19. What is the concept of Incremental conductance method in MPPT ?

A: The incremental conductance method in MPPT is an algorithm that uses the slope of a solar panels power voltage (P-V) characteristic curve to determine the position of the operation point relative to maximum power point.

The algorithm thus compares the incremental conductance (dI/dV (or) $\Delta I/\Delta V$) with instantaneous conductance ($-I/V$) to make decision.

→ $\Delta I/\Delta V > -I/V$ operating point is left of MPP, controller increases the voltage.

→ $\Delta I/\Delta V < -I/V$, operating point is right of MPP, controller decreases the voltage.

→ $\Delta I/\Delta V = -I/V$, system is at MPP and operating point is maintained.

b) Define stand alone PV system and mention two types of batteries used in PV system.

A stand alone PV system is a solar energy system that operates independently from the utility power grid. It typically stores the energy generated by the solar panels is a Battery Bank for use during the night or periods of low sunlight.

Batteries used :-

1) Lead Acid Batteries

2) Lithium ion Batteries

c) What is grid integration ? And mention any two Economic factor of wind Energy conversion System.

A: Grid Integration is the practice of Electrical power System planning, Operation and inter connection that enables the cost effective, reliable and efficient in corporation of electricity generation from diverse sources especially Variable renewable Energy sources like wind and solar into main Electrical grid

Economic factors :

1) capital cost
2) Annual average wind speed (Resource Availability)

d) What is vector control ? Brief

Also known as field oriented control [FOC] is an advanced control method for AC electric motors that provides precise and independent control of motor speed and Torque, similar to a DC motor.

The core idea of vector control is to Manage the complex 3-ϕ AC with in a motor as two orthogonal DC (current components)

1) Direct axis current (I_d) : control Magnetic flux of motor
2) Quadrature axis current (I_q) : control motor Torque.

e) What is the need for Hybrid Energy System ?

1) Reliability and Stability.
2) Energy and security and Independence
3) Maximum Resource utilization
4) Maximum; Environmental Benefits.

PART-B

UNIT- I

2. a) Explain Role and working of a diode in solar PV systems

A diode is 2 terminal electronic component that acts as a one way electrical valve allowing current to flow in one direction while blocking it in the opposite direction.

primarily serve two main protective and following functioning Roles in solar installations as

1) Blocking Diode and 2) Bypass diodes

1) Blocking Diodes (Isolation Diodes)

Role ÷ prevents stored energy from the battery bank (or) parallel connected panels from flowing backward into a solar panel when it is not generating power.

working ÷ when the panel voltage is lower than battery voltage, the diode blocks the reverse current flow, preventing the panel from acting as load and discharging the battery.

2) Bypass Diodes ÷

Role : protects shaded (or) faulty solar cell from damage caused by "hot spots" and ensures the rest of the panel can continue operating.

working ÷ when a group of cells is shaded, the bypass diode provides an alternate, low resistance path for the current to flow around the faulty section, thus preventing overheating and maintaining partial panel output.

b) Elaborate on function and operation of a power conditioning unit in PV systems.

The power conditioning unit (PCU) is the essential interface between a PV array, energy storage and the electrical load (or) utility grid.

	Function	Operation
1)	DC-AC Inversion	converts DC produced by solar panels into stable AC.
2)	voltage/ current Regulation	Adjusts the voltage levels to match required standards and ensures current Quality.
3)	MPPT tracking	use algorithms to continuously find optimal operating voltage and current of PV array to extract maximum possible power from panels at any given moment
4)	Grid Management	synchronizes the output frequency and voltage precisely with utility grid and manage power flow
5)	Battery Management	Regulates charging and discharging of battery banks using integrated charge controllers the maximize battery life span and system efficiency.

3. a) Compare the PO with Incremental conductance method of MPPT.

Feature	Perturb and observe	Incremental conductance
principle	Continuously perturbs the operating voltage and observes if power increas or decreases to adjust next step	compare instantaneous conductance (I/V) with Incremental conductance $(\Delta I/\Delta V)$ to determine location of MPP
complexity	simpler algorithm easier to implement with fewer sensors	More complex algorithm.

