CBCS SCHEME

USN 2VD22EE416

21EE732

Seventh Semester B.E./B.Tech. Degree Examination, Dec.2024/Jan.2025

Smart Grid

Time: 3 hrs.

Max. Marks: 100

Note: ***Answer any FIVE full questions, choosing ONE full question from each module.***

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. What is a smart grid, and what are the five key aspects that drive its development and functionality? **(10 Marks)**

b. Explain the architecture of the future intelligent grid system, and how will it enhance grid efficiency and flexibility? **(10 Marks)**

OR

2 a. What is load flow analysis and how it is applied in smart grid design. **(10 Marks)**

b. Explain Multi Agent Systems (MAS) technology, including its architecture and key characteristics. **(10 Marks)**

Module-2

3 a. What are stability analysis tools, and how do their characteristics differ in analytic tools for the smart grid. **(10 Marks)**

b. How can stability constraints be optimized through preventive voltage stability control in a power grid? **(10 Marks)**

OR

4 a. What are the primary methods for analyzing and ensuring angle stability in power systems? **(10 Marks)**

b. What are the methods used for voltage stability Indexing, and what analysis techniques are applied in steady –state voltage stability studies. **(10 Marks)**

Module-3

5 a. What is the role of decision support tools (DST) in decision–making and how does AHP contribute to this process. **(10 Marks)**

b. What optimization techniques are used in smart grid planning and how do their limitations affect smart grid applications. **(10 Marks)**

OR

6 a. Explain heuristic optimization, and how can it be applied to smart grid planning with the proposed strategy. **(10 Marks)**

b. Why is smart grid pathway design essential for the successful development and implementation of a smart grid, and what are its key features? **(10 Marks)**

Module-4

7 a. What sustainable energy options are essential for the smart grid, and how do renewable energy resources contribute to its functionality. **(10 Marks)**

b. Explain Demand Response Technology tree. **(10 Marks)**

OR

8 a. What are electric vehicles (EV) and plug in hybrid electric vehicles (PHEVs), and how do they contribute to energy sustainability and smart grid integration. **(10 Marks)**

b. Write short notes on microgrid topology and storage technologies. **(10 Marks)**

Module-5

9 a. List the critical objectives of technical research in the smart grid. **(10 Marks)**

b. What is a sample microgrid testbed environment and how is it used to evaluate microgrid operations? **(10 Marks)**

OR

10 a. What are the benefits of smart transmission in the context of modern power grids? **(10 Marks)**

b. Explain in detail about smart grid cyber security. **(10 Marks)**

* * * * *

Solution of VTU Question paper Dec-24 | Jan-25
Smart Grid [21EE732]

Prepared By :- Varaprasad Gaonkar
Assistant Professor
Dept. of E and E
KLS VDIT Haliyal.

Module - 01.

01.a. What is a smart grid? and what are the five key aspects that drive its development and functionality? [10 Marks]

The smart grid is an advanced digital two-way power flow power system capable of self-healing and adaptive resilient and sustainable, with foresight for prediction under different uncetainties. It is equipped for interoperability with present and future standards of components, devices and systems that are cyber-secured against malicious attack.

Five key aspects of smart grid development and functionality are.

i. Computational intelligence :- It is a term used to describe the advanced analytical tools needed to optimize the bulk power network. The toolbox include heuristic, evolution programming, decision support tools etc.

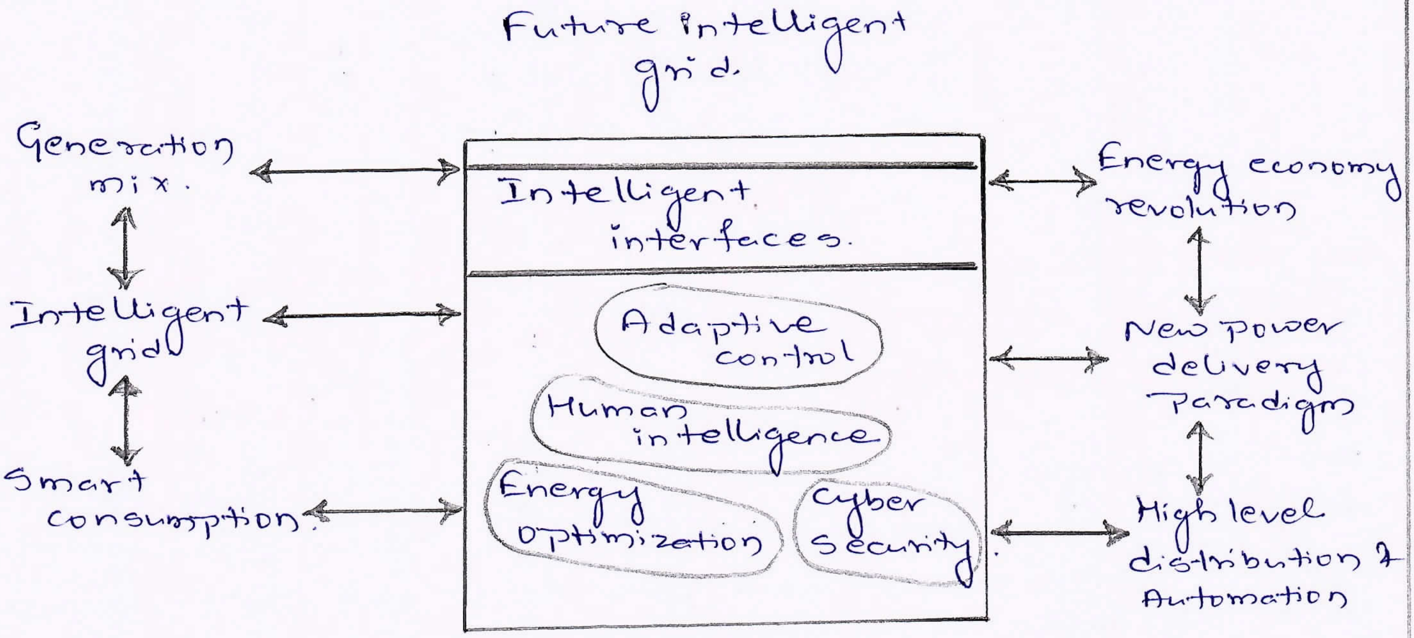
ii. Power system enhancement :- Expanded use of renewable energy resources will help to offset the impacts of carbon emissions from thermal and fossil energy, meet demand uncertainty, and increase reliability of delivery.

