CODE	COURSE NAME	CATEGORY	L	T	P	CREDIT
EET454	SWITCHED MODE POWER CONVERTERS	PEC	2	1	0	3

Preamble: This course builds upon the course EET 306: Power Electronics, to give the students a detailed exposure to switched-mode power converter analysis and design. The objectives of this course are:

1. To give a comprehensive exposure to the power converter topologies widely used in the industry for power supply applications.
2. To equip the students with necessary theoretical knowledge to develop practical power converter designs.

Prerequisite: EET306 POWER ELECTRONICS

Course Outcomes: After the completion of the course the student will be able to

CO 1	Develop the basic design for non-isolated DC-DC converter topologies.
CO 2	Analyse isolated DC-DC converter topologies.
CO 3	Describe the operation of Switched mode inverters and rectifiers.
CO 4	Distinguish between inverter modulation strategies.
CO 5	Describe the operation of Soft switching resonant converters.

Mapping of course outcomes with program outcomes

	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12
CO 1	3	2	1	1								2
CO 2	3	2	1	1								2
CO 3	3	1	1									2
CO 4	3	1	1									2
CO 5	3	1	1									2

Assessment Pattern

Bloom's Category	Continuous Assessment Tests		End Semester Examination
	1	2	
Remember	10	10	20
Understand	10	10	50
Apply	20	20	30
Analyse	10	10	
Evaluate			
Create			

Mark distribution

Total Marks	CIE	ESE	ESE Duration
150	50	100	3 hours

Continuous Internal Evaluation Pattern:

Attendance : 10 marks
Continuous Assessment Test (2 numbers) : 25 marks
Assignment/Quiz/Course project : 15 marks

End Semester Examination Pattern: There will be two parts; Part A and Part B. Part A contain 10 questions with 2 questions from each module, having 3 marks for each question. Students should answer all questions. Part B contains 2 questions from each module of which student should answer any one. Each question can have maximum 2 sub-divisions and carry 14 marks.

Course Level Assessment Questions

Course Outcome 1 (CO1):

1. Design the power circuits of basic dc-dc converters (K2, K3 and K4 level, PO1, PO2, PO3, PO4)
2. Analyse and determine the mode of operation of the given circuit. (K2, K3, K4, PO1, PO2)
3. Design dc-dc non-isolated converters to operate under given conditions/specifications. (K2, K3, K4, PO1, PO2, PO3, PO4)
4. What is the primary difference between switched mode power conversion and linear power conversion? (K1, PO1)

Course Outcome 2 (CO2)

1. Analyse circuits of isolated dc-dc topologies. give relevant waveforms. (K2, K3, K4 levels, PO1, PO2).
2. Explain unidirectional and bidirectional magnetic core excitation.(K1, PO1)
3. Explain double ended forward converter with neat diagram. (K1, PO1)
4. Describe the operation of the push-pull dc-dc converter. Also derive the expression of output voltage. (K1, PO1, PO2)

Course Outcome 3(CO3):

1. Describe the operation of three-phase/single-phase rectifiers (K2, K3, PO1)

2. Explain active wave shaping of input line current through PFC boost converter. (K1, PO1)

3. With a neat circuit diagram, explain the working of the switched mode rectifier. (K1, PO1)

4. Find the Switch utilization factor for single phase full bridge dc-dc converter.(K1, PO1, PO2)

Course Outcome 4 (CO4):

1. Compare PWM schemes and select an appropriate method for given application (K2, K3, K4, PO1)

2. Explain switching times and space vector sequence of space vector modulation. (K1, PO1)

3. With waveform explain hysteresis current control . (K1, PO1)

4. With waveform explain programmed harmonic elimination of single phase inverter. (K1, PO1)

Course Outcome 5 (CO5):

1. Distinguish between hard-switching and soft-switching methods. (K2, PO1)

2. Explain with a neat diagram, series resonant and parallel resonant circuit . Also draw the frequency characteristics . (K1, PO1)

3. Explain significance of Zero voltage and Zero current switching in dc –dc converters. (K1, PO1)

4. Illustrate how switching losses are reduced in ZVS configuration. (K1, PO1, PO2)

Model Question Paper

QP CODE: **Pages:**

Reg No.:_______________

Name:_________________

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY EIGHTH SEMESTER

B.TECH DEGREE EXAMINATION,

MONTH & YEAR

Course Code: EET454

Course Name: SWITCHED MODE POWER CONVERTERS

Max. Marks: 100 **Duration: 3 hours**

PART A

Answer all questions; each question carries 3 marks.