Tracking Speed	Generally Good tracking speed, but may struggle under very rapid changes in irradiance.	faster and more accurate tracking.
oscillations	Tends to oscillate slightly around the MPP in a steady state.	Accurate and identier the MPP, stopping perturbation and minimizing steady oscillations
Applications	suitable for low cost, less critical applications.	suitable for high performance system requiring precision and fast response

b) Discuss the effect the partial shading on solar cells and modules with examples.

Effect of partial shading.

1) current mismatch: solar cells in a module are wired in series, meaning they all operate at current level of weakest cell. The healthy cells are forced to operate below their maximum power point.

2) voltage Drop: shaded cells exhibit high resistance. They drop the over all string voltage significantly, leading to a drastic reduction in module's total power output.

3) Hotspot formation:- The current generated by healthy cells is dissipated as heat with in the shaded, high resistance cell. This phenomenon known as a "hotspot", can cause localized temperature to skyrocket, leading to permanent damage, delamination or even five hazards.

Examples:-

1) A single leaf : A small object like single leaf covering just one cell can reduce output of an entire 60 cell panel by over 50% of not mitigated by bypass diode

2) A shadow cart by a chimney moving across a roof during the day can cause specific strings of panels to consistently underperform at certain times, reducing overall daily energy harvest.

UNIT – II.

4a Illustrate the inverter control strategies for solar PV system.

It involve managing flow and quality of power delivered from solar panels to electrical grid or local grid.

strategies :-

1) MPPT control :- The inverter uses algorithms to continuously adjust the operating voltage of the solar panels to find the point of max. power o/p.

2) current control :- (Grid following Mode)
The control system often using proportional-integral (PI) or proportional-Resonant (PR) controllers in a synchronous rotating dq reference frame, regulates amplitude and phase of the injected current.
This allows independent control of P and Q power flow into grid, which helps maintain a high power factor and low harmonic distortion.

3) voltage control (Grid forming Mode)
The inverter operates as a voltage source, actively regulating the output voltage and frequency at point of common coupling. This enables system to operate autonomously and black start a local grid if needed.

4) Grid support functions:
Anti-Island :- The inverter must detect when main grid has gone down and disconnect immediatly to protect

maintenance workers and equipment

Fault Ride through: The inverter is required to stay connected during minor voltage sags or swells in the grid and provide active and reactive current support to aid grid recovery rather than immediately disconnecting.

6) Describe the topology and operation of a module integrated inverter.

The micro inverter typically employs a two stage power conversion topology to maximize efficiency and meet grid standards.

1) DC-DC stage (front end)

This initial stage is a converter (eg: flyback, boost or push pull) that performs two keys functions.

MPPT: It runs the MPPT algorithm to ensure the specific panel operate as its peak efficiency regardless of shading or temperature.

voltage Boosting and isolation: It boosts the low, variable DC voltage from panel to a higher regulated DC level and often provide galvanic isolation via a high frequency transformer.

2) DC AC stage (Rear End)

This final stage, typically a full bridge inverter circuit takes the high DC voltage and convertes it into a clean grid, synchronous sinusoidal AC waveform. An output filter is used to ensure high power quality before the power is fed into the electrical system.

5a Explain the working of a String inverter and its applications.

A: String inverters are power Electronic devices used in solar pv systems that connect to a string of multipler solar panels to convert their combined DC electricity into AC electricity suitable for the grid or local consumption.

working:

1) DC input ! Multiple solar panels are wired in series to build a high DC voltage.

2) MPPT operation : The inverter continuously adjusts the operating point of the entire string to perform MPPT. It finds the optimal voltage and current for the entire group of panels to maximize energy harvest.

3. DC-AC conversion

The raw DC voltage is inverted into a clean, grid complia-nt AC waveform using power semiconductors and internal filtering mechanisms.

4. Synchronization and safety ÷

In grid tield systems, the inverter synchronizes its AC output perfectly with the utility grid's voltage and frequency providing necessary safety features like anti islanding protection.

Applications ÷

1) Residential solar installations.

2) commercial rooftaps.

3) Small to medium utility scale projects

4) Off grid systems.