iii. Communication and standards :- Advanced automation will generate vast amount of data. New algorithms will help it become adaptive and capable of predicting with foresight

iv. Environment and economics :- Fully developed smart grid will allow customer involvement, enhance generation and transmission, minimizies system vulnerability, resiliency and improves power quality. It also creates new jobs.

v. Testbed :- These will help to simulate different conditions on a smart grid.

Q1.b. Explain the architecture of the future intelligent grid system, and how will it enhance grid efficiency and flexibility. [10 Marks]

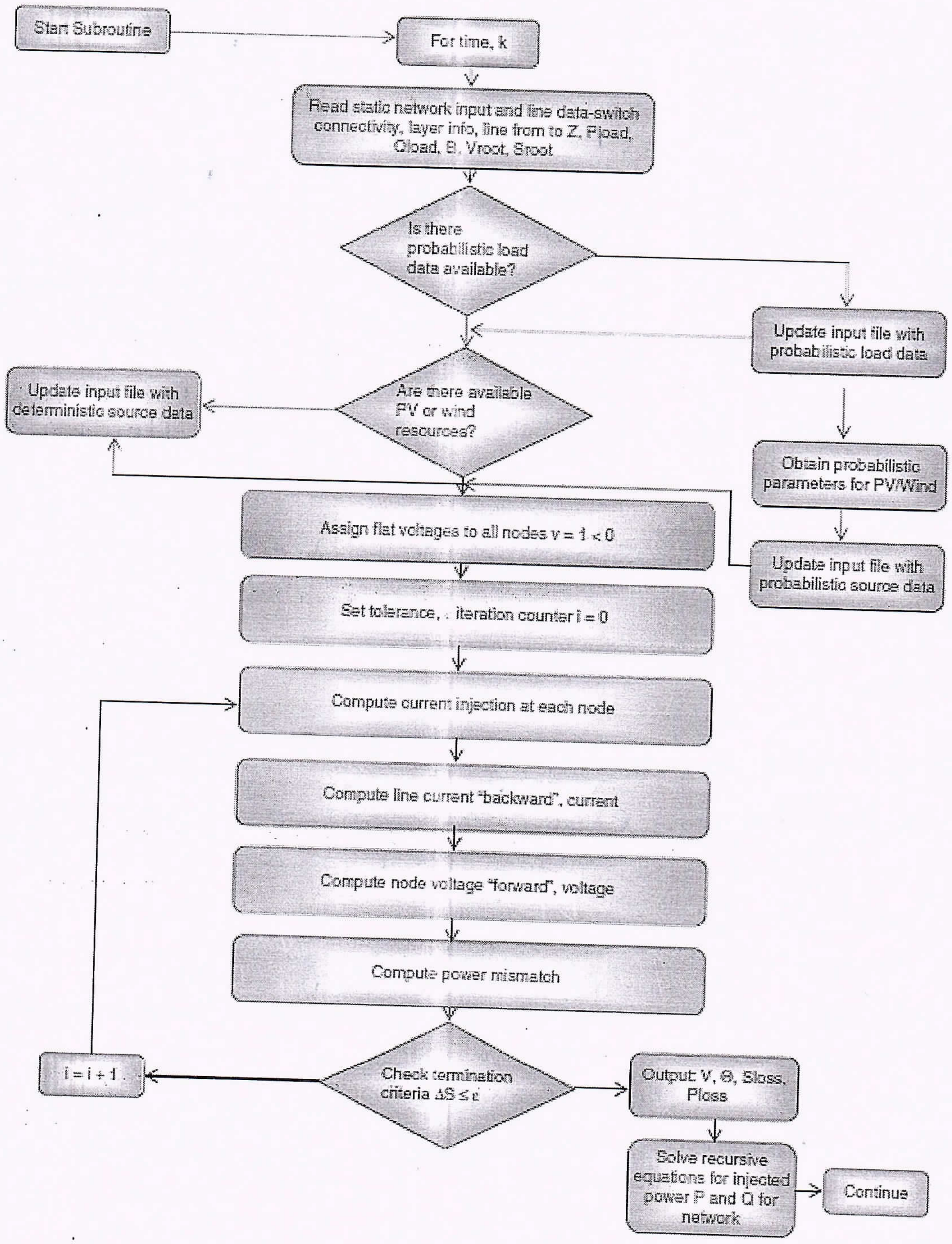


* Smart devices monitor real time information. These are integrated in distribution system.
* Due to the variability of renewable energy and the disjoint between peak availability and peak consumption it is important to have storage.
* The transmission system interconnects all substation and load centers. New grid is capable of two way power control and it helps in proper control.
