UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: March 2021

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

[Three Hours]

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

Q1. A DC power supply converts AC power from the main supply to steady DC power. The regulator stage of a DC power supply ensures a constant output voltage despite variations in the AC line voltage or circuit loading.

a) i) State two advantages of using a switching regulator over a linear regulator in a DC power supply.

ii) Forward converter is one of the popular switching regulator topologies used in DC power supplies. The circuit diagram of an ideal forward converter is shown in Figure Q1. Draw the circuit diagram of a practical forward converter and explain the reason for using a tertiary winding in the practical forward converter circuit.

[3.0 Marks]

b) A forward converter needs to be designed to give 48 V DC output voltage for the input voltage variation of 150 V - 220 V. The power rating of this converter is 2 kW. The frequency of 20 kHz is chosen as the switching frequency of the MOSFET switch. Consider the circuit diagram of the forward converter shown in Figure Q1 along with the tertiary winding with N_T turns and diode D_3 connected in series.

i) Calculate appropriate turns ratio for $N_p: N_s$ if $N_p: N_T$ is chosen to be 2:1.

ii) Calculate the maximum voltages across the switch S_w and diode D_3.

iii) Draw the following waveforms over two switching cycles.
Voltage across diode D_3
Voltage across switch S_w

iv) Calculate the size of the filter inductor needed to maintain continuous conduction of inductor current at minimum load current of 4.0 A.

v) Calculate the size of the filter capacitor required to maintain 1 V peak-to-peak ripple in the output voltage.

vi) Briefly explain how you will select the switch S_w, and the three diodes when designing this forward converter.

[9.0 Marks]

Q2. a) An alternating current transmission system incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability is known as a Flexible AC Transmission System (FACTS).

i) State two types of shunt type FACTS controllers and draw their circuit diagrams and V-I characteristics.

ii) State two types of series FACTS controllers and draw their circuit diagrams.

[4.0 Marks]

b) Figure Q2 shows a bipolar High Voltage DC (HVDC) transmission link which connects two AC grids in India namely X and Y. The rated capacity of this link is 500 MW. The length of the transmission line is 350 km and the resistance of the conductor is 0.06 Ω/km.
At a certain loading condition, the total power of 490 MW is transmitted from X side to Y side. At this loading condition, the DC voltage at X side is 505 kV. The AC side line-to-line voltage at X side is 130 kV.

i) Explain a reason for using 12-pulse converters instead of 6-pulse converters in HVDC transmission applications.

ii) Calculate the DC current and the power loss in the DC line.

iii) Calculate the firing angle of the thyristor converters at X side if all 6-pulse converters at that side operate at the same firing angle. The leakage reactances of the transformers at side X are 45.0 Ω.

Hint: The DC voltage of a 6-pulse phase-controlled rectifier is given by

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

iv) Calculate the DC voltage at Y side of the DC link.

v) Calculate the total reactive power drawn by the converters at X side.

vi) From where do the converters get the reactive power mentioned in v)?

[8.0 Marks]

Q3. a) i) Explain why power electronic converters are required in grid connected and off-grid applications of solar photovoltaic systems.

ii) Draw a block diagram of a stand-alone PV system that can supply both DC loads and single-phase AC loads. Explain the function of each power electronic converter used in your system.

iii) Draw circuit diagrams of all the power electronic converters used in your system in part ii).

[5.0 Marks]

b) In order to maximize the energy extraction, wind turbines need to be operated at variable speeds.

i) Explain how power electronic converters allow variable speed operation of a synchronous generator used in a grid connected wind energy conversion system.

ii) Draw the block diagram of a grid connected wind energy conversion system that uses a Synchronous Generator. The system should be able to maximize the energy extraction from the wind. Name all the power electronic converters used in this system.

iii) Suppose you have to design a wind energy conversion system using a doubly fed induction generator (DFIG) which is able to maximize energy extraction from the wind. Draw the block diagram of the proposed design.

iv) Explain the functions of each power electronic converter used in your proposed design in part iii).

[7.0 Marks]

Q4. a) i) Explain why a power electronic based washing machine is energy efficient than a conventional washing machine.

ii) Explain the function of power electronics in electric welding device.

iii) Draw block diagrams of two electric welding circuits where electric isolation is provided using a low frequency transformer.

iv) Draw a block diagram of the electrical circuit of an induction cooker. Name all the components.

v) What types of power electronic converter topologies are used for the conversion of DC to high frequency AC in an induction cooker? Draw the circuit diagram of one power electronic converter topology used in induction cooking applications.

[6.0 Marks]

b) An induction heater is connected to point A in a power system. The power grid beyond point A can be approximated by a voltage source and an equivalent reactance of 0.98 Ω as shown in Figure Q4. The line-to-line voltage of the voltage source is 415 V, 50 Hz and it does not contain harmonics. The rms value of the current drawn by the induction heater is 17.8 A. The harmonic content of the current drawn by the induction heater is listed in Table Q4. The active and reactive power drawn by the induction heater are 10 kW and 8 kVAr respectively.

i) Calculate the Total Harmonic Distortion (THD) level of the current drawn by the induction heater.

ii) Calculate the displacement power factor of the load.

iii) Calculate the THD level of the phase voltage at point A.
Hint: You may assume the difference between the voltage angles at the source and point A is zero.

[6.0 Marks]

Q5. a) i) Draw the circuit diagram of a matrix converter to connect 3-phase voltage source with a 3-phase load.

ii) What are the constraints involved when switching the switches of the matrix converter?

iii) State three advantages of a Z-source converter when compared with a conventional Voltage Source Converter (VSC).