1. What is the primary difference between switched mode power conversion linear power conversion?

2. Draw the circuit diagram of a dc-dc converter that, when operated in continuous conduction mode yields continuous currents in both input and output terminals, and inverted output voltage.

3. Draw the circuit diagram of a two-switch flyback converter and explain why it cannot operate with duty ratios beyond 50%.

4. What are the advantages of a current-fed isolated dc-dc converter?

5. In a single-phase full-bridge PWM inverter operating with Sine PWM and in linear modulation range, what would be the maximum possible rms value of the fundamental voltage that can be obtained at the output if the dc voltage is fixed at 500V?

6. Draw the circuit diagram of the single-phase boost power factor correction rectifier topology. Which signals need to be sensed in order to control this converter?

7. How many space vectors can be produced by a three-phase bridge inverter? Represent them in a table in the given format below:

Sl. No.	Switch states	Space vector magnitude	Location (angle)

8. Differentiate between current controlled voltage source inverter and hysteresis current controlled inverter.

9. Differentiate between PWM hard-switching and Soft-switching.

10 Draw the ZCS switch configuration and explain how the position of the resonant components aid in zero-current switching.

PART B

Answer any one complete question from each section; each question carries 14 mark

11 (a) Derive an expression for the peak-to-peak current ripple in the inductor in a buck converter operating in continuous conduction mode, in terms of the output voltage, operating duty ratio and the value of the inductor. Draw the relevant waveforms used in the derivation. (4)

(b) A photovoltaic panel is rated for an output voltage range between 15 V to 18 V, 36 W peak output power. This panel is to be connected to a dc load that demands a fixed dc voltage of 12 V, with ripple less than 1% of the rated output voltage. Assume the converter is to be operated in discontinuous conduction mode when the load is less than 50% of the rated output power. Select a converter topology suitable for this application, and design it to meet the given specifications. Evaluate the duty ratio D when the input voltage is 18 V and the load is 30% of the rated output power, with the component values selected for the design. (10)

OR

12 (a) A Ćuk converter is supplied with an input voltage that varies between 5V and 10V. The output is required to be regulated at 15V. Find the duty ratio range. Assume the converter is working with continuous conduction mode for the entire range. If the load power is 50W, evaluate the input currents for the minimum and maximum input voltages, assuming an ideal converter. (5)

(b) Develop the voltage transfer ratio of a buck converter operating in Discontinuous Conduction Mode. (9)

13 (a) Compare the features of single-switch and two-switch flyback converter topologies. (4)

(b) It is required to design a power converter with the following features:
(i). Electrical isolation is required.
(ii). Gate drives should be referenced to the same electrical potential.
(iii). The input voltage is 200 V, and the output voltage is 12 V; Power is 250 W.
A junior technician came up with the options: Two-switch Flyback converter, Two-switch forward converter, Push-pull converter, Full-bridge isolated converter and Half-bridge isolated converter. As a design engineer, which out of these options will you choose that can meet the requirements? Develop a basic design of the inductor and capacitor, by assuming a current ripple of 20% of output current and 1% of nominal output voltage as voltage ripple. Evaluate the duty ratio and choose an appropriate turns ratio for the transformer. (10)

OR

14 (a) A flyback converter with 15V input voltage is operating with a duty ratio of 0.4. If the turns ratio of the coupled inductor is 1:0.5, evaluate the output voltage. Assume continuous conduction mode. What is the peak voltage appearing across the switch? Draw the waveforms of the input current, output diode current and voltage across the switch under the given operating conditions and mark the salient features. (6)

(b) For a forward converter with Vd=48V+/-10%; Vo= 5V (regulated); fs=100kHz; Pload=15-50W. If the flux reset winding N3=N1, calculate the turns ratio N2/N1 if this turns ratio is desired to be as small as possible. (8)

15 (a) What are the dominant harmonics in the output line-to-line voltage of a three-phase bridge inverter operating in square-wave mode? Show the line voltage waveform and the harmonic spectrum upto the first 7 dominant harmonics (not upto the 7th). (5)

(b) Describe a single-phase power factor corrected rectification scheme utilising boost converter and its control. Explain how the input current is actively shaped for reduced THD. (9)