* Advanced metering infrastructure will facilitate dynamic pricing, demand response, and real time energy usage monitoring
* Energy Management system, improves resource allocation, reduces energy waste and support demand side mangement
* cybersecurity framework, ensures grid reliability and data integrity.
* Artificial inteligence and big data analytics, enhances situational awareness and operational efficiency.

Q2.a. What is load flow analysis and how it is applied in smart grid design. [10 Marks]

Load flow analysis is a fundamental study in power system engineering used to determine the steady-state operating conditions of an electric power system under a given set of loads and generation. It provides critical information about voltage levels, power flows and losses across the network.

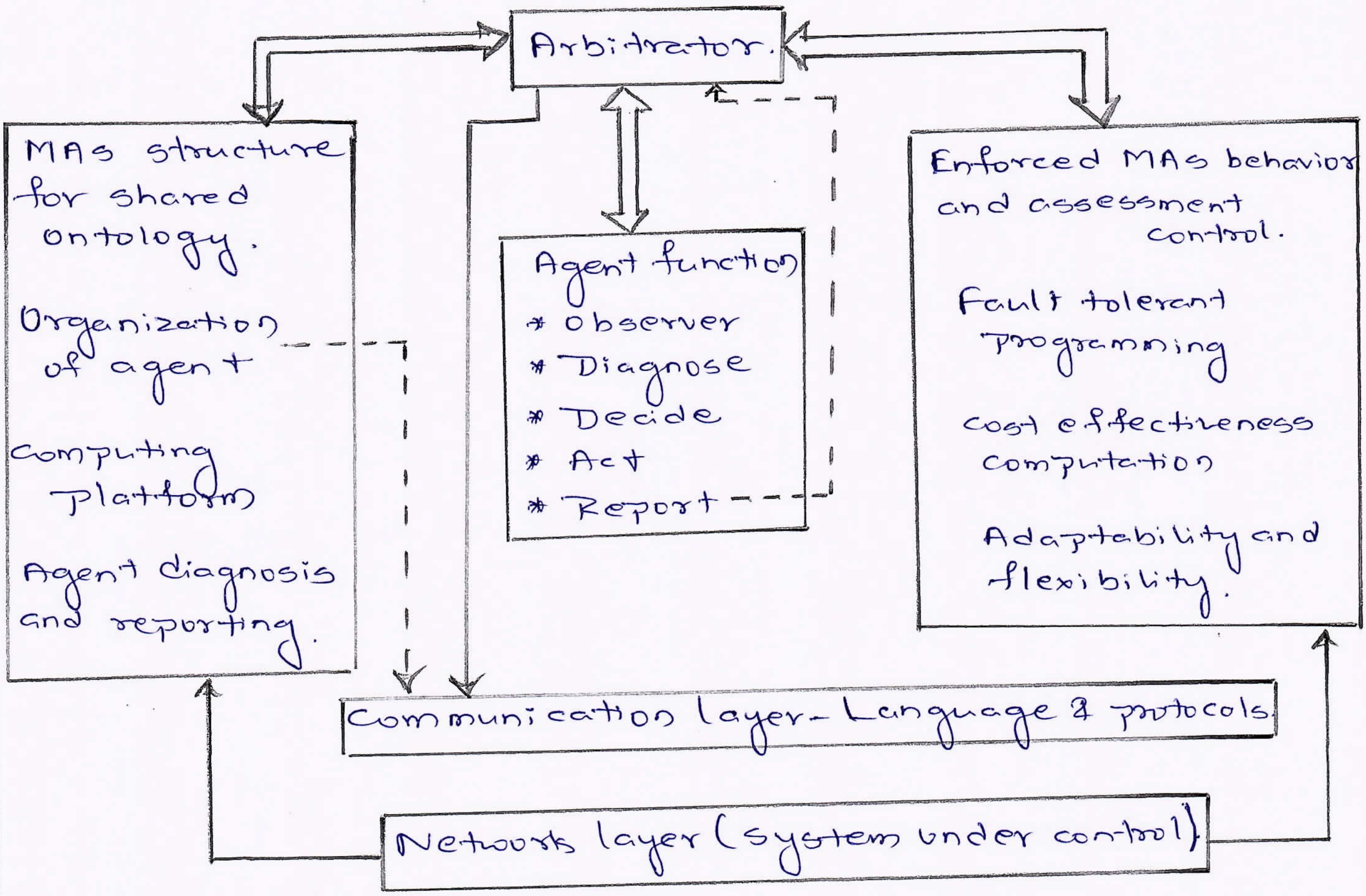
Flow chart of proposed load flow methodology for smart grid design is shown below.