6) Discuss the role of micro inverters in modern pv system?

Micro inverters play a crucial role in modern pv systems by optimizing the performance, reliability, moving away from centralized power processing toward module level control

Role:

1) Module level optimization (Decentralized MPPT)
2) Mitigations shading losses
3) Enhanced safety
4) System Monitoring and Diagnostics
5) Design flexibility and Modulating
6) Increased Reliability (Redundancy)

UNIT-3

6a Explain the working principles of different types of wind turbines generator.

Types of Generators in WECS

Electric Motors / gen. used in Wind Turbines

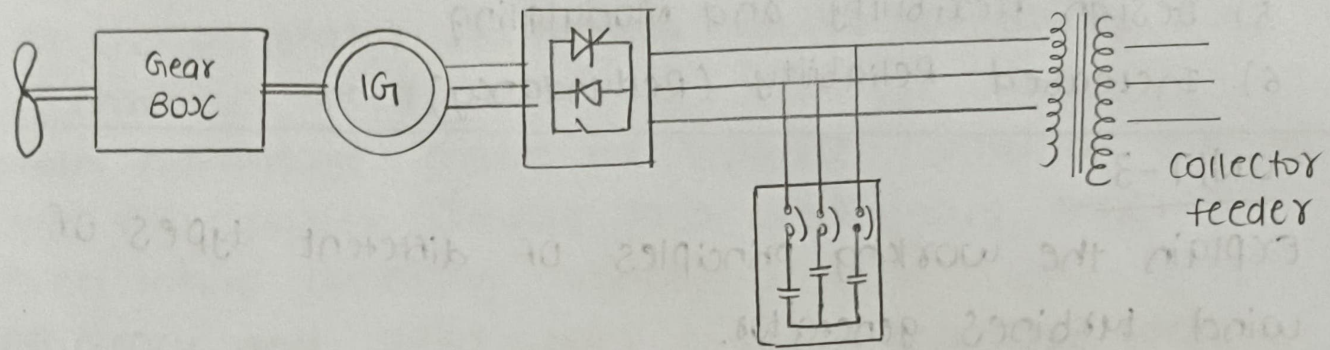
- Asynchronous operation
  - Doubly fed Iduction Generator
    - Slip ring fed rotor
    - Brushless Rotor
  - Squirrel cage Induction generators
- Synchronous Operation
  - Wound Rotor generator
    - Slipring fed rotor
    - Brushless Rotor
  - Permanent Magenetic generators
    - Insert mounted Magnets
    - Surface mounted magnets

Type-1:

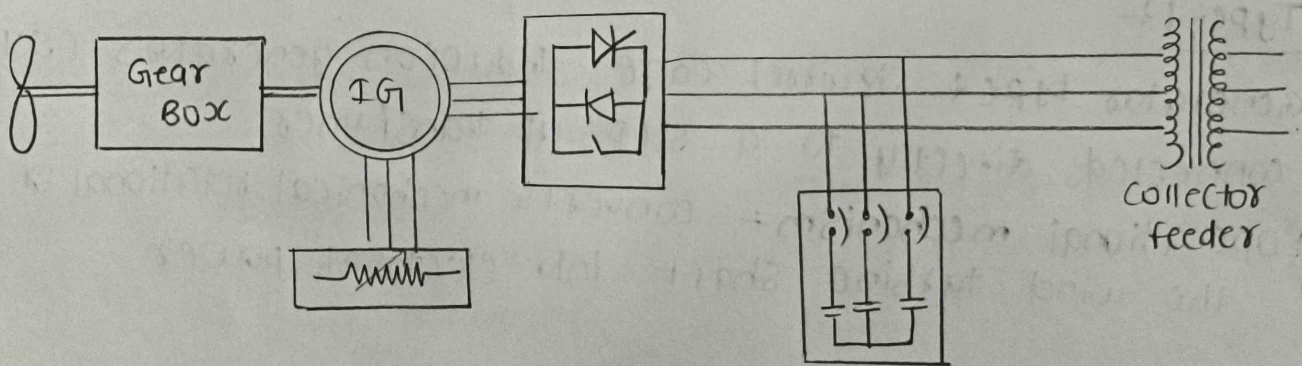
Generator type: Squirrel cage Induction generators (SCIG) connected directly to a step up transformer

Operational mechanism: converts mechanical rotational of the wind turbine shaft into electrical power

Output control: The kinetic inertia of the drive systems helps control the pace of changes in electrical output during sudden wind speed variations.
Drawbacks and solutions: consumer reactive Energy and can generate large currents. These issues are mange using a delicate states and capacitor banks.