OR

16 (a) In a single phase full bridge sine PWM inverter, the input dc voltage varies in a range of 295-325 V. Because of the low distortion required in the output, the inverter is operated in the linear modulation range. What is the highest output fundamental rms voltage that can be obtained from this inverter? If the inverter is to be rated at 2 kVA, calculate the combined switch utilisation ratio of the inverter when it is supplying rated VA. Assume the load current is sinusoidal. (6)

(b) Explain how a single-phase full-bridge topology can be used as a utility interfaced high-power factor rectifier. (8)

17 (a) For a Space Vector PWM based inverter, the dc voltage is 600 V. The switching frequency is 20 kHz. The reference voltage vector is 200□30^{o} Vrms, at a particular sampling interval.
(i). Identify the active vectors to be used during the given sampling interval. Indicate the corresponding switch states.
(ii). The dwell-times of the active vectors and the zero vector during the interval.
(iii). Evaluate the dwell times when the reference vector is at 180^{o} out-of phase with the original location. (8)

(b) What is Selective Harmonic Elimination? Explain with respect to a single-phase inverter. (6)

OR

18 (a) Explain the working of a current controlled voltage source inverter with fixed switching frequency. (6)

(b) Explain how the number of switchings per sampling period are minimised by proper sequencing of the active and zero vectors in Space Vector Modulation. (8)

19 (a) Differentiate between ZCS and ZVS topologies. What are the parasitic elements which are usefully employed in these topologies? (6)

(b) With circuit diagram and relevant waveforms, describe the operation of a series loaded resonant converter operating in discontinuous conduction mode. (8)

OR

20 (a) The ZCS and ZVS resonant switches are dual implementations. Explain why. (6)

(b) Which of the load resonant converters is a voltage-boosting converter? Explain with relevant diagrams/graphs. (8)

Syllabus

Module 1

Switched Mode non-isolated DC-to-DC Converters:

Linear Vs Switching Power Electronics.

Buck, Boost, Buck-boost and Ćuk converters: Principles of steady-state analysis - Inductor volt-seconds balance and capacitor amp-seconds balance – Operation in Continuous Conduction Mode (CCM)- Voltage Gain – design of filter inductance & capacitance - boundary between continuous and discontinuous conduction – critical values of inductance/load resistance - Examples for buck and boost converters.

Discontinuous Conduction Mode (DCM) of buck converter with constant output voltage – Output voltage ripple in DCM. Voltage Gain in DCM for buck converters.

Module 2

DC-DC converters with electrical isolation:

High-frequency transformers for DC-DC converters: unidirectional magnetic core excitation & bidirectional core excitation.

Fly back converter: Operation and waveforms in continuous & discontinuous conduction modes – Voltage gain.

CCM operation of double ended fly-back converter.

Forward converter in CCM: Basic forward converter with ideal transformer – practical forward converter with core reset – double ended forward converter

Push-Pull, Half-Bridge and Full-Bridge converters: Operation in Continuous Conduction Mode (CCM) – Flux-walking in isolated converters.

Current-source DC-DC converter.

Module 3

Switched Mode DC to AC converters:

Review of single-phase bridge inverters - 3-phase Sine-PWM inverter: – Linear Modulation, RMS fundamental line to line voltage & RMS fundamental line-to-line voltage – Overmodulation - Square wave operation in three-phase inverters - Switch utilisation ratio of 1-phase & 3-phase full-bridge inverters.

PWM Rectifiers: Generation of current harmonics in diode bridge rectifiers - Power factor - Improved single-phase utility interface - Active shaping of input line current through PFC boost converter - Single phase Switched mode rectifier.

Module 4

Modulation Schemes:

Space Vector Modulation: Concept of space vector – space vector modulation – reference vector & switching (dwell) times – space vector sequence – comparison of sine PWM & space vector PWM.

Programmed (selective) harmonic elimination switching in single phase inverters (Formulation example with elimination of two harmonics at a time) – current controlled voltage source inverter -

Hysteresis current control.

Module 5

Softswitching and resonant converters:

Hard-switched Vs Soft-switched converters -

Resonant Converters - Basic resonant circuit concepts – series resonant circuit – parallel resonant circuit – series-loaded and parallel loaded resonant converters (Operation in discontinuous conduction mode with $\omega s < 0.5 \omega r$).

Resonant Switch (Quasi-resonant) Converters: ZCS buck converter - L type - ZVS buck converter – comparison of ZCS & ZVS Resonant Converters.