Q2.b. Explain Multi Agent Systems (MAS) technology. including its architecture and key charateristics. [10 Marks]

Multi Agent Systems are a computational system in which several agents cooperate to achive a desired task. The performance of MAS can be decided by the interactions among various agents. Agents cooperate to achive more than if they act individually.

Simplified multiagent architecture is shown below.



*. Control agent monitors system voltage and frequency.

* Distributed Energy Resource agent monitors DER information monitoring and controlling DER power levels and connect/disconnect status.

* User agent act as a customer gateway.

* Database agent serves as a data access point for other agents.

* common agent attributes are, autonomy, collaborative behavior, knowledge level communication ability. etc.

Module - 02

03.a. What are stability analysis tools, and how do their characteristics differ in analytic tools for the smart grid. [10 Marks]

Stability analysis tools are essential for assessing the stability of power systems. These tools help evaluate how a power system responds to disturbances and ensure that it can maintain stable operation under various conditions. The characteristics of stability analysis tools for smart grid differ from traditional analytic tools in several ways.

i. Robustness - Smart grid stability tools are designed to maintain their performance under various perturbations and uncertainties. This means they can effectively handel unexpected changes in system conditions, unlike traditional tools that may not account for such variability.

ii. Scalability - The ability to accomodate growing amounts of work is crucial in smart grids, which often involve integrating renewable energy resources and advanced control devices. Smart grid tools are built to scale efficiently as the system expands, whereas older tools may struggle with increased complexity and size.

iii. Stochasticity - Smart grid stability analysis incorporates probabilistic elements, allowing for the analysis of time developments in terms of probability. This is particularly important for modern power systems that experience random fluctuations in load and generation, which traditional tools may not adequately address.

iv. Real time data utilization - Smart grid tools leverage real time measurements and data processing to provide up-to-date assessment of system stability. Traditional tools rely on static models

v. Predictive capabilities - Advanced algorithms in smart grid tools can predict potential stability issues and suggest corrective action before problems arise. In contrast traditional tools may focus more on reactive measures after disturbances occur.

Q3.b. How can stability constraints be optimized through preventive voltage stability control in a power grid? (10 Marks)

Stability constraints in a power grid can be optimize through preventive stability control by implementing various strategies and technologies aimed at maintaining system stability before disturbances occurs.

i. Controllable reactive power sources - Utilizing devices such as generators, shunt reactors, shunt capacitors and on load tap changers allows for the adjustment of reactive power in the system. By managing the excitation of generators and switching of capacitors and reactors, operators can maintain voltage stability levels and improve overall system stability.

ii. Automatic Voltage regulators - These devices continuously adjust the excitation of generators to ensure that voltage levels remain within acceptable limits. By proactively managing voltage, AVRs help prevent voltage instability and collapse, which are critical for maintaining system stability.

iii. Optimal power flow formulation - Implementing OPF techniques allows for the optimization of power system operation while considering stability constraints. This involves determining the best generation dispatch and reactive power support to minimize losses and maintain stability under various operating conditions.

iv. Preventive control scheme - Developing control scheme that assess system conditions and apply corrective actions before instability occurs is essential. This includes monitoring stability indices and implementing control actions based on predictive models to ensure that the system remains stable under potential contingencies.

v. Stability index calculation - By calculating stability indices operator can identify critical states and take preventive measures.

vi. Integration of advanced technologies - Use of FACTS devices may help to improve stability.

04.a. What are the primary methods for analyzing and ensuring angle stability in power systems?

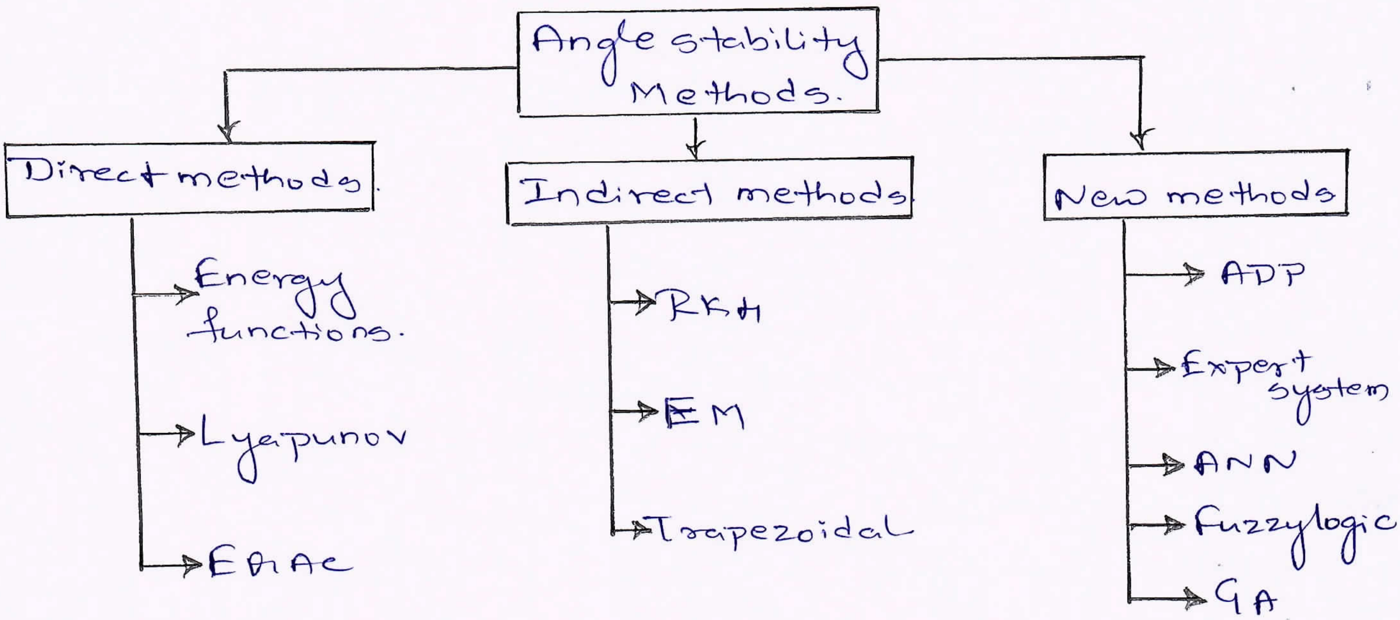
(10 Marks)