Type-2:
Generator type: wound Rotor induction generator
voltage control Mechanism: A variable resistor is induced in the rotor circuit, allowing for quick and smooth control of the rotor voltage and continuous power generator
Resistor placement: The variable resistor can be added externally via power electronics and External Resistors or internally mounted with in the rotor to eliminate the need for slip ring.
Speed and power curve Adjustment: Adding Resistance changes the power curve, requiring the generator to spin faster to produce the same power output.
Benefits: These technique provides better control over turbine blade pace, increases flexibility in Energy capture.



Type-3:

Generator used: Doubly fed Asynchronous generator

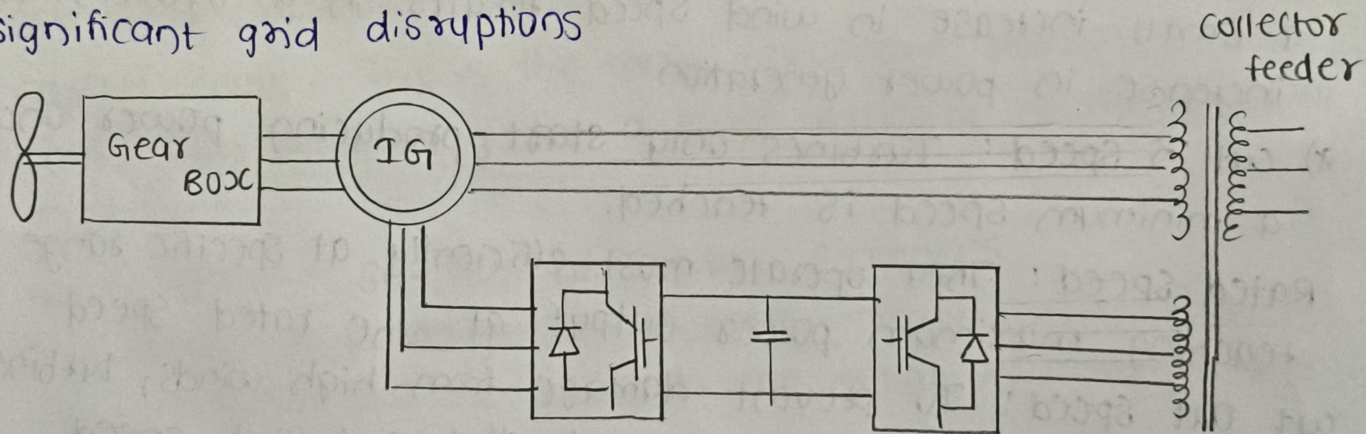
control Mechanism: uses rotor side and grid side converter to precisely control power output By injecting a small amount of power into the rotor circuit.

power delivery: power can be delivered to the grid wheth--er the generator is running faster or slower than synchronous speed.

Main Advantage: Allows for separate control of reactive and real power similar to a synchronous generator, even while operating Asynchronously.

Efficiency and speed: offer a wider operational speed range and increased over all efficiency compared to earlier design.

stability: Employs vector or field oriented control techniques to adjust Torque quickly, maintaining stability during significant grid disruptions



Type-4:

