacity modulated heat pump differ from a conventional heat pump?

ii) Figure Q3(a) shows the block diagram of a load-proportional capacity modulated heat pump. What is the purpose of Block-A in this system?

iii) Draw a circuit diagram of a power electronic converter that can be used for Block-A.

iv) What is the function of power electronics in an induction cooker?

(4.0 Marks)

b) Suppose you are given a low frequency (50 Hz) transformer and a diode bridge rectifier. You are asked to design an electric welding circuit using these two components along with the other required components.

i) What are the three main requirements need to be considered when designing an electric welder?

ii) Draw the block diagram of the proposed electric welding system.

iii) Explain how you can achieve the requirements mentioned in part b)(i) in your proposed design.

iv) Suppose, you are asked to use a high frequency transformer in your design instead of the low frequency transformer. You also need to use the diode bridge rectifier, which was previously given. Now draw the block diagram of the new proposed electric welding system and name all the main components of the system. You may use other required components in your design.

v) What are the advantages of the design proposed in part iv) compared to the design proposed in part ii)?

(8.0 Marks)

Q4. a) Electromagnetic Interference (EMI) and harmonics are the major problems caused by power electronic devices.

i) Explain how the EMI generation take place in power electronic devices.

ii) State three measures that can be taken to reduce EMI generation from power electronic circuits?

iii) State two solutions used for improving the total harmonic distortion (THD) of the current drawn from the grid from a typical single-phase power electronic device.

(3.5 marks)

b) A 40.0 kVA three-phase balanced, Y connected, non-linear load is connected to the secondary side of a three phase 11 kV/415 V, Δ/Y, 50 kVA, 50 Hz transformer. The short circuit reactance of the transformer is 0.5 Ω, whereas its short circuit resistance can be assumed zero. The load is operating at 0.8 lagging power factor. The rms value of the current drawn from the grid by the load is 57 A. The harmonic spectrum of the load current is shown in Figure Q4(b).

i) Calculate the THD level of the current drawn by the non-linear load.

ii) Calculate the rms value of the fundamental current component.

iii) Calculate the displacement power factor (DPF) of the load.

iv) Calculate the THD level of the phase-voltages at PCC when the line-voltage at the secondary side of the transformer is 415 V. The secondary side voltage of the transformer contains only the 50 Hz component.

(8.5 Marks)

Q5. a) i) Matrix converter is a single-stage converter that has an array of $m \times n$ bidirectional power switches to connect directly a m-phase voltage source to an n-phase load. State the two constraints involved in switching of switches in a matrix converter?

ii) Draw two possible configurations of bi-directional switches, which can be used for matrix converters.

iii) State three limitations of traditional voltage source converters and current source converters that can be overcome by a Z-source converter.

(3.5 Marks)

b) The buck converter shown in Figure Q5(b) gives a 12 V output voltage for input voltage of 100 V. The power rating of this converter is 240 W. The circuit shown in the figure needs to be modified to improve the efficiency and to reduce the EMI generation from this converter.

i) Draw the circuit diagram of the modified step-down dc-dc converter that uses zero current switching (ZCS).

ii) Draw the waveforms of the current through the switch, and the voltage across the capacitor that is added to the circuit in part i).

Hint: Current through the inductor $i_L(t)$ and the voltage across the capacitor $v_C(t)$ of a LC series resonant circuit with usual notations are given by

$$i_L(t) = I_{Lo} \cos \omega_o(t - t_o) + \frac{V_d - V_{co}}{Z_o} \sin \omega_o(t - t_o)$$
$$v_C(t) = V_d - (V_d - V_{co}) \cos \omega_o(t - t_o) + Z_o I_{Lo} \sin \omega_o(t - t_o)$$

Current through the inductor $i_L(t)$ and the voltage across the capacitor $v_C(t)$ of a LC parallel resonant circuit with usual notations are given by

$$i_L(t) = I_d + (I_{Lo} - I_d) \cos \omega_o(t - t_o) + \frac{V_{co}}{Z_o} \sin \omega_o(t - t_o)$$
$$v_C(t) = Z_o(I_d - I_{Lo}) \sin \omega_o(t - t_o) + V_{co} \cos \omega_o(t - t_o)$$

Where $\omega_o = \frac{1}{\sqrt{L_r C_r}}$ and $Z_o = \sqrt{\frac{L_r}{C_r}}$

iii) The current rating of the switch used in the above buck converter circuit is 200 A. Calculate appropriate sizes for the inductor and the capacitor in the LC resonant circuit.

