



End-Sem Examination-I, Winter 2025

Academic Year: 2025-2026

Semester: I

Name of Program: Electrical Engineering

Pattern: 2024

Name of Course: Renewable Energy System (Elective-I)

Code: 2406504A

Max Marks: 60

Duration: 2:30 Hr.

Set A

Paper Solution

Q 1. Explain the I-V characteristics of a solar PV cell and describe how these characteristics are affected by temperature and irradiance.

Answer: The current-voltage (I-V) characteristics of a solar photovoltaic (PV) cell describe how the electric current (I) output of the cell varies with the applied voltage (V) across its terminals. These characteristics are crucial in understanding the performance of solar cells and are typically represented in an I-V curve, which shows the relationship between the current and voltage under specific conditions of sunlight (irradiance) and temperature.

I-V Characteristics of a Solar PV Cell

1. Short-Circuit Current (I_{sc}): The current when the voltage across the cell is zero (terminals are shorted).
2. Open-Circuit Voltage (V_{oc}): The voltage when the current is zero (no load connected).
3. Maximum Power Point (MPP): The point on the I-V curve where the product of current and voltage ($I \times V$) is maximized.
4. Fill Factor (FF): A measure of the "squareness" of the I-V curve. Higher FF indicates a more efficient solar cell.
5. Efficiency (η): The ratio of output electrical power to incident solar power.

Q 2. Describe the basic principle of wind energy conversion and list the factors affecting wind power generation.

Answer: Basic Principle of Wind Energy Conversion: Wind energy conversion is the process of transforming the kinetic energy of wind into mechanical energy and subsequently into electrical energy using a wind energy conversion system (WECS), most commonly a wind turbine.

Conversion Process: Wind Strikes the Blades: The rotor blades of a wind turbine are designed like airplane wings. When wind blows, it creates a pressure difference on either side of the blade due to its aerofoil shape.



Rotor Turns the Shaft: The rotor is connected to a low-speed shaft. In most turbines, this shaft is connected via a gearbox to a high-speed shaft that drives the generator.

Electrical Energy Generation: The high-speed shaft drives the generator, converting mechanical energy into electrical energy via electromagnetic induction.

Power Conditioning: The generated electricity may be DC or variable-frequency AC, depending on the generator type. It is then converted and conditioned into grid-compatible AC power using power electronics (like inverters).

Transmission: The electricity is transmitted to the grid or stored locally.

Turbine Design and Efficiency: Blade shape, material, and pitch control affect energy capture. The efficiency of gearboxes, generators, and power electronics also influence total power output. Downtime due to maintenance or failures reduces annual energy output.

Q. 3. (a) Explain the key design considerations for a hybrid solar PV-wind system.

Answer: Designing a hybrid solar PV–wind system involves combining two renewable energy sources—solar and wind—to ensure more consistent and reliable power generation. This hybrid approach compensates for the intermittent nature of each source and is especially useful in areas with variable weather conditions.

The key design considerations for such a system:

Load Profile Analysis—Identify the total energy demand (in kWh/day) and peak power (in kW). Determine daily, weekly, and seasonal variations in electricity consumption.

Type of Load: AC or DC loads. Single-phase or three-phase supply requirement.

Resource Assessment:

1. **Solar Resource Analysis** - Assess average solar irradiance (W/m^2) over the year. Analyze daily and seasonal variations in sunlight hours.
2. **Wind Resource Analysis:** Evaluate average wind speeds at the site. Perform wind speed frequency distribution analysis (Weibull distribution).

Component Sizing:

1. **Solar PV Array:** Size based on energy demand during sunny hours. Consider: Panel efficiency, Tilt angle and orientation, Derating factors (dust, shading, temperature)
2. **Wind Turbine:** Sized to meet energy demands when solar is unavailable. Selection based on: Cut-in, rated, and cut-out speeds, Rotor diameter, Hub height
3. **Battery Storage System:** Stores excess energy for use during low generation periods. Sizing depends on: Depth of discharge (DoD), Days of autonomy, Battery type (Li-ion, lead-acid, etc.)
4. **Inverter/Power Conditioning Unit (PCU):** Converts DC to AC.