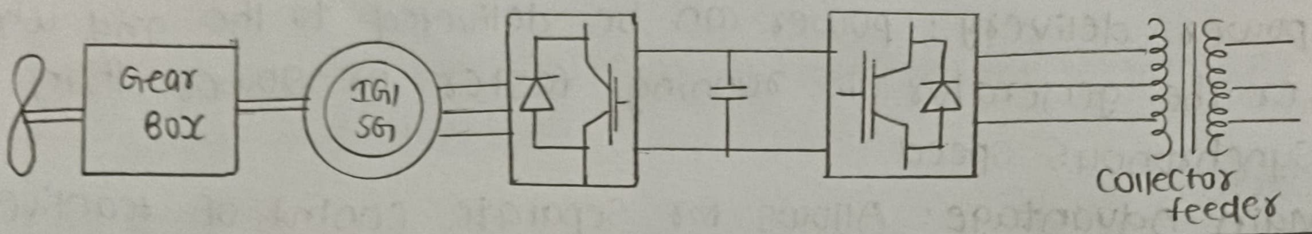
operation Flexibility: Designed for flexible operation, allowing it to spin at its most efficient speed for maximum power generator.

grid connection: connects to the power grid via a full scare, Back to Back frequency.

Gearbox Elimination: Does not require a gearbox to adjust its speed, it can operate electicity at a lower frequency than the grid frequency.

Machine types: Can utilize various generator types including wound rotor synchronous machines.

power control: An inverter is essential for controlling power flow and must be capable of handling the turbine's entire output as well as providing reactive power compensation



b) Discuss the characteristics of wind and how it affects wind turbine performance.

Wind is characterized by its variability in speed, direction and turbulence

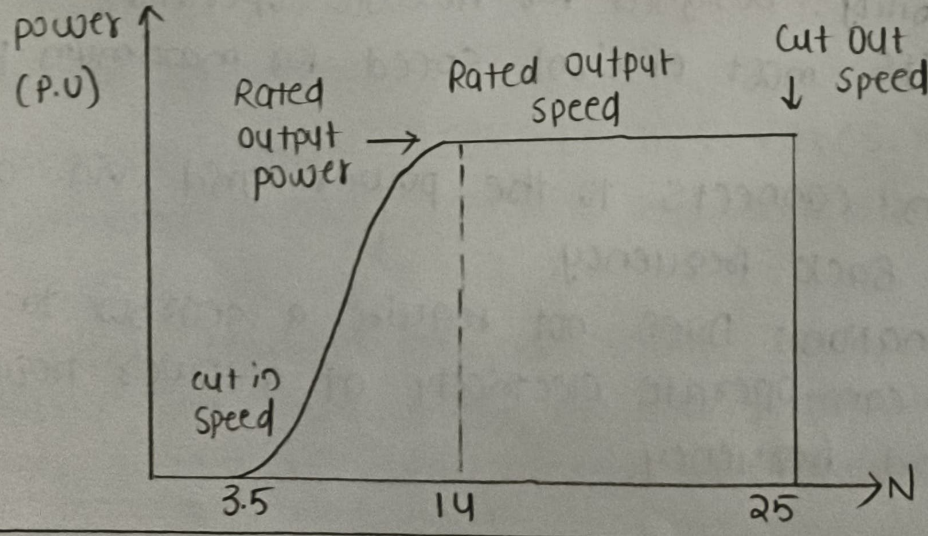
wind speed:

1) power output: The power available from the wind is proportional to the cube of its speed ($P \alpha V3$). This means a small increase in wind speed results in a substantial increase in power generation

*) cut in speed: Turbines only start producing power once a minimum speed is reached.

Rated speed: They operate most efficiently at specific range reaching maximum power output at the rated speed.

cut out speed: To prevent damage from high winds, turbines shut down if the wind exceeds the cut out speed.



Effects :

1) Wind direction : Turbines must yaw (turn) to face the wind to maximize energy capture frequent or rapid changes in direction requires the turbine's control system to work harder, reducing efficiency and potentially increases mechanical stress.

2) Turbulence : Refers to rapid, irregular fluctuations in wind speed and direction.

3) Reduced Efficiency : High turbulence decreases aerodynamic efficiency and consistent power output.

4) Increased Stress : It causes fluctuating loads on the blades, gearbox and tower leading to increased mechanical wear and tear and potentially shortening the turbine's lifespan

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7a) Analyze the economics of WECS including cost and payback considerations.

cost considerations :

1) capital costs : This is the most significant portion of the total cost, often accounting for a large majority of the overall expense.

wind turbine : 60-70% of capital Expenses

2) Operational and Maintenance costs : These ongoing costs are relatively low compared to the initial investment and traditional energy source.