There are several methods for analyzing and ensuring angle stability in power systems.

i. Transient stability analysis - This method evaluates the systems response to large disturbances. It involves simulating the dynamic behavior of the system over time to determine whether generators remain in synchronism. This uses numerical techniques to solve differential equations.

ii. Lyapunov Stability theorem - This method is helpful for analyzing nonlinear system and can provide insights into the stability margines of the system.

iii. Artificial Intelligence method - This uses heuristic and computational intelligence to estimate the stability margin and compuatational indices. The method includes the expert system for classifying contingencies identifying and estimating the instability margin.



Q4.b. What are the methods used for voltage stability indexing, and what analysis techniques are applied in steady-state voltage stability studies. [10 Marks]

Methods used for voltage stability indexing are

i. L-index - It is calculated from load flow results and provides a measure of the voltage stability margin at a bus. It indicates how close the system is to voltage collapse by assessing the relationship between reactive power demand and supply. A lower L-index value suggests a higher risk of voltage instability.

ii. Voltage collapse proximity indicator (VCPI) - It is defined as a vector of ratios of incremental generated reactive power at a generator to the increase in reactive load demand. It helps identify buses or areas in the system that are most vulnerable to voltage collapse.

iii. Energy method - It analyze the energy function of the system, considering voltage variations and reactive loads. By assessing the energy landscape, operators can identify stability limits and potential points of collapse.

Following are the analysis techniques applied in steady state voltage stability studies.

i. Power flow analysis.
ii. PV and QV curve analysis.
iii. Sensitivity analysis.
iv. Continuation power flow method.
v. Eigen value analysis.
vi. Voltage stability
vii. Bifurcation analysis
viii. Energy method.
ix. Modal analysis.

Module-03.

05a. What is the role of decision support tools (DST) in decision-making and how does AHP contribute to this process. [10 Marks]

Decision support tools are crucial in complex decision making environments like smart grid mangement. They help by processing large datasets into actionable insights, assessing risks, evaluating multiple criteria simulating scenarios and fostering effective communication amoung stakeholders.

→ Key roles of DST

* Data mangement - transform raw data into meaningful insights.
* Risk assessment. identify risks and uncertainties using simulations and probabilistic analyses.
* Multi criteria evaluation - Consider conflicting criteria for holistic decision-making.
* Scenario planning - Simulate outcomes to evaluate the impact of decisions.
* communication facilitation - provide a common framework for stakeholder collaboration.

→ Contribution of Analytical Hierarchical Processing (AHP)

* Structured framework - breaking down complex decisions into manageable hierarchies.
* Pairwise comparisons - evaluating the relative importance of criteria and alternatives.
* Result synthesis - Consolidating comparision into a single score for each option.
* Handeling diverse data - accommodating both qualitative and quantitative inputs.
* Consistency - ensuring credible and systematic judgments.

Q5. b. What optimization techniques are used in smart grid planning and how do their limitations affect smart grid applications. [10 Marks]

In smart grid planning, various optimization techniques are used to improve efficiency and adaptability.

i. Linear programming - used to optimize costs and resource allocation within linear constraints. Limitations are static in nature, struggles with renewable energy variability and dynamic demands.

ii. Nonlinear programming. It can handel complex, nonlinear relationships in objectives and constraints. Limitations are computationally intensive, prone to local minima in dynamic systems.

iii. Mixed integer programming - it uses combination of continuous and discrete variables for scheduling and unit commitment. Limitations are exponential complexity. less practical for large systems.

iv. Dynamic programming - Optimizes multistage decisions over time with limitations like dimensionality issues in large, complex systems.

v. Stochastic programming - models uncertainty, ideal for renewable energy integration. Limitations, are, it requires detailed probabilistic data, complex to implement

vi. Heuristic methods (GA, PSO etc) - flexible approaches for solving complex problems. Limitations are no guaranteed optimality.

→ Effects of limitation on smart grids.