Note: Assignments may be given to develop simulations of the converter topologies in open-loop and/or closed-loop using appropriate simulation tools. Assignments may also be given to develop design automation scripts/tools using Python, MATLAB, C, Spreadsheets etc.

Text Books

1. Ned Mohan, Tore M. Undeland and William P. Robbins, "Power Electronics: Converters, Applications and Design," Third Edition, John Wiley and Sons, 2003.

Reference Books

1. Joseph Vithayathil, "Power Electronics: Principles and Applications," Tata McGrawhill edition.
2. Robert W. Erickson and Dragan Maksimovic, "Fundamentals of Power Electronics," Second Edition, Springer International Edition (Indian reprint).
3. L. Umanand, "Power Electronics: Elements and Applications," Wiley India, 2009.

Course Contents and Lecture Schedule

No	Topic	No. of Lectures
1	**Non-isolated DC-DC converters:**	**7 Hours**
1.1	Introduction: Linear Vs Switching Power Electronics. Buck and Boost Converters: Topology, principles of low-ripple approximation and inductor volt-sec/capacitor amp-sec balance., Application in developing the voltage transformation ratio in CCM. Evaluation of Inductances and Capacitance for specified current/voltage ripple.	2
1.2	Buck-boost and Cuk Converters: Topology, Application of inductor volt-sec balance/Capacitor amp-sec balance in developing the voltage transformation ratio in CCM. Evaluation of Inductances and Capacitor for specified current/voltage ripple.	2
1.3	Boundary between continuous and discontinuous conduction modes– critical values of inductance/load resistance - Examples for buck and boost converters.	1
1.4	Discontinuous Conduction Mode (DCM) of buck converter with constant output voltage – Output voltage ripple in DCM. Voltage Gain in DCM for buck converters.	2
2	**DC-DC converters with electrical isolation:**	**8 Hours**
2.1	High-frequency transformers for DC-DC converters: unidirectional magnetic core excitation & bidirectional core excitation.	1
2.2	Fly back converter: Operation and waveforms in continuous & discontinuous conduction modes – Voltage gain; CCM operation of double ended fly-back converter.	2

2.3	Forward converter in CCM: Basic forward converter with ideal transformer – practical forward converter with core reset – double ended forward converter.	2
2.4	Push-Pull, Half-Bridge and Full-Bridge converters: Operation in Continuous Conduction Mode (CCM) – Flux-walking in isolated converters.	2
2.5	Current-source DC-DC converter	1
3	**Switched Mode Inverters and Rectifiers**	**6 hours**
3.1	Review of single-phase bridge inverters - 3-phase voltage source inverter: 3-phase Sine-PWM inverter – RMS line to line voltage & RMS fundamental line-to-line voltage – square wave operation - Switch utilisation ratio of 1-phase & 3-phase full-bridge inverters.	2
3.2	**PWM Rectifiers: (Ch. 8 of Ref. 1):** Generation of current harmonics in diode bridge rectifiers - Power factor - Improved single-phase utility interface - Active shaping of input line current through PFC boost converter -Single phase Switched mode rectifier operation and control.	4
4	**Modulation Schemes:**	**7 Hours**
4.1	Concept of space vector; Origin of flux space phasor representation.	1
4.2	Space vector modulation – reference vector & switching times – space vector sequence	2
4.3	Comparison of sine PWM & space vector PWM.	1
4.4	Programmed (selective) harmonic elimination switching in single phase inverters (example with elimination of third and fifth harmonics)	2
4.5	Current controlled voltage source inverter - Hysteresis current control.	1
5	**Softswitching and Resonant Converters:**	**8 hours**
5.1	Softswitching and resonant converters: Hard-switched Vs Soft-switched converters - Switching losses and transition of voltage and current during switching in Hard Switched converters.	1
5.2	Resonant Converters - Basic resonant circuit concepts – series resonant circuit – parallel resonant circuit	2

5.3	Series-loaded (Operation in discontinuous conduction mode with $\omega_{sw} < 0.5\ \omega_r$; ω_{sw}:Switching frequency and ω_r: Resonant frequency)	1
5.4	Parallel loaded resonant converters (Operation in discontinuous conduction mode with $\omega_{sw} < 0.5\ \omega_r$; ω_{sw}:Switching frequency and ω_r: Resonant frequency).	1
5.5	Resonant Switch (Quasi-resonant) Converters: ZCS buck converter - L type.	2
5.6	ZVS buck converter – Comparison of ZCS & ZVS Resonant Converters.	1