Typically 1-2% of Total capital cost annually.

payback considerations :

1) Financial payback period : This varies greatly depending on wind Resource quality and available incentives

→ 1-6 years.

2) Energy payback period : Energy consumed during manufacturing and installations vs Energy produced, a wind turbine "pays back" its Initial Energy investment within a very short

time frame, 6-8 months.

b) Describe the challenges and techniques of linking wind turbines to the grid.

A: The challenges of linking wind turbines are primarily due to winds intermittency which causes power output variations and makes balancing supply difficult. key issues including maintaining grid stability, ensuring sufficient reactive power for voltage control and over coming limitations in existing Transmission infrastructure to transport power from often remote wind sites.

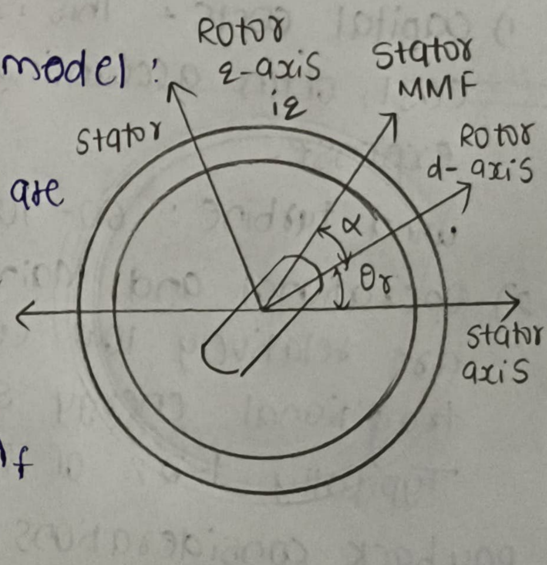
Techniques:

1) use of Advanced power Electronics in modern turbines for precise control of power output and voltage support
2) Grid operators use improved wind power forcasting for better planning.
3) Install energy storage system to balance supply and demand

UNIT-4:

8b) Discuss the modelling of PMSG

PMSM (machine) by parks Transform model:



Parks Transform Modelling of PMSM

1) voltage Equations from the model are given by

$V_q = R_s i_q + \omega_r \lambda_d + P\lambda_q \rightarrow ①$

$V_d = R_s i_d - \omega_r \lambda_q + P\lambda_d \rightarrow ②$

Flux linkages $\lambda_q = L_q i_q$ $\lambda_d = L_d i_d + \lambda_f$

By substituting in eq ① and ② in Matrix form as

$$\begin{bmatrix} V_q \\ V_d \end{bmatrix} = \begin{bmatrix} R_s + PL_q & \omega_r L_d \\ -\omega_r L_q & R_s + PL_d \end{bmatrix} \begin{bmatrix} i_q \\ i_d \end{bmatrix} + \begin{bmatrix} \omega_r \lambda_f \\ P\lambda_f \end{bmatrix}$$

The developed Torque motor given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left[\lambda_d i_q - \lambda_q i_d\right]$$

Applying park's Transformation :