* Inflexibility.
* computational burdens.
* local optima.
* Scalability
* Uncertainty management

06. a. Explain heuristic optimization and how can it be applied to smart grid planning with the proposed strategy. [10 Marks]

Heuristic optimization provides efficient, flexible and robust solutions for complex and dynamic systems like smart grids. These methods prioritize satisfactory solutions over guaranteed optimality, making them suitable for real-time and uncertain environments.

* Key charateristics.
  - Flexibility - adapts to various problems and scenarios.
  - Robustness - handles uncertainties like variable energy generation and consumption.
  - Speed - delivers timely solutions for real time operations.

* Heuristic optimization addresses key challenges such as resource allocation, demand forecasting, renewable energy integration and operational reliability.

* Proposed strategy for smart grid optimization.

01. Modeling objectives - define objective functions that include customer welfare and power uncertainty. Integrate RER to account for generation variability.
02. Simulating and updating models - run simulations to reflect current and future grid conditions. Update models regularly with new data for enhanced accuracy and adaptability.
03. Probabilistic load flow analysis - analyze base case and contingencies using probabilistic frameworks to identify potential risks and impacts.
04. Optimization techniques - Use hybrid adaptive dynamic programming for dynamic environments. Apply GA or PSO for exploring multi-dimensional solutions efficiently.
05. Real-time monitoring and adjustment - Implement real time data systems for continuous performance monitoring.
06. Contingency analysis - identify critical risks and develop mitigation strategies to ensure reliability during unforeseen events.

06.b. Why is smart grid pathway design essential for the successful development and implementation of a smart grid, and what are its key features?

[10 Marks]

* Importance of smart grid pathway design.

01. Technology integration - ensures seamless incorporation of renewable energy, smart meters and automation devices for a flexible network.

02. Managing complexity - Outlines clear roles and processes for effective coordination amoung components and stakeholders.

03. Reliability and resilience - enhances grid stability against disturbances and variability.

04. Regulatory compliance - guides adherence to regulatory frameworks for smoother implementation.

05. Investment planning - aligns projects with objectives to secure funding for large scale deployments.

06. Stakeholder engagement - promotes collaboration amoung utilities, regulators and consumers.

* Key features.

01. Multi-layered approach - covers system planning, operations and device management comprehensively.

02. Adaptive framework - allows revisions based on real-time data and evolving needs.

03. Advanced optimization - improves efficiency, reliability and security with cutting edge techniques.

04. Predictive analytics - Utilizes real time data for dynamic operational adjustments.

05. Sustainability focus - promotes renewable energy and energy efficient practices while minimizing environmental impact

06. Consumer engagement - enhances participation through demand side mangement and smart technologies.

Module-04

07.a. What sustainable energy options are essential for the smart grid. and how do renewable energy resources contribute to its functionality. [10 Marks]

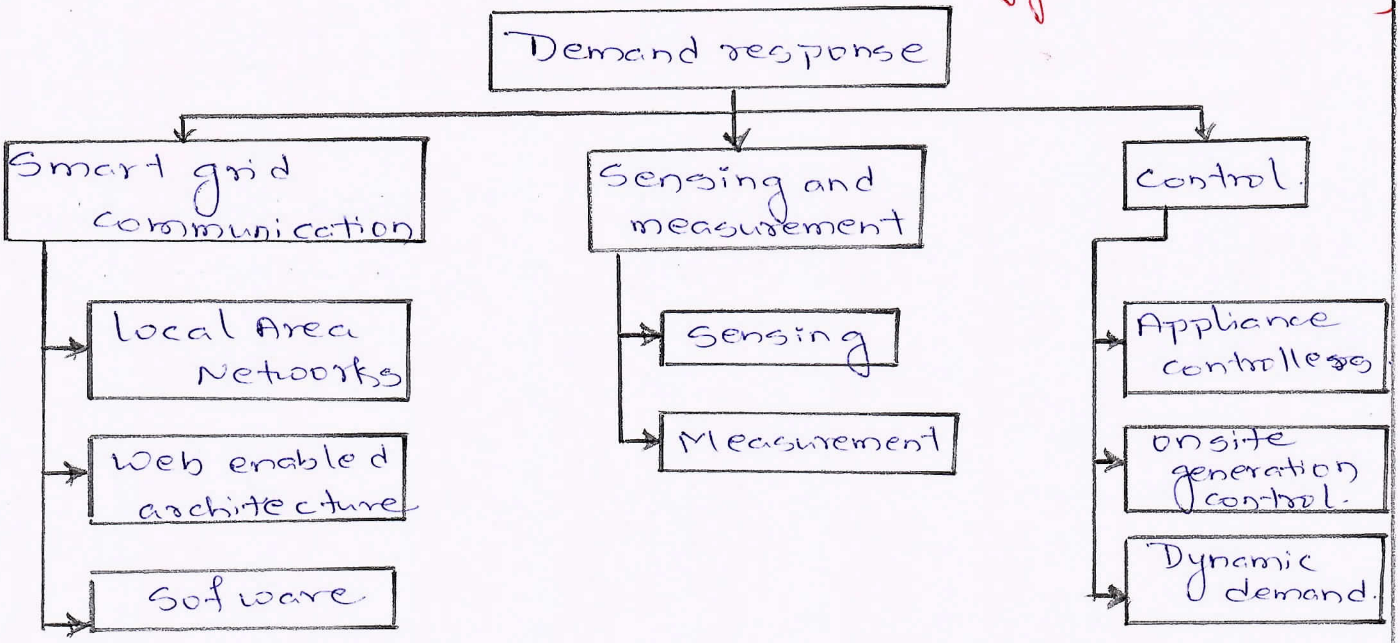
Sustainable energy options are essential for the smart grid. enabling cleaner energy production and integration of distributed energy resources. Some of sustainable energy options are