OR

Q. 3. b) Describe the working of a Maximum Power Point Tracking (MPPT) algorithm with an example.

Answer: **Maximum Power Point Tracking (MPPT)** is a technique used in photovoltaic (PV) solar systems to maximize the power output from solar panels by adjusting the electrical operating point of the modules or array. Solar panels have a non-linear current-voltage (I-V) characteristic, and their power output depends on environmental conditions like sunlight and temperature. The MPPT controller ensures the solar panel operates at the **Maximum Power Point (MPP)** to extract the highest possible power.

The power output of a PV panel is given by: $P=V \times I$

Where: P: Power output, V: Voltage across the panel, I: Current drawn from the panel

From the I-V curve of a solar panel, the MPP is the point where the product $V \times I$ is maximum.

MPPT Algorithm Working – Step by Step (Using Perturb and Observe Method):

· **Measure Present Power:** Measure voltage $V(k)$ and current $I(k)$ from the PV panel.

Calculate power: $P(k)=V(k) \times I(k)$

· **Perturb the Voltage:** Slightly change the voltage (increase or decrease), which perturbs the system.

· **Measure New Power:** After perturbation, measure new voltage $V(k+1)$, current $I(k+1)$

Calculate new power: $P(k+1)=V(k+1) \times I(k+1)$

· **Compare Power Levels:** If $P(k+1) > P(k)$, it means the system is moving towards MPP.

Continue in the same direction (increase or decrease voltage).

If $P(k+1) < P(k)$, the system is moving away from MPP.

Reverse the direction of perturbation.

· **Repeat:** The process continues until the MPP is reached.

Q 3. c) Differentiate between off-grid and grid-synchronized inverter systems.

Answer: **Difference between off-grid and grid-synchronized inverter systems as below:**

Parameter	Off-grid Inverter	Grid-synchronized (On-grid) Inverter
Connection	Works independently from the utility grid	Operates in parallel with the utility grid



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Power Source	Solar/Wind + Battery bank	Solar/Wind directly feeds into the grid
Energy Storage	Required (battery) for power availability at all times	Not required , but optional for hybrid systems
Operation	Supplies power directly to local loads	Injects power into the grid and synchronizes with grid voltage
Synchronization	No need for phase matching with grid	Must synchronize voltage, frequency, and phase with the grid
Backup Power	Can supply power during outages	Cannot operate during grid failure unless hybrid/inverter has backup
Application	Remote/rural areas without grid access	Urban/grid-connected areas for net metering

OR

Q 3. d) Discuss the role of Maximum Power Point Tracking (MPPT) in a hybrid PV-wind system. How does it differ for wind turbines and PV arrays?

Answer: **Role of MPPT in Hybrid PV-Wind System & Its Differences**

In a hybrid PV-wind energy system, MPPT plays a crucial role in optimizing power extraction from both energy sources despite their different characteristics.

Role of MPPT:

Maximizes Power Extraction: Ensures both PV and wind systems operate at their maximum power points under varying environmental conditions (sunlight, wind speed).

Enhances System Efficiency: By operating each source at its optimum point, overall hybrid system efficiency is improved.

Power Coordination: Maintains balance between power generation and storage/load.

Q 4. a) Describe the control schemes of a single-phase grid-connected PV inverter.

Answer: **Control Schemes of Single-Phase Grid-Connected PV Inverter**

A single-phase grid-connected PV inverter uses control schemes to:



Synchronize with the grid (voltage and frequency), Control power injection (active/reactive), Ensure power quality and safety.

Control Schemes:

Phase-Locked Loop (PLL): Detects grid phase and synchronizes inverter output.

Current Control Loop: Controls the output current injected into the grid.

Techniques: PI controllers, hysteresis control, or predictive control

Voltage Control Loop: Regulates the DC-link voltage.

Ensures stable operation of MPPT and inverter.

Power Control: Controls the amount of active (P) and reactive power (Q) injected.

OR

Q 4. b) Explain transformer-less inverter advantages and safety challenges.

Answer: **Transformer-less Inverter: Advantages and Safety Challenges**

Advantages:

Higher Efficiency: Eliminates transformer losses (~1-2%).