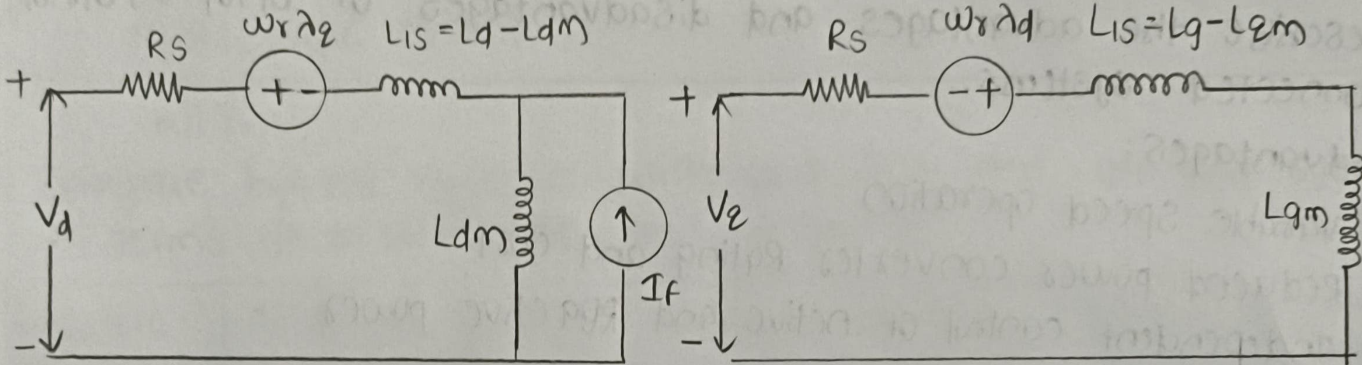
V_{abc} to V_{dq0} Conversion

$$\begin{bmatrix} V_q \\ V_d \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos\theta_r & \cos(\theta_r-120) & \cos(\theta_r+120) \\ \sin\theta_r & \sin(\theta_r-120) & \sin(\theta_r+120) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \frac{2}{3} * \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

V_{dq0} to V_{abc} conversion

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta_r & \sin\theta_r & 1 \\ \cos(\theta_r-120) & \sin(\theta_r-120) & 1 \\ \cos(\theta_r+120) & \sin(\theta_r+120) & 1 \end{bmatrix} \begin{bmatrix} V_q \\ V_d \\ V_0 \end{bmatrix}$$

Equivalent circuit of PMSM without damper winding.



UNIT – IV

8a) Describe structure operation of Doubly Fed I.G.

DFIG is a wound rotor I.G in which both the stator and Rotor are connected to 3-Ø power source

Structure :

1) Stator : The stationary part of the generator whose windings are connected directly to the main power grid

2) Rotor side converter (RSC) : A power electronic converter (AC-DC-AC IGBT Based) connected to their rotor via slip rings
→ Primary role is to control flow of current into or out of the rotor windings.

3) Grid side converter (GSC) : Another power converter linked back to back with the RSC via a DC link capacitor, which acts as an energy buffer to maintain a stable DC voltage.

working ÷

By adjusting the frequency and phase of this injected current the DFIG maintains a consistent synchronous magnetic field speed relative to grid frequency regardless of the turbine's actual mechanical rotational speed. The majority of generated power flows directly from stator to the grid, while only "slip power" flows through the power electronics which allows for robust variable speed operation high efficiency and independent active and reactive power control for grid support.

Advanced control strategies :

1) PI controllers..

9a) Describe the advantages and disadvantages of DFIG in Grid connected systems.

Advantages:

1) variable speed operation
2) Reduced power converter Rating and cost.
3) Independent control of Active and Reactive power.
4) constant frequency output.
5) cost Effectiveness.
6) Grid integration and stability support.

Disadvantages :

1) sensitivity to grid faults
2) Increases maintenance needs
3) Requires Gearbox
4) complex control Requirements.
5) Harmonic components.

b) Discuss the control of power converters for WECS

To control strategies typically focus on two main components

1) RSC GSC

control of RSC :

1) vector control or field Oriented control and Direct power control

2) Active power control - by controlling q-axis current component of rotor current
3) Reactive power control - controlling d-axis component

Control of GSC:
1) Voltage oriented control (VOC) or Direct power control (DPC)
2) Grid Reactive power / p.f. control
3) user PLL to synchronize the converter output with grid voltage angle and frequency, ensuring smooth and stable connection.

Advanced control strategies:
1) PI controllers
2) Model predictive control
3) Fuzzy logic control.