[4.5 Marks]

b) You need to design a low weight, small size, high-power step-down DC-DC converter for solar photovoltaic applications. The efficiency of the converter also needs to be maximized.

i) What type of techniques are you going to use to achieve the above requirements in your design?

ii) Draw the circuit diagram of the proposed step-down DC-DC converter.

iii) Explain with the use of necessary voltage and/or current waveforms how the power losses can be minimized in your proposed converter in ii).

iv) The power rating of the step-down DC-DC converter mentioned above is 10 kW. The input and output DC voltages of the step-down DC-DC converter are 1000 V and 800 V respectively. Calculate appropriate values for the inductor and the capacitor of the resonant circuit if resonant converter is used.

[7.5 Marks]

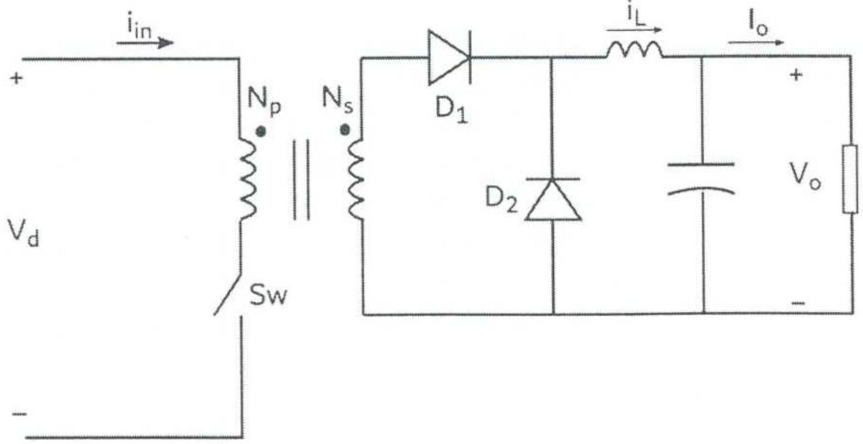

Figure Q1. Circuit diagram of an ideal forward converter.

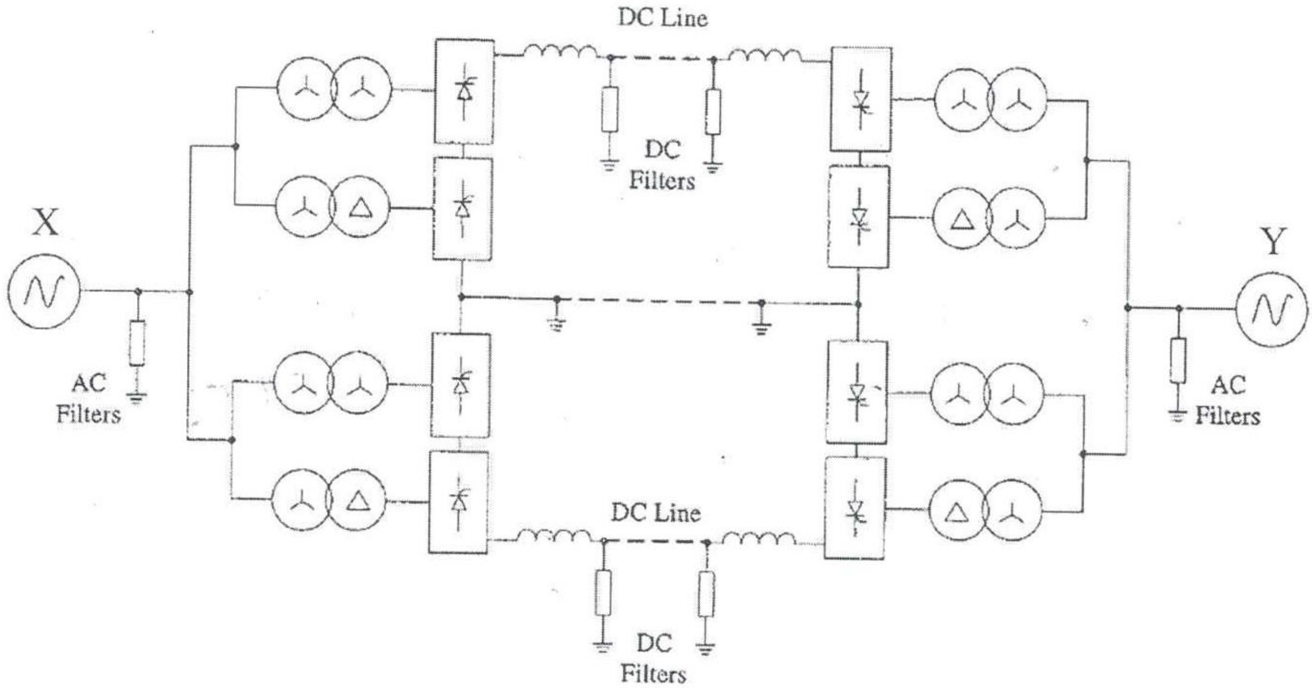

Figure Q2. Bipolar HVDC transmission system.

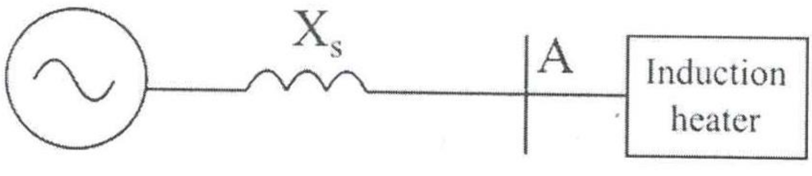

Figure Q4.

Table Q4.

h	3	5	7	9	11	13	15	$h > 15$
$\frac{I_h}{I_1}\%$	68.4	29.9	7.8	4.3	3.9	1.2	0.3	≈ 0