(8.5 Marks)

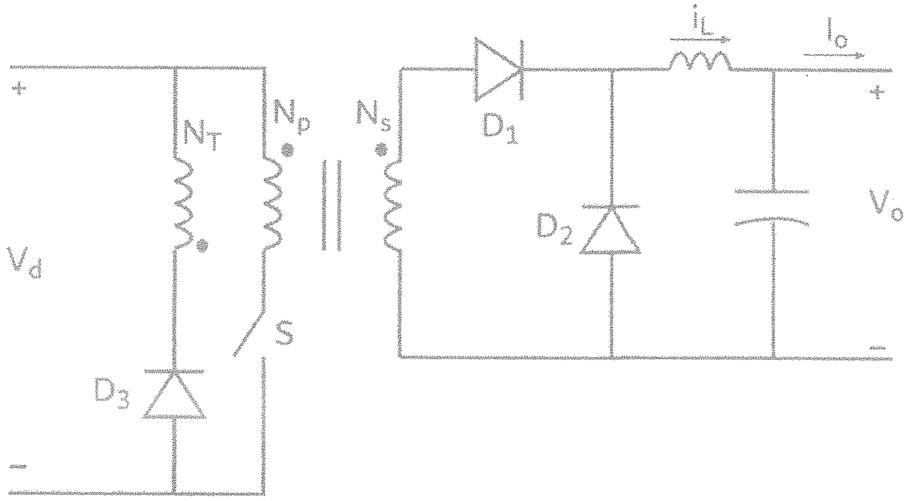

Figure Q1(a).

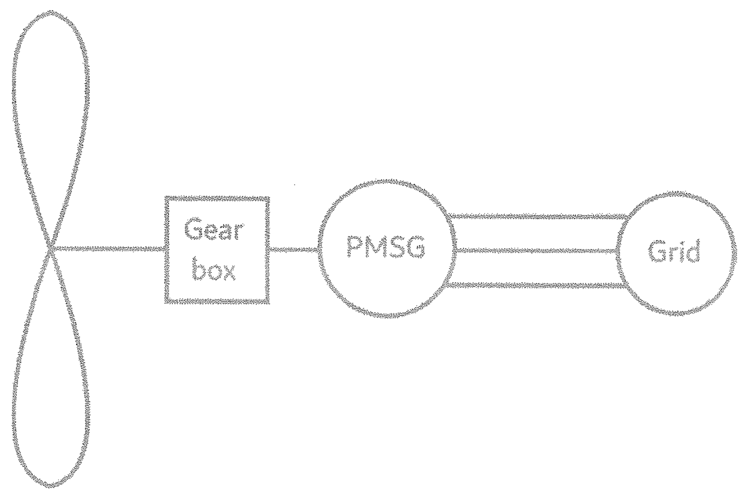

Figure Q2(b).

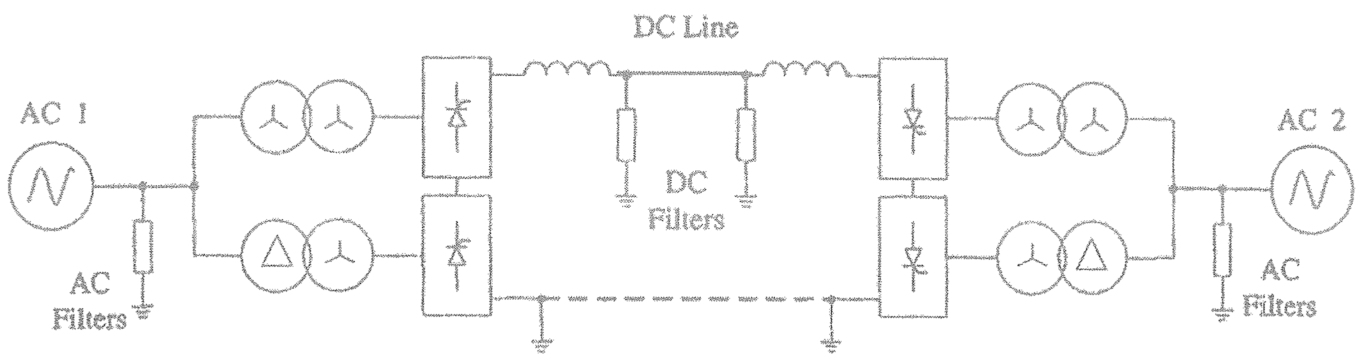

Figure Q2(c).