Compact Design: Reduces size and weight.

Lower Cost: No transformer = reduced component and manufacturing costs.

Better MPPT Response: Less energy lost in transformation, better control.

Safety Challenges:

Leakage Currents: Without galvanic isolation, parasitic capacitance causes leakage currents.

Ground Fault Risks: Increased shock hazard if protective systems fail.

Standards Compliance: Must follow stringent safety standards (e.g., IEC 62109).

Common Mode Voltage: Must be mitigated using special topology or filters.

Q 4. c) Discuss the role of energy storage systems in wind/solar integrated designs and Interpret the system reliability.

Answer: **Role of Energy Storage Systems (ESS) in Wind/Solar Integrated Designs**



Roles:

Energy Balancing: Stores excess energy during high generation and supplies during low generation or peak demand.

Voltage and Frequency Regulation: Maintains system stability in variable renewable inputs.

Backup Power: Ensures continuous supply during outages or low generation periods.

Peak Shaving: Reduces demand charges by supplying stored energy during peak hours.

Grid Independence: Enables off-grid operation or microgrid formation.

System Reliability Interpretation:

Higher Reliability: ESS mitigates intermittency of solar/wind, ensuring stable supply.

Reduced Outages: Supports load when generation drops, reducing downtime.

Enhanced Power Quality: Smooths fluctuations, providing cleaner power.

OR

Q 4. d) Explain the operation of a grid-connected single-phase PV inverter using a block diagram.

Answer: Operation of Grid-connected Single-phase PV Inverter:

Operation Steps:

DC Generation: PV panel generates DC power.

MPPT Control: Extracts maximum power from solar using algorithms.

DC-DC Converter: Regulates voltage for inverter.

DC-AC Inversion: Converts DC to AC using inverter switches (e.g., IGBTs).

Synchronization: Matches output with grid voltage/frequency using PLL.

Grid Injection: Controlled current is injected into the grid.

Q 5. a) Explain the concept of smart Grid in the power system network.

Answer: A **Smart Grid** is a modernized electrical grid that uses digital communication and automation to improve efficiency, reliability, and sustainability of electricity supply.



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Features:

Two-way communication between utility and consumers.

Integration of renewable energy sources.

Real-time monitoring and control.

Demand response and load management.

Enhanced fault detection and self-healing.

Benefits:

Reduces transmission losses.

Improves outage management.

Enables dynamic pricing and energy usage optimization.

OR

Q 5. b) List and explain smart grid technologies used for protection and control.

Answer:

Smart Grid Technologies for Protection and Control

Key Technologies:

Phasor Measurement Units (PMU): Real-time monitoring and control., Detects faults quickly across wide areas.

Advanced Metering Infrastructure (AMI): Smart meters for real-time billing and data analytics

Wide Area Monitoring System (WAMS): Uses PMUs and GPS to monitor system health.

Supervisory Control and Data Acquisition (SCADA):

Centralized control and visualization system.

Fault Current Limiters:

Prevents overload during short circuits.

Digital Relays and Protection Devices:



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Programmable for adaptive protection schemes.

Q 5. c) What is a Phasor Measurement Unit (PMU) and how is it used in wide-area monitoring?

Answer: PMU is a device that measures **real-time synchronized phasors** (voltage and current) using GPS time stamping.

Uses:

Wide-Area Monitoring: Provides a snapshot of the grid's health.

Fault Detection and Isolation: Quick identification of fault location.

Grid Stability Analysis: Monitors phase angle and frequency deviation.

Blackout Prevention: Helps in early warning systems for instability.

OR

Q 5. d) Compare the difference between Conventional Grid and Smart Grid.

Answer:

Difference Between Conventional Grid and Smart Grid:

Feature	Conventional Grid	Smart Grid
Communication	One-way (Utility → Consumer)	Two-way (Utility ↔ Consumer)
Monitoring	Manual or limited	Real-time and automated
Reliability	Limited fault detection	Self-healing with intelligent protection
Consumer Role	Passive	Active (e.g., Consumers, demand response)
Integration of Renewable	Difficult	Seamless with control and storage