01. Solar energy - Photovoltaic systems and concentrated solar power provide emission free, efficient electricity generation.
02. Wind energy - Wind turbines deliver cost effective emission free energy.
03. Biomass plants utilize organic materials, balancing sustainability with manageble emissions.
04. Hydropower - small and micro systems offer reliable low impact energy.
05. Geothermal energy - Geothermal plants provide efficient, low emission electricity and heating.
06. Fuel cells - highly efficient, low emission technology using hydrogen for electricity.

* Contribution to smart grid functionality.

01. Reliability and efficiency - diversifies energy supply and reduces fossil fuel dependency.
02. Real time energy mangement - smart grid optimize variable renewable outputs to meet demand.
03. Distributed generation - Produces energy closer to consumption points, reducing transmission losses.
04. Demand response - Aligns energy use with renewable availability, easing peak demand pressures.
05. Energy storage - stores excess renewable energy. improving grid flexibility and reliability.
06. Emission reduction - promotes low emission energy use, supporting global sustainability goals.

07. b. Explain Demand Response Technology tree. (10 Marks)



Demand Response strategies enable electricity consumers to adjust power usage based on supply conditions or pricing signals, optimizing energy use and grid reliability. DR applications can be categarized into four components.

01. Energy efficiency. - Reduce energy consumption without compromising service quality. Ex. Use of LED bulb.

02. Price based demand response - influences usage through pricing signals. a. Time of use (TOU). b. Day ahead pricing c. Real time pricing.

03. Incentive - based demand response. offers financial incentives for reducing or shifting energy use a. capacity services, b. demand bidding. c. Direct load control.

04. Time scale commitments and dispatch. focus on resource scheduling and mangement. a. long term planning. b. mid term planning. c. real time dispatch.

08.a. What are electric vehicles (EV) and plug in hybrid electric vehicles (PHEV's) and how do they contribute to energy sustainability and smart grid integration. [10 Marks]

EVs and PHEVs are key to sustainable energy systems contributing to reduced emission, enhanced energy efficiency.

* Electric vehicles - Powered entirely by electricity stored in batteries, with no internal combustion engine.
* Plug in Hybrid Electric vehicles - Rechargeble via outlets or stations. these can operate on electric power for short trips or switch to gasoline for longer distances.

* Contributions to energy sustainability.

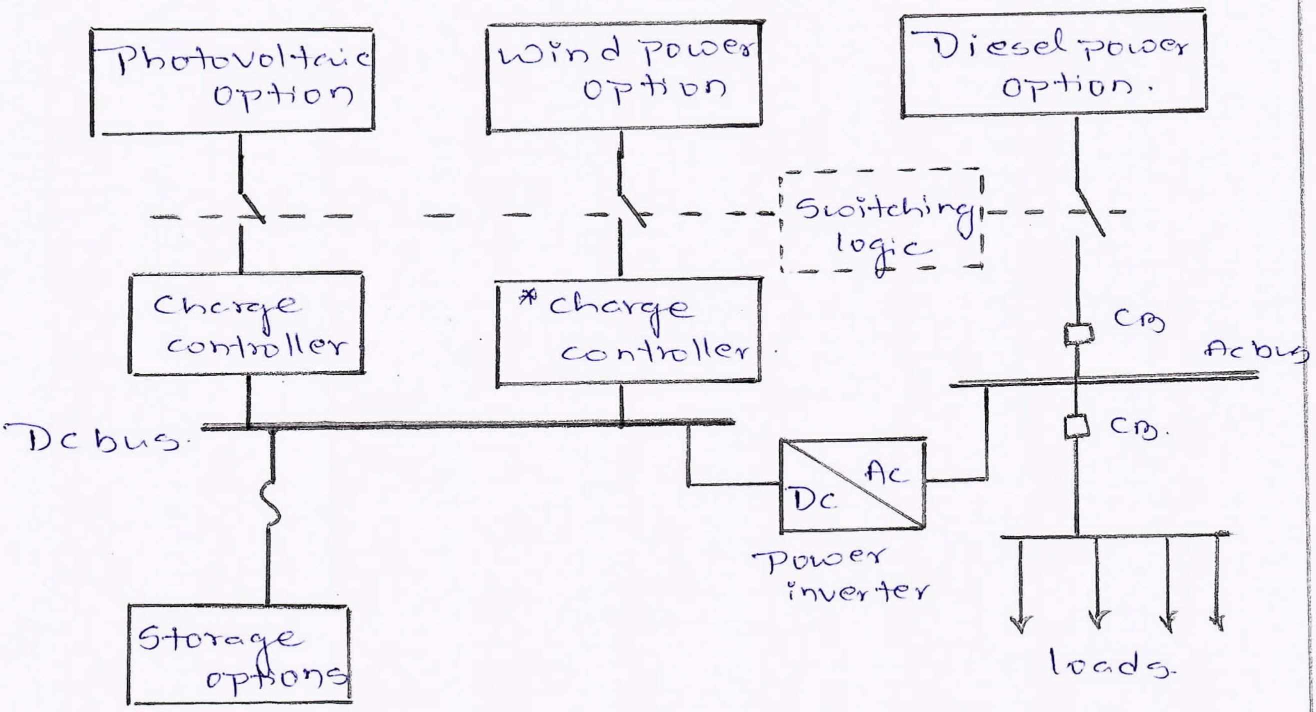
01. Emission reduction - lower greenhouse gas emissions, especially when charged using renewable energy.
02. Reduced oil dependence - Electricity replaces gasoline, enhancing energy security.
03. Improved efficiency - Electric motors are more efficient than combustion engines.