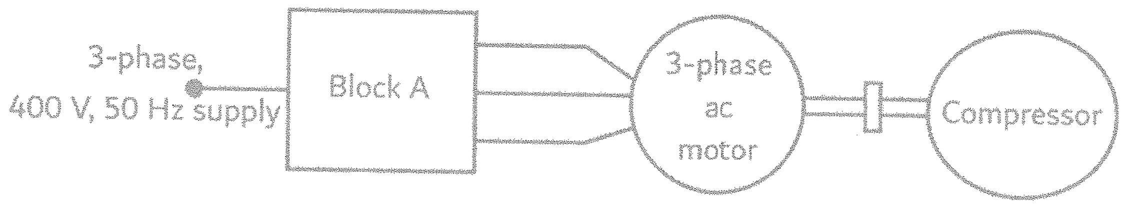

Figure Q3(a).

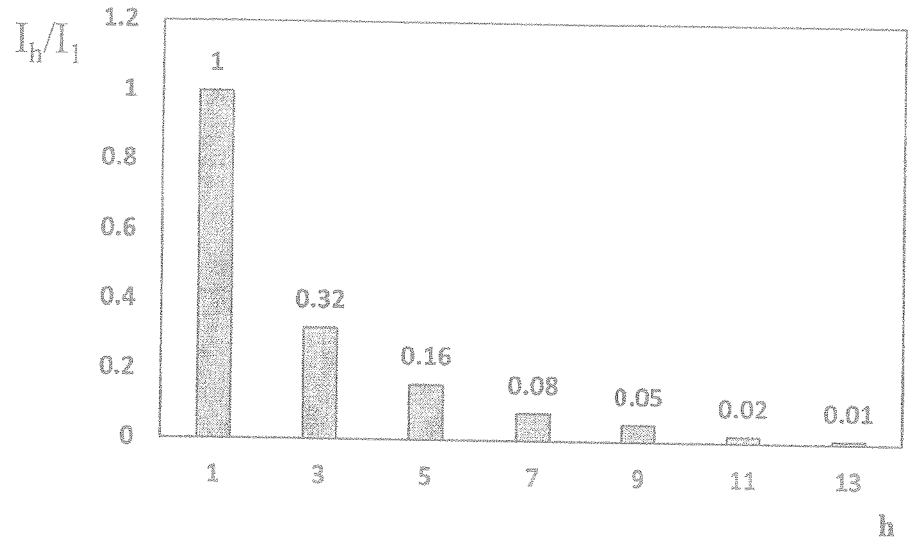

Figure Q4(b).

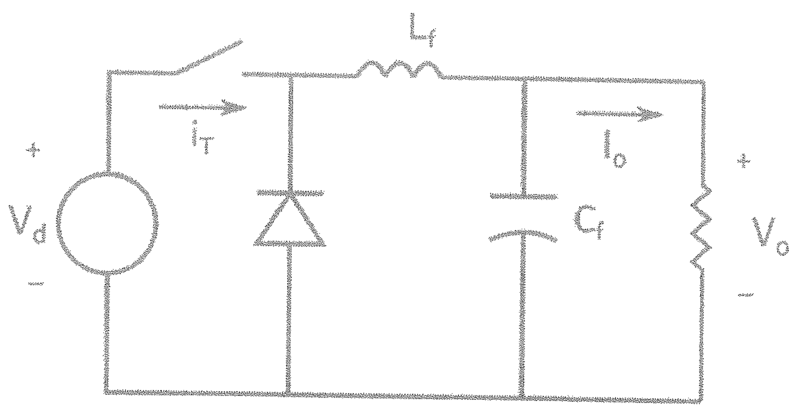

Figure Q5(b).