B.Sc (HONS) IN ECE, PART-III, SIXTH SEMESTER EXAMINATION, 2019
INDUSTRIAL AND POWER ELECTRONICS
Subject Code: ECE-313
Time: 3 hours
Full marks: 80

N.B. The figures in the right margin indicate full marks. Answer any five questions

Question 1

(a) Power Electronics and Applications [4 marks]

Power Electronics: Power electronics is the branch of electrical engineering that deals with the conversion, control, and conditioning of electric power using semiconductor devices. It involves the application of solid-state electronics to the control and conversion of electric power.

Applications:

- Motor drives and speed control systems
- Power supplies (SMPS, UPS, battery chargers)
- Lighting control systems
- Renewable energy systems (solar inverters, wind power converters)
- Electric vehicles and hybrid vehicles
- Welding equipment
- Induction heating systems

(b) Optical Transducer and Comparison [6 marks]

Optical Transducer: An optical transducer is a device that converts light energy into electrical energy or vice versa. It uses optical phenomena to measure physical quantities like displacement, pressure, temperature, or strain.

Capacitive vs Inductive Transducer:

Aspect	Capacitive Transducer	Inductive Transducer
Principle	Changes in capacitance due to variation in distance, area, or dielectric	Changes in inductance due to variation in reluctance, permeability, or geometry
Sensitivity	High sensitivity	Moderate sensitivity
Temperature Effect	Less affected by temperature	More affected by temperature changes
Power Consumption	Very low power consumption	Higher power consumption
Frequency Response	Good high-frequency response	Limited high-frequency response
Applications	Proximity sensors, pressure measurement	Position measurement, proximity detection

(c) Strain Gauge and Gauge Factor [6 marks]

Strain Gauge: A strain gauge is a sensor used to measure strain on an object. It consists of a metallic foil pattern arranged in a grid on a backing material, which changes its electrical resistance when subjected to mechanical deformation.

Gauge Factor Derivation:

Let the original resistance be R_0 and length be L_0. When strain ε is applied:

- New length: $L = L_0(1 + \varepsilon)$
- New area: $A = A_0(1 - v\varepsilon)$ where v is Poisson's ratio
- Change in resistivity: $\Delta\rho/\rho_0 = C\varepsilon$ where C is a constant

The resistance of a conductor: $R = \rho L/A$

Taking the differential: $dR/R_0 = d\rho/\rho_0 + dL/L_0 - dA/A_0$

Substituting the strain relationships: $dR/R_0 = C\varepsilon + \varepsilon + v\varepsilon = \varepsilon(C + 1 + v)$

Gauge Factor (GF) = $(\Delta R/R_0)/\varepsilon = C + 1 + v$

For metallic strain gauges, GF ≈ 2 to 2.5

Question 2

(a) SCR and Two Transistor Model [6 marks]

SCR (Silicon Controlled Rectifier): SCR is a four-layer (PNPN), three-terminal semiconductor device that acts as a switch. It can be turned ON by a gate pulse but can only be turned OFF when the anode current falls below the holding current.

Two Transistor Model: The SCR can be represented as two interconnected transistors:

- PNP transistor (Q_1): Formed by P_1-N_1-P_2 layers
- NPN transistor (Q_2): Formed by N_1-P_2-N_2 layers

Operation:

- Collector of Q_1 is connected to base of Q_2
- Collector of Q_2 is connected to base of Q_1
- When gate current is applied, Q_2 starts conducting
- This provides base current to Q_1, which then conducts
- Once both transistors are ON, they maintain each other in saturation
- The device remains ON until anode current < holding current

(b) UJT as Relaxation Oscillator [6 marks]

UJT (Unijunction Transistor): UJT is a three-terminal device with one PN junction. It has an emitter and two bases (B_1 and B_2).

Relaxation Oscillator Operation:

- A capacitor C charges through resistor R towards the supply voltage
- When VC reaches the peak point voltage (VP), the UJT fires
- The capacitor rapidly discharges through the UJT and load resistor
- The cycle repeats when VC falls below the valley point voltage

Key Parameters:

- Peak point voltage: $V_P = \eta V_{BB} + V_D$ (where η = intrinsic standoff ratio ≈ 0.6)
- Frequency: $f \approx 1/(RC \ln(1/(1-\eta)))$

Applications: Timing circuits, pulse generators, SCR triggering circuits

(c) LVDT Operation Principle [4 marks]

LVDT (Linear Variable Differential Transformer): LVDT is an inductive transducer that converts linear displacement into electrical signal.