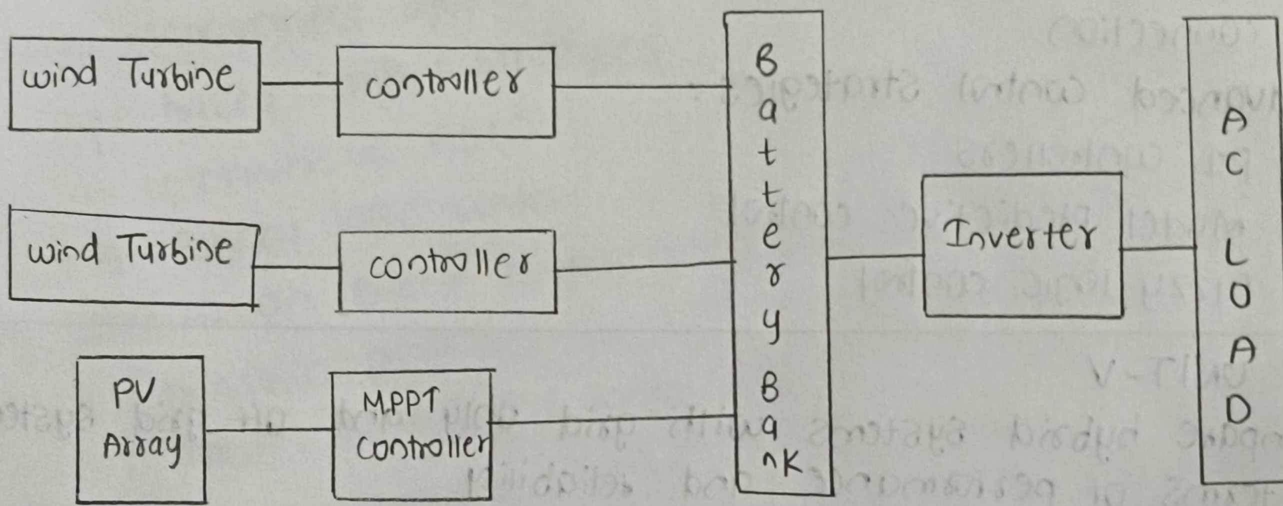
UNIT-V

10a) Compare hybrid systems with grid only and off grid systems in terms of performance and reliability.

Feature	Grid only systems	Off grid systems	Hybrid systems
power source	Grid electricity, supplemented by renewables	Solely local generation	Local generation, battery storage and utility grid
Reliability	High but entirely dependent on grid stability	Reliable in remote areas without a grid but dependent on wheather (or) battery capacity	provides seamless power during grid outage using battery backup with the grid as full back (or) supplemental source
performa-nce	High efficiency, as no energy is lost to battery storage	performance depends on precise sizing and energy management; energy can be wasted if battery are full	Balances efficiency and flexibility.
Best Suited for	urban Areas	Remote locations	Area with frequent power outages.

b) Discuss the architecture of a solar wind hybrid system and its integration with the grid.

Another example of a hybrid energy system is a photovoltaic array coupled with a wind turbine. This would create more output from wind turbine during the winter, where as during the summer the solar panels would produce their peak output. Hybrid Energy System often yield greater economic and environmental returns than wind, solar, geothermal or trigeneration stand alone systems by themselves



11a) Explain the challenges in the design and implementation of hybrid energy systems.

A: Operational challenges:

1) Intermittency and variability of Renewable sources
2) complex control and Energy Management.
3) system sizing and optimization
4) Energy storage limitations.
5) Grid integration and stability issues.
6) Forecasting Inaccuracies.

Economic and Regulatory Challanges

1) High initial capital cost.
2) Lack of supportive policy framework.
3) Market integration and pricing issues.
4) Financial viability and investment Risks.
5) Maintenance and Replacement costs.

b) Discuss the control strategies for hybrid Renewable Energy systems.

Typically employ one of three primary control Architectures

Control Architecture:

1) Centralized Control: A single central controller gathers data from all energy sources, storage systems and loads to make co-ordinated decisions for the entire systems.

2) Distributed control: local controllers communicate with each other to co-ordinate actions and achieve global objective.

3) Hybrid control: Combination of both centralized and distributed control.

Energy Management System (Strategies)

1) Rule based control strategies.
   i) Deterministic Rules
   ii) Fuzzy logic control
2) Optimization Based control strategies
   i) Dynamic programming
   ii) Model predictive control (MPC)
3) Intelligent control strategies
   Neutral Networks and Reinforcement learning

Hierachical control:

1) primary control (local/inner loop)
2) secondary control (central/Microgrid level)
3) Teritiary control (supervisory / Grid level)