* Smart grid integration.

01. Vehicle to Grid (V2G) technology - It enables EV and PHEVs to supply stored energy back to the grid during peak demand, stabilizing the grid.
02. Demand response - flexible charging times reduce peak loads and align with renewable energy availability.
03. Load balancing. Charging during excess renewable generation improves grid stability.
04. Enhanced renewable utilization - EVs and PHEVs acts as distributed energy sources, supporting greater renewable energy adoption.

Q8.b. Write a note on microgrid topology and storage technologies. [10 Marks]

Microgrid topology refers to the arrangement and interconnection of various componentes within a microgrid system, which is a localized energy system capable of operating independently or in conjunction with the main power grid. Simple microgrid topology is shown below.



* Storage technologies.

01. Batteries.. Lead acid, Lithium ion, flow, sodium sulfur etc.
02. Supercapacitors - Store energy in an electric field. ideal for rapid charge and discharge cycles.
03. Pumped hydro storage - Uses water elevation to store and release energy, suitable for peak demand management.
04. Compressed air energy storage - compresses air in caverns, releasing it to power turbines when needed.
05. Flywheels - store kinetic energy in rotating masses, delivering high power for short duration

Module-05.

09.a. List the critical objectives of technical research in the smart grid. [10 Marks]

The critical objectives of technical research in smart grid are

01. Develop methods to quantify peak load reductions and energy efficiency savings from smart meters, demand response, distributed generation and energy storage.
02. Explore how DR, DG and storage systems can support grid ancillary services.
03. Advance technologies for data mining, visualization secure communication and distributed computing in wide area networks.
04. Test reliability technologies, especially for communication networks, under local and wide-area outage scenarios.
05. Determine network requirements for implementing advanced grid technologies.
06. Assess the potential for transitioning to time of use (TOU) and real time electricity pricing.
07. Encourage using underutilized generation capacity to substitute electricity for liquid fuels in transportation.
08. Develop algorithms for electric transmission system software
09. Create protocols enabling utilities to access energy stored in vehicles to support peak loads.

09.b. What is a sample microgrid testbed environment and how is it used to evaluate microgrid operations? [10 Marks]

Microgrid testbed is a controlled experimental setup that simulates microgrid operations, integrating components like distributed energy resources, energy storage, loads, control systems and communication infrastructure. It is designed to evaluate performance reliability and efficiency under various scenarios.

* Uses of Microgrid testbed.

01. Performance evaluation - assesses efficiency and reliability of microgrid operations.

02. Scenario testing. simulates load changes, renewable fluctuations and grid disturbances.

03. Control strategy development - tests new algorithms for optimizing operations and integrating renewables.

04. Cybersecurity assessment - evaluates resilience against potential cyber threats.

05. Training and education - provides hands on experience for students and professionals.

06. Data collection and analysis - gathers insights for improving designs and functionality.

10. a. What are the benefits of smart transmission in the context of modern power grids? (10 Marks)

Smart transmission investment provides many benefits to power customers and electricity markets. Some of them are.

01. Increased reliability.

02. Increased electricity throughput at lower delivered cost.

03. More efficient fuel use of generation, yielding lower air emissions.

04. Greater use of Renewable energy resource and clean energy sources, with lower operational integration costs.

05. More efficient use of energy storage, reduce the costs of peak demands.

06. Facilitate third party participation in power system.

07. Improving information available to customers and market participants about grid connections, electricity prices and usage.

10.b. Explain in details about smart grid cyber security. [10 Marks]

Key components of smart grid cyber security are

01. threat identification and risk assessment - identifies potential threats like malware and insider attacks and prioritize security measures based on threat impact and likelihood.
02. security protocols and standards - use of interopera-bility standards to ensure secure communication. Encryption protects data in transit and at rest.
03. Access control and authentication - multifactor authenti-cation and role based access control restrict unauthorized access.
04. Network security - firewalls, intrusion detection systems and network segmentation limit attack impacts.
05. Incident response and recovery - Incident response plans and regular training prepare for and mitigate cyber incidents.
06. Continuous monitoring and threat intelligence
07. Regulatory compliance - adherence to regulations lik NERC CIP ensures critical infrastructure protection.

* Challenges are
01. System complexity.
02. Legacy systems.
03. Interconnectedness.
04. Resource constraints.
05. Evolving threats.

Varaprasad Gaonkar

HEAD
Dept. of Electrical & Electronics Engg
KLS's V.D. Institute of Technology
HALIYAL-581 329.