Construction:

- Primary winding in the center
- Two secondary windings on either side
- Movable ferromagnetic core

Operation:

- AC excitation applied to primary winding
- Secondary windings connected in series opposition
- When core is at center: equal coupling, output = 0
- When core moves: differential coupling produces proportional output voltage
- Output magnitude proportional to displacement, phase indicates direction

Question 3(a) Single Phase Full-Wave Controlled Rectifier [6 marks]

Principle: Uses two SCRs to control both half-cycles of AC input. SCRs are triggered at firing angle α from the natural conduction point.

Average Output Voltage: For resistive load: $V_{dc} = (2V_m/\pi) \cos \alpha$

RMS Output Voltage: $V_{rms} = V_m/\sqrt{2} \times \sqrt{[(\pi - \alpha + \sin(2\alpha)/2)/\pi]}$

Where:

- V_m = peak input voltage
- α = firing angle

Key Points:

- Continuous current flow through load
- Better transformer utilization than half-wave
- Ripple frequency = 2 × supply frequency

(b) PUT and Four Quadrant Converter [6 marks]

PUT (Programmable Unijunction Transistor): PUT is a thyristor that can be programmed to have different switching characteristics by external resistors connected to the gate.

Four Quadrant Converter: A converter that can operate in all four quadrants of the voltage-current plane:

Quadrant	Voltage	Current	Operation Mode
I	+ve	+ve	Forward motoring
II	+ve	-ve	Forward regenerative braking
III	-ve	-ve	Reverse motoring
IV	-ve	+ve	Reverse regenerative braking

Applications: AC/DC motor drives, bidirectional power flow systems

(c) TRIAC Operation Principle [4 marks]

TRIAC: A bidirectional thyristor that can conduct in both directions when triggered.

Operation:

- Equivalent to two SCRs connected in parallel but opposite directions
- Can be triggered by positive or negative gate pulses
- Once triggered, conducts until current falls below holding current
- Used for AC power control applications
- Gate sensitivity may differ for different trigger modes

Question 4 (a) IGBT Definition and Operation [6 marks]

IGBT (Insulated Gate Bipolar Transistor): IGBT combines the advantages of MOSFET (voltage-controlled, high input impedance) and BJT (low on-state voltage drop, high current capability).

Structure: Three-terminal device with gate, collector, and emitter.

Operation:

- Voltage-controlled device like MOSFET
- Gate-emitter voltage > threshold voltage turns ON the device
- Minority carrier injection from P+ substrate reduces on-state voltage
- Turn-off initiated by removing gate voltage
- Current tailing occurs during turn-off due to stored minority carriers

Advantages:

- High input impedance
- Fast switching speed
- Low conduction losses
- Easy gate drive requirements

(b) Single Phase Center Tapped Step-up Cycloconverter [6 marks]

Cycloconverter: Converts AC power at one frequency to AC power at another frequency without intermediate DC conversion.

Center-tapped Configuration:

- Uses center-tapped transformer

- Two sets of thyristors for positive and negative groups
- Output frequency fo = input frequency fs/n (where n is integer)

For fo = fs/6:

- Each thyristor conducts for 60° (π/3 radians)
- Six thyristors required for complete cycle
- Output frequency is 1/6 of input frequency
- Step-up achieved through transformer turns ratio

(c) Active vs Passive Transducer [4 marks]

Active Transducer	Passive Transducer
Generates own electrical energy	Requires external power source
No external power needed	External excitation required
Examples: Thermocouple, piezoelectric	Examples: LVDT, strain gauge, thermistor
Output is generated signal	Output is modified signal

Question 5(a) Phase Control by Thyristor and DC Chopper [4 marks]

Phase Control by Thyristor:

- Controls power by delaying the firing angle α
- Average output voltage varies with cos α
- Used in AC voltage controllers and controlled rectifiers
- Smooth power control achieved

DC Chopper:

- Controls DC power by switching ON and OFF periodically
- Average output voltage controlled by duty cycle (D = ton/T)
- High efficiency power control method
- Used in DC motor drives and DC-DC converters

(b) PWM and PWM Control of Inverters [6 marks]

PWM (Pulse Width Modulation): A technique to control power by varying the width of pulses in a pulse train while keeping the frequency constant.

PWM Control Technique - Sinusoidal PWM:

- High-frequency triangular carrier wave compared with sinusoidal reference
- When reference > carrier: output = +Vdc/2
- When reference < carrier: output = -Vdc/2
- Modulation index (ma) = Vref/Vcarrier
- Output voltage magnitude controlled by ma
- Output frequency controlled by reference frequency

Advantages:

- Reduced harmonic content
- Better output waveform quality
- Efficient switching
- Variable voltage and frequency control

(c) Push-Pull Inverter [6 marks]

Push-Pull Inverter: A type of DC-AC converter using center-tapped transformer.

Operation:

- Two switches operate alternately
- Each switch conducts for 180°
- Center-tapped transformer provides isolation and voltage scaling
- Primary current alternates direction every half cycle

Advantages:

- Simple control circuit
- Good transformer utilization
- Natural isolation provided
- Suitable for low voltage, high current applications

Disadvantages:

- Transformer center-tap required
- Switch voltage stress = 2Vin
- Flux imbalance possible

Question 6(a) Position Control of DC Drives [5 marks]

Position Control System:

- Closed-loop control system for precise positioning
- Components: Position sensor, controller, power converter, DC motor
- Feedback from encoder or resolver provides actual position
- Error signal = Reference position - Actual position

Control Techniques:

- Proportional-Integral-Derivative (PID) control
- Position loop, velocity loop, and current loop
- High gain for accuracy, proper compensation for stability
- Applications: Robotics, machine tools, servo systems

(b) Microcomputer Control of DC Drives [5 marks]

Microcomputer Control Features:

- Digital signal processing for control algorithms
- Programmable control strategies
- Real-time monitoring and diagnostics

- Communication interfaces for system integration
- Adaptive control and parameter optimization

Implementation:

- ADC for feedback signal conversion
- Digital controllers (PI, PID, fuzzy logic)
- PWM generation for power converter control
- Protection algorithms and fault detection
- User interface and parameter setting

(c) DC Chopper [2 marks]

DC Chopper: A power electronic circuit that converts fixed DC voltage to variable DC voltage by switching ON and OFF at high frequency.

Types: Step-down (Buck), Step-up (Boost), Buck-Boost choppers.

(d) DC vs AC Motor [4 marks]

DC Motor	**AC Motor**
Direct current supply	Alternating current supply
Good speed control	Speed control requires converters
High starting torque	Moderate starting torque
Requires commutator and brushes	No brushes (in most types)
Higher maintenance	Lower maintenance
Costlier	Less expensive
Better speed regulation	Speed depends on frequency

Question 7 - Short Notes [4×4=16 marks]

(a) Programmable PUT

- Thyristor with programmable characteristics
- Gate voltage determines switching point
- External resistor network sets intrinsic standoff ratio
- Used in timing circuits and oscillators

(b) GTO (Gate Turn-Off Thyristor)

- Thyristor that can be turned OFF by gate signal
- Negative gate current for turn-off

- Faster switching than conventional SCR
- Applications: Inverters, choppers, motor drives

(c) LVDT (Linear Variable Differential Transformer)

- Inductive position transducer
- Primary winding with two secondary windings
- Output voltage proportional to core displacement
- High accuracy and repeatability

(d) Schottky Diode

- Metal-semiconductor junction diode
- Low forward voltage drop (0.2-0.3V)
- Fast switching speed
- Used in high-frequency applications and power supplies

(e) DIAC (Diode AC Switch)

- Bidirectional trigger diode
- Breaks over at specific voltage in both directions
- Used to trigger TRIAC
- Provides symmetric triggering

(f) Step-up Single Phase Cycloconverter

- Converts AC at one frequency to higher voltage AC
- Uses transformer for voltage step-up
- Thyristor switching for frequency control
- Applications: Variable frequency drives